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Dynamics of the species diversity and composition of the ruderal vegetation of Slovak and Czech cities

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Ključne besede: tujerodne invazivne vrste, neofiti, Shannon–Wiener diverzitetni indeks, vrstna poravnanost, sinantropne rastlinske združbe.

Abstract

This study reports the results of the evaluation of changes in the species diversity and composition of ruderal vegetation of three Slovak and one Czech city over the time. The dataset of 1489 relevés from five ruderal syntaxa from the cities Bratislava, Malacky, Trnava and Brno was used. Data were from two different time periods, the older dataset from the years 1960–1982, the more recent dataset from the years 2005–2016. The statistical analysis revealed the decrease of Shannon–Wiener diversity index of all (native + alien) species in the majority of classes of ruderal vegetation of cities. The analysis of the changes in the Pielou's measure of species evenness showed that in some of the classes and cities, the species evenness remained unchanged, in the other ones it decreased. The percentage of native species in the ruderal vegetation did not change over the time, but the percentage of invasive alien species in the majority of syntaxa and cities increased significantly. In total, 38 invasive taxa were recorded in the ruderal vegetation of cities. Most of them are neophytes, therophytes and belong to the family Asteraceae. The majority of invasive taxa were recorded in both time periods. Some of the invasive species, e.g. *Fallopia japonica* and *Juncus tenuis* were recorded only in the more recent time period. Our results contribute to the knowledge about biological invasions in the cities.

Izvleček

V članku objavljamo rezultate analize sprememb vrstne pestrosti in sestave ruderalne vegetacije treh mest na Slovaškem in enega na Češkem skozi čas. Uporabili smo 1489 vegetacijskih popisov petih ruderalnih sintaksonov iz mest Bratislava, Malacky, Trnava in Brno. Podatke smo razdelili na dve časovni obdobji, starejši podatkovni niz iz obdobja 1960–1982 in novejši niz iz obdobja 2005–2016. S statistično analizo smo pokazali, da se je Shannon–Wienerjev diverzitetni indeks vseh vrst (domorodnih in tujerodnih) v večini razredov ruderalne vegetacije v mestih zmanjšal. Analiza sprememb mere vrstne poravnanosti (Pielou) je pokazala, da je vrstna poravnanost v določenih razredih in mestih ostala nespremenjena, v določenih pa se je zmanjšala. Odstotek domorodnih vrst v ruderalni vegetaciji se ni spreminjal s časom, značilno pa se je tako v sintaksonih kot v mestih povečal odstotek invazivnih tujerodnih vrst. Skupaj smo v ruderalni mestni vegetaciji zabeležili 38 invazivnih taksonov. Večinoma so neofiti, terofiti in jih uvrščamo v družino Asteraceae. Večino invazivnih taksonov smo zabeležili v obeh časovnih obdobjih, nekatere invazivne vrste, kot sta na primer *Fallopia japonica* in *Juncus tenuis,* pa smo smo opazili le v novejšem obdobju. Rezultati naše raziskave prispevajo k poznavanju bioloških invazij v mestih.

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Introduction

Urban areas represent strongly anthropogenically altered environments. The unique character of urban areas is reflected by the well adapted species and communities (Sukopp 2002, Forman 2014). There exist considerable habitat heterogeneity, and lot of possibilities for species immigration in urban areas (Sukopp & Werner 1983). All these features cause the general high plant species diversity of cities, but on smaller scales the diversity and the number of species can vary considerably (Sukopp & Werner 1983, Pyšek 1989, 1993, Kühn et al. 2004, Schmidt et al. 2014).

The large part of the species composition of the flora and vegetation of cities is formed by alien species (Pyšek 1998, Chytrý et al. 2005, Vilá et al. 2007, Simonová & Lososová 2008, Medvecká et al. 2009, 2014). Therefore, it is very useful to focus on the research of the alien species in the cities. It is important to differentiate among various ruderal habitats, since the urban environment creates a wide range of different habitat types and there is also a large variability of ruderal plant communities that colonize them (Jarolímek et al. 1997) and they differ in the proportion of alien species (Simonová & Lososová 2008, Medvecká et al. 2009).

It is also important to take into the consideration the fact, that not all of the alien species represent the same threats. Only a small fraction of introduced species can survive in new areas for a long time, start to spread rapidly and become invasive (Mack et al. 2000, Pyšek & Tichý 2001). Hence, it is important to differentiate which alien species are casual, naturalised or invasive (Richardson et al. 2000), because only the invasive species present an actual problem.

Many researchers focused their studies on the whole group of alien plants in urban areas (e.g. Simonová & Lososová 2008, Medvecká et al. 2009, Eliáš jun. 2009, 2011, Jehlík et al. 2013, Király et al. 2014, Aronson et al. 2015, Ferus et al. 2015, Zisenis 2015, Žabka et al. 2015), or various other habitats (Diekmann et al. 2016), but invasive species in ruderal habitats (Tokaryuk et al. 2012) or towns (Bomanowska et al. 2017, Štajerová et al. 2017) have been rarely the object of special studies. Our study is deeper focused on the invasive group of the alien species and their representation in cities.

In the last decades, habitat alteration and introductions of alien plants have resulted in changes in the European urban flora and vegetation and typical of these trends are an increasing proportion of neophytes (Pyšek & Mandák 1997, Chocholoušková & Pyšek 2003, Lososová & Simonová 2008, Gregor et al. 2012) and the decreasing proportion of native species accordingly (Chocholoušková & Pyšek 2003, Lososová & Simonová 2008) over the time. Human activities that make ruderal habitats of studied cities prone to invasions by neophytes (e.g. transport of goods and construction activities) and the increasing anthropogenic influence in the studied cities during the last decades could be reflected by changes in the diversity and species composition, e.g. by an increasing proportion of invasive species in the studied cities. Hence, it is crucial to pay attention to dynamics of the diversity and species composition over the time.

Local diversity (or biodiversity) can be well-expressed by the various indicators, among which the Shannon–Wiener diversity index [H'] is one of the most commonly used metric in ecological studies for measuring species diversity (Hill 1973, Kent & Coker 1992, Magurran 1988, 2004). Diversity is sometimes measured also with a species evenness index (Stirling & Wilsey 2001).

The impact of some invasive species on the Shannon–Wiener diversity [H'] and evenness [J] in various invaded plant communities was studied e.g. in Czech Republic (Hejda & Pyšek 2006, Hejda et al. 2009), changes in plant species diversity (measured by Shannon index) of aquatic ecosystems in the agricultural landscape in West Poland in the last 30 years analysed by Gołdyn (2010). The forest structure and woody vegetation diversity (measured by Shannon index and evenness index) of riparian communities in response to an urbanization gradient was studied in West Georgia, USA (Burton et al. 2005), the measurement of the effects of invasive species *Bothriochloa ischaemum* on Shannon–Wiener diversity diversity was done in central Texas, USA (Gabbard & Fowler 2007), effects of an exotic invasive macrophyte *Urochloa subquadripara* on native plant community species richness and Shannon diversity in Neotropical reservoirs and lakes were evaluated by Michelan et al. (2010), but there is no study dealing with invasive species and diversity dynamics of ruderal vegetation from Slovakia.

Understanding of behaviour of invasive species in cities is of crucial importance, because cities can represent the sources from which invasive species spread into native vegetation (Sukopp & Werner 1983). The knowledge about the invasive species dynamics can help to minimalize their invasions in the future. Therefore, our study is focused on the changes in the diversity and species composition, especially changes invasive species proportion in cities.

The aims of our study are: (1) to analyze the changes in the diversity of all (native + alien) taxa in the various syntaxa of ruderal vegetation of cities over the time; (2) to analyze the changes in the evenness of all (native + alien) taxa; (3) to analyze the changes in the average ratio of native taxa; (4) to analyze the changes in the average percentage of invasive alien taxa (not of all alien taxa, because the study is focused only to the invasive group of alien taxa).

Methods

Study area and relevé data

In the study, we used 1489 relevés of the ruderal plant communities of the phytosociological classes *Polygono-Poetea annuae*, *Sisymbrietea*, *Digitario sanguinalis-Eragrostietea minoris*, *Artemisietea vulgaris*, and *Epilobietea angustifolii* from the cities Bratislava, Malacky, Trnava and Brno. The characteristics of studied cities are shown in the Table 1.

The class *Polygono-Poetea annuae* is comprised of subcosmopolitan therophyte-rich dwarf-herb ruderal vegetation, which grows in trampled habitats, e.g. the edge of pavements, playgrounds, or parking lots. The class *Sisymbrietea* includes zoo-anthropogenic and modern anthropogenic vegetation of disturbed sites, growing in cool- and cold-temperate regions of Eurasia. The class *Digitario sanguinalis-Eragrostietea minoris* is comprised of thermophilous anthropogenic vegetation rich in grasses and summer-annual C4 species, growing in the southern nemoral, mediterranean, steppe and semi-desert parts of Europe. The class *Artemisietea vulgaris* includes perennial subxerophilous ruderal vegetation of the temperate and submediterranean zones of Europe. The class *Epilobietea angustifolii* is comprised of tall-herb semi-natural and anthropogenic perennial vegetation, which grow on wet ruderal areas with high nitrogen content in the soil, disturbed forest edges, nutrient-rich riparian fringes and in forest clearings in the temperate and boreal zones of Eurasia. Described syntaxonomical scheme we used was recently proposed by Mucina et al. (2016).

We used data from two different time periods. The old dataset consisted of 954 relevés from the years 1960–1982 and was compiled from relevés published by Eliáš (1977, 1978, 1979), Jarolímek (1983) and relevés from the Slovak and Czech National Phytosociological Databases (Chytrý & Rafajová 2003, Hegedüšová 2007, Šibík 2012) which match study area, the time period and the selected syntaxa. We selected relevés by the original classification of authors.

The more recent dataset consisted of 535 relevés from the years 2005–2016, out of which 465 were made by authors of the study (Rendeková et al. 2014, Rendeková 2016a, b, c, plus the unpublished relevés made by Rendeková) and 70 relevés which match study area, the time period and the selected syntaxa were obtained from the Slovak and Czech National Phytosociological Databases (Chytrý & Rafajová 2003, Hegedüšová 2007, Šibík 2012).

The phytosociological research in both periods was performed according to the methods of the Zürich-Montpellier school (Braun-Blanquet 1964). In the old time period, the old Braun-Blanquet cover-abundance scale was used. In the more recent period, the modified Braun-Blanquet cover-abundance scale, extended by 2m, 2a and 2b values (Barkman et al. 1964) was used. The area of the data collection in both periods concerns the same districts of the studied cities.

Data analysis

All relevés were imported into the TURBOVEG database (Hennekens & Schaminée 2001) and edited in the JUICE 7.0 programme (Tichý 2002). The relevés made by the authors of the study were classified into the ruderal syntaxa using hierarchical clustering in the programme

Table 1: Characteristic of the studied cities
Tabela 1: Značilnosti preučevanih mest.

city	Bratislava	Malacky	Trnava	Brno
location	southwestern Slovakia	southwestern Slovakia	western Slovakia	south-eastern part of the Czech Republic
area	368 km²	25 km²	71,54 km²	230 km²
approximate population (2016)	426,000	17,300	65,500	378,000
climate	moderate to warm, continental	warm, lightly humid with mild winters	warm	humid continental and borderline oceanic with cold winters and hot to warm summers
number of analysed relevés	695	188	209	397
total number of taxa in whole dataset	672	291	313	403
number of invasive taxa in dataset	26	15	17	26

The table was compiled according to the works of Trnka (1998), Kollár & Kollár (2004), Peel et al. (2007), Hrnčiarová et al. (2009), Macejka & Marek (2009), Feráková & Jarolímek (2011), Macejka (2015).

SYN-TAX 2000 (Podani 2001). Various linkage methods and distance measures were tried. A beta-flexible method (β = −0.25) in combination with Wishart's index, a beta-flexible method (β = −0.25) in combination with Ružička's coefficient, and the Group Average method in combination with Wishart's index proved to be the most effective parameters and were used in most of the hierarchical clustering analyses. The assignment of the other relevés to syntaxa followed the original assignment made by authors of relevés (Eliáš 1977, 1978, 1979, Jarolímek 1983, Chytrý & Rafajová 2003, Hegedüšová 2007, Šibík 2012).

Bryophytes and the taxa of vascular plants determined only to the genus level were excluded from the analysis and the taxa which occurred in more than one layer were merged. As different cover-abundance scales have been used in the old and the more recent relevés, to make the data comparable, the values 2m, 2a, and 2b in both datasets were converted to value 2.

The diversity was expressed by the Shannon–Wiener diversity index [H'], because this index is one of the most commonly used metric in ecological studies for measuring species diversity (Hill 1973, Kent & Coker 1992, Magurran 1988, 2004). We also calculated the species evenness, as the diversity can be measured also with the evenness index (Stirling & Wilsey 2001).

The Shannon–Wiener index of diversity [H'] (e.g. Magurran 1988) and Pielou's measure of species evenness [J=H'/ln(S)], where H' is the Shannon diversity index and S is the number of taxa in every relevé] of all (native + alien) taxa were calculated for every relevé, using the JUICE 7.0 programme.

Then, the taxa in every relevé were divided into native and alien. Alien taxa were divided into casual, naturalized, and invasive. This division was made according to the 'List of alien vascular plant species of Slovak Republic' (Medvecká et al. 2012) for the relevés from Slovak cities, and according to the 'Catalogue of alien plants of the Czech Republic' (Pyšek et al. 2012) for the relevés from Brno. Afterwards, the average percentage number of native taxa and of invasive alien taxa in each relevé was calculated using the JUICE 7.0 programme. We did not calculate average percentual number of all alien taxa, because the study is focused only to the invasive group of alien taxa.

Afterwards, the changes in the average values the Shannon–Wiener index of diversity, Pielou's measure of species evenness, percentual number of native taxa, and the percentual number of invasive alien taxa between the old and the more recent datasets of each class of each city were compared using the Main Effects ANOVA analysis in the STATISTICA 7.0 programme (Hill & Lewicki 2007).

As explanatory feature, the changes in total proportion of recorded invasive alien taxa in the categories of families, Raunkiær's life forms, origin, and residence time between the old and the more recent period was calculated for all relevés of ruderal vegetation (all phytosociological classes together). This calculation was made separately for the group of Slovak cities (Bratislava, Malacky, Tranava together) and separately for Brno (Czech city). The families, Raunkiær's life forms, origin, and residence time of invasive taxa were determined according to the 'List of alien vascular plant species of the Slovak Republic' (Medvecká et al. 2012) and 'Catalogue of alien plants of the Czech Republic' (Pyšek et al. 2012).

As explanatory variable to show if some ecological characteristics of the vegetation types have been changed the mean Ellenberg indicator values for light, temperature, continentality, moisture, soil reaction, and nutrients (Ellenberg et al. 1991) based on species presence, were calculated, using the JUICE 7.0 programme and the changes in the mean Ellenberg indicator values between old and recent data were compared using t-test for independent samples in the STATISTICA 7.0 programme.

Nomenclature

The nomenclature of the taxa follows Marhold (1998), the nomenclature of the syntaxa follows Mucina et al. (2016).

Results

In the majority of the cities, the class *Artemisietea vulgaris* was the class with the highest average values of Shannon–Wiener diversity index of all (native + alien) taxa and average values of the Pielou's measure of species evenness. The classes *Polygono-Poetea annuae* and *Digitario sanguinalis-Eragrostietea minoris* were the classes with the lowest average values of diversity index and species evenness (Figures 1–4).

The highest average percentual number of native species was recorded in the class *Polygono-Poetea annuae*, relatively high also in the classes *Artemisietea vulgaris* and *Epilobietea angustifolii*. The lowest percentual number of native species was recorded in the class *Sisymbrietea*, and relatively low also in the class *Digitario sanguinalis-Eragrostietea minoris* (Figures 5–6).

The average values of the percentual number of invasive species were very high in the class *Digitario sanguinalis-Eragrostietea minoris*, especially in the more recent time period (Figure 7). The percentual number of invasive taxa in this class in the years 2005–2016 in Trnava was as high as 28.6%, in Brno 28.9%. In Bratislava, on the other hand, the percentual number of invasive taxa in

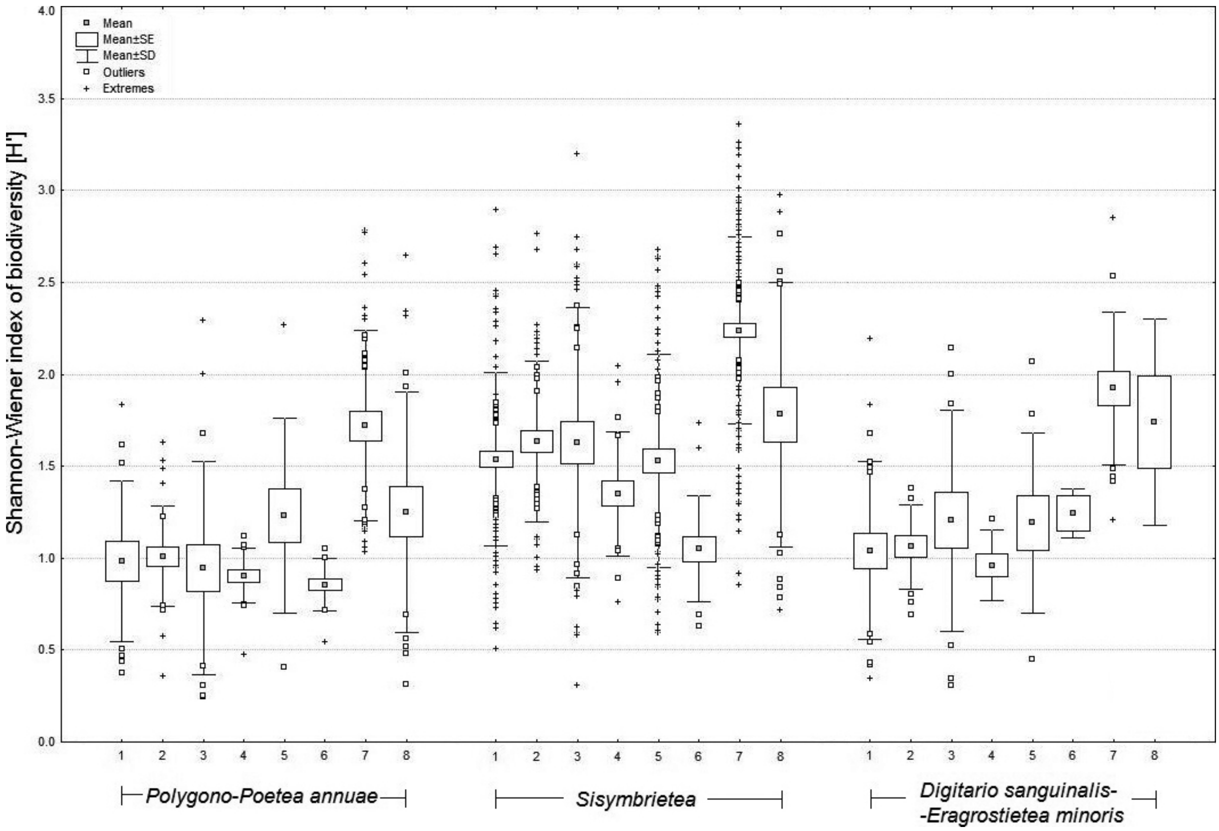

Figure 1: The comparison of the Shannon–Wiener index of diversity [H'] in the old and the more recent relevés of the classes *Polygono-Poetea annuae*, *Sisymbrietea*, and *Digitario sanguinalis-Eragrostietea minoris* in various cities

Explanation:

1 – Bratislava, old time period (years 1960–1982);

2 – Bratislava, more recent time period (years 2005–2016);

3 – Malacky, old time period (years 1960–1982);

4 – Malacky, more recent time period (years 2005–2016);

5 – Trnava, old time period (years 1960–1982);

6 – Trnava, more recent time period (years 2005–2016);

7 – Brno, old time period (years 1960–1982);

8 – Brno, more recent time period (years 2005–2016).

Slika 1: Primerjava Shannon–Wienerjevega diverzitetnega indeksa [H'] med starejšimi in novejšimi vegetacijskimi popisi razredov *Polygono-Poetea annuae*, *Sisymbrietea*, in *Digitario sanguinalis-Eragrostietea minoris* v različnih mestih.

Legenda:

1 – Bratislava, starejše obdobje (leta 1960–1982);

2 – Bratislava, novejše obdobje (leta 2005–2016);

3 – Malacky, starejše obdobje (leta 1960–1982);

4 – Malacky, novejše obdobje (leta 2005–2016);

5 – Trnava, starejše obdobje (leta 1960–1982);

6 – Trnava, novejše obdobje (leta 2005–2016);

7 – Brno, starejše obdobje (leta 1960–1982);

8 – Brno, novejše obdobje (leta 2005–2016)

the class *Digitario sanguinalis-Eragrostietea minoris* was the highest (33.7%) in the old time period. Such high values were not recorded in any other analysed class. Moreover, in the majority of other cities the values in the class *Digitario sanguinalis-Eragrostietea minoris* were also relatively high – approximately 15%. The second most invaded class was the class *Sisymbrietea*, where the average percentual number of invasive species in the majority of cities was more than 10% and only in one city (Malacky) it was less than 10% (Figure 7). The classes *Artemisietea vulgaris* and *Epilobietea angustifolii* were less invaded (Figure 8).

In total, 38 invasive taxa were recorded in the ruderal vegetation of the studied Slovak and Czech cities (Table 2). The majority of them are considered to be invasive in both countries. There were 13 taxa, which are invasive only in the Czech Republic and 6 taxa, which are invasive only in Slovakia (Table 2). The majority of invasive taxa were recorded in both time periods. Some of the invasive species, e.g. *Fallopia japonica* and *Juncus tenuis* were recorded only in the more recent time period (Table 2). The majority of the recorded invasive taxa in all cities in both periods were neophytes, therophytes and belonged to the family Asteraceae (Figures 9–10). Most of the in-

Table 2: List of recorded invasive taxa and their occurrence in the time periods.
Tabela 2: Seznam invazivnih taksonov in njihovo pojavljanje v obeh časovnih obdobjih.

Taxon	Family	Life form	Origin	R. t.	Occurrence in the city and time period				
					BA	M	T	Slovak cities in total	Brno (Czech city in total)
Ailanthus altissima	Sim	Ph	As	neo	b	b	b	b	r
Amaranthus powellii	Ama	T	CAm SAm	arch	*	*	*	*	r
Amaranthus retroflexus	Ama	T	CAm SAm	neo	b	b	b	b	b
Ambrosia artemisiifolia	Ast	T	NAm	neo	b	r	r	b	
Apera spica-venti	Poa	T	As E	arch	b	b	b	b	~
Arrhenatherum elatius	Poa	He	E	arch	*	*	*	*	b
Aster novi-belgii agg.	Ast	He	NAm	neo	b	r		b	
Atriplex sagittata	Ama	T	As E	arch	*	*	*	*	b
Atriplex tatarica	Ama	T	Af As E	arch	b	o	b	b	~
Bassia scoparia subsp. *scoparia*	Ama	T	As E	neo	*	*	*	*	o
Bidens frondosa	Ast	T	NAm	neo	b			b	
Cardaria draba	Bra	He	Af As E	arch	b	r+	b	b	~
Cirsium arvense	Ast	He	As E	arch	*	*	*	*	b
Conium maculatum	Api	T He	Af As E	arch	*	*	*	*	o
Conyza canadensis	Ast	T	NAm	neo	b	b	b	b	b
Digitaria ischaemum	Poa	T	E	arch	*	*	*	*	r
Echinochloa crus-galli	Poa	T	As E	arch	b	b	b	b	b
Echinocystis lobata	Cuc	T	NAm	neo	r			r	
Echinops sphaerocephalus subsp. *sphaerocephalus*	Ast	He	E	neo	*	*	*	*	o
Eragrostis minor	Poa	T	E	arch	*	*	*	*	b
Fallopia japonica	Pog	G	As	neo	r			r	
Galinsoga parviflora	Ast	T	SAm	neo	b	b	b	b	b
Galinsoga urticifolia	Ast	T	CAm SAm	neo	b			b	b
Helianthus tuberosus	Ast	He	NAm	neo	r		b	r	o
Impatiens glandulifera	Bal	T	As	neo	b			b	
Impatiens parviflora	Bal	T	As	neo	b			b	b
Juncus tenuis	Jun	He	NAm	neo	r			r	~
Lycium barbarum	Sol	Ph	As	neo	b			b	o
Matricaria discoidea	Ast	T	As NAm	neo	b	b	b	b	~
Negundo aceroides	Sap	Ph	NAm	neo	b	r	r	b	r
Portulaca oleracea subsp. *oleracea*	Por	T	As E	arch	*	*	*	*	b
Robinia pseudoacacia	Fab	Ph	NAm	neo	b	o	b	b	
Rumex patientia	Pog	He	E	neo	b		r	b	~
Sisymbrium loeselii	Bra	T	Af As E	neo	*	*	*	*	b
Solidago canadensis	Ast	He	NAm	neo	r		r	r	b
Solidago gigantea	Ast	He	NAm	neo	b	r	r	b	o
Stellaria pallida	Car	T	Af As E	arch	*	*	*	*	b
Stenactis annua	Ast	T	NAm	neo	b	r	r	b	r
Xanthoxalis dillenii	Oxa	He T	NAm	neo	*	*	*	*	r

Explanation: R. t. – residence time; BA – Bratislava city, M – Malacky city, T – Trnava city;
Ama – Amaranthaceae, Api – Apiaceae, Ast – Asteraceae, Bal – Balsaminaceae, Bra – Brassicaceae, Car – Caryophyllaceae, Cuc – Cucurbitaceae, Fab – Fabaceae, Jun – Juncaceae, Oxa – Oxalidaceae, Poa – Poaceae, Pog – Polygonaceae, Por – Portulacaceae, Sap – Sapindaceae, Sim – Simaroubaceae, Sol – Solanaceae; T – therophyte, G – geophyte, He – hemicryptophyte, Ph – phanerophyte; Af – Africa, As – Asia, E – Europe, CAm – Central America, NAm – North America, SAm – South America; arch – archaeophyte, neo – neophyte; b – taxon was present in the ruderal vegetation of both time periods, o – taxon was present in the ruderal vegetation only in the old time period (in the years 1960–1982), r – taxon was present in the ruderal vegetation only in the more recent time period (in the years 2005–2016); * – taxon is not considered to be invasive in Slovakia, ~ – taxon is not considered to be invasive in the Czech Republic, + – taxon was recorded in the more recent time period in the ruderal flora in Malacky city but not in the ruderal community that could be assigned to any phytosociological class of ruderal vegetation by numerical analysis

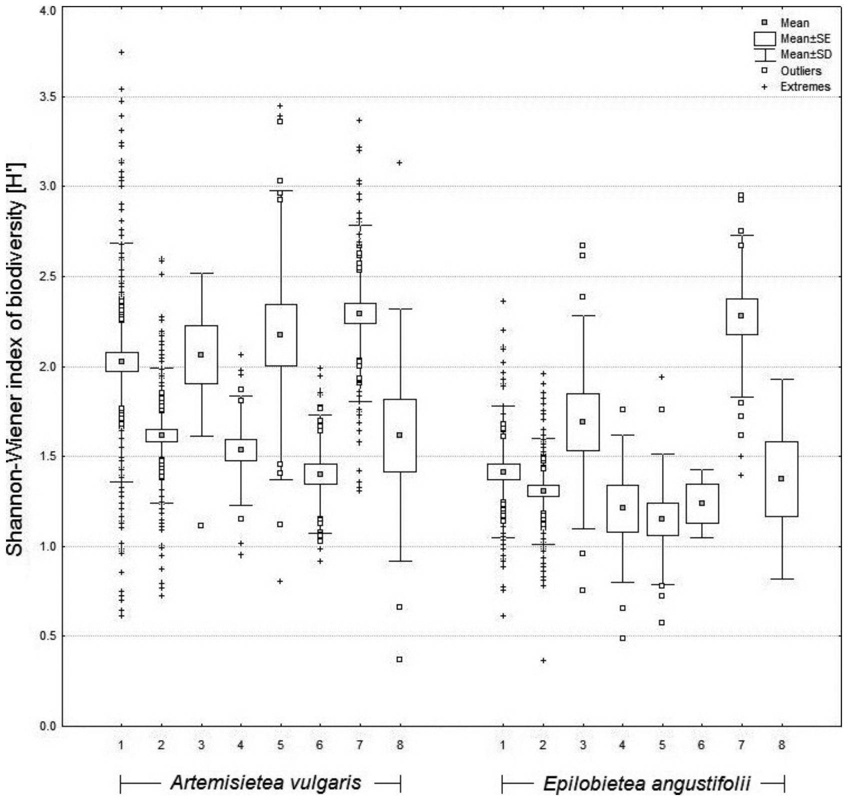

Figure 2: The comparison of the Shannon–Wiener index of diversity [H'] in the old and the more recent relevés of the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* in various cities. Explanation corresponds to those in Figure 1.

Slika 2: Primerjava Shannon–Wienerjevega diverzitetnega indeksa [H'] med starejšimi in novejšimi vegetacijskimi popisi razredov *Artemisietea vulgaris* in *Epilobietea angustifolii* v različnih mestih. Legenda je enaka kot pri Sliki 1.

vasive taxa recorded in the ruderal vegetation of Slovak cities are native to North America and relatively many are native to Asia (Figure 9). The majority of invasive taxa recorded in Brno come from Europe and many of them from Asia (Figure 10).

The statistically significant results of the analysis of the changes in the Shannon–Wiener diversity index of all (native + alien) taxa over the time showed the decrease of the average values of diversity index in the majority of classes in almost all of the cities (Figures 1–2).

The most significant decrease of Shannon–Wiener diversity index over time was recorded in the class *Artemisietea vulgaris* in Trnava [F(1, 55) = 25.7, p < 0.001; F – F ratio; p – p value; numbers in brackets behind the F ratio represents the values for degrees of freedom], where it has decreased from 2.2 to 1.4 and in Brno [F(1, 86) = 17.5, p < 0.001], where it has decreased from 2.3 to 1.6 and in the class *Epilobietea angustifolii* in Brno [F(1, 26) = 18.9, p < 0.001], where it has fallen from 2.3 to 1.4 (Figure 2).

The average values of the Shannon–Wiener diversity index decreased also in the class *Artemisietea vulgaris* in Bratislava [F(1, 277) = 36.6, p < 0.001] and Malacky [F(1, 32) = 14.9, p < 0.001] and in the class *Epilobietea angustifolii* in Bratislava [F(1, 163) = 4.4, p = 0.0380] and Malacky [F(1, 22) = 4.9, p = 0.038] (Figure 2). The decreasing trend was recorded also in the class *Polygono-Poetea annuae* in Trnava [F(1, 22) = 5.1, p = 0.034] and Brno [F(1, 64) = 10.2, p = 0.002] and in the class *Sisymbrietea* in Trnava [F(1, 94) = 11.6, p < 0.001] and Brno [F(1, 189) = 14.8, p < 0.001] (Figure 1).

The changes of the average values of the Shannon–Wiener diversity index in all of the other classes of the ruderal vegetation of the analysed Slovak and Czech cities proved to be statistically not significant (p > 0.05).

The analysis of the changes in the Pielou's measure of evenness of all (native + alien) species in the classes of ruderal vegetation over the time showed the that in almost a half of the classes and cities, the difference in the average values of evenness between the old and the more recent time period was not statistically significant (p > 0.05), the average values of the evenness remain unchanged (Figures 3–4). In Brno, for example, there have been no significant difference in any of the classes (p > 0.05). Statistically significant difference have been obtained only for some classes and cities, where the decrease of the average values of evenness was recorded. The most significant decrease in the average values of the Pielou's measure of species evenness was recorded in the class *Artemisietea vulgaris* in Malacky [F(1, 32) = 48.9, p < 0.001], where it has fallen from 0.8 to 0.55 (Figure 4). The average values of the evenness decreased in the statistically significant way in the same class also in Bratislava [F(1, 277) = 67.5,

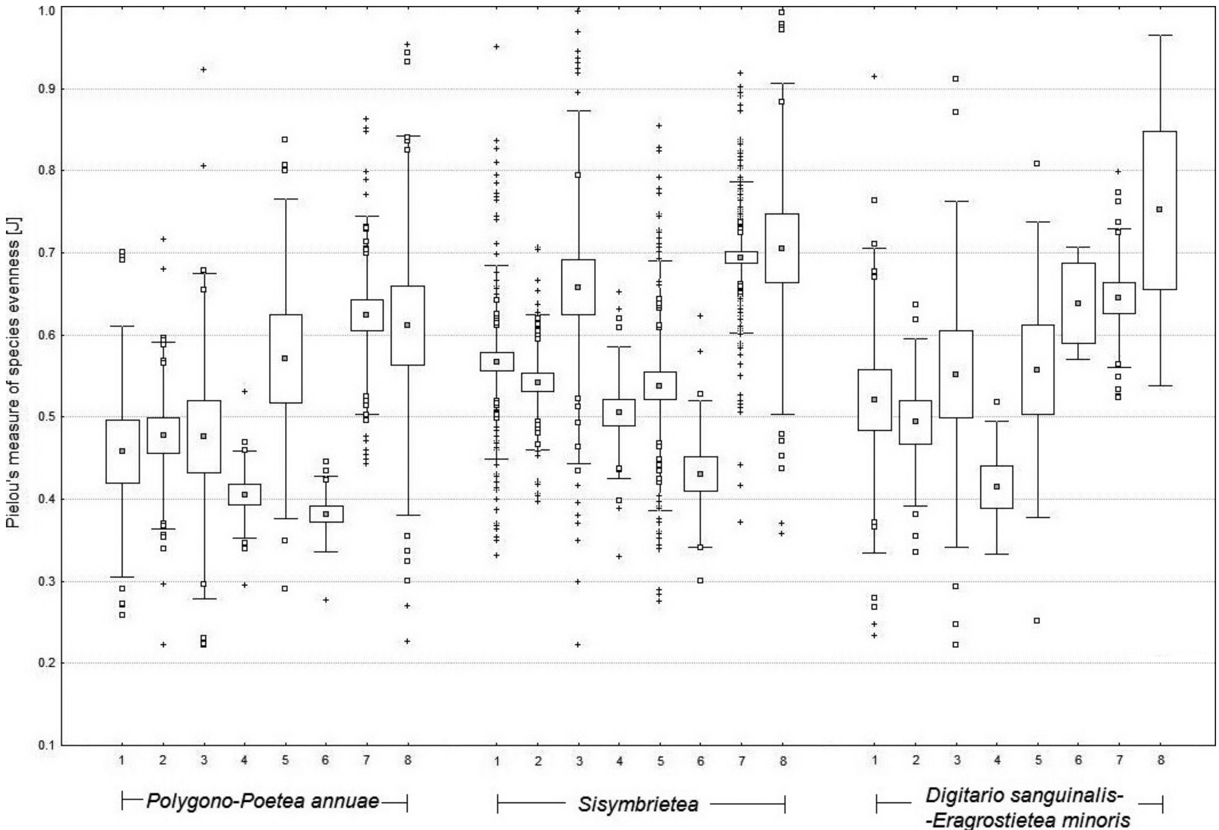

Figure 3: The comparison of the Pielou's measure of evenness [J] in the old and the more recent relevés of the classes *Polygono-Poetea annuae*, *Sisymbrietea*, and *Digitario sanguinalis-Eragrostietea minoris* in various cities. Explanation corresponds to those in Figure 1.

Slika 3: Primerjava vrstne poravnanosti po Pielou [J] med starejšimi in novejšimi vegetacijskimi popisi razredov *Polygono-Poetea annuae*, *Sisymbrietea* in *Digitario sanguinalis-Eragrostietea minoris* v različnih mestih. Legenda je enaka kot pri Sliki 1.

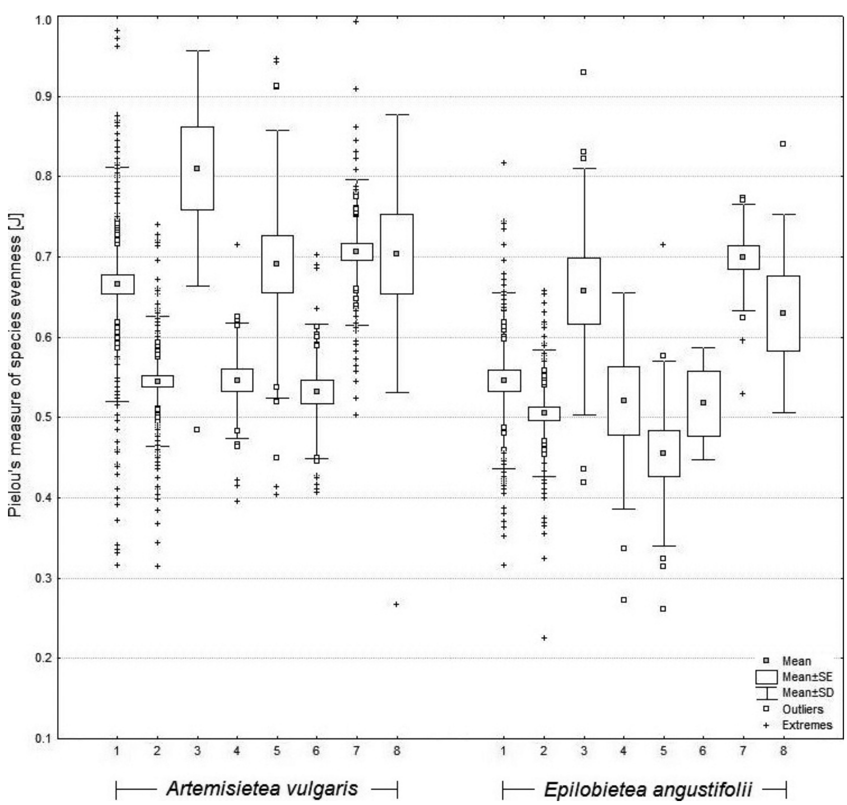

Figure 4: The comparison of the Pielou's measure of evenness [J] in the old and the more recent relevés of the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* in various cities. Explanation corresponds to those in Figure 1

Slika 4: Primerjava vrstne poravnanosti po Pielou [J] med starejšimi in novejšimi vegetacijskimi popisi razredov *Artemisietea vulgaris* in *Epilobietea angustifolii* v različnih mestih. Legenda je enaka kot pri Sliki 1.

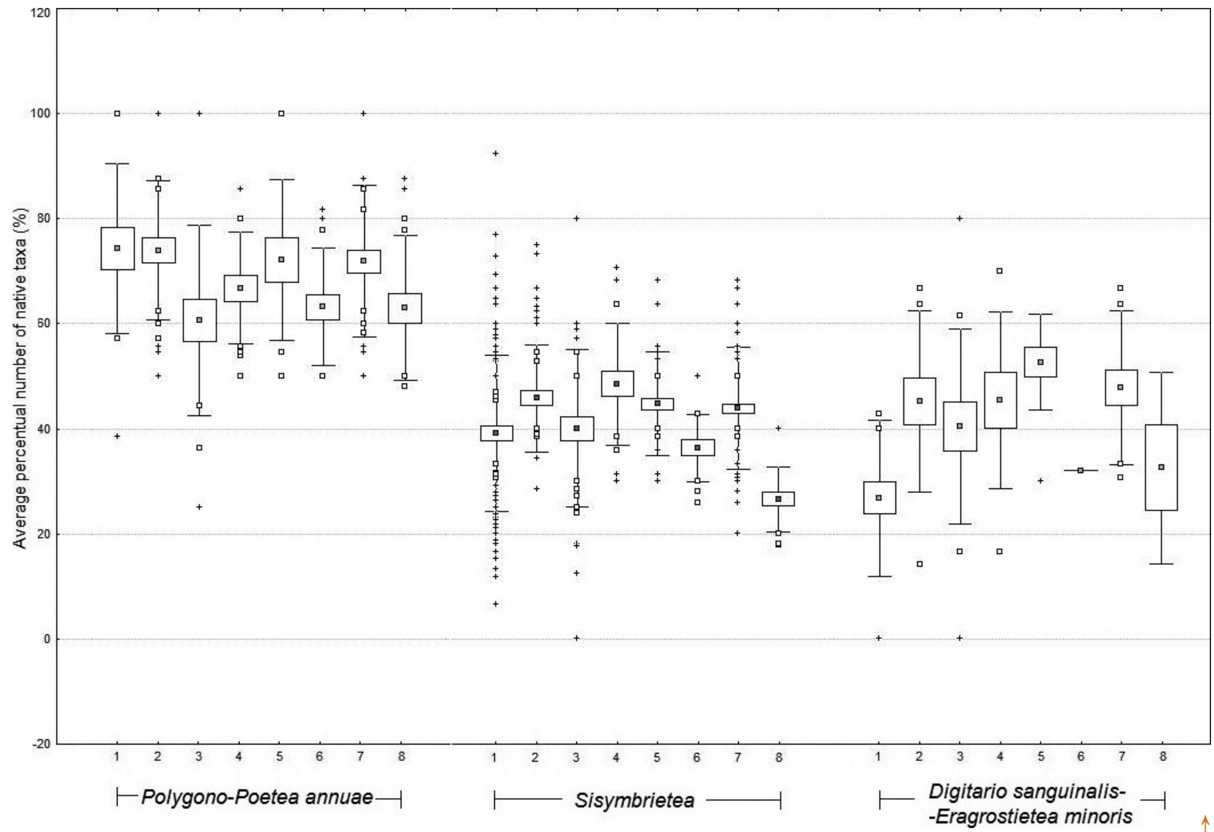

Figure 5: The comparison of the average percentual number of native taxa in the old and the more recent relevés of the classes *Polygono-Poetea annuae*, *Sisymbrietea*, and *Digitario sanguinalis-Eragrostietea minoris* in various cities. Explanation corresponds to those in Figure 1

Slika 5: Primerjava povprečnega deleža domorodnih vrst med starejšimi in novejšimi vegetacijskimi popisi razredov *Polygono-Poetea annuae*, *Sisymbrietea* in *Digitario sanguinalis-Eragrostietea minoris* v različnih mestih. Legenda je enaka kot pri Sliki 1.

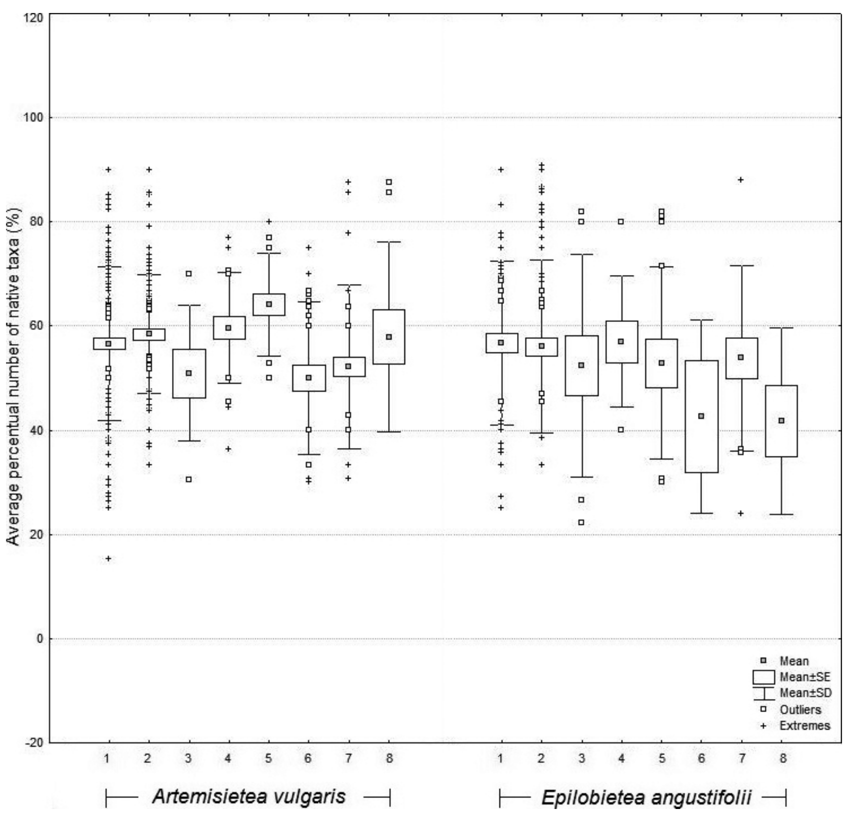

Figure 6: The comparison of the average percentual number of native taxa in the old and the more recent relevés of the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* in various cities. Explanation corresponds to those in Figure 1

Slika 6: Primerjava povprečnega deleža domorodnih vrst med starejšimi in novejšimi vegetacijskimi popisi razredov *Artemisietea vulgaris* in *Epilobietea angustifolii* v različnih mestih. Legenda je enaka kot pri Sliki 1.

p < 0.001] and Trnava [F(1, 55) = 22.7, p < 0.001] and in the class *Epilobietea angustifolii* in Bratislava [F(1, 163) = 7.6, p = 0.006] and Malacky [F(1, 22) = 5.0, p = 0.353] (Figure 4). The significant decrease of the evenness was recorded also in the class *Polygono-Poetea annuae* in Trnava [F(1, 22) = 9.9, p = 0.005] and in the class *Sisymbrietea* in Malacky [F(1, 64) = 11.2, p = 0.001] and Trnava [F(1, 94) = 8.2, p = 0.005] (Figure 3).

The analysis of the changes in the average percentual number of native species in the ruderal vegetation over the time showed that in the majority of the classes and cities there have been no statistically significant change between the old and the more recent time period (p > 0.05) (Figures 5–6). In the class *Digitario sanguinalis-Eragrostietea minoris* in Trnava, the significant decrease of the percentual number of native species was recorded [F(1, 11) = 9.4, p = 0.011] (Figure 5). The significant increase of average percentual number of native species was recorded in the class *Sisymbrietea* in Bratislava [F(1, 164) = 50.4, p < 0.001] and Malacky [F(1, 64) = 5.7, p = 0.020] (Figure 5).

The statistically significant results of the analysis of the changes in the average percetual number of invasive species in the classes of the ruderal vegetation over the time showed the increase of the percentual number of invasive species in the majority of the classes in almost all of the studied Slovak and Czech cities (Figures 7–8).

The most significant increase of the percentual number of invasive taxa was recorded in the class *Digitario sanguinalis-Eragrostietea minoris* in Trnava [F(1, 11) = 8.0, p = 0.017], where it has risen from 10.3% to 28.6% (Figure 7). A significant increase was also recorded in the same class in Brno [F(1, 22) = 17.4, p < 0.001] and in the class *Sisymbrietea* in Trnava [F(1, 94) = 17.4, p < 0.001] (Figure 7). The average percentual number of invasive species increased also in the class *Artemisietea vulgaris* in all of the studied cities {Bratislava [F(1, 277) = 34.1, p < 0.001], Malacky [F(1, 32) = 9.2, p = 0.0048], Trnava [F(1, 55) = 17.1, p < 0.001], Brno [F(1, 86) = 9.7, p = 0.0025]}and in the class *Epilobietea angustifolii* in Bratislava [F(1, 163) = 22.7, p < 0.001] (Figure 8).

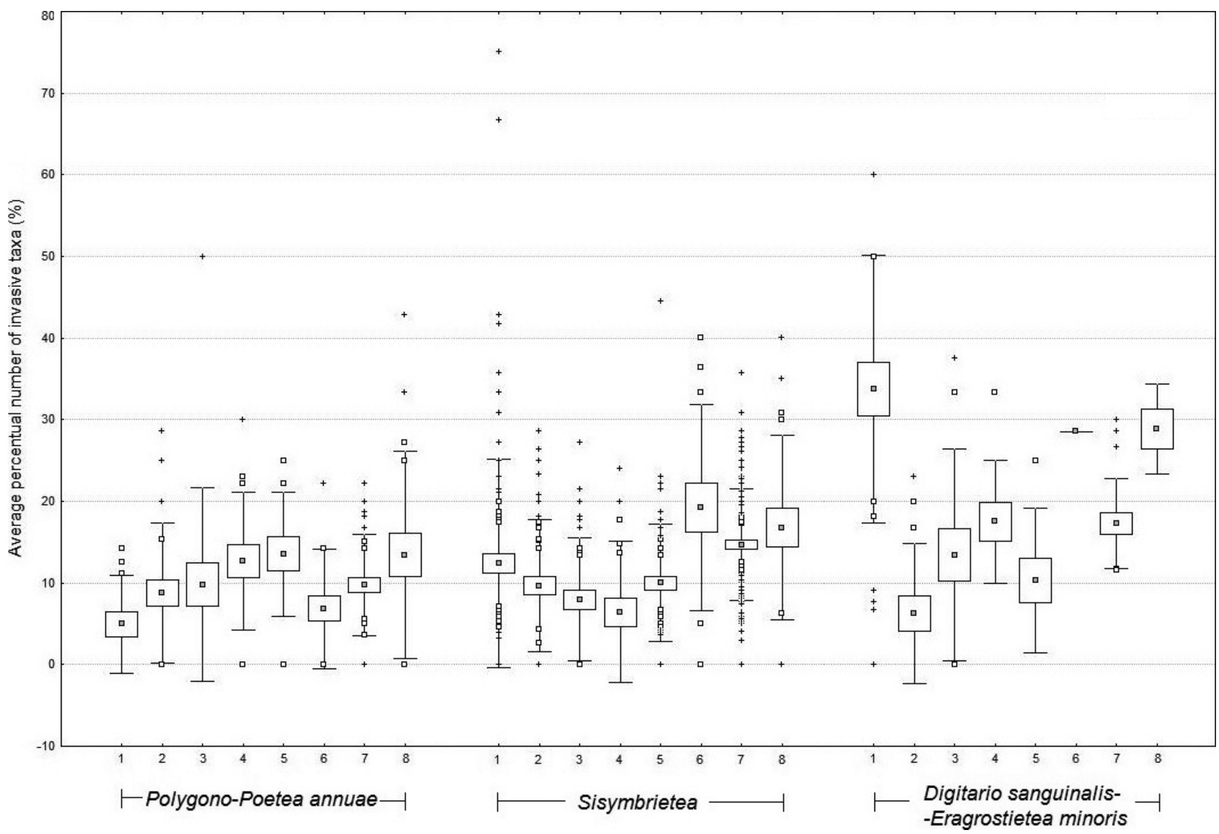

Figure 7: The comparison of the average percentual number of invasive taxa in the old and the more recent relevés of the classes *Polygono-Poetea annuae*, *Sisymbrietea*, and *Digitario sanguinalis-Eragrostietea minoris* in various cities. Explanation corresponds to those in Figure 1

Slika 7: Primerjava povprečnega deleža invazivnih vrst med starejšimi in novejšimi vegetacijskimi popisi razredov *Polygono-Poetea annuae*, *Sisymbrietea* in *Digitario sanguinalis-Eragrostietea minoris* v različnih mestih. Legenda je enaka kot pri Sliki 1.

The statistically significant decrease of the percetual number of invasive species was recorded only in the in the class *Polygono-Poetea annuae* in Trnava [F(1, 22) = 4.7, p = 0.0413] (Figure 7), in the class *Digitario sanguinalis-Eragrostietea minoris* in Bratislava [F(1, 38) = 35.8, p < 0.001] (Figure 7), and in the class *Epilobietea angustifolii* in Brno [F(1, 26) = 5.8, p = 0.0239] (Figure 8).

The changes of the average percentual number of invasive species in all of the other classes of the ruderal vegetation of the studied Slovak and Czech cities proved to be statistically not significant (p > 0.05).

The analysis of the changes in mean Ellenberg indicator values over the time by the t-test for independent samples revealed a statistically significant increase in mean Ellenberg indicator values for temperature between the old and the more recent period (p < 0.05) (Figure 11b). There was a slight increase in mean values for light (Figure 11a) and nutrients (Figure 11f) and a slight decrease of mean values for moisture (Figure 11d) and soil reaction (Figure 11a), but these little changes proved to be statistically not significant (p > 0.05).

Discussion

The lowest percentual number of native species was recorded in the class *Sisymbrietea*, and relatively low also in the class *Digitario sanguinalis-Eragrostietea minoris* (Figures 5–6). On the other hand, these classes were the classes with the highest average values of the percentual number of invasive species (Figures 7–8). The highest percentual number of invasive species was recorded in the class *Digitario sanguinalis-Eragrostietea minoris*, the class *Sisymbrietea* was the second one most invaded. The proportion of invasive species in the other three classes, especially in the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* was lower (Figures 7–8). On the other hand, these classes have the higher proportion of native species (Figures 5–6). Probably, the alien invasive species in the vegetation of classes *Digitario sanguinalis-Eragrostietea minoris* and *Sisymbrietea* replaced native species. The interesting fact is that in the class *Digitario sanguinalis-Eragrostietea minoris* in Trnava, the significant decrease of the percentual number of native species over the time was recorded (Figure 5) and at the same time, in this class and city, the percentual number of invasive taxa increased significantly (Figure 7). The increase of invasive alien species can be associated with the retreat of native species. The increase of invasive species could also play a role in a overall decrease of species diversity, because many of the plant communities, which were recorded in the more recent time period were formed monodominantly by invasive species and thus had a very low diversity.

Our results agree with the findings of some other authors (McKinney & Lockwood 1999, Olden et al. 2004), which indicate the process of homogenization of the biota at larger scale. According to these authors, many species are declining and are being replaced by a much smaller number of expanding species, mainly aliens, and this whole process results in a more uniform biosphere with lower diversity.

The similar trend has been recorded in urban floras and vegetation. The decrease in species diversity over the time

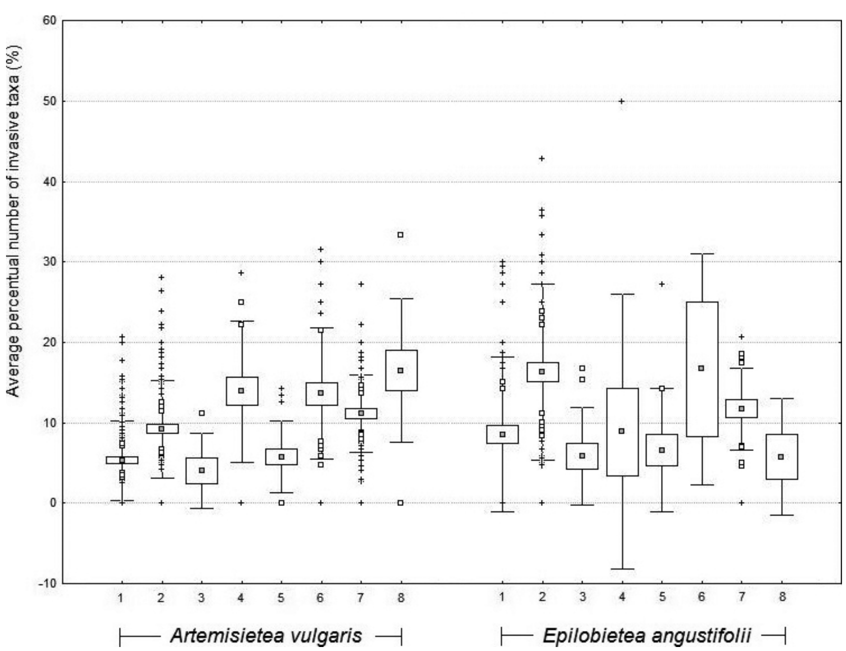

Figure 8: The comparison of the average percentual number of invasive taxa in the old and the more recent relevés of the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* in various cities. Explanation corresponds to those in Figure 1

Slika 8: Primerjava povprečnega deleža invazivnih vrst med starejšimi in novejšimi vegetacijskimi popisi razredov *Artemisietea vulgaris* in *Epilobietea angustifolii* v različnih mestih. Legenda je enaka kot pri Sliki 1.

Slovak cities

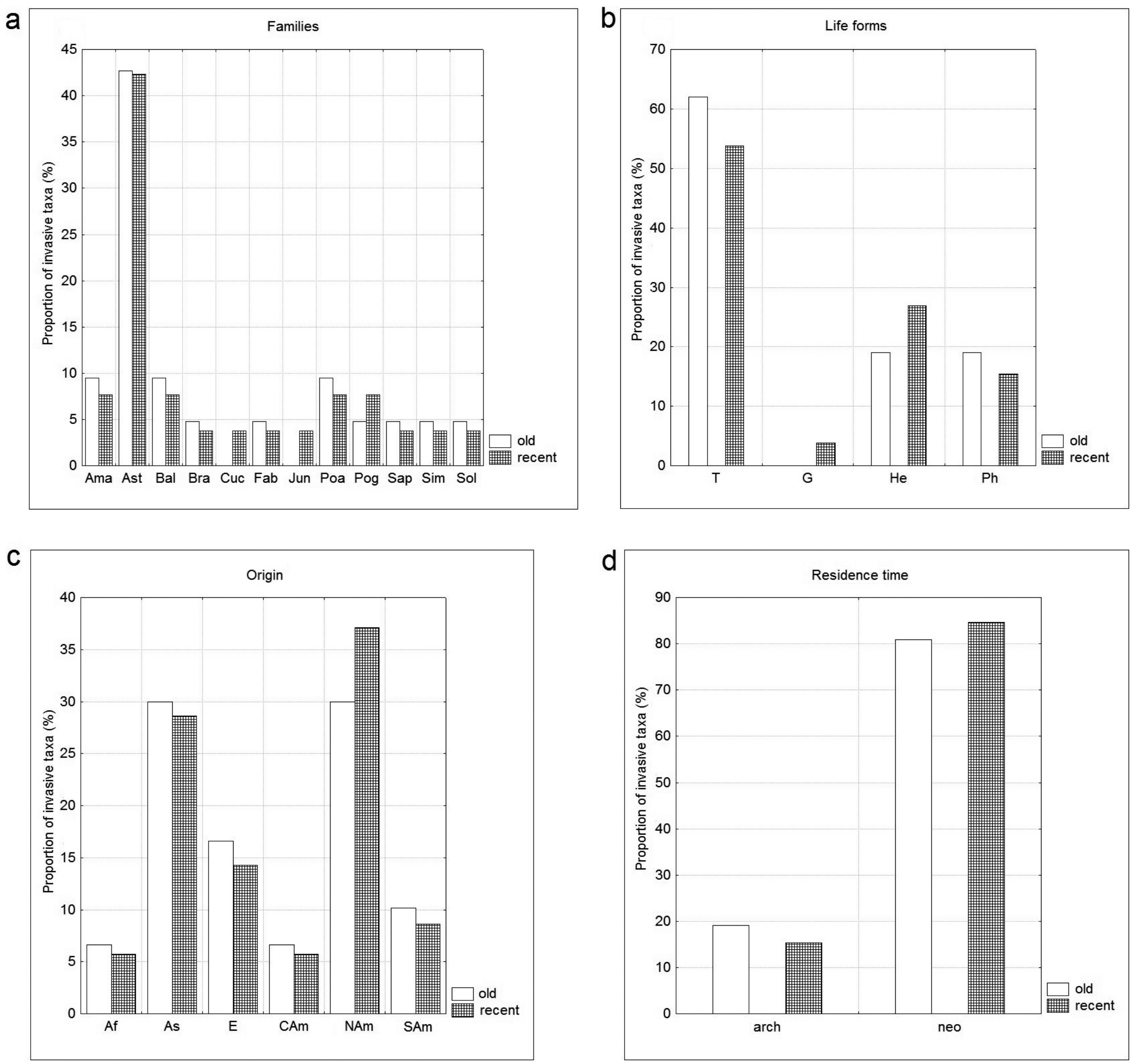

Figure 9: The total proportion of the recorded invasive taxa in the ruderal vegetation (all syntaxa together) of Slovak cities in categories of families (a), Raunkiær's life forms (b), countries of orgin (c), residence time status (d).

Explanation: Ama – Amaranthaceae, Ast – Asteraceae, Bal – Balsaminaceae, Bra – Brassicaceae, Cuc – Cucurbitaceae, Fab – Fabaceae, Jun – Juncaceae, Poa – Poaceae, Pog – Polygonaceae, Sap – Sapindaceae, Sim – Simaroubaceae, Sol – Solanaceae; T – therophyte, G – geophyte, He – hemicryptophyte, Ph – phanerophyte; Af – Africa, As – Asia, E – Europe, CAm – Central America, NAm – North America, SAm – South America; arch – archaeophyte, neo – neophyte.

Slika 9: Delež invazivnih taksonov v ruderalni vegetaciji (vsi sintaksoni skupaj) v slovaških mestih in uvrstitev v družine (a), Raunkiærjeve življenske oblike (b), izvorna celina (c), čas vnosa (d).

Legenda: Ama – Amaranthaceae, Ast – Asteraceae, Bal – Balsaminaceae, Bra – Brassicaceae, Cuc – Cucurbitaceae, Fab – Fabaceae, Jun – Juncaceae, Poa – Poaceae, Pog – Polygonaceae, Sap – Sapindaceae, Sim – Simaroubaceae, Sol – Solanaceae; T – therophyte, G – geophyte, He – hemicryptophyte, Ph – phanerophyte; Af – Africa, As – Asia, E – Europe, CAm – Central America, NAm – North America, SAm – South America; arch – arheofiti, neo – neofiti.

was recorded in the ruderal vegetation of some European cities (Pyšek et al. 2004). Similarly, the results of the analysis of dynamics of ruderal species diversity in the Harbin city in China showed that the number of ruderal species decreased in the past half century (Chen et al. 2014). The majority of recorded invasive taxa in Slovakia and Czech Republic are neophytes, the minority of them are archaeophytes (Figures 9–10). In many European urban habi-

Brno (Czech city)

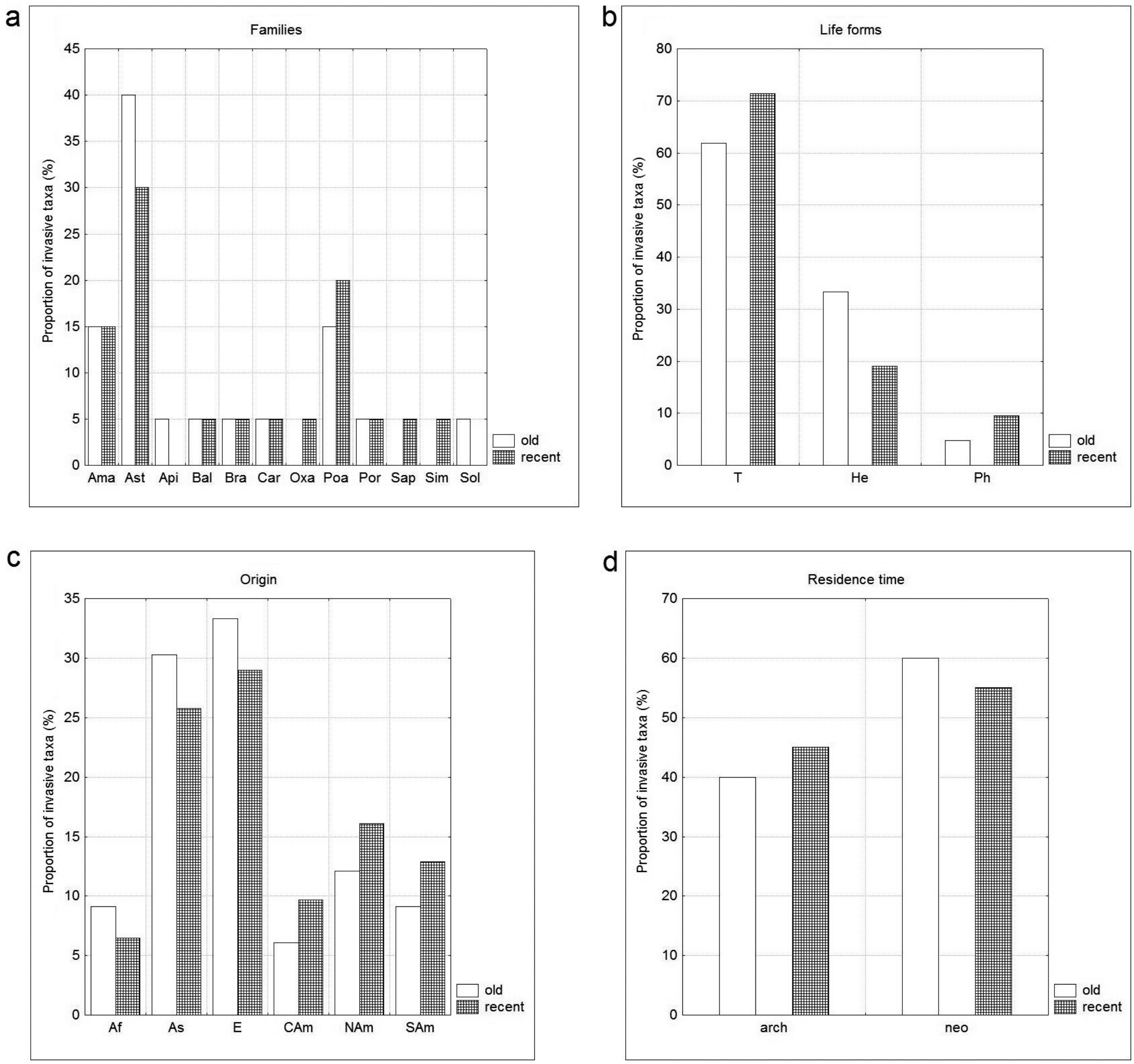

Figure 10: The total proportion of the recorded invasive taxa in the ruderal vegetation (all syntaxa together) of Brno (Czech city) in categories of families (a), Raunkiær's life forms (b), countries of orgin (c), residence time status (d)

Explanation:

Ama – Amaranthaceae, Ast – Asteraceae, Api – Apiaceae, Bal – Balsaminaceae, Bra – Brassicaceae, Car – Caryophyllaceae, Oxa – Oxalidaceae, Poa – Poaceae, Por – Portulacaceae, Sap – Sapindaceae, Sim – Simaroubaceae, Sol – Solanaceae; T – therophyte, He – hemicryptophyte, Ph – phanerophyte; Af – Africa, As – Asia, E – Europe, CAm – Central America, NAm – North America, SAm – South America; arch – archaeophyte, neo – neophyte.

Slika 10: Delež invazivnih taksonov v ruderalni vegetaciji (vsi sintaksoni skupaj) v Brnu (Češka) in uvrstitev v družine (a), Raunkiærjeve življenske oblike (b), izvorna celina (c), čas vnosa (d).

Legenda:

Ama – Amaranthaceae, Ast – Asteraceae, Bal – Balsaminaceae, Bra – Brassicaceae, Cuc – Cucurbitaceae, Fab – Fabaceae, Jun – Juncaceae, Poa – Poaceae, Pog – Polygonaceae, Sap – Sapindaceae, Sim – Simaroubaceae, Sol – Solanaceae; T – therophyte, G – geophyte, He – hemicryptophyte, Ph – phanerophyte; Af – Africa, As – Asia, E – Europe, CAm – Central America, NAm – North America, SAm – South America; arch – arheofiti, neo – neofiti.

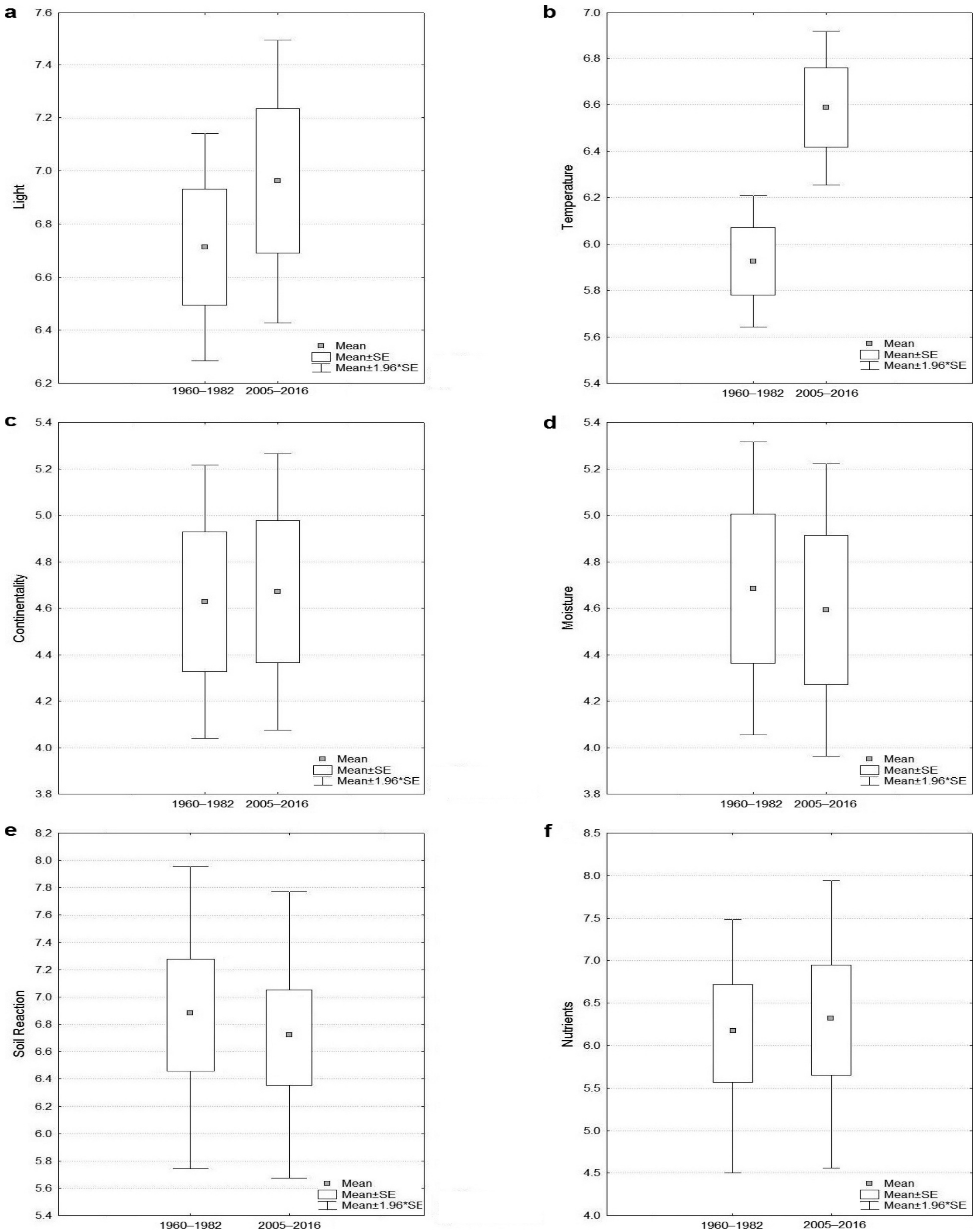

Figure 11: Changes in the mean Ellenberg indicator values for light (a), temperature (b), continentality (c), moisture (d), soil reaction (e) and nutrients (f) between the old (years 1960–1982) and the more recent (years 2005–2016) time period.

Slika 11: Sprememba povprečnih Ellenbergovih indikatorskih vrednosti za svetlobo (a), temperaturo (b), kontinentalnost (c), vlažnost (d), reakcijo tal (e) in hranila (f) med starejšim (1960–1982) in novejšim (2005–2016) obdobjem.

tats, the trend of increasing proportion of neophytes over the time have been observed (Pyšek & Mandák 1997, Chocholoušková & Pyšek 2003, Lososová & Simonová 2008, Gregor et al. 2012), and the proportion of native species decreased accordingly (Chocholoušková & Pyšek 2003, Lososová & Simonová 2008). Over time, significant increase in the proportion of neophytes was recorded not only in the urban areas, but also in the hardwood floodplain forests in the Pannonian Region (Petrášová et al. 2013) and in many other habitats in Slovakia (Medvecká et al. 2014).

The increase of invasive species in the ruderal vegetation of the studied Slovak and Czech cities (Figures 7–8) can be explained by the increase in mean Ellenberg indicator values for temperature and light and decrease of values for moisture between the old and the more recent period (Figure 11), because some of recorded invasive species are native to warmer and drier regions (Figures 9–10). Increasing drought in cities could be evocated by pavement and road construction, and land drainage for the purpose of other construction activities. Moreover, the boom of building activity itself could contribute to the increase of invasive taxa proportion as some invasive neophyte species are encouraged by building activity (Kowarik 1990).

There can be several explanation for the fact that the classes *Digitario sanguinalis-Eragrostietea minoris* and *Sisymbrietea* are rich in the invasive alien species and the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* are less invaded (Figures 7–8). The majority of the recorded invasive taxa in all cities in both periods were therophytes (Figures 9–10). The classes *Digitario sanguinalis-Eragrostietea minoris* and *Sisymbrietea* are comprised of therophyte-rich ruderal vegetation, while the proportion of therophytes in the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* is lower (Mucina et al. 2016). Therefore, the high proportion of the invasive species in the classes *Digitario sanguinalis-Eragrostietea minoris* and *Sisymbrietea* is not surprising. The thermophilous vegetation of the class *Digitario sanguinalis-Eragrostietea minoris* rich in grasses and other C4 species can host many invasive species also because of the fact that relatively many of recorded invasive species belong to the family Poaceae and originate from warmer regions (Figures 9–10) and therefore, are adapted to the dry conditions.

There can be also other reasons explaining the recorded proportion of the invasive species in various classes. The resistance of the community to invasion may correlate with the structure of the community and with effect of disturbance, which creates empty niches and raises the probability of colonising by alien species generally (Hobbs & Huenneke 1992, Mack et al. 2000). This tendency can be seen also in the studies from Czech Republic (Chytrý et al. 2005, 2008, Simonová & Lososová 2008) in the case of the proportion of alien taxa. These studies confirm that habitats with dense vegetation have low proportion of alien taxa, while habitats types with open vegetation, where the vegetation is sparse due to disturbances, contain many alien taxa. According to these studies, the disturbance regime is the main difference between the most invaded and other habitats. All of the habitats most invaded by alien plants experience strong disturbances. For ruderal habitats, the impact of disturbance was found to be the most significant determinant of invasion (Chytrý et al. 2005, 2008, Simonová & Lososová 2008). The recorded communities of the classes *Sisymbrietea* and *Digitario sanguinalis-Eragrostietea minoris* were sparse and many of them were recorded in habitats with high level of disturbance, e.g. construction sites. Some of the recorded communities of the class *Digitario sanguinalis-Eragrostietea minoris* belong to the alliance *Eragrostio-Polygonion arenastri* which comprises summer-dry trampled ruderal communities on sandy soils of Western and Central Europe (Mucina et al. 2016). Trampling is a strong disturbance too (Čarni & Mucina 1998). The recorded communities of the classes *Artemisietea vulgaris* and *Epilobietea angustifolii* were denser and the majority of them occupied not so extremely disturbed ruderal habitats.

There are also other reasons for high proportion of the invasive species in the class *Digitario sanguinalis-Eragrostietea minoris* and lower proportion of the invasive species in the another classes such as *Artemisietea vulgaris* and *Epilobietea angustifolii*. Communities with higher biodiversity (e.g. the class *Artemisietea vulgaris* in our case) are more stable and therefore more resistant to invasions, because a community with high biodiversity is unlikely to have any vacant niches that cannot be defended from an immigrant (Case 1990, Tilman 1997, Mack et al. 2000). The class *Digitario sanguinalis-Eragrostietea minoris* has the highest average percentual number of the invasive species (Figures 7–8) probably because it has low diversity and average percentual number of native species (Figures 1–6) and therefore has vacant niches that cannot be defended from aliens. The reason why the class *Digitario sanguinalis-Eragrostietea minoris* has low diversity and average percentual number of native species can be that the communities of this class grow on trampled habitats, where only very few species can survive.

The high proprotion of the invasive species could be consequence of the vulnerable plant community with poor biodiversity (Case 1990, Tilman 1997). *Vice versa*, lower biodiversity could be already a consequence of high proportion of the invasive taxa (Manchester & Bullock 2000, Stohlgren et al. 2011). One of the causes of the biodiversity loss is the invasion of alien species (Manchester & Bullock

2000, Stohlgren et al. 2011). The extinctions, for which invasive taxa are responsible, cause the global diversity to be reduced much faster than it is recovered (Russel & Blackburn 2017). Understanding of behaviour of invasive species in cities is very important, because cities represent the sources from which invasive species spread into native vegetation (Sukopp & Werner 1983). Our study confirmed the presumption that various human activities in urban environment can be reflected by an increasing proportion of alien invasive species over the time. These results can be useful and helpful in solving nature protection issues.

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References

Aronson, M. F. J., Handel, S. N., La Puma, I. P. & Clemants, S. E. 2015: Urbanization promotes non-native woody species and diverse plant assemblages in the New York metropolitan region. Urban Ecosystems 18(1): 31–45.

Barkman, J. J., Doing, H. & Segal, S. 1964: Kritische Bemerkungen und Vorschläge zur quantitativen Vegetationsanalyse. Acta Botanica Neerlandica 13(3): 394–419.

Bomanowska, A., Rewicz, A., Wolski, G. J. & Katarzyna, K. 2017: Invasive alien pants in protected areas within city borders, Lódź (Poland). Pakistan Journal of Botany 49(1): 311–316.

Braun-Blanquet, J. 1964: Pflanzensoziologie, Grundzüge der Vegetationskunde, 3rd edn. Springer-Verlag, Wien, 865 pp.

Burton, M. L., Samuelson, L. J. & Pan, S. 2005: Riparian woody plant diversity and forest structure along an urban-rural gradient. Urban Ecosystems 8: 93–106.

Case, T. J. 1990: Invasion resistance arises in strongly interacting species-rich model competition communities. Proceedings of the National Academy of Sciences of USA 87(24): 9610–9614.

Chen, X., Wang, W., Liang, H., Liu, X. & Da, L. 2014: Dynamics of ruderal species diversity under the rapid urbanization over the past half century in Harbin, Northeast China. Urban Ecosystems 17: 455–472.

Chocholoušková, Z. & Pyšek, P. 2003: Changes in composition and structure of urban flora over 120 years: a case study of the city of Plzeň. Flora 198: 366–376.

Chytrý, M. & Rafajová, M. 2003: Czech national phytosociological database: basic statistics of the available vegetation-plot data. Preslia 75: 1–15.

Chytrý, M., Pyšek, P., Tichý, L., Knollová, I., & Danihelka, J. 2005: Invasions by alien plants in the Czech Republic: a quantitative assessment across habitats. Preslia 77: 339–354.

Chytrý, M., Jarošík, V., Pyšek, P., Hájek, O., Knollová, I., Tichý, L. & Danihelka, J. 2008: Separating habitat invasibility by alien plants from the actual level of invasion. Ecology 89(6): 1541–1553.

Čarni, A. & Mucina, L. 1998: Vegetation of trampled soil dominated by C4 plants in Europe. Journal of Vegetation Science 9(1): 45–56.

Diekmann, M., Effertz, H., Baranowski, M. & Dupré, C. 2016: Weak effects on plant diversity of two invasive *Impatiens* species. Plant Ecology 217(12): 1503–1514.

Eliáš, P. 1977: Jarné efemérne ruderálne spoločenstvá Trnavy. Biologia 32: 11–23.

Eliáš, P. 1978: *Sambucetum ebuli* a iné ruderálne spoločenstvá v meste Trnava. Preslia 50: 225–252.

Eliáš, P. 1979: Predbežný prehľad ruderálnych spoločenstiev mesta Trnavy. Západné Slovensko 6: 271–309.

Eliáš, P. jun. 2009: First record of *Euphorbia maculata* L. (Euphorbiaceae) in Slovakia. Thaiszia – Journal of Botany 19: 21–25.

Eliáš, P. jun. 2011: *Geranium purpureum* Vill. – new alien species to the Slovak flora. Thaiszia – Journal of Botany 21: 21–28.

Ellenberg, H., Weber, H. E., Düll, R., Wirth, V., Weber, W. & Paulissen, D. 1991: Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18: 1–248.

Feráková, V. & Jarolímek, I. 2011: Bratislava. In: Kelcey, J. K. & Müller, N. (eds.): Plants and habitats of European cities. Springer, New York, pp. 79–129.

Ferus, P., Sîrbu, C., Eliáš, P. jun., Konôpková, J., Ďurišová, Ľ., Samuil, C. & Oprea, A. 2015: Reciprocal contamination by invasive plants: analysis of trade exchange between Slovakia and Romania. Biologia 70(7): 893–904.

Forman, R. T. T. 2014: Urban ecology, science of cities. Cambridge University Press, Camridge, 476 pp.

Gabbard, B. L. & Fowler, N. L. 2007: Wide ecological amplitude of a diversity-reducing invasive grass. Biological Invasions 9: 149–160.

Gołdyn, H. 2010: Changes in plant species diversity of aquatic ecosystems in the agricultural landscape in West Poland in the last 30 years. Biodiversity and Conservation 19(1): 61–80.

Gregor, T., Bönsel, D., Starke-Ottich, I. & Zizka, G. 2012: Drivers of floristic change in large cities – A case study of Frankfurt/Main (Germany). Landscape and Urban Planning 104: 230–237.

Hegedüšová, K. 2007: Central database of phytosociological samples (CDF) in Slovakia. Bulletin Slovenskej botanickej spoločnosti 29: 124–129.

Hejda, M., Pyšek, P. & Jarošík, V. 2009: Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology 97(3): 393–403.

Hejda, M. & Pyšek, P. 2006: What is the impact of *Impatiens glandulifera* on species diversity of invaded riparian vegetation? Biological Conservation 132(2): 143–152.

Hennekens, S. M. & Schaminée, J. H. J. 2001: TURBOVEG, a comprehensive data base management system for vegetation data. Journal of Vegetation Science 12(4): 589–591.

Hill, M. O. 1973: Diversity and evenness: a unifying notation and its consequences. Ecology 54: 427–432.

Hill, T. & Lewicki, P. 2007: STATISTICS: Methods and Applications. Tulsa, OK: StatSoft.

Hobbs, R. J. & Huenneke, L. F. 1992: Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6(3): 324–337.

Hrnčiarová, T., Mackovčin, P. & Zvara, I. (eds.). 2009: Atlas krajiny České republiky (Landscape atlas of the Czech Republic). Výzkumný ústav Silva Taroucy pro krajinu a okrasné zahradnictví, Průhonice a Ministerstvo životního prostředí České republiky, Praha, 332 pp.

Jarolímek, I. 1983: Ruderálne spoločenstvá Bratislavy. PhD Thesis. Depon. in Botanický ústav SAV (Institute of Botany SAS), Bratislava.

Jarolímek, I., Zaliberová, M., Mucina, L. & Mochnacký, S. 1997: Rastlinné spoločenstvá Slovenska. 2. Synantropná vegetácia. Veda, Bratislava, 420 pp.

Jehlík, V., Májeková, J. & Zaliberová, M. 2013: New discovered adventive plants from eastern Slovakia. Thaiszia – Journal of Botany 23(1): 61–66.

Kent, M. & Coker, P. 1992: Vegetation description and analysis: A practical approach. John Wiley & Sons, Inc., 623 pp.

Király, G., Eliáš, P. jun. & Dítě, D. 2014: Two thermophilic alien species new to the flora of Slovakia. Thaiszia – Journal of Botany 24(2): 125–134.

Kollár, T. & Kollár, D. 2004: Trnava a okolie. Dajama, Bratislava, 160 pp.

Kowarik, I. 1990: Some responses of flora and vegetation to urbanization in Central Europe. In: Sukopp, H., Hejný, S. & Kowarik, I. (eds): Urban ecology. SPB Academic Publishing, The Hague, pp. 45–74.

Kühn, I., Brandl, R. & Klotz, S. 2004: The flora of German cities is naturally species rich. Evolutionary ecology research 6: 749–764.

Lososová, Z. & Simonová, D. 2008: Changes during the 20th century in species composition of synanthropic vegetation in Moravia (Cezch Republic). Preslia 80: 291–305.

Macejka, M. & Marek, M. 2009: Malacké pohľady, výber z článkov 2006 – 2009. MLOK o.z., Malacky, 183 pp.

Macejka, M. 2015: Malacky v dejinách. Záhorácke kruhy o.z., Malacky, 200 pp.

Mack, R. N., Simberloff, D., Lonsdale,W. M., Evans, H., Clout, M. & Bazzaz, F. A. 2000: Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10(3): 689–710.

Magurran, A. E. 1988: Ecological diversity and measurment. Princeton University Press, Princeton, 354 pp.

Magurran, A. E. 2004: Measuring biological diversity. Blackwell Science Ltd., Oxford, UK, 256 pp.

Manchester, S. J. & Bullock, J. M. 2000: The impacts of non-native species on UK biodiversity and the effectiveness of control. Journal of Applied Ecology 37(5): 845–864.

Marhold, K. 1998: Ferns and flowering plants. In: Marhold, K. & Hindák, F. (eds.): Checklist of non-vascular and vascular plants of Slovakia. Veda, Bratislava, pp. 333–687.

McKinney, M. L. & Lockwood, J. 1999: Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in Ecology & Evolution 14: 450–453.

Medvecká, J., Jarolímek, I. & Zaliberová, M. 2009: Dynamics and distribution of neophytes in the Horná Orava Region (North Slovakia). Hacquetia 8(2): 147–158.

Medvecká, J., Kliment, J., Májeková, J., Halada, Ľ., Zaliberová, M., Gojdičová, E., Feráková, V. & Jarolímek, I. 2012: Inventory of alien species of Slovakia. Preslia 84: 257–309.

Medvecká, J., Jarolímek, I., Senko, D. & Svitok, M. 2014: Fifty years of plant invasions dynamics in Slovakia along a 2,500 m altitudinal gradient. Biological Invasions 16(8): 1627–1638.

Michelan, T. S., Thomaz, S. M., Mormul, R. P. & Carvalho, P. 2010: Effects of an exotic invasive macrophyte (tropical signalgrass) on native plant community composition, species richness and functional diversity. Freshwater Biology 55(6): 1315–1326.

Mucina, L., Bültmann, H., Dierßen, K., Theurillat, J. P., Raus, T., Čarni, A., Šumberová, K., Willner, W., Dengler, J., Gavilán García, R., Chytrý, M., Hájek, M., Di Pietro, R., Iakushenko, D., Pallas, J., Daniëls, F. J. A., Bergmeier, E., Santos Guerra, A., Ermakov, N., Valachovič, M., Schaminée, J. H. J., Lysenko, T., Didukh, Y. P., Pignatti, S., Rodwell, J. S., Capelo, J., Weber, H. E., Solomeshch, A., Dimopoulos, P., Aguiar, C., Hennekens, S. M. & Tichý, L. 2016: Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Applied Vegetation Science 19(S1): 3–264.

Olden, J. D., LeRoy Poff, N., Douglas, M. R., Douglas, M. E. & Fausch, K. D. 2004: Ecological and evolutionary consequences of biotic homogenization. Trends in Ecology & Evolution 19: 18–24.

Peel, M. C., Finlayson, B. L. & McMahon, T. A. 2007: Updated world map of the Köppen–Geiger climate classification. Hydrology and Earth System Sciences 11: 1633–1644.

Petrášová, M., Jarolímek, I. & Medvecká, J. 2013: Neophytes in Pannonian hardwood floodplain forests – history, present situation and trends. Forest Ecology and Management 308: 31–39.

Podani, J. 2001: SYN-TAX 2000, Computer program for data analysis in ecology and systematics for Windows 95, 98 & NT, User's manual. Scientia Publ., Budapest, 53 pp.

Pyšek, P. 1989: On the richness of Central European urban flora. Preslia 61: 320–334.

Pyšek, P. 1993: Factors affecting the diversity of flora and vegetation in central European settlements. Vegetatio 106: 89–100.

Pyšek, P. & Mandák, B. 1997: Fifteen years of changes in the representation of alien species in Czech village flora. In: Brock, J. H., Wade, M., Pyšek, P. & Green, D. (eds.): Plant invasions: studies from North America and Europe. Backhuys Publishers, Leiden, pp. 183–190.

Pyšek, P. 1998: Alien and native species in Central European urban floras: a quantitative comparison. Journal of Biogeography 25:155–163.

Pyšek, P. & Tichý, L. 2001: Rostlinné invaze. Rezekvítek, Brno, 40 pp.

Pyšek, P., Chocholoušková, Z., Pyšek, A., Jarošík, V., Chytrý, M. & Tichý, L. 2004: Trends in species diversity and composition of urban vegetation over three decades. Journal of Vegetation Science 15: 781–788.

Pyšek, P., Danihelka, J., Sádlo, J., Chrtek, J. Jr., Chytrý, M., Jarošík, V., Kaplan, Z., Krahulec, F., Moravcová, L., Pergl, J., Štajerová, K. & Tichý, L. 2012: Catalogue of alien plants of the Czech Republic (2nd edition): checklist update, taxonomic diversity and invasion patterns. Preslia 84: 155–255.

Rendeková, A., Kerekeš, E. & Miškovic, J. 2014: Rare and interesting ruderal plant communities of Bratislava. Acta Botanica Universitatis Comenianae 49: 13–18.

Rendeková, A. 2016a: Little-known ruderal plant communities recorded in Bratislava. Acta Botanica Universitatis Comenianae 51: 23–29.

Rendeková, A. 2016b: Overview of ruderal plant communities of Malacky city. Acta Botanica Universitatis Comenianae 51: 31–50.

Rendeková, A. 2016c: Dynamika synantropnej flóry a vegetácie v mestských aglomeráciách. Writing to PhD. Thesis. Depon. in Katedra botaniky PríF UK, Bratislava.

Richardson, D. M., Pyšek, P., Rejmánek, M., Barbour, M. G., Panetta, F. D. & West, C. J. 2000: Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions 6(2): 93–107.

Russell, J. C. & Blackburn, T. M. 2017: The rise of invasive species denialism. Trends in Ecology & Evolution 32(1): 3–6.

Schmidt, K. J., Poppendieck, H. H. & Jensen, K. 2014: Effects of urban structure on plant species richness in a large European city. Urban Ecosystems 17(2): 427–444.

Simonová, D. & Lososová, Z. 2008: Which factors determine plant invasions in man-made habitats in the Czech Republic? Perspectives in Plant Ecology, Evolution and Systematics 10(2): 89–100.

Stirling, G. & Wilsey, B. J. 2001: Empirical relationships between species richness, evenness, and proportional diversity. American Naturalist 158: 286–299.

Stohlgren, T. J., Pyšek, P., Kartesz, J., Nishino, M., Pauchard, A.,Winter, M., Pino, J., Richardson, D. M., Wilson, J. R. U., Murray, B. R., Phillips, M. L., Ming-yang, L., Celesti-Grapow, L. & Font, X. 2011: Widespread plant species: natives versus aliens in our changing world. Biological Invasions 13(9): 1931–1944.

Sukopp, H. & Werner, P. 1983: Urban environments and vegetation. In: Holzner, W., Werger, M. J. A. & Ikusima, I. (eds.): Man's impact on vegetation. Dr W. Junk Publishers, The Hague, pp. 247–260.

Sukopp, H. 2002: On the early history of urban ecology in Europe. Preslia 74: 373–393.

Šibík, J. 2012: Slovak vegetation database. In: Dengler, J., Oldeland, J., Jansen, F., Chytrý, M., Ewald, J., Finckh, M., Glöckler, F., Lopez-Gonzalez, G., Peet, R. K. & Schaminée, J. H. J. (eds.): Vegetation databases for the 21st century. Biodiversity & Ecology 4(1): 429–429.

Štajerová, K., Šmilauer, P., Bruna, J. & Pyšek, P. 2017: Distribution of invasive plants in urban environment is strongly spatially structured. Landscape Ecology 32: 681–692.

Tichý, L. 2002: JUICE, software for vegetation classification. Journal of Vegetation Science 13: 451–453.

Tilman, D. 1997: Community invasibility, recruitment limitation, and grassland biodiversity. Ecology 78(1): 81–92.

Tokaryuk, A. I., Chorney, I. I., Korzhan, K. V., Budzhak, V. V., Velychko, M. V., Protopopova, V. V. & Shevera, M. V. 2012: The participation of invasive plants in the synanthropic plant communities in the Bukovinian Cis-Carpathian (Ukraine). Thaiszia – Journal of Botany 22(2): 243–254.

Trnka, A. 1998: Príroda Trnavy. Trnavská univerzita, Trnava, 163 pp.

Vilá, M., Pino, J. & Font, X. 2007: Regional assessment of plant invasions across different habitat types. Journal of Vegetation Science 18(1): 35–42.

Zisenis, M. 2015: Alien plant species: a real fear for urban ecosystems in Europe? Urban Ecosystems 18(2): 355–370.

Žabka, M., Ďurišová, Ľ. & Eliáš, P. jun. 2015: Spreading of alien species in disturbed area: a case study from Opatovce nad Nitrou (SW Slovakia). Thaiszia – Journal of Botany 25(2): 143–151.