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Cultural monuments and nature conservation: a review of the role of kurgans in the conservation and restoration of steppe vegetation

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Abstract Steppe is among the most endangered biomes of the world, especially in Eastern Europe, where more than 90 % of original steppes have been destroyed due to conversion into croplands, afforestation and other human activities. Currently, steppe vegetation is often restricted to places unsuitable for ploughing, such as ancient burial mounds called kurgans. The aim of our study was to collect and synthesise existing knowledge on kurgans by a review of research papers and grey literature. The proportion of kurgans covered by steppe vegetation increases from west to east and from lowlands to uplands. Despite their small size, kurgans act as biodiversity hotspots and harbour many red-listed species. High overall species richness and a high proportion of grassland specialists are maintained by a pronounced fine-scale environmental heterogeneity. The main

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factors threatening the biodiversity of kurgans are intensified agriculture and construction works. We conclude that kurgans can play a crucial role in preserving steppe vegetation, especially in intensively used agricultural landscapes in the western part of the steppe zone. Despite the vital role of kurgans in sustaining steppe vegetation, we identified serious knowledge gaps on their distribution, vegetation, flora and fauna and their potential role in steppe restoration.

Keywords Agro-biodiversity · Barrow · Eurasia · Fragmentation · Grassland restoration · Mound

Introduction

Agricultural intensification is an increasing threat to natural ecosystems worldwide (Tilman 1999). Over the past centuries, Eurasian grasslands have suffered a dramatic decline in their area and species diversity; the major threatening factors include habitat loss, fragmentation and degradation (Dengler et al. 2014; Evju et al. 2015; Brinkert et al. 2016, this issue; Mathar et al. 2016, this issue). This phenomenon is especially true for steppe, which is one of the most endangered biomes of the world (Habel et al. 2013). Steppe habitats face serious conflicts between agriculture and nature conservation, because many types of steppe occur on soils excellent for arable farming (e.g. chernozem, dark chestnut and chestnut soils; Hölzel et al. 2002). Steppes are characterised by naturally treeless vegetation dominated by perennial xerophilous grass and herb species. The steppe zone is located in the continental parts of Eurasia from the Danube Delta to Mongolia (Bohn et al. 2003). The pristine area of Eurasian steppe vegetation originally covered 8–13 million km^2 based on the estimations of Wesche and Treiber (2012). Formerly continuous steppes were ploughed in many regions, causing the fragmentation and isolation of remaining stands (Kamp et al. 2012; Smelansky and Tishkov 2012). It is estimated that 57 % of the original area of Eurasian steppes with chernozem soils has been converted to arable fields (Chibilyov 2002).

From west to east, the magnitude of agricultural intensification decreases in the steppe zone. The northern and western parts of the Ukrainian steppes were the most seriously damaged: only 5–8 % of their former area remained till nowadays (Sudnik-Wójcikowska and Moysiyenko 2012). The highest proportion of virgin steppes can be found in Mongolia, where 72 % of the original steppe area still exists (White et al. 2000). In Russia, tens of thousands of square kilometres were ploughed in the past 250 years (Smelansky and Tishkov 2012). In Kazakhstan, where agricultural intensification started later, 250,000 km^2 of steppe (approximately 90 % of steppes on chernozem and 60 % of dry steppes) were ploughed between 1954 and 1960 during the ‘‘Virgin Lands Campaign’’ (Rachkovskaya and Bragina 2012). However, in recent decades this process has reversed; the collapse of the Soviet Union initiated a large-scale abandonment of arable lands due to vanishing markets, outmigration and privatisation (Alcantara et al. 2013). Abandonment of former croplands is typical both in the European (more than 80,000 km^2 in the Pontic steppes; Schierhorn et al. 2013) and Asian parts of the steppe zone (e.g. 120,000 km^2 in Kazakhstan; Brinkert et al. 2016, this issue). Extended areas of abandoned croplands provide a unique possibility for spontaneous recovery of steppes (Hölzel et al. 2002; Brinkert et al. 2016, this issue). However, spontaneous succession is successful only if propagule sources are available in the landscape (Török et al. 2011).

Besides the reported dramatic loss in the continuity and area of the former steppes, the area of national parks, nature reserves or other protected areas preserving steppe vegetation is very small in the whole steppe zone. In the western part, there are fewer and smaller protected areas compared to the eastern part (Bohn et al. 2003; Rachkovskaya and Bragina 2012); thus, in the western part of the steppe zone sites preserving steppe vegetation are especially important for nature conservation. In many regions, steppe vegetation is now restricted to small fragments, such as rocky outcrops, ravines, field margins, roadside verges and other areas unsuitable for arable farming (Sudnik-Wójcikowska et al. 2011). Besides these, ancient burial mounds of the steppe region called "kurgans" also play a crucial role in preserving steppe vegetation, especially in intensive agricultural landscapes. Kurgans are especially important as they integrate natural and cultural values (Information Box 1). Their cultural and spiritual importance contributed to their relatively undisturbed state for centuries, which supported the maintenance of steppe vegetation (Kuksova 2011; Moysiyenko and Sudnik-Wójcikowska 2012; Deák et al. 2015a). Even though several

Information Box 1 Origin, distribution and cultural importance of kurgans

Kurgans are ancient soil monuments rising from the surrounding landscape (Tóth 2006), generally created as burial sites (Demkin et al. 2014). There is as yet no generally accepted definition of a kurgan, thus, we propose the following: kurgans are artificial hemispheric structures made of soil or stone, which originally functioned as burial sites for various cultures of the steppe region. The terms barrows, mounds, tumuli, mogili or halom describe similar structures that are widespread in the steppe and forest steppe zones from Hungary to Mongolia (Tóth 2006; Törbat et al. 2009; Sudnik-Wójcikowska et al. 2011).

The earliest known kurgans date back to a period from the Late Eneolithic (3500 BC) to the Medieval (15th century) period. Several cultures typical for the steppe regions built kurgans: the Yamna culture (3300–2600 BC), Kimmerians (1300–800 BC), Scythians (900–100 BC), Sarmatians (600 BC–400 AD), Thracians (800 BC–100 AD), Hungarians (700 BC –Medieval), Cumanians (1300 BC–Medieval) and others (Tóth 2006; Demkin et al. 2008; Rowinska et al. 2010; Sudnik-Wójcikowska and Moysiyenko 2012). Originally, kurgans were created for burial purposes and contained urns or skeleton graves. Later on, houses and chapels were built on some of them, or they functioned as sentinel mounds (Tóth 2006; Sudnik-Wójcikowska et al. 2011; Demkin et al. 2014).

Kurgans are sources of information for archaeology and ethnography, contributing to the understanding of ancient cultures (Paczoski 1933; Margulan et al. 1966; Sudnik-Wójcikowska and Moysiyenko 2012). Paleopedological, paleoecological, malacological and palynological studies have revealed characteristics of the landscape, climate and vegetation at the time when the kurgan was constructed (Barczi et al. 2009; Hejcman et al. 2013; Szilágyi et al. 2013; Demkin et al. 2014). These studies contribute to our understanding of climate change and landscape-level processes such as desertification or salinisation (Demkin et al. 2008). Nowadays, some of them are sacred places or memorial sites for former battles (Paczoski 1933; Bede 2014). They are part of the folklore and literature; several legends, tales and poems involve kurgans in their story (Sudnik-Wójcikowska and Moysiyenko 2012; Bede 2014).

The historical number of kurgans can be estimated using archaeological evidence and historical maps, although these are not available for all regions. The number of kurgans was approximately 40,000 in Hungary (Tóth et al. 2014), 500,000 in Ukraine (Sudnik-Wójcikowska and Moysiyenko 2012) and 50,000 in Bulgaria (Kitov 1993) before the industrial revolution (eighteenth century). Based on published data, the estimated number of existing kurgans in the whole steppe zone is between 400,000 and 600,000, which is equivalent to only about 20 % of their historical number. There is a huge uncertainty in the estimation because in most countries, no systematic surveys have been done and there is no consensus about the definition of kurgans. For instance, there is a considerable difference between the estimations of the number of kurgans in Hungary (Table 1): Tóth et al. (2014) used a landscape-based definition, while Bede (2012) used a more sophisticated archaeological one, which revealed more kurgans. Surveys carried out on huge areas often underestimate the number of kurgans compared to the results of local studies (Table 1); e.g. there are considerable differences between the Russian federal database and the data provided in Demkin et al. (2014)

papers have been published on their archaeological, historical and folkloristic values, their natural values are poorly explored in most regions.

Our aim was to evaluate the available publications and synthesise the knowledge on the kurgans of the Eurasian steppe and forest steppe zones. We focused on the following issues: (i) to give an overview of the most typical land cover types, management and conservation status of the kurgans (ii) to evaluate the role of kurgans in preserving steppe vegetation and species, (iii) to identify the most important threatening factors affecting kurgans and their biodiversity, (iv) to provide recommendations for the conservation and restoration of steppe vegetation on kurgans and finally, (v) to evaluate the role of kurgans in steppe restoration actions. We also aimed at to identify the knowledge gaps in order to support conservation actions and facilitate future research.

Methods

During our literature search we focused on published data on the vegetation, flora and fauna of the kurgans in the steppe and forest steppe zones of Eurasia. For delineation of the steppe and forest steppe zones we used the map of the steppe zonobiome of Walter and Breckle (1986). We used the Map of the Natural Vegetation of Europe (Bohn et al. 2003) for the categorisation of vegetation types in Europe and Lavrenko et al. (1991) for Asian regions. We focused on the vegetation formations of the Steppe (M), Forest steppe (L) and the category of azonal Inland halophytic vegetation (P32). We carried out a literature search on ISI Web of Science using the keywords ('kurgan' OR 'barrow' OR 'mound') AND ('steppe' OR 'grassland'), which returned 352 hits (papers published before March 2015). We refined the results to the countries of the Eurasian steppe and forest steppe zones, which resulted in 62 hits. These 62 papers were scanned by title and abstract. In case of 57 hits, the title was ambiguous or the papers contained only archaeological information, and only 5 papers dealt with the vegetation of kurgans (4 from Ukraine and 1 from Hungary). No paper was found focusing on their recent fauna. We used the reference lists of the five relevant studies, and also the papers in which these studies were cited, to add papers not already found during the database search. Given the limited number of publications, we decided to widen our search and to include further information published in national journals and grey literature. For this we used Google Scholar with the same keywords as used in the Web of Science. We also searched for grey literature in national libraries and by using the reference lists of the papers published in the above listed languages. In total, we found 79 publications on the vegetation of kurgans and no publication on the recent fauna of kurgans. During the evaluation of threatening factors we included expert opinions of the regionally affiliated co-authors when there was no literature available, to fill the knowledge gaps. In spite of our extended literature search, there might be further information in non-electronic sources or in languages other than English, Russian, Ukrainian and Hungarian, which we could not include in our review.

Results and discussion

Data availability

We found published studies on kurgans from eight countries: Hungary, Romania, Moldova, Bulgaria, Ukraine, Russia, Kazakhstan and Mongolia (Table 1). These regions cover many

Table 1 Distribution and present number of kurgans in the Eurasian steppe and forest steppe zones

Country	Region	Steppe type	Present number of kurgans	Reference	Number of publications
Hungary	Great Plain (52,000 km^2) Békés county (5631 km^2)	L2, P2	1649[a] Several thousand[a]	Tóth et al. (2014) Bede (2012)	33 (1)
Romania	Dobrogea (23,065 km^2)	N/A	8758[b]	Oltean (2013)	1
Moldova	South-Eastern Moldova	M1	More than 10,000	Romanchuk (2012)	0
Bulgaria	Danube Plain, Thracian Plain (37,555 km^2) Dobrogea (23,065 km^2)	M1, L2	15,000[a] 8758[b]	Kitov (1993) Oltean (2013)	2
Ukraine	Kherson, Mykolaiv, Kirovograd, Poltava, Cherkasy and Kyiv Oblasts (32,100 km^2)	M1, M2, L1	100,000–150,000[a]	Mozolevsky and Polin (2005), Sudnik-Wójcikowska et al. (2011)	28 (4)
Russia	From the Black Sea to Chukchi Peninsula (ca. 2500,000 km^2) From the Black Sea to Chukchi Peninsula (ca. 2,500,000 km^2) Altai Republic (Dzhazator) (284 km^2)	M1, M2, L1, MS, TS, SD, MO	Several hundred thousand 3181[c] 371	Demkin et al. (2014) http://kulturnoe-nasledie.ru/ Bourgeois and Gheyle (2007)	15
Kazakhstan	From the Volga delta to the Altai (ca. 1,800,000 km^2) Kara Kaba valley (25 km^2)	SD, MO	2129[d] 305	Database of the Ministry of Justice (http://adilet.zan.kz) Bourgeois and Gheyle (2007)	0
Mongolia	Altai (Baian-Ölgii) (45,704 km^2)	N/A	60	Törbat et al. (2009)	0

After the region, the areas in brackets refer to the area of the certain kurgan surveys. "Reference" refers to publications on the number of kurgans in the given countries. "Number of publications" refers to the total number of publications on the vegetation of kurgans, while publications from the ISI Web of Science are given in brackets. To categorise the steppe types in Europe we used the categories of Bohn et al. (2003), for Asia we used Lavrenko et al. (1991)

[a] Some of them are not in the steppe or forest steppe zones

[b] Number of kurgans in Southern Dobrogea without differentiation at the country level

[c] Number of registered kurgans in Russia

[d] Number of registered kurgans in Kazakhstan

Abbreviations for Europe: Subcontinental meadow steppes and steppe-like dry grasslands—L1; Sub-Mediterranean-subcontinental herb grass steppes, partly meadow steppes—L2; True steppes—M1 and Desert steppes—M2; Halophytic vegetation—P2. Abbreviations for Asia: *MS* meadow steppes, *TS* true steppes, *SD* semidesert sodgrass and semishrub-sodgrass steppes, *MO* mountain steppe

steppe types and represent a considerable part of the steppe and forest steppe zones. The vast majority of publications focused on the vegetation of kurgans in Hungary, Ukraine and Russia. There was a considerable lack of information from the eastern regions (Table 1). We found that most papers focused only on a few particular kurgans, while systematic regional-level surveys were scarce (but see Sudnik-Wójcikowska et al. 2011 for Ukraine and Tóth 2006 for Hungary). In several regions (such as Bulgaria, Mongolia or Kazakhstan) kurgans were more frequently the objects of archaeological research than botanical and/or ecological research. A likely reason for this is that, despite of the huge losses in recent centuries, considerable areas of steppe remain intact in Mongolia and Kazakhstan so that ecological research is not restricted to fragments on kurgans.

Land cover types and management

In the western part of the steppe zone, the proportion of kurgans covered by steppe vegetation is lower than in the eastern part. In Hungary, the proportion of kurgans covered by natural or semi-natural grasslands is 7 % (from a survey of 1649 kurgans; Tóth 2006), while in Ukraine this proportion is 23 % (from a survey of a 32,100 km^2 area harbouring 450 well-preserved kurgans; Sudnik-Wójcikowska et al. 2011). Kurgans covered by steppe vegetation are often grazed (Paczoski 1933; Bykov et al. 2009; Penksza et al. 2011a). In the western regions management has often ceased, especially on kurgans embedded in large agricultural fields.

The proportion of kurgans covered by arable lands decreases from west to east and from lowland to upland regions. Horticulture on kurgans is mentioned from Hungary and Bulgaria (Tóth 1998; Oltean 2013). The presence of settlements on kurgans is typical in the western regions (Hungary and Romania; Bede 2012; Oltean 2013). In Hungary and Bulgaria, some of the kurgans are covered by tree plantations; in Bulgaria kurgans are often covered by natural shrub or low forest vegetation (Balázs 2006; Tóth 2006).

Conservation status

Kurgans as unique landforms are under legal protection in many countries. In Bulgaria, Ukraine, Russia and Kazakhstan, kurgans are protected because of their cultural and historical values, but the protection is not extended to their flora and fauna. Hungary is the only country where all kurgans are protected under the nature conservation law ("*ex lege*" protection) regardless of whether they are situated in a protected area or not. In larger protected areas they usually have a better conservation status due to the reduced risk of ploughing or afforestation (lower proportion of damaged structure, higher proportion of kurgans covered by steppe vegetation, more protected species; Tóth and Tóth 2003; Balázs 2006).

Kurgans as biodiversity hotspots

Despite their small area, kurgans generally support a high diversity of vegetation types and grassland specialist species (Moysiyenko and Sudnik-Wójcikowska 2008; Moysiyenko et al. 2014; Bede et al. 2015; Deák et al. 2015a; see Online Resources ESM 1–2). The high biodiversity of kurgans is supported by the high variety of micro-sites provided by the heterogeneous topography (Lisetskii et al. 2014; Sudnik-Wójcikowska and Moysiyenko 2014; see Information Box 2). The topographic heterogeneity is strongly linked to the presence of abiotic filters, such as salt and drought stress, which support several characteristic grassland species and suppress generalist, competitor and/or weed species (Deák et al. 2014a, 2015b).

Because of the differences in topography, the vegetation of the top and the foot zones often differ remarkably (Joó et al. 2007; Bykov et al. 2009; Sudnik-Wójcikowska and Moysiyenko 2014). In many cases the top of the kurgans is covered by open grasslands

Information Box 2 Specific environmental conditions on the kurgans

The diameter of kurgans can range from a few metres up to 100 m (Kitov 1993; Tóth 2006; Demkin et al. 2014; Sudnik-Wójcikowska and Moysiyenko 2014). According to Tóth and Tóth (2003), their average volume is 6727 m^3 in Hungary; however, it can reach up to 133,973 m^3 (Tóth et al. 2014). Their original height typically ranges between 3 and 15 m (Kitov 1993; Mozolevsky and Polin 2005); but can reach 20 m like in case of the kurgan Oguz. Several authors use a minimum threshold of 3 m in height for being a kurgan in a favourable state (Tóth 2006; Sudnik-Wójcikowska et al. 2011).

Given their specific origin and shape, kurgans provide diverse combination of various micro-sites in a small area. Kurgans were usually built on a natural plateau, using the humus-rich topsoil of the neighbouring areas taken from concentric trenches around the grave (Demkin et al. 2014). In most cases they were built from chernosemic or chestnut soil, but in some cases it can be alkali soil as well (Tóth 1998; Barczi et al. 2009; Demkin et al. 2014; Lisetskii et al. 2014). In mountainous areas like the Altai, stones and rock were also used for their construction (Törbat et al. 2009).

Top, slope and foot zones of kurgans are characterised by different abiotic conditions (Sudnik-Wójcikowska et al. 2011). Sudnik-Wójcikowska and Moysiyenko (2008a, 2014) found that on kurgans in the desert steppe zone, salinity and moisture considerably decreased from the foot to the top, and the top of the kurgan is the most exposed to solar radiation (see also Penksza et al. 2011b). The special shape of the kurgans supports rapid water runoff towards to the foot, which also creates dry conditions at the top and slope regions. Slope aspect also plays an important role in the species distribution on the kurgans, especially under the harsh environmental conditions in desert steppe areas (M2) (Sudnik-Wójcikowska and Moysiyenko 2008b; Lisetskii et al. 2014).

harbouring drought-tolerant species, while on the slopes and the foot closed loess, alkali or sand grasslands are situated (Penksza et al. 2011b; Deák et al. 2015a). The highest biodiversity can usually be found in the foot region where the species pool of the neighbouring areas and the kurgan are mixed (Sudnik-Wójcikowska and Moysiyenko 2010; Penksza et al. 2011a), while the highest proportion of the characteristic species of the phytosociological class *Festuco-Brometea* are present on the slopes (Moysiyenko and Sudnik-Wójcikowska 2008). Due to the lower solar radiation, the northern slope and foot of the kurgans are more species-rich and harbour more steppe specialist species compared to the southern slopes (Sudnik-Wójcikowska and Moysiyenko; Bykov et al. 2009; Lisetskii et al. 2014).

The most comprehensive checklist of the vascular flora of kurgans focuses on those in Ukraine (Sudnik-Wójcikowska and Moysiyenko 2012). The authors found a total of 721 species on 106 kurgans, including 71 species of special conservation interest (IUCN Red List, European Red List and regional Red List species, see Online Resource ESM2). They found ten European Red List species: *Astragalus borysthenicus*, *A. dasyanthus*, *A. pallescens*, *Cerastium ucrainicum*, *Crocus reticulatus*, *Dianthus lanceolatus*, *Elytrigia stipifolia*, *Galium volhynicum*, *Phlomis hybrida* and *Senecio borysthenicus*. Based on the information in this paper, we estimated that these 106 kurgans harbour approximately 14 % of the flora of Ukraine (in total 5100 species; Mosyakin and Fedoronchuk 1999). This extraordinarily high species richness is present on an estimated area of 1.07 km^2, which corresponds to c. 0.000002 % of the area of the country. We assume that kurgans are also likely to be biodiversity hotspots for other taxonomic groups, but we unfortunately did not find any publications on their fauna.

Threats

We identified several threats to the physical structure and/or the vegetation of the kurgans. According to their origin we assigned these threats to the following main categories:

Table 2 Threats to kurgans

Factor	Country						Citation
Construction works and urbanisation	HU	RO	BG	UA	RU	KZ	
Settlements[a]	x	x	x	x		x*	Moysiyenko and Sudnik-Wójcikowska (2008); Rowinska et al. (2010); Bede (2012); Oltean (2013); Sudnik-Wójcikowska et al. (2011); Tóth et al. (2014)
Infrastructure (roads, channels)[a]	x	x	x	x	x*	x*	Moysiyenko and Sudnik-Wójcikowska (2008); Barczi et al. (2009); Rowinska et al. (2010); Bede (2012); Oltean (2013); Sudnik-Wójcikowska et al. (2011); Tóth et al. (2014)
Objects, single buildings[a]	x			x	x*	x*	Tóth (2004); Sudnik-Wójcikowska and Moysiyenko (2013)
Reservoirs and fishponds[a]	x			x			Tóth (2004); Moysiyenko and Sudnik-Wójcikowska (2008)
Soil extraction for construction works[a]			x*	x			Tóth (2006); Moysiyenko and Sudnik-Wójcikowska (2008); Rowinska et al. (2010); Bede (2012); Sudnik-Wójcikowska et al. (2011)
Transporting soil on the kurgan[a]	x						Tóth (1998)
Agriculture							
Ploughing[a,b]	x	x	x	x	x	x*	Moysiyenko and Sudnik-Wójcikowska (2008); Rowinska et al. (2010); Kuksova (2011); Sudnik-Wójcikowska et al. (2011); Oltean (2013); Rákóczi and Barczi (2014); Tóth et al. (2014)
Orchards, vineyards[b]	x	x	x				Tóth (1998); Oltean (2013)
Application of chemicals[b]	x						Tóth (1998); Bede (2014)
Afforestation[a,b]	x		x*		x*		Balázs (2006); Tóth (2006); Bede (2014)
Overgrazing[b]	x			x	x		Paczoski (1933); Sudnik-Wójcikowska et al. (2011); Bede (2014)
Establishment of corralsb	x						Bede (2014)
Establishment of fishponds[a]	x						Tóth (2004)
Soil extraction for horticulture[a]				x			Moysiyenko and Sudnik-Wójcikowska (2008), Rowińska et al. (2010)
Other anthropogenic							
Archaeological excavations[a,b]	x		x*	x	x	x	Margulan et al. (1966); Bykov and Khrustaleva (2008); Moysiyenko and Sudnik-Wójcikowska (2008); Rowinska et al. (2010); Sudnik-Wójcikowska et al. (2011); Tóth et al. (2014)
Trampling due to tourism[b]	x			x			Sudnik-Wójcikowska and Moysiyenko (2013)

Table 2 continued

Factor	Country						Citation
Construction works and urbanisation	HU	RO	BG	UA	RU	KZ	
Fire[b]	x			x		x*	Tóth (1998); Moysiyenko and Sudnik-Wójcikowska (2008); Rowinska et al. (2010); Sudnik-Wójcikowska et al. (2011); Sudnik-Wójcikowska and Moysiyenko (2012)
Collecting plants				x			Sudnik-Wójcikowska and Moysiyenko (2013)
Establishing military range[a,b]	x						Barczi et al. (2009)
Wars				x			Moysiyenko and Sudnik-Wójcikowska (2008); Rowinska et al. (2010)
Garbage deposition[b]	x						Balázs (2006); Moysiyenko and Sudnik-Wójcikowska (2008); Sudnik-Wójcikowska et al. (2011)
Biotic							
Encroachment of weeds[b]	x			x			Penksza et al. (2011b); Moysiyenko and Sudnik-Wójcikowska (2008); Bede (2014)
Encroachment of terrestrial reed[b]	x						Tóth and Tóth (2003)
Encroachment of native woody species[b]	x		x*				Barczi et al. (2009); Bede (2012)
Encroachment of woody invasives[b]	x			x			Barczi et al. (2009); Penksza et al. (2011b)

Country names are abbreviated using their ISO code: *HU* Hungary, *RO* Romania, *BG* Bulgaria, *UA* Ukraine, *RU* Russia, *KZ* Kazakhstan

[a] Affects the structure of the kurgan

[b] Affects the vegetation of the kurgan

* Unpublished data based on expert opinion of the authors

construction works and urbanisation, agriculture, other anthropogenic and biotic threatening factors (Table 2; see Online Resource ESM 3).

Construction works and urbanisation The construction of settlements, roads or the excavation of material for building purposes is identified as causing the destruction of kurgans across the whole of their range (Sudnik-Wójcikowska et al. 2011; Oltean 2013; Tóth et al. 2014). Construction of buildings, statues, electric pylons and geodetic objects generally did not cause the complete destruction of the kurgan, but often led to a partial loss of the soil and degradation of the vegetation (Tóth 2004). Establishment of these artificial objects supported the spread of undesirable species due to soil disturbance and trampling. Disturbed kurgans were often prone to the encroachment of native disturbance-tolerant and weed species including terrestrial reed (*Phragmites australis*), and in many cases even to non-native invasive species (*Robinia pseudoacacia, Elaeagnus angustifolia* or *Lycium barbarum*; Tóth and Tóth 2003; Barczi et al. 2009; Penksza et al. 2011a; Bede 2012; Sudnik-Wójcikowska and Moysiyenko 2014). However, small objects built on the kurgans could preserve the structure and the vegetation of the kurgans, because farmers generally avoided ploughing in the buffer zone of these objects.

Agriculture Almost all studies highlighted that ploughing has been a major threat both to the structure and to the natural vegetation of kurgans since the nineteenth century (Moysiyenko and Sudnik-Wójcikowska 2008; Rowińska et al. 2010; Kuksova 2011; Oltean 2013; Sudnik-Wójcikowska and Moysiyenko 2013; Medvedev 2014; Rákóczi and Barczi 2014; Tóth et al. 2014). As a consequence of agricultural intensification, many of the smaller or less steep kurgans were levelled and ploughed. In many regions only kurgans with the steepest slopes remained intact, as it was impossible to use the ploughing machinery there (Bede 2012; Sudnik-Wójcikowska et al. 2011). Erosion caused by ploughing became more significant in the 1950s in parallel with the use of heavy machinery in agriculture (Bede 2012). In Hungary, 17 % of kurgans have disappeared mainly due to agricultural intensification since the 1970s (Tóth 2006). Besides ploughing, chemical inputs applied on or around kurgans results in nutrient enrichment and degradation of their grassland vegetation (Bede 2014). In agricultural landscapes, the foot of kurgans is exposed to a heavy seed rain of arable weeds from the adjacent croplands (Sudnik-Wójcikowska and Moysiyenko 2008b, 2010). Weed encroachment is also typical in the top region, probably because the high proportion of open micro-sites—formed by the dry micro-climate, increased solar radiation and intense water runoff—is favourable for weeds (Sudnik-Wójcikowska and Moysiyenko 2008a; Penksza et al. 2011b). Windbreaks can be a major source of the invasion of exotic species, such as *Ailanthus altissima, Amorpha fruticosa, Elaeagnus angustifolia, Fraxinus pennsylvanica* and *Ulmus pumila* (Sudnik-Wójcikowska et al. 2011).

Many kurgans that could not be ploughed have been afforested, especially in the western part of the steppe and forest steppe zones (Balázs 2006). Soil preparation works and the roots of the trees can seriously damage the soil surface, often leading to erosion and the loss of the archaeological evidence. The shading of the closed forest canopy suppresses grassland specialists and can result in the expansion of generalist or shade species (Tóth 1998; Balázs 2006).

Even though remnants of steppe vegetation have survived on some of the kurgans, their landscape context has in almost all cases been drastically altered in recent centuries, and the proportion of arable fields has increased considerably, especially in the forest steppe zone and the western part of the steppe zone (Sudnik-Wójcikowska et al. 2011). As a consequence, the vegetation on the kurgans is often isolated from similar vegetation patches by arable land, which poses a serious threat to biodiversity (Kuksova 2011; Sudnik-Wójcikowska and Moysiyenko 2012; Dembicz 2012; Dembicz et al. 2016, this issue). Small, isolated patches are more susceptible to environmental pollution, eutrophication and the loss of pollinators (Ouborg et al. 2006). Isolated fragments often harbour fewer specialist species than those connected to natural grasslands (Novák and Konvička 2006; Evju et al. 2015). A further consequence of isolation can be the decrease in the genetic variability of characteristic species, via reduced inter-population gene flow, increased level of genetic drift and inbreeding (Dembicz 2012).

Both intensive use and abandonment can result in the degradation of the vegetation of kurgans. In many regions, especially in Kalmykia (Russia), overgrazing leads to nutrient enrichment and the encroachment of weedy species. In other regions (e.g. in Hungary) abandonment is considered as a serious problem (Deák et al. 2015a; Paczoski 1933), which leads to litter accumulation, encroachment of herbaceous competitors or woody species, and causes the decline of diversity in the long run (Valkó et al. 2014).

Other anthropogenic threatening factors Several studies reported that archaeological excavations can considerably damage both the structure and the vegetation of the kurgans, which might be a conflict between ecologists and archaeologists (Margulan et al. 1966; Bykov and Khrustaleva 2008; Sudnik-Wójcikowska et al. 2011; Tóth et al. 2014). Frequent anthropogenic fires were reported as threatening factors (Tóth 1998; Moysiyenko and Sudnik-Wójcikowska 2008), which lead to the dominance of competitor grass species and the disappearance of target species (Valkó et al. 2014). However, periodic fires with a frequency of 15–20 years are natural features in steppe ecosystems (Sudnik-Wójcikowska et al. 2011) that can have a positive effect on the vegetation by favouring certain grassland specialist species via eliminating litter and hindering woody encroachment (Deák et al. 2014b).

Biotic threatening factors Biotic threatening factors were most typical in the western part of the steppe and forest steppe zones. Encroachment of weeds (e.g. *Bromus sterilis*, *Carduus acanthoides* and *Onopordum acanthium*), terrestrial reed (*Phragmites communis*), native woody species (*Crataegus monogyna* and *Sambucus nigra*) and invasive woody species (especially *Robinia pseudoacacia* and *Elaeagnus angustifolia*) were reported as major biotic threatening factors (Tóth and Tóth 2003; Moysiyenko and Sudnik-Wójcikowska 2008; Barczi et al. 2009).

We found that most of the threatening factors, even the biotic ones, were associated with some kind of human activity, and mostly linked with the intensification of land use (Rowińska et al. 2010; Kuksova 2011; Sudnik-Wójcikowska et al. 2011, 2013; Rákóczi and Barczi 2014). Accordingly, there was a decreasing trend from the west to the east in the presence and intensity of ploughing, establishment of orchards, use of chemicals, soil extraction, building of settlements and roads. Besides the geographical gradient we also found a temporal gradient in the intensity of land use: in parallel with the technological development (since the nineteenth century), destruction of kurgans considerably accelerated, which led to major losses in their numbers and to the degradation of their vegetation (Moysiyenko and Sudnik-Wójcikowska 2008, Kuksova 2011; Sudnik-Wójcikowska et al. 2011; Tóth 2004).

Recommendations for biodiversity conservation

For the effective protection of steppe vegetation on kurgans, the first step should be to set up inventory and monitoring systems at the regional and national levels. Based on up-to-date knowledge, it would be crucial to ensure the proper management of the remnant steppe vegetation and/or restore steppe vegetation where at least a basic species pool is still present. The protection of kurgans is especially important in intensively used agricultural landscapes, because they can act as core areas for landscape-scale steppe restoration projects.

Need for comprehensive surveys, databases and monitoring

Our study revealed that there is a lack of information on the flora and vegetation of the kurgans across the whole of Eurasia. Out of the several hundred thousand existing kurgans only a few thousand have ever been studied by biologists. Moreover, because of the lack of monitoring systems, up-to-date knowledge on the kurgans is available only in a very few cases. As a first step towards the effective protection of kurgans, national and regional databases should be compiled, which would support the work of the decision makers in designating national and regional-level protection and restoration plans (Tóth 2006; Sudnik-Wójcikowska and Moysiyenko 2013; Bede 2014). The most important information would be the location, diameter, height, land cover type, vegetation, list of protected and rare species and the threatening factors. Such databases already exist for the whole area of Hungary and for a part of Ukraine (Tóth 2006; Sudnik-Wójcikowska and Moysiyenko 2012, 2013; Bede 2014). For the protection of the kurgans, regular monitoring of the conservation state would also be necessary for a representative set of kurgans, focusing on (i) changes in land use type, (ii) populations of endangered species and (iii) threatening factors. Assigning individual land registration numbers to the kurgans would further support their protection (Balázs 2006).

Need for conservation and restoration actions

Given the importance of kurgans in maintaining steppe and forest steppe vegetation, there is an urgent need for focused actions in kurgan protection. Nature conservation is often in conflict with the agricultural, forestry and archaeological sectors regarding the protection of kurgans. In many cases, nature protection is the weakest party. In the majority of the cases, kurgans (or at least their typical vegetation) are destroyed before their flora and fauna has been surveyed. To mitigate the losses, the major threats should be controlled, and it is necessary to ensure the proper management and/or restoration of the grassland vegetation. Our review shows that ploughing was a major threatening factor in all regions. In Hungary and Ukraine, ploughing of kurgans is forbidden by law. In Ukraine a protection zone is designated around the kurgans, which is 10 m for single kurgans and 50 m for kurgan groups; as compensation farmers can ask for another piece of land of the same size. Although this initiative is promising, several administrative issues make its practical application difficult, such as the lack of available compensation land adjacent to the certain area or high costs of land registration, which should be paid by the farmer. However, there are positive examples, such as in Zaporizhia Oblast where ploughing was stopped on all kurgans.

According to the land use statistics, owners often ignore the legal restrictions on ploughing (Sudnik-Wójcikowska and Moysiyenko 2012). Given that legal protection alone proved to be insufficient in many cases, we suggest involving the protection of kurgans in national systems of agri-environmental schemes. In Hungary, for maintaining the “Good Agricultural and Environmental Condition” (Council Regulation, EC 73/2009) farmers are not allowed to plough kurgans. According to this regulation, farmers get a financial compensation for the non-ploughed area; thus, they become interested in the protection of kurgans. Rákóczi and Barczi (2014) found that due to the subsidies, farmers stopped ploughing on 75 % of formerly ploughed kurgans in Eastern Hungary. This system could be further improved by special subsidies for restoring grasslands on already ploughed kurgans. There are many options for restoring steppe vegetation on kurgans such as hay transfer, sowing seed mixtures, but supporting spontaneous grassland regeneration can also be a viable solution (Török et al. 2011). In Russia, kurgans and their surroundings could be good target areas for establishing steppe belts within the framework of the agrosteppe program. The aim of this program is to establish species-rich grasslands for hay production and soil protection in areas unsuitable for agricultural use, such as slopes, eroded areas, and areas with poor soil quality (Dzybov 2007).

Including kurgans in agri-environmental schemes can be beneficial both for nature conservation and for society in general. Grassland fragments provide key ecosystem services in intensively used agricultural landscapes (Tscharntke et al. 2012). Thus, kurgans harbouring grassland fragments may provide ecosystem services such as biological pest control and crop pollination, and they also represent considerable value for landscape aesthetics. They can play a crucial role in ensuring landscape-level connectivity of habitats (serving as stepping stones), increase beta-diversity and habitat compositional and configurational complexity in intensively managed landscapes.

Because of their scattered distribution, the regional-scale protection of kurgans is challenging and has not yet been satisfactorily solved in any of the countries in which they are found. The lack of even basic knowledge on the localities, flora and fauna of kurgans makes it very difficult to design specific conservation and restoration projects. Another major issue is that the protection of small and isolated fragments is considerably more difficult and costly compared to the protection of connected landscapes (Tscharntke et al. 2012). This especially holds for kurgans that are surrounded by large agricultural fields, thus they remain inaccessible for most of the growing season (Sudnik-Wójcikowska and Moysiyenko 2014). Even though the official conservation of kurgans in large-scale projects is challenging, their small size and high natural and cultural values make them ideal objects for small-scale volunteer projects for NGOs or schools. In this way, local people can be involved in civil nature conservation by participating in the active protection of kurgans.

Prospects of kurgans in large-scale steppe restoration projects

In the western part of the steppe and forest steppe zones, the increasing rate of habitat loss and fragmentation means that there is an increasing need for the restoration of the most endangered habitats and landscape connectivity (Dembicz 2012). In this region, kurgans should be involved in the restoration projects as seed sources via natural seed rain or by using them as donor sites for hay transfer for grassland restoration. In the eastern regions, the high rate of land abandonment means that steppe vegetation has been developing spontaneously on tens of thousands of square kilometres of old-fields in recent decades (Brinkert et al. 2016, this issue). Fragments of natural grasslands play a crucial role in spontaneous succession as they are important sources of the propagules of grassland specialist species (Kuksova 2011).

Besides kurgans, these fragments of steppe vegetation are found in field margins, road verges and ravines in the steppe and forest steppe zones (Dembicz et al. 2016, this issue). Field margins and road verges can support highly biodiverse communities and can act as green corridors especially in fragmented landscapes (Šerá 2008). However, they are generally only secondary habitats, which were disturbed several times in the past (e.g. ploughing, application of herbicides, too frequent mowing, seeding with commercial seed mixtures) and their linear shape supports the spread of weeds and invasive species (Šerá 2008). Ravines are very important refuges for steppe vegetation and often harbour pristine grasslands, relatively undisturbed by humans. They are usually characterised by steep slopes with a shallow soil layer and rocky outcrops, their lower parts are often flooded in springtime (Moysiyenko and Sudnik-Wójcikowska 2010a). However, it should be noted that ravines are not present in all countries of the steppe zone, e.g. they are not typical in some regions of Kazakhstan and Hungary. A special attribute of the kurgans is that, in contrast to ravines, they preserve herb-rich and pure feather-grass steppes (M1–M3; Bohn et al. 2003) which are especially threatened by ploughing (Moysiyenko and Sudnik-Wójcikowska 2010a). In addition, kurgans also have a considerable cultural importance, which is not the case for verges and ravines.

Sudnik-Wójcikowska et al. (2011) reported that in Ukraine, kurgans could effectively contribute to the regeneration of steppe vegetation on oldfields and windbreaks. That is why we suggest designating priority areas for grassland recovery around kurgans, taking into consideration the dispersal ability of grassland specialist species (less than 100 m; Novák and Konvička 2006). Kurgans are thus suitable for micro-scale restoration projects of several tens of hectares. In some regions where the density of kurgans is high or they compose a complex network with field margins, road verges and ravines, they could potentially increase the area coverage and efficiency of grassland recovery over larger areas.

Bridging the gap between biodiversity conservation and archaeological research

Cultural monuments are typical landscape elements of the Palaearctic from Ireland to the Far East (Kuksova 2011). Barrows, henges, cairns or earth fortresses are all ancient sentinels of our history. Our study showed that beside their important historical values, cultural monuments might also harbour outstanding natural values due to their century-long undisturbed status. We emphasise that we should pay special attention to cultural monuments in national and regional nature conservation strategies. This goal can be achieved by putting much greater emphasis on the cooperation between biologists, archaeologists and social scientists (Sudnik-Wójcikowska and Moysiyenko 2012). It is inevitable that archaeological excavations of kurgans contribute to the understanding of our history, although present excavation techniques generally cause the partial or total destruction of the kurgans and their vegetation. We suggest conducting a comprehensive botanical and zoological survey on kurgans before excavations take place. To preserve the natural and landscape values of the kurgans, complete restoration of the former structure and vegetation should be required after excavation works. For the latter, the best solution would be sod transfer: removing the sod from the kurgan before the excavation, then placing it back afterwards (Moysiyenko and Sudnik-Wójcikowska 2008; Rowińska et al. 2010).

Finally, we conclude that kurgans are under-appreciated resources for nature conservation. To evaluate their role in sustaining biodiversity and use them in nature conservation projects, more research is needed on their current distribution and numbers in all regions. Systematic studies should explore their flora, fauna and vegetation, which can contribute to the understanding of the role of grassland fragments in agricultural landscapes.

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