Classification of mesic and semi-dry grasslands in Hungary

Attila Lengyel[1*], [†]Eszter Illyés, Norbert Bauer[2], János Csiky[3], Gergely Király[4], Dragica Purger[5], Zoltán Botta-Dukát[1]

[1]MTA Centre for Ecological Research, Institute of Ecology and Botany; Alkotmány u. 2-4., H–2163 Vácrátót, Hungary; e-mails: lengyel.attila@okologia.mta.hu, botta-dukat.zoltan@okologia.mta.hu;

[2]Hungarian Natural History Museum, Department of Botany; Pf. 222, H–1476 Budapest, Hungary; e-mail: bauer@bot.nhmus.hu;

[3]University of Pécs, Faculty of Sciences, Institute of Biology, Department of Ecology; H–7624 Pécs, Ifjúság u. 6., Hungary; e-mail: moon@ttk.pte.hu;

[4] University of West Hungary, Institute of Silviculture and Forest Protection; Ady E. u. 5., H–9400 Sopron, Hungary; e-mail: kiraly.gergely@emk.nyme.hu;

[5]BioRes Bt.; Barackvirág u. 27., H–7624 Pécs, Hungary; e-mail: dragica@gamma.ttk.pte.hu;

[*]corresponding author

In memoriam Eszter Illyés (1979–2012)

Abstract

Mesic and semi-dry grasslands are among the most valuable and species-rich anthropogeneous habitat types in Hungary. In contrast with their high respect in nature conservation, their vegetation diversity and syntaxonomy were neglected for a long time. In this paper we present their first

country-level synthesis and syntaxonomical review based on numerical classification of the *Arrhenatheretalia* order, and an update on *Brometalia erecti*.

After careful data selection and resampling, we classified 1204 relevés to 60 clusters. Clusters representing the same association were merged on the basis of a minimum spanning tree and expert assessment of their species composition. Species composition, geographical distribution, and environmental background of each mesic and semi-dry grassland association are discussed. The relationships of associations were also examined by ordination. Evaluation of clusters and associations were based only on those relevés which were unambiguously classified.

We recognized 11 associations in the *Arrhenatheretalia* order in two alliances. In the *Arrhenatherion* alliance, several new association names are adopted from the literature of foreign countries, as well as a new one is proposed. According to our concept, *Arrhenatherion* includes *Ranunculo-Alopecuretum*, a meso-hygrophilous type; *Filipendulo-Arrhenatheretum* and *Anthoxantho-Festucetum pratensis*, which are typical for meadows of changing soil water level but have different geographic distribution; *Pastinaco–Arrhenatheretum*, that is a widespread mesic meadow with many generalist species; *Ranunculo bulbosi-Arrhenatheretum* containing drought-tolerant and less nutrient-demanding species; *Tanaceto-Arrhenatheretum*, a semi-ruderal type; and *Diantho-Arrhenatheretum*, that harbours many species of montane meadows. In the *Cynosurion*, four associations are distinguished. *Cynosuro-Lolietum* is an intensively grazed type on nutrient-rich, mesic or moist soil in humid climate; *Alopecuro-Festucetum pseudovinae* is also a heavily grazed type, but in more continental climate and on packed soil. *Anthoxantho-Festucetum pseudovinae* and *Colchico-Festucetum rupicolae* are lowland mesic pastures that contain some xerophilous species, however, they differ in grazing intensity and regional species pool. Two transitional associations of *Cirsio-Brachypodion* towards more mesic types are detected for the first time in Hungary: *Filipendulo-Brometum* with sub-Atlantic distribution and *Brachypodio-Molinietum* with more montane and Carpathian distribution. We also recognized *Sanguisorbo-*

Brometum, that is a common semi-dry grassland type of rocky soils in Transdanubia; *Polygalo-Brachypodietum*, a colline type with many Pontic species; *Trifolio-Brachypodietum*, an association of more forested and montane landscapes, and *Euphorbio-Brachypodietum*, the semi-dry grassland type of Pannonian loess regions. We rejected the presence of *Phyteumo-Trisetion* and *Bromion erecti* in Hungary.

Keywords

Arrhenatheretalia, *Brometalia erecti*, Carpathian Basin, classification, clustering, meadow, Hungary, phytosociology, syntaxonomy

Introduction

Mesic and semi-dry grasslands are among the most valuable and species-rich anthropogeneous habitat types in Hungary. They are typically located on formerly forested sites, and they are maintained by mowing and grazing, while after abandonment they can easily transform into other vegetation types following the colonization of shrubs, trees or tall forbs. Factors influencing the dynamics and richness of semi-natural grasslands are subject of numerous studies in Europe, and most of them agree that the continuous, low-intensity management as well as spatial and temporal heterogeneity of the environment are essential for sustaining their diversity (Linusson et al. 1998, Huhta et al. 2001, Aavik et al. 2008, Marini et al. 2008, Bernhardt-Römermann et al. 2011, Burrascano et al. 2013, Fajmonová et al. 2013, Janeček et al. 2013, Michalcová et al. 2014, Mathar et al. 2015). As traditional, extensive management declines in Hungary, natural and economic values posed by semi-natural grasslands are also under threat (Molnár et al. 2008a, b); therefore documenting their diversity is an urgent task.

Due to the intensive research of Central European grasslands since the earliest decades of phytosociology (Braun-Blanquet 1930), when many of the currently known and widely applied syntaxon names were established, by the end of the 1990s or the first years of the 21st century, comprehensive, national monographs of these vegetation types were published in some countries (e.g. Austria: Ellmauer & Mucina 1993, Czech Republic: Chytrý 2007, Slovakia: Janišová et al. 2007, Hegedüšová Vantarová & Škodová 2014). On the contrary, diversity and syntaxonomy of secondary vegetation in Hungary received relatively little attention in comparison with other vegetation types, besides investigations with economic and agricultural purposes (e.g. Jeanplong 1987, Vinczeffy 2006) and restoration studies (Török et al. 2011, 2012). Most studies in the 20th century present qualitative descriptions of associations of narrow geographical areas (e.g. Juhász-Nagy 1959, Máthé & Kovács 1960, Kovács 1994, Varga 1997, Lájer 2002). Not surprisingly, to date country-level summaries relied on generalizations of such local observations, adoptions of results from foreign literature and subjective experiences of field botanists (Soó 1971, 1973, Borhidi & Sánta 1999, Borhidi 2003). Quantitative studies appeared only in the 21st century, when Horváth (2002, 2010) thoroughly studied the loess forest-steppe vegetation of the Mezőföld region and described the unique, xeromesic grassland of the Pannonian, loess-covered lowland and colline areas as a new association, *Euphorbio-Brachypodietum*. Illyés et al. (2007) studied the geographical variation of semi-dry grasslands in Central Europe along a continentality gradient, and then revised their syntaxonomy in Hungary (Illyés et al. 2009). Bauer (2012, 2014) presented the classification of dry and semi-dry grasslands (*Festuco-Brometea*) of the Bakony Mts and its adjacent regions. In contrast to these recent contributions to the knowledge of semi-dry grasslands, the mesic meadows and pastures remained rather neglected by the Hungarian phytosociologists. Apart from the numerical classification of mesic grasslands of South Transdanubia (Lengyel et al. 2012a), we are not aware of any contribution that would help clarify the classification and syntaxonomy of this vegetation type on a quantitative basis. Therefore, their numerical revision is more than timely now.

In the latest syntaxonomical synthesis of Hungarian vegetation (Borhidi et al. 2012) some of the recent updates by Illyés et al. (2007, 2009) and Bauer (2012) have been adopted, however, there are still many questions to be answered. The complete list and hierarchy of the respective syntaxa according to Borhidi et al. (2012) are presented in Appendix 1. Mesic grasslands are represented by the *Arrhenatheretalia* order of the *Molinio-Arrhenatheretea* class. Within *Arrhenatheretalia*, three alliances are present in Hungary according to Borhidi et al. (2012): *Arrhenatherion elatioris* containing mesic, mown meadows of colline to submontane regions, *Cynosurion cristati* containing heavily grazed or frequently cut, mesic grasslands with similar distribution, and *Phyteumo-Trisetion* for hay meadows of montane and (sub-)atlantic areas with moderate nutrient supply. Semi-dry grasslands form a separate order within *Festuco-Brometea* class, called *Brometalia erecti* Koch 1926. It is to be noted that the interpretation of this name is ambiguous and some authors (e.g. Korneck 1974, Mucina et al. 2009) argue that the name *Brachypodietalia pinnati* Korneck 1974 should be used instead. However, in this study we follow the traditional nomenclature of orders, also applied recently by Austrian (Willner et al. 2013a, b), Slovak (Janišová et al. 2007, Hegedüšová Vantarová & Škodová 2014), and Czech authors (Chytrý 2007). According to Borhidi et al. (2012), *Brometalia erecti* order is represented by two alliances in Hungary: the subcontinental *Cirsio-Brachypodion* and the (sub-)Atlantic and Mediterranean *Bromion erecti*. However, the presence of *Bromion erecti* in Hungary is questioned by Illyés et al. (2007, 2009). Many of the stands of semi-dry and mesic grasslands are difficult to assign to the already described types due to the presence of transitions and the high number of shared species among different lower syntaxa. Nevertheless, there is a continuous variation even between associations of *Arrhenatheretalia* and *Brometalia erecti* orders, despite they are assigned to different classes.

Our aim is to prepare the numerical classification of Hungarian mesic and semi-dry grasslands jointly. Such a common analysis of these two vegetation orders would have the potential to 1) revise the mesic meadow and pasture associations, 2) clarify the situation of transitions between mesic and semi-dry grasslands that caused most complications in former analyses, and 3) to refine the previous classifications and update our knowledge of semi-dry grasslands in Hungary.

Materials and Methods

A data set comprising 2055 phytosociological relevés from Hungary was gathered. Their main sources were the 'CoenoDat' Hungarian plot database (GIVD ID EU-HU-003, Csiky et al. 2012) and private databases. Relevés needed to fulfil one of the following two criteria: 1) to be assigned by the original author to the *Arrhenatheretalia* or the *Brometalia erecti* order, or to their transitions; 2) to contain at least 8 of a list of characteristic species of *Arrhenatheretalia* and *Brometalia erecti* obtained from the vegetation monographs of Slovakia (Janišová et al. 2007) and the Czech Republic (Chytrý 2007). Only those relevés were included for which geographical coordinates were available. More than 90% of the relevés were collected after 1995, while the oldest ones are from the 1950s. Plot size varied between 4 and 25 m^2. From the 50 relevés by Juhász-Nagy (1959) we found no information on plot size but we assumed that he followed the practice of Hungarian phytosociologists of his time who recorded grassland relevés in 4 to 50 m^2 plots. Species covers were originally estimated on different scales. Cover codes on Braun-Blanquet-type scales were translated to percentages according to the mid-value of their categories. In the analyses the square-root transformed values of the percentage covers were used. The phytosociological tables by Juhász-Nagy (1959) were incomplete because for species with only a single occurrence no cover value was reported. We considered such species with "+" category on the Braun-Blanquet cover scale supposing that locally rare species should not have significant effect on the classification if otherwise the table represents a well defined type (Lengyel et al. 2012b). The nomenclature of plant taxa follows Király (2009). Some species with taxonomic or identification issues were merged into species aggregates (Appendix 2). The records of non-vascular plants, shrubs and trees were deleted from the relevés. For the calculation of between-plot dissimilarities, Marczewski-Steinhaus index was used which is the dissimilarity version of the abundance form of Jaccard index (Podani 2000).

The initial data set included many relevés which belonged to syntaxa out of our scope. Filtering a data set in order to restrict it more on the focal vegetation unit is a very difficult task if the vegetation unit itself lacks formal definition, and this is now the case for Hungarian mesic and semi-dry grasslands. If the filtering is performed by a too strict rule, the risk of excluding relevés originally belonging to the type under scope is high, and this is a more serious error than keeping out-of-scope types in the sample. We decided to leave enough relevés in our data set from out-of-scope types in order to better detect their transitions with the focal types. To achieve this, a preliminary classification was applied. At the beginning, the unbalanced distribution of plots in compositional similarity and geographical space was reduced by heterogeneity-constrained random resampling with geographical stratification (Lengyel et al. 2011). The retained 1340 relevés were classified hierarchically by the beta-flexible method (beta = -0.25). We informally evaluated the resulting 50 clusters on the basis of species composition and author-supplied syntaxon assignments, and decided whether a cluster contains relevés that potentially belong to the target syntaxa, that is, *Arrhenatheretalia* and *Brometalia* orders. After this, the distance of each relevé, including those which were omitted during resampling, to each cluster was calculated using the Associa method (van Tongeren et al. 2008). Relevés (re-)assigned to clusters representing out-of-scope types were eliminated from the data set. Excluded relevés represented wet meadows with dominance of *Molinia caerulea* agg., alkali grasslands with *Peucedanum officinale*, open, dry grasslands with the dominance of *Stipa* spp., *Festuca valesiaca*, *F. pseudodalmatica*, *F. rupicola*, *Carex humilis*, and *Chrysopogon gryllus*. However, a certain number of relevés of out-of-scope types still remained in this filtered data set that contained 1424 relevés.

The HCR resampling procedure with the same settings as mentioned above was carried out on this filtered data set which reduced its size to 1204 relevés. The geographical distribution of the relevés of the final data set is shown on Fig. 1. Many hierarchical classification methods were tried in order to recover as many patterns as possible from this data set. A common weakness of simple, hierarchical classifications was that the resulting clusters consisted of relevés which belonged to different associations. Such clusters may not be useful for syntaxonomic purposes, thus we tried improving our methodology by three solutions. Firstly, a non-hierarchical method, partitioning around medoids (PAM, Kaufman & Rousseeuw 1990), was used for classifying relevés, and we looked for hierarchical relations less formally on the basis of among-cluster patterns and syntaxonomical interpretation. Non-hierarchical methods tend to obtain more homogenous clusters without constraining the classification into a perfectly nested structure (Podani 2000). Secondly, a relatively fine solution consisting of 60 clusters were examined, ensuring that each cluster can represent a relatively narrow vegetation unit. Several methods (Optimclass with several different thresholds for p-values, Tichý et al. 2010; average silhouette, Kaufman & Rousseeuw 1990; the bootstrap method by Tichý et. al. 2011) were tried for finding the optimal number of clusters, but they all gave different results; however, in several cases, optima fell between 40 and 60 clusters, therefore, the 60-cluster solution seemed to be fine enough to detect all important types, allowing that some of the clusters may eventually belong to the same association. Thirdly, the silhouette index (Rousseeuw 1987) was calculated for each relevé and only those with a positive silhouette value were taken into account during the evaluation of clusters. Hereafter we call the relevés with positive silhouette value within a frame of any classification 'core relevés', while those with non-positive silhouette value as 'non-core relevés'. For analysing the relationships of clusters, a matrix was calculated that contains average dissimilarities between core relevés of pairs of clusters. This dissimilarity matrix was classified by the minimum spanning tree method (MST, Podani 2000). The MST is the 2-dimensional, non-hierarchical representation of the single linkage clustering with lengths of between-neighbour branches corresponding to chaining values at the vertical axis of a dendrogram. MST can reveal closest neighbourhoods of clusters, thus it is an effective tool for analysing gradual variation among clusters. In some cases certain clusters came out as representatives of the same association. For studying the relationships between associations, we merged the relevés of such clusters into one group, including non-core relevés. Only such clusters were allowed for merging which appeared as closest neighbours in the MST. After merging, we re-calculated the silhouette values of relevés, therefore, we re-defined the sets of core relevés for each cluster or group of clusters. Only core relevés obtained after merging were used for constructing synoptic tables and summary statistics. The fidelity of species to clusters was expressed by the phi coefficient (Chytrý et al. 2002) with equalized group sizes (Tichý & Chytrý 2006). Only fidelities with phi $\geq$ 20 (on 0 to 100 scale) and Fisher's exact test p $\leq$ 1e-3 were considered meaningful.

The relationships of associations was also examined by principal coordinates analysis (PCoA) ordination of core relevés. The associations were graphed on a spider plot for two dimensions. Two separate ordinations were performed: one including both orders, and one separately for *Arrhenatheretalia*.

Data management and calculations were performed by softwares TurboVeg (Hennekens & Schaminée 2001), Juice (Tichý 2002), and R (R Core Team 2013), the latter one with the vegan (Oksanen et al. 2013), MASS (Venables & Ripley 2002), cluster (Maechler et al. 2013), vegclust (De Cáceres et al. 2010), and rapport (Blagotić & Daróczi 2013) packages.

Results & Discussion

Interpretation of the minimum spanning tree

There were 831 relevés with positive silhouette values in the 60 clusters of the PAM classification. The minimum spanning tree (Fig. 2) revealed major gradients in species composition of the data set. The left part of the graph, from Clusters 1 to 30, constituted mostly of mesic types (including all associations of *Arrhenatheretalia* order), while on the right side, from Clusters 31 to 60, drier types are presented (including all but one association of *Brometalia erecti* order). Within the mesic part, two large and a smaller, well-interpretable branches connected by Cluster 14 can be recognized.

The first main branch consisted of Clusters 1 to 11. This group of clusters represented lowland or colline hay meadow associations on mostly nutrient-rich, mesic or wet soils. Clusters 1 to 7 includes *Arrhenatherion* communities dominated by *Arrhenatherum elatius* (*Ranunculo bulbosi-Arrhenatheretum*, *Tanaceto-Arrhenatheretum*, *Pastinaco-Arrhenatheretum*), and an unidentified cluster. In Clusters 8 to 13 the species of wet meadows have high frequency and cover; however, these types differ in syntaxonomical affiliation: Clusters 8 to 10 are wet meadows (in *Deschampsion*; out of scope), Cluster 11 and 13 are two associations in *Arrhenatherion* with temporal or permanent effect of high ground water (*Filipendulo-Arrhenatheretum*, *Ranunculo repentis-Alopecuretum*), while Cluster 12 contains intermediate stands and old-fields oversown with *Alopecurus pratensis*. The small branch from Clusters 14 to 18 contains mostly lowland pastures with dry (typically mid- to late summer) and wet (especially autumn spring) periods during the year (*Colchico-Festucetum rupicolae*, *Anthoxantho-Festucetum pseudovinae*, *Alopecuro-Festucetum pseudovinae*). They are characterized by the mixture of mesophilous and xerophilous species. Cluster 19 and 20 are two types with high cover of *Arrhenatherum elatius* and high frequency of xerophilous species (*Diantho-Arrhenatheretum* and an unidentified type). The common feature of Clusters 21 to 28 is that they are distributed in the most humid areas of Hungary, and they contain many montane, acidophilous or hygrophilous species. These clusters vary in management regime, since there are pastures, hay meadows, and abandoned types among them. According to the syntaxonomic system, they include types from *Arrhenatherion (Anthoxantho-Festucetum pratensis)*, *Cynosurion* (unidentified at association level), *Cirsio-Brachypodion (Brachypodio-Molinietum)*, and *Violion caninae* (out of scope) alliances. Cluster 29 and 30 are also joined to this branch of clusters, making a transition towards the nutrient-rich and less acidic but intensively grazed *Cynosuro-Lolietum* association of *Cynosurion*. In the semi-dry half of the minimum spanning tree, Clusters 31 to 40 are semi-dry or dry types with high participation of species of rocky grasslands. Within this branch, there is a moisture gradient from Clusters 31 and 32 (mesic-xeromesic; *Filipendulo-Brometum* and a transitional type) through Cluster 33 to 36 (xeromesic;

Sanguisorbo-Brometum) to Clusters 37 to 40 (dry grasslands; *Festucion valesiacae* and *Bromo-Festucion pallentis*; out of scope). Grasslands represented by Cluster 41 and onwards with a few exceptions thrive on deeper soils, either on loess-covered lowlands or colline to montane forest clearings, and they are usually dominated by *Brachypodium pinnatum*. Four well-delimited associations are recognized within this large group of clusters, which are differentiated according to base-rock, phytogeographical character, and landscape context. Clusters 41 to 43 belong to *Polygalo-Brachypodietum*, which is a termophilous, colline type. Clusters 44 to 48 represent *Euphorbio-Brachypodietum*, the widespread semi-dry grassland of loess-covered lowland plateaus and foothills. Clusters 57 to 59 include *Trifolio-Brachypodietum* that is distributed in montane, forested areas. The latter two associations are accompanied by some clusters of out-of-scope types (Clusters 49 to 51: *Festucion rupicolae* and *Geranion sanguinei*, Cluster 60: *Stipenion tirsae*) and clusters with unclear interpretation but belonging to *Cirsio-Brachypodion* (Clusters 53 to 56).

Description of identified associations of Arrhenatheretalia and Brometalia erecti orders

After merging clusters representing the same type, 33 groups remained, for which there were 898 core relevés. The summaries of types identified as associations of *Arrhenatheretalia* and *Brometalia* orders with faithful, constant, and dominant species, and their distribution maps are presented in Appendix 3. A synoptic table is also supplied in Appendix 4.

Ranunculo bulbosi-Arrhenatheretum Ellmauer 1993 [in *Arrhenatherion*; Clusters 2 & 3]

This association has not been reported before from Hungary. According to Chytrý (2007), Willner et al. (2013b), and Uhliarová et al. (2014), *Ranunculo-Arrhenatheretum* is characterized by the dominance of *Arrhenatherum elatius* and the presence of less nutrient-demanding species of mesic and semi-dry meadows. In our data set, its dominant species are *Arrhenatherum elatius*, *Bromus erectus*, *Danthonia alpina,* and *Trisetum flavescens*. The accompanying species are elements of mesic or semi-dry, mown meadows with moderate nutrient availability (e.g. *Festuca rubra*, *Ranunculus polyanthemos*, *Vicia sativa* agg., *Rhinanthus minor*, *Anthoxanthum odoratum*, *Salvia* *pratensis*). This association includes two variants according to soil base status, Cluster 1 representing the base-rich subtype and Cluster 2 being the acidic one. Its relations to similar associations are presented at the discussion of respective types.

Tanaceto-Arrhenatheretum Fischer ex Ellmauer 1993 [in *Arrhenatherion*; Clusters 4, 5 & 6]

This association is also reported for the first time from Hungary. Its relevés represent mostly semi-ruderal stands dominated by *Arrhenatherum elatius* that are either abandoned meadows, disturbed or successional sites. Its characteristic features are the presence of ruderal and disturbance-tolerant species (e.g. *Medicago sativa*, *Eragrostis minor*, *Convolvulus arvensis*, *Artemisia vulgaris*, *Tanacetum vulgare*, *Anchusa officinalis*, *Potentilla argentea*) and the relatively low frequency of typical elements of *Arrhenatherion* (Ellmauer & Mucina 1993).

Pastinaco-Arrhenatheretum (Knapp 1954) Passarge 1964 [in *Arrhenatherion*; Cluster 7]

The dominant species is usually *Arrhenatherum elatius*, but other tall grasses (*Alopecurus pratensis*, *Bromus erectus*, *Dactylis glomerata*, *Festuca pratensis*) are also frequent. Constant and differential species are typical elements of productive, mesic meadows (e.g. *Cirsium canum*, *Pastinaca sativa*, *Ranunculus acris*, *Galium mollugo* agg.). These relevés come from colline to montane regions of different parts of Hungary. *Pastinaco-Arrhenatheretum* is often considered as a 'central' type among *Arrhenatherion* and it is especially difficult to distinguish from some very closely related associations (see also Stančić 2008, Willner et al. 2013b). According to our concept, *Pastinaco-Arrhenatheretum* in Hungary can be recognized by the dominance of tall grasses (see species mentioned above), the presence of mid-height grasses (e.g. *Trisetum flavescens*, *Poa pratensis*), and the high frequency of generalistic mesic meadow-elements (e.g. *Trifolium pratense*, *Vicia sativa* agg., *Leucanthemum vulgare* agg., *Campanula patula*, *Ranunculus acris*, *Galium mollugo* agg., *Cirsium canum*, *Pastinaca sativa*, *Tragopogon orientalis*). Although *Geranium pratense* is a diagnostic species of this association in neighbour countries with more mountainous landscape, in Hungary it is rare and occurs on moister habitats. Species typical of more nutrient-poor habitats (e.g. *Agrostis capillaris*, *Festuca rubra*, *Luzula campestris* agg., *Thymus pulegioides*) and shared elements with semi-dry grasslands (*Plantago media*, *Salvia pratensis*, *Trifolium montanum*, *Briza media*) are rare (however, not completely absent), thus they can be used for separation from the otherwise very similar *Ranunculo bulbosi-Arrhenatheretum*. In *Pastinaco-Arrhenatheretum*, species of *Molinietalia* (e.g. *Symphytum officinale*, *Ranunculus repens*, *Carex otrubae*, *Gentiana pneumonanthe*, *Selinum carvifolia*, *Succisa pratensis*) are also rare in general, aiding its separation from wet meadows where they are much more common. Several subassociations of *Pastinaco-Arrhenatheretum* are reported by Hungarian authors (Lájer 2002, Borhidi 2003) but we could not recognize them as separate clusters.

Filipendulo vulgaris-Arrhenatheretum Hundt & Hübl ex Ellmauer 1995 [in *Arrhenatherion*; Cluster 11]

The relevés representing this association not yet reported from Hungary are mostly from the southern and western parts of Transdanubia. These stands are situated on floodplains and along brooks on intermittently moist, less aired soils that have a wet and a dry period during the year. Due to the fluctuation of the water table, *Filipendulo-Arrhenatheretum* has a rather transitional character between semi-dry, mesic and wet conditions, containing species with different optima along the moisture gradient. An important feature of these grasslands is the presence of species that indicate fluctuation of soil moisture, e.g. *Alopecurus pratensis*, *Betonica officinalis, Potentilla alba,* and high cover of *Holcus lanatus* and *Helictotrichon pubescens*. There is usually no single dominant species of this type, probably because of the less stable water supply. According to Ellmauer & Mucina (1993) and Willner et al. (2013b), this association develops on less nutrient-rich soils than *Pastinaco-Arrhenatheretum*, and this is indicated by the presence of species like *Anthoxanthum odoratum*, *Briza media*, and *Luzula campestris* agg. It differs from *Ranunculo bulbosi-Arrhenatheretum* in the higher frequency of species indicating temporarily moist, packed soils, e.g. *Holcus lanatus*, *Betonica officinalis*, *Potentilla alba*, and in the lower frequency of drought-tolerant species, e.g. *Plantago media*, *Securigera varia*, *Centaurea scabiosa*, *Onobrychis viciifolia*. Nevertheless, Cluster 11 differs from the Austrian data of *Filipendulo-Arrhenatheretum* in that *Bromus erectus* is rare, whereas it is constant and can reach high cover in the relevés of Willner et al. (2013b). In Hungarian relevés *Arrhenatherum elatius* neither is a typical dominant species, although, it is subconstant, and sometimes it can reach over 20% cover. Some of the relevés in Cluster 11 are dominated by *Holcus lanatus* and also contain several species of wetter meadows, like *Lychnis flos-cuculi*, *Cardamine pratensis*, *Silaum silaus*, and *Sanguisorba officinalis*. Such relevés resemble the *Holcetum lanati* Issler 1934 association in *Deschampsion* alliance, however, this is not sufficiently differentiated from *Arrhenatherion* communities (Stančić 2008). Here we interpret *Filipendulo vulgaris-Arrhenatheretum* in a broad sense, including wetter stands similar to *Holcetum lanati*, and drier ones, where the cover of *Festuca rupicola* reaches 15%. Further studies may clarify the relationship of *Holcetum lanati* and other associations of *Molinion* and *Arrhenatherion*.

<u>*Ranunculo repentis-Alopecuretum pratensis* Ellmauer 1993</u> [in *Arrhenatherion*; Cluster 13]

Cluster 13 represents mesic meadows on nutrient-rich soils with the dominance of *Alopecurus pratensis, Trisetum flavescens, Festuca pratensis*, and other nutrient-demanding species. The constant and faithful species are also nutrient-demanding elements of *Arrhenatherion*, e.g. *Poa trivialis*, *Trisetum flavescens*, *Taraxacum officinale*, and *Glechoma hederacea*. In the Hungarian phytosociological literature, formerly this type was frequently identified with "*Alopecuro-Arrhenatheretum* (Máthé & Kovács) Soó 1971". This name was introduced by Soó (1971) and it included the *"Arrhenatheretum alopecuretosum"* and the *"Festuco-Cynosuretum arrhenatheretosum"* tables by Máthé & Kovács (1960). However, as it is pointed out by Borhidi et al. (2012), all these three names are invalid. Based on the original relevés, Borhidi et al. (2012) described *Anthoxantho-Festucetum pratensis* Borhidi 2012 for replacing the former name, and *Anthyllido-Festucetum rubrae arrhenatheretosum* Borhidi 2012 to validate the latter one (for update on this subassociation, see *Diantho-Arrhenatheretum*). However, according to the original relevés by Máthé & Kovács (1960) and the descriptions by Borhidi et al. (2012), both syntaxa are characterized by species of nutrient-poor soils, e.g. *Polygala vulgaris*, *Ranunculus auricomus*, *Dianthus deltoides*, therefore, Cluster 13 should not be identified with any of them, and the former interpretation of *"Alopecuro-Arrhenatheretum"* by Hungarian authors was mistaken. Nevertheless, the *Ranunculo repentis-Alopecuretum* Ellmauer 1993 association described from Austria is rather similar to Cluster 13, therefore we introduce it in Hungary. It occurs in the valleys of colline and montane areas. From *Pastinaco-Arrhenatheretum*, *Ranunculo-Alopecuretum* differs in the higher proportion of nutrient-demanding and wet grassland species, e.g. *Alopecurus pratensis*, *Crepis biennis*, *Carex hirta*, *Poa trivialis*; however, the delimitation of these two associations is unclear. The relationship between *Ranunculo-Alopecuretum* and *Deschampsion* associations also needs further studies.

Diantho-Arrhenatheretum (Máthé & Kovács 1960) Lengyel *nom. nov.* [in *Arrhenatherion*; Cluster 20]

Synonyms: *Festuco rubrae-Cynosuretum arrhenatheretosum* Máthé & Kovács 1960, *Anthyllido-Festucetum rubrae arrhenatheretosum* (Máthé & Kovács 1960) Borhidi 2012

Lectotypus: Máthé & Kovács (1960), Table III., Relevé 5, designated by A. Borhidi for *Anthyllido-Festucetum rubrae arrhenatheretosum* in Borhidi et al. (2012).

Cluster 20 shows high similarity with the relevés and description of *Anthyllido-Festucetum rubrae arrhenatheretosum* (Máthé & Kovács 1960) Borhidi 2012. (For more discussion on *Anthyllido-Festucetum rubrae*, see *Festuca rubra*-type.) However, in our classification we could not recognize the other subassociations with satisfactory confidence, including the typical one, of *Anthyllido-Festucetum*, therefore we propose to raise *arrhenatheretosum* to the association level with the name *Diantho deltoidis-Arrhantheretum elatioris* (Máthé & Kovács 1960) Lengyel *nom. nov.*. *Diantho-Arrhenatheretum* is a meadow type found on mountain areas that were traditionally mown and grazed in the past, but after the cessation of grazing tall grasses became dominant. The characteristic feature of this cluster is the joint occurrence of less nutrient-demanding plants (e.g. *Agrostis capillaris*, *Festuca rubra*, *Viola canina, Thymus pulegioides*) and drought-tolerant species (e.g. *Teucrium chamaedrys*, *Trifolium montanum*, *Thesium linophyllon*), elements of forest edges (e.g. *Melampyrum nemorosum*, *Luzula luzuloides*, *Primula veris, Cruciata glabra*), and the dominance of tall grasses, usually *Arrhenatherum elatius* or *Helictotrichon pubescens*. *Diantho-Arrhenatheretum* is similar to other nutrient-poor types of *Arrhenatherion*: *Ranunculo bulbosi-Arrhenatheretum* and *Filipendulo vulgaris-Arrhenatheretum*. From the latter two, *Diantho-Arrhenatheretum* differs in the higher number and constancy of elements of *Violion caninae* (e.g. *Thymus pulegioides*, *Dianthus deltoides, Viola canina, Carlina acaulis*), and forest edge species (e.g. *Luzula luzuloides*, *Primula veris*, *Cruciata glabra*). This association shows a landscape-scale change in vegetation due to the disappearance of traditional, extensive farming, since it is most common in higher elevation in the place of former mountain pastures. Nowadays these stands are mown or abandoned.

Anthoxantho-Festucetum pratensis Borhidi 2012 [in *Arrhenatherion*; Cluster 23]

The dominant species are *Festuca pratensis* and *Agrostis capillaris*, while there are many elements of wet meadows, forests, and clearings among the diagnostic species: *Ranunculus auricomus*, *Galium boreale*, *Carex pallescens*, *Lysimachia nummularia*, and *Ranunculus repens*. Similarly to *Filipendulo-Arrhenatheretum*, this type thrives on soils with wet and dry periods during a year but *Anthoxantho-Festucetum pratensis* is distributed on colder areas, and it contains more species of wet meadows and montane forests (e.g. *Carex pallescens*, *Ranunculus auricomus*), and acidic grasslands (e.g. *Agrostis capillaris*, *Polygala vulgaris*, *Viola canina*, *Dianthus deltoides*). Many of the sampled stands belonging to this cluster were grazed formerly as it is indicated by the presence of *Cynosurion* elements (e.g. *Plantago major*, *Leontodon autumnalis*, *Cynosurus cristatus*). This association is distributed in higher elevations of the North Hungarian Mountains.

Colchico autumnalis-Festucetum rupicolae Lengyel, Csiky, Dénes & Király *ass. nov. hoc loco* [in *Cynosurion*; Clusters 14 to 16]

Holotypus – Author: Andrea Dénes; Date: 20/May/1997; Location (WGS84): N 45.885°, E 17.764°, Drávafok (Hungary); Altitude: 100 m.a.s.l. Relevé area: 16 m^2. Species covers are in percentages. Herb layer: *Festuca rupicola* 35, *Luzula campestris* agg. 20, *Anthoxanthum odoratum* 15, *Filipendula vulgaris* 15, *Plantago lanceolata* 7, *Holcus lanatus* 4, *Centaurea jacea* agg. 3, *Colchicum autumnale* 2, *Ononis arvensis* s.lat. 2, *Saxifraga bulbifera* 1, *Trifolium montanum* 1, *Achillea millefolium* agg. 0.5, *Ajuga genevensis* 0.5, *Betonica officinalis* 0.5, *Carex caryophyllea* 0.5, *Cerastium vulgare* 0.5, *Euphorbia cyparissias* 0.5, *Fragaria viridis* 0.5, *Galium verum* 0.5, *Lathyrus pratensis* 0.5, *Leontodon hispidus* 0.5, *Leucanthemum vulgare* agg. 0.5, *Moenchia mantica* 0.5, *Myosotis ramosissima* 0.5, *Orchis morio* 0.5, *Ornithogalum umbellatum* agg. 0.5, *Pastinaca sativa* 0.5, *Polygala comosa* 0.5, *Ranunculus acris* 0.5, *Ranunculus bulbosus* 0.5, *Rumex acetosa* .lat. 0.5, *Taraxacum officinale* 0.5, *Veronica chamaedrys* agg. 0.5, *Viola canina* 0.5. Total cover of herb layer: 100%. Cryptogamous plants were not recorded.

This association includes extensive pastures and, occasionally, less productive hayfields that have a transitional position between mesic and semi-dry grasslands. They are similar to but drier than the driest forms of *Filipendulo vulgaris-Arrhenatheretum* but still contain many mesophilous species. The dominant species is usually *Festuca rupicola*, but other, short or medium-height grasses (e.g. *Briza media, Cynosurus cristatus*) can also be abundant, while tall grasses are scarce. Most relevés come from lowlands and floodplains from the Transdanubian Region and the north-eastern part of the Great Hungarian Plain. Such stands can develop on the place of former wet habitats that had been dried due to river regulation and also in clearings of alluvial forests that had been cut in favour of pasturing. They are typically located in the highest parts of the sandy dunes, just emerging from the levels directly affected by spring flood events. Cluster 14 and 15 contain relevés of the most typical, species-rich and moderately grazed or mown stands, while Cluster 16 represents a more weedy, heavily grazed subtype, however, we consider all the three belonging to the same association. Some of the relevés were published under the name *Anthoxantho-Festucetum* *pseudovinae* Juhász-Nagy 1959 and were assigned to its least intensively grazed variant dominated by *Festuca rupicola* (Juhász-Nagy 1959). Borhidi (2003) referred to the same type as "*Anthoxantho-Festucetum rupicolae* Dénes 1997", however, Dénes (1997) did not present a valid syntaxonomic description (Weber et al. 2000: 5. §). In our classification, the relevés from the *Festuca rupicola*-variant of *Anthoxantho-Festucetum pseudovinae* by Juhász-Nagy together with many other relevés from Transdanubia were separated from the 'typical' *Anthoxantho-Festucetum pseudovinae*, therefore, we describe the type represented by Clusters 14 to 16 as a new association, *Colchico autumnalis-Festucetum rupicolae*. As this is typically a pasture type, and physiognomically it is more similar to *Cynosurion* communities, we assign it to this alliance. However, a much needed international revision of *Cynosurion* communities may refine its position in the future. *Colchico autumnalis-Festucetum rupicolae* can be recognized by the dominance of *Festuca rupicola* with *Briza media* and *Anthoxanthum odoratum* as subdominant grasses, the low cover of tall grasses (*Helictotrichon pubescens*, *Alopecurus pratensis*, *Arrhenatherum elatius*), the occurrence of mesic meadow species (e.g. *Campanula patula*, *Leucanthemum vulgare, Colchicum autumnale, Trisetum flavescens*), drought-tolerant species (e.g. *Dianthus pontederae*, *Trifolium montanum*, *Filipendula vulgaris, Viola hirta*), and, occasionally, species preferring periodically waterlogged soils (e.g. *Carex pallescens*, *C. tomentosa, Sanguisorba officinalis*). Species of nutrient-poor and acidic grasslands are also often present (e.g. *Luzula campestris*, *Agrostis capillaris*, *Rumex acetosella*). This association is found in the peripherial areas of lowlands of the Carpathian Basin but can also occur in colline landscapes. The *Colchico autumnalis-Festucetum rupicolae* is maintained by moderate grazing, but after abandonment or replacement of grazing by mowing, stands can transform into *Filipendulo-Arrhenatheretum*.

Anthoxantho odorati-Festucetum pseudovinae Juhász-Nagy 1959 [in *Cynosurion*; Cluster 17]

Lectotypus: Juhász-Nagy (1959), Table IV., Relevé 14., designated here.

Cluster 17 represents a type that is similar to the previous one in its environmental conditions, but it is more heavily grazed and the dominant species is usually *Festuca pseudovina* instead of *F. rupicola*. Most of the relevés are from Juhász-Nagy's (1959) tables of the typical form of *Anthoxantho-Festucetum pseudovinae*. In the original description no holotype relevé was selected, therefore we identify Relevé 14 in Table IV of Juhász-Nagy (1959) as a lectotype. Despite some similarities in species composition and environmental conditions between *Anthoxantho-Festucetum pseudovinae* and *Colchico-Festucetum rupicolae*, we suggest to treat them as two separate associations. Their dominant species are different that can indicate difference in management or environmental factors, and several species in the original description of the former are absent or rare in the relevés from the wide distribution range of the latter. Such characteristic elements mentioned by Juhász-Nagy (1959) are *Hieracium auriculoides*, *H. caespitosum*, *Viola pumila*, and *Linum catharticum*, which could have been typical elements of grasslands of the Bereg Plain. The presence of grazing-tolerant species (e.g. *Veronica serpyllifolia*, *Myosotis stricta*) and the lack or low frequency of mesophilous species of more humid regions (e.g. *Trisetum flavescens*, *Cynosurus cristatus*, *Moenchia mantica*) are also indicative of *Anthoxantho-Festucetum pseudovinae*. Since this is a low-grass pasture type with many grazing-tolerant species, we consider this association within the alliance *Cynosurion*, in contrast with Borhidi et al. (2012) who assigned it to *Arrhenatherion*. Most relevés come from the north-eastern corner of the Great Hungarian Plain, and from lowland areas of West Transdanubia. According to Juhász-Nagy (1959), this type was much widespread in floodplains, but due to the decline of extensive animal husbandry and probably also due to the drop of ground water level in the Great Hungarian Plain, it became much rarer.

Alopecuro pratensis-Festucetum pseudovinae Juhász-Nagy 1959 [in *Cynosurion*; Cluster 18]

Alopecuro-Festucetum pseudovinae is a wetter substituent of *Anthoxantho-Festucetum pseudovinae* with more water-demanding species but similar, or even heavier effect of grazing. The relevés are from Juhász-Nagy's (1959) paper, in which they were included in the original description of the association. Soon after its description, Soó (1964) mentioned it as a subassociation *Carici vulpinae-Alopecuretum pratensis festucetosum pseudovinae* within *Molinietalia*, but later Botta-Dukát (2004) proposed to exclude it from the syntaxa of wet meadows. Similarly to the concept applied in Slovakia (Janišová et al. 2014), we consider *Alopecuro-Festucetum pseudovinae* an association in *Cynosurion*. This type develops on packed soils of wet meadows, as a result of heavy grazing. The stands are dominated by *Festuca pseudovina*, taller grasses are usually not abundant. The accompanying species are remnants of the original wet habitats (e.g. *Alopecurus pratensis*, *Inula britannica*), disturbance-tolerant plants of lowland areas (e.g. *Eryngium planum*, *Galega officinalis*) and pioneer species (e.g. *Erophila verna*, *Anthemis arvensis*, *Ranunculus sardous*) but elements of *Arrhenatheretalia* order are usually rare. In the Great Hungarian Plain, degraded wet meadows dominated by *Festuca pseudovina* are common in various environmental and land-use conditions, and their appropriate place in the syntaxonomic system should be clarified in further studies.

Cynosuro cristati-Lolietum perennis Br.-Bl. & De Leeuw 1936 [in *Cynosurion*; Cluster 30]

Synonym: *Lolio-Cynosuretum* Tx. 1937, for explanation on nomenclature, see Willner et al. 2013b

This association represents overgrazed, nutrient-rich pastures on mesic or wet soils. They are usually dominated by *Trifolium repens*, *Cynodon dactylon*, or *Cynosurus cristatus*, while the most faithful species are *Lolium perenne*, *Bromus racemosus* agg., and *Poa annua*. However, in the moister stands, more hygrophilous and salt-tolerant species also occur, e.g. *Carex distans*, *Agrostis stolonifera* agg., and, (regionally) *Hordeum secalinum*. We use the name *Cynosuro-Lolietum* in a broad sense now, because we include also those relevés which are from wetter habitats and are probably transitional towards *Deschampsion*. Their more accurate position should be investigated in the future. From *Colchico-Festucetum rupicolae*, *Anthoxantho-Festucetum pseudovinae*, and *Alopecuro-Festucetum pseudovinae* it can be easily separated by the low cover of xerophilous *Festuca* species and the high cover and frequency of nutrient-demanding, grazing-tolerant species (e.g. *Trifolium repens*, *Lolium perenne*, *Poa annua*, *Agrostis stolonifera*). This association was previously reported from submontane and montane regions of Hungary (Borhidi et al. 2012), but it is also distributed at lower elevations, if the climate is humid enough to provide mesic conditions.

Brachypodio pinnati-Molinietum arundinaceae Klika 1939 [in *Cirsio-Brachypodion*; Cluster 26]

The relevés of Cluster 26 are collected from meadows of mountain ranges, dominated by *Brachypodium pinnatum* and containing species of semi-dry grasslands (e.g. *Cirsium pannonicum*, *Helianthemum ovatum*, *Carex montana*), acidic grasslands (e.g. *Viola canina*, *Luzula campestris*), forest edges (e.g. *Cruciata glabra*, *Genista germanica*, *Potentilla alba*) and *Molinion* meadows (e.g. *Molinia caerulea* agg., *Succisa pratensis*, *Gladiolus imbricatus*). According to its mixed species composition, we identify this cluster with the *Brachypodio pinnati-Molinietum arundinaceae* Klika 1939 that until now was known only from the Czech and Slovak parts of the Western Carpathians (Chytrý 2007, Škodová & Ujházy 2014, Chytrý et al. 2015). However, its stands in Hungary are rather fragmental, and their development may also be a result of their special situation regarding vegetation dynamics. These stands were mown in the past, but currently many of them are abandoned. After abandonment, *Brachypodium pinnatum* and *Molinia caerulea* agg. spread and can quickly become dominant. The occurrence of some forest species (e.g. *Convallaria majalis*, *Symphytum tuberosum* agg.) is probably due to the landscape context, that is, mixed patches of forests and meadows. The presence of forest and edge species is also due to the mass effect, since these stands are usually situated in smaller forest clearings. Stands with such species composition are rare in Hungary, we have data only from a few locations in the Mátra, Bükk, and Zemplén Mts. This association can be recognized by containing xeromesic, mesic, wet grassland, and forest edge elements. *Brachypodio-Molinietum* was assigned to *Bromion* by Chytrý (2007) and Škodová & Ujházy (2014), however, we follow the concept of Roleček et al. (2014) who classified it to *Cirsio-Brachypodion*.

Filipendulo vulgaris-Brometum erecti Hundt & Hübl ex Willner 2013 [in *Cirsio-Brachypodion*; Cluster 31]

In Cluster 31, the dominant species is *Bromus erectus*, and it is accompanied by a mixture of mesophilous and xero-mesophilous species, e.g. *Dianthus carthusianorum*, *Saxifraga bulbifera*, *Festuca rupicola*. In the Hungarian literature, this type is sometimes referred to as "*Arrhenathero-Brometum erecti* Balázs 1951", however this is an invalid name, since Balázs (1951) used it only as a workname without the purpose of describing a new syntaxon. "*Arrhenathero-Brometum*" is not mentioned by Borhidi et al. (2012), but he assigns similar stands to *Onobrychido viciifoliae-Brometum erecti* within the alliance *Bromion erecti*. Illyés et al. (2009) did not support the presence of the *Bromion* alliance in Hungary, however, their data set probably did not contain enough relevés of the transitional types between *Brometalia erecti* and *Arrhenatheretalia* orders. According to Willner et al. (2013a,b), *Onobrychido-Brometum* and the *Bromion* alliance do not reach the Carpathian Basin, thus such transitional types should not be identified as *Onobrychido-Brometum*. Instead, for the meadows dominated by *Bromus erectus* and containing species of semi-dry and mesic grasslands, they described a new association in *Cirsio-Brachypodion*, *Filipendulo vulgaris-Brometum erecti* Hundt & Hübl ex Willner 2013. They consider also the records of *Onobrychido-Brometum* (sensu Janišová et al. 2007) in Slovakia referring to *Filipendulo-Brometum*. We treat Cluster 31 as belonging to this association. In Hungary this type differs from *Arrhenatherion* associations in the dominance of *Bromus erectus* and the higher frequency of xerophilous species (e.g. *Centaurea scabiosa*, *Festuca rupicola*, *Thesium linophyllon*, *Seseli annuum*) and less nutrient-demanding species of intermittently wet to semi-dry sites (e.g. *Sesleria uliginosa*, *Sanguisorba officinalis*, *Betonica officinalis*). In Austria, *Filipendulo-Brometum* shows a continuous transition with *Filipendulo-Arrhenatheretum*. In our classification, we identified Cluster 31, that is dominated by *Bromus erectus*, with *Filipendulo-Brometum*, and Cluster 11 that is (co-)dominated by other species, with *Filipendulo-Arrhenatheretum*, therefore their differentiation may be less problematic in Hungary. Besides the dominant species, *Filipendulo-Brometum* usually develops on drier and more calcareous sites than *Filipendulo-Arrhenatheretum*; for that reason, the proportion of xerophilous and calciphilous species is also indicative. From other associations of *Cirsio-*

Brachypodion, *Filipendulo-Brometum* can be separated by the high cover of *Bromus erectus* and the presence of moisture-demanding species, while species of rocky habitats are usually absent.

Sanguisorbo minoris-Brometum erecti Illyés, Bauer & Botta-Dukát 2009 (in *Cirsio-Brachypodion*; Clusters 33 to 36]

Clusters 33 to 36 represent dry to semi-dry grasslands dominated by *Bromus erectus* from shallow soils of the calcareous mountains and colline ranges. We identify these clusters with the association *Sanguisorbo minoris-Brometum erecti* Illyés, Bauer & Botta-Dukát 2009. This syntaxon has been described recently by Illyés et al. (2009) as the common, calciphilous semi-dry grassland type of the Transdanubian Region with *Bromus erectus* as the dominant grass and many species of *Festuco-Brometea*. The generalist species of calcareous, dry grasslands (e.g. *Teucrium chamaedrys*, *Festuca valesiaca*, *Thymus pannonicus* agg., *Sanguisorba minor*) are common in this association. Several variants can be recognized. In stands on deeper soils (mostly Cluster 33) and with better nutrient- and water-supply, meadow species (e.g. *Lotus corniculatus agg.*, *Arrhenatherum elatius*, *Knautia arvensis* agg.) are more frequent, however, they typically do not reach that high proportion as in *Filipendulo-Brometum*. In more open stands with eroded or shallow stony soils and rarely bare rock surfaces (mostly Cluster 34), calcareous species of shallow and dry soils (e.g. *Stipa capillata*, *S. pennata*, *Carex humilis*) are characteristic, although, such stands also contain indicators of grazing due to their past management regime (e.g. *Lepidium campestre*, *Eryngium campestre*). Stands situated mosaically in smaller clearings of thermophilous oak forests (mostly Cluster 36) are rich in forest edge species (e.g. *Euphorbia angulata*, *Campanula persicifolia*, *Geranium sanguineum*). From *Filipendulo-Brometum, Sanguisorbo-Brometum* can be separated by the lower cover or absence of some rather acidophilous species (e.g. *Luzula campestris, Moenchia mantica, Anthoxanthum odoratum*), the high frequency of calciphilous rocky and dry grassland species (e.g. *Acinos arvensis, Anthyllis vulneraria* subsp. *polyphylla, Aster linosyris, Euphorbia seguieriana, Hippocrepis comosa, Stachys recta*) instead of mesophilous ones. In the Slovak and Czech literature

Scabioso ochroleucae-Brachypodietum pinnati is reported to thrive on similar habitats and eventually dominated by *Bromus erectus*. However, *Sanguisorbo-Brometum* lacks many of the diagnostic species of *Scabioso-Brachypodietum*, e.g. *Cirsium acaule*, *Carlina acaulis*, *Ononis spinosa*, and *Linum catharticum*. Moreover, *Brachypodium pinnatum* is rather rare in *Sanguisorbo-Brometum* (see also Illyés et al. 2009), while it is the most typical dominant species of *Scabioso-Brachypodietum*. About separation from other associations of *Cirsio-Brachypodion*, see therein.

<u>*Polygalo majoris-Brachypodietum pinnati*</u> Wagner 1941 [in *Cirsio-Brachypodion*; Clusters 41, 42 & 43]

This association represents species-rich, semi-dry grasslands from the colline region with the dominance of *Brachypodium pinnatum*, sometimes *Bromus erectus* or *Inula ensifolia*, with a wide pool of termophilous and calciphilous species, e.g. *Adonis vernalis*, *Polygala major*, *Carex halleriana*, *Onobrychis arenaria*, *Pulsatilla grandis*. According to the interpretation by Borhidi et al. (2012), this syntaxon is represented by two variants in Hungary: a western one containing sub-Mediterranean and Pontic-Pannonian elements, and an eastern one with montane and continental species. Illyés et al. (2009) identified a small cluster with distinct distribution from the Bükk Mts as the eastern variant with many montane species (e.g. *Carlina acaulis*, *Dracocephalum ruyschiana*, *Primula elatior*), while they did not support the existence of the western type. We could not confirm this montane type in our classification as a variant of *Polygalo-Brachypodietum*, but according to the descriptions and evaluations by Illyés et al. (2009), it is probably more similar to our Cluster 26, i.e. to *Brachypodio-Molinietum* and should be interpreted under this association or as a transition to it. It is notable that according to Škodová & Ujházy (2014) in Slovakia *Brachypodio-Molinietum* forms a transition towards *Polygalo-Brachypodietum*. Such transitional subtypes contain many of the diagnostic species of *Polygalo-Brachypodietum*, but they also contain mesophilous species. In our classification, *Polygalo-Brachypodietum* differs from *Sanguisorbo-Brometum* in the higher cover of *Brachypodium pinnatum*, the higher frequency and cover of forbs (e.g. *Inula ensifolia*, *Chamaecytisus austriacus* agg., *Pulsatilla grandis*, *Polygala major, Onobrychis arenaria, Scorzonera hispanica, Cirsium pannonicum, Peucedanum cervaria*), among which the proportion of Pontic-Pannonian species is high. *Polygalo-Brachypodietum* harbours less montane, mesophilous, and *Molinion*-species than *Brachypodio-Molinietum*.

Euphorbio pannonicae-Brachypodietum pinnati Horváth 2010 [in *Cirsio-Brachypodion*; Clusters 44 to 48]

This association is a semi-dry grassland dominated by *Brachypodium pinnatum*, and distributed in the Pannonian loess-covered lowlands and foothills. Similarly to *Polygalo-Brachypodietum*, it is also rich in forbs but mostly in species preferring deeper soils on loess (e.g. *Euphorbia glareosa*, *Filipendula vulgaris*, *Thalictrum minus*, *Inula hirta*, *Ranunculus polyanthemos*). It has a few loess specialist species (e.g. *Nepeta parviflora*, *Ajuga laxmannii*, *Viola ambigua*, *Taraxacum serotinum*), that are very distinctive elements, however, since they are rare even within this type, they did not obtain high enough fidelity values. This community differs from *Polygalo-Brachypodietum* in the lower proportion of Pontic and sub-Mediterranean species (e.g. *Aster amellus*, *Polygala major*, *Inula ensifolia*, *Pulsatilla grandis, Carex halleriana*). A subtype of *Euphorbio-Brachypodietum* is dominated by *Bromus erectus* thus confusion is possible with *Sanguisorbo-Brometum.* However, in *Euphorbio-Brachypodietum* species of shallow, dry soils (e.g. *Acinos arvensis*, *Sanguisorba minor*, *Dianthus pontederae*, *Hippocrepis comosa*, *Petrorhagia saxifraga*), are least frequent.

Trifolio medii-Brachypodietum pinnati Illyés, Bauer & Botta-Dukát 2009 [in *Cirsio-Brachypodion*; Clusters 57 to 59]

Clusters 57 to 59 are from grasslands dominated by *Danthonia alpina*, *Brachypodium pinnatum*, or *Helictotrichon adsurgens* from the North Hungarian Mountains. They contain many forest edge species (e.g. *Pulmonaria mollis*, *Trifolium medium*, *Aconitum anthora*, *Dictamnus albus*), species which are shared with mesic meadows (e.g. *Briza media*, *Filipendula vulgaris*, *Salvia pratensis*) and rather acidotolerant species (e.g. *Potentilla alba*, *Luzula campestris* agg.). This association was described with the name *Trifolio medii-Brachypodietum pinnati* by Illyés et al. (2009). It differs from *Polygalo-Brachypodietum* and *Euphorbio-Brachypodietum* in the higher frequency of forest edge species, mesophilous, and acidophilous grassland plants and the lower proportion of Pontic and Pannonian species. From *Brachypodio-Molinietum* it can be separated by the lower proportion of montane and wet meadow species (e.g. *Cruciata glabra*, *Potentilla erecta*, *Carex pallescens*, *Viola canina*, *Succisa pratensis*, *Molinia caerulea*), although some generalist species that are frequent also on *Molinion* meadows (e.g. *Betonica officinalis*, *Serratula tinctoria*, *Potentilla alba*) can occur in *Trifolio-Brachypodietum*. Considering the definitions and descriptions of *Brachypodio-Molinietum* (Chytrý 2007, Janišová et al. 2007, Škodová & Ujházy 2014), relevés fulfilling our criteria of *Trifolio-Brachypodietum* were probably previously assigned to *Brachypodio-Molinietum* in Slovakia. The relationship between these two associations needs to be clarified in the future.

Description of types assigned to alliances without identification at association level

<u>*Sanguisorba officinalis*-type</u> [in *Arrhenatherion*; Cluster 27]

Cluster 27 represents a type that is distributed in the most humid, western part of Transdanubia on slightly acidic soils. The most common dominant species is *Sanguisorba officinalis*, that is accompanied by elements of *Arrhenatherion* (e.g. *Trisetum flavescens*, *Tragopogon orientalis*, *Festuca rubra*), *Polygono-Trisetion* (e.g. *Hypericum maculatum* agg., *Pimpinella major*), and *Violion caninae* (e.g. *Viola canina*, *Danthonia decumbens*). The co-occurrence of these species groups points to *Poo-Trisetetum flavescentis* association in *Arrhenatherion*. However, *Poo-Trisetetum* is known as a very variable but usually intensively mown meadow type of humid areas, mostly dominated by *Trisetum flavescens*, *Poa trivialis*, *P. pratensis*, *Festuca rubra*, and other medium-tall grasses (Dierschke 1997, Chytrý 2007, Uhliarová et al. 2014). In contrast, the stands of Cluster 27 are managed extensively by infrequent mowing (maximum once a year), resulting in high cover of forbs (e.g. *Sanguisorba officinalis*, *Betonica officinalis*, *Hieracium umbellatum*) instead of graminoids. Despite its distinctness, we could not identify Cluster 27 with either *Poo-*

Trisetetum or other associations previously known from Hungary and the neighbour countries. Further analyses with the involvement of Austrian and Slovenian data of montane meadows may help clarify its syntaxonomical position.

Agrostis capillaris-Trifolium pratense-type [in *Cynosurion*; Cluster 21]

Cluster 21 contains relevés from mesic pastures and nutrient-poor meadows from the colline and montane sites. The dominant species (*Agrostis capillaris*, *Trifolium pratense*, *Holcus lanatus*), and also the constant, and diagnostic species (e.g. *Anthoxanthum odoratum*, *Festuca rubra*, *Trisetum flavescens*, *Clinopodium vulgare*) are rather generalist, therefore, it is difficult to delimit its variation along environmental and land-use gradients, or identify it at the association level. However, there are some typical elements of pastures among the diagnostic species, e.g. *Plantago major*, *Cynosurus cristatus*, *Trifolium dubium*, and *Phleum pratense* agg. (mostly *Phleum bertolonii*), thus we consider this type belonging to *Cynosurion*. Although *Festuco commutatae-Cynosuretum* is mentioned as the mesic pasture association of colline and montane regions (e.g. Soó 1973, Borhidi et al. 2012), its descriptions often highlight the presence of montane species, e.g. *Alchemilla* spp., *Danthonia decumbens*, *Carlina acaulis*, *Rhinanthus alectorolophus*, *Rh. wagneri*, which are rare or absent in this cluster. According to Ellmauer & Mucina (1993), there are several elements of nutrient-poor grasslands among the diagnostic species of *Festuco-Cynosuretum*, e.g. *Thymus pulegioides* and *Potentilla erecta*, which are also not typical in Cluster 21. Therefore, we assign this cluster to *Cynosurion*, and note that the identification at the association level needs further studies.

Vulpia-Festuca rubra-grasslands [in *Cynosurion*; Cluster 29]

Cluster 29 includes relevés from overgrazed pastures and old-fields from eroded soils. It is characterized by species of disturbed, open, nutrient-poor vegetation, like *Sherardia arvensis*, *Vulpia* spp., *Aphanes arvensis* agg., and *Trifolium striatum*, while the dominant species is *Festuca rubra*. This type is likely to be a disturbed variant of other associations in the *Cynosurion* alliance.

It is probably more widespread on leached soils in the more humid regions of Hungary than as it is represented in our database, because such stands are often considered as disturbed, pioneer or transitional types, and thus rarely recorded by phytosociologists. Due to the shortness of data, we cannot evaluate it in more detail here.

<u>*Linum tenuifolium-Brachypodium pinnatum*-type</u> [in *Cirsio-Brachypodion*; Clusters 55 & 56]

Cluster 55 and 56 are from grasslands of calcareous, shallow soils, dominated by *Brachypodium pinnatum*. Accompanying species are xerophilous and calciphilous, e.g. *Linum tenuifolium*, *Carex liparicarpos*, *Seseli hippomarathrum*, *Teucrium montanum*. This type is similar to *Lino tenuifolii-Brachypodietum pinnati* (Dostál 1933) Soó 1971 according to the description of Borhidi et al. (2012). According to Soó (1971) this name includes *Polygalo-Brachypodietum* from Austria (Wagner 1941), while Škodová (2014) considers it as a syntaxonomical synonym of *Scabioso-Brachypodietum* Klika 1933. Since the nomenclature of *Scabioso-Brachypodietum* and its delimitation from other associations is unclear, we avoid using this name. In this cluster, Pontic and Pannonian elements (e.g. *Aster amellus*, *Polygala major*, *Inula ensifolia*) and shared species of semi-dry and mesic grasslands (e.g. *Campanula glomerata*, *Filipendula vulgaris*, *Ranunculus polyanthemos*, *Salvia pratensis*) are rarer, while some species of drier grasslands (e.g. *Festuca valesiaca*, *Carex liparicarpos, Teucrium montanum*) are more frequent. The occurrence of grazing tolerant species (e.g. *Ononis spinosa*, *Eryngium campestre*, *Carlina vulgaris*) may be an indicator of former pasturing that may have led to lower species richness. Despite the dominant species, its environmental background and species pool are similar to the *Sanguisorbo-Brometum* on thicker soils.

Description of out-of-scope types with nomenclatural relations to Arrhenatheretalia or Brometalia erecti

<u>*Festuca rubra*-type</u> [in *Violion caninae*; Cluster 22]

Cluster 22 comprises nutrient-poor, montane, mesic grasslands that are either grazed or recently abandoned. The dominant species are *Festuca rubra*, *Agrostis capillaris*, *Galium verum*, and *Anthoxanthum odoratum*, and the differential species are *Thymus pulegioides*, *Viola canina*, *Solidago virgaurea*, and *Veronica officinalis*. Previously mesic grasslands of nutrient-poor sites dominated by *Festuca rubra* and *Agrostis capillaris* were traditionally assigned to *Anthyllido-Festucetum rubrae* (in *Arrhenatherion*) in Hungary; however, the species composition of Cluster 22 does not match satisfactorily with its descriptions (Soó 1971, Borhidi 2003). Moreover, there are issues concerning the separation of this association from other nutrient-poor grasslands. According to Borhidi et al. (2012), *Anthyllido-Festucetum* includes three subassociations: *typicum*, *agrostidetosum*, and *arrhenatheretosum*; each of them relying on nomenclatural tables originally published by Máthé & Kovács (1960) as subassociations of *Festuco-Cynosuretum* (but see *Diantho-Arrhenatheretum* for our concept on the *Arrhenatherum*-dominated type). However, Jurko (1974) classified these tables to *Anthoxantho-Agrostietum tenuis* Sillinger 1930. The differentiation between *Anthyllido-Festucetum rubrae* and *Anthoxantho-Agrostietum tenuis* was never made explicit by any authors, and it is very likely that they should be considered synonyms (or *pro parte* synonyms). However, there is also a disagreement among foreign authors on the interpretation of *Anthoxantho-Agrostietum*. Jurko (1974) classified many nutrient-poor grassland types to this association within *Cynosurion*, including variants which are now treated under *Violion caninae*. More recently authors tended to use this syntaxon name in a narrower sense, although, in slightly different ways, that is also mirrored by its assignment to alliances. Chytrý (2007) assigned *Anthoxantho-Agrostietum* to *Cynosurion*, Janišová et al. (2007), Rozbrojová et al. (2010), and Uhliarová et al. (2014) classified it to *Arrhenatherion*, while Willner et al. (2013b) considered it as a part of *Violion caninae*. The species composition of Cluster 22 is also very similar to *Campanulo rotundifoliae-Dianthetum deltoidis* (in *Violion caninae*) in the Czech Republic according to Chytrý (2007). However, according to Ujházy & Kliment (2014), an important feature of this association is the constant occurrence and significant (over 5%) cover of *Nardus stricta*, that is absent in Cluster

22. The delimitation between *Campanulo-Dianthetum* and *Anthoxantho-Agrostietum* is also unclear, therefore, Willner et al. (2013b) treated the former as a part of *"Anthoxantho-Agrostietum s. lat."*. The syntaxonomy of nutrient-poor, mesic grasslands obviously needs a supra-national revision, therefore, we cannot identify Cluster 22 at the level of association. Since in this type the proportion of mesotrophic species of *Arrhenatherion* and *Cynosurion* is rather low, similarly to Willner et al. (2013b) we consider it in *Violion caninae*, that is out of the scope of this paper.

Stipenion tirsae Borhidi 2012 [in *Festucion valesiacae*; Cluster 60]

Cluster 60 represents a type dominated by *Stipa tirsa*, and this is out of our scope. Although, similar grasslands (with the name *Stipetum tirsae* Meusel 1938) are classified to *Cirsio-Brachypodion* by Dengler et al. (2012), we follow a more common viewpoint that considers *Stipenion tirsae* as a separate suballiance in *Festucion valesiacae* (Borhidi et al. 2012; see also Chytrý 2007, Hegedüšová Vantarová & Škodová 2014).

Ordinations

In the principal coordinates analysis of all identified associations, 9.59% and 6.18% of the total variation were explained by the first two axes, respectively. *Arrhenatheretalia* and *Brometalia erecti* were separated along Axis 1 (Fig. 3) with more mesic associations being on the left and semi-dry association on the right side of the diagram. Associations of *Brometalia* containing a high proportion of mesophilous species (*Brachypodio-Molinietum*, *Filipendulo-Brometum*) are placed in intermediate position. The two driest associations, *Sanguisorbo-Brometum* and *Euphorbio-Brachypodietum* are well separated from all other associations, while *Polygalo-Brachypodietum* and *Trifolio-Brachypodietum* are in central position in the variation range of *Cirsio-Brachypodion*. Fig. 4 shows the ordination of *Arrhenatheretalia* associations. The first two axes revealed 11.04% and 5.74% of the total variation, respectively. Along Axis 1 the types dominated by *Arrhenatherum elatius* (*Tanaceto-Arrhenatheretum*, *Ranunculo-Arrhenatheretum*, *Pastinaco-Arrhenatheretum*) are placed on the left-hand side. *Cynosurion* communities are separated along Axis 2, with

Anthoxantho-Festucetum pseudovinae and *Alopecuro-Festucetum pseudovinae* being the most extremes along this gradient, while *Colchico-Festucetum* and *Cynosuro-Lolietum* are closer to *Arrhenatherion* communities. The species-rich meadow associations with various management and environmental background (i.e. *Filipendulo-Arrhenatheretum*, *Anthoxantho-Festucetum pratensis*, *Diantho-Arrhenatheretum*, *Ranunculo-Alopecuretum*) are close to each other at the bottom right-hand corner of the diagram.

Syntaxonomical summary

On the basis of our classification, we suggest the following system for the mesic and semi-dry grasslands in Hungary:

Order: *Arrhenatheretalia* Tx. 1931 (in *Molinio-Arrhenatheretea*)

1. Alliance: *Arrhenatherion elatioris* Koch 1926
   - 1.1. Association: *Ranunculo bulbosi-Arrhenatheretum* Ellmauer 1993
   - 1.2. Association: *Tanaceto vulgaris-Arrhenatheretum* Fischer ex Ellmauer 1993
   - 1.3. Association: *Pastinaco sativae-Arrhenatheretum* (Knapp 1954) Passarge 1964
   - 1.4. Association: *Filipendulo vulgaris-Arrhenatheretum* Hundt & Hübl ex Ellmauer 1995
   - 1.5. Association: *Diantho deltoidis-Arrhenatheretum* (Máthé & Kovács 1960) Lengyel *nom. nov.*
   - 1.6. Association: *Anthoxantho odorati-Festucetum pratensis* Borhidi 2012
   - 1.7. Association: *Ranunculo repentis-Alopecuretum pratensis* Ellmauer 1993
2. Alliance: *Cynosurion cristati* Tüxen 1947
   - 2.1. Association: *Colchico autumnalis-Festucetum rupicolae* Lengyel, Csiky, Dénes & Király *ass. nov.*
   - 2.2. Association: *Anthoxantho odorati-Festucetum pseudovinae* Juhász-Nagy 1959
   - 2.3. Association: *Alopecuro pratensis-Festucetum pseudovinae* Juhász-Nagy 1959
   - 2.4. Association: *Cynosuro cristati-Lolietum perennis* Br.-Bl. & De Leeuw 1936

Order: *Brometalia erecti* Br.-Bl. 1936 (in *Festuco-Brometea*)

1. Alliance: *Cirsio pannonici-Brachypodion pinnati* Hadač & Klika 1944
    - 1.1. Association: *Brachypodio pinnati-Molinietum arundinaceae* Klika 1939
    - 1.2. Association: *Filipendulo vulgaris-Brometum erecti* Hundt & Hübl ex Willner 2013
    - 1.3. Association: *Sanguisorbo minoris-Brometum erecti* Illyés, Bauer & Botta-Dukát 2009
    - 1.4. Association: *Polygalo majoris-Brachypodietum pinnati* Wagner 1941
    - 1.5. Association: *Euphorbio pannonicae-Brachypodietum pinnati* Horváth 2010
    - 1.6. Association: *Trifolio medii-Brachypodietum pinnati* Illyés, Bauer & Botta-Dukát 2009

With the above suggestions, we introduce significant changes in syntaxonomy of the *Arrhenatheretalia* and *Brometalia erecti* orders in Hungary. In the *Arrhenatherion* order, five new associations have been introduced. Four of them (*Ranunculo bulbosi-Arrhenatheretum*, *Filipendulo-Arrhenatheretum*, *Tanaceto-Arrhenatheretum*, *Ranunculo-Alopecuretum*) are adopted from the Austrian and Slovak literature, while a former subassociation has been proposed to be raised at the association level with the name *Diantho-Arrhenatheretum*. We excluded the *Anthyllido-Festucetum rubrae* from the *Arrhenatherion* communities in Hungary. *Anthoxantho-Festucetum pseudovinae*, that was assigned to *Arrhenatherion* by Borhidi et al. (2012), has been moved to *Cynosurion*. *Alopecuro-Festucetum pseudovinae* as a separate association appeared in synthetic reviews for the first time in literature of Hungarian vegetation after its original publication. *Colchico-Festucetum rupicolae* has been described as a new association. According to Willner et al. (2013b), the name *Cynosuro-Lolietum* has been adopted in order to replace the invalid name *Lolio-Cynosuretum*. Neither our analyses nor our field experiences supported the presence of *Phyteumo-Trisetion* alliance in Hungary. In *Brometalia erecti*, the most fundamental changes regarded the treatment of *Bromion erecti*. *Carlino acaulis-Brometum* was not recognized as a separate cluster in our analysis. The type that was mentioned as *Onobychido-Brometum* by Borhidi et al. (2012) was identified with *Filipendulo-Brometum* (belonging to *Cirsio-Brachypodion*), which is a new element in the list of Hungarian syntaxa. Therefore, we suggest rejecting both names, *Carlino-Brometum* and *Onobrychido-Brometum* that were considered as the representatives of *Bromion* in our country. We detected *Brachypodio-Molinietum* for the first time in Hungary and assigned it to *Cirsio-Brachypodion*. Apart from detecting *Filipendulo-Brometum* and *Brachypodio-Molinietum* as associations new to the country, our findings about *Cirsio-Brachypodion* are in a good match with Illyés et al. (2009). We supported the presence of *Polygalo-Brachypodietum*, *Euphorbio-Brachypodietum*, *Trifolio-Brachypodietum*, and *Sanguisorbo-Brometum* in Hungary. We could not recognize and interpret *Poo badensis-Caricetum montanae* (see Varga 1997) and *Lino-Brachypodietum* unambiguously; therefore, we also suggest removing the latter two from the list of Hungarian syntaxa. We separated four vegetation types belonging to *Arrhenatheretalia* or *Brometalia* but without identification at the association level. Further studies should focus on the clarification of their position.

Possible biases and open questions

Present work is currently the most comprehensive synthesis of mesic and semi-dry grasslands in Hungary that was based on statistical analysis of a large data set of phytosociological relevés. The size of the data set applied falls short compared to certain national syntheses (Chytrý 2007, Hegedüšová Vantarová & Škodová 2014), however, we still consider it sufficient for detecting the most significant types in Hungary. Although, we paid great attention to fully cover the compositional variation of the target syntaxa, there are differences among regions in the degree of representativeness. Clearly, areas which were subject to more detailed, regional studies in the near past (e.g. Bakony Region: Bauer 2012; South Transdanubia: Lengyel et al. 2012a) are better represented than others, and not all of such inequalities may have been corrected by the applied geographically stratified HCR resampling. Moreover, geographical biases may have interacted with the uneven temporal coverage. Relevés by Juhász-Nagy (1959) from the Bereg Plain played a big role in the recognition of *Anthoxantho-Festucetum pseudovinae* and *Alopecuro-Festucetum* *pseudovinae*, since Cluster 17 and 18 were formed almost only of these relevés. At the time of sampling, in the 1950s, the management of meadows and pastures may have been different from the current one, not only in the Bereg Plain but across the country (Molnár et al. 2012). Moreover, the Bereg Plain is a rather special and marginal part of the distribution of mesic grasslands due to its continental climate. In addition, comparison of old and recent phytosociological data is always biased due to differences in the concept of sampling and taxonomy (Podani 2006). In addition, the relevés by Juhász-Nagy (1959) lacked information on plot size and covers of rare species, however, we expected insignificant influence of these shortcomings on the classification. Unfortunately, we have no more recent data from the Bereg Plain. For these reasons, we admit that biogeographical patterns, temporal changes in the management and conceptual differences in the methodology may have equally contributed to the separation of these two clusters, and therefore, the information on these types presented here should be interpreted with more caution. Nevertheless, *Festuca rupicola*-dominated relevés of Juhász-Nagy (1959) were classified together with many relevés from Transdanubia with clearly similar habitat conditions, which can be interpreted as a positive example of the applicability of old data for current investigations.

During the evaluation of types (i.e. one or more clusters assigned to the same low syntaxon) we only considered relevés with positive silhouette values, i.e. those which are surely more similar to the other relevés in the same type than to relevés of the most similar other type. With this decision we made separations between types clearer in order to ease their interpretation. However, it is important to bear in mind that our descriptions refer to the most typical forms of each association (or their variants, in some cases). Undoubtedly, transitional stands do exist between several types and many of them cannot be reliably identified syntaxonomically.

In our classification we aimed at identifying vegetation types at the association level, however, no revisions of associations can avoid questions related to higher-level syntaxa. Despite many arguments about their nomenclature and interpretation, e.g. *Brometalia erecti*, regarding the treatment of orders and alliances we followed the concept of Borhidi et al. (2012).

We clustered the data set at a relatively fine resolution (60 clusters), and then evaluated relationships between clusters by a minimum spanning tree, literature data, and field experiences. Then, certain clusters were merged, if they were judged as belonging to the same association. In cases of several associations, when it was reasonable, we preferred to adopt names from literatures of neighbour countries in order to reduce idiosyncrasy in the syntaxonomy of Hungarian grasslands. Such adoptions were done on the basis of informal examination of phytosociological data or textural descriptions of associations from reference literature, but no quantitative approaches were applied for the assignment of unclassified relevés to existing types. Although, several supervised or semi-supervised methods have been published with this aim (van Tongeren et al. 2008, Tichý et al. 2014), due to the strong biogeographical pattern in species composition of grasslands, we experienced their limitations when the geographical origin of the reference data differed from that of the relevés to be classified. Due to the lack of quantitative support for the adoption of certain names applied in foreign literature and for rejection of names previously used in Hungary, in the future, the distribution and geographical variation of grassland syntaxa should be revised in a supra-national analysis. Such broader-scale investigations should be supplemented by studies on local and regional scales with the aim of revealing dynamics, local variation, and conservation aspects of these threatened vegetation types.

Acknowledgements

We are grateful to Monika Janišová, Iveta Škodová, Wolfgang Willner, and Zsolt Molnár for valuable discussions on the interpretation of grassland syntaxa and nomenclature. Special thanks to the three anonymous referees whose comments significantly improved our manuscript. We thank Andrea Dénes for giving access to her data. The work of Attila Lengyel was supported by the

European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP-4.2.4.A/ 2-11/1-2012-0001 'National Excellence Program'. The study of Gergely Király was supported by the project "Agrárklíma.2 VKSZ-12-1-2013-0034".

References

Aavik T., Jõgar Ü., Liira J., Tulva I. & Zobel, M. (2008): Plant diversity in a calcareous wooded meadow – The significance of management continuity. – J. Veg. Sci. 19: 475–484.

Balázs F. (1951): Mérések a B-szám megállapítására [Measurements for the determination of the B-value]. – Mosonm. Mg. Kís. Int. Évk. 1: 29–37.

Bauer N. (2012): Dry grasslands of the Bakony Region. PhD dissertation, University of Pécs, Hungary, 131 pp.

Bauer N. (2014): A Bakony-vidék szárazgyepjei. Sztyeprétek és sziklagyepek osztályozása és növényföldrajzi karaktere [Dry grasslands of the Bakony Region. Classification and phytogeographical character of dry and rocky grasslands]. – MTM, Budapest, A Bakony természettudományi kutatásának eredményei 33: 336 pp.

Bernhardt-Römermann M., Römermann C., Sperlich S. & Schmidt W. (2011): Explaining grassland biomass – the contribution of climate, species and functional diversity depends on fertilization and mowing frequency. – J. App. Ecol. 48: 1088–1097.

Blagotić A. & Daróczi G. (2013): Rapport: a report templating system. – R package version 0.51, URL: http://cran.r-project.org/package=rapport

Borhidi A. (2003): Magyarország növénytársulásai [Plant communities of Hungary]. – Akadémiai Kiadó, Budapest, 610 pp.

Borhidi A., Kevey B. & Lendvai G. (2012): Plant communities of Hungary. – Akadémiai Kiadó, Budapest, 544 pp.

Borhidi A. & Sánta A. (eds.) (1999): Vörös könyv Magyarország növénytársulásairól 1–2. [Red data book of Hungarian plant communities 1–2.]. – Természetbúvár Alapítvány Kiadó, Budapest 367 pp., 404 pp.

Botta-Dukát Z. (2004): A magyarországi mocsárrétek cönológiai irodalmának áttekintése és szüntaxonómiai revíziója [Deschampsion caespitosae meadows in Hungary: review of literature and numeric syntaxonomical revision]. – Kanitzia 12: 43–73.

Braun-Blanquet J. (1930): Zentralalpen und Tatra, eine pflanzensoziologische Parallele. – Veröff. Geobot. Inst. Rübel 6: 81–123.

Burrascano S., Anzellotti I., Carli E., Del Vico E., Facioni L., Pretto F., Sabatini F. M., Tilia A. & Blasi C. (2013): Drivers of beta-diversity variation in *Bromus erectus* semi-natural dry grasslands. – App. Veg. Sci. 16: 404–416.

Chytrý M., Dražil T., Hájek M., Kalníková V., Preislerová Z., Šibík J., Ujházy K., Axmanová I., Bernátová D., Blanár D., Dančák M., Dřevojan P., Fajmon K., Galvánek D., Hájková P., Herben T., Hrivnák R., Janeček Š., Janišová M., Jiráská Š., Kliment J., Kochjarová J., Lepš J., Leskovjanská A., Merunková K., Mládek J., Slezák M., Šeffer J., Šefferová V., Škodová I., Uhlířová J., Ujházyová M. & Vymazalová M. (2015): The most species-rich plant communities in the Czech Republic and Slovakia (with new world records). – Preslia 87: 217–278.

Chytrý M. (ed). (2007): Vegetation of the Czech Republic. 1, Grassland and heathland vegetation. – Academia, Praha, 528 pp.

Chytrý M., Tichý L., Holt J. & Botta-Dukát Z., (2002): Determination of diagnostic species with statistical fidelity measures. – J. Veg. Sci. 13: 79–90.

Csiky J., Botta-Dukát Z., Horváth F. & Lájer K. (2012): CoenoDat Hungarian Phytosociological Database. – Biodiversity & Ecology 4: 394.

De Cáceres M., Font X. & Oliva F. (2010): The management of vegetation classifications with fuzzy clustering. – J. Veg. Sci. 21: 1138–1151.

Dengler J., Becker T., Ruprecht E., Szabó A., Becker U., Beldean M., Bita-Nicolae C., Dolnik C., Goia I., Peyrat J., Sutcliffe L. M. E., Turtureanu P. D., Uğurlu E. (2012): *Festuco-Brometea* communities of the Transylvanian Plateau (Romania) – a preliminary overview on syntaxonomy, ecology, and biodiversity. – Tuexenia 32: 319–359.

Dénes A. (1997): Az *Anthoxantho-Festucetum rupicolae* társulás előfordulása a Dráva-síki kaszálóréteken [*Anthoxantho-Festucetum rupicolae* in meadows of Drava Lowland]. – Kitaibelia 2(2): 274–275.

Dierschke H. (1997): Synopsis der Pflanzengesellschaften Deutschlands. Heft 3. *Molinio–Arrhenatheretea* (E 1). Kulturgrasland verwandte Vegetationstypen. Teil 1: *Arrhenatheretalia*. Wiesen und Weiden frischer Standorte. Floristisch-soziologische Arbeitsgemeinschaft & Reinhold-Tüxen-Gesellschaft. Göttingen, 74 pp.

Ellmauer T. & Mucina L. (1993): *Molinio-Arrhenatheretea*. – In: Mucina L., Grabherr G. & Ellmauer T.: Die Pflanzengesellschaften Österreichs. Teil I. Anthropogene Vegetation. Verlag Gustav Fischer, Jena, pp. 297–401.

Fajmonová Z., Zelený D., Syrovátka V., Vončina G. & Hájek M. (2013): Distribution of habitat specialists in semi-natural grasslands. – J. Veg. Sci. 24: 616–627.

Hegedüšová Vantarová K. & Škodová I. (eds.) (2014): Rastlinné spoločenstvá Slovenska. 5. Travinno-bylinná vegetácia. – Veda, Bratislava, 581 pp.

Hennekens S. M. & Schaminée J. H. J. (2001): TURBOVEG, a comprehensive data base management system for vegetation data. – J. Veg. Sci. 12: 589–591.

Horváth A. (2002): A mezőföldi löszvegetáció términtázati szerveződése [Organization of spatial pattern of loess vegetation in the Mezőföld region]. Synbiologica Hungarica 5 – Scientia Kiadó, Budapest, 174 pp.

Horváth A. (2010): Validation of description of the xeromesophilous loess grassland association, *Euphorbio pannonicae-Brachypodietum pinnati*. – Acta Bot. Hung. 52 (1-2): 103–122.

Huhta A.-P., Rautio P., Tuomi J. & Laine K. (2001): Restorative mowing on an abandoned semi-natural meadow: short-term and predicted long-term effects. – J. Veg. Sci. 12: 677–686.

Illyés E. Chytrý M., Botta-Dukát Z., Jandt U., Škodová I., Janišová M., Willner W. & Hájek O. (2007): Semi-dry grasslands along a climatic gradient across Central Europe: Vegetation classification with validation. – J. Veg. Sci. 18: 835–846.

Illyés E., Bauer N. & Botta-Dukát Z. (2009): Classification of semi-dry grassland vegetation in Hungary. – Preslia 81: 239–260.

Janeček Š., de Bello F., Horník J., Bartoš M., Černý T., Doležal J., Dvorský M., Fajmon K., Janečková P., Jiráská Š., Mudrák O. & Klimešová J. (2013): Effects of land-use changes on plant functional and taxonomic diversity along a productivity gradient in wet meadows. – J. Veg. Sci. 24: 898–909.

Janišová M., Zaliberová M., Dúbravková D. & Uhliarová E. (2014): *Cynosurion cristati*. – In: Hegedüšová Vantarová K. & Škodová I. (eds.): Rastlinné spoločenstvá Slovenska. 5. Travinno-bylinná vegetácia [Plant communities of Slovakia 5. Grassland vegetation]. – Veda, Bratislava, 239–251 p.

Janišová M., Hájková P., Hegedüšová K., Hrivnák R., Kliment J., Michálková D., Ružičková H., Řezničková M., Tichý L., Škodová I., Uhliarová E., Ujházy K. & Zaliberová M. (2007): Grassland vegetation of Slovak Republic: electronic expert system for identification of syntaxa. – Botanicky ústav SAV, Bratislava, 263 pp.

Jeanplong J. (1987): Jelentősebb hasznosítható réttársulások az Alpokalja Vas megyei részén [The main useable meadow associations of Alpokalja in Vas county]. – Praenorica Folia Historico-naturalia 2: 85–94.

Juhász-Nagy P. (1959): A Beregi-sík rét-legelőtársulásai [Meadow and pasture associations of the Bereg Plain]. – Acta Universitatis Debreceniensis 4: 195–228.

Jurko A. (1974): Prodromus der *Cynosurion*-Gesellschaften in den Westkarpaten. – Folia Geobot. Phytotax. 9: 1–44.

Kaufman L. & Rousseeuw P. J. (1990): Finding groups in data. An introduction to cluster analysis. – Wiley, New York, NY, US.

Király G. (ed.) (2009): Új Magyar füvészkönyv. Magyarország hajtásos növényei. Határozókulcsok. [New Hungarian Herbal. The Vascular Plants of Hungary. Identification key]. – Aggteleki Nemzeti Park Igazgatóság, Jósvafő, 616 pp.

Korneck D. (1974): Xerothermvegetation in Rheinland-Pfalz und Nachbargebieten. – Schriftenr. Vegetationskd. 7: 1–196.

Kovács J. A. (1994): A Kőszegi-hegység és a Kőszeg-hegyalja réttársulásai [Meadow associations of the Kőszeg Mts and Kőszeg-hegyalja]. In: Bartha D. (ed.): A Kőszegi-hegység vegetációja [Vegetation of the Kőszeg Mts]. – Sopron—Kőszeg, pp. 147–174.

Lájer K. (2002): Florisztikai és cönológiai vizsgálatok a somogyi Dráva-völgy rétjein [Floristical and coenological studies on meadows of the Somogy county valley of river Dráva]. – Kitaibelia 7(2): 187–205.

Lengyel A., Chytrý M. & Tichý L. (2011): Heterogeneity-constrained resampling of phytosociological databases. – J. Veg. Sci. 22: 175–183.

Lengyel A., Purger D. & Csiky J. (2012a): Classification of mesic grasslands and their transitions of South Transdanubia (Hungary). – Acta Bot. Croat. 71(1): 31–50.

Lengyel A., Csiky J. & Botta-Dukát Z. (2012b): How do locally infrequent species influence numerical classification? A simulation study. – Comm. Ecol. 13(1): 64–71.

Linusson A.-C., Berlin G. A. I. & Olsson E. G. A. (1998): Reduced community diversity in semi-natural meadows in southern Sweden, 1965–1990. – Plant Ecol. 136(1): 77–94.

Maechler M., Rousseeuw P., Struyf A., Hubert M. & Hornik, K. (2013): cluster: Cluster Analysis Basics and Extensions. – R package version 1.14.4. URL: http://cran.r-project.org/web/packages/cluster/index.html

Marini L., Fontana P., Scotton M. & Klimek S. (2008): Vascular plant and orthoptera diversity in relation to grassland management and landscape composition in the European Alps. – J. App. Ecol. 45(1): 361–370.

Mathar W., Kleinebecker T. & Hölzel N. (2015): Environmental variation as a key process of co-existence in flood-meadows. – J. Veg. Sci. 26: 480–491.

Máthé I. & Kovács M. (1960): Vegetationsstudien im Mátragebirge. – Acta Bot. Acad. Sci. Hung. 6: 343–382.

Michalcová D., Chytrý M., Pechanec V., Hájek O., Jongepier J. W., Danihelka J., Grulich V., Šumberová K., Preislerová Z., Ghisla A., Bacaro G. & Zelený D. (2014): High plant diversity of grasslands in a landscape context: a comparison of contrasting regions in Central Europe. – Folia Geobot. 49(2): 117–135.

Molnár Zs., Biró M., Bartha S. & Fekete G. (2012): Past Trends, Present State and Future Prospects of Hungarian Forest-Steppes. In: Werger M. J. A. & van Staalduinen M. A. (eds.): Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World. – Springer, Dordrecht, Heidelberg, New York, London, pp. 209–252.

Molnár Zs., Biró M., Bölöni J. & Horváth F. (2008a): Distribution of the (semi-)natural habitats in Hungary I. Marshes and grasslands. – Acta Bot. Hung. 50 (Suppl. 1): 59–105.

Molnár Zs., Bölöni J. & Horváth F. (2008b): Threatening factors encountered: Actual endangerment of the Hungarian (semi-)natural habitats. – Acta Bot. Hung. 50 (Suppl. 1): 199–217.

Mucina L., Dengler J., Bergmeier E., Čarni A., Dimopoulos P., Jahn R. & Matevski V. (2009): New and validated high-rank syntaxa from Europe. – Lazaroa 30: 267–276.

Oksanen J., Blanchet F. G., Kindt R., Legendre P., Minchin P. R., O'Hara R. B., Simpson G. L., Solymos P., Stevens M. H. H. & Wagner H. (2013): vegan: Community Ecology Package. version 2.0-8. – URL: http://CRAN.R-project.org/package=vegan

Podani J. (2000): Introduction to the exploration of multivariate biological data. – Backhuys Publishers, Leiden, NL. 407 pp.

Podani J. (2006): Braun-Blanquet's legacy and data analysis in vegetation science. – J. Veg. Sci. 17(1): 113–117

R Core Team (2013): R: A language and environment for statistical computing. – R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org/.

Roleček J., Čornej I. I. & Tokarjuk A. I. (2014): Understanding the extreme species richness of semi-dry grasslands in east-central Europe: a comparative approach. – Preslia 86: 13–34.

Rozbrojová Z., Hájek M. & Hájek O. (2010): Vegetation diversity of mesic meadows and pastures in the West Carpathians. – Preslia 82: 307–332.

Rousseeuw P. J. (1987): Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. – J. Comp. and Appl. Math. 20: 53–65.

Škodová I. (2014): *Cirsio-Brachypodion pinnati*. – In: Hegedüšová Vantarová K. & Škodová I. (eds.): Rastlinné spoločenstvá Slovenska. 5. Travinno-bylinná vegetácia [Plant communities of Slovakia 5. Grassland vegetation]. – Veda, Bratislava, 104–116 p.

Škodová I. & Ujházy K. (2014): *Bromion erecti*. – In: Hegedüšová Vantarová K. & Škodová I. (eds.): Rastlinné spoločenstvá Slovenska. 5. Travinno-bylinná vegetácia [Plant communities of Slovakia 5. Grassland vegetation]. – Veda, Bratislava, 117–130 p.

Soó R. (1964): A Magyar flóra és vegetáció rendszertani-növényföldrajzi kézikönyve. I. Synopsis systemtico-geobotanicae florae vegetationisque Hungariae. – Akadémiai Kiadó, Budapest. 589 pp.

Soó R. (1971): Aufzählung der Assoziationen der ungarischen Vegetation nach den neueren zönosystematisch-nomenklatorischen Ergebnissen. – Acta Bot. Acad. Sci. Hung. 17: 127–179.

Soó R. (1973): Magyarország növénytársulásainak részletes kritikai rendszere [Critical revision of the Hungarian plant communities]. In Soó R.: A Magyar flóra és vegetáció rendszertani-növényföldrajzi kézikönyve. V. Synopsis systemtico-geobotanicae florae vegetationisque Hungariae. – Akadémiai Kiadó, Budapest, pp. 525–538.

Stančić Z. (2008): Classification of mesic and wet grasslands in northwest Croatia. – Biologia (Bratislava) 63: 1089–1103.

Tichý L. (2002): JUICE, software for vegetation classification. – J. Veg. Sci. 13: 451–453.

Tichý L., Chytrý M. & Šmarda P. (2011): Evaluating the stability of the classification of community data. – Ecography 34: 807–813.

Tichý L. & Chytrý M. (2006): Statistical determination of diagnostic species for site groups of unequal size. – J. Veg. Sci. 17: 809–818.

Tichý L., Chytrý M., Hájek M., Talbot S. S. & Botta-Dukát Z. (2010): OptimClass: Using species-to-cluster fidelity to determine the optimal partition in classification of ecological communities. – J. Veg. Sci. 21: 287–299.

Tichý L., Chytrý M., & Botta-Dukát Z. (2014): Semi-supervised classification of vegetation: preserving the good old units and searching for new ones. – J. Veg. Sci. 25: 1504–1512.

Török P., Kelemen A., Valkó O., Deák B., Lukács B. & Tóthmérész B. (2011): Lucerne-dominated fields recover native grass diversity without intensive management actions. – J. App. Ecol. 48: 257–264.

Török P., Miglécz T., Valkó O., Kelemen A., Tóth K., Lengyel Sz. & Tóthmérész B. (2012): Fast restoration of grassland vegetation by a combination of seed mixture sowing and low-diversity hay transfer. – Ecol. Eng. 44: 133–138.

Uhliarová E., Janišová M., Ujházy K., Škodová I. & Hájek M. (2014): *Arrhenatherion elatioris*. – In: Hegedüšová Vantarová K. & Škodová I. (eds.): Rastlinné spoločenstvá Slovenska. 5. Travinno-bylinná vegetácia [Plant communities of Slovakia 5. Grassland vegetation]. – Veda, Bratislava, 202–239 p.

van Tongeren O., Gremmen N. & Hennekens S. (2008): Assignment of relevés to pre-defined classes by supervised clustering of plant communities using a new composite index. – J. Veg. Sci. 19: 525–536.

Varga Z. (1997): Trockenrasen im pannonischen Raum: Zusammenhang der physiognomischen Struktur und der florischtischen Komposition mit den Insektenzönosen. – Phytocoenologia 27 (4): 509–571.

Venables W. N. & Ripley B. D. (2002): Modern Applied Statistics with S. Fourth Edition. – Springer, New York

Vinczeffy I. (2006): A legelő értéke [The value of the pasture]. – Gyepgazdálkodási Közlemények (Grassland Studies) 4: 131–139.

Wagner H. (1941): Die Trockenrasengesellschaften am Alpenostrand, Eine Pflanzensoziologische Studie. – Denkschriften Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Klasse 104: 1–81.

Weber H. E., Moravec J. & Theurillat J-P. (2000): International Code of Phytosociological Nomenclature. – J. Veg. Sci. 11: 739–768.

Willner W., Sauberer N., Staudinger M. & Schratt-Ehrendorfer L. (2013a): Syntaxonomic revision of the Pannonian grasslands of Austria – Part I: Introduction and general overview. – Tuexenia 33: 399–420.

Willner W., Sauberer N., Staudinger M., Grass V., Kraus R., Moder D., Rötzer H. & Wrbka T. (2013b): Syntaxonomic revision of the Pannonian grasslands of Austria – Part II: Vienna Woods (Wienerwald). – Tuexenia 33: 421–458.

Figure captions

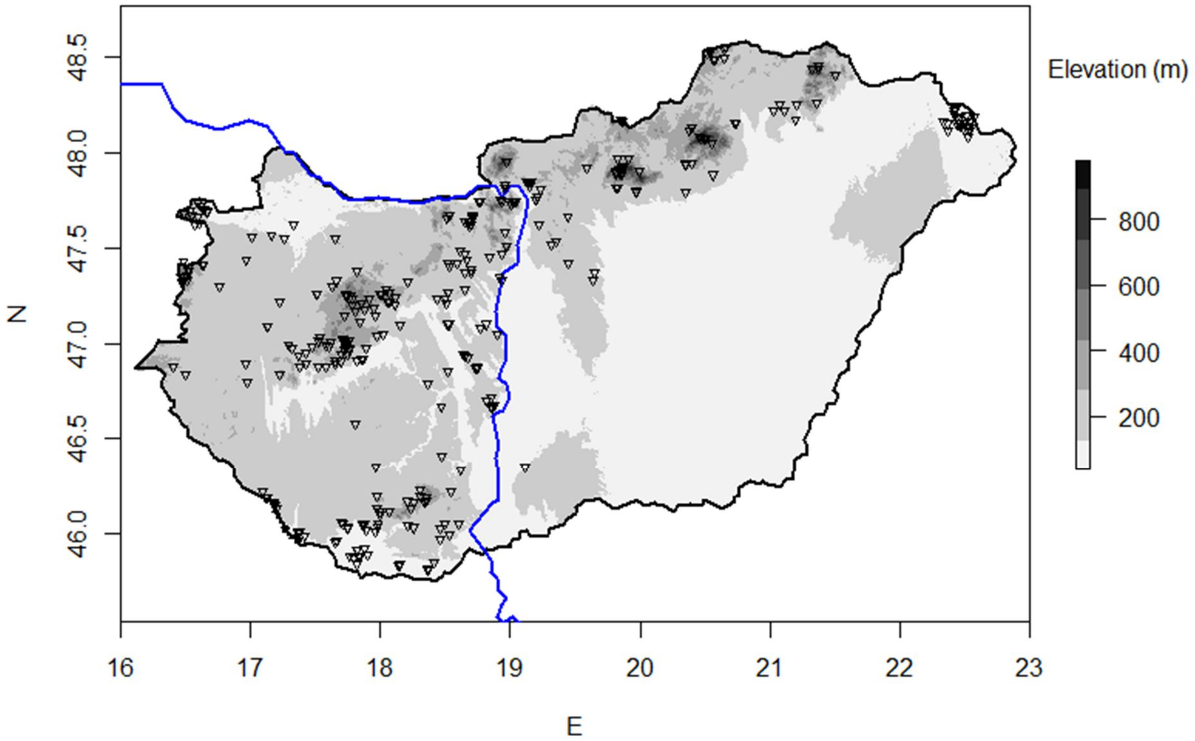
Figure 1. The geographical distribution of the analyzed relevés

Figure 2. The minimum spanning tree of the 60 distinguished clusters

Figure 3. Principal coordinates analysis of all distinguished associations. A – *Ranunculo-Arrhenatheretum*; B – *Tanaceto-Arrhenatheretum*; C – *Pastinaco-Arrhenatheretum*; D – *Filipendulo-Arrhenatheretum*; E – *Ranunculo-Alopecuretum*; F – *Diantho-Arrhenatheretum*; G – *Anthoxantho-Festucetum pratensis*; H – *Colchico-Festucetum*; I – *Anthoxantho-Festucetum pseudovinae*; J – *Alopecuro-Festucetum pseudovinae*; K – *Cynosuro-Lolietum*; L – *Brachypodio-Molinietum*; M – *Filipendulo-Brometum*; N – *Sanguisorbo-Brometum*; O – *Polygalo-Brachypodietum*; P – *Euphorbio-Brachypodietum*; Q – *Trifolio-Brachypodietum*.

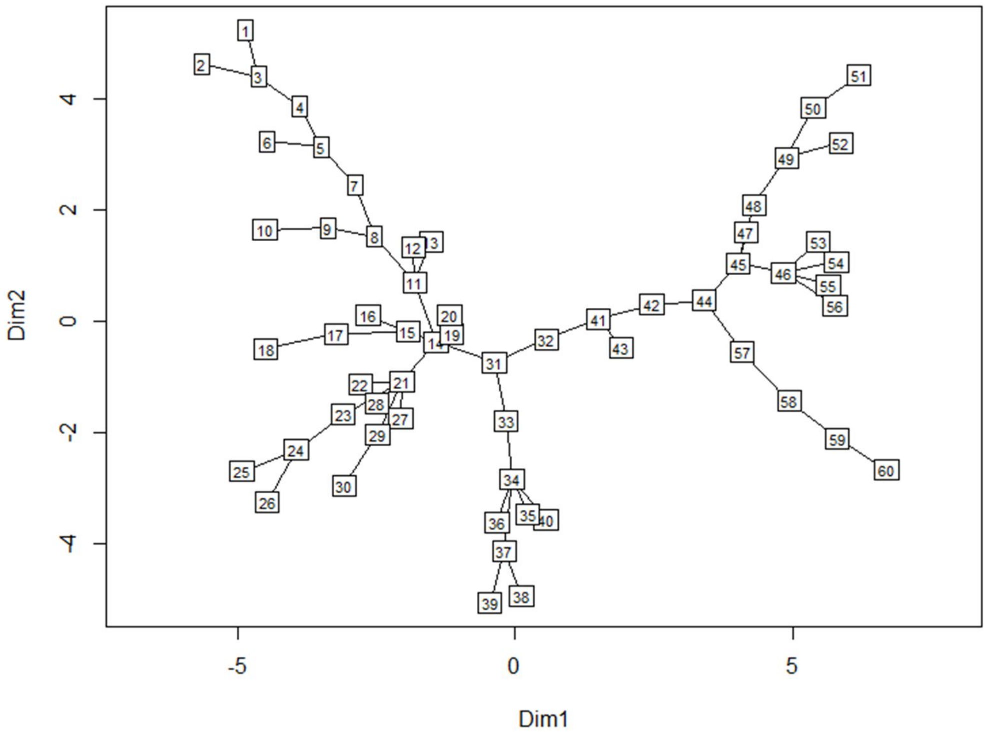
Figure 4. Principal coordinates analysis of the associations in *Arrhenatheretalia* order. A – *Ranunculo-Arrhenatheretum*; B – *Tanaceto-Arrhenatheretum*; C – *Pastinaco-Arrhenatheretum*; D – *Filipendulo-Arrhenatheretum*; E – *Ranunculo-Alopecuretum*; F – *Diantho-Arrhenatheretum*; G – *Anthoxantho-Festucetum pratensis*; H – *Colchico-Festucetum*; I – *Anthoxantho-Festucetum pseudovinae*; J – *Alopecuro-Festucetum pseudovinae*; K – *Cynosuro-Lolietum*.

Figure 1.



Elevation (m)
800
600
400
200
48.5
48.0
47.5
47.0
46.5
46.0
N
16
17
18
19
20
21
22
23
E

Figure 2.



1 Figure 3.

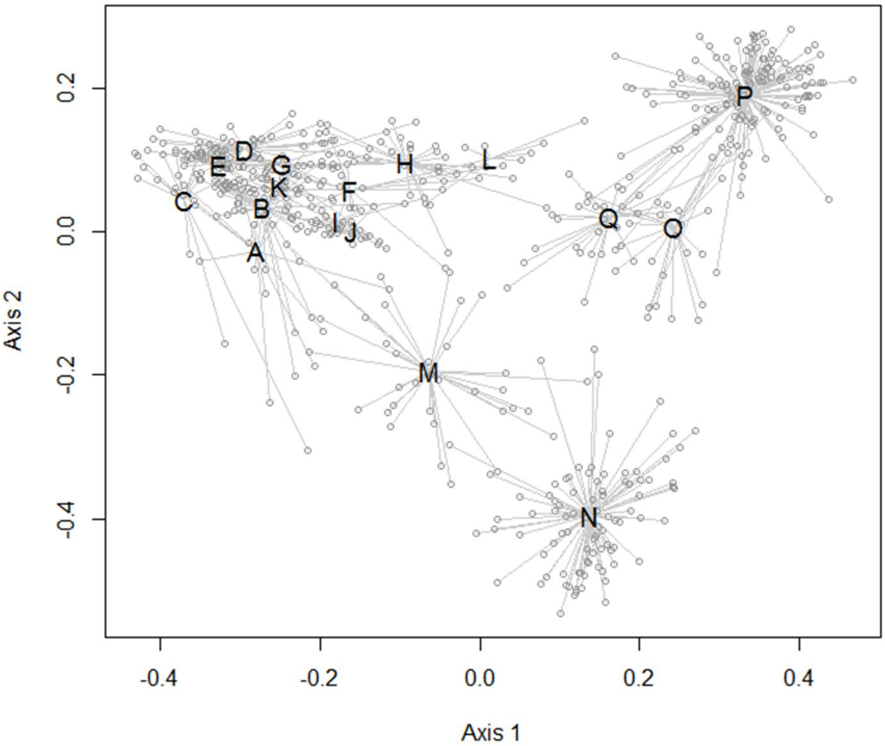


Figure 4.