

DOI: 10.5586/asbp.3621

Publication history

Received: 2018-11-14

Accepted: 2019-04-22

Published: 2019-06-10

Handling editor

Zygmunt Dajdok, Faculty of Biological Sciences, University of Wrocław, Poland

Authors' contributions

AR, KM: substantial contribution to the idea and design of research; AR: field data collection; AR, JM, MH: analyses and interpretation; AR, ME: writing the manuscript

Funding

This research was supported by the grant agency VEGA (Bratislava) under grant Nos. 1/0885/16 and 1/0767/17.

Competing interests

No competing interests have been declared.

Copyright notice© The Author(s) 2019. This is an Open Access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits redistribution, commercial and noncommercial, provided that the article is properly cited.**Citation**Rendeková, Mičieta K, Hrabovský M, Eliašová M, Miškovic J. Effects of invasive plant species on species diversity: implications on ruderal vegetation in Bratislava City, Slovakia, Central Europe. *Acta Soc Bot Pol.* 2019;88(2):3621. <https://doi.org/10.5586/asbp.3621>**Digital signature**

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ORIGINAL RESEARCH PAPER

Effects of invasive plant species on species diversity: implications on ruderal vegetation in Bratislava City, Slovakia, Central Europe

Alena Rendeková^{1*}, Karol Mičieta¹, Michal Hrabovský¹, Mariana Eliašová², Ján Miškovic¹¹ Department of Botany, Faculty of Natural Sciences, Comenius University in Bratislava, Révová 39, 811 02 Bratislava, Slovakia² Department of Ecology, Slovak University of Agriculture, Mariánska 10, 949 01 Nitra, Slovakia* Corresponding author. Email: alenaarendekova@gmail.com**Abstract**

Invasive species pose one of the most serious global environmental threats. Our study aimed to examine the correlation between the proportion of invasive alien taxa and species diversity of ruderal vegetation in the urban ecosystem of Bratislava, located in Central Europe. Ruderal habitats serve as the means of spread of invasive species to seminatural and natural habitats. Twenty-six invasive taxa were recorded among the ruderal vegetation of Bratislava. The majority of the recorded invasive species were neophytes, which came from North America and represent the Asteraceae family. Half of them were introduced accidentally, whereas the remaining species were introduced deliberately. Correlation and regression analyses showed that the proportion of invasive taxa has a negative effect on the species diversity of all the analyzed syntaxa in the ruderal vegetation of Bratislava.

Keywords

alien taxa; evenness; neophytes; ruderal plant communities; Shannon–Wiener diversity index; urban ecology

Introduction

The introduction of alien plant species to new areas is a problem addressed by numerous studies [1–13]. A majority of the introduced alien species rarely survive and reproduce in nonindigenous areas. Nevertheless, a small fraction of the introduced species can persist in new areas for a long time, which tend to spread rapidly and present a potential danger for the biodiversity, characteristics that are needed for the alien species to be considered invasive [14,15]. Invasive species possess features that allow them to outcompete other species, e.g., high reproductive rate, ability of vegetative reproduction, high dispersal ability, fast growth, and ability to survive in a wide range of environmental conditions.

Therefore, it is important to differentiate alien species into casual, naturalized, and invasive [2], because currently, only the invasive species pose an environmental problem. While casual and naturalized alien species can also be potentially dangerous, invasive species already represent a serious environmental danger to the conservation of biological diversity and ecosystem functions [3,14,16–18]. This is why we focused our study on the invasive group of alien species.

Many studies have investigated the reasons behind some ecosystems and communities being more vulnerable to colonization by invasive alien species than others [10,16,19–22]. Generally, ruderal ecosystems and communities have higher proportions

of alien and invasive species, making them some of the most invaded communities [5,6,8,23,24]. Many ruderal habitats (e.g., construction sites) experience strong disturbances, resulting in the creation of empty niches that promote the expansion of alien species [14]. Several ruderal habitats situated in cities are drier than their surrounding habitats, making them more suitable for alien species, many of which originate from warm and dry regions. The growth of some alien species can also be encouraged by building activity [25], which typically takes place near many ruderal habitats.

While numerous studies have focused on the biodiversity in urban and ruderal areas [26–30], they have not paid specific attention to the correlation between the biodiversity and the susceptibility of invasion by alien invasive plant species. Understanding the effects of invasive species on plant diversity in ruderal areas [31] can serve to prevent future invasions and manage alternative urban landscape configuration. In our study, we examine the relationship between the biodiversity and the proportion of invasive species, to assess the generality of the pattern of biodiversity loss due to the invasion of plants in ruderal habitats.

The study was carried out in Bratislava City, which is an appropriate area for studying ruderal vegetation and invasive species. The process of urbanization in Bratislava is associated with human activities such as trampling, construction, and gardening. Many ornamental alien plants grown in gardens invade the ruderal vegetation in nearby gardens. During the last few decades, intensive construction activity has taken place in Bratislava. The habitats with high level of disturbances, such as construction sites, provide empty niches for the spread of alien plants. Bratislava also represents an important transportation hub, with several routes, railways, waterways, and airways built across the city. Owing to its geographical position in Central Europe, Bratislava serves as a major crossroads for international trade traffic. The traffic network serves as a means of spread for many alien species [32].

The proportion of invasive species in ruderal vegetation can be well expressed by their percentage cover. The biodiversity can be well expressed by the Shannon–Wiener diversity index [33]. Therefore, the aim of our study was to assess the relationship between the percentage cover of invasive taxa and the total number of species, as well as the relationship between the percentage cover of invasive taxa and the Shannon–Wiener diversity index for the ruderal vegetation in the city of Bratislava.

Material and methods

Study area

The study was carried out in Bratislava, the capital city of Slovakia, which is located in Central Europe and covers 367.9 km². The city lies near the borders with the Czech Republic, Hungary, and Austria. Bratislava has a population of approximately 425,500 inhabitants. The city has moderate-to-warm continental climate. It lies in one of the warmest and driest zones of Slovakia. The natural soils of Bratislava in ruderal areas have been substituted by anthropogenic ones [32].

The synanthropization process in Bratislava is associated with human activities such as trampling, construction, and gardening, as many of the planted species are turning into ruderal plants. Many ornamental plants brought from abroad are now commonly found in the gardens of Bratislava. Bratislava is an appropriate site for the study of invasive species, as it represents an important transportation hub and contains a large number of habitats that are important for the spread of alien and invasive species, e.g., habitats with a high level of disturbances, such as construction sites. The disturbance regime, building activities, and trampling comprise the factors that determine the invasion of alien species into ruderal vegetation in Bratislava [32].

The ruderal vegetation of Bratislava is composed of trampled ruderal communities, therophyte-rich ruderal communities, subxerophilous ruderal perennial vegetation, and wet ruderal perennial vegetation [32].

Vegetation data

Data used in the analyses consisted of 687 phytosociological relevés of ruderal communities of Bratislava [34–37], which belong to phytosociological classes such as *Artemisietea vulgaris*, *Digitario sanguinalis-Eragrostietea minoris*, *Epilobietea angustifolii*, *Polygono-Poetea annuae*, and *Sisymbrietea*. Class *Artemisietea vulgaris* includes perennial subxerophilous ruderal vegetation of the temperate and sub-Mediterranean zones of Europe. Class *Digitario sanguinalis-Eragrostietea minoris* comprises thermophilous anthropogenic vegetation, rich in grasses and summer-annual C_4 species, growing in the southern nemoral, Mediterranean, steppe, and semidesert parts of Europe. Class *Epilobietea angustifolii* includes tall-herb seminatural and ruderal perennial vegetation, which grow on wet urban areas with high nitrogen content in the soil, disturbed forest edges, nutrient-rich riparian fringes, and forest clearings in the temperate and boreal zones of Eurasia. Class *Polygono-Poetea annuae* is comprised of subcosmopolitan therophyte-rich dwarf-herb ruderal vegetation, which grow in trampled habitats, e.g., the edges of pavements, playgrounds, or parking lots. Class *Sisymbrietea* includes zoo-anthropogenic and modern anthropogenic vegetation of disturbed ruderal sites, growing in cool- and cold-temperate regions of Eurasia [38].

The sizes of the relevés sites ranged from 1 m² to 50 m², depending on the particular community (based on previously reported methodology, e.g., [39,40]). The data were divided into groups of the same phytosociological classes and plot sizes: for class *Polygono-Poetea annuae*, 1 m², for class *Sisymbrietea*, 25 m², for class *Digitario sanguinalis-Eragrostietea minoris*, 5 m², for class *Artemisietea vulgaris*, 30 m², and for class *Epilobietea angustifolii*, 50 m². The data had been collected during two periods: the old data (381 relevés) was collected during 1975–1985, and the more recent data (306 relevés) was collected during 2000–2014. Relevés were made according to the Braun-Blanquet method [41].

Data analysis

The relevés were stored in the Turboveg database [42], and exported from there into JUICE for further analyses [43]. Afterwards, the data were classified into the ruderal syntaxa using the hierarchical clustering in the SYN-TAX 2000 [44]. A beta-flexible method ($\beta = -0.25$), in combination with Wishart's index, was used in most of the hierarchical clustering analyses.

Prior to the analyses, bryophytes and vascular plants that could be identified only to the genus level were excluded from the analysis, whereas taxa that occurred in more than one layer (e.g., in herb layer as well as in the shrub or tree layer) were merged and analyzed in only one layer.

The total number of species and the Shannon–Wiener index of biodiversity (H') [45] for every relevé was calculated using the JUICE 7.0 program.

Taxa with invasive status were identified based on the list of alien vascular plant species in the Slovak Republic [12]. The percentage cover of invasive taxa in every relevé was calculated for each class according to the method described by Chytrý et al. [5], using the JUICE 7.0 program.

Afterwards, the average number of species, biodiversity index and percentage cover of invasive taxa were calculated for each class. The Spearman rank correlation coefficient were calculated to assess to relationship between the percentage cover of invasive taxa and the species diversity. The coefficient of determination, R^2 , was calculated and added to the graphs.

The total proportion of recorded invasive taxa in ruderal vegetation of Bratislava, in terms of families, Raunkiær's life forms, origin, residence time, and introduction mode, was also calculated. The families, Raunkiær's life forms, origin of species, residence time, and introduction mode of invasive taxa were determined based on the list of alien vascular plant species in the Slovak Republic [12].

The STATISTICA 7.0 program [45] was used for all statistical analyses.

Nomenclature

The nomenclature of the taxa follows Marhold [46], while the nomenclature of the syntaxa follows Mucina et al. [38].

Results

In total, 26 invasive taxa were recorded in the ruderal vegetation of Bratislava (Tab. 1). The recorded invasive taxa belonged to 12 families (Tab. 1), with the majority belonging to the Asteraceae (42.3%), followed by Amaranthaceae (7.7%), Balsaminaceae (7.7%), Poaceae (7.7%), and Polygonaceae (7.7%). More than half (53.8%) of them were therophytes, while hemicryptophytes (26.9%) were also relatively frequent. In contrast, phanerophytes (15.4%) and geophytes (3.8%) were less frequent (Tab. 1). The majority (37.1%) of the recorded invasive taxa originated from North America, while many others originating from Asia (28.6%) and Europe (14.3%). In comparison, relatively few taxa were native to South America (8.6%), Central America (5.7%), and Africa (5.7%) (Tab. 1). The majority of the recorded invasive taxa were neophytes, and only four of them (*Apera spica-venti*, *Atriplex tatarica*, *Cardaria draba*, and *Echinochloa crus-galli*) were archaeophytes (Tab. 1). Half of the recorded invasive taxa were introduced accidentally, whereas 42% of them were introduced deliberately, while two of the taxa (*Impatiens glandulifera* and *Solidago canadensis*) were introduced both accidentally and deliberately (Tab. 1).

The results of correlation analysis are presented in Fig. 1–Fig. 10. The average percentage cover of invasive species was negatively related with the total number of species in all phytosociological classes for both time periods: old relevés of class *Polygono-Poetea annuae* [$R^2 = 0.7903$ ($p < 0.05$)] (Fig. 1A), recent relevés of class *Polygono-Poetea annuae* [$R^2 = 0.4903$ ($p < 0.05$)] (Fig. 1B), old relevés of class *Sisymbrietea* [$R^2 = 0.8698$ ($p < 0.05$)] (Fig. 2A), recent relevés of class *Sisymbrietea* [$R^2 = 0.7282$ ($p < 0.05$)] (Fig. 2B), old relevés of class *Digitario sanguinalis-Eragrostietea minoris* [$R^2 = 0.7348$ ($p < 0.05$)] (Fig. 3A), recent relevés of class *Digitario sanguinalis-Eragrostietea minoris* [$R^2 = 0.9673$, ($p < 0.05$)] (Fig. 3B), old relevés of class *Artemisietea vulgaris* [$R^2 = 0.7995$ ($p < 0.05$)] (Fig. 4A), recent relevés of class *Artemisietea vulgaris* [$R^2 = 0.9101$ ($p < 0.05$)] (Fig. 4B), old relevés of class *Epilobieteae angustifolii* [$R^2 = 0.6625$ ($p < 0.05$)] (Fig. 5A), and recent relevés of class *Epilobieteae angustifolii* [$R^2 = 0.8101$ ($p < 0.05$)] (Fig. 5B).

A negative correlation was obtained between the average percentage cover of invasive taxa and the average values of Shannon–Wiener diversity index in: old relevés of class *Polygono-Poetea annuae* [$R^2 = 0.4914$ ($p < 0.05$)] (Fig. 6A), recent relevés of class *Polygono-Poetea annuae* [$R^2 = 0.7182$ ($p < 0.05$)] (Fig. 6B), old relevés of class *Sisymbrietea* [$R^2 = 0.4843$ ($p < 0.05$)] (Fig. 7A), recent relevés of class *Sisymbrietea* [$R^2 = 0.6878$ ($p < 0.05$)] (Fig. 7B), old relevés of class *Digitario sanguinalis-Eragrostietea minoris* [$R^2 = 0.5182$ ($p < 0.05$)] (Fig. 8A), recent relevés of class *Digitario sanguinalis-Eragrostietea minoris* [$R^2 = 0.8963$ ($p < 0.05$)] (Fig. 8B), old relevés of class *Artemisietea vulgaris* [$R^2 = 0.6240$ ($p < 0.05$)] (Fig. 9A), recent relevés of class *Artemisietea vulgaris* [$R^2 = 0.4178$ ($p < 0.05$)] (Fig. 9B), old relevés of class *Epilobieteae angustifolii* [$R^2 = 0.6941$ ($p < 0.05$)] (Fig. 10A), and recent relevés of class *Epilobieteae angustifolii* [$R^2 = 0.4823$ ($p < 0.05$)] (Fig. 10B).

Based on these results, we could conclude that the proportion of invasive taxa has a negative effect on the species diversity for all the studied types of ruderal vegetation (Fig. 10–Fig. 10).

Discussion

Based on the current inventory of the alien flora of Slovakia, 29 alien taxa were classified as invasive [12], with almost all of them (26) recorded in the ruderal vegetation of Bratislava (Tab. 1). The majority of the recorded invasive species belonged to the Asteraceae, Amaranthaceae, and Poaceae families (Tab. 1). The prevailing presence of

Tab. 1 List of recorded invasive taxa and their occurrence in ruderal vegetation of Bratislava.

Taxon	Family	Life form	Origin	Residence time	P-P		S		D-E		AV		EA		
					or	rr	or	rr	or	rr	or	rr	or	rr	
<i>Ailanthus altissima</i>	Sim	Ph	As	neo	d			9.4				1.3	6.6	2.9	3.3
<i>Amaranthus retroflexus</i>	Ama	T	CAM SAM	neo	a			21.9	7.5	65.0	42.9	1.3			
<i>Ambrosia artemisiifolia</i>	Ast	T	NAM	neo	a	21.4	4.4	15.1				4.4	21.4	2.9	4.4
<i>Apera spica-venti</i>	Poa	T	As E	arch	a		1.8	1.9				1.3	4.1		
<i>Aster novi-belgii</i> agg.	Ast	He	NAM	neo	d			13.2				2.5	8.3	18.6	41.1
<i>Atriplex tatarica</i>	Ama	T	Af As E	arch	a	7.1	43.9	26.4	40.0			13.9	6.6	2.9	
<i>Bidens frondosa</i>	Ast	T	NAM	neo	a							0.6			2.2
<i>Cardaria draba</i>	Bra	He	Af As E	arch	a	3.6	11.4	9.4				22.8	19.8	1.4	2.2
<i>Conyza canadensis</i>	Ast	T	NAM	neo	a	7.1	34.2	41.5	65.0	64.3		24.7	23.9	2.9	2.2
<i>Echinochloa crus-galli</i>	Poa	T	As E	arch	a	7.1	14.0	26.4	8.0	21.4		0.6	4.1		3.3
<i>Echinocystis lobata</i>	Cuc	T	NAM	neo	d										2.2
<i>Fallopia japonica</i>	Pog	G	As	neo	d										2.2
<i>Galinsoga parviflora</i>	Ast	T	SAM	neo	a		7.9			7.1				1.4	
<i>Galinsoga urticifolia</i>	Ast	T	CAM SAM	neo	a			3.8						2.9	1.1
<i>Helianthus tuberosus</i>	Ast	He	NAM	neo	d			5.6					4.1		14.4
<i>Impatiens glandulifera</i>	Bal	T	As	neo	ad									7.1	8.8
<i>Impatiens parviflora</i>	Bal	T	As	neo	d			1.9				0.6	0.9	14.3	14.4
<i>Juncus tenuis</i>	Jun	He	NAM	neo	a			3.6							
<i>Lycium barbarum</i>	Sol	Ph	As	neo	d									8.6	11.1
<i>Matricaria discoidea</i>	Ast	T	As NAM	neo	a	35.7	28.6	7.0	1.9	4.0		0.6			
<i>Negundo aceroides</i>	Sap	Ph	NAM	neo	d			3.6	0.9	3.8			2.5		6.7
<i>Robinia pseudoacacia</i>	Fab	Ph	NAM	neo	d			2.6	5.7			0.6	4.1	18.6	26.6
<i>Rumex patientia</i>	Pog	He	E	neo	d			0.9	1.9			4.4	6.6	8.6	6.7
<i>Solidago canadensis</i>	Ast	He	NAM	neo	ad			3.8					6.6		14.4
<i>Solidago gigantea</i>	Ast	He	NAM	neo	d			4.4	11.3			7.6	13.2	28.6	32.2
<i>Stenactis annua</i>	Ast	T	NAM	neo	a	10.7	6.1	47.2				26.6	60.3	10.0	10.0

Tab. 1 Continued

Explanation: Ama – Amaranthaceae; Ast – Asteraceae; Bal – Balsaminaceae; Bra – Brassicaceae; Cuc – Cucurbitaceae; Fab – Fabaceae; Jun – Juncaceae; Pog – Poaceae; Sap – Sapindaceae; Sim – Simaroubaceae; Sol – Solanaceae; G – geophyte; He – hemipterophyte; Ph – phanerophyte; T – therophyte; Af – Africa; As – Asia; CAm – Central America; E – Europe; NAm – North America; SAM – South America; arch – archaeophyte; neo – neophyte; I m – introduction mode; a – accidental; d – deliberate; ad – both means; P-P – *Polygono-Poetea annuae*; S – *Sisymbrietea*; D-E – *Digitario sanguinalis-Eragrostietea minoris*; AV – *Artemisietea vulgaris*; EA – *Epilobieteae angustifolii*; o r – old relevés; r r – recent relevés.

invasive plant species from these three families has also been recorded in agrocoenoses of Slovakia [47], Slovak alien flora [12], Czech alien flora [4], Greek alien flora [9], Finnish alien weed flora [48], and alien flora of Europe [7]. Many authors deal with invasive and alien plant species also in Poland [49–54] and Germany [55–57]. Asteraceae and Poaceae families were most affected by invasive species also in Poland [51].

The tendency of families to beget alien invasive species can be explained by their biological features. The Asteraceae family is one of the most evolutionary advanced plant families [58]. The members of this family possess many features that are advantageous for invasion, e.g., high reproductive rate, large proportion of self-pollinated species, self-dispersal and vegetative spread, specialized dispersal structures (pappus, hooked seeds, etc.), and high level of apomixis, which account for their superior ability to invade adventive areas [59,60].

Similarly, successful dispersal mechanisms in the Poaceae family may explain why it is one of the most commonly invaded families. Some invasive alien species from the Amaranthaceae family achieve success via high reproductive rate, long viability of seeds, and C₄ photosynthesis [58,60].

In addition to these biological features, the plant species from these families also exhibit qualities that made them valuable to early humans, some of which are still useful today. They were used for food, medicine, and as ornamental plants, which caused their deliberate introduction into new areas. The ability to pass through geographical as well as ecological barriers enables alien species to establish themselves successfully in a new area and start competing with the resident vegetation.

The majority of the recorded invasive species were neophytes (Tab. 1). Similarly, the majority of alien invasive species of Slovak flora were neophytes. Only four of them were archaeophytes, i.e., *Apera spica-venti*, *Atriplex tatarica*, *Cardaria draba*, and *Echinochloa crus-galli*, all of which were recorded in the ruderal vegetation of Bratislava during both time periods (Tab. 1). A similar observation has been reported for the Czech alien flora [4] and Greek alien flora [9], where majority of the alien species are neophytes. If we consider the archaeophytes as remnants from past invasions, it is likely that they are gradually being replaced by recent invasive neophyte taxa, in accordance with the “competitive exclusion principle” [61,62].

The highest number of invasive alien species (22) were recorded in the communities of class *Epilobieteae angustifolii* (Tab. 1), as this also included the communities from the alliance *Senecionion fluviatilis*, which frequently occur on disturbed and nitrogen-rich riparian habitats exposed to invasion [63]. The surplus of nutrients and amount of ground water are crucial factors for the growth of some invasive species such as *Impatiens glandulifera* [64]. Moreover, the riparian habitats of class *Epilobieteae angustifolii* are strongly disturbed by both floods and various human activities. The resistance to plant invasion correlates with the effect of the disturbance, which creates empty niches and increases the probability of colonization by alien species [14,65]. This has also been reported in the studies from the Czech Republic [5,8,22], thus confirming that the effect of disturbance is one of the most significant determinants of invasion.

Communities of class *Sisymbrietea* were also considerably invaded by invasive species. Class *Sisymbrietea* accounted for 20 of the invasive species. This can be explained by the fact that the communities of this class occur on newly disturbed habitats, which contain numerous empty niches, allowing invasive species to expand widely. These habitats also experience strong disturbances, which further promote invasive species.

Trampled habitats of classes *Polygono-Poetea annuae* and *Digitario sanguinalis-Eragrostietea minoris* hosted the least number of invasive species among all the classes (Tab. 1). The lowest proportion of alien species in trampled sites was also reported for the anthropogenic vegetation of the Czech Republic [8] and the Northwest Balkans [66]. Strong trampling causes compaction of the soil, thereby decreasing its aeration. The decreased soil porosity limits access to water and nutrients, which stresses plants [67], and colonization by nonadapted invasive species is typically not successful.

Invasion of non-native species in ruderal areas is problematic for many reasons. Invasive species can negatively affect ecosystem services and have negative effects on environmental, agricultural, animal, as well as human domain (e.g., causing allergic reactions). Some of these species are noxious weeds in the arable land of Bratislava [32]. Some of them (e.g., *Ambrosia artemisiifolia* or *Solidago* sp.) stimulate allergies. Many studies have focused on the allergenic plants in Bratislava, e.g., Drábova-Kochjarová

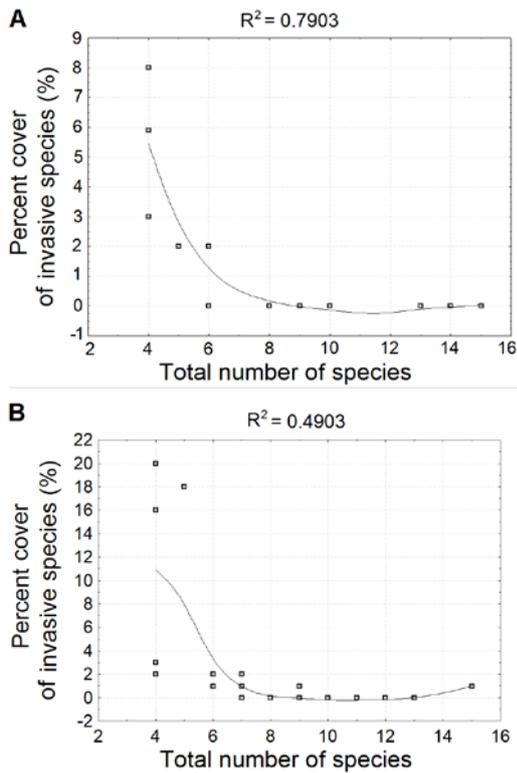


Fig. 1 The relationship between the percentage cover of invasive taxa and the total number of species in the plant communities of class *Polygono-Poetea annuae* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

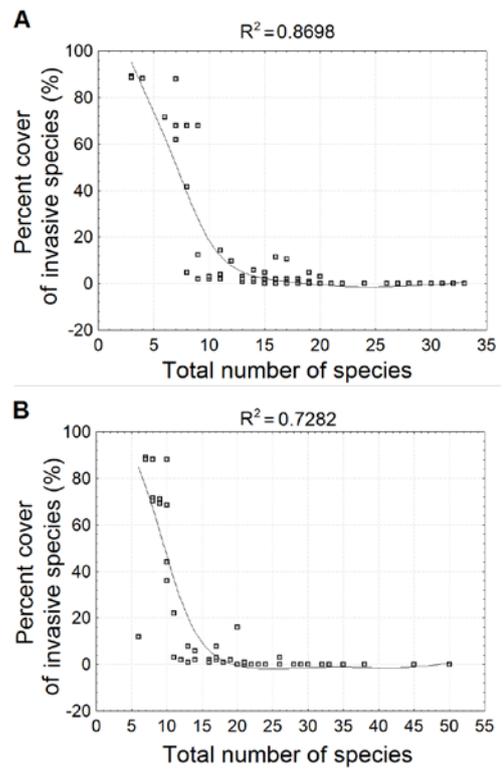


Fig. 2 The relationship between the percentage cover of invasive taxa and the total number of species in the plant communities of class *Sisymbrietea* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

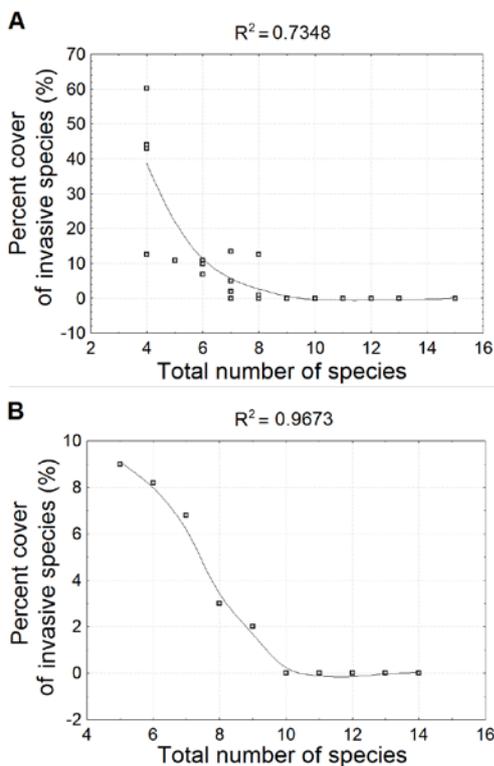


Fig. 3 The relationship between the percentage cover of invasive taxa and the total number of species in the plant communities of class *Digitario sanguinalis-Eragrostietea minoris* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

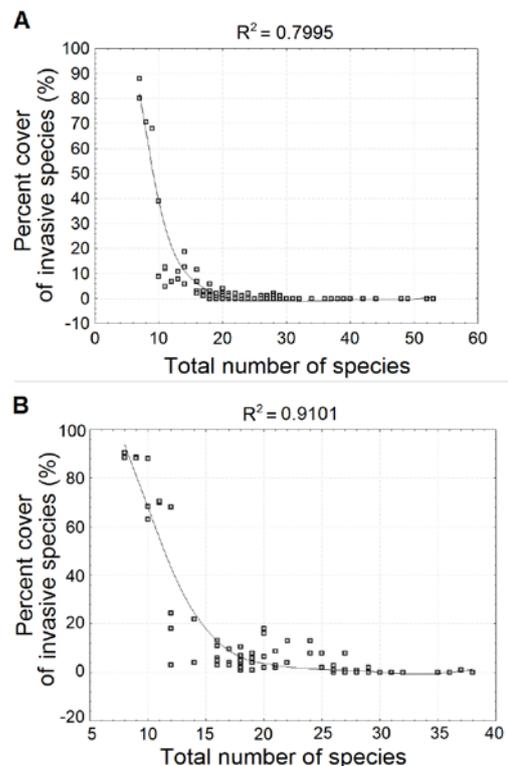


Fig. 4 The relationship between the percentage cover of invasive taxa and the total number of species in the plant communities of class *Artemisieta vulgaris* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

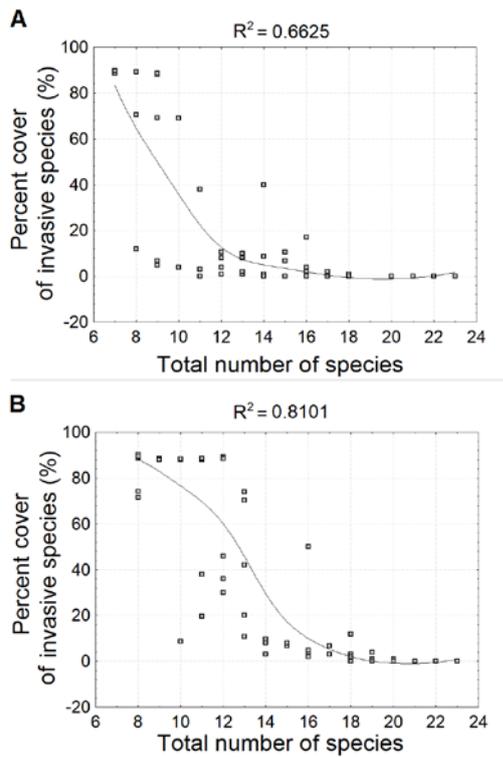


Fig. 5 The relationship between the percentage cover of invasive taxa and the total number of species in the plant communities of class *Epilobietea angustifolii* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

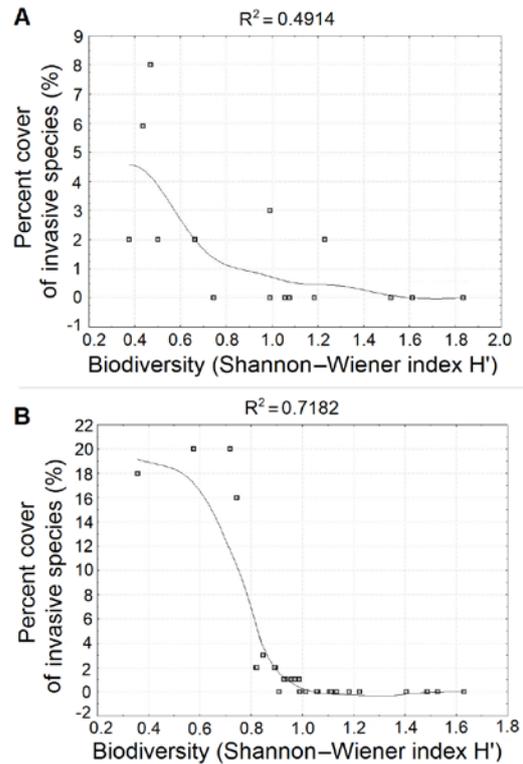


Fig. 6 The relationship between the percentage cover of invasive taxa and the Shannon–Wiener diversity index in the plant communities of class *Polygono-Poetea annuae* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

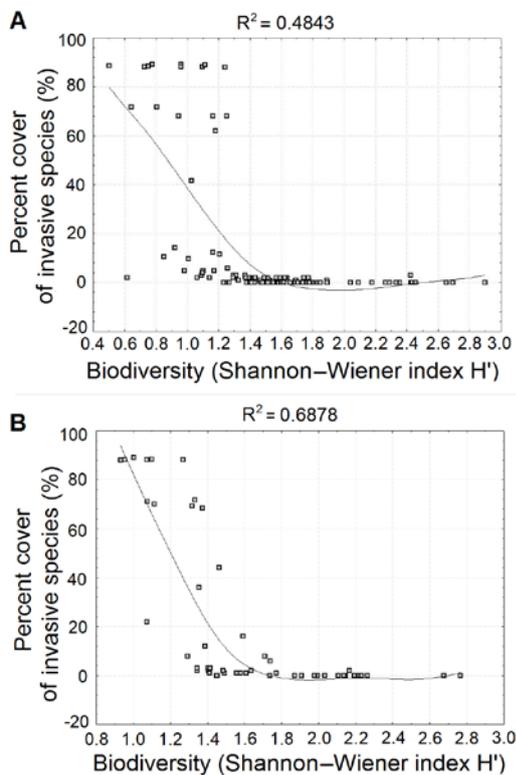


Fig. 7 The relationship between the percentage cover of invasive taxa and the Shannon–Wiener diversity index in the plant communities of class *Sisymbrietea* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

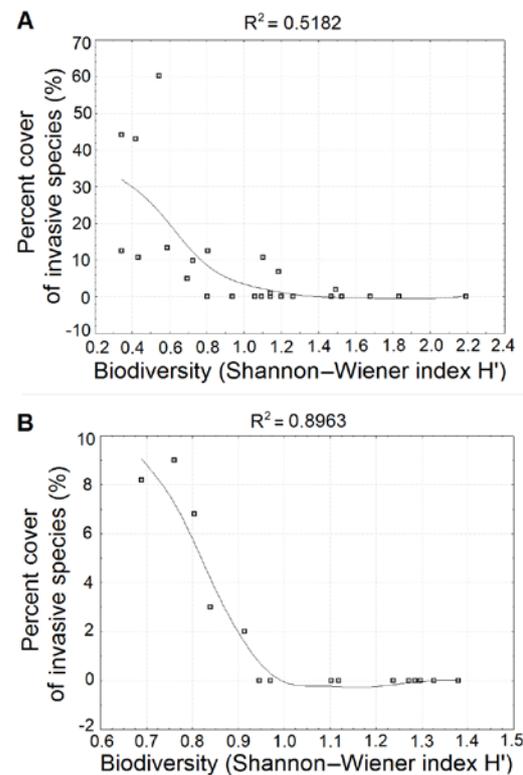


Fig. 8 The relationship between the percentage cover of invasive taxa and the Shannon–Wiener diversity index in the plant communities of class *Digitario sanguinalis-Eragrostietea minoris* in the old (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

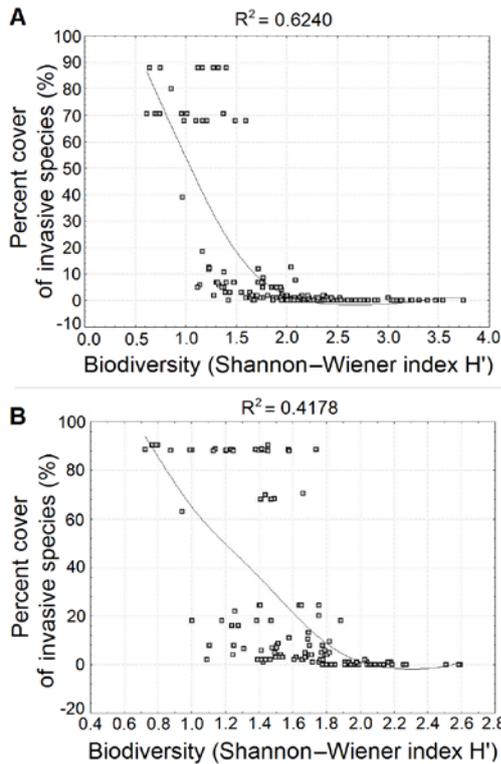


Fig. 9 The relationship between the percentage cover of invasive taxa and the Shannon–Wiener diversity index in the plant communities of class *Artemisietea vulgaris* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

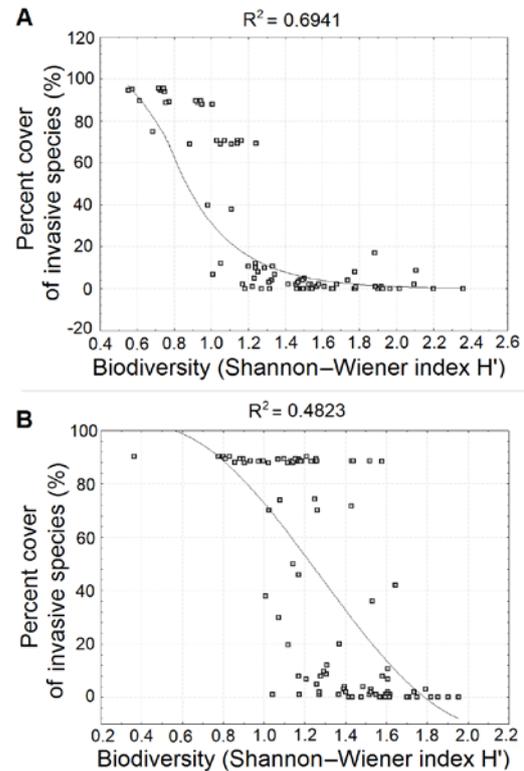


Fig. 10 The relationship between the percentage cover of invasive taxa and the Shannon–Wiener diversity index in the plant communities of class *Epilobietea angustifolii* in the old relevés (A) and recent relevés (B) of the ruderal vegetation of Bratislava.

[68] listed many vascular plant species that are sources of allergens from the municipal part of Petržalka. Many species that cause pollinosis have been recorded by Feráková [32] in the floodplain area of Bratislava near Morava and Danube rivers. Botanists often collaborate with medical professionals, as confirmation of allergenic species is typically based on clinical tests. Majority of allergenic plant species occur on abandoned areas of Bratislava that are colonized by ruderal vegetation [32]. The ragweed (*Ambrosia artemisiifolia*) pollen is increasingly important from an allergological point of view in parts of Central and Eastern Europe [69]. This species was recorded in most of the classes of ruderal vegetation of Bratislava. Record of *A. artemisiifolia* in plant communities of *Polygono-Poetea annuae* class is of particular interest, because this type of community typically occurs at the edges of pavements or playgrounds. A reduction in the occurrence of *A. artemisiifolia* should be one of the most important management goals of ruderal vegetation of Bratislava in the near future.

Based on the results of the correlation analysis, we concluded that invasive taxa have a negative effect on the biodiversity of ruderal communities in Bratislava. While invasive alien taxa may increase the local biodiversity [70], or have a weak or no effect on the local and regional biodiversity [31], it is still a fact that the extinctions caused by invasive taxa result in a severe decline in the global biodiversity, which is likely faster than its recovery rate [70]. For example, aggregations of invasive species such as *Fallopia japonica* and *Helianthus tuberosus*, which were recorded in the recent relevés in Bratislava (Tab. 1), can almost completely rebuilt the structure of a plant community. The adverse effects of these species have also been reported across urban and suburban habitats in Poland [54,71].

Urban ecosystems are not only the key point of entry for many invasive species, but they also serve as the foci for their secondary release or escape into surrounding landscape [72]. The role of cities as launching sites for the introduction of invasive species and their spread into natural areas, and as targets of a range of socioecological effects, highlights the need for further research to address key limitations that hinder our understanding of invasion dynamics in urban settings [73].

Conclusions

Many studies have shown that invasive species can cause huge declines in biodiversity levels, e.g., predatory animals in native island ecosystems. The effects of invasive plant species on the biodiversity are more disputable. From the results of our study, we could conclude that the negative effects of invasive plant species on biodiversity are observed in anthropogenic conditions. These findings can be a valuable tool for addressing scientific questions about the ecology of invasive plant species and their effects on biodiversity. Moreover, our results also have practical applications for nature conservation, invasive species management, and restoration of urban habitats.

Acknowledgments

We sincerely thank Dr. Jarolímek for providing us his phytosociological data and Aaron Fishbone for English grammar proofreading of the manuscript.

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