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ORIGINAL RESEARCH PAPER

Changes in presence of alien species in the ruderal vegetation of a representative ecosystem in a major city over 30 years: a case study from Bratislava

Alena Rendeková[1]*, Ján Miškovic[1], Karol Mičieta[1], Michal Hrabovský[1], Ivan Jarolímek[2]

[1] Department of Botany, Faculty of Natural Sciences, Comenius University in Bratislava, Révová 39, 811 02 Bratislava, Slovakia
[2] Institute of Botany, Slovak Academy of Sciences, Dúbravská cesta 9, 845 23 Bratislava, Slovakia

* Corresponding author. Email: alenarendekova@gmail.com

Abstract

The study is focused on evaluating changes in the presence of alien species in ruderal vegetation. Two datasets comprising phytosociological relevés of ruderal communities during two time periods within the Bratislava City (in southwestern Slovakia) were analyzed. The old dataset consisted of 387 relevés recorded in the years 1975–1982, and the more recent dataset consisted of 308 relevés from the years 2011–2014. The relevés from both time periods were assigned to phytosociological classes via the same procedure – numerical classification (hierarchical clustering) using HIERCLUS software. The average values of the percentage number and percentage cover of the archaeophytes and neophytes as groups in the earlier and more recent relevés of each class were compared by the main effects ANOVA analysis in the STATISTICA 7.0 software. The proportion of each taxon of archaeophytes and neophytes in both datasets was also calculated. The invasive status, origin, and life forms of alien species in both datasets were compared. In total, both datasets comprised 120 archaeophytes and 71 neophytes. The old dataset contained more archeaophytes than the more recent dataset. On the contrary, the more recent dataset contained more neophytes than the old dataset. In the years 2011–2014, more invasive neophytes were recorded than in the past. The results revealed a statistically significant decrease in the average percentage number of archaeophytes in the classes *Stellarietea mediae*, *Artemisietea vulgaris*, and *Galio-Urticetea*, and a decrease in the average percentage cover of archaeophytes in the class *Artemisietea vulgaris*, compared to the past. On the contrary, a statistically significant increase in the average percentage number and cover of neophytes in the classes *Artemisietea vulgaris* and *Galio-Urticetea* was recorded. Some rare species of archaeophytes were only recorded 30 years ago (e.g., *Kickxia elatine*, *Silene gallica*). Furthermore, several species of neophytes (including some invasive taxa, e.g., *Fallopia japonica*, *Helianthus tuberosus*, *Juncus tenuis*) occur only currently in the ruderal vegetation of Bratislava.

Keywords

archaeophyte; non-native taxa dynamics; invasive plant species; neophyte; synanthropic plant communities; Slovakia; urban ecology

Introduction

Human activity is presently an important factor which significantly impacts ecosystems and individual coenoses. Cities are places where human activity significantly influences an ecosystem [1,2]. Cities represent unique environments with specific conditions reflected by well-adapted organisms and unique communities. Environmental conditions change very rapidly in urban areas, which has a significant effect on phytocoenoses. Human activities and changes in city environments are closely related to the diversity, frequency, and distribution of alien plant species (archaeophytes and neophytes), which are notably represented in ruderal communities [3]. The degree of impact of alien species in each group of plant communities varies [4,5]. Therefore, the study of alien species dynamics in various ruderal habitats is very important.

Numerous authors have focused on the study of the alien species in synanthropic habitats in Poland [6–8], or analyzed changes in synanthropic flora and vegetation in Poland [9,10] and Germany [11]. Several studies from the Czech Republic [12–15] and Germany [16] are related to the dynamics of the representation of alien species in ruderal vegetation. Zisenis [17] focused on the examination of the impact of neophytes on urban ecosystems in Germany. Brun [18] presented a study of the biodiversity changes in cultivated and ruderal environments since the Neolithic period in eastern France. Basnou et al. [19] examined the effects of land use change on alien plant invasion in urban Mediterranean coastal habitats (the metropolitan region of Barcelona, NE Spain). Short-term changes in alien species representation in urban areas in Great Britain were analyzed by Botham et al. [20]. Chen et al. [21] studied the dynamics of ruderal species diversity in Harbin, a large city in Northeast China. Kopel et al. [22] analyzed of the ruderal vegetation dynamics in the fringe of the city of Haifa. Kanpp et al. [23] studied the changes of Central European urban flora and Lososová et al. [24] studied alien plant taxa in urban habitats across numerous cities in Central Europe. There is no study focusing on the long-term changes of alien species in ruderal vegetation in Slovakia. Medvecká et al. [25] studied the dynamics of alien species in Slovakia, but they focused on various vegetation types and did not pay special attention to ruderal habitats.

This was one of the reasons we chose the area of Bratislava, the capital city of Slovakia, for our survey. We studied the dynamics of alien species in ruderal vegetation within the city over the time period of approximately 30 years. The area and time horizon offered space for research of the dynamics of alien species and ruderal communities, as Bratislava provides a number of habitats which are important for the dispersing of alien species (e.g., the traffic network or the recently disturbed areas of construction sites) and the conditions for the existence of ruderal vegetation over the last 30 years have changed significantly. Notable changes occurred in 1993, when Bratislava became the capital of the independent Slovak Republic. Intensive construction began in the city around this time, and many open areas that had been previously covered with vegetation were gradually built-up. Around the buildings artificial lawns were created and their vegetation was cultivated. Cooperative farms disappeared, and vast areas of vineyards were abandoned. In gardens, fewer crops and more ornamental plants that people often brought from abroad were grown [26].

The general aim of this study is to determine whether the presence of alien species in various groups of ruderal plant communities in Bratislava changed over time and if so, in what scope. Therefore, the following aims and hypothesis were formulated:

- The first aim: to assess the changes of the participation of archaeophytes and neophytes as groups in different classes of the ruderal vegetation of Bratislava over time. Hypothesis: we expected that the average percentage number and percentage cover of alien species in all classes of ruderal vegetation of Bratislava would increase in comparison to the past.
- The second aim: to assess changes in the participation of every alien plant species in all distinguished classes of the ruderal vegetation of Bratislava over time.

Material and methods

Study area

The study area was defined by the borders of the city of Bratislava. Bratislava, the capital city of Slovakia, is situated in the southwestern part of the country, near the borders with the Czech Republic, Hungary, and Austria, in Central Europe. The coordinates of the city centre are N 48°08′30″, E 17°06′30″. The altitude ranges from 126 to 514 m a.s.l. The area of Bratislava lies within three orographic units: flatland Podunajská rovina, lowland Borská nížina, and Malé Karpaty Mts [26].

The climatic conditions of the area range from moderate to warm continental character and the city is one of the warmest and driest regions of Slovakia. In recent years, transitions from winter to summer and summer to winter are becoming fast, while the fall and spring periods are becoming shorter. Average temperature in the coldest month (January) ranges from −1.1°C to 2.0°C, and in the warmest month (July) from 19.3°C to 21.0°C. In city areas, which belong to the Podunajská rovina, the warmest and driest climate conditions prevail, with a mean annual temperature of 10.3°C and mean annual precipitation of 573 mm. Climate conditions in the Borská nížina are somewhat colder and more humid. The most humid and cold zone with a mean annual temperature of 9.5°C and mean annual precipitation of 661 mm is located in the Malé Karpaty Mts. The average duration of sunshine is one of the longest in Slovakia (50% = 2100 h/year; in the vegetation period it is 60% = 1600 h). In ruderal habitats, soil conditions are influenced by human actions and natural soils are covered by anthropogenic ones [26].

The natural potential vegetation of Bratislava consisted mainly of forests: Carpathian *Quercus-Carpinus* forests and *Fraxinus-Ulmus-Quercus* floodplain forests in the Borská nížina, Carpathian *Quercus-Carpinus* forests, acidophilous *Fagus* forests, Pontic-Pannonian *Quercus* forests in the Malé Karpaty Mts, and *Fraxinus-Ulmus-Quercus* floodplain forests and *Salix-Populus* floodplain forests in the Podunajská rovina [26].

Relevé data

Two datasets, approximately 30 years apart, from Bratislava were analyzed. The old dataset consisted of 387 phytosociological relevés recorded in the years 1975–1982 [27], and the more recent dataset consisted of 302 relevés recorded in the years 2011–2013 [28] and six unpublished reléves recorded in 2014 by Rendeková. Phytosociological research in both periods was performed using the methods of the Zürich–Montpellier school [29]. In the years 1975–1982, the old Braun-Blanquet cover-abundance scale was used. In 2011–2014, a modified Braun-Blanquet cover-abundance scale was used, extended by 2m (cover 1–5%, abundance high), 2a (cover 5–12.5%), and 2b (cover 12.5–25%) values [30].

The relevés in 2011–2014 were not sampled at exactly the same localities as old relevés (Fig. 1, Fig. 2), because some of the old localities had been built-up, which made sampling the precise localities impossible. The area of data collection in the years 1975–1981 concerns the same parts and districts of Bratislava as the area of data collection in the years 2011–2014 (Fig. 1, Fig. 2). The relevés were sampled according to the current occurrence and distribution of the ruderal communities. We tried to record all of the types of ruderal vegetation and we tried to choose localities in every city district (Fig. 1, Fig. 2) so that they were distributed throughout the entire non-built-up area of the city. The study area covered a wide spectrum of ruderal habitats, e.g., the edges of pavements, trampled areas at bus stops, parking lots and playgrounds, disturbed areas at construction sites, and waste deposits near gardening settlements, termophilic habitats along walls, fences, edges of roads and railways, termophilic and softly wet habitats in abandoned areas among buildings, eutrophic habitats in dumps, or the wet disturbed banks of the Danube and Morava rivers.

Data analysis

All of the relevés were imported into a TURBOVEG database [31] and edited in a JUICE 7.0 software [32]. Phytosociological data from both time periods were subsequently analyzed by numerical classification. The old and recent data were evaluated by the same procedure – hierarchical clustering in the HIERCLUS software, which is a component of the package used in the case of the old data – NCLAS [33], and also component of the software package used in the case of the recent data – SYN-TAX

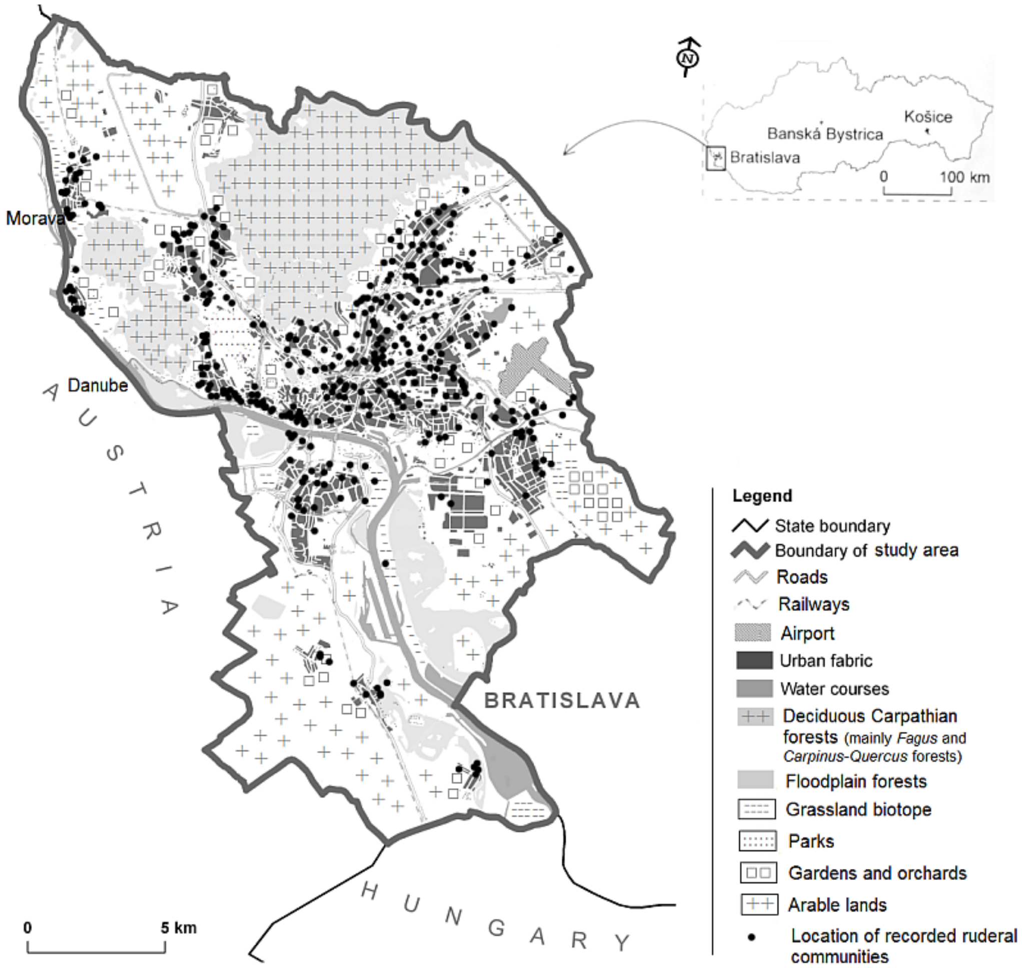

Fig. 1 Types of land use and the distribution of ruderal communities recorded in the study area in 1975–1982 (after Feráková and Jarolímek [26]).

2000 [34]. A beta-flexible method (β = −0.25) in combination with Wishart's index proved to be the most effective linkage method and distance measure, and these parameters were used in most of the analyses.

The relevés were classified into syntaxonomical units based on the results of numerical analyses. For comparison of the old and recent datasets, relevés of ruderal communities belonging to four phytosociological classes were used: *Polygono arenastri-Poëtea annuae* Rivas-Martínez 1975 corr. Rivas-Martínez et al. 1991, *Stellarietea mediae* R. Tx. et al. ex von Rochow 1951, *Artemisietea vulgaris* Lohmeyer et al. ex von Rochow 1951, and *Galio-Urticetea* Passarge ex Kopecký 1969. The definition of phytosociological classes was the same in the both time periods. The class *Polygono arenastri-Poëtea annuae* comprises the plant communities formed mostly by therophytes, growing in trampled habitats. Plant communities with a predominance of annual therophytes with a ruderal life strategy belong to the class *Stellarietea mediae*. This type of vegetation grows at sites which have been newly created and are frequently disturbed. The class *Artemisietea vulgaris* includes vegetation of biennial and perennial hemicryptophytes, growing in ruderal habitats of xerothermic to mesic character. The class *Galio-Urticetea* comprises vegetation whose species composition consists mainly of perennial hemicryptophytes. This type of vegetation is common at wet and softly wet sites with high nitrogen content in the soil [35,36].

Native and alien species (including the classification of archaeophytes or neophytes) in both, the old and the recent relevés of each vegetation class were classified according to the list of alien vascular plant species in the Slovak Republic [37]. Bryophytes and taxa of vascular plants determined only to the genus level were excluded and taxa which occurred in more than one layer were merged. Because different cover-abundance scales have been used in old and recent relevés, to make data comparable,

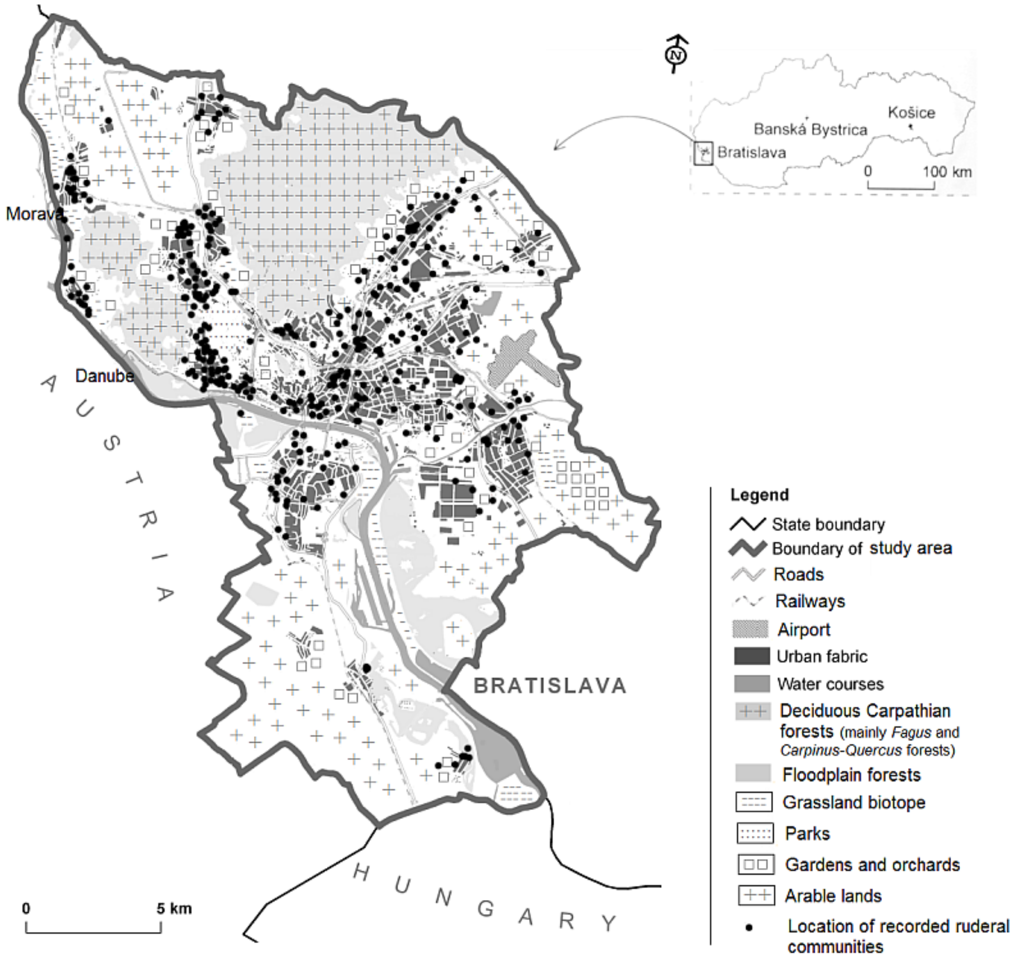

Fig. 2 Types of land use and the distribution of ruderal communities recorded in the study area in 2011–2014 (after Feráková and Jarolímek [26]).

the values 2m, 2a, and 2b in all relevés were converted to value 2 and then evaluation of alien species representation was preceded.

The percentage number and percentage cover of archaeophytes and the same of neophytes in every relevé belonging to the related class were calculated using the JUICE 7.0. The percentage cover was calculated according to the method described by Chytrý et al. [38]. Subsequently, the average values for the whole dataset of each class were calculated and the average values of alien species representation in old and recent relevés of each class were compared by the main effects ANOVA analysis in the STATISTICA 7.0 [39]. The STATISTICA was used for the construction of box plots as well. The percentage presence of each archaeophyte and neophyte taxon in the relevés of every phytosociological class was also calculated. Archaeophytes and neophytes in old and recent dataset were compared in terms of invasive status, origin, and life forms. The invasive status, origin, and Raunkiær's life forms of alien species were determined according to the list of alien vascular plant species in the Slovak Republic [37].

Nomenclature

The nomenclature of taxa follows Marhold [40], and the nomenclature of syntaxa follows Jarolímek et al. [41]. The names of taxa which are not included in Marhold [40] are presented in the following publications: taxa *Fallopia ×bohemica*, *Geranium purpureum* in Kubát et al. [42], and taxon *Euphorbia maculata* in Jávorka and Csapody [43].

Tab. 1 Comparison of the number of recorded relevés and species in studied vegetation types in past and recent periods.

	Polygono arenastri-Poëtea annuae		*Stellarietea mediae*		*Artemisietea vulgaris*		*Galio-Urticetea*	
	1975–1982	**2011–2014**	**1975–1982**	**2011–2014**	**1975–1982**	**2011–2014**	**1975–1982**	**2011–2014**
No. of relevés	16	29	139	67	181	123	51	89
No. of species	34	55	207	196	265	208	141	171

Results

The total numbers of all species recorded in the whole sets of the relevés in most of the phytosociological classes did not change much in comparison to the past (Tab. 1).

The numbers of alien species has changed in the compared period. In total, both datasets together comprised 120 archaeophytes and 71 neophytes. There were more archaeophytes recorded in the past than in the recent periods. On the contrary, there were more neophytes recorded in the recent than in the past. One hundred and seven archaeophytes were recorded in the past and 87 archaeophytes were recorded in the recent periods, 47 neopyhtes were recorded in the past and 56 nephytes were recorded in the recent (Tab. S1, Tab. S2).

The majority of the archaeophytes recorded in the recent periods, as well as in the past, are naturalized. Only four of the archaeophytes in Slovak flora are considered invasive (*Apera spica-venti*, *Atriplex tatarica*, *Cardaria draba*, *Echinochloa crus-galli*) and all of them were recorded in Bratislava in both time periods (Tab. S1).

Fifty-one percent of the neophytes recorded in the past were naturalized, while from those recorded in the recent periods, only 44.6% were naturalized. The number of recorded invasive neophytes increased compared to the past. Seventeen invasive neophytes (which makes 36.2% of all neophytes) were present in the ruderal vegetation of Bratislava in the past and 22 invasive neophytes (39.3%) were present in the years 2011–2014 (Tab. S2).

The contribution of archaeophytes and neophytes in the ruderal vegetation of Bratislava recorded in the past and in the recent periods with respect to their origin is similar (Tab. S1, Tab. S2).

Most of the archaeophytes recorded in the past come from Europe (41.3%), relatively many of them are from Asia (39.7%), less are from Africa (18.6%), and the origin of one (0.4%) is unknown. Most archaeophytes recorded in the recent periods are native to Europe (42.1%), relatively many of them are from Asia (40.1%), less are from Africa (17.3%), and one (0.5%) is an anecophyte (come from cultivation) (Tab. S1).

Most of the neophytes recorded in the past come from Asia (27.9%) and North America (27.9%), followed by Europe (18.0%) and South America (11.5%). Relatively few of them are native to Central America (4.9%) and Africa (4.9%), one neophyte (1.6%) is native to Australia, and one (1.6%) originates from hybridization. The origin of one neophyte (1.6%) recorded in the past is unknown. Most of the neophytes recorded in recent periods originate from Asia (29.7%), and relatively many of them from North America (27.0%), followed by Europe (20.3%), South America (8.1%), Central America (5.4%), and Africa (5.4%). Two neophytes (2.7%) are hybrids and the origin of one neophytic species (1.4%) recorded in the recent periods is unknown (Tab. S2).

The distribution of archaeophytes in categories of life forms in the past was similar to recent periods. Of the total number of archaeophytes recorded in the past, 62.6% are therophytes, and hemicryptophytes (30.9%) are also relatively abundant. Geophytes (3.3%), phanerophytes (2.4%), and chamaephytes (0.8%) are less frequent. The majority of archaeophytes recorded in the years 2011–2014 (57.4%) are therophytes, hemicryptophytes (34.7%) are also relatively well represented. Geophytes (5.0%) and phanerophytes (3.0%) are less frequent (Tab. S1).

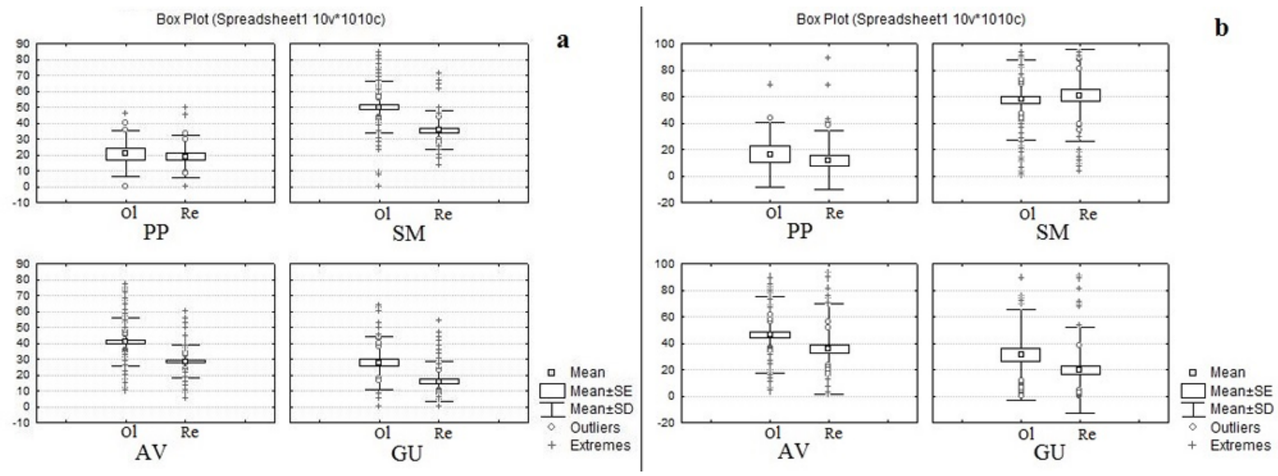

Fig. 3 Changes in the average percentage number (**a**) and average percentage cover (**b**) of archaeophytes between past and recent periods in studied vegetation types. PP – *Polygono arenastri-Poëtea annuae*; SM – *Stellarietea mediae*; AV – *Artemisietea vulgaris*; GU – *Galio-Urticetea*; Ol – old phytosociological relevés (from the years 1975–1982); Re – recent phytosociological relevés (from the years 2011–2014).

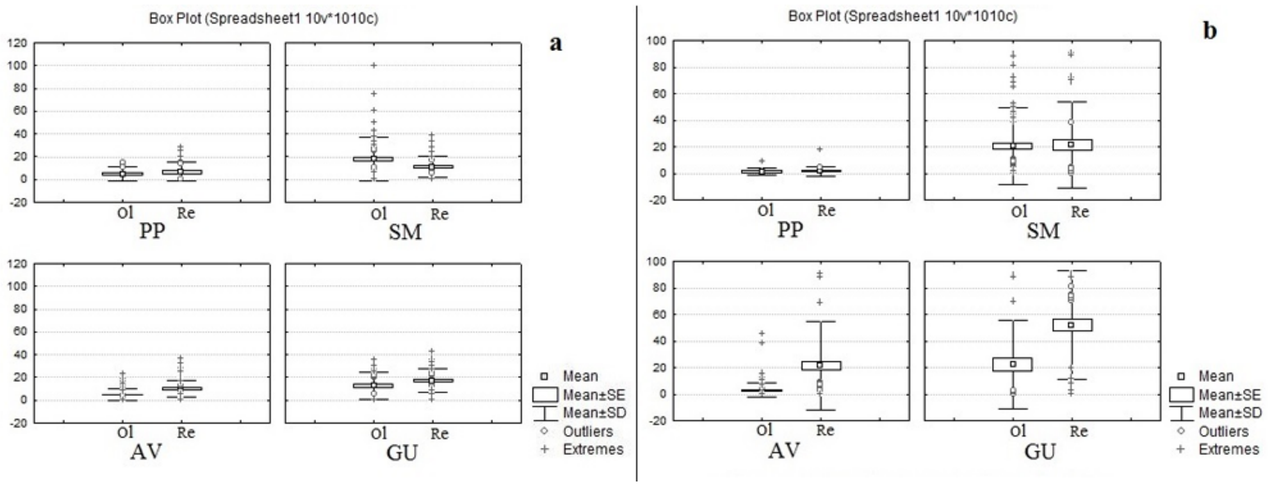

Fig. 4 Changes in the average percentage number (**a**) and average percentage cover (**b**) of neophytes between past and recent periods in studied vegetation types. Explanation corresponds to those in Fig. 3.

In the past, there were slightly more therophytes (61.7%) among recorded neophytes than in the recent periods (49.1%). In the recent periods, there were slightly more phanerophytes (19.3%) among neophytes than in the past (12.8%). In both periods, the majority of recorded neophytes were therophytes, hemicryptophytes were also relatively abundant (21.3% in the past, 24.6% in the recent periods), and a smaller percentage (4.3% in the past, 7.0% in the recent periods) of neophytes were geophytes (Tab. S2).

A comparison of the average representation of alien species in the ruderal vegetation of Bratislava in the years 1975–1982 and 2011–2014 showed that for the majority of the classes our hypothesis was not confirmed in the case of archaeophytes (Fig. 3a,b) and the hypothesis was confirmed in the case of neophytes (Fig. 4a,b).

The average percentage number of archaeophytes (Fig. 3a) in the relevés of communities decreased in a statistically significant way in the classes *Stellarietea mediae* [$F(1, 204) = 40.5$, $p < 0.001$; F – F ratio; p – p value; numbers in bracket behind the F ratio represents values for degrees of freedom], *Artemisietea vulgaris* [$F(1, 302) = 57.2$, $p < 0.001$], and *Galio-Urticetea* [$F(1, 138) = 21.8$, $p < 0.001$]. The slight decrease in *Polygono arenastri-Poëtea annuae* proved to be statistically insignificant.

The average percentage cover of archaeophytes (Fig. 3b) decreased significantly in the class *Artemisietea vulgaris* [$F(1, 302) = 9.4$, $p = 0.002$]. The decreased average values in *Polygono arenastri-Poëtea annuae*, *Galio-Urticetea*, and slightly increased average values in *Stellarietea mediae* proved to be statistically insignificant.

The average percentage number of neophytes (Fig. 4a) increased in the classes *Artemisietea vulgaris* [$F(1, 302) = 57.9$, $p < 0.001$], *Galio-Urticetea* [$F(1, 138) = 5.7$, $p = 0.018$], and slightly decreased in the class *Stellarietea mediae* ($F(1, 204) = 6.7$, $p = 0.010$]. The small increase of average values in *Polygono arenastri-Poëtea annuae* proved to be statistically insignificant.

The average percentage cover of neophytes (Fig. 4b) increased notably in the classes *Artemisietea vulgaris* [$F(1, 302) = 52.4$, $p < 0.001$] and *Galio-Urticetea* [$F(1, 138) = 19.1$, $p < 0.001$]. In *Artemisietea vulgaris*, it increased from 2.96% to 21.39% and in *Galio-Urticetea* from 22.2% to 51.7%. The small increase of average values in the classes *Polygono arenastri-Poëtea annuae* and *Stellarietea mediae* proved to be statistically insignificant.

The frequency of occurrence of many particular species of archaeophytes in the relevés of all classes decreased compared to the past (Tab. S3). A significant decrease was recorded in the case of species such as *Artemisia absinthium*, *Carduus acanthoides*, *Lepidium ruderale*, *Onopordum acanthium*, and *Sisymbrium loeselii*. Moreover, there were a great number of archaeophytes that were recorded only 30 years ago and currently do not occur in the ruderal vegetation of the study area at all (Tab. S3). On the other hand, several archaeophytes are more frequent at present, notably species *Portulaca oleracea* and the invasive archaeophyte *Echinochloa crus-galli*.

The frequency of occurrence of the majority of species of neophytes in the relevés of all classes rose compared to the past (Tab. S4). A great number of invasive species belong to these (e.g., *Ailanthus altissima*, *Ambrosia artemisiifolia*, *Solidago gigantea*, *Negundo aceroides*). At present, the invasive neophyte, *Aster novi-belgii* agg., is also significantly more frequent. This neophyte is widely spread primarily in the communities of the class *Galio-Urticetea*. It was recorded only in 7.8% of the relevés of this class from the past, but increased even to 51.7% of the relevés from the years 2011–2014. A significant increase was also recorded in the case of the invasive neophyte *Stenactis annua*, but the increase was specific mainly for the class *Artemisietea vulgaris*, not for all the classes. This neophyte was recorded only in 19.9% of the old relevés of the class *Artemisietea vulgaris*, but increased even to 60.2% of the recent relevés.

In the years 2011–2014, we recorded many neophytes that were not present in communities of any class in the past (Tab. S4). Some invasive species are present among them: *Fallopia japonica*, *Helianthus tuberosus*, *Solidago canadensis*, and also neophytes, which were only found recently in the Slovak Republic: *Euphorbia maculata* in the year 2007 [44] and *Geranium purpureum* in the year 2010 [45].

Discussion

The results of the presented study reveal remarkable changes in the average representation of alien species in ruderal vegetation over time (Fig. 3, Fig. 4). Although the majority of our results proved to be statistically significant, changes in the proportion of alien species in the class *Polygono arenastri-Poëtea annuae* proved to be insignificant. This can be explained by the fact that in trampled habitats, where communities of the class *Polygono arenastri-Poëtea annuae* occur, only a few species can survive and consequently communities of this class are species-poor [35,36] and also poor in terms of the participation of alien species [4,5]. In 2011–2014, the class *Polygono arenastri-Poëtea annuae* was invaded mainly by the invasive neophyte *Ambrosia artemisiifolia* (Tab. S4). The species *Ambrosia artemisiifolia*, with a short life cycle, is able to survive and reproduce in the extreme conditions of these habitats [46], therefore the probability of its presence in such niches is higher than for other invasive species.

Comparison of the phytosociological classes of ruderal vegetation of Bratislava in the past and recent from the aspect of the occurrence of particular alien species showed notable changes as well (Tab. S3, Tab. S4). We think that one of the reasons for the recent decrease of the representation of various archaeophyte species compared to the past could be the changes in gardening methods which occurred in Bratislava within the studied time period. Several ruderal phytocoenoses in the study area develop near gardens from which the species can penetrate the stands. During the last 30 years, several small-area gardens with good conditions for archaeophytes have disappeared in the city. Many of these gardens have been abandoned or they have been built-up. In the remaining gardens, gardeners now grow fewer crops [26]. Among these crops are several archaeophytes (such as *Armoracia rusticana*, *Raphanus raphanistrum*, *Sinapis arvensis*) that are present in a smaller percentage of recent relevés or in none, although they were present in ruderal communities in the past (Tab. S3). Large areas of Bratislava's vineyards have also been abandoned or built-up during the studied time period, which may have caused the decrease in occurrence of another archaeophyte – the species *Vitis vinifera* (Tab. S3).

At present, many archaeophytes belong to the category of endangered species, among them especially segetal species [7,35,40,47]. Some of the endangered and rarer archaeophytes (*Chenopodium murale*, *Cyanus segetum*, *Kickxia elatine*, *Silene dichotoma*, *S. gallica*) also occurred in the ruderal vegetation of Bratislava, however, only in the past. Moreover, our conclusions also prove that the decline in the number of archaeophytes known in the case of segetal communities [48,49] shows up in ruderal communities as well.

We believe that the change of the spectrum of plants grown in gardens could be connected not only to the decrease of the share of archaeophytes, but on the other hand, it could also be connected with the increase of the proportion of neophytes, which has been recorded many times (Tab. S4). Even 24 neophytes occur only recently in the ruderal vegetation of Bratislava. Currently, citizens prefer growing ornamental plants, of which several are neophytes. These species were not grown at all 30 years ago or were planted less often [26]. We have observed neophytes such as *Aster novi-belgii* agg., *Fallopia japonica*, *F.* ×*bohemica*, *Helianthus tuberosus* grown in gardens in various parts of the city. Some recorded stands in which these neophytes are dominant occurred in the vicinity of gardens [28]. Different numbers of recorded relevés in the past and in the recent periods (Tab. 1) could also result in the fact that the results of analysis showed changes in the representation of alien species, but the numbers of recorded relevés are related to changes in the spectrum of recorded ruderal communities and changes in the spectrum of communities are related to changes in land-use (gardening methods, etc.). A similar explanation was given by Pyšek and Mandák [12]. They considered changes in the variety of plant species available on the gardening market in the last few years to be one of the reasons for the increase of neophytes in village flora in the Czech Republic, because these plants, by escaping from cultivation, represent an important contribution to the neophyte pool. Additionally, although the numbers of relevés recorded in Bratislava in the past and in the recent periods are different, total numbers of all species recorded in the whole sets of relevés did not change much in comparison to the past (Tab. 1), which partially annulled the option that the changes in the representation of alien species are caused by different numbers of recorded relevés. Another reason for the increase in the representation of neophytes may be the boom of building activity in Bratislava in the last decades [26], as some neophyte species are encouraged by such building activity [50].

The frequency of occurrence of some invasive neophytes increased compared to the past (Tab. S4), although we did not pay special attention to communities formed by invasive plants during the phytosociological research carried out in recent periods. Although the old and recent relevés were not made in exactly the same localities, they were recorded in the same parts of Bratislava and in a similar spectrum of ruderal habitats (Fig. 1, Fig. 2). However, we do not exclude that some of the species (e.g., *Solidago canadensis*) could have occurred in Bratislava also in the years 1975–1982, even though they were not recorded.

Botanists dealing with the study of changes in the representation of alien species in other territories have come to similar conclusions as we did. Compared to the past, a decrease in the proportion of archaeophytes [13,14,16,25] and an increase in the proportion of neophytes in nearly all anthropogenic habitats in Europe [12,13,15,16,20], the Middle East [22], and New Zealand [51] has been recorded. A similar upward trend in the proportion of neophytes was observed not only in urban areas but also in other types of habitats. Over time, a significant increase in the number and cover of neophytes was found in the hardwood floodplain forests in the Pannonian region [52] and an increase in relative neophyte richness was also recorded in many other habitats in Slovakia [25].

The evaluation of alien species dynamics in the ruderal vegetation of Bratislava showed the following conclusions: the average values of the percentage number and percentage cover in the majority of classes decreased compared to the past in the case of archaeophytes (Fig. 3), and increased in the case of neophytes (Fig. 4). The frequency of occurrence of many species of archaeophytes fell (Tab. S3), and the frequency of many species of neophytes rose (Tab. S4) compared to the past. Changes in species composition of urban ruderal vegetation are part of a global process of synanthropization of the biota. This brings two main consequences – a decrease of biodiversity and the homogenization of biota. The analysis of two datasets of ruderal vegetation from Bratislava 30 years apart has fully supported the presumption that increasing anthropogenic pressure during the last decades is reflected in an increasing proportion and abundance of alien species, especially invasive neophytes, which are the main drivers of the process of homogenization of vegetation.

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Supplementary material

The following supplementary material for this article is available at http://pbsociety.org.pl/journals/index.php/asbp/rt/suppFiles/asbp.3538/0:

Tab. S1 Invasion status, origin and life forms (according to the Raunkiær classification) of archaeophytes recorded in ruderal vegetation of Bratislava in the past and recent periods.

Tab. S2 Invasion status, origin and life forms (according to the Raunkiær classification) of neophytes recorded in ruderal vegetation of Bratislava in the past and recent periods.

Tab. S3 Comparison of phytosociological classes of ruderal vegetation of Bratislava in the past and recent periods from the aspect of the occurrence of archaeophytes.

Tab. S4 Comparison of phytosociological classes of ruderal vegetation of Bratislava in the past and recent periods from the aspect of the occurrence of neophytes.

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