

## **Dry grassland vegetation of Central Podolia (Ukraine) – a preliminary overview of its syntaxonomy, ecology and biodiversity**

### **Die Trockenrasenvegetation Zentral-Podoliens (Ukraine) – eine vorläufige Übersicht zu Syntaxonomie, Ökologie und Biodiversität**

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#### **Abstract**

We present the data of the 2<sup>nd</sup> research expedition of the European Dry Grassland Group (EDGG), which was conducted in 2010 in Central Podolia, Ukraine. The aim was to collect plot data to compare Ukrainian dry grasslands with those of other parts of Europe in terms of syntaxonomy and biodiversity. We sampled 21 nested-plot series (0.0001–100 m<sup>2</sup>) and 184 normal plots (10 m<sup>2</sup>) covering the full variety of dry grassland types occurring in the study region. For all plots, we recorded species composition of terrestrial vascular plants, bryophytes and lichens, while for the 226 10-m<sup>2</sup> plots we estimated

and measured percentage cover of all species, structural, topographic, soil and landuse parameters. The 10-m<sup>2</sup> plots were used for phytosociological classification based on iteratively refined TWINSpan classification as well as for DCA ordination. Differences between the derived vegetation types with respect to environmental conditions and species richness were assessed with ANOVAs. We assigned our plots to nine association-level units but refrained from placing them into formal associations with two exceptions. In the study area, dry grasslands of the *Festuco-Brometea* were far more common than those of the *Koelerio-Corynephoretea*. Among the *Festuco-Brometea*, xeric *Festucetalia valesiaca* grasslands were more frequent and represented by the *Festucion valesiaca* (2 associations, including the *Allio taurici-Dichanthietum ischaemi* ass. nova) and the *Stipion lessingiana* (1) compared to the *Brachypodietalia pinnati* with the *Agrostio vinealis-Avenulion schelliana* (3). The *Koelerio-Corynephoretea* were represented by three associations, each from a different order and alliance: basiphilous outcrops (*Alyso alyssoidis-Sedetalia: Alyso alyssoidis-Sedion?*), acidophilous outcrops (*Sedo-Scleranthetalia: Veronico dillenii-Sedion albi?*) and mesoxeric sandy grasslands (*Trifolio arvensis-Festucetalia ovinae: Agrostion vinealis*). We discuss the issue of the mesoxeric order *Galietales veri* placed within the *Molinio-Arrhenatheretea* by Ukrainian authors and conclude that the content of that order would probably be better placed in the mesoxeric orders of the *Koelerio-Corynephoretea* and *Festuco-Brometea*. Other syntaxonomic questions could not be solved with our geographically limited dataset and await a supraregional analysis, e.g. whether the Ukrainian outcrop communities should be assigned to the same alliances as known from Central Europe or rather represent new vicariant units. The analysis of the biodiversity patterns showed that at a grain size of 10 m<sup>2</sup>, Podolian *Koelerio-Corynephoretea* communities were overall richer than *Festuco-Brometea* communities (46.4 vs. 40.6 species). This difference was due to the *Koelerio-Corynephoretea* containing twice as many bryophytes and nine times more lichens, while vascular plant species richness did not differ significantly between classes. The orders within the classes showed no real differences in species richness. The richness patterns observed in Podolia were almost the opposite of those usually found in dry grasslands, where *Brachypodietalia pinnati* are richer than *Festucetalia valesiaca*, and these richer than stands of the *Koelerio-Corynephoretea* – and we do not have a good explanation for these idiosyncrasies. In conclusion, Podolian dry grasslands behave quite unexpectedly regarding biodiversity, and their syntaxonomy is still poorly understood. These knowledge gaps can only be addressed with supra-national analyses based on comprehensive datasets.

**Keywords:** bryophyte, conservation, European Dry Grassland Group, *Festuco-Brometea*, *Galietales veri*, *Koelerio-Corynephoretea*, lichen, nomenclatural revision, species richness, vegetation classification

**Erweiterte deutsche Zusammenfassung am Ende des Textes**

## 1. Introduction

Palearctic dry grasslands and steppes are biodiversity hotspots for many taxa (VRAHNAKIS et al. 2013). They comprise the most species rich plant communities in terms of vascular plants at scales below 100 m<sup>2</sup>, with, for example, 42 species on 0.04 m<sup>2</sup>, 98 on 10 m<sup>2</sup> and 131 on 49 m<sup>2</sup> (KULL & ZOBEL 1991, KLIMEŠ et al. 2001, DENGLER et al. 2012a, WILSON et al. 2012). This finding is inspiring for ecologists who seek to explain how such extreme richness can emerge, i.e. how so many species manage to co-exist at small spatial scale (e.g. MERUNKOVÁ et al. 2012, WILSON et al. 2012, DENGLER et al. 2014). One particularly interesting aspect is that the other vegetation type holding the world records in vascular plant species densities (i.e. at grain sizes from 100 m<sup>2</sup> upwards) are neotropical rain forests (WILSON et al. 2012), which exist under completely different ecological conditions. The latter are natural communities, occupy extensive contiguous areas and have had a much longer habitat continuity than the semi-natural dry grasslands of eastern Central Europe, which inhabit much smaller and isolated habitat patches and could have existed at best for a

couple of thousand years. While the various European record grasslands listed by WILSON et al. (2012) are all man-made meadows resulting from continuous mowing, it is possible that the absence of natural steppes in this list simply could be due to the fact that almost no extensive biodiversity sampling has been carried out there. The few published richness counts on defined areas in natural Palaearctic steppes indeed indicate that these can also be extraordinarily rich, albeit below the global maxima, for example with 117 vascular plant species on 100 m<sup>2</sup> in a Russian meadow steppe near Kursk (European Russia: WALTER & BRECKLE 1986) or 87 species on 1 m<sup>2</sup> in a forest-steppe near Kharkov (Ukraine: LYSENKO 2007).

These considerations prompted the European Dry Grassland Group (EDGG; <http://www.edgg.org>; VRAHNAKIS et al. 2013) to conduct its second research expedition to Ukraine, where there are both man-made dry grasslands and zonal steppes. Generally, the lowland territory of the country is characterized from northwest to southeast by a sequence from temperate forests through forest steppes to steppes, following a precipitation gradient from 750 to 400 mm per year (WALTER & BRECKLE 1986, BARABASH et al. 2003, BOHN et al. 2004, see also KUZEMKO 2009). Specifically, our study was directed to the forest-steppe zone, which stretches as a transitional band of approx. 250–600 km width between forests and steppes across the whole of Eastern Europe and the southern part of Siberia, from the Carpathians to the Altai Mts. (nearly 6,000 km). This zone, with a mean annual precipitation of 530–650 mm, corresponds to zono-ecotones VII/VI (west of the Ural Mts.) and VII/VIII (to the east) of WALTER & BRECKLE (1986). The natural vegetation of forest steppes are mosaic macrocomplexes, in which, depending on aspect and slope, typical deciduous forest and meadow steppe co-exist as sharply delimited patches (BOHN et al. 2004). Nowadays, the meadow steppes of the European forest-steppe zone have been almost completely transformed into arable land, while the natural forests here have been cut down or replaced by plantations. The anthropogenic transformation of the forest steppe has led to a heated debate over its southern border and has prompted some authors to suggest that the forest steppe or even the steppe is of anthropogenic origin (see LAVRENKO 1980, WALTER & BRECKLE 1986). However, now it is largely accepted that the distinction between these two zones is caused by natural factors, especially climate (see DIDUKH 2007).

Studying steppes in Ukraine is also interesting from a phytosociological point of view since, compared to other parts of Europe, they cover (still) huge areas, comprise a wide variety of different community types and can be seen as one of the major floristic sources of the semi-natural dry grasslands in the forested part of Europe (e.g. POTT 1995, WILMANN 1997). These steppe communities have been extensively studied on the basis of the traditional approach of Soviet geobotany, the so-called eco-phytocenotic (dominant) approach (e.g. ALEKSANDROVA 1973), resulting in several monographs (BILYK 1973, LAVRENKO 1980, MALYNOVSKY 1991). Studies of the Ukrainian steppe vegetation using the Braun-Blanquet approach of phytosociology (BRAUN-BLANQUET 1964, WESTHOFF & VAN DER MAAREL 1973, DENGLER et al. 2008) began in the mid-1980s (KOSTYLIOV et al. 1984, 1986, OSYCHNIUK et al. 1984, SOLODKOVA et al., 1986). Since then, many papers on the basiphilous vegetation of the class *Festuco-Brometea* have been published from different regions of the country (KUKOVYTSIA et al. 1994, KOROTCHENKO & DIDUKH 1997, KONTAR 2000, GONCHARENKO 2003, KUZEMKO 2004, KOROTCHENKO et al. 2009a, 2009b, etc.). Similarly, following an early paper by a visiting Czech scientist (VICHEREK 1972), various regional studies have focussed on the communities of rocky outcrops and sands (class *Koelerio-Corynephoretea*, including *Sedo-Scleranthetea* and *Festucetea vaginatae*) (DIDUKH & KOROTCHENKO 1996, SHEVCHYK et al. 1996, DIDUKH & KONTAR 1999, KONTAR 2000, ONYSCHENKO 2001). Much of this

work has been summarized in the *Syntaxonomy of vegetation of Ukraine* (SOLOMAKHA 2008), which includes all syntaxa ever mentioned for Ukraine at the time of publication, but without critical evaluation and synthesis. Altogether 27 dry grassland alliances with 126 associations were listed at that point, often with unclear floristic and ecological differentiation, but the “inflation” of units has continued in recent years. Attempts to achieve a supraregionally valid system with floristically clearly defined units are rare, KUZEMKO (2009) with her study on the sandy dry grasslands in the forest and forest steppe zone being an exception. Moreover, the syntaxonomic system in Ukraine has so far developed in relative isolation from other parts of Europe due to limited access to relevant literature in both directions and linguistic constraints, leading to many inconsistencies towards recent plot-based classifications elsewhere (e.g. BERG et al. 2004, CHYTRÝ 2007, JANIŠOVÁ 2007, PEDASHENKO et al. 2013, WILLNER et al. 2013). Similarly, existing European-scale classifications of dry grasslands (ROYER 1991, RODWELL et al. 2002) have only marginally been driven by data from Ukraine, although it is doubtlessly a diversity centre of these community types. Finally, while the major role of bryophytes and lichens for overall biodiversity of dry grasslands (e.g. DENGLER 2005, LÖBEL et al. 2006) as well as their classification (e.g. BERG & DENGLER 2005) is often acknowledged, non-vascular plants have only rarely been included in studies of these communities in Ukraine (but see DIDUKH & KONTAR 1999, KONTAR 2000).

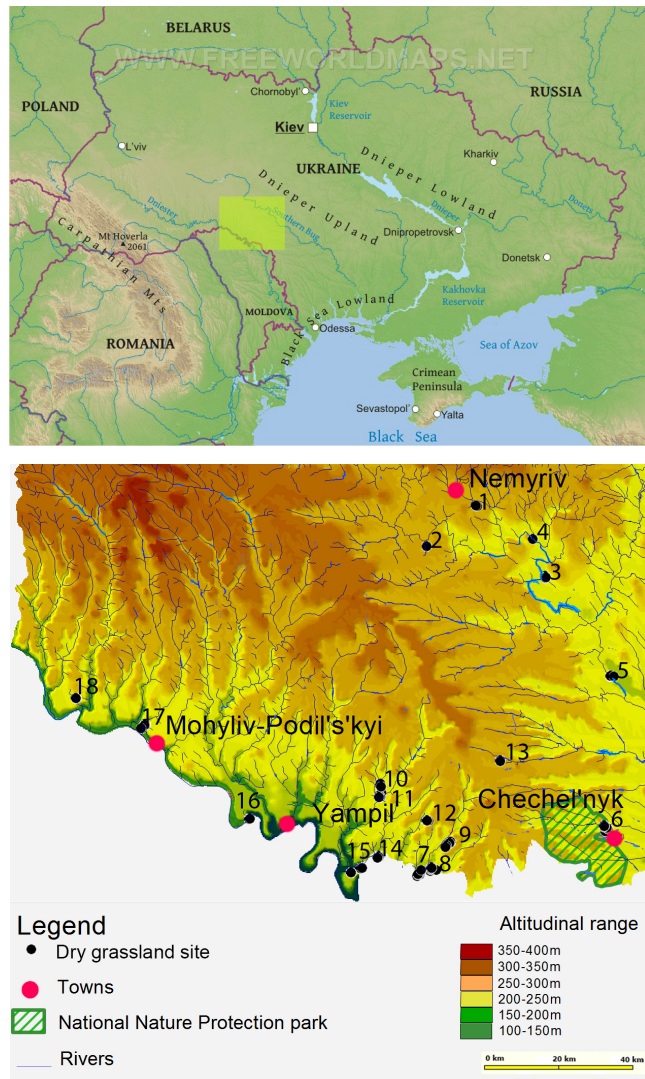
The aim of the second EDGG expedition in 2010 to Ukraine dry grasslands thus was to contribute to filling the knowledge gaps by collecting standardised biodiversity data of vascular plants, bryophytes and lichens and to bridge the divide in syntaxonomical concepts by bringing together experienced vegetation ecologists from different parts of Europe. As a concrete study region we chose Central Podolia because it hosts a high diversity of dry grasslands, caused by a variety of environmental conditions, but had rarely been sampled in terms of phytosociology before. While dry grasslands in Western Podolia are reasonably well documented (KUKOVYTSIA et al. 1994, ABDULOVA & DIDUKH 1999, ABDULOVA 2002, KOROTCHENKO 2004), we are not aware of any publication from the rest of the Podolian territory prior to our own study. With this publication based on the expedition data, we address the following topics: (1) Characterisation of the dry grassland communities occurring in the region and determination of their diagnostic taxa with statistical methods. (2) Placement of these community types into a supraregional classification scheme, including the search for correct syntaxon names. (3) Understanding the environmental factors that underly community differentiation. (4) Documentation of the plant diversity patterns of vascular plants, bryophytes and lichens in these vegetation types at various spatial scales.

In addition to these fundamental issues, the proper documentation of dry grasslands in Central Podolia, including an assessment of their conservation value, could contribute to optimizing the existing conservation network and proper organization of environmental management.

## 2. Study area

### 2.1 Location and climate

The study area covers Central Podolia (48.95°–48.10° N and 27.55°–29.35° E), which is located in the southern part of the Vinnytsia province of Ukraine, bordering in the south to Moldova (Fig. 1). It forms the central, lower lying part of the Podolian Upland, ranging only



**Fig. 1.** Map of the study area and its location within Ukraine. The numbers indicate the 18 studied dry grassland sites according to Table 1.

**Abb. 1.** Karte des Untersuchungsgebietes und deren Lage innerhalb der Ukraine. Die Zahlen geben die 18 Trockenrasen-Standorte gemäß Tabelle 1 an.

from 73 to 251 m a.s.l., compared to 471 m a.s.l. in the western part. Specifically, we studied the dry grassland vegetation in the interfluve of the Dniester and South Bug rivers, in their valleys in the middle course, and in the valleys of Dniester tributaries (Kysyriak, Kami-anka, Tashlyk, Vilshanka, Liadova and Nemya).

The climate is subcontinental, with mean annual temperatures of 7 to 9 °C, January means of -4 to -6 °C and July means of +18 to +20 °C (LIPINSKY et al. 2003). Mean annual precipitation ranges from 600 to 650 mm, with the lowest values towards the south and southeast (LIPINSKY et al. 2003).

## 2.2 Geology and geomorphology

The study area is located on different geostructures of the East European Platform. The most ancient of them, the Ukrainian Crystalline Shield, is a stable crust, bounded by major faults of late Proterozoic and Archean age (RIABENKO 1986). The Southern Bug River Basin is a hilly plain with a network of river valleys. The surface is composed of loess deposits with an average thickness of 3–4 m in the watersheds, which increases to 10–25 m on valley bottoms. In the deeply incised Dniester valley, Jurassic and Cretaceous sandstone and limestone reach the surface as outcrops. Here, watershed areas are covered by loamy and clayey loess of 1.5–2 m thickness (MARINICH et al. 1985).

## 2.3 Soils

The soil typology of the study area is quite simple: grey and dark grey soils under forests and chernozems under (former) meadow steppes. The latter occur as typical, carbonate-rich and lixiviated ones (VERNANDER et al. 1986). Typical chernozems are found on flat plateaus, while in hilly regions carbonate-rich types occur and in depressions lixiviated types. Eroded types of chernozems are confined to the inflections between plateaus and slopes of valleys or ravines. Under the meadow-steppe vegetation on loess, chernozems with humus content of 3.5–5.0% and pH of 7.0–7.5 have developed. Around outcrops of limestone rendzinas transitional to chernozems (in Ukrainian classification: sod-calcareous soils) occur, and around granite outcrops soil cover is represented by detrital rankers (in Ukrainian classification detrital skeletal soils) (TYKHONENKO 2005, KYRYLCHUK 2013).

## 2.4 Potential natural vegetation and phytogeography

The study was conducted within two geobotanical districts, (i) the Central Podolian District of hornbeam-oak and oak forests and dry meadows (South Bug Basin) and (ii) the Southern Podolian District of oak forests and meadow steppes, located in the Dniestr Basin (BARBARYCH 1977).

In the Central Podolian District, grey forest soils with the features of podzolization are typical and natural meadow steppes absent. Therefore, BARBARYCH (1977) in their earlier zonation assigned this region to the forest zone. Essentially, this area corresponds to unit F41 (East Polish-Ukrainian lime-pedunculatae oak-hornbeam forests) of the *Map of potential natural vegetation of Europe* (BOHN et al. 2004), with smaller patches of F44 (Podolian-Moldavian thermophilous hornbeam-pedunculate oak forests) and F62 (East pre-Carpathian-Moldavian sessile oak-hornbeam forests).

The Southern Podolian District, by contrast, has a more dissected relief and is characterised by the presence of chernozemic soils, natural occurrence of vast areas of meadow steppes and minor areas of forests, including thermophilous types (BARBARYCH 1977, DIDUKH & SHELYAG-SOSONKO 2003). This area more or less coincides with unit L2 (Sub-Mediterranean-subcontinental herb-grass steppes) of BOHN et al. (2004).

Phytogeographically, the study area belongs to the west-Pontic subprovince of the Pontic-South Siberian floristic region (MEUSEL & JÄGER 1992). Many typical species of the Central European flora (*Fagus sylvatica*, *Quercus petraea*, *Tilia platyphyllos*, *Sorbus torminalis*, *Acer pseudoplatanus*, *Euphorbia amygdaloides*, *Dentaria glandulosa*, *Hepatica nobilis*, *Aconitum moldavicum*) reach their eastern distributional limits here, while steppic species such as *Herniaria polygama*, *Dianthus campestris*, *Delphinium cuneatum* and *Ranunculus pedatus* are at their western limits (KLEOPOV 1990, DIDUKH et al. 2004, 2010, ILJINSKA et

al. 2007). There are some subendemic taxa in the steppe vegetation of Central Podolia (e.g. *Anchusa pseudochroleuca*, *Euphorbia valdevillosocarpa*, *E. volhynica*, *Linum basarabicum*, *Carlina onopordifolia*, *Dianthus pseudoserotinus*) MOSYAKIN & FEDORONCHUK 1999), but of these, only *Allium podolicum* is accepted as valid taxon by *Flora Europaea* (TUTIN et al. 1968–1993).

## 2.5 Land use and conservation

Nowadays, the steppes of Ukraine have almost entirely been transformed into arable fields, which cover 53.8% of the national territory (STATE AGENCY OF LAND RESOURCES OF UKRAINE 2010). In Vinnitsa province, 76.2% of the area is used agriculturally, including 65.3% arable fields, 1.9% hayfields and 7.1% pastures (YAVORSKA 2005). The natural steppe vegetation of the region has survived only on small areas on the slopes of river valleys and ravines as well as along forest edges. In Ukraine, both natural and semi-natural grasslands were traditionally used as hayfields and pastures and played an important role also for beekeeping. However, in recent decades, changes in socio-economic conditions also led to changes in land use in the region, particularly a decrease in the number of livestock and thus reduced grazing impact. Many formerly agriculturally used grasslands have been abandoned and are now in different successional stages of shrub and tree encroachment, resulting in a significant reduction of areas of secondary grasslands. Moreover, for many years the steep slopes of river valleys had been afforested with non-native trees, especially *Pinus nigra* subsp. *pallasiana*. In recent years, afforestation of the steppe areas in forest-steppe and steppe regions of Ukraine has reached truly catastrophic scales. This policy destroyed the last remnants of the steppe vegetation by creating huge plantations of *Robinia pseudacacia*, *Elaeagnus angustifolia* and *Quercus rubra* (PARNIKOZA & VASILUK 2010, BURKOVSKY & TARASOVA 2011, BURKOVSKY et al. 2013).

Despite the high diversity of vegetation, flora and fauna, Vinnytsia province has one of the lowest fractions of protected areas within Ukraine of only 1.9% (MINISTRY OF ECOLOGY AND NATURAL RESOURCES OF UKRAINE 2011). Until recently, there were only few small reserves (*zakaznik*, corresponding to IUCN category IV) of national or local level: “Antsiopolovsky”, “Korostovetsky”, “Pribuz’ky”, “Romashkovo”, “Enchanted Valley”, “Grigorivska Hill”, “Bronnitska Hill”. In 2009, the National Park “Karmelukove Podillya” and the regional landscape park “Dniester” were established. All these reserves contain dry grassland vegetation to varying degrees. Some were investigated in the course of our expedition (see Table 1) and some others became protected after our expedition as the Regional Landscape Park “Nemyrivske Pobuzhzhia”.

## 3. Methods

### 3.1 Vegetation sampling

The field sampling was carried out in the second half of July 2010. With our sampling, we tried to represent as much as possible of the variability of dry grassland communities in the study region within the limited time of the expedition. To represent the geographic variability we selected 18 sites with dry grassland communities in the valleys of the Southern Bug, Dniester and the Dniester tributaries and their surroundings (Fig. 1, Table 1, Appendix S1). Within each site, we selected homogeneous plots subjectively so that they reflected the full range of grassland types in terms of physiognomy, slope exposition, bedrock, soil development and land use type.

**Table 1.** Overview of the studied dry grassland sites, with the number of plots sampled. The associations are numbered according to Section 4.1.

**Tabelle 1.** Übersicht der Untersuchungsflächen der Trockenrasen mit der Anzahl an Aufnahmen und Angabe der Assoziationen (Nummerierung wie in Kapitel 4.1).

No.	District	Locality	Protected area	Normal plots	Nested series	Total plots	Recorded associations
1	Nemiriv	Ancient settlement "Nemyrivske"		4	0	4	2.1.2
2	Tulchyn	Granite outcrops and steppe plots near villages Sokilets and Pechera	"Prybuz'ky" reserve	2	0	2	1.2.1, 2.1.2
3	Nemiriv	Granite outcrops near Antsypolivka village	"Antsypolovsky" reserve	5	1	7	1.2.1, 2.1.2
4	Nemiriv	Pivdenny Bug valley near Raihorod village	Regional Landscape Park "Nemirivske Pobuzhzhia"	0	1	2	2.1.2
5	Trostanets	Granite outcrops and steppe between villages Chetvertynivka and Mytkivka		6	2	10	1.2.1, 2.1.2, 2.2.1
6	Chechelnyk	<i>Carlina onopordifolia</i> site "Romashkovo"	National Nature Park "Karmelukove Podillya"	14	2	18	1.3.1, 2.1.1, 2.2.1
7	Pischanka	Kysymiak underground river valley near Bolgan village		13	2	17	2.1.3, 2.2.1, 2.2.2, 2.2.3
8	Pischanka	Kamianka river valley between villages Bolgan and Kukuly		23	2	27	1.1.1, 2.2.1, 2.2.2, 2.2.3
9	Pischanka	Locality "Enchanted valley" near Dmytrashkivka village	"Enchanted valley" reserve	24	2	28	1.1.1, 2.1.2, 2.1.3, 2.2.1, 2.2.2, 2.2.3
10	Kryzhopil	Limestone outcrops near Leonivka village		13	1	15	1.1.1, 2.1.1, 2.1.3, 2.2.1, 2.2.2
11	Kryzhopil	Tashlyk river valley near Verbka village		11	1	13	2.1.1, 2.1.3, 2.2.1, 2.2.2, 2.2.3
12	Kryzhopil	Limestone outcrops near Faihorog village		10	1	12	2.1.3, 2.2.3
13	Kryzhopil	Pasture on the sand basis near Temivka village		3	1	5	2.1.3, 2.2.1
14	Yampil	Vilshanka river valley near Verkhnia Slobidka village		14	1	16	2.2.1, 2.2.2, 2.2.3
15	Yampil	Vilshanka river valley near Velyka Kisnytsia village		10	1	12	2.1.3, 2.2.1, 2.2.2, 2.2.3
16	Yampil	Dnister river valley near Mykhailivka village		9	1	11	2.2.1, 2.2.3
17	Mohyliv-Podilsky	Locality "Ozarynetska mountain" in Nemya river valley near Mohyliv-Podilsky town	Regional Landscape Park "Dnister"	17	1	19	2.1.3, 2.2.1, 2.2.3
18	Mohyliv-Podilsky	Liadova river valley near Khonkivtsi village		6	1	8	2.2.1, 2.2.3
Total				184	21	226	



We followed the sampling approach of the EDGG Expeditions (DENGLER et al. 2012a), combining two types of plots: (i) nested-plot series ( $n = 21$ ) with plots of the sizes of 0.0001, 0.001, 0.01, 1, 10 and 100 m<sup>2</sup>, where all plot sizes except the largest are replicated in two opposite corners (see DENGLER 2009) and (ii) additional normal plots of 10 m<sup>2</sup> ( $n = 184$ ). We recorded all terricolous vascular plants, bryophytes and lichens that were superficially present (i.e. shoot presence = any-part system; DENGLER 2008).

To verify the determination of lichens, extracts of some specimens were analyzed by thin-layer chromatography using solvent A (CULBERSON & AMMANN 1979). The taxonomy of vascular plants follows *Flora Europaea* (TUTIN et al. 1968–1993) or *Atlas Florae Europaeae* (JALAS & SUOMINEN 1994, JALAS et al. 1996, 1999, KURTTU et al. 2004–2010), depending on which of the treatments in the two series was the more recent. For mosses we followed HILL et al. (2006), for liverworts GROLLE & LONG (2000) and for lichens SANTESSON et al. (2004). In a few cases, additions to and deviations from these checklists were necessary as documented in Tables 2 and 3.

All vegetation-plot data used in this article are stored in and available from three vegetation-plot databases: *Database Species-Area Relationships in Palaeartic Grasslands* (DENGLER et al. 2012b; EU-00-003 in the *Global Index of Vegetation-Plot Databases* (GIVD, <http://www.givd.info>; see DENGLER et al. 2011), *Ukrainian Grasslands Database* (KUZEMKO 2012; EU-UA-001) and *European Vegetation Archive* (EVA; <http://euroveg.org/eva-database>).

### 3.2 Structural and environmental parameters

In the 10-m<sup>2</sup> plots ( $n = 226$ ), we estimated the cover of the shrub, herb and moss layers and that of litter, dead wood, open fine earth, gravel as well as stones + rocks. We determined geographic coordinates and altitude with a GPS, aspect with a compass, and slope with an inclinometer. The latter two parameters were used to calculate the heat load index according to OLSSON et al. (2009), which is a relative measure that takes the highest positive values on steep southwest facing slopes, zero in level areas, and negative values on northeast facing slopes. Microrelief was measured as maximum vertical deviation from an imaginary plane through the plot. We classified present land use roughly into rough categories regarding “grazing intensity” (0 = not grazed; 1 = low; 2 = medium; 3 = high) and “burning” (0 = no; 1 = yes) based on our knowledge of the sites and/or visible signs in the plots.

**Table 2.** Supraspecific taxa used in the paper in addition to those defined in the given checklists.

**Tabelle 2.** Supraspezifische Taxa, die in dieser Publikation zusätzlich zu den in den angegebenen Referenzlisten definierten Aggregaten genutzt werden.

Group	Taxon	Reference	Included species
Vascular plants	<i>Centaurea jacea</i> agg.	EHRENDORFER (1973)	<i>C. haynaldii</i> , <i>C. bracteata</i> , <i>C. weldeniana</i> , <i>C. rocheliana</i> , <i>C. pannonica</i> , <i>C. vinyalsii</i> , <i>C. dracunculifolia</i> , <i>C. jacea</i> , <i>C. decipiens</i> , <i>C. subjacea</i> , <i>C. macroptilon</i> , <i>C. microptilon</i>
Vascular plant	<i>Festuca</i> Ser. <i>Valesiaca</i>	PAWLUS (1985)	<i>F. pseudodalmatica</i> , <i>F. pseudovina</i> , <i>F. rupicola</i> , <i>F. valesiaca</i>
Bryophyte	<i>Bryum capillare</i> agg.	FREY et al. (1995)	<i>B. canariense</i> , <i>B. capillare</i> , <i>B. donianum</i> , <i>B. elegans</i> , <i>B. moravicum</i> , <i>B. torquescens</i>
Bryophyte	<i>Hedwigia ciliata</i> agg.	Ad hoc taxon	<i>H. ciliata</i> , <i>H. stellata</i>
Bryophyte	<i>Schistidium apocarpum</i> agg.	BLOM (1996)	various
Bryophyte	<i>Syntrichia ruralis</i> agg.	Ad hoc taxon	<i>S. calcicola</i> , <i>S. montana</i> , <i>S. ruralis</i> var. <i>ruraliformis</i> , <i>S. ruralis</i> var. <i>ruralis</i> , <i>S. subpapillosissima</i>
Lichen	<i>Cladonia pyxidata</i> agg.	ad hoc taxon	<i>C. asahina</i> , <i>C. chlorophaea</i> , <i>C. cryptochlorophaea</i> , <i>C. grayi</i> , <i>C. merochlorophaea</i> , <i>C. monomorpha</i> , <i>C. novochlorophaea</i> , <i>C. pocillum</i> , <i>C. pyxidata</i>

**Table 3.** Additional vascular plant taxa used in this publication that are not listed in the given checklists.

**Tabelle 3.** Zusätzliche Gefäßpflanzentaxa die in dieser Publikation Verwendung finden, aber in den angeführten taxonomischen Referenzlisten nicht enthalten sind.

Taxon	Author citation	Reference	Treatment in <i>Flora Europaea</i>
<i>Carlina acanthifolia</i> subsp. <i>utzka</i>	(Hacq.) Meusel & Kästner	EURO+MED (2014)	<i>C. acanthifolia</i> subsp. <i>acanthifolia</i>
<i>Dactylis glomerata</i> subsp. <i>glomerata</i>		EURO+MED (2014)	No subspecies formally accepted, but “vide” taxon
<i>Euphorbia nicaeensis</i> subsp. <i>stepposa</i>	(Zoz) Greuter & Burdet	EURO+MED (2014)	<i>E. nicaeensis</i> subsp. <i>glareosa</i>
<i>Leucanthemum ircutianum</i>	DC.	EURO+MED (2014)	<i>L. vulgare</i> , with various “vide” taxa
<i>Medicago sativa</i> nothosp. <i>varia</i>	(Martyn) Arcang.	EURO+MED (2014)	= <i>M. sativa</i> subsp. <i>nigra</i> × <i>M. sativa</i> subsp. <i>sativa</i>
<i>Pimpinella saxifraga</i> subsp. <i>nigra</i>	(Mill.) Gaudin	MOSSBERG & STENBERG (2003)	No subspecies accepted
<i>Tulipa biebersteiniana</i>	Schult. & Schult. f.	EURO+MED (2014)	<i>T. sylvestris</i> subsp. <i>australis</i>

Mixed soil samples of the uppermost 10 cm were taken from three to five random locations within each plot and air-dried during the expedition. The soil type and the proportions of sand, silt and clay were estimated by finger test according to SCHLICHTING et al. (1995). Proportion of skeleton was measured by sieving soil with a 2-mm sieve after separation from organic sieving residue. Soil pH and electric conductivity were measured electrometrically in a suspension of 10 g soil and 25 ml and 50 ml deionised water, respectively. To determine total C and N content, soil samples were prepared by drying for 36 hours at 70 °C, passed through a 2-mm sieve and ground in a mill. The C/N ratio was measured with a C/N analyser (Elementar, Vario EL III). Inorganic C content was determined by measuring the C/N ratio of ashed soil (600 °C). To achieve the  $C_{org}/N_{tot}$  ratio,  $C_{org}$  was calculated as  $C_{tot} - C_{inorg}$ .

Additionally, we calculated mean unweighted indicator values (IVs) of the recorded vascular plants, based on the indicator system of DIDUKH (2011), which is similar to ELLENBERG et al. (1991), but includes more parameters (14) with an often finer resolution (9- to 23-step scales). Since our sampling was conducted in a climatically homogenous region, we used only six indicator values of the edaphotope, namely moisture (name in publication: “water regime”, scale 1–23), moisture variability (“variability of damping”, 1–11), pH (“soil acidity”, 1–15), carbonate content (1–13) and salinity (“total salt regime”, 1–19). To assess the conservation relevance of grassland stands and types, we calculated the number of vascular plant species with conservation values per plot, based on the *Red Data Book of Ukraine* (DIDUKH 2009) and the list of regionally rare plants of Vinnytsia province (ANDRIENKO & PEREGRYM 2012).

### 3.3 Data preparation for numerical analyses

Prior to numerical analyses (TWINSPAN, determination of diagnostic species, ordination) we standardised our relevé data (see JANSEN & DENGLER 2010): (i) occurrences of species in shrub and herb layer were combined; (ii) taxa determined only at genus level or coarser were removed except for *Nostoc* spp. and *Weissia* spp. (which were never/rarely determined at species level but have a clear diagnostic value even at genus level); (iii) taxa that were recorded with different taxonomic precision were joined at the aggregated level (aggregate level in case of closely related species, species level in case of polytypic species); (iv) records of the type “*Genus* cf. *species*” were joined with “*Genus species*”; (v) some cover values not applicable in JUICE were changed to the nearest allowed values. In the relevé tables (Tables 5–8 in the supplement) both the aggregated data are shown in normal font and the original data below these in smaller font and italics.

### 3.4 Vegetation classification

Vegetation classification was performed on all 226 relevés of 10-m<sup>2</sup> plots. To get an initial idea of the data structure, we conducted a TWINSpan (Two-Way Indicator Species Analysis; HILL 1979) in the modified version proposed by ROLEČEK et al. (2009) and implemented in JUICE (TICHÝ 2002). We used the default settings of JUICE (pseudospecies cut levels: 0%, 2%, 5% and 10%; minimum group size: 5) and tried cluster numbers up to 12.

As the TWINSpan analysis showed that the three-cluster resolution corresponded very closely to phytosociological orders known from the literature (“ordinal clusters”), and the nine-cluster resolution was the lowest resolution with floristically well-defined units (“association-level clusters”), we used these two TWINSpan resolutions as starting points for further refinement. We calculated phi coefficients of association (CHYTRÝ et al. 2002) for the TWINSpan units at the three- and nine-cluster resolutions, assuming equal cluster size (TICHÝ & CHYTRÝ 2006). First we sorted species according to decreasing phi values within the ordinal clusters. Then we identified relevés in which diagnostic species of another cluster than their own prevailed and reassigned them when this overall led to an increase of the phi values of diagnostic species as proposed and applied, *inter alia*, by LUTHER-MOSEBACH et al. (2012) and DENGLER et al. (2012a). The modified TWINSpan was then run within each of the three main clusters, followed by the same procedure (calculation of phi values, sorting of species blocks, checking for and reassigning of outlying relevés). The whole procedure was repeated iteratively until no further improvement in the crispness of the classification could be achieved. All manual rearrangements of relevés are indicated in the Tables 5–8 in the supplement.

We considered species as highly diagnostic when  $\phi > 0.50$  and as diagnostic when  $\phi > 0.25$  (see CHYTRÝ 2007), provided the concentration was significant according to Fisher’s exact test at  $\alpha = 0.05$ . According to this definition, species can be diagnostic for several nested syntaxa. Such “transgressive” diagnostic species were only accepted additionally at higher levels when the species had positive phi-values in more than half of the included associations. When a species was diagnostic for more than one association of a higher unit, it was accepted only on the higher level. Note that the term “diagnostic species” is meant in the regional context and encompasses both differential and character species. However, based on our knowledge of the literature on dry grasslands in various parts of Europe, we provide an expert assessment whether a taxon can only be considered as differential species (D), a character species of a higher syntaxon (C) or potentially a character species of an association (CC).

Finally, we tried to assign our units to phytosociological associations, alliances and orders described in the literature. This phytosociological classification involved an extensive search for original literature and check for validity and legitimacy of names according to the *International Code of Phytosociological Nomenclature* (WEBER et al. 2000; further ICPN). For all syntaxon names mentioned, the nomenclatural assessment is presented in Appendix S1.

In the association descriptions (Subsection 4.4), we characterise the communities within the context of this work, using standardised terminology in relation to the mean value found in all our stands.

### 3.5 Statistical evaluation of environmental factors and species composition

To visualise the multivariate floristic similarity patterns, we carried out a detrended correspondence analysis (DCA) with  $\log(x + 1)$ -transformed percent cover values in PC-Ord 6.08 (MCCUNE & MEF-FORT 1999) with down-weighting of rare species. In the ordination diagram, environmental factors and vegetation parameters correlated to one of the axes with  $r^2 \geq 0.20$  were displayed as vectors. Differences in environmental conditions and vegetation parameters between communities were assessed at different hierarchical levels (class, association) with one-way ANOVAs in SPSS 20 (SP Inc., Chicago, USA) after having tested whether the prerequisites of linear models (normal distribution, equal variance) were sufficiently met by visually inspecting the distribution of the residuals (QUINN & KEOUGH 2002). When an ANOVA resulted in a significant pattern, we used Tukey’s HSD *post hoc* test at  $\alpha = 0.05$  to determine homogenous groups.

## 4. Vegetation classification

All syntaxon names mentioned in Section 4 are nomenclaturally evaluated in Appendix S2. The authors of all accepted syntaxon names are given in Section 4.1, those for other syntaxa in Appendix S2, while in the text we refrain from providing author citations and nomenclatural assessments except in ambiguous cases.

### 4.1 Proposed syntaxonomic scheme

Here we present the syntaxonomic scheme followed in the text and tables, although various aspects are still tentative or even disputed within the team of authors. Reasons for the applied system and alternative views are discussed in Sections 4.2–4.4. Unclear alliance assignments are marked with “???”.

Class 1: *Koelerio-Corynephoretea* Klika in Klika & Novák 1941

– Subclass 1a: *Sedo-Scleranthenea* (Br.-Bl. 1955) Dengler in Dengler et al. 2003

Order 1.1: *Alyssso alyssoidis-Sedetalia* Moravec 1967 – Basiphilous outcrop communities

Alliance???: *Alyssso alyssoidis-Sedion* Oberd. & T. Müller in T. Müller 1961

Association 1.1.1: *Ajuga chamaepitys* subsp. *chia-Sedum acre* community

Order 1.2: *Sedo-Scleranthetalia* Br.-Bl. 1955 – Acidophilous outcrop communities

Alliance???: *Sedo albi-Veronicion dillenii* Korneck 1974

Association 1.2.1: *Allium podolicum-Sedum acre* community

– Subclass 1b: *Koelerio-Corynephorenea* (Klika in Klika & Novák 1941) Dengler in Dengler et al. 2003

Order 1.3: *Trifolio arvensis-Festucetalia ovinae* Moravec 1967 – Mesoxeric grasslands of sandy soils

Alliance???: *Agrostion vinealis* Sipaylova et al. 1985

Association 1.3.1: *Trifolium arvense-Festuca valesiaca* community

Class 2: *Festuco-Brometea* Br.-Bl. & Tx. ex Klika & Hadač 1944

Order 2.1: *Brachypodietalia pinnati* Korneck 1974 nom. conserv. propos. – Mesoxeric grasslands of base-rich, loamy soils

Alliance: *Agrostio vinealis-Avenulion schellianae* Royer 1991

Association 2.1.1: *Linum hirsutum-Galium verum* community

Association 2.1.2: *Fissidens viridulus-Festuca rupicola* community

Association 2.1.3: *Homalothecium lutescens-Poa angustifolia* community

Order 2.2: *Festucetalia valesiaca* Soó 1947 – Xeric grasslands of base-rich, loamy soils

Alliance: *Festucion valesiaca* Klika 1931 nom. conserv. propos.

Association 2.2.1: *Teucro pannonic-Stipetum capillatae* Didukh & Korotchenko 2000

Association 2.2.2: *Allio taurici-Dichanthietum ischaemi* Kuzemko et al. 2014

Alliance: *Stipion lessingiana* Soó 1947

Association 2.2.3: *Salvia nutans-Carex humilis* community

#### 4.2 Identity and placement of alliances and orders

Within the *Koelerio-Corynephoretea*, both the outcrop communities and the communities on deep sandy soils were represented. Since in the study area (Table 4 in the supplement) as well as Europe-wide (see Table 30 in DENGLER 2003) they share many joint character species, we consider them as subclasses *Sedo-Scleranthenea* and *Koelerio-Corynephorenea*, respectively, while in some syntaxonomic overviews they are treated as classes in their own right under equivalent names (e.g. SCHAMINÉE et al. 1996). The communities of our study could readily be assigned to three orders of common classification systems (e.g. MORAVEC 1967, MUCINA & KOLBEK 1993b, SCHAMINÉE et al. 1996, RODWELL et al. 2002, DENGLER 2003). There were both basiphilous (*Alyso alyssoidis-Sedetalia*) and acidophilous (*Sedo-Scleranthetalia*) outcrop communities, while the *Koelerio-Corynephorenea* were represented by the order of closed swards on meso-xeric sands (*Trifolio arvensis-Festucetalia ovinae*), which is geographically widespread in Europe.

The assignment to alliances within each of these three orders is more challenging, since larger-scale syntheses, particularly of the outcrop communities, are so far missing. For the basiphilous outcrop communities, we follow the common approach to place them in a common alliance for all stands in temperate Europe, *Alyso alyssoidis-Sedion*. In the case of the acidophilous outcrop communities of temperate European lowlands, the alliance would be the *Sedo albi-Veronicion dillenii*. However, Ukrainian researchers have also used the name *Hyperico perforati-Scleranthion perennis* for such stands, a name that according to the original description by MORAVEC (1967) refers to communities that are floristically, physiognomically and ecologically transitional between the orders *Sedo-Scleranthetalia* and *Trifolio-Festucetalia* in the delimitation of DENGLER (2003). If the *Hyperico-Scleranthion* were assigned to the acidophilous outcrop communities, the name *Trifolio-Festucetalia*, whose holotype it is, would become a later syntaxonomic synonym of the *Sedo-Scleranthetalia*. The name *Sedo-Scleranthetalia* would therefore not be applicable to communities of deeper sandy soils as intended by MORAVEC (1967), who intentionally distinguished this order from the *Sedo-Scleranthetalia* and adopted it in major recent syntaxonomic overviews (e.g. SCHAMINÉE et al. 1996, BERG et al. 2004). Therefore we assign our relevés preliminarily to the *Sedo-Veronicion*, whose delimitation against potential vicariant alliances, however, needs clarification (see also PEDASHENKO et al. 2013). For example, from Ukraine two new alliances of acidophilous outcrop communities have been described by DIDUKH & KONTAR (1999), *Poo compressae-Rumicion acetosellae* and *Thymo pulegioidis-Sedion sexangularis* nom. inval., based, however, on only few relevés from a limited spatial extent, leaving their supraregional relevance questionable.

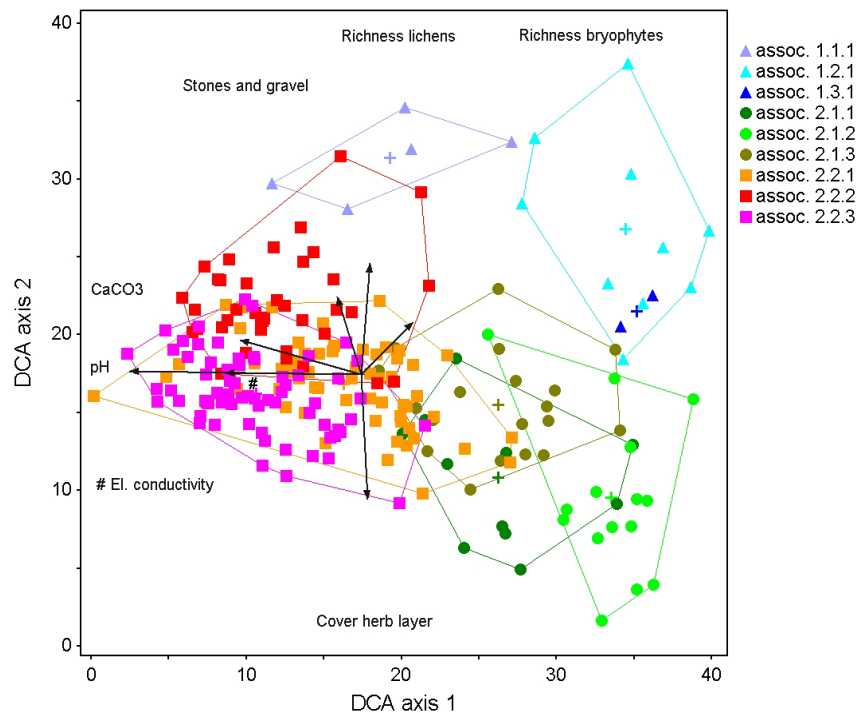
For the *Trifolio-Festucetalia*, DENGLER (2003, 2004a) proposed a system of three largely vicariant alliances, which are also distinguished by different microspecies of the *Festuca ovina* aggregate that dominate the swards: (a) *Sedo-Cerastion arvensis* (temperate-atlantic Europe; *F. filiformis* and *F. lemanii*); (b) *Hyperico perforati-Scleranthion perennis* (boreo-montane; *F. ovina* and *F. guestfalica*); (c) *Armerion elongatae* (Pleistocene, subcontinental lowlands; *F. trachyphylla*). PEDASHENKO et al. (2013) then added the *Armerio rumelico-Potentillion* as fourth vicariant alliance for the Balkan Peninsula. The stands in Central Podolia do not fit into any of these four alliances either floristically or chorologically. Therefore, we assume that they belong to an eastern vicariant of the *Armerion elongatae*. A suitable alliance concept here would be the *Agrostion vinealis*, to which we assign our plots tentatively. This alliance has been described as mesoxeric, closed swards on sandy soils in alluvial plains of Ukraine and western Russia, and was originally placed in the *Molinio-*

*Arrhenatheretea*, either in the *Arrhenatheretalia elatioris* (SIPAYLOVA et al. 1985) or the *Galietales veri* (KUZEMKO 2009, ERMAKOV 2012). Another related alliance concept is the *Thymo pulegioidis-Sedion sexangularis* nom. inval. (DIDUKH & KONTAR 1999), which comprises communities transitional between open cryptogam-, succulent- and therophyte-rich granite outcrop communities and more closed swards.

Within the *Festuco-Brometea*, the two distinguished groups can be readily identified with the two orders widely accepted in more recent surveys of other parts of Europe (e.g. MUCINA & KOLBEK 1993a, DENGLER 1994, RODWELL et al. 2002, DENGLER et al. 2012a) based on a long list of well-established diagnostic species that were also common in the stands of Central Podolia (see Table 4 in the supplement), namely the *Brachypodietalia pinnati* (= *Brometalia erecti* nom. ambig. propos., 2.1) and *Festucetalia valesiacae* (2.2).

One should note, however, that Ukrainian and Russian phytosociologists often place at least part of the content of unit 2.1 as a separate order *Galietales veri* within the class *Molinio-Arrhenatheretea* (e.g. MIRKIN & NAUMOVA 1986, RODWELL et al. 2002, KUZEMKO 2009, 2011a, ERMAKOV 2012). This is particularly true for association 2.1.3 with several *Molinio-Arrhenatheretea* character species (e.g. *Trifolium pratense*, *Lolium perenne*) among the diagnostic species. Since generally accepted character species of the *Festuco-Brometea* and the order *Brachypodietalia pinnati* are clearly prevailing (Table 4 in the supplement) and since the three associations 2.1.1–2.1.3 appear overall as a homogenous group in Table 4 in the supplement and the ordination (Fig. 2), we place all of them preliminarily in the *Brachypodietalia pinnati*. Within this order the assignment to an alliance is less clear. The stands clearly differ from typical *Cirsio-Brachypodion pinnati* communities of subcontinental Europe (e.g. DENGLER 1994, BECKER et al. 2011, ŠKODOVÁ et al. 2011, DENGLER et al. 2012a, WILLNER et al. 2013, PEDASHENKO et al. 2013) through their physiognomy is dominated by forbs instead of graminoids. Moreover, various typical species of the *Cirsio-Brachypodion* are rare or absent in the *Brachypodietalia pinnati* stands of Central Podolia (e.g. *Brachypodium pinnatum*, *Filipendula vulgaris*, *Polygala comosa*, *Carex* spp.), while a few more easterly distributed taxa appear instead (e.g. *Agrimonia eupatoria* subsp. *grandis*, *Dianthus membranaceus*, *Silene donetzica*). Only our association 2.1.1 retains some resemblance to the *Cirsio-Brachypodion* of Transylvania (DENGLER et al. 2012a). In order not to split the Podolian *Brachypodietalia pinnati* communities prematurely, we consider all of them as belonging to the same alliance, that is, an eastern vicariant of the *Cirsio-Brachypodion*. Such a concept has already been proposed by ROYER (1991) under the name *Agrostio-Avenulion schellianae*. This alliance unites all mesoxeric *Festuco-Brometea* communities between the Carpathian and the Ural Mts., corresponding to the herb-rich meadow steppes, and is based on a type relevé from the Streletskaya steppe, Kursk region, Russia. If this unit should be geographically too broad, the name *Fragario viridis-Trifolion montani* (KOROTCHENKO & DIDUKH 1997) would be available for the western (Ukrainian) part. Note that the similar name *Trifolion montani*, which was described as *Molinio-Arrhenatheretea* alliance (NAUMOVA 1986), in the protologue contained one association that would also belong here. It generally (including the type association) consists of sandy dry grasslands without many *Festuco-Brometea* species, and thus according to our concept would be a later synonym of the *Agrostion vinealis* (*Koelerio-Coryneporetea*).

The xeric group of *Festuco-Brometea* communities (2.2) quite clearly belongs to the *Festucetalia valesiacae* (xeric communities on deep soils). Only few species indicate relationships to the rocky dry grasslands of the order *Stipo pulcherrimae-Festucetalia pallentis*



**Fig. 2.** Gradient analysis (DCA) of the investigated dry grassland vegetation of Central Podolia. The data set includes 226 samples with 474 species. Eigenvalue of axis 1 is 0.349 and gradient length 3.20 standard deviation units, axis 2: 0.262/3.69, axis 3 (not shown): 0.178/2.88. Significance of the three axes at  $p = 0.001$  was given by randomisation tests with 999 runs. Vectors are only shown for relationships with  $|r| > 0.44$ .

**Abb. 2.** Gradientenanalyse (DCA) der untersuchten Trockenrasen Zentral-Podoliens. Der Datensatz beinhaltet 226 Aufnahmen mit 474 Arten. Achse 1 hat einen Eigenwert von 0,349 und eine Gradientenlänge von 3,20 Standardabweichungseinheiten, Achse 2: 0,262/3,69, Achse 3 (nicht dargestellt): 0,178/2,88. Es sind nur Vektoren dargestellt, die mit einer der beiden Achsen mit  $|r| > 0.44$  korrelieren.

(compare JANIŠOVÁ et al. 2010, DENGLER et al. 2012a, PEDASHENKO et al. 2013, WILLNER et al. 2013). These are *Carex humilis*, which is typical and sometimes dominant in association 2.2.3, and *Allium flavum*, regionally diagnostic for association 2.2.2, which, albeit in a different subspecies has been recorded as diagnostic for *Stipo-Festucetalia* associations in Romania and Bulgaria (DENGLER et al. 2012a, PEDASHENKO et al. 2013). Overall, the recorded communities seem to fit more into the *Festucetalia valesiaca*, but a larger-scale revision might well conclude that some of the more stony plots should belong to a different association in the other order. Within the *Festucetalia valesiaca* the placement of our three associations is rather challenging. Associations 2.2.1 and 2.2.2 might still fit into a widely delimited *Festucion valesiaca*, while association 2.2.3 shows clear links to the *Stipion lessingiana* (e.g. high frequency of *Salvia nutans*), albeit a bit impoverished compared to the stands in Transylvania (DENGLER et al. 2012a). Ukrainian authors have additionally introduced many more alliances of xeric *Festucetalia valesiaca* communities (see SOLOMAKHA 1996), whose justification and delimitation are in need of supra-regional, data-based revision.

### 4.3 Description of the associations

(Tables 1, 11 and Tables 4–7 in the supplement, Appendix S3)

**Association 1.1.1: *Ajuga chamaepitys* subsp. *chia*-*Sedum acre* community** (Table 5 in the supplement)

**Characterisation:** A moderately species-rich community with significant cryptogam diversity, open herb layer (mean cover: 35%) and a well-developed moss layer (41%). The constant species in the herb layer are *Sedum acre* and *Acinos arvensis*, while *Arenaria serpyllifolia*, *Poa compressa* and *Dichanthium ischaemum* are also frequent and *Aurinia saxatilis* and *Ajuga chamaepitys* subsp. *chia* have highest diagnostic value. In the moss layer, the dominant species are *Syntrichia ruralis* agg., *Abietinella abietina* and *Bryum capillare*.

**Ecology and distribution:** The community occurs at the moderately steep slopes (mean: 22°) of mostly south-eastern or south-western aspect on loamy soils that originate from limestone rocks, which often come to the surface (cover up to 68%). Both soil pH (mean: 7.5) and carbonate content (mean: 12.8%) are particularly high, skeleton content (mean: 13%) and humus content ( $C_{org}$ : 7.7%) exceed all other associations. We found this association in the Dniester River basin in the three study sites where carbonate rocks were present on the surface. In most cases, these communities have no economic use, but sometimes they are used as pasture with an average intensity of grazing.

**Syntaxonomy:** We could not find any matching association description from Ukraine or neighbouring countries and thus treat the five plots preliminarily as an informal community.

**Association 1.2.1: *Allium podolicum*-*Sedum acre* community** (Table 5 in the supplement)

**Characterisation:** The community with the highest total species richness (mean 47.2) in the study area, including the most diverse moss layer with on average 9.6 bryophyte and 5.3 lichen taxa. The herb layer is moderately closed and the moss layer well developed. The most frequent species in the herb layer are *Sedum acre*, *Potentilla argentea* agg., *Hieracium echinoides* and *Trifolium arvense*. Grasses, such as *Festuca rupicola* and *F. valesiaca* are less frequent, but can dominate when they occur. The moss layer is typically formed from *Brachythecium albicans*, *Syntrichia ruralis* agg., *Ceratodon purpureus*, *Abietinella abietina*, and the lichens *Cladonia pyxidata* agg. and *C. furcata*. Of all studied associations, this one has the highest number of diagnostic species, among which several are potentially at least regional character species, e.g. *Viola tricolor* subsp. *matutina*, *Allium podolicum* and *Veronica spicata* subsp. *incana*.

**Ecology and distribution:** The community occurs on average on the steepest slopes of all dry grassland associations of the region (mean 27°), which are mostly north-facing, thus leading to a negative heat index (mean: -0.24). The sandy soils (mean sand fraction is 43%) with an appreciable skeleton content (mean: 9%) are derived from silicate rocks, mostly granite. The siliceous origin is reflected by moderately acidic soils (mean pH: 6.0, the lowest among all communities), low conductivity and practically absent carbonates. The association occurs in the valley of the Southern Bug River, where granite of the Ukrainian crystalline shield outcrops at the surface. The areas are used as pastures with low intensity of grazing.

**Syntaxonomy:** Similar acidophilous outcrop communities have previously been described from Ukraine under various names, namely *Vincetoxico hirundinarii-Rumicetum acetosellae*, *Thymo pulegioidis-Sedetum sexangularis*, *Artemisio austriaci-Teucrietum chamaedryos* (DIDUKH & KONTAR 1999), *Melico transylvanicae-Sedetum ruprechtii* (KONTAR 2000; *Sedum ruprechtii* = *Hylotelephium maximum* subsp. *ruprechtii*) and *Aurinio*



*saxatilis-Allietum podolici* (ONYSCHENKO 2001: the author claims that his community is basiphilous, but his species-composition rather suggests that it belongs to the *Sedo-Scleranthetalia*). While it appears that these are more associations than reasonably could be distinguished among the *Sedo-Scleranthetalia* of Ukraine, proper assignment should be based on a numerical revision on the basis of more extensive plot data; therefore, we prefer to present our relevés as informal unit.

**Association 1.3.1: *Trifolium arvense-Festuca valesiaca* community** (Table 5 in the supplement)

**Characterisation:** The association is represented by only two relevés, which might not be fully representative of the community type. These two relevés are very species rich and represent the most diverse community type of the study in terms of vascular plants (mean: 43.5 species on 10 m<sup>2</sup>). While the herb layer is dense and the litter cover highest among all associations (mean: 23%), the moss layer is much more poorly developed than in the other two communities of the *Koelerio-Corynephoretea* (10%). The herb layer is dominated by *Festuca valesiaca*, with *Trifolium arvense*, *Fragaria viridis*, *Achillea millefolium* agg., *Potentilla argentea* agg. and *Hieracium pilosella* also playing an important role. A larger number of weedy species (*Convolvulus arvensis*, *Setaria viridis*, *Anagallis arvensis* and others) are also present. The moss layer has *Brachythecium albicans* as the single dominant.

**Ecology and distribution:** The two relevés occupy nearly flat areas with deep, moderately acidic soils (mean pH: 6.2) with low conductivity and practically no carbonates. Unlike the two other *Koelerio-Corynephoretea* associations, there are no stones at the soil surface and hardly any skeleton in the upper soil horizons. We found this community only in the “Romashkovo” site in the National Nature Park “Karmelukove Podillya” in the ecotone of steppe and an abandoned field, which obviously caused the penetration of the weed species in the grassland community. The stands are used as pastures with low grazing intensity.

**Syntaxonomy:** We could not find any matching association description from Ukraine or neighbouring countries and thus treat the two plots preliminarily as an informal community. Only the *Thymo pulegioidis-Sedetum sexangularis* described from similar locations (DIDUKH & KONTAR 1999) was to some extent similar, but the dominant *Festuca* species was *F. ovina* instead of *F. valesiaca* and also many other aspects differ so much that these are not likely to be the same association. Note that SOPOTLIEVA & APOSTOLOVA (2014) described a *Trifolium arvensis-Festucetum valesiaca* from Bulgaria, which they considered transitional between the *Festuco-Brometea* and *Koelerio-Corynephoretea* and placed it in the *Festucion valesiaca*, but despite two dominant species being the same, otherwise the communities differ significantly in their composition.

**Association 2.1.1: *Linum hirsutum-Galium verum* community** (Table 6 in the supplement)

**Characterisation:** A moderately species rich community with a dense herb layer and a poorly developed moss layer. In this association, forbs such as *Galium verum*, *Plantago media*, *Achillea millefolium* agg., *Centaurea scabiosa*, *Origanum vulgare*, *Senecio jacobaea*, *Stachys recta* and the dwarf shrub *Chamaecytisus austriacus* are far more frequent than the most frequent grasses (*Festuca rupicola*, *Poa angustifolia*, *Koeleria macrantha*, *Brachypodium pinnatum*). Particularly diagnostic and potential character species of the association are *Linum hirsutum*, *Carlina vulgaris* subsp. *intermedia* and *Silene donetzica*. In the moss cover, the most frequent taxon is *Weissia* spp. (with *W. longifolia*), sometimes with considerable cover.

**Ecology and distribution:** The association grows on gentle (mean: 14°), rather northerly exposed slopes. The soils are neutral (pH: 7.2) with low carbonate content and very little skeleton. This community occurs in the watershed of the Southern Bug and the Dniester rivers. In most cases, the stands are abandoned; occasionally they are used as pastures, mostly of low intensity, and in some cases burned.

**Syntaxonomy:** According to our knowledge, such a community has not previously been described from Ukraine. Within Ukraine the most similar previously described association is the *Veronico austriacae-Chamaecytisetum austriaci*, the two eponymous taxa also being characteristic for our stands, which was placed in the *Fragario viridis-Trifolium montani* by KOROTCHENKO & DIDUKH (1997). Certain similarities exist also towards the *Brachypodio pinnati-Teucrietum chamaedryos* (Lublin Upland, Poland; FIJALKOWSKI 1964) and the *Festuco sulcatae-Brachypodietum pinnati* (Transylvania, Romania; DENGLER et al. 2012a), both typically placed in the *Cirsio-Brachypodion pinnati*, but our stands are much poorer in species.

**Association 2.1.2: *Fissidens viridulus-Festuca rupicola* community** (Table 6 in the supplement, Fig. 3)

**Characterisation:** This moderately species-poor community has the lowest density of vascular plant taxa within the study (31.1 on 10 m<sup>2</sup>) while on the other hand the herb layer cover is highest on average (85%). The most frequent species are the grasses *Festuca rupicola*, *Poa angustifolia*, *Koeleria macrantha* and *Elymus repens* and the forbs *Medicago sativa* subsp. *falcata*, *Galium verum*, *Eryngium campestre* and *Asperula cynanchica*. Regionally high diagnostic values have *Trifolium montanum*, *Falcaria vulgaris* and *Campanula bononiensis*. Among the bryophytes, *Oxyrrhynchium hians* and *Weissia* spp. (with *W. longifolia* and *W. condensata*) are the most frequent ones, the latter sometimes reaching higher cover, and *Fissidens viridulus* has particular diagnostic value.

**Ecology and distribution:** The association preferentially grows on moderately steep, northerly exposed slopes. The soils have a slightly lower pH than the previous association (mean: 6.6) while carbonate and skeleton content are similarly low. The association is fairly widespread in the valley of the Southern Bug River. The sites are used as pastures with low and medium grazing intensity and burned.

**Syntaxonomy:** This community fits well into the alliance *Fragario viridis-Trifolium montani*, but matching with one of the five very narrow associations contained in the original description (KOROTCHENKO & DIDUKH 1997) is problematic, *Betonico officinalis-Trifolietum montani* and *Salvio pratensis-Poetum angustifoliae* being the best matches.

**Association 2.1.3: *Homalothecium lutescens-Poa angustifolia* community** (Table 6 in the supplement)

**Characterisation:** Stands of this association have the highest mean total richness in the study (46.3). They have a dense herb layer, but at the same time the best developed moss layer among the *Brachypodietalia pinnati* communities (34%). *Festuca valesiaca*, *Poa angustifolia*, *F. rupicola*, *Dichanthium ischaemum* and *Agrostis gigantea* play the biggest role among the grasses. The forbs represent a peculiar mixture of widespread *Festuco-Brometea* species (*Fragaria viridis*, *Teucrium chamaedryos*, *Salvia verticillata*, *Plantago media*) and typical *Molinio-Arrhenatheretea* species (*Trifolium repens*, *T. pratense*, *Cerastium fontanum* subsp. *vulgare*). The moss layer consists mainly of mats of *Homalothecium lutescens* and *Abietinella abietina*.



**Fig. 3.** *Fissidens viridulus-Festuca rupicola* [*Agrostio vinealis-Avenulion schellianae*] community (2.1.2), ancient settlement “Nemyrivske” (Site 1) (Photo: A.A. Kuzemko).

**Abb. 3.** *Fissidens viridulus-Festuca rupicola*- [*Agrostio vinealis-Avenulion schellianae*] Gesellschaft (2.1.2), historische Siedlungsanlage “Nemyrivske” (Standort 1) (Foto: A.A. Kuzemko).

**Ecology and distribution:** Similarly to association 2.1.1, this community occurs on gentle, mostly north-facing slopes with neutral, carbonate- and skeleton-poor soils. The association is widespread in the Dniester basin. The stands are used as pastures with varying intensity of pressure, from very low to high, but on average more intensively than in any other community studied.

**Syntaxonomy:** This community matches quite well the *Festuco valesiacae-Poetum angustifoliae* described from the alliance *Trifolion montani* (DENISOVA et al. 1986).

**Association 2.2.1: *Teucrio pannonici-Stipetum capillatae*** (Table 7 in the supplement)

**Characterisation:** Stands of this association are moderately species poor (mean 34.4 species on 10 m<sup>2</sup>) and characterized by a dense herb layer. The stands are dominated by *Dichanthium ischaemum* and/or *Stipa capillata* or, more rarely, *Festuca valesiaca*. Among the forbs, *Teucrium chamaedrys*, *Salvia verticillata*, *Potentilla incana* and *Astragalus onobrychis* are the most dominant ones. In the mostly poorly developed moss layer, *Abietinella abietina* and *Weissia* spp. are the most relevant taxa in terms of constancy and cover.

**Ecology and distribution:** The stands grow on moderately steep (mean: 22°), southerly exposed slopes and thus have the highest heat index among all studied associations (mean: 0.16). The soils are moderately alkaline and have considerable carbonate content. The association is geographically the most widespread dry grassland type of the region, present in 13

out of 18 analysed sites (Table 1), mainly in the basin of the Dniester River and the valleys of the Dniester tributaries. In the valley of the Southern Bug River, these communities are less frequent, with one recorded site. The stands typically have no economic use.

**Syntaxonomy:** This central association corresponds very well to the *Teucro pannonici-Stipetum capillatae* described from Pokuttya (W Ukraine) (DIDUKH & KOROTCHENKO 2000) and we consider it the same, except we did not find the eponymous *Teucrium* species.

**Association 2.2.2: *Allio taurici-Dichanthietum ischaemi*** (Table 7 in the supplement)

**Characterisation:** A moderately species rich community with a moderately closed herb layer (71%) and the best developed moss layer among the *Festucetalia valesiaca* communities. Similar to the previous association, the stands are mostly dominated by *Dichanthium ischaemum*, *Stipa capillata*, *Festuca valesiaca* or in this case also *Stipa pulcherrima*. While also the dominant forb species are mostly the same as in association 2.2.1 (*Potentilla incana*, *Salvia verticillata*, *Teucrium chamaedrys*, *T. montanum*), a set of additional diagnostic forbs clearly differentiate this community, most notably *Allium flavum* subsp. *tauricum*, *Leontodon crispus*, *Teucrium polium* and *Alyssum rostratum*. In the moss layer, *Weissia* spp. and *Abietinella abietina* are most frequent, while *Homalothecium lutescens* sometimes dominates.

**Ecology and distribution:** The stands occur on slopes of varying steepness (mean 18°, maximum: 36°). The soils are moderately alkaline (mean pH: 7.5), and have the highest conductivity (186 µS/cm) and carbonate content (13.5%) among all identified associations. The association is present in those localities with significant limestone outcrops. It is common in the valleys of the Dniester River tributaries: Kysyrniak, Kamianka, Tashlyk and Vilshanka. The stands are used as pastures with varying grazing intensity or abandoned.

**Syntaxonomy:** As we could not find a convincing match in the literature for this regionally frequent and floristically clearly differentiated unit, we describe it as a new association: ***Allio taurici-Dichanthietum ischaemi* ass. nova hoc loco**; Holotypus: Table 7 in the supplement, relevé 137 = UAR051 of this paper.

**Association 2.2.3: *Salvia nutans-Carex humilis* community** (Table 8 in the supplement)

**Characterisation:** Moderately species rich community with a moderately dense herb layer and a generally little developed moss layer (mean cover: 8%), which in rare cases can reach 50–60%. Differing from the two other *Festucetalia valesiaca* communities, in this association *Carex humilis* plays the biggest role among the graminoids, together with *Dichanthium ischaemum*, while *Stipa capillata*, *Festuca valesiaca* and *Cleistogenes serotina* subsp. *bulgarica* play a subordinate role. Next to some widespread *Festucetalia valesiaca* species (*Teucrium chamaedrys*, *Potentilla incana*, *Chamaecytisus austriacus*) some peculiar forbs, such as *Salvia nutans*, *Jurinea ledebourii*, *Adonis vernalis*, *Aster amellus* and *Inula ensifolia* give this association its special character. Like in all associations of the order in the region, *Weissia* spp. is the most constant species in the moss layer, while *Abietinella abietina* and *Homalothecium lutescens* occur more rarely but sometimes dominate.

**Ecology and distribution:** This association typically grows on gentle, mostly southerly exposed slopes with moderately alkaline soils and moderate carbonate content. The association is widespread in the Dniester basin. The stands are used as pastures, rarely abandoned, occasionally burned.

**Syntaxonomy:** This association is very similar to the Transylvanian *Stipetum pulcherrimae*, considered as the central association of the *Stipion lessingiana* (DENGLER et al. 2012a), only in some species vicariant subspecies replace each other, e.g. *Cleistogenes serot-*

*ina* subsp. *serotina* vs. subsp. *bulgarica* and *Allium flavum* subsp. *flavum* vs. subsp. *tauricum* in Transylvania and Podolia, respectively. A large-scale synthesis is needed to clarify whether two separate associations are justified or not.

## 5. Ecology, biodiversity and conservation

### 5.1 Overall characterisation of the dry grassland stands (Table 9)

In the study region, the remaining dry grasslands occur in any exposition, but only very rarely on flat areas (mean slope is 19°). Typically, they are grazed at low intensity, and approximately 10% of the plots showed indications of burning. The soils are mostly loamy and base-rich, with a mean pH above the neutral point and only 8% of the plots more acidic than pH = 6.5.

The herb layer was, with a few exceptions, closed with around 80% cover, while the moss layer was very variable, from absent to 85%. The mean total species richness in 10 m<sup>2</sup> was 41 species, but varied by a factor of more than five between the poorest (13) and richest plots (67). Bryophytes and lichens contributed on average only 7.8% and 1.5% to the plot-scale richness, were completely absent in many plots, but could reach exceptionally up to 15 and 12 species, respectively.

### 5.2 Vegetation-environment relationships

According to the ordination diagram (Fig. 2), the main floristic gradient (first DCA axis) in the dry grasslands of the region is determined by soil pH (despite the relatively little variation in soil reaction present in the dataset, see Table 9), which more or less corresponds to CaCO<sub>3</sub> and electrical conductivity. The second DCA axis then differentiates from bottom to top between stands with a closed herb layer and open stands with significant surface cover of stones and gravel and higher diversity of non-vascular plants. Four of the five phytosociological orders distinguished above are clearly separated already on the plane of the first two ordination axes, the *Festucetalia valesiaca* in the lower left corner (closed, cryptogam-poor stands on particularly base-rich soils), *Brachypodietalia pinnati* in the lower right corner (closed, cryptogam-poor stands on less base-rich soils), *Alysso-Sedetalia* in the upper left corner (open, cryptogam-rich stands on particularly base-rich soils) and the *Sedo-Scleranthetalia* in the upper right corner (open, cryptogam-rich stands on less base-rich soils). Only the two relevés of the order *Trifolio-Festucetalia* were not separated on this ordination plane, but included in the polygon of the *Sedo-Scleranthetalia*. By contrast, the three associations within of each of the orders *Festucetalia valesiaca* and *Brachypodietalia pinnati* showed high overlap in the ordination diagram.

The two vegetation classes differed ecologically mainly with regard to soil reaction, the pH in stands of the *Koelerio-Coryneporetea* being on average 0.8 units lower than in the *Festuco-Brometea* (and carbonate content and electrical conductivity changing accordingly) (Table 10). Furthermore, the *Koelerio-Coryneporetea* inhabit more stony sites with more pronounced micro-relief and more often northerly exposed than the communities of the other class (Table 10). In consequence, the herb layer of the *Festuco-Brometea* is dense and the moss layer sparse, whereas in the *Koelerio-Coryneporetea* the herb layer is more open, allowing the development of a moss layer with on average four-fold coverage (Table 10). The ANOVAs at association level (Table 11) show significant patterns for most parameters,

**Table 9.** Characterisation of the analysed 10-m<sup>2</sup> dry grassland plots in Central Podolia in terms of environmental conditions, vegetation structure and biodiversity ( $n = 226$  except for few parameters where values for a small number of plots were missing).

**Table 9.** Zusammenfassung von abiotischen Standortparametern, Vegetationsstruktur und Diversität der Vegetationsaufnahmen (10 m<sup>2</sup> Flächen;  $n=226$ , mit Ausnahmen weniger fehlender Werte einzelner Vegetationsaufnahmen) für Trockenrasen in Zentral Podolien.

Parameter	Min	Max	Mean $\pm$ SD
Altitude [m a.s.l.]	73	251	161 $\pm$ 39
Inclination [°]	1	48	19 $\pm$ 9
Heat index	-0.94	0.85	0.02 $\pm$ 0.30
Microrelief [cm]	0	100	7 $\pm$ 12
Grazing intensity: 0 = none ( $n = 100$ ); 1 = low ( $n = 61$ ); 2 = medium ( $n = 45$ ); 3 = high ( $n = 20$ )			
Burning: no ( $n = 201$ ); unclear ( $n = 3$ ); yes ( $n = 22$ )			
Total vegetation cover [%]	30	100	83 $\pm$ 14
Cover shrub layer [%]	0	25	1 $\pm$ 2
Cover herb layer [%]	15	100	78 $\pm$ 16
Cover moss layer [%]	0	85	13 $\pm$ 19
Cover dead wood [%]	0	2	0 $\pm$ 0
Cover litter [%]	0	90	12 $\pm$ 15
Cover stones and rocks [%]	0	68	4 $\pm$ 9
Cover gravel [%]	0	75	3 $\pm$ 8
Cover fine earth [%]	0	38	7 $\pm$ 7
Proportion skeleton [%]	0	37	6 $\pm$ 8
Proportion sand [%]	5	80	36 $\pm$ 20
Proportion silt [%]	5	90	40 $\pm$ 25
Proportion clay [%]	5	55	24 $\pm$ 11
pH [H <sub>2</sub> O]	4.89	7.79	7.29 $\pm$ 0.46
CaCO <sub>3</sub> content [%]	0.0	35.3	7 $\pm$ 8
Conductivity [ $\mu$ S/cm]	40	232	162 $\pm$ 42
C <sub>total</sub> [%]	1.3	15.8	6 $\pm$ 3
N <sub>total</sub> [%]	0.1	1.3	0 $\pm$ 0
C <sub>org</sub> /N <sub>org</sub> [mol/mol]	6.0	27.4	13.5 $\pm$ 2.4
Species richness (total)	15	67	41.1 $\pm$ 10.3
Species richness (vascular plants)	14	64	37.2 $\pm$ 9.6
Species richness (non-vascular plants)	0	20	3.9 $\pm$ 3.5
Species richness (bryophytes)	0	15	3.2 $\pm$ 2.5
Species richness (lichens)	0	12	0.6 $\pm$ 1.5

for example, the five orders are more or less separated according to those parameters already identified in the ordination diagram. The three *Brachypodietalia pinnati* associations were differentiated significantly according to two ecological/structural parameters, with the association 2.1.2 growing on less base-rich soils than the other two, and the association 2.1.3 having a far more developed moss layer than the others. By contrast, within the *Festucetalia valesiaca* the three distinguished associations did not show significant differences in any of the considered parameters (Table 11).

**Table 10.** Environmental conditions with significant differences and vegetation parameters in comparison of the two classes of dry grasslands in Central Podolia. Means and standard deviations are given. IV = Indicator value, <sup>log</sup> = *p* calculation on basis of log (*x* + 1)-transformed data.

**Tabelle 10.** Umweltbedingungen mit signifikanten Differenzen und Vegetationseigenschaften im Vergleich der beiden Trockenrasenklassen in Zentral-Podolien. Mittelwerte und Standardabweichungen sind dargestellt. IV = Indikatorwert, <sup>log</sup> = *p*-Berechnung auf Basis von log (*x* + 1)-transformierten Daten.

Class	<i>Koelerio-Corynephoretea</i> <i>n</i> = 17	<i>Festuco-Brometea</i> <i>n</i> = 209	<i>p</i> from <i>t</i> -test
Heat index	-0.14 ± 0.36	0.03 ± 0.30	0.027
Microrelief (cm)	19 ± 31	6 ± 8	< 0.001
Cover stones and gravel (%)	19 ± 20	6 ± 11	< 0.001 <sup>log</sup>
Skeleton content of soil (weight %)	10 ± 9	6 ± 7	0.030 <sup>log</sup>
pH of soil (in H <sub>2</sub> O)	6.5 ± 0.8	7.3 ± 0.3	< 0.001
CaCO <sub>3</sub> content of soil (weight %)	3.9 ± 7.0	7.9 ± 7.7	< 0.001 <sup>log</sup>
Conductivity of soil (μS/cm)	111 ± 57	167 ± 36	< 0.001
N <sub>tot</sub> (mmol/g dry soil)	0.4 ± 0.2	0.3 ± 0.1	0.001
C <sub>org</sub> (mmol/g dry soil)	4.5 ± 2.7	3.6 ± 1.2	0.014
C <sub>org</sub> /N <sub>org</sub> ratio of soil	12.3 ± 0.9	13.6 ± 2.4	0.022
IV moisture variability (1–11)	6.9 ± 0.4	6.4 ± 0.3	< 0.001
IV pH (1–15)	8.4 ± 0.2	8.8 ± 0.2	< 0.001
IV carbonate content (1–13)	7.6 ± 0.5	8.9 ± 0.6	< 0.001
IV salinity (1–19)	8.1 ± 0.3	8.4 ± 0.3	< 0.001
Cover herb layer (%)	56 ± 22	79 ± 17	< 0.001
Cover moss layer (%)	40 ± 22	11 ± 17	< 0.001 <sup>log</sup>
Species richness of all taxa (10 m <sup>2</sup> )	46.4 ± 9.4	40.7 ± 10.4	0.029
Species richness of vascular plants (10 m <sup>2</sup> )	34.7 ± 9.5	37.4 ± 9.7	0.272
Species richness of bryophytes (10 m <sup>2</sup> )	7.8 ± 3.8	3.3 ± 2.3	< 0.001
Species richness of lichens (10 m <sup>2</sup> )	3.7 ± 3.7	0.4 ± 0.8	< 0.001 <sup>log</sup>

Regarding the indicator values, those for carbonate content and pH were well correlated with the measured soil properties. However, the relation between IV salinity and electrical conductivity was much looser and IV nitrogen content appeared unrelated to the actual nitrogen content – but in all cases the overall variability in the dataset was low. Since we had no directly measured soil moisture data, the indicator values of moisture and moisture variability contributed to the interpretation. While the overall differentiation between associations was small (maximum 1.1 units difference on the 23-point scale of moisture), the results indicated the stands of the orders *Trifolio-Festucetalia* and *Brachypodietalia pinnati* as more humid, those of the *Sedo-Scleranthetalia* as intermediate and those of the *Alyso-Sedetalia* and the *Festucetalia valesiacae* as driest (Table 11). Regarding the moisture variability, the differentiation was between the two classes, with the *Koelerio-Corynephoretea* being indicative of more variable moisture conditions (Table 10).

**Table 11.** Environmental conditions and vegetation characteristics with significant differences among the nine dry grassland associations of Central Podolia (for association codes, see Chapter 4.1). Means and standard deviations are given. Different letters indicate significant differences between associations at  $p < 0.05$  from Tukey tests. IV = indicator value,  $\log_{10}$  = calculation of  $p$  on basis of  $\log(x + 1)$ -transformed data.

Association	1.1.1 $n = 5$	1.2.1 $n = 10$	1.3.1 $n = 2$	2.1.1 $n = 11$	2.1.2 $n = 15$	2.1.3 $n = 19$	2.2.1 $n = 59$	2.2.2 $n = 38$	2.2.3 $n = 67$	$p$ from ANOVA
Slope inclination (°)	22 ± 1.5 <sup>a</sup>	27 ± 9 <sup>a</sup>	7 ± 1 <sup>b</sup>	14 ± 9 <sup>ab</sup>	24 ± 10 <sup>a</sup>	16 ± 11 <sup>ab</sup>	22 ± 10 <sup>a</sup>	18 ± 9 <sup>ab</sup>	18 ± 7 <sup>ab</sup>	< 0.001
Heat index	0.05 ± 0.26	-0.24 ± 0.41	-0.12 ± 0.02	-0.08 ± 0.25	-0.21 ± 0.40	-0.19 ± 0.22	0.16 ± 0.31	0.00 ± 0.22	0.06 ± 0.25	< 0.001
Microrelief (cm)	29 ± 40 <sup>a</sup>	17 ± 30 <sup>ab</sup>	4 ± 2 <sup>b</sup>	6 ± 5 <sup>b</sup>	4 ± 2 <sup>b</sup>	4 ± 3 <sup>b</sup>	6 ± 6 <sup>b</sup>	8 ± 14 <sup>b</sup>	6 ± 6 <sup>b</sup>	< 0.001
Cover stones and gravel (%)	37 ± 23 <sup>a</sup>	13 ± 12 <sup>ab</sup>	0 ± 0 <sup>d</sup>	1 ± 3 <sup>cd</sup>	0 ± 2 <sup>d</sup>	3 ± 11 <sup>cd</sup>	6 ± 13 <sup>bcd</sup>	10 ± 13 <sup>abc</sup>	7 ± 9 <sup>bcd</sup>	< 0.001, $\log$
Skeleton content of soil (weight %)	13 ± 6 <sup>a</sup>	9 ± 11 <sup>abc</sup>	6 ± 9 <sup>abc</sup>	2 ± 4 <sup>c</sup>	3 ± 3 <sup>bc</sup>	5 ± 9 <sup>bc</sup>	6 ± 9 <sup>abc</sup>	10 ± 6 <sup>ab</sup>	6 ± 6 <sup>abc</sup>	< 0.001, $\log$
pH of soil (in HO)	7.5 ± 0.1 <sup>a</sup>	6.0 ± 0.6 <sup>d</sup>	6.2 ± 0.0 <sup>cd</sup>	7.2 ± 0.3 <sup>ab</sup>	6.6 ± 0.5 <sup>c</sup>	7.1 ± 0.4 <sup>b</sup>	7.4 ± 0.3 <sup>ab</sup>	7.5 ± 0.1 <sup>ab</sup>	7.5 ± 0.1 <sup>ab</sup>	< 0.001
CaCO <sub>3</sub> content of soil (weight %)	12.8 ± 7.2 <sup>a</sup>	0.2 ± 0.1 <sup>d</sup>	0.1 ± 0.0 <sup>d</sup>	2.5 ± 4.6 <sup>bcd</sup>	1.2 ± 3.1 <sup>d</sup>	2.1 ± 5.2 <sup>cd</sup>	8.7 ± 9.1 <sup>abc</sup>	13.4 ± 6.1 <sup>a</sup>	8.2 ± 6.1 <sup>ab</sup>	< 0.001, $\log$
Conductivity of soil (µS/cm)	180 ± 20 <sup>a</sup>	86 ± 41 <sup>c</sup>	64 ± 4 <sup>c</sup>	152 ± 64 <sup>ab</sup>	107 ± 30 <sup>bc</sup>	158 ± 41 <sup>a</sup>	164 ± 36 <sup>a</sup>	186 ± 20 <sup>a</sup>	176 ± 19 <sup>a</sup>	< 0.001
N <sub>tot</sub> (mmol/g dry soil)	0.6 ± 0.3 <sup>a</sup>	0.3 ± 0.1 <sup>b</sup>	0.2 ± 0.0 <sup>b</sup>	0.2 ± 0.1 <sup>b</sup>	0.2 ± 0.0 <sup>b</sup>	0.2 ± 0.1 <sup>b</sup>	0.2 ± 0.1 <sup>b</sup>	0.3 ± 0.1 <sup>b</sup>	0.3 ± 0.1 <sup>b</sup>	< 0.001
C <sub>org</sub> (mmol/g dry soil)	7.7 ± 3.2 <sup>a</sup>	3.3 ± 0.9 <sup>bc</sup>	2.4 ± 0.1 <sup>c</sup>	3.2 ± 2.1 <sup>bc</sup>	3.0 ± 0.6 <sup>bc</sup>	3.0 ± 1.2 <sup>bc</sup>	3.3 ± 1.1 <sup>bc</sup>	4.3 ± 1.2 <sup>b</sup>	3.9 ± 0.9 <sup>bc</sup>	< 0.001
C <sub>org</sub> /N <sub>org</sub> ratio of soil	12.7 ± 1.4	12.0 ± 0.8	12.3 ± 0.2	12.6 ± 1.5	12.3 ± 0.8	12.9 ± 1.1	14.5 ± 3.5	13.1 ± 1.2	13.8 ± 1.9	0.001
IV moisture (1–23)	8.6 ± 0.4 <sup>d</sup>	9.0 ± 0.4 <sup>bcd</sup>	9.6 ± 0.3 <sup>a</sup>	9.4 ± 0.3 <sup>ab</sup>	9.3 ± 0.4 <sup>abc</sup>	9.5 ± 0.3 <sup>a</sup>	8.8 ± 0.3 <sup>cd</sup>	8.5 ± 0.2 <sup>d</sup>	8.6 ± 0.3 <sup>d</sup>	< 0.001
IV moisture variability (1–11)	7.0 ± 0.4 <sup>a</sup>	6.9 ± 0.4 <sup>ab</sup>	7.0 ± 0.4 <sup>a</sup>	6.5 ± 0.3 <sup>cd</sup>	6.5 ± 0.3 <sup>bcd</sup>	6.7 ± 0.3 <sup>abc</sup>	6.4 ± 0.2 <sup>cd</sup>	6.4 ± 0.3 <sup>cd</sup>	6.2 ± 0.2 <sup>d</sup>	< 0.001
IV pH (1–15)	8.6 ± 0.2 <sup>cd</sup>	8.4 ± 0.2 <sup>de</sup>	8.2 ± 0.2 <sup>e</sup>	8.6 ± 0.3 <sup>bcd</sup>	8.6 ± 0.2 <sup>cd</sup>	8.5 ± 0.3 <sup>d</sup>	8.9 ± 0.2 <sup>abc</sup>	8.9 ± 0.2 <sup>ab</sup>	9.0 ± 0.1 <sup>a</sup>	< 0.001
IV carbonate content (1–13)	7.9 ± 0.6 <sup>cd</sup>	7.4 ± 0.4 <sup>d</sup>	7.5 ± 0.4 <sup>d</sup>	8.3 ± 0.5 <sup>bc</sup>	8.2 ± 0.3 <sup>bc</sup>	8.3 ± 0.6 <sup>bc</sup>	8.8 ± 0.6 <sup>ab</sup>	9.1 ± 0.4 <sup>a</sup>	9.3 ± 0.3 <sup>a</sup>	< 0.001
IV salinity (1–19)	8.4 ± 0.3 <sup>abc</sup>	8.0 ± 0.2 <sup>d</sup>	8.0 ± 0.1 <sup>cd</sup>	8.0 ± 0.3 <sup>bcd</sup>	8.2 ± 0.5 <sup>abcd</sup>	8.3 ± 0.2 <sup>abcd</sup>	8.4 ± 0.3 <sup>ab</sup>	8.6 ± 0.3 <sup>a</sup>	8.3 ± 0.3 <sup>abcd</sup>	< 0.001
IV nitrogen content (1–11)	4.7 ± 0.5 <sup>bc</sup>	4.8 ± 0.4 <sup>bc</sup>	5.3 ± 0.6 <sup>a</sup>	5.1 ± 0.2 <sup>ab</sup>	5.1 ± 0.2 <sup>ab</sup>	5.0 ± 0.3 <sup>abc</sup>	4.9 ± 0.4 <sup>abc</sup>	4.7 ± 0.2 <sup>bc</sup>	4.6 ± 0.2 <sup>c</sup>	< 0.001
Cover herb layer (%)	35 ± 17 <sup>b</sup>	60 ± 18 <sup>ab</sup>	83 ± 11 <sup>a</sup>	84 ± 30 <sup>a</sup>	85 ± 25 <sup>a</sup>	83 ± 15 <sup>a</sup>	80 ± 14 <sup>a</sup>	71 ± 16 <sup>a</sup>	79 ± 15 <sup>ab</sup>	< 0.001
Cover moss layer (%)	41 ± 26 <sup>a</sup>	38 ± 14 <sup>a</sup>	46 ± 48 <sup>abc</sup>	4 ± 4 <sup>c</sup>	7 ± 11 <sup>bc</sup>	34 ± 30 <sup>ab</sup>	8 ± 15 <sup>bc</sup>	13 ± 12 <sup>abc</sup>	8 ± 13 <sup>bc</sup>	< 0.001, $\log$
Species richness all taxa (10 m <sup>2</sup> )	44.8 ± 8.9	47.2 ± 10.9	46.0 ± 1.4	40.9 ± 8.1	34.9 ± 10.8	46.3 ± 11.3	34.7 ± 9.0	42.1 ± 8.5	44.8 ± 9.3	< 0.001
Species richness vascular plants (10 m <sup>2</sup> )	36.2 ± 9.7	32.2 ± 9.6	43.5 ± 0.7	38.1 ± 7.0	31.1 ± 8.4	42.8 ± 10.8	32.1 ± 8.1	37.3 ± 8.1	41.8 ± 8.9	< 0.001
Species richness bryophytes (10 m <sup>2</sup> )	6.2 ± 2.2 <sup>b</sup>	9.6 ± 3.3 <sup>a</sup>	2.5 ± 2.1 <sup>c</sup>	2.5 ± 2.0 <sup>c</sup>	3.7 ± 3.7 <sup>bc</sup>	3.3 ± 1.5 <sup>bc</sup>	2.4 ± 1.6 <sup>c</sup>	3.5 ± 1.8 <sup>bc</sup>	2.4 ± 1.7 <sup>c</sup>	< 0.001
Species richness lichens (10 m <sup>2</sup> )	2.2 ± 1.5 <sup>ab</sup>	5.3 ± 4.1 <sup>a</sup>	0.0 ± 0.0 <sup>c</sup>	0.1 ± 0.3 <sup>c</sup>	0.1 ± 0.4 <sup>c</sup>	0.1 ± 0.3 <sup>c</sup>	0.2 ± 0.4 <sup>c</sup>	0.9 ± 1.1 <sup>bc</sup>	0.4 ± 0.8 <sup>c</sup>	< 0.001, $\log$

**Table 11.** Umweltbedingungen und Vegetationseigenschaften, die sich zwischen den neun Trockenrasen-Assoziationen Zentral-Podoliens signifikant unterscheiden (Assoziationsnummern, siehe Kapitel 4.1). Mittelwerte und Standardabweichungen sind dargestellt. Unterschiedliche Buchstaben kennzeichnen signifikante Unterschiede zwischen Assoziationen bei  $p < 0.05$  nach Tukey-Tests. IV = Indikatorwert,  $\log_{10}$  =  $p$ -Wert-Berechnung auf Basis von  $\log(x + 1)$ -transformierten Daten.



### 5.3 Biodiversity patterns

The plot-scale total richness at 10 m<sup>2</sup> varied only slightly between syntaxa. Stands of the *Koelerio-Corynephoretea* were on average 5 species (12%) more diverse than those of the *Festuco-Brometea* (Table 5). Also the variability among the nine associations was low, with a range from 34.9 species (in association 2.1.2, *Brachypodietalia pinnati*) to 47.2 species (*Sedo-Scleranthetalia*). Regarding vascular plant species richness, the two classes were not statistically different, while the *Koelerio-Corynephoretea* had more than twice as many bryophytes per plot and lichens were nearly absent from *Festuco-Brometea* stands (Table 10). For both cryptogam groups, the *Sedo-Scleranthetalia* were the richest order, followed by the *Alysso-Sedetalia* and then the associations of the three other orders on more or less similarly low levels.

The analysis of the scale-dependent biodiversity (available for three orders; Table 12) shows that the stands of the two *Festuco-Brometea* orders are nearly indistinguishable with respect to their richness across all scales. It is only at the two largest grain sizes (10 m<sup>2</sup> and 100 m<sup>2</sup>) that the *Festucetalia valesiaca* are slightly richer in vascular plants and slightly poorer in non-vascular plants than the *Brachypodietalia pinnati*. The sole analysed *Sedo-Scleranthetalia* stand, by contrast, deviates clearly from the *Festuco-Brometea* biodiversity plots in being species poorer at the two smallest scales (e.g. 1 species vs. 3 species on 1 cm<sup>2</sup>), but richer at the two largest scales (e.g. 108 vs. 72 species on 100 m<sup>2</sup>). The steeper species-area relationship of the *Sedo-Scleranthetalia* plot is mainly driven by bryophytes and lichens, with the vascular plants at 1 m<sup>2</sup> still being less diverse than in the *Festuco-Brometea* stands. However, on 100 m<sup>2</sup> the *Sedo-Scleranthetalia* had also 23% more vascular plants.

### 5.4 Conservation values

The associations with the highest number of red-listed species are 2.2.2 and 2.2.3 (Table 13). The most frequent red-listed species were *Stipa capillata*, *Carex humilis*, *Vinca herbacea* and *Adonis vernalis*. Most rare red-listed species were *Anchusa ochroleuca*, *Chamaecytisus albus*, *Gentiana cruciata* subsp. *cruciata*, *Pulsatilla vulgaris* subsp. *grandis* and *Stipa joannis* subsp. *joannis*. Some rare species are diagnostic for associations, including highly diagnostic species – *Allium podolicum* for association 1.2.1, *Carex humilis* and *Vinca herbacea* for association 2.2.3.

## 6. General discussion

### 6.1 Syntaxonomy

The syntaxonomic treatment of the nine distinguishable units at association level was challenging. In Ukraine, a large number of associations has been described in recent years, often based on small numbers of relevés (typically only 3–15 from a narrow region) and without ascertaining diagnostic species numerically. Comprehensive synoptic tables are still rather unusual in Ukrainian phytosociology (but see KUZEMKO 2009) as are numerical methods to seek the most appropriate classification (but see KUZEMKO 2011b). Generally, our assessment largely benefited from the different perspectives of phytosociologists from inside and outside Ukraine, and in most cases we could more or less achieve a consensus on the treatment (the few remaining controversial cases are indicated above).

**Table 12.** Scale-dependent richness values (means  $\pm$  standard deviations) for the three phytosociological orders in which we sampled nested “biodiversity plots”. The  $p$ -values from ANOVAs are given, and in case of significant differences homogeneous groups according to Tukey’s post-hoc test are indicated with superscript letters. The number of replicates ( $n$ ) apply to all plot sizes except for 100 m<sup>2</sup> where the number is half of these.

**Tabelle 12.** Artenzahlen in Abhängigkeit von der Flächengröße (Mittelwert  $\pm$  Standardabweichung) der 21 Biodiversitätsplots, zusammengefasst für die Felsgrusfluren (KC2), basiphilen Halbtrockenrasen (FB1) und kontinentalen Trockenrasen (FB2). Unterschiedliche Kleinbuchstaben bezeichnen signifikante Unterschiede gemäß Tukey’s post-hoc test. In der letzten Spalte sind die  $p$ -Werte aus den Varianzanalysen (ANOVAs) angegeben. Jeder 100 m<sup>2</sup> großen Biodiversitätsplot ( $n = 21$ ) enthält zwei geschachtelte Serien kleinerer Flächengrößen ( $n = 42$ ).

Plot size $n$	Min	Max	KC2 2 (1)	FB1 10 (5)	FB2 30 (15)	$p$
<b>Species richness all taxa</b>						
0.0001 m <sup>2</sup>	0	7	1.0 $\pm$ 0.0	2.8 $\pm$ 1.9	3.1 $\pm$ 1.5	0.222
0.001 m <sup>2</sup>	2	11	2.0 $\pm$ 0.0	4.6 $\pm$ 1.8	4.9 $\pm$ 2.0	0.132
0.01 m <sup>2</sup>	3	14	8.0 $\pm$ 4.2	8.5 $\pm$ 2.4	8.5 $\pm$ 2.8	0.965
0.1 m <sup>2</sup>	6	26	16.5 $\pm$ 0.7	17 $\pm$ 4.7	15.5 $\pm$ 4.6	0.662
1 m <sup>2</sup>	13	48	31.0 $\pm$ 2.8	27.5 $\pm$ 8.1	26.8 $\pm$ 6.5	0.695
10 m <sup>2</sup>	27	62	52.5 $\pm$ 6.4	42.2 $\pm$ 7.6	43.6 $\pm$ 9.1	0.321
100 m <sup>2</sup>	47	108	108	71 $\pm$ 8.2 <sup>(b)</sup>	72.1 $\pm$ 13.7 <sup>(a)</sup>	<b>0.040</b>
<b>Species richness vascular plants</b>						
0.0001 m <sup>2</sup>	0	7	0.0 $\pm$ 0.0 <sup>b</sup>	2.5 $\pm$ 1.8 <sup>a</sup>	2.6 $\pm$ 1.3 <sup>a</sup>	<b>0.052</b>
0.001 m <sup>2</sup>	0	11	0.5 $\pm$ 0.7 <sup>b</sup>	4.0 $\pm$ 1.8 <sup>a</sup>	4.3 $\pm$ 1.8 <sup>a</sup>	<b>0.023</b>
0.01 m <sup>2</sup>	3	13	4.5 $\pm$ 2.1	7.7 $\pm$ 2.5	7.3 $\pm$ 2.4	0.240
0.1 m <sup>2</sup>	6	21	10.5 $\pm$ 0.7	14.3 $\pm$ 3.6	13.9 $\pm$ 4.2	0.468
1 m <sup>2</sup>	13	42	22.5 $\pm$ 3.5	24.4 $\pm$ 7	24.5 $\pm$ 6.3	0.910
10 m <sup>2</sup>	26	56	37.0 $\pm$ 7.1	37 $\pm$ 5.6	40.3 $\pm$ 8.8	0.508
100 m <sup>2</sup>	42	86	80	63.4 $\pm$ 9.6	67 $\pm$ 12.7	0.465
<b>Species richness bryophytes</b>						
0.0001 m <sup>2</sup>	0	3	1.0 $\pm$ 0.0	0.3 $\pm$ 0.5	0.4 $\pm$ 0.7	0.409
0.001 m <sup>2</sup>	0	3	1.5 $\pm$ 0.7	0.6 $\pm$ 0.5	0.6 $\pm$ 0.8	0.236
0.01 m <sup>2</sup>	0	5	3.5 $\pm$ 2.1 <sup>a</sup>	0.8 $\pm$ 0.4 <sup>b</sup>	1.2 $\pm$ 1.1 <sup>b</sup>	<b>0.006</b>
0.1 m <sup>2</sup>	0	6	5.5 $\pm$ 0.7 <sup>a</sup>	2.7 $\pm$ 1.9 <sup>b</sup>	1.5 $\pm$ 1.3 <sup>b</sup>	<b>&lt; 0.001</b>
1 m <sup>2</sup>	0	8	7.5 $\pm$ 0.7 <sup>a</sup>	3.1 $\pm$ 2 <sup>b</sup>	2.0 $\pm$ 1.6 <sup>b</sup>	<b>&lt; 0.001</b>
10 m <sup>2</sup>	0	14	11 $\pm$ 4.2 <sup>a</sup>	5.2 $\pm$ 3.7 <sup>b</sup>	3.0 $\pm$ 1.9 <sup>b</sup>	<b>&lt; 0.001</b>
100 m <sup>2</sup>	1	17	17	7.6 $\pm$ 5.7 <sup>(a)</sup>	4.5 $\pm$ 2.4 <sup>(b)</sup>	<b>0.005</b>
<b>Species richness lichens</b>						
0.0001 m <sup>2</sup>	0	0	0	0	0	-
0.001 m <sup>2</sup>	0	0	0	0	0	-
0.01 m <sup>2</sup>	0	1	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.03 $\pm$ 0.2	0.826
0.1 m <sup>2</sup>	0	1	0.5 $\pm$ 0.7 <sup>a</sup>	0.0 $\pm$ 0.0 <sup>b</sup>	0.1 $\pm$ 0.3 <sup>b</sup>	<b>0.042</b>
1 m <sup>2</sup>	0	2	1.0 $\pm$ 1.4 <sup>a</sup>	0.0 $\pm$ 0.0 <sup>b</sup>	0.2 $\pm$ 0.5 <sup>b</sup>	<b>0.027</b>
10 m <sup>2</sup>	0	8	4.5 $\pm$ 4.9 <sup>a</sup>	0.0 $\pm$ 0.0 <sup>b</sup>	0.2 $\pm$ 0.6 <sup>b</sup>	<b>&lt; 0.001</b>
100 m <sup>2</sup>	0	11	11	0.0 $\pm$ 0.0 <sup>(b)</sup>	0.5 $\pm$ 0.8 <sup>(a)</sup>	<b>&lt; 0.001</b>

**Table 13.** Distribution of rare and endangered vascular plant taxa in nine dry grassland associations in Central Podolia (for association codes, see Section 4.1). Status of red-listed species: RBU – Red Data Book of Ukraine (DIDUKH et al. 2009), RLVP – Red Data Book of the Vinnytsia province (ANDRIENKO & PEREGRYM 2012); category: u = presumably threatened, v = vulnerable. For each taxon, percentage constancies for all relevés (= Total) and per association are given.

**Tabelle 13.** Verteilung seltener und gefährdeter Gefäßpflanzen auf die neun unterschiedenen Trockenrasen-Gesellschaften in Zentral-Podolien. (Zahlencode der Gesellschaften vgl. Kapitel 4.1). Rote Liste Status: RBU – Rote Liste der Ukraine (DIDUKH et al. 2009), RLVP – Rote Liste der Region Winnyzja (ANDRIENKO & PEREGRYM 2012); Kategorie: u = Gefährdung anzunehmen, v = gefährdet. Für jede Art wird die Stetigkeit (in %) innerhalb der Gesellschaft und bezogen auf alle Vegetationsaufnahmen (= Total, %) angegeben.

Taxon	Status	Total	1.1.1	1.2.1	1.3.1	2.1.1	2.1.2	2.1.3	2.2.1	2.2.2	2.2.3
<i>Adonis vernalis</i>	RBU/u	23.5	–	–	–	27	–	5	7	21	55
<i>Allium podolicum</i>	RLVP	3.5	–	50	–	9	13	–	–	–	–
<i>Anchusa ochroleuca</i>	RLVP	0.4	–	–	–	–	–	–	2	–	–
<i>Anemone sylvestris</i>	RLVP	6.6	–	–	–	18	–	21	2	–	12
<i>Aster amellus</i>	RLVP	18.6	–	–	–	27	7	16	3	–	49
<i>Carex humilis</i>	RLVP	23.9	–	–	–	–	–	5	7	16	64
<i>Chamaecytisus albus</i>	RBU/v	0.4	–	–	–	–	–	–	2	–	–
<i>Chamaecytisus podolicus</i>	RBU/v	1.8	–	–	–	–	7	–	5	–	–
<i>Clematis integrifolia</i>	RLVP	1.3	–	–	–	–	–	–	–	3	3
<i>Gentiana cruciata</i> subsp. <i>cruciata</i>	RLVP	0.4	–	–	–	–	–	5	–	–	–
<i>Iris aphylla</i>	RLVP	2.7	–	20	–	–	7	–	–	–	5
<i>Iris pumila</i> subsp. <i>pumila</i>	RLVP	1.3	–	–	–	–	–	–	2	–	3
<i>Linum tenuifolium</i>	RLVP	16.8	20	–	–	–	–	–	7	29	33
<i>Muscari tenuiflorum</i>	RLVP	11.5	–	20	–	–	7	–	14	3	21
<i>Phlomis tuberosa</i>	RLVP	3.5	–	10	–	27	13	–	–	3	2
<i>Polygala sibirica</i>	RLVP	22.6	40	–	–	–	–	11	14	53	28
<i>Potentilla alba</i>	RLVP	0.9	–	–	–	–	–	–	2	3	–
<i>Prunus fruticosa</i>	RLVP	3.1	–	10	–	36	–	–	3	–	–
<i>Prunus tenella</i>	RLVP	0.9	–	–	–	–	–	–	–	–	3
<i>Pulsatilla pratensis</i>	RBU/u	8.8	–	10	–	–	20	16	–	–	19
<i>Pulsatilla vulgaris</i> subsp. <i>grandis</i>	RBU/v	0.4	–	–	–	–	–	–	–	–	2
<i>Salvia aethiopsis</i>	RLVP	0.9	–	–	–	–	–	5	–	3	–
<i>Stipa capillata</i>	RBU/u	38.5	20	–	–	9	–	11	34	68	55
<i>Stipa joannis</i> subsp. <i>joannis</i>	RBU/v	0.4	–	–	–	–	7	–	–	–	–
<i>Stipa pulcherrima</i>	RBU/v	4.0	20	–	–	–	–	–	3	13	2
<i>Vinca herbacea</i>	RLVP	23.9	–	–	–	9	–	–	12	18	58
<i>Viola rupestris</i> subsp. <i>rupestris</i>	RLVP	2.2	–	–	–	–	–	5	3	–	3
<i>Xeranthemum annuum</i>	RLVP	5.8	–	–	–	–	–	5	7	21	–
Mean number of red-listed taxa on 10 m <sup>2</sup>			1.0	1.2	0.0	1.6	0.8	1.1	1.3	2.5	4.2

Taking into account our spatially restricted dataset, we decided to adopt formal association names only in two cases of wide-spread *Festucetalia valesiaca* communities, one of which was described as new for science. At the higher syntaxonomic levels, our data together with our literature review support the occurrence of six (or seven, if association 2.1.1 is considered as belonging to the *Cirsio-Brachypodion*) alliances from five different orders.

Most notably from the Ukrainian perspective and relevant for the unification of classification schemes at continental level, our data did not support the traditional Ukrainian-Russian concept of a mesoxeric order *Galietales veri* within the *Molinio-Arrhenatheretea*. Instead, the stands could be well placed within the mesoxeric orders of the *Koelerio-Corynephoretea* and *Festuco-Brometea*, i.e. *Trifolium arvensis-Festucetalia ovinae* and *Brachypodietalia pinnati*. This finding coincides with unpublished results of a TWINSpan analysis of an extensive dataset of all grassland types of the Forest-Steppe zone of Ukraine by the first author (see KUZEMKO 2011b). She found that the main division was between dry grasslands (*Festuco-Brometea* and *Koelerio-Corynephoretea*) on the one hand and other grasslands (*Molinio-Arrhenatheretea* and *Phragmito-Magno-Caricetea*) on the other. The two main alliances normally placed in the *Galietales veri* by Ukrainian and Russian authors (MIRKIN & NAUMOVA 1986, ERMAKOV 2012), *Agrostion vinealis* and “*Trifolium montani*”, in her TWINSpan analysis were neatly placed within the two subclusters of the dry grasslands, exactly corresponding to the *Koelerio-Corynephoretea* and *Festuco-Brometea* (KUZEMKO 2011b). It appears that the *Galietales veri* are not needed any longer, but their content can be distributed between the two dry grassland classes and to a lesser extent between *Molinio-Arrhenatheretea* and *Trifolium-Geranietea*. However, our analyses also confirmed that the prevailing Ukrainian types of mesoxeric grasslands are sufficiently different from their counterparts in eastern Central Europe to justify the establishment of vicariant alliances. These are namely the *Agrostion vinealis* corresponding to the *Armerion elongatae*, and the *Agrostion vinealis-Avenulion schellianae* (*Trifolium montani* auct.) corresponding to the *Cirsio-Brachypodion*. Regarding the xeric *Festuco-Brometea* units, we could clearly distinguish two alliances, *Festucion valesiaca* and *Stipion lessingiana*, the latter being new to Ukraine compared to the overview of SOLOMAKHA (1996).

Finally, several other questions remain open and need to be addressed by a supra-national synthesis because our dataset was too limited in number and geographic extent: (a) Do some of our *Festucetalia valesiaca* relevés (from assoc. 2.2.2) rather belong to the *Stipo pulcherrimae-Festucetalia pallentis*? (b) Do some of our *Brachypodietalia pinnati* relevés (from assoc. 2.1.1) rather belong to the *Cirsio-Brachypodion*? (c) Do the basiphilous and acidophilous outcrop communities belong to the same alliances as those in Central Europe or does Ukraine have vicariant alliances?

## 6.2 Biodiversity

Compared to dry grasslands and steppes in other Palaearctic regions, the mean total richness values of 40.6 species on 10 m<sup>2</sup> in *Festuco-Brometea* communities are relatively low. For example, averages were lower in NE Germany (32.1; DENGLER 2004b) and Bulgaria (40.3; PEDASHENKO et al. 2013), but higher in Öland (48.2 on 9 m<sup>2</sup>; S. Löbel unpubl., see LÖBEL & DENGLER 2008), central Siberia (49.2; JANIŠOVÁ et al. 2013), Estonia (53.2 on 9 m<sup>2</sup>; S. Boch unpubl., see DENGLER & BOCH 2008) and Transylvania (60.5; DENGLER et al. 2012a). By contrast, the recorded mean richness of 46.4 species on 10 m<sup>2</sup> of *Koelerio-Corynephoretea* are higher than in most other European regions, such as NE Germany (20.8; DENGLER 2004b), Bulgaria (35.8; PEDASHENKO et al. 2013), Estonia (41.5 on 9 m<sup>2</sup>; S. Boch

unpubl., see DENGLER & BOCH 2008); only Öland had higher values (58.5 on 9 m<sup>2</sup>; S. Löbel unpubl., see LÖBEL & DENGLER 2008). The relatively low species densities in the Ukrainian *Festuco-Brometea* communities are counterintuitive because one should expect a higher regional species pool in a region where natural steppes were widespread until a few decades ago and this pool should cause also higher plot-scale richness. Likewise, also the unusually high diversity of the regionally rare *Koelerio-Corynephoretea* communities is unexpected.

Generally, the ranking of the different dry grassland types according to their richness in Central Podolia was quite unusual in comparison to other regions. Normally, *Brachypodietalia pinnati* plots are clearly richer than *Festucetalia valesicae* plots (e.g. DENGLER 2004b, BECKER & BRÄNDEL 2007, DENGLER et al. 2012a), while there was no appreciable difference in our case (see Table 4 in the supplement). This might partly be attributed to a species pool effect: in Central Podolia the stands of the xeric order were clearly more frequent than those of the mesoxeric order (164 vs. 45 relevés, with the sampling approximately proportional to frequency), while in Central Europe it is the other way round (e.g. DENGLER 2004b: 75 vs. 198 plots). Further, the more extreme summer droughts might exclude several mesophilic species that augment the species composition in *Brachypodietalia pinnati* stands in more oceanic regions of Europe. Also the usually higher richness in stands of the subclass *Sedo-Scleranthenea* (outcrop communities) vs. those of the subclass *Koelerio-Corynephorenea* (communities on deep sands) (e.g. DENGLER & BOCH 2008, LÖBEL & DENGLER 2008) did not occur in the study region, but this comparison might be biased by the fact that we had only two somewhat transitional relevés of the latter unit.

### 6.3 Ecology

According to our DCA, the main floristic gradient was strongly related to soil reaction. Because the pH range was short in our study (2.9 pH units, but 89% of plots within one pH unit), we had not expect this result. Typically, ordination analyses of dry grassland vegetation find soil reaction to define the main floristic gradient when the pH ranges are large (e.g. PEDASHENKO et al. 2013). For pH ranges similar to our case, other variables are usually more important for community composition, often those related to water supply (BECKER et al. 2011, 2012, DENGLER et al. 2012a). The fact that soil reaction in the study region was the strongest driver of community differentiation, despite the relatively small pH differences, could have two main explanations, both of which are at least partly true in our case. (1) Other ecological drivers, such as soil texture, land use and climate were even more homogenous among the plots. (2) The first axis of the DCA is not just a pH gradient, but evidently soil moisture and pH coincide, i.e. the mesoxeric sites are slightly but systematically less base-rich.

### 6.4 Conservation

Remarkably, the two most frequent dry grassland communities, associations 2.2.2 and 2.2.3, had the highest concentration of red-listed species. This particularly refers to stands in the Dniester basin. However, most sites of the associations with highest participation of red-listed species are outside existing protected areas, specifically in Kryzhopol and Pischanka districts. This demonstrates the need to optimize the network of protected areas in the territory of Central Podolia. Moreover, our finding might indicate that a sole focus on red-listed

vascular plants might ignore the value of the much rarer and supposedly regionally more threatened communities of the *Koelerio-Corynephoretea* as habitat for highly specialised organisms such as the many bryophyte and lichen species we only found there.

## 6.5 Conclusion and outlook

Our results are in many respects unexpected. Syntaxonomically, while we distinguished nine regionally well-defined communities at association rank, their placement into alliances and sometimes orders was not always clear due to “unusual” species combinations from a Central, Western and Northern European perspective. Diversity-wise, the recorded patterns were unusual and challenging for current explanations of diversity patterns in Palaeartic grassland communities. In many cases, we do not have good ideas how to explain this unusual behaviour. Rather, we feel that this riddle can only be solved when more such standardised biodiversity data together with comprehensive environmental data are sampled in grasslands from so far understudied regions. The EDGG Expeditions have proven to be a useful format to fill such knowledge gaps and thus have been and will be continued in the future (see VRAHNAKIS et al. 2013). With making the data of this and other EDGG expeditions available in public vegetation-plot databases, particularly the emerging European Vegetation Archive (EVA; <http://euroveg.org/eva-database>), other researchers are invited to use them for the development of large-scale consistent classification schemes and better understanding of small-scale species richness pattern.

## Erweiterte deutsche Zusammenfassung

**Einleitung** – Halbnatürliche Grasländer gehören auf der Skalenebene unter 100 m<sup>2</sup> weltweit zu den artenreichsten bekannten Vegetationstypen (WILSON et al. 2012). Hierzu gehören insbesondere einige europäische Halbtrockenrasen, die alle eine enge Beziehung zur extensiven landwirtschaftlichen Nutzung aufweisen und damit anthropogenen Ursprungs sind. Es gibt dagegen wenig vergleichbare Daten zu den halbnatürlichen und natürlichen Graslandgesellschaften der europäischen Steppenregionen, etwa in der Ukraine. Die ukrainische Vegetationskunde stand lange in der Tradition der russischen Schule mit ihrem dominanzbasiertem Klassifikationssystem (ALEXANDROVA 1973). Seit etwa zwei Jahrzehnten werden aber zunehmend pflanzensoziologische Klassifikationen veröffentlicht. Ein transnationaler Datenvergleich mit Vegetationsaufnahmen aus anderen europäischen Ländern war bisher schwierig und soll daher mit dieser Studie unterstützt werden, um eine einheitliche Klassifikation der europäischen Trockenrasen zu ermöglichen. Die *European Dry Grassland Group* (EDDG) hat sich zum Ziel gesetzt, nach einer standardisierten Erfassungsmethode (DENGLER 2009) in bisher wenig untersuchten Gebieten Europas vergleichbares Datenmaterial zur Trockenrasenvegetation zu erheben und in eine konsistente supranationale Klassifikation einzubringen. Ziele der zweiten Forschungsexpedition der EDGG im Jahre 2010 nach Zentral-Podolien waren daher (1) die Abgrenzung der im Untersuchungsgebiet vorkommenden Trockenrasentypen und Ermittlung ihrer Kennarten mit statistischen Methoden; (2) die Einordnung dieser Einheiten in das europäische syntaxonomische System; (3) ein Grundverständnis der ökologischen Faktoren, welche zur Differenzierung dieser Einheiten führen; und (4) die Dokumentation der Diversitätsmuster von Gefäßpflanzen, Moosen und Flechten auf verschiedenen räumlichen Skalenebenen.

**Untersuchungsgebiet** – Unser Untersuchungsgebiet umfasst Zentral-Podolien, also das Hügelland zwischen den Stromtälern des Dnjestr und des südlichen Bug an der Grenze zu Moldawien (48,95°–48,10° N and 27,55°–29,35° O, Abb. 1). Das Klima ist subkontinental mit Jahresmitteltemperaturen von 7 bis 9 °C, einem Januarmittel von -4 bis -6 °C und Julimittel von +18 bis +20 °C sowie einem mittleren Jahresniederschlag zwischen 600 und 650 mm (LIPINSKY et al. 2003). Geologisch ist das Gebiet in den aus silikatischen Gesteinen aufgebauten ukrainischen Schild und das südliche Bug-

Becken geteilt. Letzteres ist in weiten Teilen mit Löss bedeckt, die nur stellenweise vom darunterliegenden Kalk- oder Sandstein durchbrochen werden. Entsprechend vielfältig sind die Böden. Es gibt sowohl basenarme Podsole wie auch fruchtbare Schwarzerden über basenreichen Löss. Die potentiell natürliche Vegetation Zentral-Podoliens stellen Hainbuchen-Eichenwälder und Eichenwälder sowie Halbtrocken- und Trockenrasen dar, die in Süd-Podolien von Eichenwäldern und Gras-Steppen abgelöst werden (BARBARYCH 1977).

**Methoden** –Die Erfassung der Daten zur Diversität von Pflanzenbeständen folgt einem standardisierten Design (DENGLER 2009). In der Ukraine wurden 21 „Biodiversitätsplots“ mit zwei Serien geschachtelter Flächen zwischen 0.0001 und 100 m<sup>2</sup> (*nested plots*) sowie weitere 184 normale Vegetationsaufnahmen mit einer Flächengröße von 10 m<sup>2</sup> aufgenommen, die das Spektrum der Trockenrasenvegetation im Untersuchungsgebiet widerspiegeln. Für alle Flächengrößen wurde die Präsenz der terrestrischen Gefäßpflanzen, Moose und Flechten erhoben. Für alle 10 m<sup>2</sup>-Flächen (226) wurden zudem die Vegetationsbedeckung geschätzt sowie Vegetationshöhe, Topographie, Bodenparameter und Landnutzung erfasst. Diese Vegetationsaufnahmen bildeten Grundlage der pflanzensoziologischen Klassifikation mittels TWINSpan und Ermittlung diagnostischer Arten basierend auf phi-Werten (CHYTRÝ et al. 2002). Zusätzlich wurde eine Ordination und indirekte Gradientenanalyse mittels DCA durchgeführt. Unterschiede der Vegetationseinheiten hinsichtlich abiotischen Standortfaktoren und Artenreichtum wurden durch Varianzanalysen (ANOVAs) statistisch geprüft.

**Vegetation** – Die Kombination von TWINSpan und Ermittlung diagnostischer Arten resultierte in neun Einheiten auf Assoziationsebene. Diese wurden dann höheren syntaxonomischen Einheiten im System der europäischen Trockenrasen zugeordnet (siehe syntaxonomische Übersicht in Kapitel 4.1). Eine der gefundenen Einheiten konnte einer zuvor beschriebenen Assoziation zugeordnet werden (*Teucrio pannonic-Stipetum capillatae* Didukh & Korotchenko 2000), eine weitere beschreiben wir neu (*Allio taurici-Dichanthietum ischaemi* ass. nova), während die restlichen aufgrund der unübersichtlichen syntaxonomischen Lage in der Ukraine vorläufig als ranglose Gesellschaften geführt und ihre Beziehungen zu in der Literatur beschriebenen Assoziationen diskutiert werden. Im Untersuchungsgebiet herrschen basiphile Trockenrasen der Klasse *Festuco-Brometea* vor, während Felsgrusfluren und Sandtrockenrasen der Klasse *Koelerio-Coryneporetea* auf wenige Sonderstandorte beschränkt sind. Unter den *Festuco-Brometea* wiederum sind die xerothermen kontinentalen Trockenrasen der Ordnung *Festucetalia valesiacae* häufiger und durch die Verbände *Festucion valesiacae* (2 Assoziationen) und *Stipion lessingianae* (1 Assoziation) vertreten. Die basiphilen Halbtrockenrasen der Ordnung *Brachypodietalia pinnati* sind mit dem Verband *Agrostio vinealis-Avenulion schellianae* und drei Gesellschaften vertreten. Die *Koelerio-Coryneporetea* kommen mit drei Gesellschaften aus verschiedenen Ordnungen zugeordnet werden können (Verbandszuordnung vorläufig): (1) Basiphile Felsgrusfluren (*Alyso alyssoidis-Sedetalia: Alyso alyssoidis-Sedion*), (2) azidophile Felsgrusfluren (*Sedo-Scleranthetalia: Veronico dillenii-Sedion albi*) und (3) mesophile Schafschwingel-Silikatmagerrasen (*Trifolio arvensis-Festucetalia ovinae: Agrostion vinealis*). Wir diskutieren die syntaxonomische Stellung der Ordnung *Galietalia veri*, die von ukrainischen Autoren normalerweise als mesophiles Grünland in die Klasse *Molinio-Arrhenatheretea* gestellt wird und schlussfolgern, dass die Gesellschaften bei einem supranationalen Vergleich eher zu den mesoxerischen Ordnungen der *Koelerio-Coryneporetea* und *Festuco-Brometea* gestellt werden sollten. Weitere syntaxonomische Fragen der Zuordnung ukrainischer Pflanzengesellschaften konnten aufgrund der noch geringen Aufnahmezahlen und des beschränkten Untersuchungsgebietes noch nicht geklärt werden und bedürfen weiterer Daten und einer supranationalen Auswertung.

**Ökologie, Biodiversität und Naturschutz** – Die standörtliche Differenzierung zwischen den Beständen der beiden Klassen *Festuco-Brometea* und *Koelerio-Coryneporetea* wird in Abbildung 2, Tabelle 10 und 11 zusammengefasst. Dabei fällt ein durchgehend hoher pH-Wert von  $\geq 6$  auch in den *Sedo-Scleranthetalia*- und *Trifolio-Festucetalia*-Gesellschaften auf silikatischen Böden auf. Die Auswertung der Biodiversitätsmuster der podolischen Trockenrasen ergab für Flächengrößen von 10 m<sup>2</sup> für die *Koelerio-Coryneporetea*-Gesellschaften im Mittel einen Artenreichtum von 46,4 Arten gegenüber

40,6 Arten in den *Festuco-Brometea*-Beständen. Unterschiede in der Artenzusammensetzung zeigen sich in der doppelt so hohen Anzahl von Moosen und sogar einem neunfach höherem Anteil an Flechten in den *Koelerio-Coryneporetea*-Gesellschaften, während die Unterschiede im Artenreichtum der Gefäßpflanzen nicht signifikant sind. Dies unterstreicht die Bedeutung der Flechten und Moose für die Artenvielfalt in Trockenrasengesellschaften. Die Ordnungen innerhalb der Klassen zeigten dagegen praktisch keine signifikanten Unterschiede im Artenreichtum. Bemerkenswert ist dennoch, dass die Gesellschaften der kontinentalen Trockenrasen (*Festucetalia valesiacae*) einen geringfügig höheren Artenreichtum aufweisen als die basiphilen Halbtrockenrasen (*Brachypodietalia pinnati*). Dies war in anderen Untersuchungen aus Mittel- und Osteuropa eher umgekehrt (BECKER et al. 2011). Auch wenn im Vergleich zu einer Trockenrasenstudie aus Rumänien (DENGLER et al. 2012) keine weltweiten Spitzenwerte im Artenreichtum der Trockenrasen in Podolien gefunden wurden, so ist doch der in allen Gesellschaften überdurchschnittlich hohe Artenreichtum von im Mittel 41 Arten auf 10 m<sup>2</sup> (Tab. 9) hervorzuheben, darunter zahlreiche seltene und gefährdete Arten (Tab. 13), die diese Vegetationstypen auch für den Arten- und Biotopschutz bedeutsam erscheinen lassen.

**Schlussfolgerungen und Ausblick** – Die Trockenrasengesellschaften Podoliens sind überdurchschnittlich artenreich und vielfältig, die Klärung ihrer syntaxonomische Stellung im gesamteuropäischen Kontext steht aber erst in den Anfängen und die Abgrenzung vieler Assoziationen ist noch unklar. Diese Wissenslücken sollten künftig durch eine verbesserte Datengrundlage und eine supranationale Auswertung der Daten geschlossen werden.

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## Supplements and Appendices

**This article comprises five loose oversize supplements.**

**Zu diesem Artikel gehören fünf Loseblattbeilagen in Übergröße.**

**Supplement 1.** Table 4. Abridged synoptic table of the dry grassland communities in Central Podolia (Ukraine).

**Beilage 1.** Tabelle 4. Gekürzte synoptische Tabelle der Trockenrasen-Gesellschaften von Zentral-Podolien (Ukraine).



**Supplement 2.** Table 5. Relevé table of the *Koelerio-Corynephoretea* communities (associations 1.1.1–1.3.1) in Central Podolia (Ukraine).

**Beilage 2.** Tabelle 5. Vegetationsaufnahmen der *Koelerio-Corynephoretea*-Gesellschaften (Assoziationen 1.1.1–1.3.1) in Zentral-Podolien (Ukraine).

**Supplement 3.** Table 6. Relevé table of the *Brachypodietalia pinnati* communities (associations 2.1.1–2.1.3) in Central Podolia (Ukraine).

**Beilage 3.** Tabelle 6. Vegetationsaufnahmen der *Brachypodietalia pinnati*-Gesellschaften (Assoziationen 2.1.1–2.1.3) in Zentral-Podolien (Ukraine).

**Supplement 4.** Table 7. Relevé table of the *Festucetalia valesiacae* communities, part A (associations 2.2.1–2.2.2) in Central Podolia (Ukraine).

**Beilage 4.** Tabelle 7. Vegetationsaufnahmen der *Festucetalia valesiacae*-Gesellschaften, Teil A (Assoziationen 2.2.1–2.2.2) in Zentral-Podolien (Ukraine).

**Supplement 5.** Table 8. Relevé table of the *Festucetalia valesiacae* communities, part B (association 2.2.3) in Central Podolia (Ukraine).

**Beilage 5.** Tabelle 8. Vegetationsaufnahmen der *Festucetalia valesiacae*-Gesellschaften, Teil B (Assoziation 2.2.3) in Zentral-Podolien (Ukraine).

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

**Zusätzliche unterstützende Information ist in der Online-Version dieses Artikels zu finden.**

**Appendix S1.** Geographic origin of the relevés.

**Anhang S1.** Herkunftsnachweis der Aufnahmen.

**Appendix S2.** Nomenclatural assessment and revision of the syntaxa mentioned in Section 4.

**Anhang S2.** Nomenklatorische Bewertung und Revision der in Kapitel 4 erwähnten Syntaxa.

**Appendix S3.** Photo collection of the dry grassland types in Central Podolia.

**Anhang S3.** Fotoauswahl der Trockenrasentypen Zentral-Podoliens.

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