



The vascular flora of Pécs and its immediate vicinity (South Hungary) I.: species richness and the distribution of native and alien plants

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Abstract

Urbanization is one of the major causes of species loss and the homogenization of the world's flora. Our coarse-scale floristic mapping project of the largest south Transdanubian city, Pécs, is the first grid-based urban study in Hungary that reveals the current pattern of the vascular flora. Beyond the general description of the project, the species richness, the number of native, archaeophyte, neophyte and legally protected taxa are presented in the scale of the grid units (2.2 km²) and according to the residential area of the city. Relationships between the number and proportion of natives, archaeophytes, neophytes, protected species versus the proportion of built-up areas, forest coverage and elevation are estimated by linear regression models. Among the 1458 spontaneous or subsponaneous vascular plant species of the study area 131 are legally protected. The average number of species per grid unit is 338. Regression models show that the number of aliens decreases with forest coverage and increases with the rate of built-up areas, while number of natives shows opposite trends as a function of the same variables. These opposite trends lead to the conclusion that in the case of the vascular flora of Pécs the “poor get richer” theory is supported. Among the most frequent species hemicryptophytes, widespread, native and zoochorous plants are dominant. The most widespread four invasive taxa are native to North America.

Keywords Grid mapping · Nature conservation · Pannonian basin · Plant invasions · Urban biodiversity

Introduction

In our rapidly changing world, one of the greatest threats to local biodiversity is urbanization (McKinney 2006; Knapp et al. 2008; Hahs et al. 2009). As 68% of the human population will live in cities by 2050 [1], urbanization process in and around human settlements will become even stronger in the future (Williams et al. 2015). Populated areas are often located in or near to local diversity centres (Araújo 2003; Kühn et al. 2004), and therefore these areas and their biota have become particularly vulnerable. The urban environment

strongly filters the local flora, allowing only species with certain characteristics to survive, and therefore it results in a global biotic homogenization (Dolan et al. 2017). In Europe most research on urban flora was performed in settlements of Central and Western Europe (e.g. Lososová et al. 2012), only a few examples can be found in Southern and Eastern Europe (e.g. Mosyakin and Yavorska 2002; Milović and Mitić 2012; Celesti-Grapow et al. 2013; Maslo 2014), and therefore the available data do not allow for general conclusions on the European urban flora yet. In addition to their functions, human settlements serve as important hotspots for colonization for certain adventive plants (Pergl et al. 2016; Ceplová et al. 2017), which may spread from these areas in the near future. Human activity accelerates the spread of certain species between settlements by providing similar abiotic and biotic conditions. This, together with the expected impact of climate change and with the co-migration of the vegetation, many (thermophilic) plant species may colonize populated areas in the near future (Lososová et al. 2018). Studying the urban floras is also important from the aspects of protecting the native vegetation and of invasion biology.

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According to Elton's invasion biological hypothesis ("poor get richer" theory) a negative correlation is expected between native and alien species richness (Elton 1958). However, this "biotic resistance hypothesis" was rejected in several studies (Stohlgren et al. 2003) and led to the formulation of a complementary hypothesis, the "rich get richer" theory. On the other hand, Elton's "poor get richer" theory was supported by Ricotta et al. (2010) in the urban region of Brussels.

Despite the negative association between urban environment and biodiversity loss, there is no precedent a systematic vascular flora survey based on grid mapping in the case of Hungarian settlements. Consequently, we know almost nothing about the species richness and the distribution of native and alien plant species in the urban areas of the country. Most Hungarian studies dealt with the emergence, establishment and spread of certain species (e.g. Wolf and Király 2014; Takács and Löki 2015). In some cases only parts of a settlement were investigated (e.g. Czúcz 2005; Hüse et al. 2016) and rarely was an entire settlement surveyed. In these latter cases the authors usually dealt with only one taxonomic group (e.g. Bodnár 1956; Somlyay and Lőkös 2000; Schmotzer 2019), the entire flora was rarely examined (e.g. Borbás 1879; Jeanplong 1977a). Some of the most extensive botanical works reveal the flora of a settlement and its wider surroundings (e.g. Jeanplong 1977b), but in most cases the authors inaccurately define the study area (e.g. Zólyomi 1958).

As opposed to the earlier examples in Hungary, we studied the entire (spontaneous and sub-spontaneous) vascular flora of a Hungarian county seat throughout its administrative area in a systematic manner. Accordingly, in this paper we present the descriptive statistic results of the first systematic flora survey of the largest south Transdanubian city (Pécs) and its immediate vicinity: (1) the species richness in two scales, (2) the ratio and distribution patterns of the native and alien vascular plant species, (3) the proportion and distribution of protected species, (4) the relationship between the above variables and the built-up areas, forest coverage and elevation, as well as (5) the list of the most widespread taxa of Pécs.

Materials and methods

Study area

The city of Pécs is located in South Hungary on the southern foothills of the Mecsek Mts (46° 04' N, 18° 14' E). The most built-up areas lie on the Pécs Plain and on the northern side of the South Baranya Hills. The residential area of the city is 162.77 km², the number of inhabitants was 142,873 in 2019 (Központi Statisztikai Hivatal 2019). The altitude

ranges between 115 and 611 m a.s.l. (mean slope angle: 6.59°), densely populated areas lie below 200 m (the altitude of the city centre is 127 m). The climate is submediterranean and except the highest regions of the city, the area is the warmest part of Hungary (mean annual temperature: 9.9 °C) with relatively high precipitation (mean annual precipitation: 673 mm/year) (Dövényi 2010). Most of the forested areas lie in the western and northern parts of the municipal area, mainly at higher elevations on the slopes of the Mecsek Mts. The heavily modified and built-up areas (residential areas, urban brown fields, agricultural areas etc.) are located in the southern and the eastern parts of the city, most of them in the Pécs Plain and the Baranya Hills and partly on the southern slopes of the Mecsek Mts (Fig. 1, [2]).

Species data

In this study the municipality area of Pécs was divided into a grid according to the network of the Hungarian Flora Mapping Project (hereinafter HFMP), which follows the Central European floristic mapping project (Niklfeld 1971). By quartering the Central European grid units, we get the HFMP units, which have an area of approximately 35 km² (Király 2003; Bartha et al. 2015). In the case of Pécs 12 HFMP grid units cover—in whole or in part—the residential area of the city. These quadrates were divided into 16 equal units (2.2 km² sized grid units) following the graticule. A total of 104 of these plots cover (completely or partially) the present administrative area of the city. 55 of them (hereinafter PGU, abbreviated from partial grid

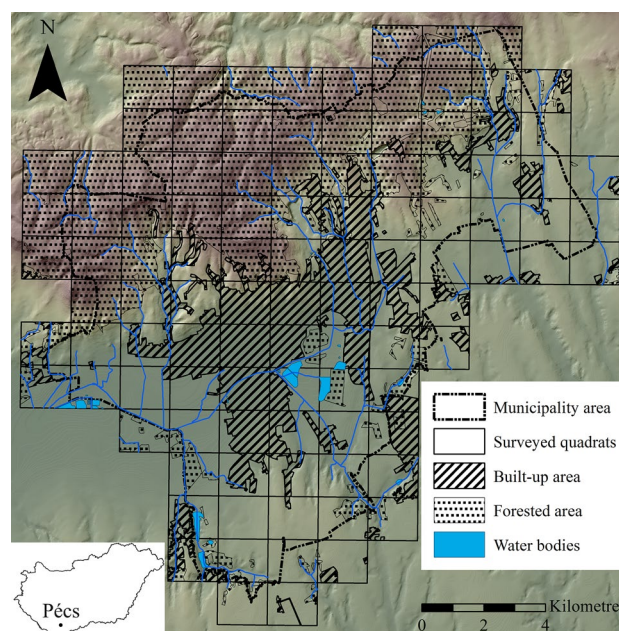


Fig. 1 Location of Pécs in Hungary (inset map) and the flora mapping grid of the city

unit) extended beyond the city border. The entire area of each PGU was surveyed to allow the comparison of the units (Fig. 1). The study area (hereafter referred to as Pécs) represents a larger area (~225.5 km²) than the administrative area of Pécs and includes its immediate vicinity as well. Consistent with Forman's (2014) concept, the surveyed grid units represent the city area (Pécs) and parts of the settlements in the agglomeration area (Bogád, Cserkút, Hosszúhetény, Keszü, Kozármisleny, Kökény, Kővágószőlős, Martonfa, Pereked, Pécsudvard, Pogány, Romonya), including the farmlands and/or semi-natural forests of the peri-urban and/or exurban zones as well. Therefore, in this approach, "urban flora" was treated in the broadest sense (e.g. Godefroid 2001). Like in indirect gradient analysis, in our study the position of a grid unit along the urban–rural gradient was more or less independent from the geographical position, and was defined by the ratio of built-up areas and/or the ratio of forest coverage within a unit.

The floristic census was executed from 2008 to 2014. Each unit was surveyed three times, in spring (between late February and early May), and in early and late summer (between late May and early September). We recorded and compiled data exclusively of the spontaneously and subsponaneously occurring species, while planted and clonally growing escapes were not added to the species lists. The taxonomically problematic species (e.g. certain *Hieracium* microspecies, *Verbascum* and *Viola* hybrids) were also left out from the census. The nomenclature of species follows Király (2009), and in the case of species excluded from this list we used the database of The Plant List [3]. Those species (hereinafter frequent species) that exceed the 91% threshold frequency value according to their presence/absence data within the 104 grid units are listed in Table 2.

For analysing the flora the following species attributes were considered: (1) the immigration status of the species (according to Pyšek 1995; Terpó et al. 1999; Balogh et al. 2004): native species—those present in the local flora before the Neolithic times or immigrated there without direct or indirect human intervention, archaeophytes—introduced before the discovery of America, approx. 1500 A. D—and neophytes—introduced after that date, (2) the status of legal protection (according to Magyar Közlöny 2015), and (3) in the case of the most widespread species the dispersal types (anemo-, hydro-, endozoo- and autochorous species), life forms (annual and biennial species, perennial herbaceous species, shrubs and trees) and chorological types (adventive, cosmopolitan, European, continental, Mediterranean, boreal and mountain, and endemic species) according to Soó (1964, 1966, 1968, 1971, 1973, 1980), Horváth et al. (1995) and Terpó et al. (1999).

Data analysis

For analyzing the relationships between plant species richness and environmental variables, in each grid unit two variables of land cover (percentage of built-up area and forested area per units) [4] were measured with ArcMap GIS (v.10.0, ESRI, Redlands, CA, USA). In the cases of PGUs the built-up areas and the forest coverage belonging to settlements other than Pécs were also considered. The proportions of native species, archaeo- and neophytes were calculated in relation to the total species numbers of the grid units. The above ratios, the proportion and number of species in the grid units and the elevation were logarithmically transformed to linearize the relationship with the dependent variable. Correlations of species traits in individual grid units were explored using separate simple linear regressions for the transformed ratio of species traits. The Holm method was applied on the tests' *p* values to control the family-wise error rate. The statistical analyses were carried out in R version 3.2.4. (R Core Team 2016).

Results

1458 spontaneous or subsponaneous species were registered during the 6 years survey period in Pécs. Among them 1011 were native. Out of the 447 aliens, 152 are archaeophytes, while 295 are neophytes. The average number of plant species per grid unit was 338 (min. 199, max. 577, sd 77). The observed mean of natives was 252 (min. 116, max. 436, sd 66), the mean of archaeophytes was 51 (min. 8, max. 88, sd 18), while the mean of neophytes was 35 (min. 6, max. 115, sd 21) per cell. Built-up areas tend to concentrate at lower elevations (Fig. 6A), where the proportion of aliens was higher (Fig. 5B, C), and forest coverage tends to grow towards higher elevations (Fig. 6B), where the proportion of natives was also higher (Fig. 5A). The proportion of natives positively correlates with the forest coverage ($F_{1,102} = 219.10$, $R^2 = 0.68$, $p_{\text{corr}} < 0.01$) and negatively to the percentage of built-up areas ($F_{1,102} = 64.24$, $R^2 = 0.38$, $p_{\text{corr}} < 0.01$) (Table 2, Figs. 3A, 4A). In contrast with natives, neophytes are negatively correlated with forest coverage ($F_{1,102} = 137.00$, $R^2 = 0.57$, $p_{\text{corr}} < 0.01$) and positively with the percentage of built-up areas ($F_{1,102} = 86.32$, $R^2 = 0.45$, $p_{\text{corr}} < 0.01$) (Table 2, Figs. 3C, 4C).

As a result of the above preferences native taxa are more frequent on the high-standing, north-western side of the city (Fig. 2A), while neophytes prefer the central part of Pécs (Fig. 2C). The highest archaeophyte proportion was observed in the low-lying, south-eastern zone of the city (Fig. 2B).

131 of the listed taxa are legally protected in Hungary. The observed mean of protected species per unit was 12

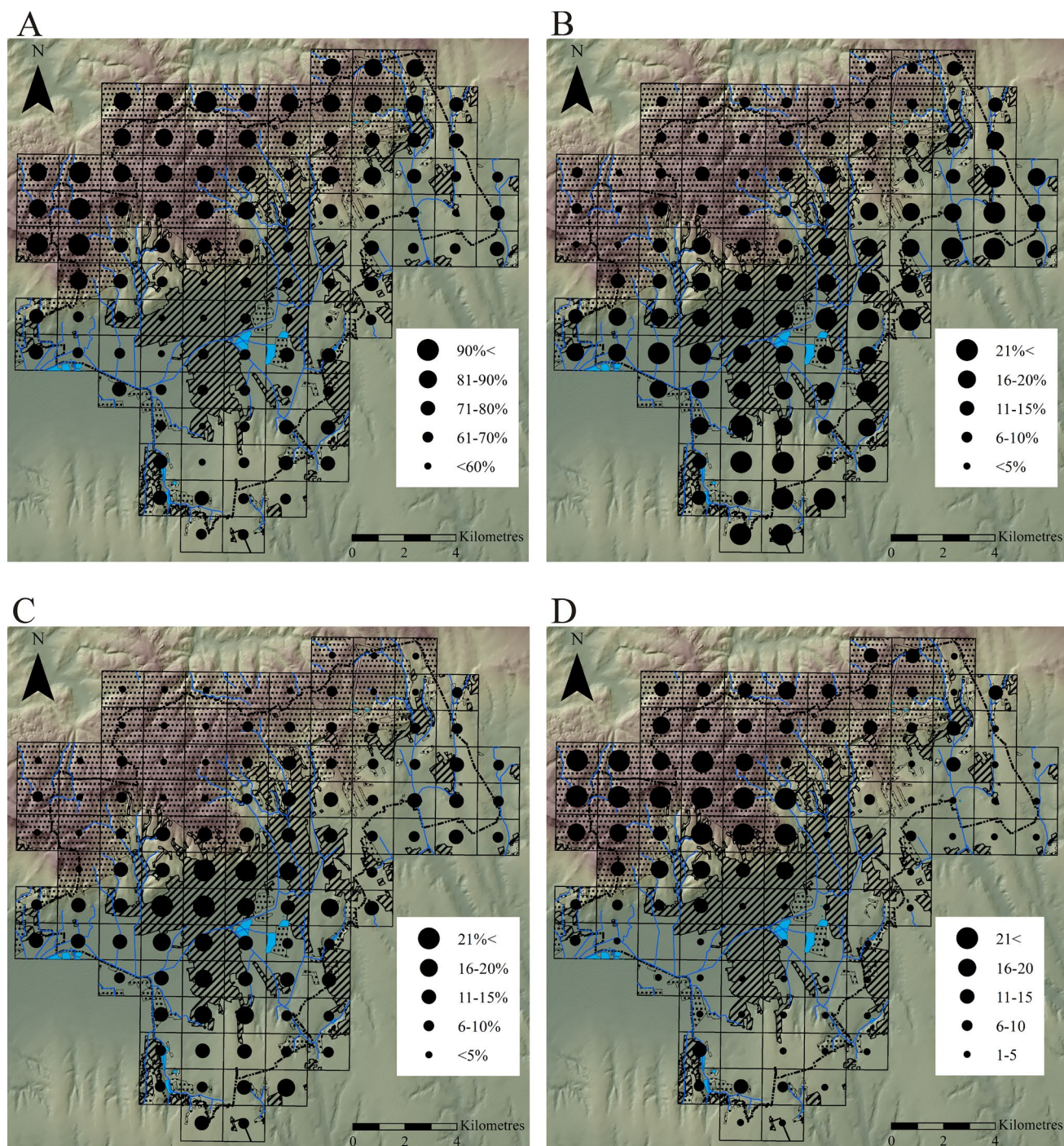


Fig. 2 Distribution of species frequencies based on the immigration and protection status of the species in Pécs, Hungary. Percentages of species numbers per grid units are shown in the cases of immigra-

(min. 0, max. 49, sd 11). Linear correlation between the legally protected species number and the species richness per unit was significantly positive ($F_{1,102} = 27.56$, $R^2 = 0.21$, $p_{\text{corr}} < 0.01$) (Table 1, Fig. 6D). The mapping units with the highest number of legally protected species were found on the north-western part of the city (Fig. 2D). This is the most

tion types and the total species numbers per grid units in the case of protected species. **A** native species, **B** archaeophytes, **C** neophytes, **D** protected species. For the legend of map patterns see Fig. 1

forested part of Pécs. Correlation between the forest coverage and the number of legally protected species in a unit was significantly positive ($F_{1,102} = 78.35$, $R^2 = 0.43$, $p_{\text{corr}} < 0.01$) (Table 2, Fig. 4D).

According to the selected threshold value, 52 species were considered as frequent species. Among these taxa

Table 1 Simple linear regression statistics for land cover types versus the proportion of species per grid units based on the immigration status of species and the number of species based on the protection status of species; and for land cover types versus mean elevation

Simple linear regression							
Model	Direction	<i>F</i>	<i>df</i>	Intercept	<i>x</i>	<i>R</i> ²	<i>p</i> _{corr}
Built-up area vs. native species	Negative	64.24	1, 102	4.41	−0.05	0.38	***
Built-up area vs. archaeophytes	Positive	35.29	1, 102	2.49	0.12	0.25	***
Built-up area vs. neophytes	Positive	86.32	1, 102	7.16	2.19	0.45	***
Built-up area vs. protected species	Negative	18.02	1, 102	2.37	−0.23	0.14	***
Forested area vs. natives species	Positive	219.10	1, 102	4.16	0.06	0.68	***
Forested area vs. archaeophytes	Negative	141.30	1, 102	3.14	−0.17	0.58	***
Forested area vs. neophytes	Negative	137.00	1, 102	16.77	−2.18	0.57	***
Forested area vs. protected species	Positive	78.35	1, 102	1.05	0.37	0.43	***
Mean elevation vs. native species	Positive	27.89	1, 102	3.79	0.32	0.21	***
Mean elevation vs. archaeophytes	Negative	73.67	1, 102	8.00	−0.76	0.41	***
Mean elevation vs. neophytes	Negative	58.98	1, 102	8.45	−0.92	0.36	***
Mean elevation vs. protected species	Positive	114.80	1, 102	−8.03	1.87	0.52	***
Mean elevation vs. built-up area	Negative	22.44	1, 102	5.57	−0.49	0.17	***
Mean elevation vs. forested area	Positive	248.90	1, 102	5.11	0.68	0.71	***
Built-up area vs. alien-native ratio	Positive	64.08	1, 102	3.08	0.22	0.38	***
Species number vs. protected species number	Positive	27.56	1, 102	−9.77	2.06	0.21	***

*p*_{corr} = corrected *p* value
 n.s. *p* < 0.1; ***p* < 0.05; ****p* < 0.01

hemicryptophytes (55.8%), widespread (Eurasian 28.8%, cosmopolitan 26.9%), native (82.7%), and zoochorous (endo- 48%, epizoochorous 15.4%) species were dominant (Table 2.). Four of them [*Ambrosia artemisiifolia* L., *Conyza canadensis* (L.) Cronquist, *Erigeron annuus* (L.) Pers. and *Solidago gigantea* Aiton)] are invasive aliens and native to North America.

Discussion

The high number of spontaneous and subspontaneous vascular plant species is striking compared to other areas of Hungary, since more than 53% of the species having been recorded in Hungary (Király 2009) are present in an area less than 0.2% of the country. In this and in a coarser scale (i.e. HFMP) the observed richness is unique in the country (Bartha et al. 2019). It is often supposed, however, that this richness is a result of the introduced aliens, mainly the neophytes (Kühn et al. 2004). When considering native and alien taxa separately the outcome does not differ: more than half of the native species of Hungary (Király, l.c.) are present in the city flora. Among aliens 41.7% of the neophytes recorded in the current list of the Hungarian neophytes (Balogh et al. 2004) were found in Pécs, more than 70% of the archaeophytes mentioned in the Hungarian archaeophyte list (Terpó et al. 1999) were present in the city. This richness of the archaeophytes can be explained by the spatial distribution of arable lands, backyards, orchards and vineyards, which traditionally occupy the lower region of the city (on the south-east) (G.

Detky 2010). The rate of natives:archaeophytes:neophytes (7:1:2) in Pécs is highly different from the rate of these taxa (2:1:1) in other European cities (Chochołoušková and Pyšek 2003). As in other cases worldwide (Araújo 2003; Kühn et al. 2004), the strikingly high proportion of natives in Pécs can be a result of the originally diverse biota that made this area attractive for the city founders. Since the persistence of species against disturbances is a time dependent process (MacDougall et al. 2013), the survival of native species in urban ecosystems depends on the beginning of intensive urbanization. Therefore the difference in the native:archaeophyte:neophyte ratio between the European mean and Pécs can be the consequence of the slow and late industrialization and urbanization of Pécs in the middle of the twentieth century (Fórián 2007).

Distribution maps showed that spatial patterns of native and alien species are different (Fig. 2), the proportion of aliens is higher in more built-up areas (Fig. 3), while natives are more abundant in the forested regions (Fig. 4). With increasing mean elevation, the number of native species increases, while the number and rate of aliens decreases (Fig. 5). According to Li et al. (2018) settlements and human activities are generally located at lower altitudes and are expanding mostly towards flat areas, therefore the non-native species accumulate mainly in lower parts of urban areas and reach the higher elevations later (Gou et al. 2018). Similar tendencies in settlement development were observed in the past decades in the case of Pécs, where the city tended to expand mostly towards the southern flatlands and partially towards the lower slopes of the Mecsek Mts (Gyenzisz

Table 2 List of frequent species (threshold frequency value $\geq 91\%$)

Species	Frequency	Life form	Chorotype	Status	Dispersal type
<i>Clematis vitalba</i>	100.0	N-E	SME	*	Anemo.
<i>Geum urbanum</i>	100.0	He	CIR	*	Epi.
<i>Urtica dioica</i>	100.0	He	COS	*	Endo.
<i>Dactylis glomerata</i>	99.0	He	COS	*	Endo.
<i>Erigeron annuus</i>	99.0	Th	ADV	Inv.	Anemo.
<i>Poa annua</i>	99.0	Th-TH	COS	*	Endo.
<i>Stellaria media</i>	99.0	Th-TH	COS	*	Anemo.
<i>Trifolium pratense</i>	99.0	He	EUA	*	Endo.
<i>Trifolium repens</i>	99.0	He	COS	*	Endo.
<i>Calamagrostis epigeios</i>	98.1	He	EUA	*	Epi.
<i>Galium mollugo</i>	98.1	He	CIR	*	Epi.
<i>Plantago major</i>	98.1	He	COS	*	Anemo.
<i>Rubus fruticosus</i> agg.	98.1	He-N	CIR	*	Endo.
<i>Capsella bursa-pastoris</i>	97.1	Th-TH	COS	+	Anemo.
<i>Polygonum aviculare</i>	97.1	Th	COS	*	Epi.
<i>Rosa canina</i> agg.	97.1	M	EUR	*	Endo.
<i>Sambucus nigra</i>	97.1	MM-M	EUR	*	Endo.
<i>Taraxacum officinale</i> agg.	97.1	He	EUA	*	Anemo.
<i>Artemisia vulgaris</i>	96.2	He(Ch)	CIR	*	Anemo.
<i>Daucus carota</i>	96.2	Th-TH	COS	*	Anemo.
<i>Prunus spinosa</i>	96.2	M	EUR	*	Endo.
<i>Ambrosia artemisiifolia</i>	95.2	Th	ADV	Inv.	Epi.
<i>Cichorium intybus</i>	95.2	He(Th)	EUA	+	Anemo.
<i>Cirsium arvense</i>	95.2	G	EUA	*	Anemo.
<i>Cornus sanguinea</i>	95.2	M	SME	*	Endo.
<i>Hypericum perforatum</i>	95.2	He	EUA	*	Anemo.
<i>Medicago lupulina</i>	95.2	Th-TH	EUA	*	Epi.
<i>Solidago gigantea</i>	95.2	He	ADV	Inv.	Anemo.
<i>Crataegus monogyna</i>	94.2	M	EUR	*	Endo.
<i>Elymus repens</i>	94.2	He	CIR	*	Endo.
<i>Euonymus europaeus</i>	94.2	M	EUR	*	Endo.
<i>Galium aparine</i>	94.2	Th	COS	+	Epi.
<i>Potentilla reptans</i>	94.2	He	COS	*	Endo.
<i>Rubus caesius</i>	94.2	He-N	EUA	*	Endo.
<i>Achillea collina</i>	93.3	He	CON	*	Endo.
<i>Alliaria petiolata</i>	93.3	TH-He	EUA	*	Endo.
<i>Arrhenatherum elatius</i>	93.3	He	EUA	*	Endo.
<i>Ballota nigra</i>	93.3	He(Ch)	SME	+	Epi.
<i>Lolium perenne</i>	93.3	He	COS	*	Endo.
<i>Lotus corniculatus</i>	93.3	He	EUA	*	Auto.
<i>Picris hieracioides</i>	93.3	TH-He	EUA	*	Anemo.
<i>Plantago lanceolata</i>	93.3	He	COS	*	Endo.
<i>Poa pratensis</i>	93.3	He	CIR	*	Endo.
<i>Acer campestre</i>	92.3	MM	EUR	*	Anemo.
<i>Convolvulus arvensis</i>	92.3	He	SME	*	Endo.
<i>Conyza canadensis</i>	92.3	Th-TH	ADV	Inv.	Anemo.
<i>Euphorbia cyparissias</i>	92.3	He(G)	EUA	*	Auto.
<i>Glechoma hederacea</i>	92.3	He(Ch-G)	EUA	*	Endo.
<i>Ligustrum vulgare</i>	92.3	M	AsM	*	Endo.
<i>Centaurea jacea</i>	91.3	He	EUA	*	Endo.
<i>Potentilla argentea</i>	91.3	He	CIR	*	Anemo.
<i>Verbena officinalis</i>	91.3	Th-He	COS	+	Anemo.

Life forms: Th = annuals, TH = biennials, Ch = chamaephytes, G = geophytes, He = hemicryptophytes, HH = hydrophytes, N = dwarf shrubs, M = shrubs, M-E/N-E = vines, MM = trees; chorotype: ADV = adventive (archaeo- and neophytes), COS = cosmopolitan, CIR = circumpolar, EUA = Eurasian,

Table 2 (continued)

EUR = European, CON = continental, MED = Mediterranean, SME = sub-Mediterranean, AsM = atlantic sub-Mediterranean; status: * = native species, + = archaeophyte, inv. = invasive neophyte; dispersal type: Anemo. = anemochorous, Auto. = autochorous, Endo. = endozoochorous, Epi. = epizoochorous, Hydro. = hydrochorous species

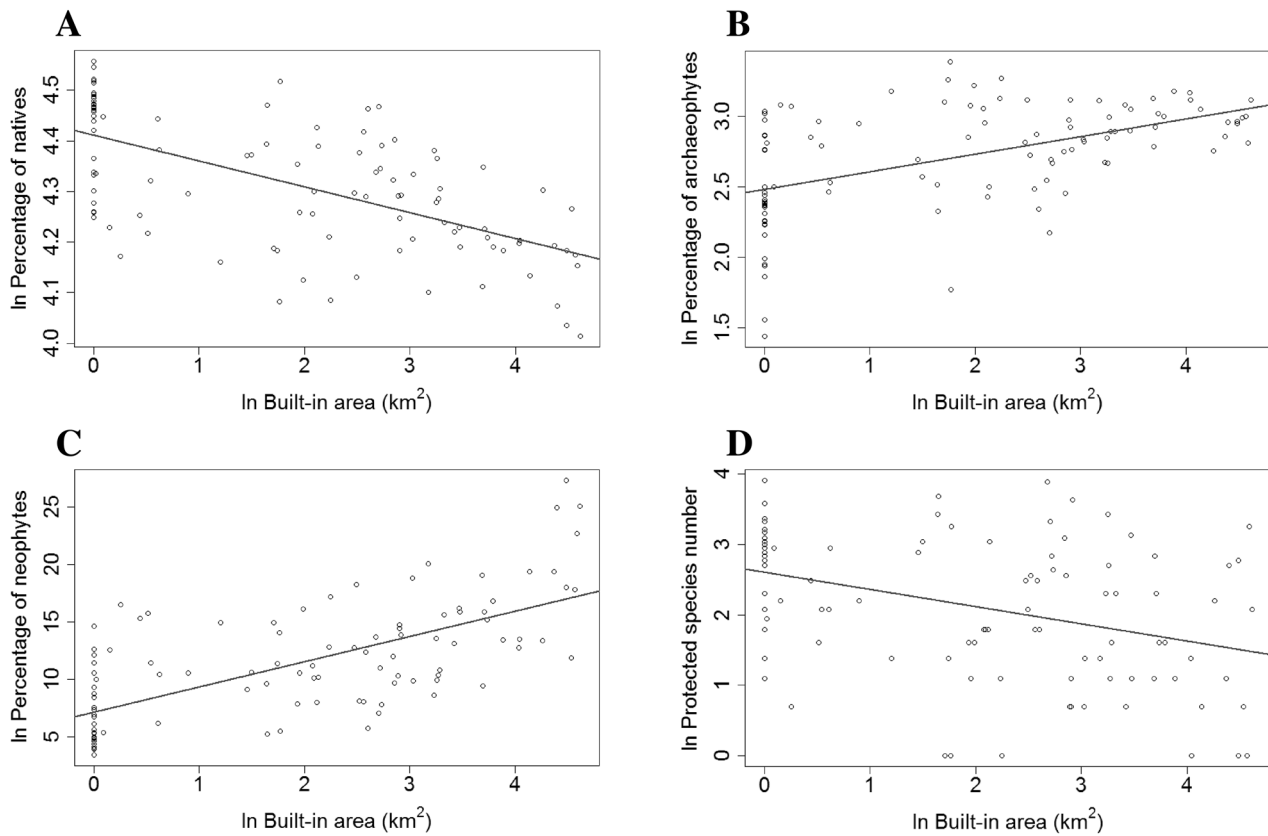


Fig. 3 Relationship between **A** the built-up area and the proportion of native species ($y = -0.05x + 4.41$); **B** the built-up area and the proportion of archaeophytes in the sampling units ($y = 0.12x + 2.49$); **C** the

built-up area and the proportion of neophytes ($y = 2.19x + 7.16$); **D** the built-up area and the number of protected species ($y = -0.25x + 2.61$)

2009). The accumulation of non-native species in the city centre and in the low-lying parts of the settlement may be the result of the current settlement structure, the high amount of traffic, and the high density of inhabitants there. In contrast the high proportion of native species observed in the higher regions of the city can be related to nature conservation (e.g. Natura 2000 areas) and the extensive (semi)natural habitats, ultimately results of less intensive urbanization effects. In an indirect manner, these opposite trends lead to the conclusion that in the case of the vascular flora of Pécs the Eltonian (i.e. “poor get richer”) principle (Elton 1958) and not the “rich get richer” theory (Stohlgren et al. 2003) is supported. Thus aliens became more frequent and displaced native species where human activities (disturbances) were more explicit (Fig. 6C). This result supports the main findings of a grid-based analysis of the urban flora in Brussels (Ricotta et al. 2010) and could be a consequence of a general process in cities. It is noteworthy that according to this deduction

(Gou et al. 2018; Li et al. 2018) spatial (vertical) and temporal (migratory) constraints and not the biotic resistance (Elton 1958; Stohlgren et al. 2003) was responsible for these opposite trends.

Since most of the protected species are native to Hungary (Magyar Közlöny 2015), it is not surprising that the distribution of legally protected species and that of natives showed almost the same pattern in Pécs (Figs. 2A, D, 6D). From the nature conservational point of view, the most valuable part of the city is the north-western, forested exurban corner of Pécs, on the slopes of the Mecsek Mts. Fortunately, most of this area is part of the Natura 2000 network [5]. The dominant urban habitats of these slopes are the private gardens and vineyards, and this strongly increases the propagule pressure of aliens (Pergl et al. 2016) and makes these areas vulnerable to biological invasions. Since alien species reach the forested areas primarily from the urban areas (Duguay et al. 2007), this valuable part of the city, rich in native and

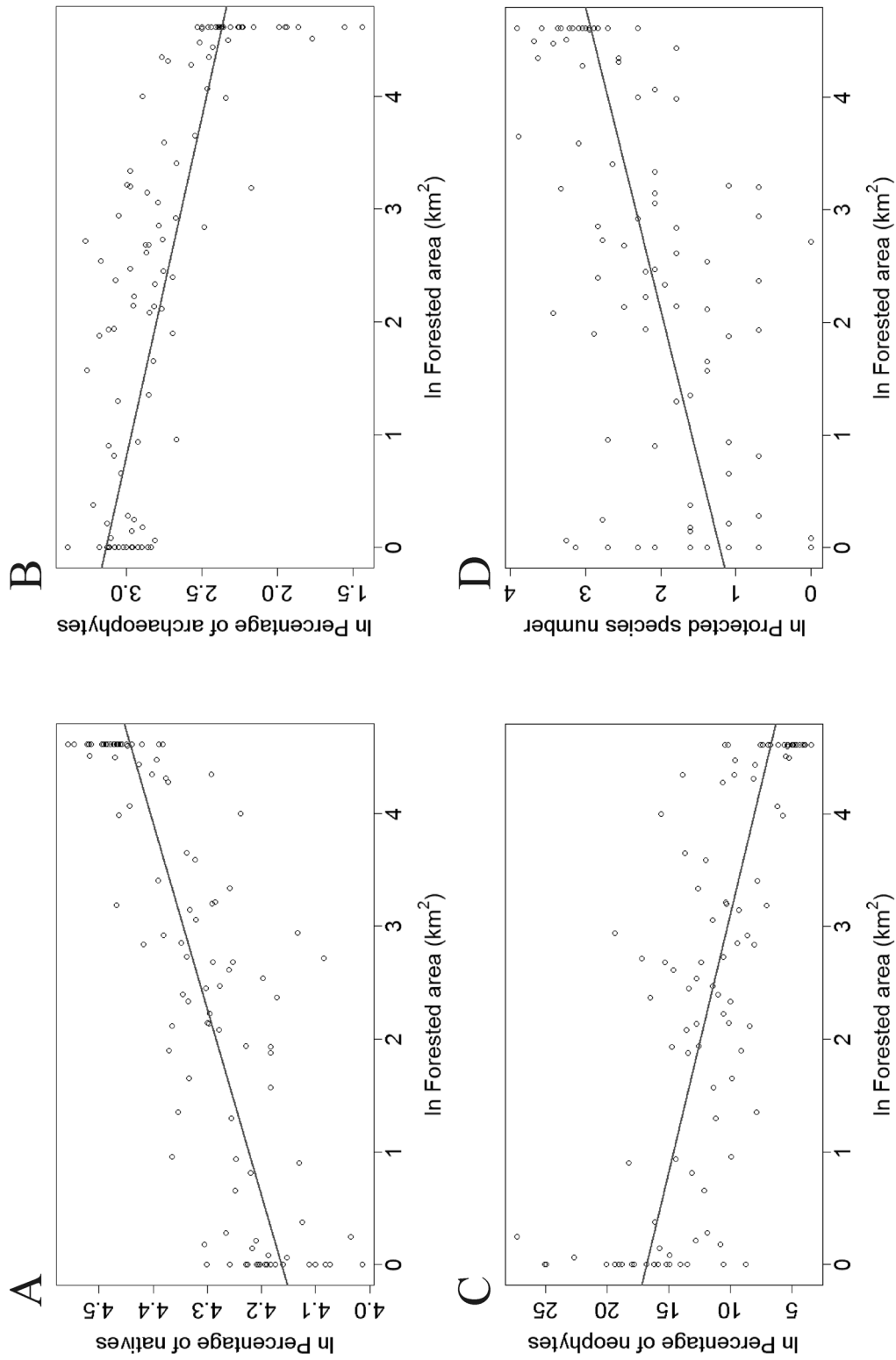


Fig. 4 Relationship between **A** the forested area and the proportion of native species ($y = 0.06x + 4.16$); **B** the forested area and the proportion of archaeophytes ($y = -0.17x + 3.14$); **C** the forested area and the proportion of neophytes ($y = -2.18x + 16.77$); **D** the forested area and the number of protected species ($y = 0.37x + 1.22$)

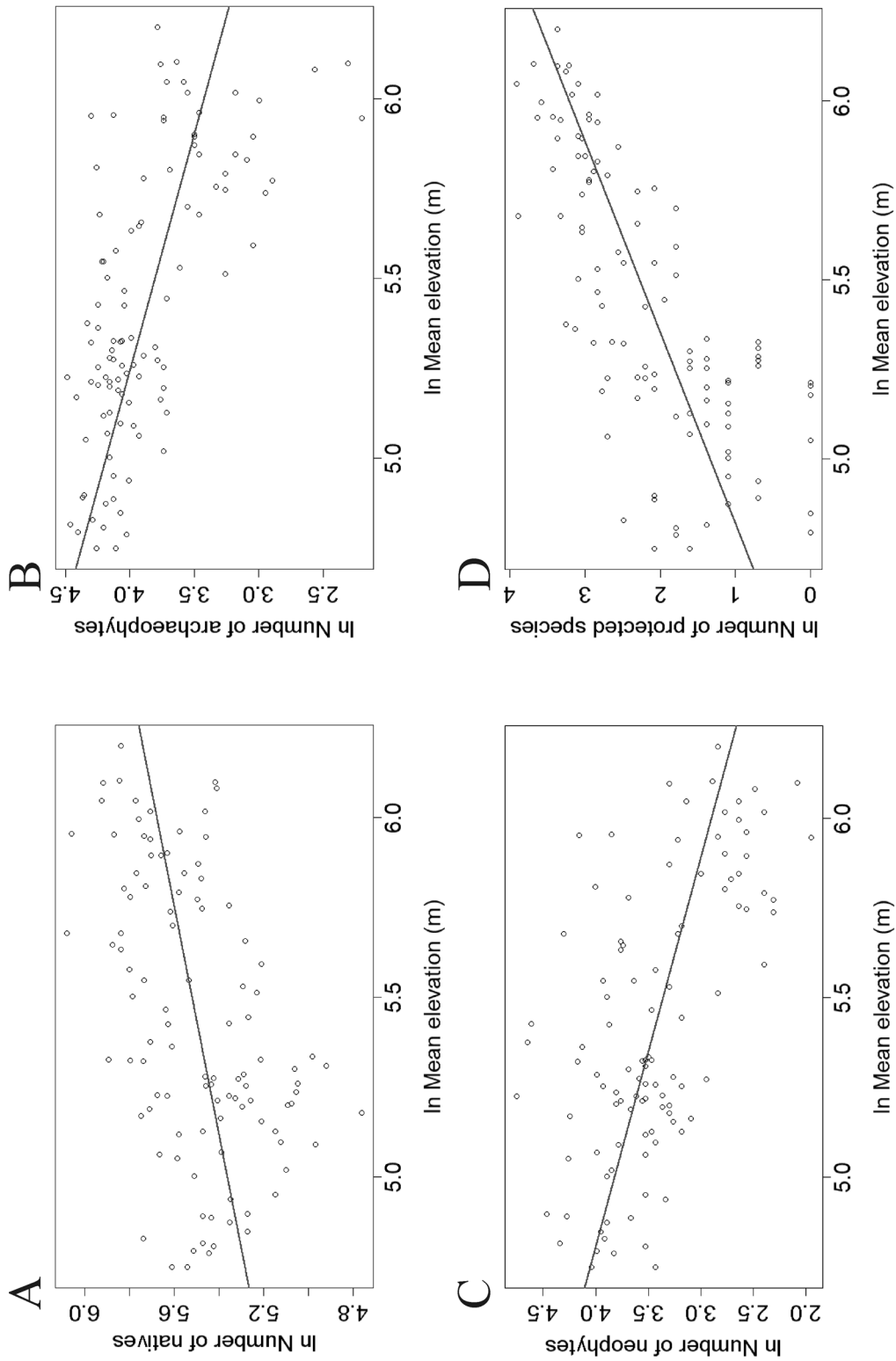


Fig. 5 Relationship between the mean elevation per grid units and **A** the proportion of native species ($y=0.32x+3.79$); and **B** the proportion of archaeophytes ($y=-0.76x+8.00$); and **C** the proportion of neophytes ($y=-0.92+8.45$); and **D** the number of protected species ($y=1.87x-8.03$)

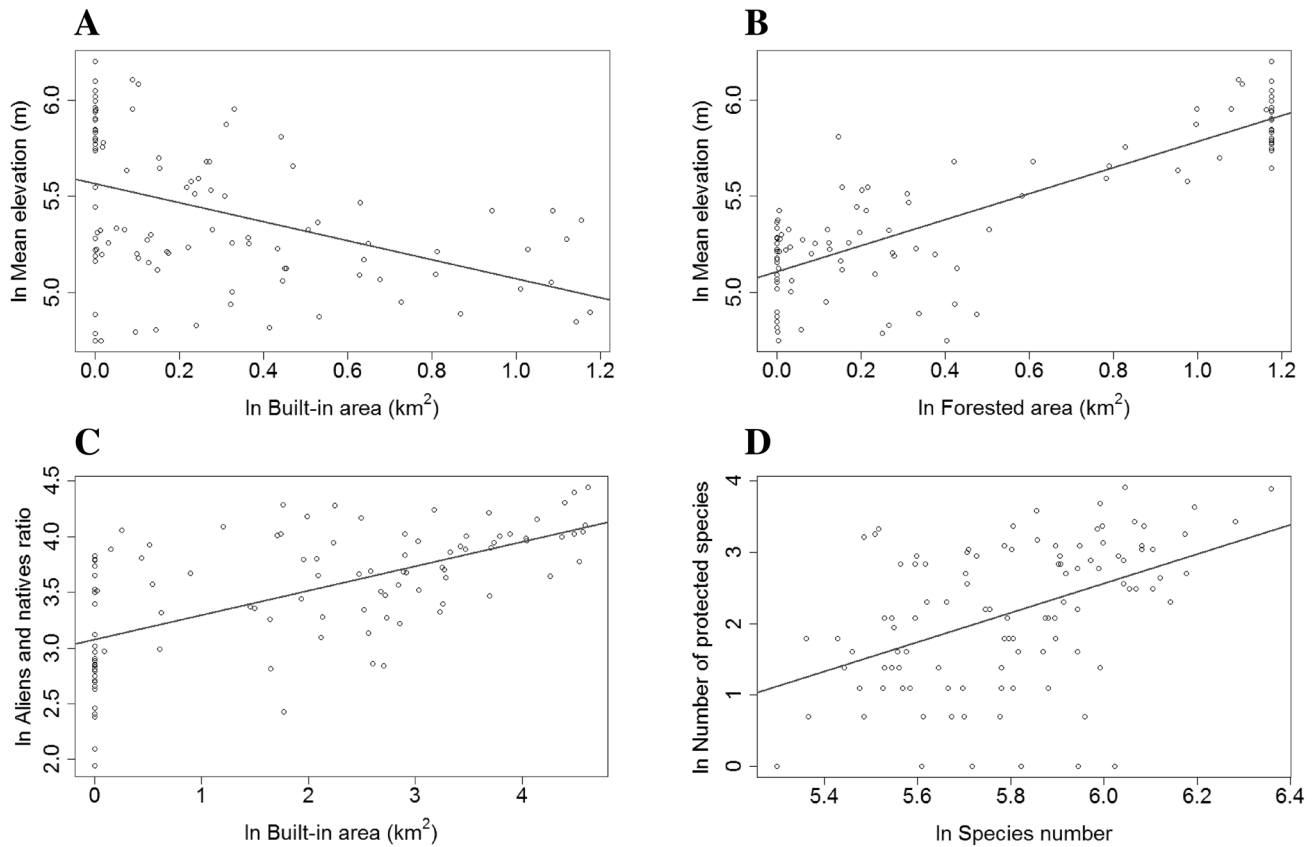


Fig. 6 Relationship between **A** the mean elevation per grid units and the built-up area ($y = -0.49x + 5.57$); **B** the mean elevation per grid units and the forested area ($y = 0.68x + 5.11$); **C** the built-

up area and the alien/native species ratio in the sampling units ($y = 0.22x + 3.08$); **D** the species number and the protected species number ($y = 2.06x - 9.77$)

protected species, needs active management in the future (e.g. education, information of owners, control and eradication of neophytes).

Species traits of the frequent species fit the general trends in the country (Horváth et al. 1995; Botta-Dukát et al. 2004; Király 2009), since hemicryptophyte, widespread and native species are the most frequent taxa and the most frequent invasive species are native to North America.

Conclusion for future biology

Although urban vascular flora mapping has a long tradition in Europe, this study is the first grid-based approach that surveyed the spontaneous and sub-spontaneous flora of a city in Hungary. Results of grid-based mapping like this give the opportunity to reveal the species richness at different scales and give a baseline to highlight long-term changes in urban ecosystems in the future. Since micro- and macroclimate of urban ecosystems is warmer than that of their surroundings (i.e. urban heat dome of large cities), species that can adapt to the present urban climate are

more likely to survive in exurban, peri-urban and rural habitats in a warmer climate of the future [6]. Ordering the registered species according to their frequency as well as producing distribution maps can help zoologists to plan experiments along urban gradients (e.g. for studying phytophagous taxa). Studying the rate of alien and native taxa per units in the city gives the opportunity to test general concepts like the “poor get richer” and “rich get richer” theories. Since Pécs lies in the transition zone between the Pannonian Basin and the Balkans, for sketching a more reliable picture of the general Pannonian flora in urban ecosystems, it is necessary to map the flora of other cities in Hungary as well.

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Authors' contribution TW, KD and JCs collected the field data, KS compiled the base GIS data. TW and JCs analyzed the data, prepared the tables and figures and drafted the article.

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Data accessibility The article's supporting data and digital research materials are available on request from the corresponding author TW.

Compliance with ethical standards

Conflict of interest The authors have no competing interest.

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