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Report of new maxima of fine-scale vascular plant species richness recorded in East-Central European semi-dry grasslands

Kurzbericht über neue Maximalwerte der Artenvielfalt von Gefäßpflanzen auf Kleinflächen in ostmitteleuropäischen Halbtrockenrasen

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Abstract

We report new maximum values of vascular plant species richness ever recorded at 10 m^2 and 16 m^2-plots. Both come from sites where world record species numbers were reported before but from different plot size or with indication of different management regime. Our results support the view that extreme species richness is a temporally stable feature of managed East-Central European semi-dry grasslands. We observed that low to medium-intensity grazing may support species-rich vegetation similarly to mowing, at least in short-term.

Keywords: extreme species richness, permanent plots, plant diversity, Romania, steppe meadows, Ukraine

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

Species-rich ecosystems always attracted the attention of ecologists and conservation biologists. Apart from conservation interests, they are important for ecological theory, as their study may help to understand the mechanisms of species coexistence and diversity maintenance (LEVINE & HILLERISLAMBERS 2012, WILSON et al. 2012). They may also challenge some basic theoretical concepts such as the limiting similarity hypothesis (MCARTHUR & LEVINS 1967, GRIME 2006, KRAFT et al. 2015) or the species pool concept (PÄRTEL et al. 1996, ZOBEL 1997, AARSSEN & SCHAMP 2002). Generally, it is unclear what determines the upper limits of fine-scale species richness under certain species pool size. The term „species-rich community“ has been used rather vaguely in the literature, referring to globally extremely rich communities, but also to communities richest in a particular region or just containing more species than prevailing communities. A ground-breaking synthesis of

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WILSON et al. (2012) revealed that global maxima of vascular plant species richness from vegetation plots smaller than 100 m^2 come all from temperate grasslands. Few new maxima were published later (e.g. ROLEČEK et al. 2014, CHYTRÝ et al. 2015) and all of them confirmed the exclusive position of this habitat. Particularly, East-Central European semi-dry grasslands of the *Cirsio-Brachypodion pinnati* alliance proved to be the richest known communities world-wide on the grain sizes between 9 and 49 m^2.

In the recent years we have been conducting a multidisciplinary research of semi-dry grasslands and open-canopy forests in south-eastern Czech Republic, particularly in the forest-steppe part of the White Carpathians Mts. Our goal is to explain their specific species composition and extreme species richness (ROLEČEK 2007, 2017, HÁJKOVÁ et al. 2011, 2018, HÁJEK et al. 2016). This study has brought us to other forest-steppe regions of East-Central Europe, where similar plant communities occur: western Ukraine and Romanian Transylvania (ROLEČEK et al. 2014, 2019). It turned out that semi-dry grasslands in these regions and White Carpathians share not only similar species composition, but also extreme species richness (DENGLER et al. 2012, ROLEČEK et al. 2014, WILLNER et al. 2019). To understand this phenomenon better, since 2014 we have been visiting these grasslands and establishing permanent plots in extremely species-rich patches. Here we report two new maxima of fine-scale vascular plant species richness recorded in 2018 on frequently used plot sizes and discuss differences and temporal dynamics in their species composition.

2. Methods

We revisited two sites with known maxima of vascular plant species richness per 9 m^2 (Dziurkach site near Spas'ka village, Chernivtsi region, Ukraine; ROLEČEK et al. 2014) and 10 m^2 (Valea Lui Craiu site, Fânaţele Clujului, Cluj region, Romania; DENGLER et al. 2012) to make a documentary about extremely species-rich steppe meadows and evaluate changes in their species composition. At Dziurkach, we resampled a 16 m^2 (4 m × 4 m) permanent plot established in 2015, where 111 species were recorded that year (world maximum at that time; P. Dřevojan, I. Jongepierová, P. Novák & J. Roleček, unpublished). At Valea Lui Craiu, we sampled vegetation in the place where DENGLER et al. (2012) reported 98 species, a world maximum of species richness per 10 m^2, traced using GPS and published coordinates. We established a permanent 3.3 m × 3.3 m plot there, marked with four nine-inch nails and washers placed in the corners and nailed into the ground. We used standard methodology for phytosociological sampling (DENGLER et al. 2008). The plot boundaries were exactly delimited with an inflexible string and presence of species rooted within the plot was recorded. Species abundances were estimated using extended Braun-Blanquet cover-abundance scale. Three to four persons participated in species recording, which took about two hours. The nomenclature and taxonomy of plant taxa follow the Euro+Med PlantBase (EURO+MED 2006-), except for the critical taxa included in the following species complexes (aggregates): *Arabis hirsuta* agg. (*A. allionii*, *A. collina*, *A. hirsuta*, *A. hornungiana*, *A. nemorensis*, *A. sagittata*, *A. sudetica*), *Dianthus carthusianorum* agg. (*D. borbasii*, *D. carthusianorum*, *D. collinus*, *D. giganteiformis*, *D. giganteus*, *D. membranaceus*, *D. pontederae*, *D. rogowiczii*), *Knautia arvensis* agg. (*K. arvensis*, *K. kitaibelii*), *Leucanthemum vulgare* agg. (*L. adustum*, *L. ircutianum*, *L. vulgare*), *Poa pratensis* agg. (*P. angustifolia*, *P. pratensis*) and *Veronica chamaedrys* agg. (*V. chamaedrys*, *V. vindobonensis*).

Ecological differences between the two relevés were evaluated by calculating unweighted means of ecological indicator values (DIDUKH 2011) of the present species. To simply evaluate temporal dynamics of the extremely species-rich plots, we compared their current species composition with previous records.

3. Results

We recorded 119 and 106 species per 16 and 10 m^2-plots, respectively. Full relevés with header data are given below. Mean ecological indicator values of the species present in the two relevés are summarized in Table 1.

Table 1. Mean ecological indicator values of DIDUKH (2011) calculated for the two relevés with reported maxima of species richness.

Tabelle 1. Mittlere ökologische Zeigerwerte nach DIDUKH (2011) für die beiden neuen Vegetationsaufnahmen mit Maximalwerten des Artenreichtums.

Site	Soil Humidity	Acidity	Nitrogen Content	Thermal Climate	Light
Valea Lui Craiu, RO	10.20	8.45	5.16	8.94	7.41
Dziurkach, UA	11.40	7.98	5.44	8.57	7.10

Ukraine, Chernivtsi region, Spas'ka village, Dziurkach site, latitude 48°18'08.2"N, longitude 25°46'21.0"E (WGS-84), altitude 415 m a.s.l., date 21 June 2018, plot size 16 m^2, slope inclination 7°, slope aspect 120°, herb layer cover 85%, moss layer cover 1%, mown, semi-dry grassland on calcareous tertiary sediment.

Herb layer: *Brachypodium pinnatum* 2b, *Inula salicina* 2a, *Peucedanum oreoselinum* 2a, *Serratula tinctoria* 2a, *Trifolium pannonicum* 2a, *Viola hirta* 2a, *Anthericum ramosum* 1, *Carex montana* 1, *Centaurea jacea* 1, *Dactylis glomerata* 1, *Euphorbia illirica* 1, *Filipendula vulgaris* 1, *Iris graminea* 1, *Pteridium aquilinum* 1, *Sanguisorba officinalis* 1, *Trisetum flavescens* 1, *Achillea millefolium* agg. +, *Agrostis capillaris* +, *A. vinealis* +, *Angelica sylvestris* +, *Anthoxanthum odoratum* +, *Arabis hirsuta* agg. +, *Arrhenatherum elatius* +, *Avenula pubescens* +, *Briza media* +, *Campanula glomerata* +, *C. persicifolia* +, *Erigeron annuus* +, *Carex caryophyllea* +, *C. filiformis* +, *C. michelii* +, *C. spicata* +, *Clematis vitalba* +, *Clinopodium vulgare* +, *Colchicum autumnale* +, *Convallaria majalis* +, *Cruciata glabra* +, *Cuscuta epithymum* +, *Dianthus carthusianorum* agg. +, *Elytrigia repens* +, *Equisetum arvense* +, *E. telmateia* +, *Euphorbia angulata* +, *Ferulago sylvatica* +, *Festuca rubra* +, *Filipendula ulmaria* +, *Fragaria viridis* +, *Galium boreale* +, *G. verum* +, *Gladiolus imbricatus* +, *Gymnadenia conopsea* +, *Heracleum sphondylium* +, *Holcus lanatus* +, *Hypericum maculatum* +, *Hypochaeris maculata* +, *Knautia arvensis* agg. +, *Laserpitium latifolium* +, *Lathyrus niger* +, *L. pratensis* +, *Leucanthemum vulgare* agg. +, *Linum catharticum* +, *Lotus corniculatus* +, *Luzula campestris* +, *Lysimachia vulgaris* +, *Medicago falcata* +, *Ophioglossum vulgatum* +, *Pilosella onegensis* +, *Pimpinella major* +, *Plantago lanceolata* +, *P. media* +, *Poa pratensis* agg. +, *Polygonatum odoratum* +, *Potentilla erecta* +, *P. reptans* +, *P. thuringiaca* +, *Primula veris* +, *Prunella grandiflora* +, *Pulmonaria mollis* +, *Ranunculus acris* +, *R. auricomus* coll. +, *R. polyanthemos* +, *Rumex acetosa* +, *Salvia pratensis* +, *Schedonorus pratensis* +, *Securigera varia* +, *Silene flos-cuculi* +, *S. nutans* +, *Stachys officinalis* +, *Stellaria graminea* +, *Symphytum tuberosum* +, *Tanacetum corymbosum* +, *Taraxacum* sect. *Taraxacum* +, *Thalictrum lucidum* +, *Trifolium montanum* +, *Valeriana stolonifera* subsp. *angustifolia* +, *Veratrum lobelianum* +, *V. nigrum* +, *Vicia cracca/tenuifolia* +, *Vincetoxicum hirundinaria* +, *Viola canina* +, *Campanula patula* r, *C. trachelium* r, *Centaurea scabiosa* r, *Dactylorhiza fuchsii* r, *Danthonia decumbens* r, *Hieracium umbellatum* r, *Lilium martagon* r, *Phleum pratense* r, *Platanthera bifolia* r, *Poa palustris* r, *Polygala comosa* r, *Veronica chamaedrys* agg. r, *Vicia hirsuta/tetrasperma* r, *Thalictrum aquilegiifolium* r; *Acer pseudoplatanus* +, *Crataegus* sp. r, *Quercus* sp. +, *Prunus domestica* +, *Rosa* sp. r.

Fig. 1. Sampling of vegetation plot with 119 species per 16 m^2 at Dziurkach site near Spas'ka village, Chernivtsi region, Ukraine (Photo: J. Roleček, 21.06.2018).

Abb. 1. Vegetationsaufnahme der 16 m^2-Fläche mit 119 festgestellten Arten im Gebiet Dziurkach unweit von Spaska bei Czernowitz in der Ukraine (Foto: J. Roleček, 21.06.2018).

Fig. 2. Sampling of vegetation plot with 106 species per 10 m^2 at Valea Lui Craiu site, Fânaţele Clujului, Cluj region, Romania. Low height of herb layer, presence of disturbed patches and high abundance of the toxic *Adonis vernalis* in the grazed stand are apparent (Photo: J. Roleček, 25.06.2018).

Abb. 2. Vegetationsaufnahme der 10 m^2-Fläche mit 106 festgestellten Arten bei Valea Lui Craiu, Fânaţele Clujului, nördlich von Cluj in Rumänien. In den beweideten Beständen fallen die niedrige Krautschicht, Störstellen und hohe Deckung des giftigen *Adonis vernalis* auf (Foto: J. Roleček, 25.06.2018).

Romania, Cluj region, Fânaţele Clujului, Valea Lui Craiu site, latitude 46°50'24.2"N, longitude 23°39'23.0"E (WGS-84), altitude 540 m a.s.l., date 25 June 2018, plot size 10 m^2, slope inclination 12°, slope aspect 340°, herb layer cover 65%, moss layer cover 20%, herb layer mean height 10 cm, herb layer maximum height 50 cm, grazed by sheep, semi-dry grassland on calcareous tertiary sediment.

Herb layer: *Adonis vernalis* 2a, *Brachypodium pinnatum* 2a, *Festuca stricta* subsp. *sulcata* 2a, *Carex michelii* 1, *C. montana* 1, *Plantago media* 1, *Salvia pratensis* 1, *Schedonorus pratensis* 1, *Tephroseris integrifolia* 1, *Teucrium chamaedrys* 1, *Achillea millefolium* agg. +, *Agrostis capillaris* +, *A. vinealis* +, *Ajuga laxmannii* +, *Anthericum ramosum* +, *Anthoxanthum odoratum* +, *Arabis hirsuta* agg. +, *Asperula cynanchica* +, *Brassicaceae* indet. +, *Briza media* +, *Calamagrostis epigejos* +, *Campanula glomerata* +, *C. persicifolia* +, *Capsella bursa-pastoris* +, *Carex filiformis* +, *Cerastium holosteoides* +, *Clinopodium vulgare* +, *Cruciata glabra* +, *Cyanus triumfettii* +, *Dactylis glomerata* +, *Dianthus carthusianorum* agg. +, *Elytrigia intermedia* +, *E. repens* +, *Equisetum palustre* +, *Euphorbia angulata* +, *Festuca rubra* +, *Filipendula vulgaris* +, *Galium album* +, *G. glaucum* +, *Geranium sanguineum* +, *Helictochloa* sp. +, *Iris aphylla* +, *Jacobaea vulgaris* +, *Jurinea mollis* +, *Koeleria* cf. *macrantha* +, *Leontodon hispidus* +, *Leucanthemum vulgare* agg. +, *Linum catharticum* +, *L. nervosum* +, *Lotus corniculatus* +, *Medicago falcata* +, *M. lupulina* +, *Mercurialis ovata* +, *Nepeta nuda* +, *Onobrychis arenaria* +, *Picris hieracioides* +, *Pimpinella saxifraga* +, *Plantago lanceolata* +, *Poa pratensis* agg. +, *Polygala comosa* +, *Polygonatum odoratum* +, *Primula veris* +, *Pulmonaria mollis* +, *Ranunculus auricomus* coll. +, *R. polyanthemos* +, *Rumex acetosa* +, *Scabiosa ochroleuca* +, *Securigera varia* +, *Seseli annuum/peucedanoides* +, *Stachys officinalis* +, *S. recta* +, *Taraxacum* sect. *Taraxacum* +, *Thymus pulegioides* subsp. *pannonicus* +, *Torilis arvensis* +, *Trifolium alpestre* +, *T. dubium* +, *T. montanum* +, *T. pannonicum* +, *T. repens* +, *Valeriana stolonifera* subsp. *angustifolia* +, *Veronica chamaedrys* agg. +, *Vicia cracca/tenuifolia* +, *Viola hirta* +, *V. mirabilis* +, *Xeranthemum cylindraceum* +, *Agrimonia eupatoria* r, *Bromopsis erecta* r, *Cirsium pannonicum* r, *Convolvulus arvensis* r, *Crepis praemorsa* r, *Danthonia alpina* r, *Daucus carota* r, *Inula salicina* r, *Prunella grandiflora* r, *Salvia austriaca* r, *S. verticillata* r, *Solidago virgaurea* r, *Tanacetum corymbosum* r, *Thalictrum aquilegiifolium* r, *Thesium linophyllon* r, *Trifolium arvense* r, *Verbascum phoeniceum* r, *Veronica austriaca* subsp. *dentata* r, *Vincetoxicum hirundinaria* r; *Prunus spinosa* r.

At Dziurkach site, 96 species identifications were identical between 2018 and 2015 records and three differed only in the level of identification: *Cuscuta epithymum* (2018) versus *Cuscuta* sp. (2015), *Quercus* sp. juv. (2018) versus *Q. robur* juv. (2015) and *Thalictrum aquilegiifolium* (2018) versus *T. aquilegiifolium/minus* (2015). There were 20 unique species identifications in the record from 2018 and 12 in the record from 2015.

At Valea Lui Craiu site, 61 species identifications were identical between 2018 and 2009 records and nine and eight, respectively, differed only in the level of identification: e.g. *Helictochloa* sp. (2018) versus *H. pratensis* (2009), *Seseli annuum/peucedanoides* (2018) versus *S. annuum* and *S. peucedanoides* (2009) and *Viccia cracca/tenuifolia* (2018) versus *V. cracca* (2009). There were 37 unique species identifications in the record from 2018 and 28 in the record from 2009.

4. Discussion

4.1 Species composition

The two relevés with richness maxima share 51 species, which means a substantial similarity. The shared species include two major ecological groups: common mesic meadow species (e.g. *Plantago lanceolata*, *Rumex acetosa* and *Schedonorus pratensis*) and what might be called forest-steppe species, i.e. species of subxerophilous grasslands, open-canopy forests and forest fringes (e.g. *Brachypodium pinnatum*, *Carex montana* and *Tanacetum corymbosum*). The latter group is a bit more represented and includes some of the best diagnostic species of the alliance *Cirsio-Brachypodion pinnati* Hadač et Klika ex Klika 1951.

According to current view, both vegetation plot-records can be classified to broadly conceived association *Brachypodio pinnati-Molinietum arundinaceae* Klika 1939 (WILLNER et al. 2019), described from the White Carpathians Mts. (Czech Republic). Vegetation composition at Dziurkach site is rather close to more mesic stands in middle altitudes of the White Carpathians. On the other hand, vegetation around the plot at Valea Lui Craiu shares some more xerophilous elements with the type relevés coming from the foothills of White Carpathians (e.g. *Koeleria macrantha*, *Polygala major* and *Pontechium maculatum*; KLIKA 1939). However, differences in ecological profiles of the species present in the two plots are not big, as illustrated by their similar mean indicator values (Table 1; DIDUKH 2011).

4.2 Temporal dynamics

All of the unique identifications in Dziurkach records from 2018 and 2015 concern species with low abundance (cover below 1%) and can be perhaps in many cases ascribed to misidentifications and overlooking, mostly of juvenile and sterile plants: *Fragaria viridis* (2018) versus *F. vesca* (2015), *Agrostis capillaris* and *A. vinealis* (2018) versus *A. capillaris* (2015), possibly some of *Carex* records, etc. On the other hand, single records of conspicuous species such as *Pedicularis exaltata* (2015) and also of some juveniles most probably reflect real species turnover. It should be noted that we resampled the plot without consulting the 2015 species list and that one of the authors (P.D.) participated in both recordings, so we can assume similar approach to sampling and species identification.

We traced the 2018 Valea Lui Craiu plot using the published coordinates, so inaccuracy in order of metres and associated moderate differences in species composition could be expected. All but two unique identifications in 2009 concern species with low abundance (cover below 1%) and in many cases can be perhaps ascribed to methodological biases, i.e. misidentifications, overlooking and inaccurate positioning of the resampling plot. However, we assume that at least part of the differences results from real species turnover, accelerated by change of site management regime. While in 2009 the plot was reported to be mown (DENGLER et al. 2012), in 2018 it was grazed by sheep with medium intensity. It was manifested not only in the low cover and height of the herb layer, but also in the occurrence of some disturbance indicators such as *Capsella bursa-pastoris*, *Daucus carota*, *Equisetum palustre* and *Xeranthemum cylindraceum*. Also the unusually high cover of rosette hemicryptophytes (particularly *Tephroseris integrifolia*) and the toxic *Adonis vernalis*, as well as the appearance of the notorious epizoochorous species (*Agrimonia eupatoria*, *Torilis arvensis*), probably results from grazing. We assume that some grazing might have occurred

already prior to 2009, as there were found some disturbance indicators also that year. The impact of grazing on species richness should be further monitored to prevent the adverse effects of overgrazing (DUPRÉ & DIEKMANN 2001, GODÓ et al. 2017).

Considering the possible causes of species turnover, we cannot exclude the role of disturbance connected with sampling. It may promote colonization of new individuals, which makes the monitoring of extreme species richness an even more complex issue. And, last but not least, it is obvious that vegetation plot-recording in extremely species-rich grasslands, albeit carefully performed by several experienced phytosociologists, is far from perfect and we expect more species to be noted and identified with increasing effort. Nevertheless, it is also clear that extreme species richness remains a temporally quite stable feature of favourably managed East-Central European semi-dry grasslands.

Erweiterte deutsche Zusammenfassung

Einleitung – Kenntnisse des maximalen Artenreichtums von Vegetationsbeständen bilden eine wichtige Grundlage für die theoretische Ökologie und den Naturschutz. Alle weltweit gemessenen Maximalwerte des Artenreichtums von Gefäßpflanzen auf Flächen < 100 m² stammen aus dem temperaten Grasland. In diesem Artikel beschreiben wir aus dem ost-mitteleuropäischen Grasland zwei neue Maximalwerte des Artenreichtums von Gefäßpflanzen auf solchen Kleinflächen.

Methoden – Zwei Orte in der West-Ukraine und in Transylvanien in Rumänien mit bekannten Maximalwerten der Gefäßpflanzenarten wurden erneut aufgesucht, um den Artentreichtum der dortigen Wiesensteppen erneut zu dokumentieren und mögliche Veränderungen auch in der Artenzusammensetzung zu evaluieren. Die Aufnahmeflächen wurden dafür mit einer nicht dehnbaren Schnur exakt definiert; die Aufnahme der Vegetation erfolgte nach der pflanzensoziologischen Standardaufnahmemethode. Die Zeit der Aufnahme betrug jeweils etwa 2 Stunden und an den Aufnahmen nahmen jeweils drei bis vier Personen teil.

Ergebnisse und Diskussion – In der Ukraine wurden in 2018 an der Lokalität Dziurkach unweit von Spaska westlich von Czernowitz auf 16 m² 119 Gefäßpflanzenarten und in Rumänien bei Valea Lui Craiu, Fânaţele Clujului, nördlich von Cluj auf 10 m² 106 Gefäßpflanzenarten gezählt. Bei der Erstaufname in 2015 in der Ukraine waren lediglich 111 und in 2009 in Rumänien 98 Gefäßpflanzenarten gezählt worden. Beide Aufnahmen werden hier vollständig dokumentiert. Die Artenzusammensetzung der beiden (neuen) Aufnahmen ähnelte sich und entsprach einem weitgefassten *Brachypodio pinnati-Molinietum arundinaceae* im *Cirsio-Brachypodion*. Die beiden Aufnahmepaare (alte vs. neue Aufnahme) unterschieden sich insgesamt kaum; die meisten der insgesamt wenigen Unterschiede sind wohl auf Fehlbestimmungen schwieriger Taxa, ein Übersehen von juvenilen oder vegetativen Individuen oder auch nicht völlig exakte Übereinstimmung der beiden Flächen zurückzuführen. Andere Unterschiede stellen aber offenbar echte Vegetationsveränderungen dar, z. B. die Zunahme einiger kurzlebiger Ruderalarten. Die Aufnahmefläche in der Ukraine wurde zum Zeitpunkt der Untersuchung regelmäßig gemäht während diejenige in Rumänien beweidet wurde; bei letzterer war bei der Erstaufnahme noch Mahdnutzung festgestellt worden. Anscheinend war die geringe bis mittlere Beweidungsintensität dem Artenreichtum zuträglich, wie dessen leichte Zunahme zeigt. Die Artenvielfalt der beiden Flächen sollte weiterbeobachtet werden, damit z. B. negative Effekte einer möglichen Überbeweidung rechtzeitig erkannt und gestoppt werden können.

Author contribution statement

J.R. and M.H. conceived the ideas leading to this research. J.R. planned the research, participated in field sampling and led the writing. P.D. checked plant determination and nomenclature, participated in field sampling and writing. M.H. and P.H. participated in field sampling and writing.

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