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Unique botanical values in a metropolitan area and the landscape history reasons of their occurrence on the Széchenyi Hill, Budapest

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Abstract

Urban areas host several threatened species in small reserves that face habitat loss and fragmentation due to land-use change. Despite historical and current disturbances, these areas sometimes still maintain high biological diversity. As only 5% of the European Union territory was classified as natural, the permanent grasslands represent overriding value, especially in metropolitan areas. Our aim was to explore protected and adventive plant species in a small and valuable, but till now, not deeply studied area of the densely inhabited 12th district in the metropolitan city Budapest (Hungary), which is visited by large numbers of people. We compared various historical map sources in order to explain how the extension of the grasslands has changed during the past centuries and, thus, which patches are permanent grassland habitats. We found 29 protected and 1 strictly protected plant species. The highest number of protected plant species and their stands were found in the permanent grasslands. Besides urbanisation, a heavy load of tourism (especially on non-designated routes), off-road mountain biking, airsoft races, some illegal shelters for homeless people and game damage threaten this unique refuge of high natural values. The extension of grasslands between 1783 and 2016 varies from 6.7 ha to 21.5 ha. Their area constantly increased due to deforestation until 1867 and exceeded 20 ha, probably due to the mass increase in livestock grazing; then it stagnated until the 1920s, with a slight decrease due to expanding urban areas. Golf greens appeared, walker and skiing tourism increased and these apparently have not decreased the coverage of grasslands, but surely affected the composition of their species. Recent scrub encroachment and re-forestation caused a further decrease. Our distribution maps show the highest density of protected plant species on the southern slopes (2.4 hectare) that have constantly been grasslands since 1783 to date. Contrarily, the cutting of grasslands from 1861 to date contains only half of their number per area unit. Thus, the number of valuable plant specimens refers to the age of the grassland. Three species occur only in the oldest grasslands. Conservation actions should first and foremost focus on these patches.

Keywords
Adventive plant, conservation, environmental history, grassland, protected plant, protected area management, urban areas

Introduction

Urban areas occupy less than 0.5% of the Earth's total land area (Schneider et al. 2009), yet they might host several protected and threatened species (Ives et al. 2016; Kowarik 2011). These values often occur in small, fragmented reserves that are the outcome of complex social and political processes (Williams et al. 2005). The main reason for this is that urbanisation is a significant land-use change that leads to habitat loss and fragmentation (Seto et al. 2012) and cities are often located in areas of high biological diversity (Luck 2007). Plant conservation biologists have shown that, even in the urban regions, there may also exist a large proportion of threatened or rare species (Kendle and Forbes 1997; Godefroid 2001). Twenty-two per cent of the known occurrences of endangered plants in the USA fall within the 40 largest cities (Schwartz et al. 2002). A total of 48 per cent of the 962 highly threatened taxa in California is restricted to high and medium density counties (Schwartz et al. 2006). Rapidly changing cities pose a threat and a challenge to the continuity that has helped to support biodiversity (Andersson and Barthel 2016). Therefore, more attention and conservation efforts must be focused on urbanised and urbanising regions (Rosenzweig 2003).

The effectiveness of different-sized reserves has been studied for about a century, with early warnings on the positive relationship between species richness and area (Arrhenius 1921). Although several studies proved the importance of small conservation reserves (e.g. Shafer 1995), the designation of protected areas remote from cities remains the dominant conservation paradigm world-wide (Miller and Hobbs 2002). The active protection of small sites is a challenging task for nature conservation, as smaller areas suffer more from human disturbance, pollution and other negative effects coming from the surrounding matrix (Deák et al. 2016). Kendal et al. (2017) found, in their floristic survey of 68 urban grassland conservation reserves, that 87% of all native plant species were found in small reserves < 10 ha in size, more small reserves containing a greater number of species than the few large reserves of a comparable area. Small reserves can also contribute to conservation at a landscape level by providing stepping stones between larger reserves which contribute to meta-population dynamics (Dearborn and Kark 2009). In favour of keeping the biodiversity in metropolitan areas, the complexity of the land mosaic should be preserved, especially within the urban matrix (Capotorti et al. 2013, Hüse et al. 2016). The history of urbanisation affects contemporary urban vegetation assemblages. This indicates potential extinction debts, which have important consequences for biodiversity conservation planning and sustainable future scenarios (du Toit et al. 2016).

The flora of Hungary's state capital, Budapest, has been investigated since the 18th century. However, constant changes justify regular monitoring of protected species to recognise threats as well. Our aim was to prepare distribution maps of protected and adventive plant species in a small and valuable, but till now, not deeply studied area of the densely inhabited 12th district in the metropolitan city Budapest, visited by great numbers of people. We also aimed to explain how these unique species could survive despite anthropogenic effects (including land use change, expansion of built-up areas) through millennia and constant disturbance (including inhabitation and urbanisation). Seeing that the majority of protected species are hosted by grassland habitats, we explored the landscape history, in order to explain how the extension of the grasslands has changed during the past centuries and, thus, which patches are permanent grassland habitats and whether the greatest number of protected plant specimens overlaps with the permanent grasslands.

Geography and climate of the study area

The Széchenyi Hill (472 m above sea level) belongs to the Buda Hills (top peak 529 m a.s.l.). The study area is situated in the central part and southern slopes of the Széchenyi Hill and mainly covered by grasslands, although our investigations included the surrounding forested habitats as well (Figures 1, 2). Dominant basal rock is dolomite (from Upper Triassic), with a smaller ratio of Triassic limestone and freshwater limestone from the late Pliocene. During Pleistocene glacial periods, the area was not covered by ice, but affected by nearby ice sheets.

The climate is moderately cool and moderately dry. Due to rainfall distribution, it exhibits a submediterranean character. The hill occupies a transitional position between lowlands and mountains, due to the closeness of the Great Plain and the Danube. Sunny hours reach 1930 per year. Its climate is colder than the average in Budapest, with 8.7 °C annual mean temperature. Winter temperature inversion is a frequent phenomenon here: unclouded, sunny hilltops are even 10 °C warmer than valleys and lowlands in the city. Annual rainfall exceeds 650–700 mm, the most during early summer, the least around late winter. Snow cover lasts for 50 to 55 days. Rendzina soil is dominant on the surface. There are no springs on the Széchenyi Hill (Dövényi 2010).

History

According to the first written documents, which date back to the 12th century, wine cultivation had started after deforestation. Wine production slightly decreased during the Ottoman invasion and flourished again in the 18th century, but was ended by the phylloxera infestation (late 19th c.). Cottages and chalets replaced the wine plantations (Siklóssy 1929).

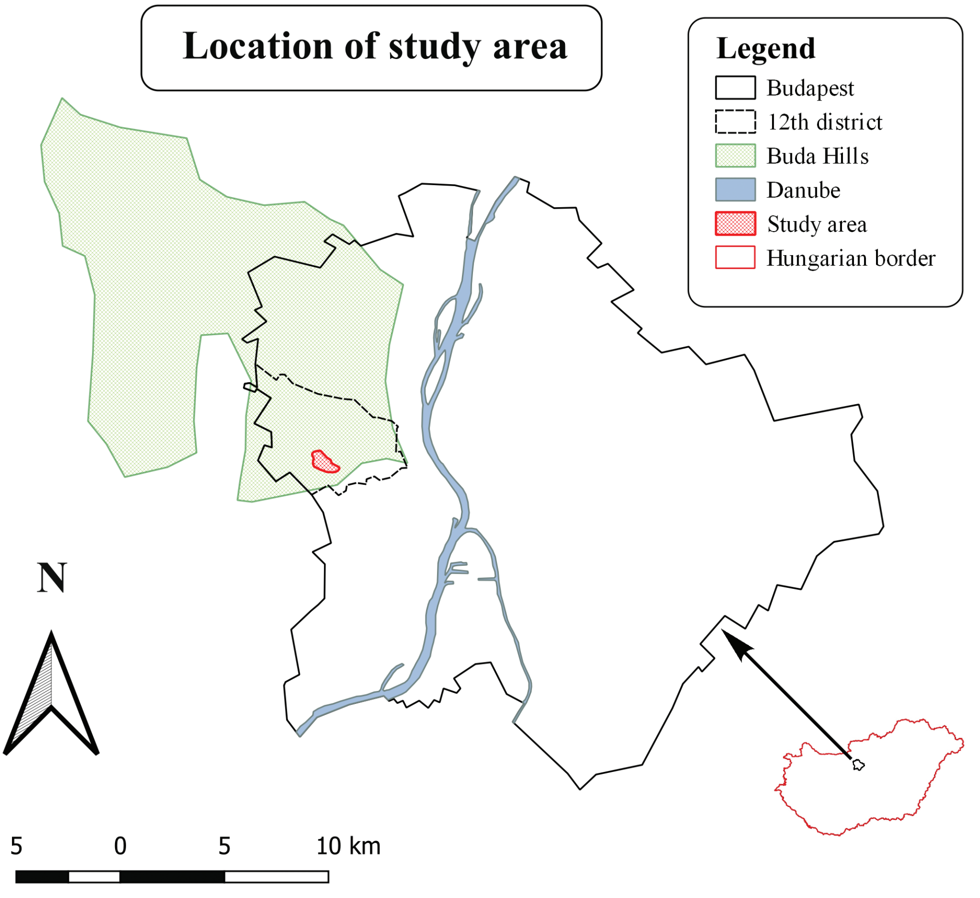

Figure 1. Location of the study area.

The process of urban citizens settling in the surroundings during the 19th century encouraged the development of public transportation. A cog-wheel railway has been running from the city-centre up to the Széchenyi Hill since 1890, giving opportunity for the development of a new district, increasing population and growing the number of tourists. New forests were planted (partly of adventive trees), recreational sites were built and touristic routes were designated. Even ski tourism has flourished after 1920 on the hill. Ten tourist hotels were built in the vicinity between 1939 and 1943, some of them at the border of the valuable grasslands. The Hungarian Golf Club was launched here in 1910, with a high-standard golfcourse and fairways which was declared the second most beautiful in Europe by a British golf magazine (Siklóssy 1929). Economic growth stopped during the two world wars, which caused serious harm to the natural values, since both airborne bombings and land battles affected the area. After World War II, a small-gauge railway (operated by pioneers in the Soviet times) started to operate, with a terminal station (and several buildings) at the border of the valuable grasslands. At the same time, the golfcourse and fairways were abandoned, their place now being covered by secondary grasslands, railway tracks and a military base. The 56-m high main television tower of Budapest was built directly on to the grassland (at the border of the study area) in 1958, completed with a 150 m high steel tower in 1973.

Official nature protection was launched in 1978 by the Buda Landscape Park, which surrounds Budapest from the north-west. Since Hungary's EU-accession (2004), the study area is also covered by the Natura 2000 ecological network.

Vegetation

Original Holocene vegetation of the area has evolved during the past 10 to 12 thousand years, with relict species remaining in forests and rock grasslands. Besides the climate, anthropogenic activities played a significant role. Original, ancient vegetation was probably intact until the Roman imperial age. The greatest changes have occurred since the mid-19th century, giving home to cultivated plants and weeds (Pénzes 1942).

High plant diversity of the Buda Hills is a consequence of its geographical situation (mix of plain, lowland, hillside), various geomorphology and micro-climatic conditions. It belongs to the Pilisense floristic district within the Bakonyicum floristic sector (part of the Pannonicum floristic region) (Fekete et al. 2017) and hosts both northern and southern species and even endemisms, such as *Linum dolomiticum*. Southern surfaces of the Széchenyi Hill are covered by Pannonian karst white oak – manna ash low woods.

During his floristical studies in 1818, József Sadler recognised that Budapest hosts several rare species and diverse habitats. Vince Borbás stated in 1879 that the vegetation of Budapest significantly differs from the Central European vegetation due to southern and eastern floristical elements. He mentions *Anthericum liliago*, *Amygdalus nana*, *Coronilla coronata*, *Iris pumila* and *Lathyrus pallescens* from the Széchenyi Hill (Pénzes 1942). Somlyay (2009) presents the main features of floristical phytogeography of the Buda Mts. based on local distribution pattern of several species with phytogeographical relevance. He mentions *Amygdalus nana* and *Phlomis tuberosa* as oriental species with evident migration routes through the Pannonian lowlands, while *Coronilla coronata* and *Crepis nicaeensis* as sub-Mediterranean species. Tamás et al. (2017b) has recently reported rare ferns from adjacent areas.

Materials and methods

Impoundment of the study area

The study area was designated based on satellite photos and detailed field surveys (Figure 2).

Investigations were undertaken in 2015 and 2016, every 2 to 4 weeks during the vegetation period. The central grassland designated for systematic research covers 8.5 hectare. The surrounding low woods, which were designated based on satellite photos

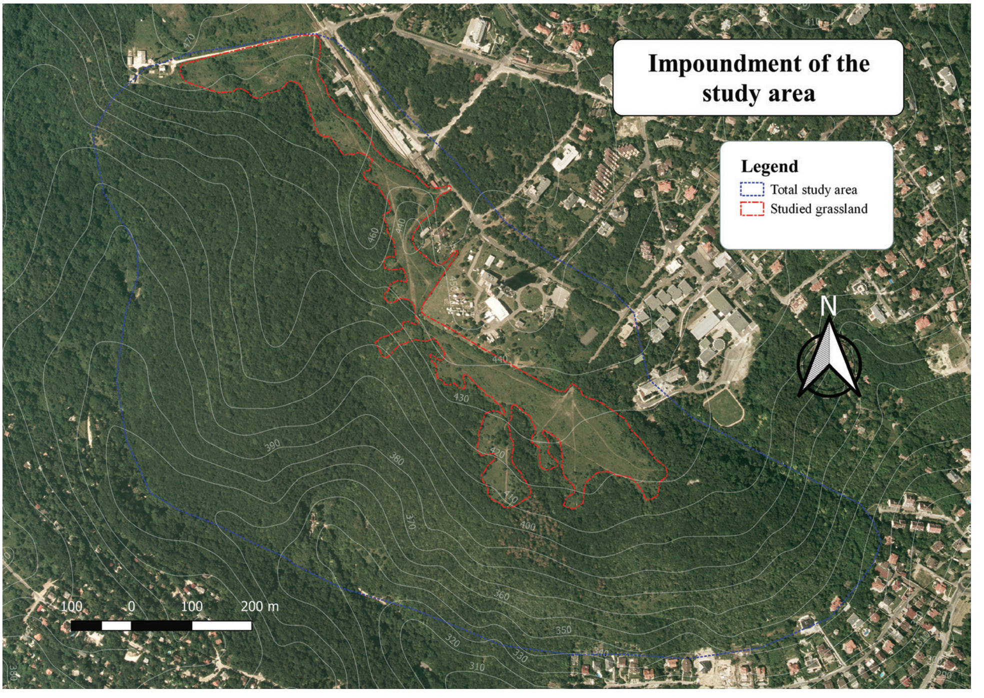

Figure 2. Impoundment of the study area (based on Google Earth satellite photos).

and cover 77.5 ha, was observed occasionally, but is also important for historical reconstructions. We strived to soundly rake over the whole area (with 'rambling method') during every visit and recorded the GPS coordinates in case of protected plants; while the other (non-protected) species were listed.

Division of individual plant specimens

Plants were determined with the help of the determination book of Király (2009). Division of individuals was not easy in many cases, due to various reasons. As several species create polycormons (e.g. *Lathyrus pallescens*, *Iris pumila*), we, therefore, decided to record two sets of data in the case of each protected taxon, the number of flowering stems and the number of stands. Determination of the latter was difficult, so we counted those stems as one patch that apparently form one stand. We used the same method in case of several non-polycormon species as well, if the stems grew so densely that made the division of each specimen impossible (e.g. in the case of *Polygala major*).

Landscape history research methods

Besides archive literature, our bases for the landscape history research were military maps and aerial photos, online maps of the mapire.eu and Google Earth and recent online aerial photographs from the Department of Geodesy, Remote Sensing and Land Offices, Hungary (for the list of sources, see Table 2). We have processed them with Quantum GIS software and impounded the grassland area with polygons. The most reliable data amongst them were the aerial photographs, while the maps were inaccurate in most cases, especially the First Military Survey (Molnár et al. 2014); georeferencing is aggravated by the lack of signed objects or landmarks that would provide suitable points of reference. In the case of recent maps and aerial photographs, the number of points of reference has been increasing and, thus, these are more accurate.

In order to answer the research question how the extension of the grasslands has changed during the past centuries and, thus, which patches are permanent grassland habitats, we impounded those areas that are indicated on the map as (or seem to be) grasslands and worked with the profile of the polygons generated by this method. In order to minimise the errors that emerge from inaccuracy, we marked a buffer zone around the designated grasslands in line with the inaccuracy rate of the map (10, 15 and 25 m). These are just approximate data, presumed on the basis of the deviation of georeferenced points from their real location and the distances between the fitting of the segments.

Results and discussion

We found 29 protected (one of them is Natura 2000 Annex species) and 1 strictly protected plant species in the grasslands and forests of the studied area (Table 1). With regard to the fact that exact number of specimens cannot be determined in every case (due to the reason presented in *Division of individual plant specimens*), the nature conservation value is provided based on the number of stands (see Suppl. material 1); thus, this is a minimum value, the real value being probably higher. The sum value of protected plants still exceeds 300,000 Euro and most of their stands are located within the mere 8.5 hectare grassland. Based in this, it is obvious that the grassland of the Széchenyi Hill covers an outstanding value. An aggregated distribution map of all protected species is presented in Figure 5.

Adventive elements (and amongst them, invasive alien species) are rare in the area, despite the fact that human population density surrounding protected areas is a significant and strong predictor of numbers of alien and invasive species (Spear et al. 2013). Tree of Heaven (*Ailanthus altissima*) is the most aggressive amongst them, but only 6 specimens were fortunately found so far. Other invasive alien species are, fortunately, rare in the area as well, such as Canadian horseweed (*Conyza canadensis*), fleabane (*Erigeron annuus*), Oregon-grape (*Mahonia aquifolium*), goldenrods (*Solidago canadensis*, *S. gigantea*) and non-invasive, but still adventive yew (*Taxus baccata*). Former surveys did not mention adventive or invasive alien species from the Széchenyi Hill. Although these few stands of invasive alien species have not threatened protected values until now, some indigenous shrub species have caused undesirable processes and difficulties for nature conservation, such as common hawthorn (*Crataegus monogyna*) and sloe (*Prunus spinosa*). Their recent expansion in dry steppes is a consequence of the abandonment of traditional landscape management patterns and leads to re-forestation and disappearance of protected values.

Table 1. Protected plant species found on the Széchenyi Hill, Budapest (strictly protected species is indicated with an asterisk; Natura 2000 Annex species in bold).

Scientific name	Minimum number of stands
Aconitum vulparia	160
Adonis vernalis	274
Allium sphaerocephalon	609
Amygdalus nana	30
Anemone sylvestris	15
Aster amellus	40
Asyneuma canescens	220
Centaurea scabiosa subsp. *sadleriana*	3280
Centaurea triumfettii	87
Cephalanthera damasonium	27
Convolvulus cantabrica	78
Coronilla coronata	165
Crepis nicaeensis	29
Dictamnus albus	1072
Erysimum odoratum	442
Iris pumila	903
Iris variegata	6
Jurinea mollis	246
*Lathyrus pallescens**	163
Limodorum abortivum	91
Linum flavum	12
Linum tenuifolium	327
Lychnis coronaria	49
Orchis purpurea	28
Phlomis tuberosa	21
Polygala major	495
Pulsatilla grandis	846
Scorzonera purpurea	60
Sorbus danubialis	8
Vinca herbacea	1952
SUM	11 735

Historical changes of the grasslands

Changes in the extension of grasslands on the Széchenyi Hill between 1783 and 2016 vary from 6.7 ha to 21.5 ha (Table 2). No data are available for the beginning of the first period, but presumably coincides with the population boom after the Liberation War 1703-1711 and lasts until 1867 (Austrian-Hungarian Conciliation). During this period, the area of grasslands constantly increased due to deforestation and finally exceeded 20 hectares, probably due to the mass increase in grazing livestock in parallel with the population boom. Coverage of grasslands stagnated until the 1920s, with a slight decrease due to expanding urban areas. Golf fairways and greens appeared during and after this period, in line with increasing tourism (both walker and skiing), which apparently have not decreased the coverage of grasslands, but surely have affected their species composition.

Table 2. Extension of grasslands on the Széchenyi Hill (1783–2016).

Year	Source of data	Area of grassland (m²)
1783	First Military Survey Map	118273
1861	Second Military Survey Map	153079
1873	Cadastre Maps of Buda	214520
1882	Third Military Survey Map	213585
1923	Renewed Third Military Survey Map	206760
1955	Aerial photograph of the Military History Map Archives	165728
1959	Renwed Gauss-Krüger projection map	127045
1978	Aerial photograph of the Military History Map Archives	108172
1987	Aerial photograph of the Military History Map Archives	106315
2004	Google Earth satellite image	81366
2016	Google Earth satellite image	67773

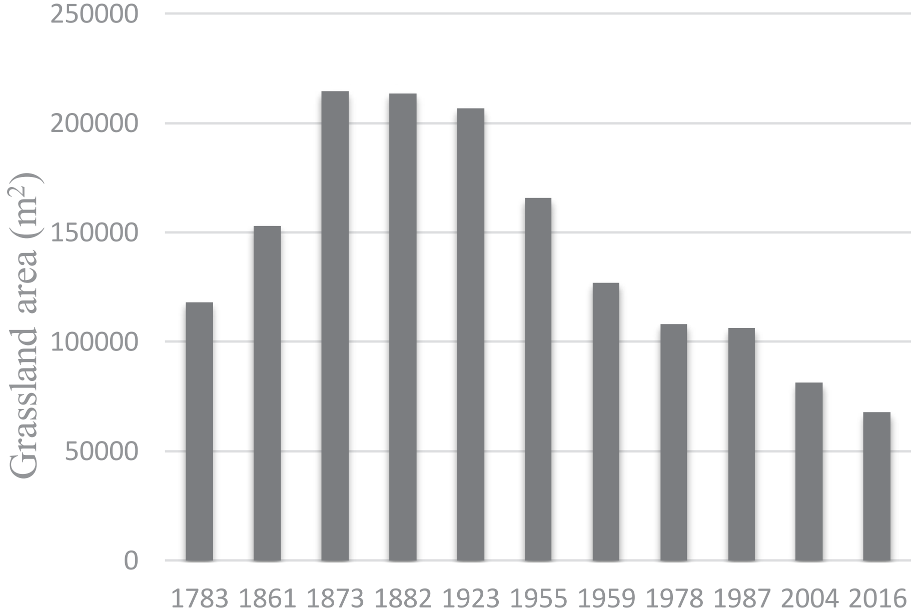

Figure 3. Changes in the extension of grasslands on the Széchenyi Hill (Budapest) from 1783 till 2016.

Creation of the Children's (that time: Pioneers') Railway and the national television broadcasting tower during the 1950s caused a massive fall in grasslands, followed by a slighter decrease until the change of political regime (1989) due to slow scrub encroachment and creation of military bases. A possible reason for this fall-off might be the declaration of the Buda Landscape park in 1978, covering also the Széchenyi Hill.

The past three decades showed another massive fall in the extension of grasslands, due to scrub encroachment and re-forestation caused by the abandonment of traditional management (but no data are available for previous management forms) (Figure 3). The current rate of decrease in grassy areas is very close to the coverage of presumed permanent grasslands.

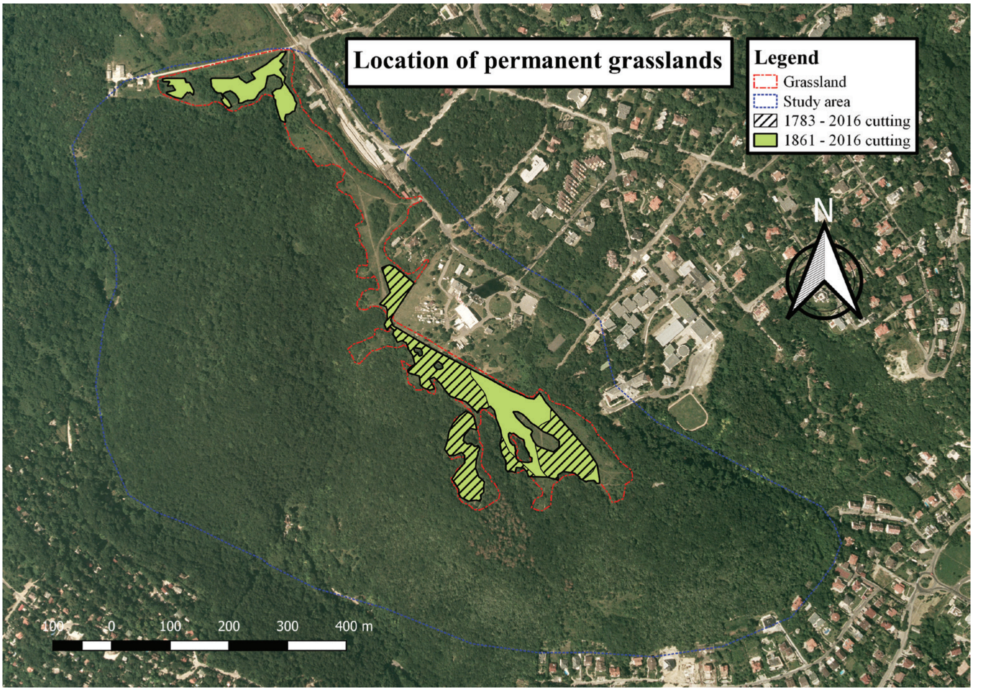

Figure 4. Presumed location of permanent grasslands on the Széchenyi Hill, Budapest.

Determination of the permanent grasslands

Permanent grasslands, i. e. those areas that have constantly been covered by grasslands (instead of forests) during the past 235 years on the basis of a cutting of historical maps, aerial photographs and satellite images, are presented in Figure 4. With regard to the relatively high inaccuracy of the First Military Survey Map (as the earliest source) and the difficulties of georeferencing due to the low number of reference points, we also prepared another cutting based on data of the past 150 years (i.e. since the Second Military Survey Map of 1861). Figure 4 shows that dominant parts of the permanent grasslands cover the southern slopes, while a small patch can be seen on the northern plateau. Our distribution maps show the highest density of protected plant species on the southern slopes, while the latter patch hosts almost none of them. A possible explanation for this phenomenon is that this patch belonged to the central part of the golf green and fairway during the 1930s and was affected by sown grass seeds (imported from England) besides trampling, which probably caused a massive shift in species composition.

The total area of permanent grasslands since 1783 to date is 24,056 m^2, while the same data since 1861 is 54,128 m^2, dominated by southern slope steppe grasslands of rocky weak soils in both cases. The greatest number of protected plant specimens per area unit can be found on those patches that have constantly been grasslands

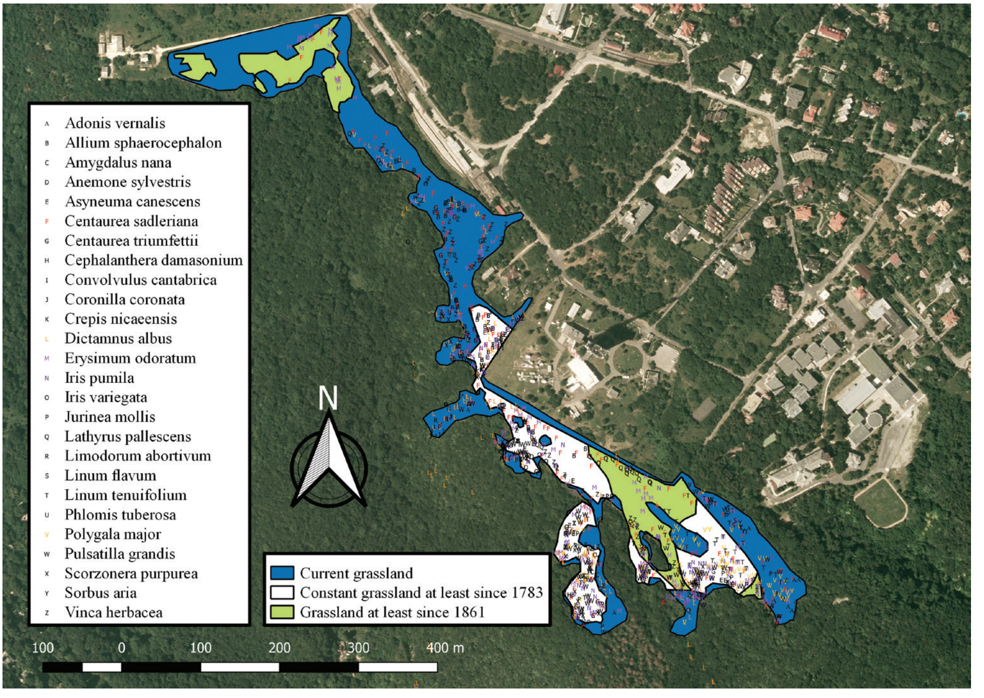

Figure 5. Protected plant species are most abundant in permanent grasslands (letter colors serve better visibility).

Table 3. Rate of protected plant species on permanent (and total) grassland areas of the Széchenyi Hill.

Studied area	Species number	Flowering stem	Number of stands	Area (m^2)	Ratio of flowering stem / area
1783 – 2016 cutting	22	15863	5117	24056	0.659
1861 – 2016 cutting	21	18834	6079	54128	0.348
Grassland in 2016	21	29997	10426	67773	0.443

since 1783 to date. Contrarily, the cutting of grasslands from 1861 to date contains only half of their number per area unit. A possible reason for this is that the newer grasslands cover mainly those areas that previously have been used for golf purposes or are situated in the central part of the current lawn and, thus, are affected by heavy trampling (Table 3).

The highest number of protected plant species, as well as the highest number of their stands, was found in the permanent grasslands (Figure 5). Thus, the number of valuable plants refers to the age of the grassland. Moreover, *Amygdalus nana*, *Crepis nicaeensis* and *Phlomis tuberosa* occur only in the oldest patches, while those species that spread slowly, such as *Iris pumila*, are most abundant in the oldest grasslands as well. *Anemone sylvestris* and *Coronilla coronata* appear at the edges of younger grassland patches surrounded by Pannonian karst white oak – manna ash low woods. *Limodo-*

rum abortivum and *Sorbus aria* are indicators of re-forestation on the younger parts. Some other protected plant species that we found, such as *Aconitum vulparia* and *Lychnis coronaria*, occur only in the surrounding forests close to the grasslands, while we have not recorded *Inula oculus-christi* and *Thlaspi jankae* in the years of our investigations, but only in the following year (2017); this is the reason we do not show them on Figure 5.

Conclusions

Hegedüs (2002) concluded by his thorough examinations that 341 plant species have disappeared from the flora of Budapest during the past 100 years, primarily due to urbanisation. This trend calls for regular and systematic monitoring of the flora, especially in case of protected species. The 29 protected and one strictly protected plant species (which has only one more location in Hungary) that we found, prove this area to be recognised as of extraordinarily rich in natural values, even in an international comparison. For example, Feráková and Jarolímek (2011) list 7 taxa that have their only occurrence in Slovakia in Bratislava and 7 Natura 2000 taxa; while Sofia's flora includes 12 statutorily protected species (Dimitrov et al. 2011) and 60 species were recorded in Warsaw that are protected by Polish law (Sudnik-Wójcikowska and Galera 2011). Half of the flora of Belgium, Germany and The Netherlands occur in Brussels, Berlin and Maastricht, respectively. A possible reason for the high biodiversity of European cities is that they have been established along landscape transition zones and rivers in regions that are naturally highly heterogeneous in terms of their landscape (Müller 2011).

Although the studied area belongs to the Buda Landscape Park, its real protection and conservation is complicated, since touristic routes lead through and is easily reachable, even by public transport. Besides urbanisation processes (i.e. expansion of built-up areas), the heavy load of tourism (especially on non-designated routes), airsoft races, some illegal shelters for homeless people and game damage (recent study from an adjacent area by Tamás et al. 2017a) threaten this unique refuge of high natural values. As soil loss is definitely larger on the steeper and longer slopes (Centeri and Pataki 2003; Centeri et al. 2015), illegal off-road mountain biking should be stopped at least in the valuable grassland patches.

Lack of information boards or fences refers to undesirably little attention being paid by nature conservation authorities. A key challenge for preserving biodiversity is balancing human perceptions, needs and use with ecological requirements (Aronson et al. 2017). By raising attention of the visitors towards unique species and spots with listing of the rules when entering protected areas and fencing the most vulnerable vegetation stands (either with wooden fence or by managing stinger shrubs such as hawthorn and sloe stands), in parallel with fighting against scrub encroachment and invasive alien species, the botanical values can be preserved in the long term. Although common hawthorn threatens the strictly protected *Lathyrus pallescens* stands, its elimination might aggravate degradation from human trampling, therefore, these interventions should be thoroughly planned. The area also plays an important role in connecting people to nature, generating support for conservation and providing opportunities for education (Soga and Gaston 2016).

Taking into account that only 5% of the European Union territory was classified by the European Commission as natural (Agnoletti and Rotherham 2015), permanent grasslands represent overriding value, especially in metropolitan areas. Our studies reveal that about 2.4 hectare permanent grassland remained on the Széchenyi Hill, giving home to the greatest number of protected plant specimens per area unit within the 8.5 ha grassland. Conservation actions should first and foremost focus on these patches. Our case shows that urban areas contain a wide range of biodiversity (Farinha-Marques et al. 2017) and the value of urban ecosystems is very high due to interaction of human, social, built and natural capital (Sutton and Anderson 2016). We could support the statement of Kendal et al. (2017) that, while the theory and evidence showing the conservation benefits of large reserves over small reserves for some organisms is clear, small urban conservation reserves can make a substantial and genuine contribution to regional conservation outcomes. We confirm the argument of Duhme and Pauleit (1998) that special attention for biodiversity conservation in central Europe has to be paid to the urban landscapes because of their high importance for nature conservation and species richness. Flora and vegetation of the Széchenyi Hill meet the synthesised set of ecological and biological criteria of Asaad et al. (2017) and, thus, we identify it of high biodiversity significance.

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Supplementary material 1

Main data of protected plant species found on the Széchenyi Hill, Budapest

Authors: Károly Menyhért Nagy, Ákos Malatinszky

Data type: (measurement/occurrence/multimedia/etc.)

Explanation note: Value in Euro is based on the relevant law that determines it in Hungarian Forint.

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