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# An analysis of research into urban flora and vegetation in Southeast Europe

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**Abstract** – In the last two decades, the number of research articles focused on urban ecosystems in Europe has increased significantly. However, the cities investigated are very unevenly distributed, and most of the studies are focused on Central Europe. The aim of this analysis was to provide a realistic insight into the results of previous research into the urban flora and vegetation of Southeast Europe. The analysis covers a total of 149 articles, classified according to the topic and concept of research. The rates of exploration of urban flora and vegetation vary considerably across the countries of Southeast Europe. The floristic approach was the most common. Although some countries of Southeast Europe have a significant number of floristic studies (e.g. Serbia and Croatia with more than 20 each), their urban flora is still insufficiently explored compared to other European regions. Also, the use of different methodologies makes it impossible to compare results in an adequate way and draw relevant conclusions. Unlike the studies in most of Europe, with a broader spatial framework and uniform methodology, in Southeast Europe they usually referred to individual cities, specific habitats or certain parts of the cities. Hence, including Southeast Europe in large-scale studies would be beneficial.

**Keywords:** Balkan Peninsula, current state of research, invasive plants, literature review, ruderal flora, ruderal vegetation

## Introduction

Human settlements present a specific environment for living beings with unique conditions that significantly influence the diversity of plant species (McKinney 2006). Urban areas are subject to intensive and frequent habitat disturbance, above all by trampling, and are characterized as well by herbicide use (Knapp et al. 2012) and nutrient enrichment leading to habitat eutrophication (Lososová et al. 2012a). Due to the presence of buildings in close proximity to each other, areas with a hard surface (asphalted, concreted or paved), mowed lawns, and pollution (heat and air), urban areas have climatic conditions that are different from those in the surrounding natural environment. Called the urban heat island effect, the phenomenon of higher temperatures in urban areas is very prominent in big cities (Gaston et al. 2010) and exerts strong influence on the species composition of urban plant communities (Wittig 2002). From the viewpoint of island biogeography, cities can be regarded as a type of ecological island isolated by its surroundings from other urban ecological islands (McGregor-Fors et al. 2011).

Urban flora is mainly distinguished by high species richness and consists of native and alien species from different parts of the world (Lososová et al. 2012a). The heterogeneity of urban habitats (Kühn et al. 2004) and the high influx of propagules, factors that are in positive correlation with the level of urbanization and size of the city (Pyšek 1998), result in high species diversity in the total urban flora (Kühn et al. 2004). The total number of plant species increases with size of the city (Pyšek 1998), but city size also influences species richness in particular habitats (Čeplová et al. 2017). Urbanization is often considered as the greatest threat to native species diversity (McKinney 2004). It affects the variety of living beings and their functional characteristics (Lososová et al. 2006). Although richer than the flora in rural areas

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(Kühn et al. 2004), the urban flora is distinguished by lower functional variety. The largest number of plants in Central European cities are human-dispersed species with big demands for nutrients and a preference for drier to mesic soil conditions (Kalusová et al. 2016).

Urban areas are especially interesting in the context of biological invasions. To be specific, human activities in cities result in a high input of propagules, resulting in a large proportion of foreign species (Pyšek 1998). Alien plant species make up about 40% of the total flora in Central European cities (Pyšek 1998), with similar participation in individual urban habitats (Lososová et al. 2012a). The number of alien species in the cities of Central Europe is still increasing (Pyšek et al. 2004), and urban areas can represent centres for the dissemination of alien introduced species into surrounding areas (Hulme et al. 2008), where some of them can become naturalized or even invasive. According to Lososová et al. (2018), new alien species in Central European cities will increase the risk of invasion in the future. This can not only induce a decrease of native species diversity but can result in biotic homogenization, i.e., to an increase in the similarity of different areas with respect to species composition (Olden et al. 2004). However, the influence of alien species on biodiversity depends on the time of their introduction (Rejmánek 2000). In cities, the presence of archaeophytes (species introduced before 1500 AD) generally led to increasing floristic homogenization, while the presence of neophytes (species introduced after 1500 AD) usually had the opposite effect (Lososová et al. 2012b).

Although urban habitats are characterized by the presence of allochthonous plant species, some preserved natural or semi-natural habitats in cities may represent a hiding place for certain specialized species, including even rare and endangered ones (Kühn et al. 2004). Urban flora is often surprisingly rich in species and presents a combination of plants with the most different habitat preferences and distribution types. Also, urban vegetation contributes to ecosystem services and affects the citizens' well-being (Bratman et al. 2012). Because of that and since the human population of Europe mostly lives in urban areas, it is of great importance to know and understand the processes that form the composition of species in spontaneous urban vegetation.

Urban ecology is a young ecological discipline. Interest in exploring urban ecosystems emerged in the 1960s and 1970s (Wittig 2002), and the number of studies with a focus on urban ecosystems in Europe has significantly increased in the last two decades (Celesti-Grapow and Blasi 1998, Kühn et al. 2004, Knapp et al. 2012, Nobis et al. 2009, Lososová et al. 2011, 2012a, b, 2016a, b, 2018, Čeplová et al. 2017, Kalusová et al. 2016). However, the investigated cities are very unevenly distributed, mainly in Central Europe, with results that can hardly be considered applicable to the whole of Europe.

The aims were to provide an analysis of research on urban flora and vegetation in the countries of Southeast Europe during the last three decades, consider trends of investigation in these countries and point out gaps in the research. An additional goal was to affirm the importance and necessity of adopting a systematic methodological approach to research on this region´s urban flora and vegetation in the future.

## Materials and methods

In order to find relevant references, we searched Google Scholar, Scopus, Web of Science, Researchgate and other online databases.A search of these databases was conducted using the following keywords: urban flora, urban vegetation, urban plants, urban plant species, urban plant communities, urban forests, ruderal flora, ruderal vegetation, wall flora and wall vegetation, in combination with names of the countries (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Montenegro, North Macedonia, Romania, Slovenia, Serbia and Kosovo) and cities (at least 15 cities with the largest population of each country) of Southeast Europe. Among the 13,700 offered and examined titles, 174 were found relating to urban flora and vegetation (On-line Suppl. Tabs. 1, 2). All studies that partially or completely treat characteristics of recent spontaneous flora and vegetation of urban habitats were included in the analysis. In addition to studies employing the floristic and phytosociological approaches, studies based on the application of remote sensing technology in research on urban vegetation from the aspect of landscape ecology were also taken into consideration. Studies of individual species or a small number of species in cities were only taken into account if they dealt with the spatial distribution, abundance, population dynamics and habitat preferences of the species in question, whereas those treating the species´ morpho-anatomy, ecophysiology and phenology were not considered. In addition, the analysis did not include studies of planted trees in parks, explorations of heavy metal content, radioactivity research, studies of the effects of pollution on plants, articles considering the importance (economic, social and psychological) of plants to humans or palynological and paleobotanical studies.

Only results published in the period from 1989 to 2018 with an abstract in English were subjected to statistical analysis. Available articles were classified according to the following criteria: topic, geographical location and the year of publication. With respect to topics, all the studies were grouped into one or more categories: 1) floristic studies, including not only those which consider just the total flora of cities, but also ones treating the flora of separate city parts or certain habitats, as well as those dealing with specific plant groups (e.g., woody plants, medicinal herbs, alien plants, allergenic plants, invasive plants, etc.); 2) phytosociological studies, including ones employing the classical approach with phytosociological tables of certain plant communities, as well studies based on the syntaxonomic approach on different levels; 3) landscape ecological studies of urban vegetation, i.e., habitat studies, using the methods of remote detection; 4) studies that refer to plant species protection, management of habitats, vegetation and plant re-

sources or planning of green surfaces in cities; 5) studies of urban and suburban forests; 6) studies of individual or several species in cities in relation to their abundance, distribution or habitat preference; 7) studies of invasive and alien species, with different approaches and types of research, including floristic, phytosociological, population-ecological, cartographic, etc.

Also included in the analysis were review articles summarizing previous research in this field, which are classified into appropriate categories.

The articles were classified on the basis of geographical location in order to provide insight into the extent to which the countries of Southeast Europe and their cities have been investigated. Some studies refer to wide regions, others treat a few cities and compare them, while some pertain to one or more countries of Southeast Europe.

In order to discern the trend of production of articles in this field, special attention was paid to the period of their publication. In this connection, articles were grouped into one of the following three categories, of articles published: 1) from 1989 to 1998; 2) from 1999 to 2008; and 3) from 2009 to 2018.

## Results

In total, 149 articles dealing with urban flora and vegetation of Southeast Europe were found by online search (Online Suppl. Tab. 1). The number increased significantly during the last three decades (Fig. 1). In the period from 1989-1998, only 12 articles were published (8% or 1.2 per year), while a total of 40 articles (26% or 4 per year) were published between 1999 and 2008. In the last decade, i.e., from 2009 to 2018, 97 articles were published (65% or 9.7 per year). The publication of the most articles in one year (17) occurred in 2016, while the average number of published references per year was 5 during the whole analysed period.

Most of the analysed studies related to the urban flora (103 titles, i.e., 69% of all analysed articles). In contrast to floristic investigations, the phytosociological approach was represented with only 12 articles (i.e., about 8%), whereas articles employing the landscape ecological approach to investigation of urban vegetation are becoming more and more interesting (27 titles, i.e., 18%). A total of nine articles (6%) partially or completely dealt with plant protection, management of urban habitats and planning of green surfaces. Floristic and spatial studies of urban and suburban forests were separated as a special category that includes 16 analysed articles (11%). There were nine articles treating the presence, abundance, distribution or habitat preference of a particular species or a small group of species in cities (6%). Special attention was paid to invasive and alien species, and 19 articles (13%) in titles or abstracts contained the words "invasive", "alien", "adventive", "neophytes" or "neophytic" (Fig. 2).

The rates of exploration of urban flora and vegetation varied considerably throughout the countries of Southeast Europe, with the following production and distribution of articles: Serbia – 31 (21%), Croatia – 27 (18%), Romania – 27 (18%), Slovenia – 24 (16%), Greece – 18 (12%), Bosnia and Herzegovina – 17 (11%), Bulgaria – 14 (9%), Montenegro – 10 (7%), Albania – 7 (5%), North Macedonia – 5 (3%) and Kosovo – 3 (2%), with several papers (9, i.e., 6%) relating to cities from more than one country (Figs. 3, 4).

The cities of Southeast Europe have been unevenly investigated in terms of urban flora and vegetation. The majority of analysed articles dealt (partially or completely) with the flora and vegetation of the following cities: Belgrade (16 articles), Ljubljana (13), Maribor (8), Bucharest (7), Mostar (6), Podgorica and Sofia (5), etc. (Fig. 5).

Among the analysed articles, 125 (i.e., 84%) were published in scientific journals, 17 (11%) were published in proceedings from scientific conferences, while the rest or 5% relate to books or monographs. The analysed articles were published in 74 different journals and in proceedings from 16 scientific conferences. Journals with the largest number of articles in this field are *Natura Croatica* and *Acta Herbo-*

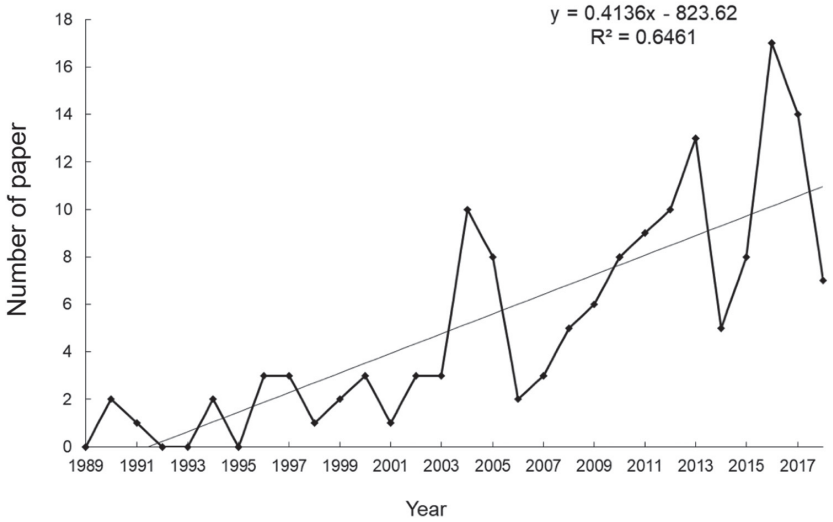


**Fig. 1.** Distribution and trend of published articles about urban flora and vegetation of Southeast Europe per year (1989-2018).

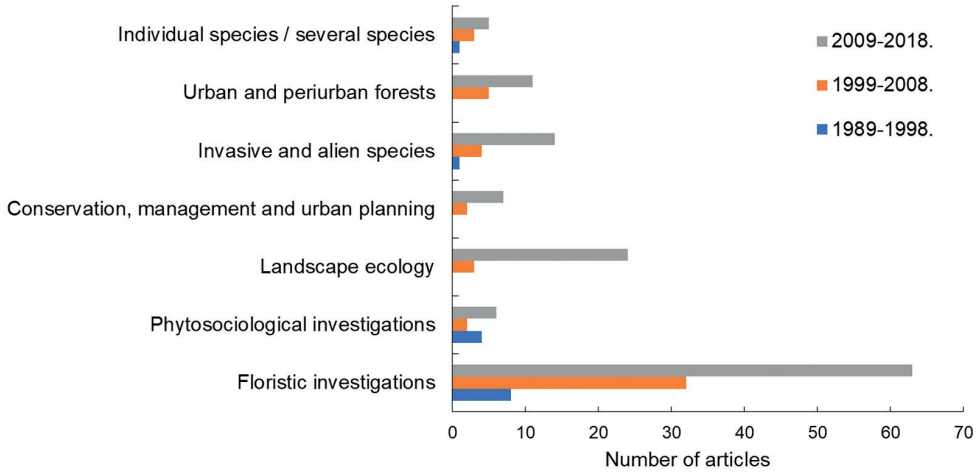


**Fig. 2.** Number of published articles about urban flora and vegetation in Southeast Europe per research theme and period.

*logica*, with 11 and 10 published articles, respectively (14% of all articles). The largest number of scientific conferences were organized in Serbia (5).

## Discussion

Analysing articles from the field of urban flora and vegetation of Southeast Europe during the last 30 years, we note that significant disparities are evident regarding the chronological and territorial distribution of investigations conducted (Fig. 3), as well as with respect to the distribution of topics of published results (Fig. 4).

### Chronological aspect of conducted investigations

The fewest articles were published in the period from 1989 to 1998, with only 8% of articles treating topics in urban flora and vegetation. Although most of the articles were conceived on the classical floristic principle, which mainly gave a survey and analysis of ruderal flora in certain cities, several articles employing the phytosociological approach relating to Belgrade (Jovanović 1994a, b) were published in that period, in addition to one such article referring to some smaller cities in Croatia and Slovenia (Čarni 1996). One of the articles from that period was devoted to the distribution and ecology of *Ailanthus altissima* (Mill.) Swingle on the territory of Belgrade (Jovanović et al. 1997), indicating that even then the problem of alien and invasive species in the cities of this region was recognized.

During the period between 1999 and 2008, significantly more articles were published (27%). Most of them were concerned with floristic research, special attention being paid to alien and invasive species in cities such as Thessaloniki (Krigas and Kokkini 2004), Šibenik and Knin (Milović 2001) and Banja Luka (Topalić-Trivunović and Šumatić 2004). Also during this period, urban and suburban forests were investigated in cities like Ljubljana (Pirnat

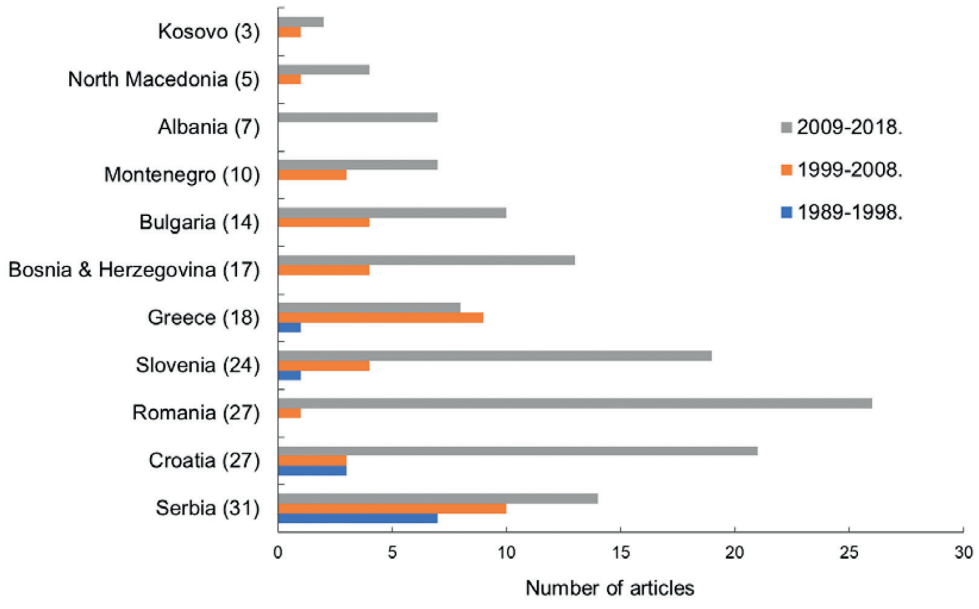


**Fig. 3.** Number of published articles about urban flora and vegetation in Southeast Europe per country and research period.

2000) and Podgorica (Stešević 2002), as well as in numerous cities in Greece (Christopoulou et al. 2007). Phytosociological articles were still less present, and the only cities whose urban plant communities were the subject of phytosociological research in this period were Timisoara (Coste and Arsene 2003) and Kranj (Šilc and Košir 2006).

About 65% of all the articles analysed were published after 2009. The floristic approach is still prevalent, but the last decade was distinguished by significantly more articles relating to alien and invasive species, as well as to landscape aspects of urban vegetation. This period was also one when investigations of urban flora and vegetation beyond the borders of certain countries and parallel analysis of the flora in different cities of Southeast Europe were conducted (Šilc et al. 2012, Jasprica et al. 2017, Salvati et al. 2017, Krajter Ostoić et al. 2018, Lososová et al. 2018, etc).

### Thematic aspect of conducted investigations

Apart from the fact that floristic investigations were generally the most numerous (69%), the largest increase in their number was noticed especially in the last decade. However, floristic studies of Southeast European cities were mostly restricted to a certain group of plants, particular habitats or specific city parts (e.g., parks, walls, old fortresses, roads and railways, lawns, cemeteries, etc). Some floristic articles consider only a specific group of plants, such as woody plants, weeds, allergenic plants and endangered or endemic species, but articles dealing with alien and invasive species were the most numerous and were additionally categorized in a separate group (see later).

Phytosociological investigations were less numerous (8%) than studies employing the floristic approach, with more than one third pertaining to cities in Slovenia. Some vegetation studies referred only to particular ruderal communities, e.g., *Chenopodio rubrii-Amaranthetum adscendentis* S. Jovanović et D. Lakušić 1990 in Belgrade (Jovanović and Lakušić 1990) and *Sambucetum ebuli* Felföldy 1942 in Pale (Petronić and Bratić 2016), whereas some articles treated other syntaxa of ruderal vegetation, e.g., the alliance *Euphorbion prostratae* Rivas-Mart. 1976 in the region of Istria (Čarni 1996). There were articles that yielded more comprehensive phytosociological information in some cities such as Belgrade (Jovanović 1994b), Timisoara (Coste and Arsene 2003), Kranj (Šilc and Košir 2006), Ljubljana (the city´s cemetery) (Šilc 2009), Žabljak (Jovanović et al. 2013) and Koper (the town harbour) (Šilc et al. 2014). However, the most extensive research of synanthropic vegetation from the classes *Polygono-Poetea annuae* Rivas-Mart. 1975, *Papavereteа rhoeadis* S. Brullo et al. 2001, *Artemisietea vulgaris*

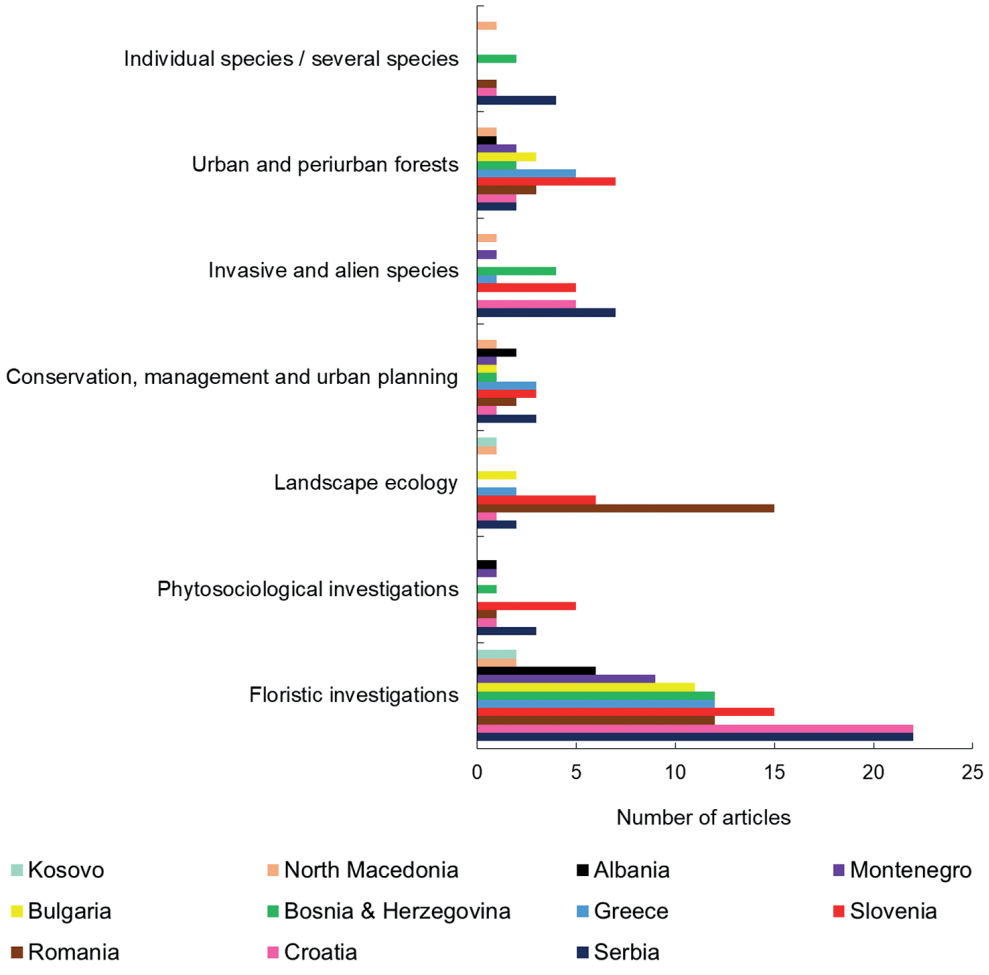


**Fig. 4.** Distribution of published articles about urban flora and vegetation of Southeast Europe per country and research field.

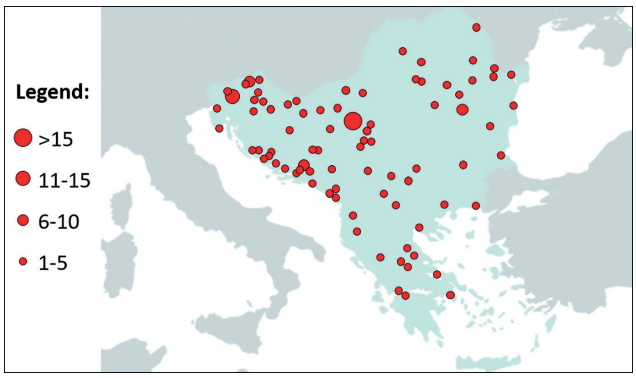


**Fig. 5.** Geographical location of investigated cities in Southeast Europe (size of the circle represents the number of publications per city).

Lohmeyer et al. in Tx. ex von Rochow 1951 and *Epilobietea angustifolii* Tx. et Preising ex von Rochow 1951 was conducted by Šilc (2010) in Slovenia using 2404 phytocoenological relevés.

Studies dealing with the landscape ecology of urban areas have recently become more and more of interest (18%). They usually treated the spatial patterns of urban vegetation and their dynamics, and for the most part involved the use of remote sensing methods. Half of these articles referred to the cities of Romania (Rosu and Oiste 2013, Petrişor 2015, Anastasiu et al. 2017). There were similar studies of wider areas, e.g., southeastern Romania (Vlad and Brătăşanu 2011), or even studies covering a large number of cities in the EU, including ones in Slovenia, Greece, Romania and Bulgaria (Salvati et al. 2017).

Studies of conservation, management and urban planning accounted for 6% of the articles analysed. For example, Grand Park in Tirana (Mesiti et al. 2015), urban forests of western Macedonia (Tsitsoni and Samara 2002), forest fragments and corridors of the suburban area of Ljubljana (Pirnat 2000), etc., have been investigated from this point of view.

Investigations of urban and suburban forests from the floristic or spatial aspects were separated as a special category that included 11% of the analysed articles (Pirnat 2000, Lacan and McBride 2009, Karlo and Sajna 2017, etc.). Similar investigations, but on larger spatial scales, have been carried out for cities in western Macedonia (Tsitsoni and Samara 2002), the whole of Greece (Christopoulou et al. 2007) and the Mediterranean region, including Southeast European countries (Krajter Ostoić et al. 2018).

Investigations on the presence, abundance, distribution or habitat preference of a particular species in the cities of Southeast Europe (6%) mainly include articles that treat a particular invasive species, such as *Ambrosia artemisiifolia* L. (Memišević-Hodžić et al. 2015), *Reynoutria japonica* Houtt. (Topalić-Trivunović and Šumatić 2004), *Helianthus* spp. (Filep et al. 2010), *Aster lanceolatus* (L.) Kuntze (Obratov-Petković et al. 2016), etc. Additionally, there were several contributions on the subject of endangered species in urban conditions, e.g., *Scirpus supinus* L. (Prlić 2017).

The largest number of articles devoted to alien and invasive species in cities of Southeast Europe came from Serbia. However, certain cities of Slovenia were included in extensive and significant investigations of urban flora in the whole area of Central Europe, while some articles based on these investigations paid special attention to alien species and their effect on the biotic homogenization of urban floras (Lososová et al. 2012a, b, 2016a). In addition, Šilc et al. (2012) analysed the presence of alien species in anthropogenic communities of numerous cities in the countries of ex – Yugoslavia.

## Comparative aspect and proposal to future research

The urban flora and vegetation of Southeast Europe has been less explored in comparison with the cities of other European regions, especially in Central Europe. At the same time, current data from Southern Europe show that plant species diversity in urban ecosystems is higher there than in climatically different parts of Central Europe (Celesti Grapow and Blasi 1998). Moreover, the methods used by different research teams vary greatly, and only few of them compare the cities of larger regions using a standardized research protocol (Lososová et al. 2011, 2012a, b, 2016a, b, 2018, Kalusová et al. 2016, Čeplová et al. 2017, etc.). Thus, it is still impossible to draw conclusions about wider regions of Southern and especially Southeast Europe.

The low proportion of articles published in SCI journals for the region of Southeast Europe was also noted. A large number of contributions (25) were available only in the form of abstracts from different scientific conferences and symposia (On-line Supplementary Tab. 2), whereas some of the studies were only available in the local language. In addition, the methods used by researchers from different countries differed, making it impossible to adequately compare results. At the same time, studies in other parts of Europe usually had a broader spatial framework and uniform methodology, while studies in Southeast Europe often referred to individual cities, to specific habitats within the city or to certain parts of the city.

Although is widely known that there are no universal standard methods that can be applied to every type of research, we can make some suggestions as to what should be taken care of during planning of field research of urban flora and vegetation regarding different spatial scales:

Community level: a) sample plot size for ruderal vegetation should be limited to max. 10 $m^2$, and urban forests to max. 100 $m^2$; b) number and arrangement of samples should be adequate for the area of the cities/towns; c) duration of survey should cover the whole vegetation season; and d) each sample plot should be georeferenced.

Habitat level: a) species composition of all vascular plants except those deliberately planted should be recorded in seven 1-ha plots in each city, each plot representing one habitat type (according Lososová et al. 2011). Typical repre-

sentative plots should be selected before from aerial photographs. b) because such research aims to obtain comparable samples with limited phenological variation, the duration of research should be limited to the period from mid- June to late- August (Lososová et al 2011); c) if the research aims to collect floristic data about ephemeral plant species, then multiple fieldwork campaigns through the whole vegetation season are needed; and d) each sample plot should be georeferenced.

It would be beneficial if the region of Southeast Europe were included with other European countries in studies on a large scale. Moreover, conducting studies in the entire region of Southeast Europe, using the standardized habitat level model applied in Central Europe by Lososová et al. (2011), should also be considered. Collaboration of researchers and scientific institutions from different countries of the region should be promoted through international meetings, as well as by means of national and international projects. This would make possible the realization of more effective comparative research on urban flora and vegetation in Southeast Europe. In addition, it would enable us to prepare a comprehensive synthesis on different levels of knowledge.

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