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SPECIAL FEATURE: VEGETATION SURVEY

Grassland vegetation of the *Molinio-Arrhenatheretea* class in the NW Balkan Peninsula

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Keywords
Balkan region; Classification; Europe; Grassland; Mesic meadows; Pastures; Phytosociology; Vegetation survey

Nomenclature
Vascular plants Tutin et al. (1964–1993) except for *Scirpus georgianus* Harper; Higher syntaxa Mucina et al. (2014)

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Virtual Special Feature: "Towards a consistent classification of European grasslands" (Eds. Jürgen Dengler, Erwin Bergmeier, Wolfgang Willner & Milan Chytrý).

Abstract

Questions: How does the floristic composition of plant species of meadows and mesic pastures vary along a broad geographical gradient in the NW Balkans? How does the current phytosociological classification of the *Molinio-Arrhenatheretea* vegetation differ among the NW Balkan countries?

Location: NW Balkans (Slovenia, Croatia, Bosnia and Herzegovina, Serbia).

Methods: 3635 relevés originally assigned to the class *Molinio-Arrhenatheretea* were classified with a beta flexible method, and the crispness of classification was checked. DCA ordination with Pignatti indicator values and climate data were applied to show the influence of site conditions on species composition.

Results: The classification was best interpreted at the level of 13 clusters, but could also be interpreted at the level of three groups of clusters. The first division was according to geography and climate: the first and third groups were concentrated in the NW part, while the second was restricted to the eastern part of the study area. The most important variable was site moisture, followed by nutrients and altitude, which corresponded with a west–east direction. The first group was very diverse and included communities on the wettest and most nutrient-rich sites (*Potentillion anserinae*, *Cynosurion cristati*, *Calthion palustris*, *Molinion caeruleae*, *Molinio-Hordeion*). The second group comprised mesophilous continental grasslands (*Trifolio-Ranunculion pedati*, *Trifolion pallidi*, *Trifolion resupinati*), while the third group consisted of grasslands from regions with abundant precipitation (*Arrhenatherion elatioris*, *Deschampsion cespitosae*, *Pancicion serbicae*, *Triseto flavescentis-Polygonion bistortae*).

Conclusions: Our analysis can be used to unify different phytosociological classifications in different countries, also showing the transitional forms of well-known Central European vegetation types that have a different floristic composition and ecology in the Balkans. This knowledge will enable classification of the same vegetation types in neighbouring Balkan countries that are less studied.

Introduction

The Balkans is a peninsula in the form of an irregular triangle that extends from Central Europe in the north to the Eastern Mediterranean in the south (Reed et al. 2004). The complexity of its physical geography and transitional location of floral (and faunal) influences have made this region a European biodiversity hotspot. The latest estimates have raised the number of autochthonous vascular plant species to 8000 in the Balkan Peninsula, which makes it one of the three (together with the Italian and Iberian Peninsulas) most important centres of floristic diversity in Europe (Stevanović et al. 2003). The Balkans is the most species-rich region in Europe in terms of plant endemism, with 2600–2700 endemic plant taxa (Stevanović et al. 2007). Moreover, the region is known for its very diverse vegetation, including various types of natural and semi-natural grasslands (Dajić-Stevanović et al. 2010; Aćić et al. 2013b).

Grasslands are habitats dominated by graminoids and are the most widely distributed vegetation type in the

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cultural landscape. In addition to natural grasslands, large areas are covered with grasslands that are a product of lengthy human influence. They thrive in various ecological conditions (wet, mesic and dry) and under different management regimes (mown, grazed, fertilized), all resulting in different biological patterns (Sebastiá 2004; Klimek et al. 2007; Putfarken et al. 2008; Wesche et al. 2012) and patterns of ecosystem functioning and diversity (Laliberté et al. 2010). Most grasslands represent semi-natural vegetation developed during a long history of human use. Different types of historical and current grassland use have resulted in various plant and vegetation diversity patterns. Traditionally managed semi-natural grasslands (hay meadows and pastures) are known to support a rich flora and are recognized for high species diversity in various regions of Europe, including the Balkans (Dajić-Stevanović et al. 2010; Wilson et al. 2012). Many grassland communities are now being threatened by rapid changes in agricultural practices, especially related to the effects of either land abandonment (Pykälä et al. 2005; Dajić Stevanović et al. 2008) or intensification (Stevens et al. 2004) as contrasting management practices, whereby the latter often results in the spread of P- and N-demanding competitive grasses tolerant to mowing (Wesche et al. 2012; Ceulemans et al. 2013).

In the agricultural landscapes of Central Europe (as well as in the Balkans), moist and mesic grasslands are among the habitat types that have experienced the severest losses (Prach 2008), thus attracting particular research and conservation attention. The class *Molinio-Arrhenatheretea* includes mown meadows and mesic pastures of temperate regions of Europe and adjacent parts of Asia (Hájková et al. 2007). In Central Europe, several alliances are widely recognized and stable in international classifications (*Arrhenatherion elatioris, Molinion caeruleae, Calthion palustris*), while the classification of lowland wet meadows is less consistent (Botta-Dukát et al. 2005). In the Balkans, due to large gradients between sub-oceanic and continental climates with a Mediterranean influence, these inconsistencies are even more pronounced and also appear in well delimited syntaxa in other parts of Europe. Another reason for ambiguous classification, in addition to various climatic influences, is that some syntaxa are at the limit of their distribution. On the other hand, grasslands of *Molinio-Arrhenatheretea* in the Central Balkans are rich in endemics (91 taxa; Tomović 2007). The frequent occurrence of endemic and rare plants has also been reported for several alliances of this class in the Central European region (Ružičková et al. 2004). Species-rich mesic meadows of *Molinio-Arrhenatheretea* were therefore included in the European Habitats Directive (92/43/EEC; European Union 1992/1995; NATURA 2000-Codes 64 and 65). Classification of grassland vegetation of the NW Balkans is thus important for incorporating these vegetation types into the European scheme.

The territory of the NW Balkans (or former Yugoslavia) has a long tradition of vegetation research, which, however, as of recently has not been transnational (Kojić et al. 1998; Trinajstić 2008; Šilc & Čarni 2012). This has led to syntaxonomic systems that are not comparable and, as Horvat et al. (1974) have already mentioned, different authors have classified grasslands into different syntaxa using local experience. The study area is a transitional region between different climatic influences, and this makes syntaxonomical classification more difficult. Two climatic zones (the Mediterranean and Central European) overlap in the Balkans, with a large transitional area and pronounced climate modifications, depending on the orientation of mountain massifs, lowlands, valleys and altitude, and to a large extent influenced by dominant winds. According to Polunin (1987), lowlands and valleys are of great importance for plant species distribution, since they enable advance of the mediterranean climate into the interior.

Another problem is that stands are transitional between syntaxa, due to changes to or even abandonment of management. Such stands make phytosociological classification even more ambiguous.

Use of large vegetation databases enables large-scale comparisons and some efforts towards identifying distinct vegetation types have already been made in the NW Balkans (Košir et al. 2008, 2013; Šilc et al. 2008; Čarni et al. 2009; Marinšek et al. 2013), but not for grasslands, and in particular not for mesic grasslands. The main aim of this study was to determine the main vegetation types of the class *Molinio-Arrhenatheretea* in the NW Balkans, to delimit alliances geographically and ecologically and to propose a vegetation classification system on a higher level.

Material

A large data set of grassland vegetation relevés (4615 relevés originally assigned by authors into the class *Molinio-Arrhenatheretea*) was compiled from the territory of the NW Balkan Peninsula (Bosnia and Herzegovina, Croatia, Serbia, Slovenia). The study area extends over 216 000 km^2 (13°22′W to 23°00′E and 46°54′N to 41°50′ S). The terrain is predominantly hilly, with 72% of the area (except for the large Pannonian plain) higher than 200 m·a.s.l.; the bedrock is mainly carbonate. The climate is very diverse: a temperate warm climate predominates, while smaller regions have mountain (boreal) and true mediterranean climates (Bertić 1987).

The data set consists mainly of published relevés, but includes some that are unpublished (GIVD EU-HR-002, EU-RS-002, EU-SI-001). The relevés are stored in TURBOVEG format (Hennekens & Schaminée 2001). Outlier

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analysis was processed using PC-ORD 5.0 (MjM Software Design, Gleneden Beach, OR, US) and 67 relevés whose species composition deviated more than ±2 SD from the mean calculated Euclidean distance of all plots were omitted.

Relevés were georeferenced *a posteriori*. To reduce the 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. Finally, 3635 relevés were included in the analysis.

Species nomenclature was checked and synonyms and taxa determined at various ranks were aggregated to a common taxonomic level (e.g. *Agrostis stolonifera* agg. = *A. gigantea*, *A. stolonifera*; *Brachypodium pinnatum* agg. = *B. pinnatum*, *B. rupestre*; *Bromus racemosus* agg. = *B. racemosus*, *B. commutatus*; *Carex flava* agg. = *C. flava*, *C. lepidocarpa*; *Centaurea jacea* agg. = *C. jacea*, *C. angustifolia*, *C. macroptilon*; *Festuca pratensis* agg. = *F. pratensis*, *F. arundinacea*; *Galium mollugo* agg. = *G. album*, *G. mollugo*; *Leucanthemum vulgare* agg. = *L. vulgare*, *L. praecox*; *Polygonum aviculare* agg. = *P. aviculare*, *P. arenastrum*; *Vicia sativa* agg. = *V. angustifolia*, *V. sativa*; *Vicia pannonica* s. lat = *V. pannonica*, *V. striata*). Records of species determined to the genus level and bryophytes and lichens were deleted from the data set since they were not consistently sampled by all of the authors. Species cover values in original relevés were estimated on different scales. They were a posteriori transformed to percentages and square-rooted.

Climatic variables (annual temperature, precipitation and BIO 18 – precipitation of the warmest quarter) were subjectively selected, since we presumed that they have strong effects on species composition. They were compiled for each relevé from the WorldClim database (Hijmans et al. 2005).

Environmental indicator values of Pignatti (2005) were used for ecological interpretation of gradients. Unweighted mean indicator values were calculated for each relevé and, in the same way, for columns in the synoptic table.

Methods

We classified the data set (3635 relevés) using cluster analysis in the PC-ORD 5.0. The Sørensen index as the distance measure and beta flexible (â = −0.25) for group linkage were used. We made several classifications with different numbers of clusters of relevés. We used the OptimClass method (Tichý et al. 2010) for identifying the optimal partition and the peak of the OptimClass1 curve showed the optimal number of clusters is 13 at threshold $P < 10^{E-10}$. We accepted this classification with 13 clusters as being the ecologically soundest. Other classifications with more clusters produced groups with ambiguous ecological and syntaxonomic significance.

The synoptic table was produced in the JUICE program and the phi (φ) coefficient was used as the measure of fidelity. Each cluster was compared to the remaining relevés in the data set, which were taken as a single undivided group. Since the clusters consisted of unequal numbers of relevés, higher φ values for larger clusters were expected. To avoid that, each of the 13 clusters was virtually equalized to 1/13 of the size of the entire data set (Tichý & Chytrý 2006). The threshold of the φ value was subjectively selected at 0.10 for a species to be considered diagnostic. This threshold was considered to be optimal for interpreting a single cluster and for preventing inflation of diagnostic species.

Relationships between clusters and environmental indicator values were visualized using DCA ordination, in which the square-rooted percentage covers of species were used. The mean ecological indicator values (based on Pignatti 2005) were plotted *a posteriori* on the DCA ordination diagram. Ordination results are presented on spider plots, in which each relevé is linked to the centroid of its cluster by a line. Analysis was performed in R (R Foundation for Statistical Computing, Vienna, AT; v 2.15.2, http://www.r-project.org) using vegan package (http://cc.oulu.fi/~jarioksa/softhelp/vegan.html).

Results

Classification

Classification could first be interpreted at the level of three groups of clusters (Fig. 1, clusters 1–6, 7–9 and 10–13; Table 1), which reflected geographic and climatic factors, with the first and third group concentrated in the NW part and the second group restricted to the E part of the study area. The first group is very diverse and includes the wettest communities on the one hand and the most nutrient-rich communities on the other. The second group comprises mesophilous continental grasslands, while the third group of clusters consists of grasslands on deeper soils from regions with high precipitation. The most meaningful and finer classification is at the level of 13 clusters (Fig. 1, Table 1).

Cluster 1 comprises nitrophilous, semi-ruderal grasslands along water bodies dominated by *Agrostis stolonifera* agg.

Cluster 2 represents typical vegetation of the alliance *Cynosurion cristati* from temperate Europe. Communities are dominated by species adapted to trampling (*Lolium perenne*, *Plantago major*), while the species *Cynosurus cristatus* in the NW Balkans is characteristic for the association *Bromo-Cynosuretum* (Cluster 12).

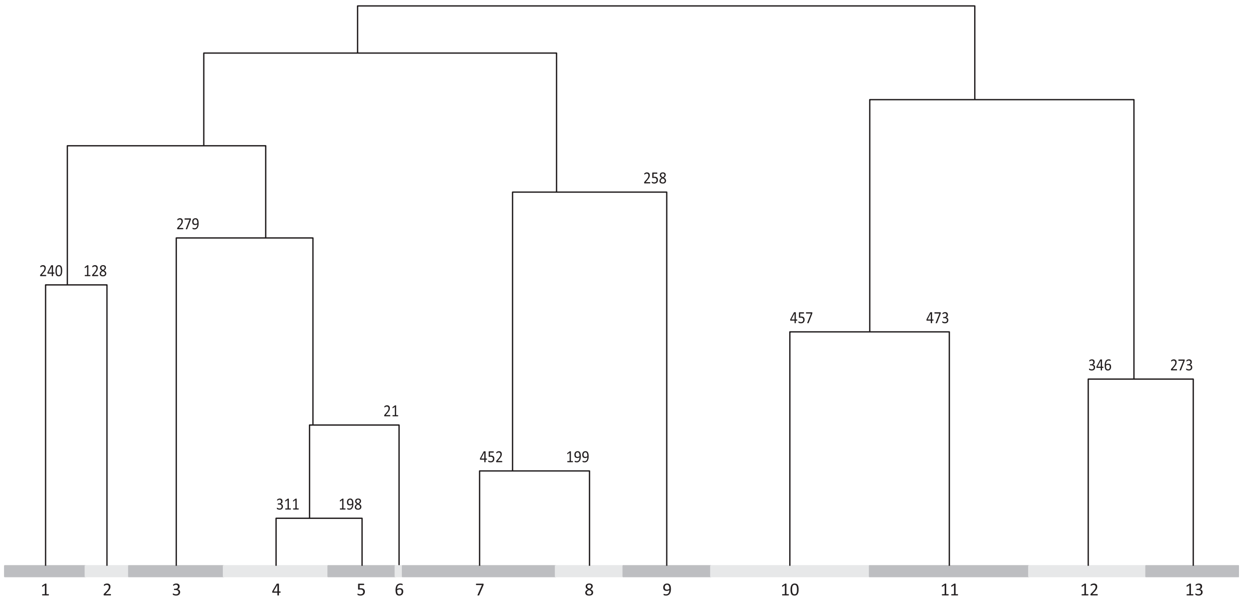

Fig. 1. Classification dendrogram of grassland dataset (3635 plots). 1 – *Potentillion anserinae*, 2 – *Cynosurion*, 3 – *Calthion*, 4 – *Molinion*, 5 – *Molinio-Hordeion secalini*, 6 – *Scirpo holoschoeni-Salicetum rosmarinifoliae*, 7 – *Trifolion pallidi*, 8 – *Trifolio-Ranunculion pedati*, 9 – *Trifolion resupinati*, 10 – *Pancicion serbicae & species poor Arrhenatheretalia*, 11 – *Arrhenatherion s.str. & Triseto flavescentis-Polygonion bistortae*, 12 – *Bromo-Cynosuretum*, 13 – *Deschampsion*. The numbers of clusters refer to Table 1 and the number of relevés included in each cluster is indicated.

Cluster 3 contains relevés of the alliance *Calthion palustris*, dominated by hygrophilous herbs. They are found on wet, nutrient-rich soils with a large altitudinal range (they are found in lowlands and up to 1800 m).

Cluster 4 comprises vegetation dominated by *Molinia caerulea* agg. distributed mostly in Slovenia with some occurrences also in the south (*Caltho-Alopecuretum* in Vojvodina and at higher altitudes in Serbia, with a mix of *Deschampsia caespitosa* and *Polygonum bistorta*). Stands are wet, and compared to other clusters nutrient-poor and acidic.

Cluster 5 corresponds to the Illyrian-Mediterranean alliance *Molinio-Hordeion secalini*, which is found on Karst poljes. It is geographically limited to Slovenia, Croatia and Bosnia and Herzegovina.

Cluster 6 represents a rare plant association *Scirpo holoschoeni-Salicetum rosmarinifoliae* found on sandy sites along rivers and classified into the *Molinion caeruleae* alliance. Communities are dominated by *Salix repens* and xeric grassland species.

Cluster 7 includes wet lowland grasslands in the eastern continental part of the NW Balkans (E Croatia and central Serbia). In addition to grasses, the most important species group consists of clovers (*Trifolium patens, T. pallidumi T. resupinatum*) and other Fabaceae (*Medicago arabica, M. polymorpha, Lathyrus tuberosus*).

Cluster 8 covers mesophilous grassland vegetation on the Pannonian plain that can thrive in sites with high variability of soil moisture and slight salinity. The grass species *Poa angustifolia, Poa palustris* and *Alopecurus pratensis* are characteristic for the communities classified into the alliance *Trifolio-Ranunculion pedati*.

Cluster 9 comprises plant communities classified into the Balkan sub-halophytic alliance *Trifolion resupinati*. These are sub-Mediterranean lowland meadows in the S and SE part of the research area.

Cluster 10 includes relevés with the largest altitudinal range. There are communities from higher altitudes (*Pancicion serbicae*) as well as stands that are poor in characteristic species or were classified to higher syntaxa (mainly into the order *Arrhenatheretalia*) and are similar in floristic composition to stands from higher altitudes. The map of this cluster therefore shows mixed geographic distribution with communities of high altitudes and depauperate stands found in lowlands.

Cluster 11 consists of typical grasslands of Central Europe that are classified into alliances *Arrhenatherion elatioris, Triseto flavescentis-Polygonion bistortae* and *Poion supinae* and dominated by the grasses *Arrhenatherum elatius, Trisetum flavescens, Dactylis glomerata, Avenula pubescens*.

Cluster 12 represents widespread wet stands of the alliance *Arrhenatherion elatioris*, mostly the association *Bromo-Cynosuretum* comprising lowland grasslands temporarily flooded in spring. Stands are characterized by *Holcus lanatus* and *Cynosurus cristatus*. In Central Europe, the latter species is characteristic for trampled and frequently mowed grasslands.

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Table 1. Synoptic table of *Molinio-Arrhenatheretea* grasslands in the NW Balkans. The frequency values are shown, shaded are species with phi values higher than 0.1. Only five species with highest fidelity are presented.

Cluster	1	2	3	4	5	6	7	8	9	10	11	12	13
No. of releves	240	128	279	311	198	21	452	199	258	457	473	346	273
% relevés for country													
Slovenia	31	25	23	68	10	0	5	0	0	24	44	33	55
Croatia	42	49	17	4	64	0	12	21	0	29	55	66	38
Bosnia and Herzegovina	4	0	1	1	26	0	3	0	0	11	0	0	0
Serbia	24	26	59	26	1	100	81	79	100	36	1	0	7
Cluster 1: *Potentillion anserinae*													
Agrostis stolonifera agg.	93	38	21	23	22	–	29	18	10	7	3	26	25
Mentha longifolia	38	6	14	3	–	–	6	2	6	6	5	1	1
Juncus inflexus	32	7	13	4	1	–	2	1	–	1	–	2	4
Alopecurus geniculatus	10	–	1	–	–	–	–	–	–	–	–	–	–
Rorippa sylvestris	46	22	8	1	6	–	21	20	25	4	1	1	2
Cluster 2: *Cynosurion*													
Lolium perenne	22	85	2	–	8	–	9	4	62	15	23	17	2
Cynodon dactylon	12	56	2	–	5	–	3	18	1	4	1	1	1
Plantago major	30	64	6	3	2	–	9	10	9	12	4	4	2
Trifolium repens	47	88	27	4	7	–	28	26	38	42	35	36	20
Poa annua	11	29	–	–	–	–	1	4	–	8	1	1	–
Cluster 3: *Calthion*													
Scirpus sylvaticus	3	–	45	3	–	–	1	–	4	2	1	4	5
Filipendula ulmaria	5	–	34	29	3	–	1	–	–	4	2	13	25
Eriophorum latifolium	–	–	21	15	1	–	–	–	–	1	–	–	1
Equisetum palustre	3	–	37	22	2	10	2	10	6	2	3	9	15
Caltha palustris	3	–	34	10	–	–	1	4	1	3	–	–	4
Cluster 4: *Molinion coeruleae*													
Molinia caerulea agg.	–	–	15	93	31	29	–	–	–	2	2	3	15
Schoenus ferrugineus	–	–	–	15	–	–	–	–	–	–	–	–	–
Potentilla erecta	2	–	28	73	8	–	1	1	–	13	15	26	44
Succisa pratensis	1	–	11	49	5	–	1	–	–	1	1	19	29
Sanguisorba officinalis	–	–	10	48	20	–	4	1	1	1	3	13	24
Cluster 5: *Molinio-Hordeion secalini*													
Scilla litardierei	–	–	–	1	47	–	–	–	–	–	–	–	2
Deschampsia media	–	–	–	–	26	–	1	–	–	–	–	–	–
Peucedanum coriaceum	–	–	–	3	39	–	1	–	–	–	–	–	6
Centaurea pannonica	1	–	–	8	33	–	1	–	–	1	1	4	1
Sesleria caerulea	–	–	–	–	17	–	1	–	–	–	–	–	–
Cluster 6: *Scirpo holoschoeni-Salicetum rosmarinifoliae*													
Salix rosmarinifolia	–	–	–	4	3	100	–	–	–	–	–	1	1
Calamagrostis epigejos	–	1	1	3	–	100	2	2	–	5	2	1	2
Scirpus holoschoenus	–	–	–	3	1	71	–	–	–	–	–	–	1
Inula salicina	–	–	1	4	8	90	11	8	–	1	4	2	6
Scabiosa ochroleuca	–	–	–	2	–	86	–	2	–	2	–	–	–
Cluster 7: *Trifolion pallidi*													
Medicago arabica	1	1	–	–	–	–	19	1	1	–	–	1	–
Trifolium pallidum	–	–	1	–	1	–	17	9	8	2	1	1	1
Poa trivialis	20	2	32	10	1	–	49	16	–	13	25	32	19
Clematis integrifolia	–	–	1	1	5	–	16	11	–	–	1	1	–
Poa pratensis	4	5	5	7	2	–	61	22	14	29	53	47	29
Cluster 8: *Trifolio-Ranunculion pedati*													
Poa angustifolia	–	–	–	1	4	5	–	28	–	3	1	1	3
Poa palustris	3	2	10	1	1	–	1	34	–	–	1	1	8
Euphorbia lucida	–	–	–	–	–	–	–	24	–	–	–	–	–
Festuca pseudovina	1	14	–	–	5	–	2	25	–	2	1	–	–
Trifolium angulatum	2	–	–	–	–	–	1	20	–	–	–	–	–

Table 1. *(Continued).*

Cluster	1	2	3	4	5	6	7	8	9	10	11	12	13
Cluster 9: *Trifolion resupinati*													
Poa trivialis subsp. *sylvicola*	–	–	–	1	17	–	1	–	83	–	1	1	1
Ranunculus velutinus	–	–	–	–	–	–	4	–	53	–	–	–	–
Trifolium balansae	–	–	–	–	–	–	–	–	25	–	–	1	–
Alopecurus rendlei	–	–	–	–	5	–	6	–	53	–	1	5	2
Tragopogon orientalis	–	–	–	1	1	38	7	1	61	6	17	8	1
Cluster 10: *Pancicion* + *Triseto-Polygonion bistortae* + species poor *Arrhenatheretalia*													
Agrostis capillaris	1	–	9	2	12	–	2	–	1	33	7	18	4
Festuca rubra agg.	–	–	4	18	9	–	3	–	–	50	27	34	25
Hypochaeris maculata	–	–	–	–	–	–	–	–	–	13	1	–	–
Silene sendtneri	–	–	–	–	–	–	–	–	–	11	–	–	–
Pimpinella serbica	–	–	–	–	–	–	–	–	–	8	–	–	–
Cluster 11: *Arrhenatherion*													
Arrhenatherum elatius	–	–	1	1	–	–	4	–	–	28	87	19	–
Trisetum flavescens	–	–	1	1	–	–	1	–	1	18	75	32	1
Dactylis glomerata	5	5	2	10	6	–	9	4	1	49	85	31	7
Salvia pratensis	–	–	–	–	1	–	6	2	–	9	43	2	–
Knautia arvensis	–	–	–	2	–	–	5	1	–	16	47	12	–
Cluster 12: *Bromo racemoso-Cynosuretum cristati*													
Cynosurus cristatus	4	5	27	13	16	–	38	–	44	39	32	86	42
Gaudinia fragilis	–	–	1	–	–	–	1	–	–	1	3	23	3
Rhinanthus minor	1	–	25	11	24	–	4	3	27	13	34	56	18
Ranunculus acris	12	2	35	50	39	–	28	13	40	24	72	94	75
Ononis arvensis	1	9	2	1	–	–	8	3	5	–	18	36	5
Cluster 13: *Deschampsion caespitosae*													
Deschampsia cespitosa	6	–	37	30	21	–	3	4	5	8	5	30	77
Agrostis canina agg.	2	–	5	10	–	–	2	10	4	1	–	16	47
Succisella inflexa	–	2	8	5	1	–	1	–	–	–	–	7	40
Ranunculus flammula	2	–	6	4	1	–	2	–	–	–	–	8	36
Juncus conglomeratus	1	–	24	16	2	–	1	4	–	1	1	24	49

Cluster 13 includes communities dominated by *Deschampsia cespitosa* on clay soils with alternating wet and dry phases. These grasslands are found in S Slovenia, the continental part of Croatia and in some localities at higher elevations in Serbia.

Ordination analyses

The first DCA axis shows the gradient of altitude and nutrients, and this gradient also corresponds to a W–E direction (Figs 2 and 3). Temperature and BIO18 (precipitation of the warmest quarter) as climatic variables also correspond to the first axis. The most important variable is moisture of the site and coincides with the second DCA axis; it is striking that continentality shows an opposite trend to moisture.

Discussion

Moisture and nutrients (fertility) were found to be the most important gradients determining the floristic composition of mesic grasslands in the NW Balkans. This is congruent with several studies of this type of grassland (Havlová et al. 2004; Härdtle et al. 2006; Zelnik & Čarni 2008). Next is the temperature (warmth) of the site, which correlates with climatic variables, in particular precipitation of warmest quarter of the year (Appendix S1). Climatic variables, especially those linked to precipitation, are important in forming plant communities, and this gradient corresponds to the NW–SE gradient along the peninsula, linking Central European communities to Pannonian and (sub)-Mediterranean ones. The importance of climate for the species composition of wet grasslands that are saturated by surface or groundwater has already been demonstrated (Ilijanić 1973; Hájek et al. 2008). The vegetation structure and species composition in SE European peninsulas is strongly influenced by biogeographic and ecological differences (Blasi et al. 2012; Eliáš et al. 2013).

In addition to site conditions, management is very important for the establishment of different grassland communities (Dierschke & Briemle 2002; Zelnik 2005). Different management practices, such as cutting, grazing, application of artificial fertilizers, sowing species, can significantly alter species composition (Waldhardt & Otte 2003; Havlová et al. 2004; Drobnik et al. 2011), which results in different grassland types (e.g. species-poor com-

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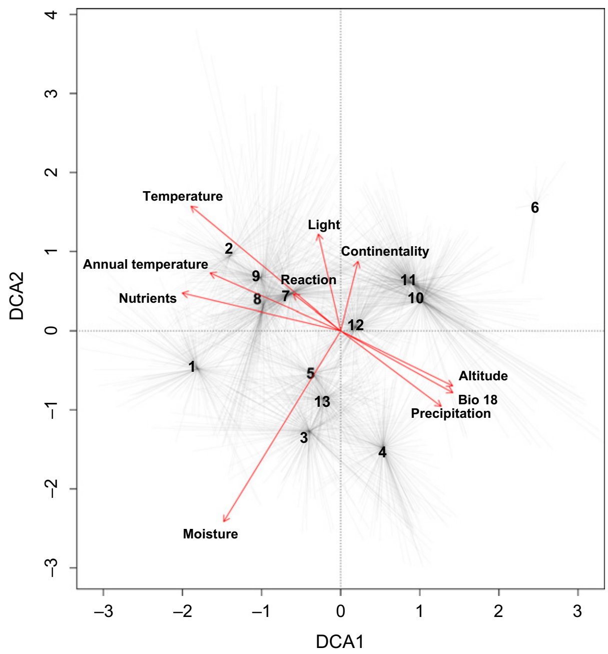

Fig. 2. DCA ordination of the whole dataset. Centroids of clusters from the classification are indicated and ecological variables (ecological indicators and the most important climatic variables) are presented. Eigen values of axes are: 1st axis 0.449 and 2nd axis 0.405 and total inertia 12.784.

munities). In large-scale analyses of vegetation databases, it is difficult to incorporate management into the analysis as an explanatory variable, and such wide geographic and climatic analyses are rare (Moog et al. 2002; Wellstein et al. 2007).

The syntaxonomic scheme of the class *Molinio-Arrhenatheretea* (Appendix S2) is the first attempt of such scope in the NW Balkans based on relevé material from a large database and on multivariate methods (classification and ordination), and to the association level. The Balkans is a transitional area in terms of climate and phytogeography, and classification of certain grassland syntaxa is therefore very difficult. Certain species with clear diagnostic values in Central Europe, for example, are at the limit of their distribution here and their coenological optima shifts. Rather than offering definite answers, our analysis therefore generates new questions about the syntaxonomic system.

Horvatić (1939) placed the geographic border between the alliances *Molinion caeruleae* and *Deschampsion cespitosae* in SE Slovenia and this is also confirmed by our analysis (Fig. 3). In the NW Balkans, *Molinion caeruleae* is found in the NW part (e.g. Slovenia), while *Deschampsion cespitosae* is limited mainly to the continental part of Croatia along the Sava River to the river Orljava (Ilijanić 1973), but occurs also in Serbia and Bulgaria. Humid climate, higher altitudes and higher amounts of organic matter are more characteristic of the *Molinion caeruleae* alliance (Zelnik & Čarni 2013). The diversity of *Molionion caeruleae* is higher in the NW Balkans than in neighbouring regions. One reason is the influence of different phytogeographic regions on species composition; another is the traditional classification into several narrower associations (acido- and basophilous, on *Sphagnum* mires). Classification also supports the findings of Botta-Dukát et al. (2005) that *Cnidion venosi* and *Deschampsion cespitosae* cannot be interpreted as two geographically vicariant alliances, Pannonian and Illyrian, respectively, as proposed by Ellmauer & Mucina (1993).

The alliance *Agrostion albae* is classified within the alliance *Deschampsion cespitosae* in several national surveys (Chytrý 2007; Borhidi et al. 2012), while it was classified as a separate alliance in Serbia (Kojić et al. 1998). In our numerical classification, communities of *Agrostion albae* from Serbia are classified into *Potentillion anserinae* (Aćić et al. 2013a).

There is a striking difference in the distribution pattern of *Deschampsion cespitosae* in the Balkans. In the NW part of the peninsula, a typical region of this alliance, stands are found on flooded lowlands up to 400 m·a.s.l. (Ilijanić 1973; Botta-Dukát et al. 2005), while in the eastern part of the Balkans they are found at higher elevations (700–1000 m·a.s.l.; Hájek et al. 2008; Milosavljević et al. 2008; Ranđelović & Zlatković 2010). It was previously considered that this alliance is absent to the east of the river Orljava and very rare in Serbia (Ilijanić 1973; Kojić et al. 1998) but these stands were later included in *Molinietum caeruleae* (Kojić et al. 2004). In the southern part of the study area, *Molinia* and *Deschampsia* occur together in stands, and the difference in nutrient availability is responsible for their habitat differentiation (Hájek et al. 2008). In the central Balkans, *Molinia* and *Deschampsia* are found at higher elevations, where climatic conditions resemble those in Central European lowlands.

Cynosurus-dominated communities are very common in the Balkans, where several associations with *Cynosurus* as a characteristic species are described. In the numerical analysis, these *Cynosurus*-dominated communities are classified into two distinct clusters. The first is the *Cynosurion cristati* alliance typical of temperate Central Europe, on grasslands that are intensively grazed and mown. Another *Cynosurus* community is the association *Bromo racemosi-Cynosuretum* found in continental Croatia and Slovenia, which develops on temporarily inundated soils and is the most widespread mown meadow in the region (Horvatić 1930). The *Cynosurion cristati* alliance is widespread in W and Central Europe, and concentrated in the sub-montane and montane zone towards the SE (Zuidhoff et al. 1995); it is represented by the well-delimited association *Lolio perennis-Cynosuretum*. The presence of the species *Cynodon dactylon* indicates the more southern and

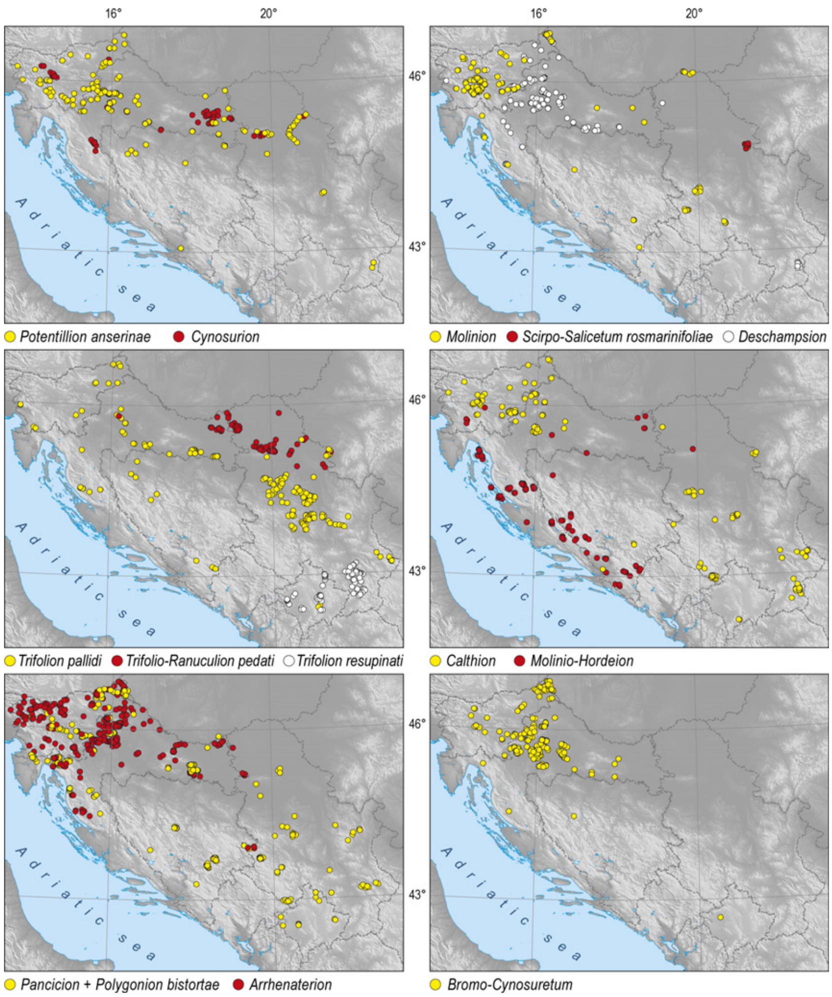

Fig. 3. The distribution of relevés included in particular clusters. The numbers of clusters refer to Table 1.

warmer character of these stands compared to this type of vegetation in Central Europe. The position of *Bromo-Cynosuretum* is unclear; according to (Stančić 2008) characteristic species have a broad ecological range and should be divided into a number of associations. In our analysis, these stands (together with some wet *Arrhenatherion elatioris* stands) are separated as a single cluster with a transitional position between Cluster 5 and 10 in the DCA diagram (Fig. 2), as also pointed out by Lengyel et al. (2012). The species composition and DCA analysis suggest that these grasslands should be classified within the alliance *Arrhenatherion elatioris*. Another possibility is classification into the alliance *Deschampsion cespitosae* but there are more species present that are characteristic for the alliance *Arrhenatherion elatioris*. Classification of *Bromo-Cynosuretum* into higher syntaxa is therefore not clear; various authors classify it into the alliance *Cynosurion cristati* or *Arrhenatherion elatioris* (Kojić et al. 1998; Trinajstić 2008; Velev et al. 2011a). Stančić (2008) indicated that some of the relevés of *Bromo-Cynosuretum* should be classified into *Arrhenatherion elatioris* and some into *Deschamspion cespitosae*.

Cluster 11 comprises the alliances *Arrhenatherion elatioris* and *Triseto flavescentis-Polygonion bistortae*, which are typical of the NW part of the study area, which is already part of the SE Alps. Relevés of these two alliances merged into one cluster since their sites are similar in terms of moisture and nutrients (Hegedüšová et al. 2011). Communities of *Arrhenatherion elatioris* from the south are less mesic and lack characteristic species, while the alliance *Triseto flavescentis-Polygonion bistortae* is not present in the central Balkans (Apostolova et al. 2007). It is replaced by the alliance *Arrhenatherion elatioris*, which occurs at elevations of 700–1600 m. The altitudinal shift of plant communities towards the south of the Balkans is well known (Horvat et al. 1974; Hájek et al. 2008) and is the reason for the ambiguous classification of vegetation that spreads over the long biogeographic gradient.

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The association *Arrhenatheretum* s. lat. is widespread in Central and Western Europe, and the dominant species gives the stands an easily recognizable physiognomy. In many cases, stands were classified as belonging to *Arrhenatheretum* s. lat. because of the presence of the dominant grass species. The association changes towards the south and communities become more ruderal (Velev et al. 2011b). In Serbia these communities were previously considered as sown grasslands (Jovanović-Dunjić et al. 1986) or were found mostly along roads (Parabućski 1990). They are also less commercially important, found in untypical ecological conditions in the Pannonian region (Vojvodina) (Kojić et al. 2005) or in the montane belt in central Serbia (Aćić et al. 2013b). *Arrhenatherion elatioris* stands from Serbia are therefore in the same cluster as ruderalized mesic grasslands from the northern part of the study area. On the other hand, stands of the alliance *Arrhenatherion elatioris* from Bulgaria are more similar to those of Central European (Velev et al. 2011b).

Pancicion serbicae is an alliance found at higher elevations, rich in endemic species and with a Dinaric distribution (Lakušić 1966). *Pancicia serbica* appears in various plant communities (forest and non-forest) and has a disjunct distribution in the Balkans (Obratov & Đukić 1998). Despite endemic species, the alliance was not clearly delimited in our analysis and merged with species-poor stands and stands classified at higher syntaxonomic levels without characteristic species. The factors filtering the species composition at higher elevations seem similar to those of human-disturbed sites at lower altitudes. Grazing disturbance and altitudinal stress resemble high human impact in the lowlands (e.g. road verges, intensive mowing). Management can blur delimited communities, especially if there is a combination of hay-cutting and grazing or a change of pasture into meadow (or vice versa) (Havlová et al. 2004).

The alliance *Trifolion pallidi* is mainly found in eastern Croatia and central Serbia and the alliance *Trifolion resupinati* is limited to southern Serbia, where the climate is warmer and more arid. Our analysis shows the distribution of *Trifolion pallidi* to be the most eastern part of Serbia, on the border with Bulgaria, although it has not so far been identified in Bulgaria (Eliáš et al. 2013). It is linked to the climax vegetation *Quercion frainetto*, and when Ilijanić (1969) described the alliance, he assumed its distribution in Bulgaria and Romania.

Short descriptions of the alliances

On the basis of the literature review and our own results, we present a unified syntaxonomic list, which is critically commented and highlights the syntaxonomic problems for further analysis (Appendix S2). Each alliance is presented in brief.

Molinion caeruleae

These grasslands are found on wet or moist soils, sometimes even on peaty soils. The water table is high during one period of the vegetation season. *Molinion* grasslands are concentrated in Slovenia, with some localities in Pannonia and central Serbia. The characteristic and dominant species is *Molinia caerluea* agg., accompanied by *Schoenus ferrugineus*, *Potentilla erecta* and *Sanguisorba officinalis*.

Calthion palustris

Wet grasslands and tall herb communities that are frequently unmanaged. They are found on flat lands along streams or on saturated soils near headwaters. Stands are distributed in Slovenia, Croatia and the mountainous parts of southern Serbia. The predominant species are *Scirpus sylvaticus*, *Filipendula ulmaria*, *Juncus effusus* and *Eriophorum latifolium* (the last species is characteristic for specific stands in Serbia).

Deschampsion cespitosae

Meadows on alluvial lowlands that are flooded from rainwater and less from water courses. Soils have impermeable layers and water stagnates for some period. These meadows occur in Slovenia and Croatia, with one location in SE Serbia. Meadows are dominated by *Deschampsia cespitosa* and *Agrostis canina* agg., other characteristic species are *Succisella inflexa*, *Ranunculus flammula* and *Gratiola officinalis*.

Molinio-Hordeion secalini

Stands of this alliance are typical grasslands from the humid part of the sub-Mediterranean region, mostly on periodically flooded Karst poljes and locally on some islands. Their distribution stretches from Slovenia through Croatia to Bosnia and Herzegovina. Characteristic species are *Scilla litardiei, Deschampsia media, Peucedanum coriaceum* and *Plantago altissima.*

Trifolion resupinati

The alliance includes lowland wet grasslands of the sub-Mediterranean part of the central Balkans (southern Serbia in the study area, with the centre of distribution in Macedonia). The climate is extreme and sites dry out in summer. The main species are *Poa sylvicola*, *Trifolium* *resupinatum* and several other species of the genus *Trifolium* (*T. balansae*, *T. nigrescens*, *T. fragiferum*).

Trifolion pallidi

The alliance consists of wet flooded meadows with less drought in summer than *Trifolion resupinati*, and colder winters than *Molinio-Hordeion secalini*. The centre of distribution of the alliance is eastern Croatia and western Serbia. Characteristic species are *Medicago arabica*, *Trifolium patens*, *Festuca pratensis* agg. and *Trifolium pallidum*.

Trifolio-Ranunculion pedati

The alliance includes grasslands of a mesic sub-halophytic character. The alliance is restricted to the Pannonian plain. Characteristic species are *Poa angustifolia*, *P. palustris* and *Trifolium angulatum* and accompanied by the halophytes *Aster canus*, *Limonium gmelinii* and *Podospermum canum*.

Cynosurion cristati

Intensively managed grasslands (pastures) on fertile soils found in the Central European floristic region of the NW Balkans (Slovenia, Croatia and Vojvodina). The main species are *Lolium perenne*, *Trifolium repens*, *Cynodon dactylon* and *Trifolium fragiferum*.

Arrhenatherion elatioris

The alliance includes mesic non-flooded meadows, regularly mown and often fertilized. It is most common in Central Europe; in the study area it is common in Slovenia and Croatia, while in southern parts these grasslands are also found in the mountain belt. Diagnostic species are *Arrhenatherum elatius*, *Dactylis glomerata*, *Galium mollugo* agg. and *Pastinaca sativa*.

Alchemillo-Ranunculion repentis

This vegetation type includes moderately trampled mesophilous communities often in shaded sites. The alliance is only found in the northern part of the study area (Slovenia and Croatia). The characteristic species are *Prunella vulgaris*, species characteristic of trampled habitats and the neophytes *Juncus tenuis* and *Duchesnea indica*.

Potentillion anserinae

The alliance comprises stands along water bodies with alternating wet and dry phase. They are distributed in the northern part of NW Balkans and on the Pannonian lowlands. Stands are dominated by *Agrostis stolonifera* agg., *Mentha longifolia* and *Juncus inflexus*.

Triseto flavescentis-Polygonion bistortae

The alliance comprises mostly pastures from submontane and montane belts (up to 1500 m·a.s.l.) from northern Slovenia. Stands are dominated by *Trisetum flavescens*, other diagnostic species are *Astrantia major*, *Bromus erectus* and *Rhinanthus alectorolophus*.

Pancicion serbicae

These are mesophilous grasslands of the upland and subalpine belts (1100–1800 m) in mountain ranges of Bosnia and Herzegovina, Kosovo, southern Serbia and also Montenegro. The characteristic species of this endemic Dinaric alliance are *Anemone narcissiflora*, *Crepis aurea* var. *bosniaca*, *Pimpinella serbica* and *Phleum alpinum*.

Poion supinae

These are meadows that are mown once a year and then grazed, in the mountain belt (800–1300 m·a.s.l.). They are found in Croatia and probably also in Slovenia. Stands are dominated by *Trisetum flavescens* accompanied by *Alchemilla xanthochlora* and species of the *Arrhenatherion elatioris* alliance.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Appendix S1. Map of relevé distribution and precipitation of the warmest quarter as the climatic variable.
Appendix S2. Syntaxonomic checklist of the *Molinio-Arrhenatheretea* class in the NW Balkans.
Appendix S3. Full synoptic table in pdf and csv format.