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Classification, ecology and biodiversity of Central Balkan dry grasslands

Klassifikation, Ökologie und Biodiversität der Trockenrasen des Zentral-Balkans

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Abstract

Dry grasslands are highly diverse vegetation types of great importance for livestock production in rural Balkan areas. We analysed a large data set of phytosociological relevés of dry grasslands (*Festuco-Brometea* and *Festucetea vaginatae* classes) in Serbia to produce the first overview of its classification, distribution, environmental conditions and biodiversity patterns. Phytocoenological relevés from relevant literature sources and our own investigations were stored in the Vegetation Database of Serbia (EU-RS-002) and the Balkan Dry Grassland Database (EU-00-013). After heterogeneity-constrained random resampling, the final dataset contained 1,897 relevés and 1,323 species. Species composition was classified hierarchically by the beta flexible method. We used species ecological indicator values for the estimation of the ecological conditions. Floristic and vegetation diversity and the conservation relevance of various dry grassland types, based on an assessment of endemic and protected species, were analysed. We identified 11 clusters, which were well characterised by their species composition and ecology. The first three clusters included loess and sand steppe grasslands mostly found in the Pannonian part of Serbia (*Festucion rupicolae* and *Festucion vaginatae*). The next three clusters consisted of Balkan ultramafic rocky grasslands of the order *Halacsyetalia sendtneri*, Balkan submediterranean mountain steppe grasslands on calcareous substrates, belonging to the order *Astragalo-Potentilletalia* and grasslands of the Balkan alliance *Saturejion montanae* on limestone. The third group of relevés comprised Balkan alliances of dry grasslands on deep soils, the *Chrysopogono-Danthonion* and sub-continental steppes of the alliance *Festucion valesiacae* in hilly areas of Serbia, mostly in the thermophilous oak zone. According to ordination analysis (DCA), the main floristic gradient was largely determined by temperature and moisture. The *Festuco-Brometea* class exhibited high floristic diversity (1,323 plant species) and very high conservation relevance in view of the large number of Balkan endemic species (204). A total of 233 species and subspecies protected by national legislation within the studied vegetation were recorded.

Keywords: Balkan endemics, *Festuco-Brometea*, *Festucetea vaginatae*, ordination, syntaxonomy

Erweiterte deutsche Zusammenfassung am Ende des Artikels

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1. Introduction

Dry grasslands are natural and semi-natural thermophilous and xerophilous communities found in the temperate and continental regions of Europe, mostly developing on calcareous bedrock with nutrient-poor soils. The majority of dry grassland communities are of a semi-natural origin, developed over centuries or even millennia of traditional land use, including mowing, grazing, temporary abandonment of arable fields and other disturbance regimes (POSCHLOD & WALLIS DE VRIES 2002, DAJIĆ STEVANOVIĆ et al. 2008, VEEN et al. 2009, ELLENBERG & LEUSCHNER 2010). In many European countries, plant communities of the *Festuco-Brometea* class receive a great deal of attention in terms of conservation management regimes, because of the recognised decline in their diversity and quality (HEGEDÜŠOVÁ & SENKO 2011).

Grasslands are a major resource for agriculture in Serbia, occupying about 1.4 million hectares, distributed within a wide altitudinal range - from lowland areas to the highest alpine zone. Semi-natural grasslands (hay meadows and pastures) in Serbia are recognised for their high species diversity and significant conservation value (LAKUŠIĆ & SABOVLJEVIĆ 2005, DAJIĆ STEVANOVIĆ et al. 2010, TOMOVIĆ et al. 2014). However, many grassland communities are at present threatened by rapid changes in agricultural practices, especially related to the effects of either land abandonment or eutrophication (DAJIĆ STEVANOVIĆ et al. 2010).

Supranational or even continent-wide classifications of dry grasslands are still rare (VRAHNAKIS et al. 2013). ROYER (1991) reported the classification of the class *Festuco-Brometea* throughout its Eurasian range. DENGLER (2003) and DENGLER & LÖBEL (2006) performed continent-wide reviews of the classes *Festuco-Brometea* and *Koelerio-Corynephoretea*. ILLYÉS et al. (2007) published a review of the *Brachypodietalia pinnati* order in Central Europe. DÚBRAVKOVÁ et al. (2010) analysed *Festuco-Brometea* communities in the Western Carpathians and the Northern Pannonian Basin and DENGLER et al. (2012) in Romania. The only review that analyses dry grasslands of the *Festuco-Brometea* class in the Balkans was published by REDŽIĆ (1999), but this lacks a synoptic table.

Phytocoenological studies of the vegetation of Serbia have a long tradition. Intensive research on grassland biodiversity in Serbia has been conducted using the Braun-Blanquet methodological approach, resulting in many publications on flora and vegetation of various geographic areas of the country (reviewed by KOJIĆ et al. 1998, 2004). On the basis of these reviews, dry grasslands in Serbia have been classified within the classes *Festuco-Brometea* and *Festucetea vaginatae*.

In our analysis, all associations of dry grasslands traditionally classified within the *Festuco-Brometea* and *Festucetea vaginatae* were selected. Although we followed the syntaxonomical system of alliances (EuroVegChecklist) recently proposed by MUCINA et al. (2015), we discuss certain disagreements with this system.

This paper is intended to present the first insight into the classification and ecology of dry grassland communities of the Central Balkans, based on numerical classification and ordination of a large data set of relevés, continuing the nomenclatural revision of dry grassland syntaxa published by AĆIĆ et al. (2014). The second aim was to highlight vegetation-environment relationships of dry grassland habitats of Serbia and Kosovo. In order to evaluate the conservation relevance of dry grasslands of the Central Balkans, the list of protected and endemic plant species was assessed and commented.

2. Study area

The Central Balkans, i.e. the territories of Serbia and Kosovo, is located in the north-central part of the Balkan Peninsula and covers an area of 88,361 km^2. The northern part of Serbia (Vojvodina) includes the south-eastern part of the Pannonian plain, where broad alluvial lowlands and adjacent loess plateaus extend along the rivers Danube, Tisa, Sava, Begej and Tamiš. Southern Serbia and the southern part of Kosovo end with the long, almost meridionally extending massif of Mt. Šar-Planina, which is part of the Scardo-Pindhian mountain system. Serbia is bordered to the east by the mountains of the Carpathian-Balkan and Rhodope systems; the west and southwest borders are formed by the river Drina with the eastern Dinaric Alps and Mt. Prokletije (which also belongs to the Dinaric Alps), respectively.

The climate is continental in the northern and south-eastern parts, with cold winter periods and semi-arid summer. In the western and south-western regions, the climate is humid-temperate, while in the central and eastern parts it is sub-continental or semi-arid temperate-continental, with transitional sub-Mediterranean parts (STEVANOVIĆ & ŠINŽAR-SEKULIĆ 2009). Four basic groups of geological substrata are present in the Central Balkans: 1. silicate rocks alkaline to ultra-alkaline reaction (serpentinites and peridotites, ophiolitic belt); 2. carbonate rocks neutral to alkaline reactions (sedimentary, clastic); 3. silicate rocks acidic to neutral pH (sedimentary, igneous, metamorphic); 4. loess and Pleistocene sediments and deposits (sands, alluvial fans) (STEVANOVIĆ & STEVANOVIĆ 1995). Due to such dissimilar climatic, geological and edaphic conditions, the flora and vegetation of the territory of Serbia are highly diverse.

3. Study area

3.1 Data collection

Phytoceonological relevés from literature sources originally assigned by authors into the classes *Festuco-Brometea* and *Festucetea vaginatae*, supplemented with our own data, were stored in the Vegetation Database of Serbia (GIVD ID EU-RS-02, AĆIĆ et al. 2012), Balkan Dry Grasslands Database (GIVD ID EU-00-13, VASSILEV et al. 2012a) and European Vegetation Archive (EVA; http://euroveg.org/eva-database), using the TURBOVEG 2 format (HENNEKENS & SCHAMINÉE 2001).

The nomenclature of plant taxa follows Flora Europaea (FLORA EUROPAEA DATABASE), except for the species *Bothriochloa ischaemum* (L.) Keng., *Bromus fibrosus* Hack., *Koeleria pyramidata* ssp. *montana* (Hausm.) Domin, *Nepeta rtanjensis* Diklić & Milojević, *Potentilla arenaria* Borkh. ex G. Gaertn., *Potentilla tommasiniana* F.W. Schultz and *Veronica austriaca* ssp. *jacquinii* (Baumg.) Eb. Fisch.

3.2 Data analysis

An outlier analysis was performed using PC-ORD 5.0 (MCCUNE & MEFFORD 1999) and relevés in which the species composition deviated more than 2 SD from the mean calculated Euclidean distance of all plots were removed. Relevés were georeferenced *a posteriori*. Plant species determined only to the genus level and mosses were omitted. To reduce over-sampling bias, the data set was subsequently geographically stratified by 6’ latitude × 10’ longitude grid cells and ten relevés were selected from each grid cell by heterogeneity-constrained random resampling (LENGYEL et al. 2011) to obtain balanced floristic diversity. After the heterogeneity-constrained random resampling, the final dataset contained 1,897 relevés and 1,323 species.

We carried out cluster analysis of the dataset in the program PC-ORD 5.0 (McCune & Mefford 1999) using Relative Sørensen as a distance measure and beta flexible (-0.25) for group linkage. Square-root transformed cover values were used. We performed several classifications with various numbers of clusters of relevés. The OptimClass method (Tichý et al. 2010) was used for identifying the optimal partition.

Clusters were characterised by their diagnostic species using the JUICE program (Tichý 2002). Diagnostic species were determined using the Phi-coefficient as a fidelity measure (Chytrý et al. 2002). The size of all groups was standardised to equal size, and Fisher's exact test ($p < 0.05$) was applied. Species with Phi-coefficient values higher than 0.20 were considered diagnostic. After preliminary examination of the groups of diagnostic species resulting from using lower or higher threshold values, this phi value was selected subjectively. The selected Phi-coefficient value limit was chosen to be both low enough for a sufficient number of diagnostic species ecologically to describe clusters and high enough to hinder too many generalist species or species diagnostic for more than one cluster becoming diagnostic species. Species with cover ≥ 25% in a minimum of 5% of the relevés were considered dominant, and species recorded in a minimum of 50% of the relevés were considered constant. Diagnostic and constant species shown in bold in the text have phi higher than 0.50.

The ecological indicator values of Pignatti et al. (2005) were used for the ecological interpretation of the gradients. Missing values for some species were added from Borhidi (1995). Unweighted mean indicator values were calculated for each relevé. Relationships between clusters and environmental indicator values were visualized using Detrended Correspondence Analysis (DCA) ordination, in which the Hellinger transformation of cover values were used, and rare species were down weighted. Original relevés and mean ecological indicator values calculated for each relevé were used in DCA. Ordination results were presented on spider plots, in which each relevé is linked to the centroid of its cluster by a line, and indicator values were plotted *a posteriori* on the DCA ordination diagram. Analysis was performed in R (R Core Team 2015) using the vegan package (Oksanen et al. 2013).

Floristic and vegetation diversity and the conservation relevance of different dry grassland types based on assessment of endangered and endemic species were analysed according to The Red Data Book of the Flora of Serbia 1 (Stevanović 1999), and the list of protected plants of Serbia (Anonymous 2010).

4. Results and discussion

4.1 Numerical classification of dry grassland syntaxa

The results of cluster analysis are presented in the dendrogram (Fig. 1) and synoptic table (Table 1 in the Supplement). The peak of the OptimClass1 curve showed that the optimal number of clusters is eleven. Four main groups (A, B, C and D) were distinguished in the dendrogram (Fig. 1). Grouping of the communities reflects their syntaxonomic classification and site conditions. Group A consists of communities of the Pannonian sand dunes and grasslands on loess; group B is made up of grasslands on extremely rocky sites and group C includes grasslands of the Balkan order *Astragalo-Potentilletalia* of montane steppic calcareous grasslands. Group D separates from the remaining communities at the highest level of classification and comprises communities of the alliances *Festucion valesiacae* and *Chrysopogono-Danthonion* on deep soils over siliceous or calcareous bedrock.

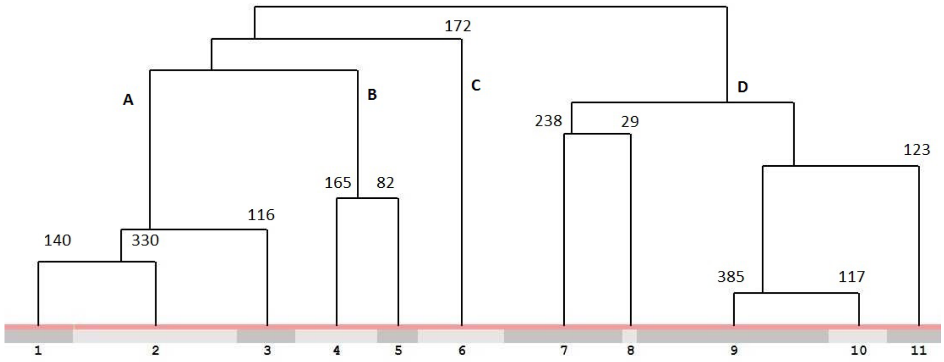

Fig. 1. Dendrogram of relevés of central Balkan dry grasslands. Cluster 1 – *Festucion rupicolae*, variant of *Cynodon dactylon*; Cluster 2 – typical *Festucion rupicolae*; Cluster 3 – *Festucion vaginatae*; Cluster 4 – *Centaureo-Bromion fibrosi*; Cluster 5 – *Saturejion montanae* and *Cirsio-Brachypodion pinnati*; Cluster 6 – *Scabioso-Trifolion dalmatici*; Cluster 7 – *Festucion valesiacae*; Cluster 8 – transitional *Agrostietum* type grassland; Cluster 9 – *Chrysopogono-Danthonion alpinae*, *Danthonietum* type; Cluster 10 – *Chrysopogono-Danthonion alpinae*, *Koelerietum* type; Cluster 11 – *Chrysopogono-Danthonion alpinae*, *Chrysopogonetum* type. For each particular cluster, the number of relevés is given within the tree.

Abb. 1. Dendrogram der Trockenrasen des Zentral-Balkans. Die Ziffern im Dendrogramm geben die Anzahl der Aufnahmen pro Cluster an. Für die Zuordnung der Cluster zu Syntaxa siehe die englische Abbildungsunterschrift.

4.2 Description of particular clusters with diagnostic species and discussion of syntaxonomy and nomenclature

Cluster 1 includes the alliance *Festucion rupicolae*, variant with *Cynodon dactylon*

Diagnostic species: *Cynodon dactylon*, *Rhinanthus borbasii*, *Poa angustifolia*, *Festuca pseudovina*
Constant species: *Cynodon dactylon*, *Bothriochloa ischaemum*, *Festuca pseudovina*
Dominant species: *Cynodon dactylon*, *Bothriochloa ischaemum*, *Festuca pseudovina*

This cluster includes Pannonian steppe communities of the alliance *Festucion rupicolae*, thriving on loess, chernozem and even on weakly to moderately saline soils (solonetz). Communities of this alliance are much influenced by grazing. The diagnostic species *Cynodon dactylon* is characteristic of grazed communities on dry and warm sites and of ruderal areas.

Steppic communities of this cluster are mainly distributed in the northern part of Serbia (Vojvodina) (Fig. 2). Relevés of the association *Cynodonto-Poetum angustifoliae* Rapaics ex Soó 1957, mainly occurring in the valley of the Zapadna Morava river (Cincović 1959), were grouped within this cluster. This plant community is also found in Hungary near lowland rivers under intensive human impact (Borhidi et al. 2012). In Slovakia, communities with *Festuca pseudovina* (*Potentillo arenariae-Festucetum pseudovinae* Soó 1955), assigned to the alliance *Festucion valesiacae* (Janišová 2007), and particularly variants with *Cynodon dactylon* (found on sandy soil on the shores of large rivers like the Danube) have been described.

The diagnostic species for this cluster is the endemic Pannonian species *Rhinanthus borbasii*, appearing at the southern border of its range. This species is also diagnostic for the suballiance *Rhinanthenion borbasii* (*Festucion rupicolae*) as an ecological-geographical type of sandy steppes of the northwest part of Serbia. The presence of some halophytes is caused by alternation with mosaics of halophytic communities of the *Festuco-Puccinellietea* class, developing in small depressions affected by saline underground waters (PARABUĆSKI & BUTORAC 1993).

Cluster 2 includes typical *Festucion rupicolae*

Diagnostic species: *Potentilla arenaria*, *Euphorbia glareosa*, *Bothriochloa ischaemum*

Constant species: *Bothriochloa ischaemum*, *Chrysopogon gryllus*

Dominant species: *Bothriochloa ischaemum*, *Chrysopogon gryllus*

The alliance *Festucion rupicolae* includes xerophilous grassland communities of the Pannonian area that mainly thrive on rich, fertile chernozem soils. Communities of this alliance have been reported for Hungary (BORHIDI 2003), Austria (MUCINA & KOLBEK 1993), Czech Republic (DÚBRAVKOVÁ et al. 2010), Romania (SANDA et al. 2008) and Bulgaria (TZONEV et al. 2009).

In Serbia, this alliance is found primarily in Vojvodina and comprises communities dominated by *Chrysopogon gryllus* and *Bothriochloa ischaemum* that develop on loess plateaus, solitary hills of Vojvodina (Fruška gora and Vršačke Mt.) and inland sand dunes.

Pannonian steppes in Serbia, the physiognomy of which is characterised by the species *Chrysopogon gryllus*, are the most species rich communities and the highest developed stage of steppe vegetation of the southern edge of the Pannonian plain (STEVANOVIĆ 1984, BUTORAC 1989, LAKUŠIĆ & SABOVLJEVIĆ 2005). The first successional phase of the steppe vegetation of inland sand dunes is characterised by the presence of xerophilous perennial grasses (e.g. *Festuca wagneri*, *Stipa capillata*, *Tragus racemosus* and *Cynodon dactylon*). Due to humus accumulation and improvement of the soil's physical and chemical properties, these communities are replaced by floristically richer steppe phytocoenoses in which *Chrysopogon gryllus* is accompanied by *Bothriochloa ischaemum*, *Thymus glabrescens*, *Carex humilis*, etc. These steppe communities can also be found in peripannonic parts of Serbia, south of the rivers Sava and Danube (Fig. 2).

The syntaxonomical status of the alliance *Festucion rupicolae* has been treated differently in different grassland classifications in Europe. In Hungary (BORHIDI 2003) and Serbia (KOJIĆ et al. 1998), the alliance *Festucion rupicolae* is considered to be steppic grassland vegetation on loess. On the other hand, DÚBRAVKOVÁ et al. (2010) reported that the alliances *Festucion rupicolae* and *Festucion valesiacae* are floristically identical and they adopt the older name *Festucion valesiacae*. MUCINA et al. (2015) support such a view. In addition,

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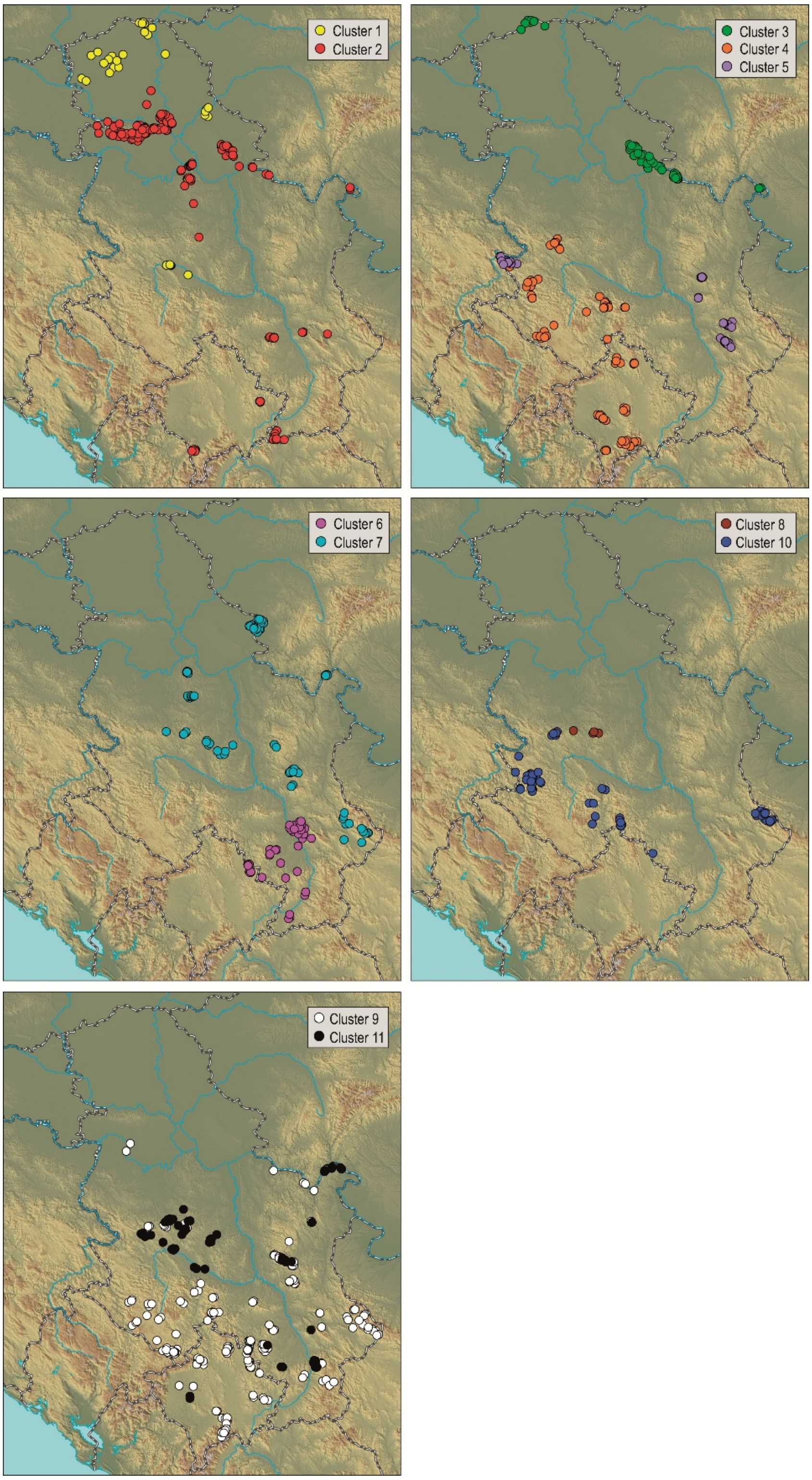
Fig. 2. Distribution maps of the clusters of Central Balkan dry grasslands. Cluster 1 – *Festucion rupicolae*- variant of *Cynodon dactylon*; Cluster 2 – typical *Festucion rupicolae*; Cluster 3 – *Festucion vaginatae*; Cluster 4 – *Centaureo-Bromion fibrosi*; Cluster 5 – *Saturejion montanae* and *Cirsio-Brachypodion pinnati*; Cluster 6 – *Scabioso-Trifolion dalmatici*; Cluster 7 – *Festucion valesiacae*; Cluster 8 – transitional *Agrostietum* type grassland; Cluster 9 – *Chrysopogono-Danthonion alpinae* – *Danthonietum* type; Cluster 10 – *Chrysopogono-Danthonion alpinae* – *Koelerietum* type; Cluster 11 – *Chrysopogono-Danthonion alpinae*, *Chrysopogonetum* type.

Abb. 2. Verbreitung der unterschiedenen Cluster der Trockenrasen des Zentral-Balkans. Für die Zuordnung der Cluster zu Syntaxa siehe die englische Abbildungsunterschrift.


Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6
Cluster 7
Cluster 8
Cluster 10
Cluster 9
Cluster 11

BORHIDI et al. (2012) proposed the recognition of two suballiances within the *Festucion valesiacae*: the *Festucenion valesiacae* and *Festucenion rupicolae*. However, numerical analysis of the *Festuco-Brometea* class in Serbia showed a clear distinction between these communities at a higher classification level (Fig. 1) and a distinction between the alliances *Festucion rupicolae* and *Festucion valesiacae*. The alliance *Festucion rupicolae* includes steppe and dry grasslands of the Pannonian forest-steppe belt on loess and the alliance *Festucion valesiacae* comprised subcontinental dry grasslands in the colline belt in the zone of *Quercus frainetto* and *Quercus cerris* forest.

Cluster 2 also includes communities on limestone, dolomite or even serpentine bedrock, mostly occurring in southeast Serbia and Kosovo. These communities from southeast Serbia and Kosovo have been traditionally classified within the alliance *Koelerio-Festucion dalmaticae* N. Ranđelović et Ružić 1983 (order *Astragalo-Potentilletalia*). According to AĆIĆ et al. (2014), this alliance was invalidly published according to the International Code of Phytosociological Nomenclature (WEBER et al. 2000). We analysed associations of the alliance *Koelerio-Festucion dalmaticae* although these relevés had a plot size from 400 to 900 m^2 because they are the only relevés from the alliance. As PODANI (2006) and LENGYEL & PODANI (2015) pointed out, data transformation and plot size should be chosen very carefully before classification analyses. Therefore, this result could be biased, but we decided to use them to have all plant community types included.

MUCINA et al. (2015) classify these communities into the alliance *Chrysopogono-Festucion dalmaticae* Borhidi 1996, which includes xerophilous steppe grasslands of the southernmost hilly areas of the Pannonian plain. Numerical analysis did not support the classification of steppe therophytic communities of southeast Serbia and Kosovo in the alliance *Chrysopogono-Festucion dalmaticae* and additional analysis of the syntaxonomical position of the alliance *Koelerio-Festucion dalmaticae* is required.

Cluster 3 includes the alliance *Festucion vaginatae*

Diagnostic species: ***Festuca vaginata***, *Tragus racemosus*, *Stipa pennata* ssp. *joannis*, *Polygonum arenarium*, *Euphorbia seguieriana*, *Koeleria glauca*, *Bassia laniflora*, *Centaurea arenaria*, *Poa bulbosa*, *Alyssum montanum* ssp. *gmelinii*

Constant species: *Festuca vaginata*, *Euphorbia seguieriana*

Dominant species: *Festuca vaginata*, *Poa bulbosa*, *Euphorbia seguieriana*

This alliance includes continental communities developed on sandy habitats dominated by *Festuca vaginata* (Fig. 2). The stands are floristically poor, with cover values up to 50%. Diagnostic species are annual herbs and perennial grasses such as *Corispermum nitidum*, *Polygonum arenarium* and *Festuca vaginata*. The habitat is known to be warm and dry. The most important habitat feature is the sandy ground, rich in calcium carbonate. In addition to extreme environmental conditions related to moving sand, including high temperature oscillations in the upper surface layer between night and day, high water permeability, intense insolation and low organic matter, plants also have to withstand the mechanical impact of sand, especially in the case of severe winds (ELLENBERG & LEUSCHNER 2010). In such extreme conditions, only spring therophytes and geophytes, lichens and mosses tolerant of drought, such as *Tortula muralis*, can survive (STJEPANOVIĆ-VESELIČIĆ 1956).

The class *Festucetea vaginatae* comprises psammophytic, xerophilous (steppe) grassland communities that occur in the Pannonian lowlands and eastern Europe. The centre of distribution of Pannonian sand communities is in Hungary. These communities also develop in Serbia, Austria, Czech Republic, Slovakia, Romania and, to a lesser extent, in Bulgaria (JANIŠOVÁ 2007, TZONEV et al. 2009, BORHIDI et al. 2012). KOJIĆ et al. (1998), CHYTRÝ

(2010) and BORHIDI et al. (2012), regard the psammophytic vegetation of the Pannonian Plain as a separate class. However, the classification proposed by MUCINA et al. (2015), based on the research of DENGLER (2003) and KUZEMKO (2009), combines these communities into the *Koelerio glaucae-Corynephoretea canescentis* Klika in Klika et Novák 1941, a class of grasslands on nutrient poor, dry sandy sites of central and northern Europe.

Psammophytic grasslands of Serbia are similar to those developed in Hungary, with some common diagnostic species, such as *Fumana procumbens*, *Centaurea arenaria*, *Koeleria glauca*, as well as the endemics, *Festuca wagneri* and *Tragopogon floccosus*. However, psammophytic communities in Serbia differ significantly, mainly because of the absence of the atlantic-boreal species *Corynephorus canescens*. *Corynephorus canescens* is the dominant species in the sand communities of Central Europe and northern and western Pannonia (STJEPANOVIĆ-VESELIČIĆ 1953, HORVAT et al. 1974). Sandy habitats in Serbia are richer in calcium and thus are more alkaline than with those in Western Europe, which are found on silicate and acid soils. The siliceous substrate causes the development of floristically poorer dry grassland communities (CHYTRÝ 2010).

In Serbia, these communities develop on the edge of the Pannonian plain and are linked to the steppe communities of the alliance *Festucion rupicolae*. Pannonian, Pontic and sub-Mediterranean species dominate in the floristic composition of the alliance *Festucion vaginatae* (HORVAT et al. 1974), whereas characteristic species of the class *Koelerio glaucae-Corynephoretea canescentis* are almost absent. The obtained differences should be further studied to clarify the position of this alliance within higher syntaxa. Since the Balkans is at the edge of the range of the *Koelerio-Corynephoretea* class, classification is not unambiguous. However, our analyses show clear floristic similarities between grasslands of the alliances *Festucion vaginatae* and *Festucion rupicolae* from the Pannonian region thus indicating classification of sandy steppic grasslands into the class *Festuco-Brometea*.

Cluster 4 includes the Balkan alliance *Centaureo-Bromion fibrosi* of the order *Halacsyetalia sendtneri*

Diagnostic species: *Euphorbia glabriflora*, *Plantago holosteum*, *Alyssum markgrafii*, *Thymus praecox* ssp. *skorpilii*, *Poa molineri*, *Bromus fibrosus*, *Sedum album*, *Thymus longicaulis*, *Teucrium montanum*, *Galium lucidum*, *Scleranthus serpentini*, *Convolvulus boissieri* ssp. *compactus*

Constant species: *Plantago holosteum*

Dominant species: *Plantago holosteum*, *Euphorbia glabriflora*, *Thymus praecox* ssp. *skorpilii*

Cluster 4 comprises thermophilous vegetation of serpentine rocky sites in hilly and mountainous areas in the Balkans, with a large number of endemic and rare communities. The order *Halacsyetalia sendtneri* was described by RITTER-STUDNIČKA (1970) and this vegetation is found in Bosnia, Serbia and Albania.

In Serbia, Kosovo and Albania, the order is represented only by the alliance *Centaureo-Bromion fibrosi*, ranging along the western and south-western parts of Serbia, and along the valley of the Ibar river towards Albania (Fig. 2). This alliance includes communities developed on serpentine rock in the zone of sub-Mediterranean *Quercus pubescens* forest. BLEČIĆ et al. (1969) described it for the first time for the territory of Kosovo. Habitats are warm, dry and sloping with serpentine bedrock between 500 and 1400 m a.s.l. Soils are shallow, often rocky, rendzinas (LAKUŠIĆ & SABOVLJEVIĆ 2005).

The diagnostic species are endemic and rare Balkan species, such as *Halacsya sendtneri*, *Alyssum markgrafii*, *Bornmuellera dieckii*, *Centaurea kosaninii*, *Convolvulus boissieri* ssp. *compactus*, *Dianthus pinifolius*, *Scabiosa fumarioides* etc. The species *Bornmuellera dieckii* is a paleo- and stenoendemic plant with a very narrow range. *Halacsya sendtneri* is a Tertiary relict (BLEČIĆ et al. 1969, STEVANOVIĆ et al. 2003, TOMOVIĆ et al. 2014). Most species of the alliance *Centaureo-Bromion fibrosi* are serpentinophytes. The Balkan Peninsula is considered a centre of diversity of serpentinophytes (RITTER-STUDNIČKA 1970, HORVAT et al. 1974). The number of Balkan endemics growing on serpentine is c. 335 taxa (species and subspecies), of which 123 are obligate serpentinophytes (STEVANOVIĆ et al. 2003).

Similar plant communities are found on metalliferous soils in northern Greece and they have been assigned to the order *Astragalo-Potentilletalia* (BABALONAS et al. 1997). Ecological analysis of the vegetation of such unfavourable habitat conditions has shown that the influence of heavy metals in the soil is not decisive for forming this vegetation type, although the influence of pH is a crucial factor (BECKER & BRÄNDEL 2007, BERGMEIER et al. 2009).

According to KOJIĆ et al. (2004), the Balkan order *Halacsyetalia sendtneri* is assigned to the class *Festuco-Brometea*, but a recent proposal by MUCINA et al. (2015) changed the position of this syntaxa to the class *Koelerio-Corynephoretea*. We are of the opinion that, based on the floristic composition (*Koeleria splendens*, *Stipa mayeri*, *Hippocrepis comosa*, *Dianthus sylvestris*, *Dorycnium germanicum*, *Medicago prostrata*) and connection with other communities developed on extreme rocky habitats (*Saturejion montanae*), the order *Halacsyetalia sendtneri* should be part of the class *Festuco-Brometea*.

KABAŠ et al. (2013) highlighted the problems of classification of communities that thrive on serpentine habitats in Serbia, indicating a need for large-scale study of this vegetation type in the Balkans.

Cluster 5 includes the alliances *Saturejion montanae* and *Cirsio-Brachypodion pinnati*

Diagnostic species: *Carex humilis*, *Bromus erectus*, *Stipa pulcherrima*, *Potentilla tommasiniana*, *Festuca panciciana*, *Galium album*, *Achillea clypeolata*, *Artemisia alba*

Constant species: *Carex humilis*, *Bromus erectus*, *Stipa pulcherrima*

Dominant species: *Carex humilis*, *Bromus erectus*, *Stipa pulcherrima*, *Potentilla tommasiniana*

Communities belonging to cluster 5 are found in mountainous parts of Serbia on limestone, with domination of the species *Carex humilis*, *Potentilla tommasiniana*, *Stipa pulcherrima* and *Bromus erectus* (Fig. 2).

Subcontinental steppe grasslands of this cluster occur at higher altitudes on shallow mountainous soil on limestone. They are also known as “mountain steppes”, whose ecological and floristic compositions resemble those of steppe communities (JOVANOVIĆ-DUNJIĆ 1983).

The xerothermic steppe associations *Potentillo tommasinianae-Caricetum humilis* Jovanović-Dunjić 1955 and *Carici humilis-Stipetum grafianae* Jovanović-Dunjić 1955 have been classified within the alliance *Festucion valesiacae* (JOVANOVIĆ-DUNJIĆ 1955, KOJIĆ et al. 1998, LAKUŠIĆ & SABOVLJEVIĆ 2005). HORVAT et al. (1974) changed the position of these communities, placing them into a new alliance *Saturejion montanae*. This alliance was not mentioned in the phytocoenological literature of Serbia and Prodromus phytocoenosum Jugoslaviae (ZUPANČIČ 1986). PEDASHENKO et al. (2013) and VASSILEV (2013) recently confirmed the existence of the Balkan alliance *Saturejion montanae* in Bulgaria.

There are only a few communities with the species *Bromus erectus* described in Serbia. These communities are found in mountainous areas and have traditionally been classified within the alliance *Bromion erecti* (KOJIĆ et al. 1998). Compared with subatlantic parts of Western Europe, where the species is mostly distributed (ELLENBERG & LEUSCHNER 2010), the climate of Serbia has much drier with warmer summers, so that *Bromus erectus* can de-

Fig. 3. Stands of the following communities **a)** *Alysso gmelini-Festucetum vaginatae* Stjepanović-Veseličić 1956 with yellow flowering *Euphorbia seguieriana* in the Special Nature Reserve Deliblato Sands (Photo: G. Tomović, 17.05.2005); **b)** *Adonido vernalis-Chrysopogonetum grylli* (Stjepanović-Veseličić 1953) Aćić et al. 2014 (alliance *Festucion rupicolae*) in the Special Nature Reserve Deliblato Sands (Photo: V. Stojanović, 24.05.2012); **c)** *Carici humilis-Stipetum grafianae* Jovanović-Dunjić 1955 (alliance *Saturejion montanae*, order *Stipo-Festucetalia pallentis*) in the Strict Nature Reserve Rtanj Mt. (Photo: N. Kuzmanović, 08.07.2014); **d)** Endemic order *Halacsyetalia sendtneri* with *Stipa novaki* and yellow inflorescence of *Halacsya sendtneri* in Brđanska gorge (Photo: K. Jakovljević, 10.05.2014).

Abb. 3. Bestände der folgenden Gesellschaften **a)** *Alysso gmelini-Festucetum vaginatae* Stjepanović-Veseličić 1956 mit gelb-blühender *Euphorbia seguieriana* im Naturschutzgebiet Deliblato-Sande (Foto: G. Tomović, 17.05.2005); **b)** *Adonido vernalis-Chrysopogonetum grylli* (Stjepanović-Veseličić 1953) Aćić et al. 2014 (*Festucion rupicolae*) im Naturschutzgebiet Deliblato-Sande (Foto: V. Stojanović, 24.05.2012); **c)** *Carici humilis-Stipetum grafianae* Jovanović-Dunjić 1955 (*Saturejion montanae*; *Stipo-Festucetalia pallentis*) im Naturschutzgebiet Rtanj-Gebirge (Foto: N. Kuzmanović, 08.07.2014); **d)** Bestände der endemischen Ordnung *Halacsyetalia sendtneri* mit *Stipa novaki* und gelb-blühender *Halacsya sendtneri* in der Brđanska-Schlucht (Foto: K. Jakovljević, 10.05.2014).

velop in mountain regions within wetter habitats. For the same reason, communities with *Bromus erectus* are not as widespread in Serbia as in Central Europe and thus did not separate into an individual cluster. Relevés with *Bromus erectus* are combined with communities of the alliance *Saturejion montanae*, which thrive in ecologically similar conditions in mountain areas on limestone.

Communities with *Bromus erectus* gradually change their floristic composition from NW towards SE Europe, with a clear decrease in the abundance of *Bromus erectus* and an increase in continental and steppe species (Illyés et al. 2007). The alliances *Bromion erecti* and *Cirsio-Brachypodion pinnati* are distinct as subatlantic and subcontinental vegetation groups for the same reason (Royer 1991, Mucina & Kolbek 1993, Chytrý 2010).

As ŠILC et al. (2014) pointed out, the altitudinal shift of plant communities towards the south of the Balkans is the reason for the uncertain classification of vegetation that spreads over a long biogeographic gradient.

The most recent classifications in Europe (DENGLER 2003, MUCINA et al. 2015) have rejected the name of the order *Brometalia erecti* because of misinterpretation, proposing instead the name *Brachypodietalia pinnati*. Communities dominated by *Bromus erectus* in Serbia should therefore be classified into the alliance *Cirsio-Brachypodion pinnati* and the order *Brachypodietalia pinnati*.

Cluster 6 includes alliance *Scabioso-Trifolion dalmatici* (*Astragalo-Potentilletalia*)

Diagnostic species: *Galium divaricatum*, *Trifolium dalmaticum*, *Thymus glabrescens*, *Taeniatherum caput-medusae*, *Achillea crithmifolia*, *Sedum sartorianum*, *Scabiosa argentea*, *Vicia lathyroides*, *Psilurus incurvus*, *Vulpia ciliata*, *Acinos alpinus*, *Veronica verna*, *Centaurea biebersteinii*, *Lotus angustissimus*, *Astragalus onobrychis* var. *chlorocarpus*, *Trifolium arvense*, *Chondrilla juncea*, *Dianthus pinifolius*, *Herniaria glabra*, *Filago arvensis*, *Astragalus onobrychis*, *Bromus japonicus*

Constant species: *Thymus glabrescens*, *Bothriochloa ischaemum*, *Trifolium campestre*, *Trifolium arvense*, *Galium divaricatum*

Dominant species: *Thymus glabrescens*, *Bothriochloa ischaemum*, *Chrysopogon gryllus*, *Astragalus onobrychis*, *Acinos alpinus*, *Galium divaricatum*

The xerophilous meadows and pastures of cluster 6 are found on shallow skeletoid soils in hilly-mountain regions. They belong to the endemic Mediterranean order *Astragalo-Potentilletalia*, which is found only in the central and southern parts of the Balkans (southern part of Serbia, Kosovo (Fig. 2), Macedonia and northern Greece) on limestone, silicate and even serpentine (ČARNI et al. 2000).

The climate of south and southeast Serbia is characterised by extremely dry and hot summers, promoting the growth of thermophilous and submediterranean species (e.g. *Chrysopogon gryllus*, *Bothriochloa ischaemum*, *Potentilla arenaria*, *Bromus squarossus*, *Hypericum rumeliacum*, *Trifolium dalmaticum* and others), which dominate in the floristic composition of these xerothermic grasslands. Characteristic species of the order are *Astragalus onobrychis* var. *chlorocarpus*, *Hypericum rumeliacum*, *Xeranthemum annuum*, *Psilurus incurvus*, *Bromus squarosus* etc. (MICEVSKI 1971).

Under traditional syntaxonomical schemes (KOJIĆ et al. 1998), three alliances of the order *Astragalo-Potentilletalia* are found in Serbia and Kosovo: the *Scabioso-Trifolion dalmatici* (on silicate at lower altitudes of 250–700 m), *Saturejo-Thymion* Micevski 1971 (distributed in Macedonia and Kosovo on marl at altitudes between 100 and 700 m) and *Koelerio-Festucion dalmaticae* Ranđelović et Ružić 1982 (on dolomite and serpentine between 600 and 1000 m a.s.l.). Numerical analysis of our data set revealed that this cluster contains associations assigned to the alliance *Scabioso-Trifolion dalmatici*, while relevés of the alliance *Koelerio-Festucion dalmaticae* were joined to the alliance of Pannonian steppic grasslands *Festucion rupicolae*. According to the traditional classification of grassland vegetation (KOJIĆ et al. 1998), the alliance *Saturejo-Thymion* has only one community in the central Balkans - *Echinario capitatae-Convolvuletum althaeoidis* Rexhepi ex Aćić et al. 2014. Numerical classification did not support such a classification and joined this community to the alliance *Festucion rupicolae*. As PIRINI et al. (2014) pointed out, the order *Astragalo-Potentilletalia* shows an intermediate geographical and floristic position among the sub-Mediterranean orders *Scorzonero-Chrysopogonetalia*, *Festucetalia valesiacae* in the east and Mediterranean pastures of the *Thero-Brachypodietea* class in the south.

The floristic composition of communities of this cluster (*Chrysopogon gryllus*, *Bothriochloa ischaemum*, *Astragalus onobrychis*, *Festuca dalmatica*, *Acinos alpinus*, *Achillea crithmifolia*, *Asperula cynanchica*) indicates that the alliance *Scabioso-Trifolion dalmatici* should remain in the order *Astragalo-Potentilletalia*, which is not in agreement with the proposal of MUCINA et al. (2015), which classifies the alliance *Saturejo-Thymion* within the *Astragalo-Potentilletalia* (*Festuco-Brometea*), while the other two alliances are in the *Koelerio-Corynephoretea* class. There are some characteristic species of the *Koelerio-Corynephoretea* class present in cluster 6 (*Veronica verna*, *Trifolium arvense*, *Filago arvensis* etc.) but species of the *Festuco-Brometea* class prevail. However, further research of these sub-Mediterranean grasslands in the southern Balkans is needed for better understanding of their syntaxonomical position.

Cluster 7 includes communities of the alliance *Festucion valesiacae*

Diagnostic species: *Festuca valesiaca*
Constant species: *Festuca valesiaca*
Dominant species: *Festuca valesiaca*

These xero-thermophilous steppe communities of Central European and continental distribution are classified within the alliance *Festucion valesiacae*. In contrast to those in Central Europe, communities from Serbia are mainly found in hilly and mountainous areas (HORVAT et al. 1974, KOJIĆ et al. 1998). These are dry, species-rich grassland steppe communities dominated by narrow leaved grasses of the genus *Stipa* and *Festuca valesiaca*. These species are well adapted to dry, warm summers and are frequent on southern and south-western slopes. The specific microclimatic conditions enable the development of steppe vegetation at higher altitudes. Communities of the alliance *Festucion valesiacae* are of secondary origin, developing under intensive human impact due to the destruction of thermophilous *Quercus cerris* and *Q. frainetto* forests.

Cluster 8 includes a transitional association with *Agrostis capillaris*

Diagnostic species: *Agrostis capillaris*, *Salvia verticillata*, *Hieracium pavichii*, *Festuca pratensis*
Constant species: *Agrostis capillaris*
Dominant species: *Agrostis capillaris*

Cluster 8 contains relevés of the *Agrostietum* type community with a transitional character and the presence of species of the *Molinio-Arrhenatheretea* class (e.g. *Festuca pratensis*, *Sanguisorba officinalis*). These characteristics might be the reason for the separation of these relevés in the form of a separate cluster.

Communities dominated by *Agrostis capillaris* are found in the mountainous part of Serbia in the zone of oak and beech forests. Their classification to the *Molinio-Arrhenatheretea* or *Festuco-Brometea* class has been very varied, depending on the author. For example, HORVAT et al. (1974), PETKOVIĆ (1985), STANČIĆ (2008) and TRINAJSTIĆ (2008) classify these communities from the Balkans into the alliance *Arrhenatherion*. Their classification was also supported by JANIŠOVÁ (2007) and ROZBROJOVÁ et al. (2010). Moreover, some authors include them in the alliance *Cynosurion* (JURKO 1974, ZUIDHOFF et al. 1995, BĂRBOS 2006, CHYTRÝ 2010, VELEV et al. 2010) while WENDELBERGER (1965) and HEGEDÜŠOVA et al. (2012) link them with the alliance *Polygono-Trisetion*. REDŽIĆ (2007) described the alliance *Festuco-Agrostion capillaris* of the Balkans and assigned it to the *Molinio-Arrhenatheretea* but it was invalidly published. In their revision of the Pannonian grasslands of Austria, WILLNER et al. (2013) classified a community with *Agrostis capillaris* into the order *Nardetalia*. On the other hand, most communities with *Agrostis capillaris* in Serbia have been classified within the alliance *Chrysopogono-Danthonion* (PAVLOVIĆ 1955, DANON 1960, OBRATOV 1992, KOJIĆ et al. 1998) of the *Festuco-Brometea* class. KOJIĆ et al. (2004) considered this vegetation to be "*Agrostietum vulgaris sensu lato*", indicating the existence of floristic and ecological differences within these grasslands, due to their wide distribution in Serbia, from hilly (KOJIĆ & DAJIĆ 1991) to high-mountain regions, up to 1600 m a.s.l. (PAVLOVIĆ 1955) and various management regimes.

In the past, these grasslands have been investigated more by agronomists (e.g. STOŠIĆ & LAZAREVIĆ 2007) than by phytosociologists, because of the significance of such grasslands for mowing and grazing. Most of the relevés of the *Agrostietum* type communities are connected to grasslands with *Danthonia alpina* (cluster 9) because of a syngenetic relationship between these communities (DIKLIĆ 1962). Further research is needed into vegetation with *Agrostis capillaris*, which would include taxonomical and phytosociological research in the Balkans and in SE Europe.

The three last clusters (9–11) belong to xeromesophilous and xerophilous grasslands of the Balkan alliance *Chrysopogono-Danthonion alpinae* growing mainly on acidic soils. The alliance *Chrysopogono-Danthonion alpinae* was published for the first time by KOJIĆ (1957) and was assigned to the order *Festucetalia valesiacae*. However, in a later syntaxonomic revision of the vegetation of Serbia (KOJIĆ et al. 2004), the alliance was classified within the order *Brometalia erecti*. Different authors have used different concepts: TZONEV et al. (2009) place this alliance in the acidophilous order *Koelerio-Phleetalia phleoidis* Korneck 1974, BERGMEIER et al. (2009) in the Balkan order *Astragalo-Potentilletalia* and, recently, VASSILEV et al. (2012b) and PEDASHENKO et al. (2013) preliminarily assigned it to *Brachypodietalia pinnati* (formerly *Brometalia erecti*) and we support this classification.

Cluster 9 includes different communities with the species *Danthonia alpina* (*Chrysopogono-Danthonion alpinae*)

Diagnostic species: *Danthonia alpina*, *Trifolium velenovskyi*

Constant species: *Agrostis capillaris*, *Danthonia alpina*

Dominant species: *Danthonia alpina*, *Agrostis capillaris*

Communities dominated by *Danthonia alpina* were grouped in cluster 9. They are widely distributed in Serbia (Fig. 2) as important grassland vegetation of mountain areas. The sites are of various expositions, mostly on deeper soils that are more or less acidic, at altitudes between 600 and 1400 m a.s.l.

The species *Danthonia alpina* dominates in dry subcontinental silicate steppe communities on acidic soils developed on sandstone, marl, dacite and andesite. These communities occur on sites of former oak forests or on serpentine steppes in western Serbia and Kosovo. The species *Danthonia alpina* also builds steppe communities on calcareous soils on karst terrains on natural potential sites of beech forests in central and eastern Serbia (LAKUŠIĆ & SABOVLJEVIĆ 2005) and has an important diagnostic character, connecting all plant communities in which it dominates into the alliance *Chrysopogono-Danthonion alpinae* (KOJIĆ et al. 2004). These communities are economically important since they cover large areas in mountain regions in Serbia and are used as hay meadows (DAJIĆ STEVANOVIĆ et al. 2010).

Cluster 10 includes various communities with the species *Koeleria pyramidata* ssp. *montana* (*Chrysopogono-Danthonion alpinae*)

Diagnostic species: *Koeleria pyramidata* ssp. *montana*, *Silene sendtneri*, *Ranunculus montanus*, *Rhinanthus alectorolophus*

Constant species: *Koeleria pyramidata* ssp. *montana*

Dominant species: *Koeleria pyramidata* ssp. *montana*, *Danthonia alpina*

The communities of cluster 10 are typical xerothermic pastures that develop on shallow and nutrient poor soils on slopes mainly of southern exposition. The grasslands are characterised by species-poor herbaceous plant communities developed on serpentine plateaus and karst terrain. Their common feature is the domination of the turf grass *Koeleria pyramidata* ssp. *montana* (LAKUŠIĆ & SABOVLJEVIĆ 2005), which is distributed in mountain areas.

Cluster 11 includes communities with the species *Chrysopogon gryllus* (*Chrysopogono-Danthonion alpinae*)

Diagnostic species: ***Chrysopogon gryllus***, *Euphrasia stricta*, *Trifolium strictum*, *Aira elegantissima*

Constant species: ***Chrysopogon gryllus***, *Leucanthemum vulgare*, *Filipendula vulgaris*

Dominant species: *Chrysopogon gryllus*

The grass *Chrysopogon gryllus* dominates in plant communities of the alliance *Chrysopogono-Danthonion*, which is distributed in the hilly-mountain regions of Serbia, in the zone of potential natural forest of *Quercus frainetto* and *Q. cerris* (Fig. 2). *Chrysopogon gryllus* has wide amplitude for several ecological factors and builds a large number of ecologically and floristically different plant communities. The role and importance of *Ch. gryllus* in Serbian grassland communities for Vojvodina (STJEPANOVIĆ-VESELIČIĆ 1953) and eastern (JOVANOVIĆ-DUNJIĆ 1954) and western Serbia (KOJIĆ 1959) has been described. Unlike Pannonian communities with *Chrysopogon gryllus* (classified within the *Festucion rupicolae*, cluster 2) of natural origin, mountain grasslands of the *Chrysopogonetum* type are semi-natural vegetation, developed due to human impact and maintained by mowing. KOJIĆ et al. (2004) thus analysed all data concerning the phytosociology of *Chrysopogon* grasslands in Serbia and divided this vegetation into two floristically, syntaxonomically and geographically distinct associations: the *Chrysopogonetum grylli serbicum* and the *Chrysopogonetum grylli pannonicum*. However, such an interpretation was considered to be invalid in terms of ICPN (WEBER et al. 2000) and a recent nomenclatural revision has been performed (AĆIĆ et al. 2014).

4.3 Syntaxonomic scheme

The syntaxonomical affiliations of dry grassland syntaxa are provided here according to the nomenclatural revision of the *Festuco-Brometea* class in the Central Balkans (AĆIĆ et al. 2014) and the present analysis.

1. *Festuco-Brometea* Br.-Bl. et Tx. ex Klika et Hadač 1944
    - 1.1 *Brachypodietalia pinnati* Korneck 1974 (syntax. syn. *Brometalia erecti* Br.-Bl. 1936)
        - 1.1.1 *Cirsio-Brachypodion pinnati* Hadač et Klika in Klika et Hadač 1944
        - 1.1.2 *Chrysopogono grylli-Danthonion alpinae* Kojić 1957
    - 1.2 *Festucetalia valesiacae* Soó 1947
        - 1.2.1 *Festucion valesiacae* Klika 1931
        - 1.2.2 *Festucion rupicolae* Soó 1940
        - 1.2.3 *Festucion vaginatae* Soó 1929
        - 1.2.4 *Artemisio-Kochion* Soó 1964

1.3 *Stipo pulcherrimae-Festucetalia pallentis* Pop 1968
1.3.1 *Saturejion montanae* Horvat in Horvat et al. 1974
1.4 *Astragalo-Potentilletalia* Micevski 1971
1.4.1 *Scabioso-Trifolion dalmatici* Horvatić et N. Ranđelović in N. Ranđelović 1977
1.5 *Halacsyetalia sendtneri* Ritter-Studnička 1970
1.5.1 *Centaureo-Bromion fibrosi* Blečić et al. 1969

4.4 Gradient analysis

Habitat environmental conditions and human impact are recognised as the key factors influencing the variability in species composition of dry grasslands (WELLSTEIN et al. 2007, DAJIĆ STEVANOVIĆ et al. 2010). In addition to climate, soil fertility together with soil chemistry and physical properties are considered to be the most influential environmental factors (MYKLESTAD 2004, JANIŠOVÁ et al. 2010). Variations in grassland floristic composition are dependent on historical management practices, including mowing, spring raking, late grazing, grazing every second year, and livestock moving among the sites (DAJIĆ STEVANOVIĆ et al. 2008).

The ordination diagram (Fig. 4) reveals that the most important ecological factors influencing the diversity of grassland vegetation types are temperature and moisture. The first axis is positively correlated to the indicator value for temperature, while the second axis is related to indicator values for moisture and nutrients. Light was an important site factor for the grouping of dry grassland communities, being positively correlated with temperature and continentality variables and negatively with the moisture factor. Moisture is considered the most important environmental factor for the floristic variability of grassland vegetation of the Balkans (AĆIĆ et al. 2013, ŠILC et al. 2014).

The right side of the ordination diagram contains relevés of the alliance *Festucion vaginatae* (cluster 3), Pannonian steppe communities developed on inland sand dunes, distributed on the driest and warmest sites. The same part of the diagram contains sub-Mediterranean communities of the Balkan order *Astragalo-Potentilletalia* (cluster 6) growing on warm open sites influenced by a Mediterranean climate.

Clusters 4 and 5 are located in the upper part of the ordination diagram, and comprise the communities of the order *Halacsyetalia sendtneri* and alliances *Saturejion montanae* and *Cirsio-Brachypodion pinnati*, occurring on open sites in which light was identified as the most important factor. Communities of the alliance *Chrysopogono-Danthonion* (cluster 8–11) are found on moist soils richer in nutrients. The alliance *Festucion valesiacae* (cluster 7) has a central position related to a gradient of site factors as shown by DÚBRAVKOVÁ et al. (2010) in an analysis of this alliance in the Carpathians and Pannonia.

4.5 Biodiversity patterns: floristic richness, endemism, legal protection and implications for conservation

The total number of 1,323 species occurring within 1,897 relevés, indicates high floristic richness of Balkan dry grasslands. According to STEVANOVIĆ et al. (1995), the flora of Serbia includes 3,662 taxa (i.e. 3,272 species and 390 subspecies assigned to 141 families), so the analysed dataset represents c. 40% of the total vascular flora of Serbia. As already pointed out, the class *Festuco-Brometea* mainly occurs on calcareous and nutrient-poor soil. Limestone areas are known to be generally much richer in number of vascular plant taxa than other types of geological substrata (STEBBINS 1980, VELCHEV 1998, MOSER et al.

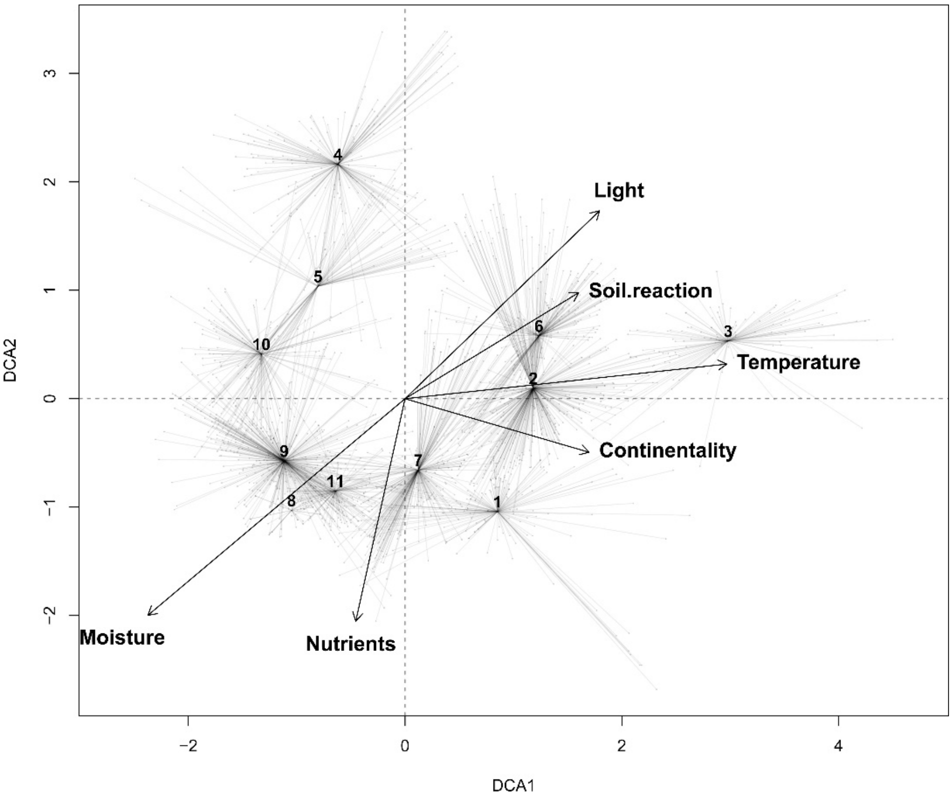


Fig. 4. DCA ordination analysis of Central Balkan dry grasslands. Eigenvalues of the first two axes were 0.63 and 0.46, respectively. Ordination results are presented as spider plots, in which each relevé is linked to the centroid of its cluster by a line. Ecological indicator values were plotted a posteriori on the DCA diagram. Cluster 1 – *Festucion rupicolae*, variant of *Cynodon dactylon*; Cluster 2 – typical *Festucion rupicolae*; Cluster 3 – *Festucion vaginatae*; Cluster 4 – *Centaureo-Bromion fibrosi*; Cluster 5 – *Saturejion montanae* and *Cirsio-Brachypodion pinnati*; Cluster 6 – *Scabioso-Trifolion dalmatici*; Cluster 7 – *Festucion valesiacae*; Cluster 8 – transitional *Agrostietum* type grassland; Cluster 9 – *Chrysopogono-Danthonion alpinae*, *Danthonietum* type; Cluster 10 – *Chrysopogono-Danthonion alpinae*, *Koelerietum* type; Cluster 11 – *Chrysopogono-Danthonion alpinae*, *Chrysopogonetum* type.

Abb. 4. DCA-Ordination der Trockenrasen des Zentral-Balkans. Die ersten beiden Achsen haben Eigenwerte von 0,63 bzw. 0,46. Jede Aufnahme ist mit dem Zentroid des entsprechenden Clusters durch eine Linie verbunden (*Spider plot*). Die ökologischen Zeigerwerte wurden nachträglich als Vektoren im Diagramm dargestellt. In der englischen Abbildungsunterschrift werden die Cluster Syntaxa zugeordnet.

2005). The high floristic richness and diversity of the flora of limestone areas covered by dry grassland vegetation of the class *Festuco-Brometea* in Serbia consequently follows this general pattern.

TURRILL (1929) and STRID &TAN (1997) defined Balkan endemics as all plant species or subspecies with natural distributions delimited by the territory of the Balkan Peninsula. On the basis of the most recent chorological, ecological and diversity analysis of Balkan endemic plants in Central Serbia and Kosovo (TOMOVIĆ et al. 2014), dry grasslands of the *Festuco-Brometea* class are characterised by a very high proportion of endemic plants. In fact, a total of 204 species and subspecies were recorded in the class *Festuco-Brometea*, representing 41% of the total number of 490 Balkan endemic plants determined for Central Serbia and Kosovo. This number of endemics ranks the class *Festuco-Brometea* in second place after the class *Asplenietea trichomanis*, which is characterised by the presence of 231 Balkan endemic taxa.

The large total numbers of plant species and endemics within the *Festuco-Brometea* class of the Balkans can be explained by several factors: First, dry grasslands cover large parts of the lowland and mountain areas in Serbia and Kosovo, so a large number of vascular plant species and subspecies (including Balkan endemics) can be expected. In addition, endemic flora that is mostly found on limestone is much more abundant than flora occurring on other geological substrata, as reported for the eastern Alps (TRIBSCH & SCHÖNSWETTER 2003), the Caucasus (KIKVIDZE & OSHAWA 2001) and the flora of Iberia and the Balearic islands (DOMÍNGUEZ LOZANO et al. 2000). Finally, several floristic studies on the endemic flora of different parts of the world (MÉDAIL & VERLAQUE 1997, DHAR 2002) have proved that most endemics occupy dry habitats, such as rocky xerophilous grasslands, screes, cliffs and rocky habitats at low, mid or high elevations.

Within the analysed data set of 1,323 plant species and subspecies, only eight plants have a nationally threatened status, of which two are considered extinct in Serbia (category EX-Srb according the National Red List - *Erysimum crepidifolium* Reichenb. and *Seseli hippomarathrum* Jacq.) and six belong to critically endangered taxa (category CR - *Achillea ochroleuca* Ehrh., *Allium atroviolaceum* Boiss., *Crambe tataria* Sebeók, *Dianthus serotinus* Waldst. & Kit., *Nepeta rtanjensis* Diklić & Milojević and *Nonea pallens* Petrović) (STEVANOVIĆ 1999). A total of 233 species and subspecies are protected by national legislation (ANONYMOUS 2010), of which 64 are strictly protected and 169 protected, which represents 17.6% of all vascular plants within our analysed data set. There is therefore an urgent need not only to identify rich endemic areas but also to include them in future Important Plant Areas and NATURA 2000 areas.

In this paper, we present the first review of the classification and ecology of dry grasslands in Serbia. The results of our study facilitate a synchronisation of the Balkan and European syntaxonomical system and the EU Habitat list leading to adequate legal conservation and proper management regimes of Balkan dry grasslands. Since the Balkan dry grasslands exhibit distinctive floristic and vegetation diversity and represent a major natural resource for agricultural production, they should be maintained in a more sustainable manner.

Erweiterte deutsche Zusammenfassung

Einleitung – Mit einer Fläche von 1,4 Mio. Hektar bildet das Grasland in Serbien eine wichtige Grundlage für die Landwirtschaft. Besonders das trockene Grasland der Klasse *Festuco-Brometea* besitzt in Serbien eine hohe Diversität und ist daher besonders schutzwürdig (DAJIĆ STEVANOVIĆ et al. 2010, HEGEDÜŠOVÁ & SENKO 2011, TOMOVIĆ et al. 2014). In dieser Studie werden die Trockenrasen Serbiens auf einer umfangreichen Datengrundlage analysiert. Erstmalig für Serbien wird eine Gesamtklassifikation der Klassen *Festuco-Brometea* und *Festucetea vaginatae* präsentiert und Einblicke in die Verbreitung, Umweltbedingungen und Biodiversitätsmuster der Gesellschaften gegeben.

Methoden – Es wurden alle für Serbien und den Kosovo in der Literatur verfügbaren Vegetationsaufnahmen, die von ihren Autoren in die Klassen *Festuco-Brometea* und *Festucetea vaginatae* gestellt worden waren, zusammen mit eigenen Aufnahmen in der *Vegetation Database of Serbia* (GIVD ID EU-RS-02; AĆIĆ et al. 2012), der *Balkan Dry Grasslands Database* (GIVD ID EU-00-13; VASSILEV et al. 2012a) und im *European Vegetation Archive* (EVA; http://euroveg.org/eva-database) archiviert. Die

Nomenklatur der Taxa folgte dabei mit Ausnahme weniger Arten der Flora Europaea (FLORA EUROPAEA DATABASE). Nach einer Ausreißeranalyse und geografischen Stratifizierung zur Vermeidung der Überrepräsentation einzelner Gebiete/Regionen, umfasste der Datensatz 1.897 Aufnahmen mit 1.323 Pflanzenarten. Mit diesem Datensatz wurde eine Clusteranalyse mit relativen Sørensen-Index als ein Entfernungsmaß und einem *flexible Beta* von -0,25 für die Gruppenzusammengehörigkeit durchgeführt (MCCUNE & MEFFORD 1999). Die erhaltenen Cluster wurden mithilfe von mit dem Programm JUICE (TICHÝ 2002) ermittelten und über den Phi-Koeffizienten (CHYTRÝ et al. 2002) definierten Charakterarten beschrieben. Die Gruppengrößen wurden auf einheitliche Größe standardisiert und ein Fisher Exact-Test ($p < 0,05$) wurde durchgeführt. Arten mit einem Phi-Koeffizient von über 0,20 wurden als diagnostisch und solche mit ≥ 25% Deckung in mindestens 5 % der Aufnahmen einer Gruppe als dominant definiert. Arten mit mindestens 50 % Frequenz wurden in der betreffenden Gruppe als stet angesehen. Zur Charakterisierung der Umweltbedingungen wurden ungewichtete mittlere Zeigerwerte nach PIGNATTI et al. (2005) herangezogen; wenn eine Art dort nicht gelistet war, wurde mit den Zeigerwerten von BORHIDI (1995) ergänzt. Beziehungen zwischen Clustern und ökologischen Zeigerwerten wurden mithilfe einer *Detrended Correspondence Analysis* (DCA) mit quadratwurzeltransformierten Deckungswerten und Herabwichtung seltener Arten mit Vegan in R (http://www.r-project.org) analysiert. Die Naturschutzbedeutung der Gesellschaften wurde schließlich auf Grundlage der Anzahl gefährdeter und endemischer Arten gemäß der Roten Liste Serbiens und der Liste der geschützten Arten Serbiens quantifiziert.

Ergebnisse und Diskussion – In der Clusteranalyse wurden vier Hauptgruppen unterschieden (Abb. 1): Die erste Hauptgruppe beinhaltete Sandtrockenrasen der pannonischen Region sowie Lößtrockenrasen. Die zweite Felstrockenrasen, die dritte montane Kalksteppenrasen der balkanischen Ordnung *Astragalo-Potentilletalia* und die vierte die verbleibenden Gesellschaften des *Festucion valesiacae* und des *Chrysopogono-Danthonion* auf tiefgründigen Silikat- oder Kalkböden.

Die 11 Cluster (Abb. 1 und 2) ließen sich wie folgt charakterisieren: Cluster 1 umfasste pannonische Steppengesellschaften des *Festucion rupicolae* mit dem Gras *Cynodon dactylon* als Charakterart; diese Art ist typisch für trockenwarme, beweidete ruderale Standorte. Cluster 2 umfasste pannonische Trockenrasen des *Festucion rupicolae* auf nährstoffreichen Lössschwarzerden in der nördlich von Save und Donau gelegenen Provinz Vojvodina (Fruška-Schlucht und Vršačke-Gebirge) sowie Binnensanddünen; hier werden die Gesellschaften meist von den Gräsern *Chrysopogon gryllus* und *Bothriochloa ischaemum* aufgebaut. Die Clusteranalyse zeigte eine klare Trennung des *Festucion rupicolae* und *Festucion valesiacae* auf hohem Niveau. Während das *Festucion rupicolae* Steppen- und Trockenrasen des pannonischen Waldsteppengürtels auf Lößstandorten umfasst, beinhaltet das *Festucion valesiacae* subkontinentale Trockenrasen der kollinen Stufe in Kontakt zu *Quercus frainetto*- und *Q. cerris*-Wäldern. Zudem umfasste Cluster 2 Gesellschaften auf Dolomit- oder Serpentinstandorten in Südost-Serbien sowie im Kosovo. Diese Gesellschaften werden traditionell zum *Koelerio-Festucion dalmaticae* (Ordnung *Astragalo-Potentilletalia*) gestellt. Nach AĆIĆ et al. (2014) wurde dieser Verband allerdings ungültig beschrieben; daher halten wir weitere syntaxonomische Untersuchungen für erforderlich. Cluster 3 beinhaltete von *Festuca vaginata* dominierte kontinentale Trockenrasen sandiger Standorte mit *Corispermum nitidum*, *Polygonum arenarium* und *Festuca vaginata* als Charakterarten (Abb. 4). Die Bestände zeigten floristische Ähnlichkeit mit den pannonischen Trockenrasen des *Festucion vaginatae* und *Festucion rupicolae*, sodass sie in die Klasse *Festuco-Brometea* gestellt werden können. Cluster 4 umfasste thermophile Serpentin-Trockenrasen des endemischen Verbands *Centaureo-Bromion fibrosi* in der endemischen Ordnung *Halacsyetalia sendtneri* im Bergland des Balkans. Die durch Cluster 5 repräsentierten Gesellschaften kommen ebenfalls im Bergland Serbiens, jedoch auf Kalkstein, vor. Sie werden von *Carex humilis*, *Potentilla tommasiniana*, *Stipa pulcherrima* und *Bromus erectus* dominiert und gehören zum *Saturejion montanae* oder *Cirsio-Brachypodion pinnati*. Cluster 6 beinhaltete xerophile Wiesen und Weiden des Verbands *Scabioso-Trifolion dalmatici* innerhalb der mediterranen Ordnung *Astragalo-Potentilletalia* in bergigen Lagen. Die floristische Zusammensetzung dieser Gesellschaften mit u. a. *Chrysopogon gryllus*, *Bothriochloa ischaemum*, *Astragalus onobrychis*, *Festuca dalmatica*, *Acinos alpinus*, *Achillea crithmifolia* und *Asperula cynanchica* deutet darauf hin, dass der Verband *Scabioso-Trifolion dalmatici* in der Ordnung *Astragalo-Potentilletalia* verbleiben sollte – was MUCINA et al. (2015) wiederentspricht. Thermophile Steppengesellschaften des Verbands *Festucion valesiacae* (Cluster 7) sind ebenfalls hauptsächlich in den Hügel- und Berglagen Serbien zu finden (HORVAT et al. 1974, KOJIĆ et al. 1998). Der Verband *Festucion valesiacae* ist eine Sekundärgesellschaft, die durch intensive menschliche Nutzung auf Standorten thermophiler *Quercus cerris*- und *Q. frainetto*-Wälder entstanden ist. Cluster 8 beinhaltete das *Agrostietum* mit Übergangscharakter zur Klasse *Molinio-Arrhenatheretea*. Die Cluster 9–11 gehören schließlich zu den xeromesophilen Gesellschaften des balkanischen Verbands *Chrysopogono-Danthonion alpinae*, dessen Bestände hauptsächlich auf sauren Böden wachsen.

Die Ordination zeigte, dass Temperatur und Feuchtigkeit die wichtigsten ökologischen Faktoren für die Differenzierung der Trockenrasengesellschaften des Zentral-Balkans darstellen. Gesellschaften des Verbands *Chrysopogono-Danthonion* kommen auf besser wasser- und nährstoffversorgten Böden vor. Der Verband *Festucion valesiacae* nahm in der DCA eine mittlere Position in Hinblick auf die untersuchten Umweltfaktoren ein, wie es auch DÚBRAVKOVÁ et al. (2010) in den Karpaten und in Pannonien zeigen konnten.

Die Klasse *Festuco-Brometea* im Zentral-Balkan weist eine hohe floristische Diversität auf und ist dadurch besonders schutzwürdig. In dem hier analysierten Datensatz finden sich insgesamt 1.323 Arten und Unterarten wovon allerdings nur acht Arten in Serbien gefährdet sind; zwei davon, *Erysimum crepidifolium* Reichenb. und *Seseli hippomarathrum* Jacq., galten in Serbien als ausgestorben, die anderen sechs Arten (*Achillea ochroleuca* Ehrh., *Allium atroviolaceum* Boiss., *Crambe tataria* Sebeók, *Dianthus serotinus* Waldst. & Kit., *Nepeta rtanjensis* Diklić & Milojević und *Nonea pallens* Petrović) als stark bedroht (STEVANOVIĆ 1999). Von den 1.323 Arten sind 233 Arten und Unterarten (17,6 %) in Serbien geschützt (ANONYMOUS 2010), 64 davon sind streng geschützt.

Die hier vorgestellten ersten Ergebnisse der Gesamtklassifikation der *Festuco-Brometea* des Zentral-Balkans, können zur Einordnung der Pflanzengesellschaften Serbiens in das europäische syntaxonomische System beitragen und so auch zu ihrem gesetzlichen Schutz nach Europarecht führen.

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