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INVASIVE PLANT SPECIES IN URBAN AND SUBURBAN HABITATS OF THE CITY OF ZAGREB

INVAZIVNE BILJNE VRSTE URBANIH I SUBURBANIH STANIŠTA NA PODRUČJU GRADA ZAGREBA

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ABSTRACT

Urban ecosystems often form a mosaic of anthropogenic and natural vegetation. Although their naturalness is frequently disrupted by human activities, they are characterized by increased species richness due to the presence of alien flora, which most commonly spreads via transport corridors and often becomes invasive in newly colonized ecosystems. Despite the fact that invasive flora in urban ecosystems remains insufficiently studied in cities of northeastern Europe and Croatia, previous research indicates a high occurrence of invasive species.

In this study, a total of 16 invasive plant species were recorded at four selected urban and suburban sites within the city of Zagreb. The family Asteraceae was the most represented, while the majority of the recorded species (69%) originated from the Americas. Hemicryptophytes and therophytes were the dominant life forms. *Ambrosia artemisiifolia* L. and *Solidago gigantea* Aiton were recorded at all sites, whereas *Ailanthus altissima* (Mill.) Swingle, *Amaranthus retroflexus* L., *Bidens frondosa* L., *Conyza bonariensis* (L.) Cronquist and *Reynoutria japonica* Houtt. were found at only one site, indicating differences in floristic composition between urban and suburban ecosystems.

Keywords: alien flora, Asteraceae, urban ecosystems, Zagreb

SAŽETAK

Gradski ekosustavi često čine mozaik antropogene i prirodne vegetacije. Iako je njihova prirodnost često narušena ljudskim djelovanjem, odlikuju se povećanim bogatstvom vrsta zahvaljujući prisutnosti alohtone flore, koja se najčešće širi prometnim koridorima te u novim ekosustavima često poprima

invazivan karakter. Unatoč činjenici da je invazivna flora urbanih ekosustava još uvijek nedovoljno istražena u gradovima sjeveroistočne Europe i Hrvatske, dosadašnja istraživanja upućuju na vrlo izraženu zastupljenost invazivnih vrsta.

Ovim istraživanjem utvrđena je prisutnost 16 invazivnih biljnih vrsta na četiri odabrane lokacije urbanih i suburbanih staništa na području grada Zagreba. Najveći broj zabilježenih vrsta pripada porodici Asteraceae, pri čemu je najviše vrsta (69 %) američkog podrijetla. Među životnim oblicima dominiraju hemikriptofiti i terofiti. Vrste *Ambrosia artemisiifolia* L. i *Solidago gigantea* Aiton zabilježene su na svim lokacijama, dok su *Ailanthus altissima* (Mill.) Swingle, *Amaranthus retroflexus* L., *Bidens frondosa* L., *Conyza bonariensis* (L.) Cronquist i *Reynoutria japonica* Houtt. pronađene samo na jednoj lokaciji, što upućuje na razlike u floističkom sastavu urbanih i suburbanih ekosustava.

Ključne riječi: alohotona flora, Asteraceae, urbani ekosustavi, Zagreb

1. INTRODUCTION

Situated almost equidistant between the major cities of Eastern and Western Europe, the city of Zagreb occupies a central position within the European continent (Njegač, 2004). Due to its geographical position, Zagreb connects the Pannonian and Mediterranean parts of Croatia (Njegač and Nejašmić, 2002), as well as Central Europe with the Adriatic region (Hrvatska enciklopedija, 2013). The city is located in the south-western part of the Pannonian Basin, at the foothills and on the slopes of Medvednica Mountain, and along the banks of the Sava River.

According to the Köppen climate classification, the climate of the Zagreb area is designated as Cfwbx, indicating a moderately warm and humid climate with warm summers, where the average air temperature in July does not exceed 22.0 °C. However, recent studies suggest that the climate of the Zagreb area is gradually becoming more arid (Ugarković et al., 2021).

Urban and suburban areas are often shaped by spatial transformations such as habitat fragmentation and degradation, which significantly affect biodiversity (Alegro et al., 2013). Habitats formed as a result of these processes are characterized by specific ecological conditions, including differing species composition and abundance (Alegro et al., 2013), as well as distinct climatic and soil properties (Ugarković et al., 2021).

The floristic composition of urban ecosystems may differ considerably from that of original or non-urban ecosystems; however, similar floristic structures may also develop independently in different urban environments (Alegro et al., 2013). According to Štajerová et al. (2017), urban ecosystems are often richer in species diversity due to their pronounced habitat heterogeneity and the presence of a significantly higher number of invasive plant species.

Data on the urban flora of cities in Southeast Europe remain scarce, primarily because research has largely focused on individual cities, specific areas, or particular urban zones. Additionally, the use of different methodologies complicates the synthesis and comparison of results, making it difficult to obtain a comprehensive overview (Jovanović and Glišić, 2021).

A similar situation is observed in Croatia, where the Zagreb area is the most intensively studied urban region (Delač et al., 2023). Although several studies have addressed the vascular flora of specific sites within Zagreb - such as Medvednica Nature Park (Bernardić, 2008), the lower course of the Bliznec stream (Nežmah & Ljubičić, 2012), Maksimir Park (Kovačić and Jelaska, 2013), Jarun (Vuković et al., 2013), Savica (Alegro et al., 2013), Ščitarjevo (Zagorac, 2016), Borongajski lug (Delač et al., 2023), Jakuševac (Bekavac et al., 2024), Dotrščina Forest Park (Budisavljević et al., 2017), and Jelenovac Forest Park (Justić et al., 2020) - there is still no unified and comprehensive dataset addressing invasive plant species across the entire urban and suburban area of Zagreb.

The main goal of this research was to analyze the occurrence and distribution of invasive plant species in selected habitats of the Zagreb area in relation to human impact.

2. MATERIALS AND METHODS

Study area

The study was conducted at four selected locations within the city of Zagreb: 1) Mihaljevac tram roundabout, 2) Bundek Park, 3) Stupnički lug, and 4) Donji Stupnik (Figure 1). Based on their spatial position, the Mihaljevac tram roundabout and Bundek Park are situated within the urban core of the city, whereas Stupnički lug and the abandoned agricultural areas in Donji Stupnik are located in suburban areas, near the administrative border between the City of Zagreb and Zagreb County. The total surface area covered by all four study sites is 1.37 km².

The Mihaljevac tram roundabout is a highly frequented traffic node characterized by intensive road and tram traffic. It is surrounded by public and social infrastructure, with two streams flowing through the area (Gradski ured za strategijsko planiranje i razvoj grada, 2009). Adjacent to the site is the Kamenjak forest-park, which has considerable ecological and recreational importance (Mikulić et al., 2023).

Bundek Park is one of the newer city parks and is classified among the most important urban green areas in Zagreb (Pomper, 2019). It is located on the southern bank of the Sava River and comprises forested areas, meadows, two lakes (one natural and one artificial), and a beach along the artificial lake (Privora et al., 2015).

Stupnički lug is a secondary old-growth forest designated as a protected area in the category of Special Forest Vegetation Reserve in 1964. Since 2013, it has been a part, together with its wider surroundings, of the EU ecological network Natura 2000 as SCI site HR2000589 Stupnički lug, designated under the EU Habitat Directive (Rauš et al., 1987; Zeleni prsten Zagrebačke županije). The site is characterized by a relict community of common hornbeam (*Carpinus betulus* L.) forest with a significant proportion of beech (*Fagus sylvatica* L.). The Lomnica stream flows through the reserve, which is nevertheless exposed to anthropogenic influences (Rauš et al., 1987).

The abandoned agricultural areas in the settlement of Donji Stupnik represent a heterogeneous habitat complex located near the border between the municipality of Stupnik and the settlement of Lučko, i.e. between the City of Zagreb and Zagreb County. The area lies between Rožmanka, Stupničke šipkovine and St. Benedict Street, in close proximity to industrial and logistics facilities as well as private households. Although crops were observed on some plots, their poor maintenance indicates that these areas are no longer under active agricultural production. A stream flows through the site, occasionally drying up, while parts of the terrain are subject to flooding during periods of heavy rainfall. Areas along the stream, drainage canals, and forest edges are frequently affected by illegal waste disposal.

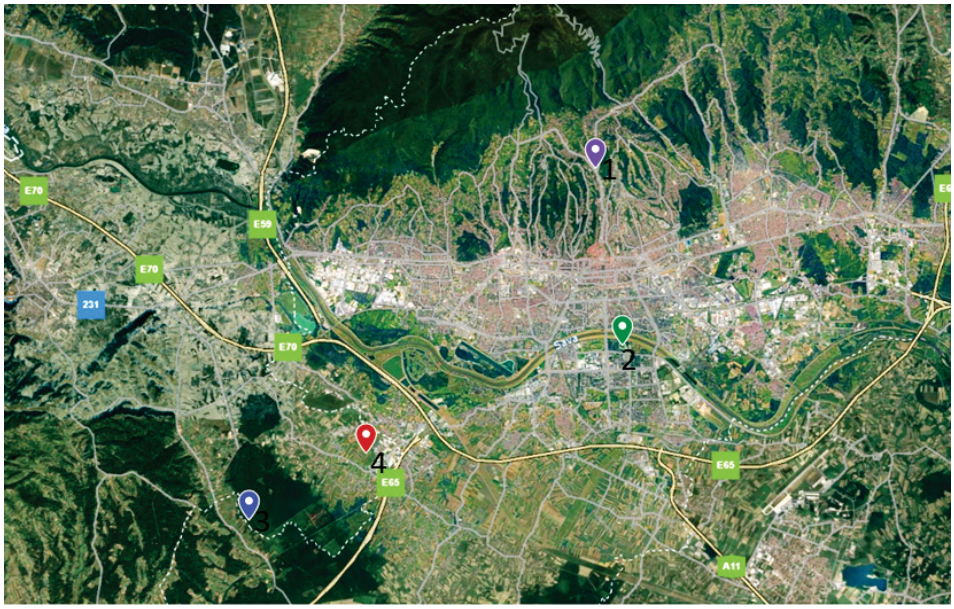

Figure 1 Study area (1. Mihaljevac tram roundabout; 2. Bundek park; 3. Stupnički lug; 4. Donji Stupnik)

Slika 1. Područje istraživanja (1. tramvajsko okretište Mihaljevac, 2. park Bundek, 3. Stupnički lug, 4. Donji Stupnik)

Field survey and data analysis

Field investigations were conducted in autumn 2023 and spring 2024. Plant species were identified using floristic literature (Nikolić et al., 2014) and a mobile application (PlantNet). Species occurrences were mapped using the GPS application (GPS Waypoints). Voucher specimens were collected, prepared as herbarium specimens, and deposited in the ZAGR Herbarium (https://herbarium.agr.hr/), under identification (ID) numbers ZAGR79421–ZAGR79428, ZAGR79690–ZAGR79696, and ZAGR79698. Life forms were assigned according to Nikolić et al. (2014), and Ellenberg indicator values were determined following Pignatti et al. (2005). The following abbreviations were used for life forms: G – geophytes, H – hemicryptophytes, T – therophytes, N – nanophanerophytes, and P – phanerophytes.

3. RESULTS AND DISCUSSION

A total of 16 invasive plant species were recorded in the study area (Table 1). The highest number of species (12) was found at the Mihaljevac tram roundabout, followed by Bundek Park (10), the abandoned agricultural areas in Donji Stupnik (9), and Stupnički lug, where the fewest species were observed (6). According to Peter et al. (2021), invasive species occupy different habitat types with varying intensity and are most abundant in environments exposed to strong anthropogenic pressure, such as urban and cultivated areas. This pattern is clearly reflected in the present study.

Ambrosia artemisiifolia and *Solidago gigantea* were recorded at all four sites, whereas *Amaranthus retroflexus*, *Bidens frondosa*, *Conyza bonariensis*, and *Reynoutria japonica* were detected at only one location. In addition to *A. artemisiifolia* and *S. gigantea*, the most abundant species were *Artemisia verlotiorum*, *Erigeron annuus*, *Parthenocissus quinquefolia*, *Solidago canadensis*, and *Veronica persica*.

Although the overall number of invasive species did not differ substantially between urban and suburban areas, urban sites showed slightly higher invasive species diversity. Štajerová et al. (2017) reported that both the diversity and cover of invasive flora decrease with increasing distance from the city centre and with increasing vegetation complexity. Urban habitats often represent extreme environmental conditions that are less suitable for native species, thereby facilitating the establishment and spread of invasive taxa.

Table 1 List of invasive species recorded at four locations in the city of Zagreb
Tablica 1. Popis invazivnih vrsta zabilježenih na četiri lokacije u gradu Zagrebu

Family Porodica	Latin name and ZAGR ID Latinsko imei ZAGR ID	Croatian name Hrvatsko ime	Life form Životni oblik	Origin Porijeklo	Location Lokalitet
Amaranthaceae	*Amaranthus retroflexus* L., ZAGR79423	oštrodlakavi šćir	T	North America	1
Asteraceae	*Ambrosia artemisiifolia* L., ZAGR79428	ambrozija	T	North America	1, 2, 3, 4
	Artemisia verlotiorum Lamotte, ZAGR79690	kineski pelin	H	Asia	1, 2, 3
	Bidens frondosa L., ZAGR79691	lisnati dvozub	T	North America	1
	Conyza bonariensis (L.) Cronquist, ZAGR79698	kovrčava hudoljetnica	T	North and South America	4
	Conyza canadensis (L.) Cronquist, ZAGR79427	kanadska hudoljetnica	H	North and South America	1, 3
	Erigeron annuus (L.) Pers. ssp. *strigosus* (Muhlenb. ex Wild.) Wagenitz, ZAGR79696	jednogodišnja krasolika	H	North America	1, 2, 4
	Solidago canadensis L., ZAGR79425	gustocvjetna zlatnica	H	North America	2, 3, 4
	Solidago gigantea Aiton, ZAGR79426	velika zlatnica	H	North America	1, 2, 3, 4
Brassicaceae	*Lepidium virginicum* L., ZAGR79422	virginska grbica	H	North and South America	2, 4
Fabaceae	*Robinia pseudoacacia* L., ZAGR79692	bagrem	P	North America	2, 3
Poaceae	*Sorghum halepense* (L.) Pers., ZAGR79421	piramidalni sirak	G	Mediterranean and Syria	2, 4
Polygonaceae	*Reynoutria japonica* Houtt., ZAGR79694	japanski dvornik	G	Asia	1
Scrophulariaceae	*Veronica persica* Poir., ZAGR79424	perzijska čestoslavica	T	Asia	1, 2, 4
Simaroubaceae	*Ailanthus altissima* (Mill.) Swingle, ZAGR79695	žljezdasti pajasen	P	Asia	1, 2
Vitaceae	*Parthenocissus quinquefolia* (L.) Planchon, ZAGR79693	petolisna lozika	P	North America	1, 2, 4

Most of the invasive species recorded in this study (11 taxa; 69%) originated from the Americas (Table 1). This pattern is consistent with previous findings for the Republic of Croatia (Boršić et al., 2008). Nikolić et al. (2013) recorded the highest number of invasive species (> 30 per grid cell) in major urban centres (primarily in Zagreb and Split areas) This pattern can be explained by intensive transport and trade connections (Zima and Štefanić, 2021). The remaining species recorded in this study originated mainly from Asia and the Mediterranean region.

The family Asteraceae was the most represented taxonomic group in the study, comprising 8 taxa (50%) (Table 1). Under similar climatic conditions in the Sisak region, Pruša et al. (2013) also reported that the majority of invasive species belonged to the family Asteraceae. Together with Brassicaceae, Fabaceae, and Poaceae, Asteraceae contains the highest number of invasive species in Europe and Croatia (Antunović et al., 2021). Their high representation in urban floras is attributed to frequent ornamental use, efficient reproductive strategies, and rapid completion of life cycles (Repić et al., 2019).

The dominant life forms among the recorded invasive species were hemicryptophytes (37.5 %) and therophytes (31.3 %) (Table 1). Hemicryptophytes prevail in Central Europe, whereas therophytes are typically associated with open and drier habitats (Raunkiaer, 1934; Midolo et al., 2024). Their regular presence in anthropogenic habitats indicates the impact of human disturbance. Therophytes possess strong invasive potential due to their short life cycles and high seed production (Boršić et al., 2008).

Mean Ellenberg indicator values (EIV) for the invasive species flora of the city of Zagreb at the four investigated locations (Table 2) correspond to species typical of the Zagreb area, indicating temperate-zone taxa adapted to both sunny and semi-shaded habitats, nutrient- and moisture-rich soils, and low salinity tolerance.

Table 2 Ellenberg values (EIV) for invasive species flora of the city of Zagreb at four investigated locations (L - light, T - temperature, C - continentality, F - soil moisture, R - reaction of soil, N - soil nutrients, S - salinity)

Tablica 2. Ellenbergove vrijednosti za floru invazivnih vrsta grada Zagreba na četiri istraživane lokacije (L - svjetlost, T - temperatura, C - kontinentalnost, F - vlažnost tla, R - reakcija tla, N - hranjivost tla, S - salinitet)

Number Redni broj	Latin name Latinsko ime	L	T	C	F	R	N	S
1.	*Ailanthus altissima* (Mill.) Swingle	6	7	5	5	5	5	0
2.	*Amaranthus retroflexus* L.	9	9	7	4	X	9	0
3.	*Ambrosia artemisiifolia* L.	9	7	6	2	X	1	0
4.	*Artemisia verlotiorum* Lamotte	7	7	6	7	5	5	0
5.	*Bidens frondosa* L.	7	7	X	9	7	8	0
6.	*Conyza bonariensis* (L.) Cronquist	8	6	5	5	X	7	0
7.	*Conyza canadensis* (L.) Cronquist	8	6	5	5	X	7	0
8.	*Erigeron annuus* (L.) Pers. ssp. *strigosus* (Mühlenb. ex Willd.) Wagenitz	7	7	5	6	5	4	0
9.	*Lepidium virginicum* L.	8	6	X	4	X	7	0
10.	*Parthenocissus quinquefolia* (L.) Planchon	5	7	5	5	5	5	0
11.	*Reynoutria japonica* Houtt.	8	6	2	8	5	7	0
12.	*Robinia pseudoacacia* L.	5	7	5	4	X	8	0
13.	*Solidago canadensis* L.	8	X	5	6	X	7	0
14.	*Solidago gigantea* Aiton	8	X	5	X	X	7	0
15.	*Sorghum halepense* (L.) Pers.	8	8	X	7	8	8	0
16.	*Veronica persica* Poir.	8	7	5	5	5	6	0
Mean value / Srednja vrijednost		7,44	6,93	5,08	5,47	5,63	6,31	0,00

At the Mihaljevac tram roundabout, 12 invasive plant species were recorded. The densest populations belonged to *Conyza canadensis*, *Erigeron annuus* ssp. *strigosus*, and *Parthenocissus quinquefolia*, predominantly occurring along roads, parking areas, forest edges of the Remetski Kamenjak forest-park, and neglected sites.

During the spring survey, newly established individuals of *Ailanthus altissima* were recorded adjacent to a recently developed construction site. These individuals were absent during the autumn survey, prior to construction activities, highlighting the strong link between human disturbance and the spread of this species (Novak and Kravarščan, 2014).

The least widespread species at this site were *Amaranthus retroflexus*, *Bidens frondosa*, *Solidago gigantea*, and *Veronica persica*. Comparable results have been reported from similar urban forest parks in Zagreb (Table 3). Studies conducted in Jakuševac (Bekavac et al., 2024), Dotrščina (Budisavljević et al., 2017), Borongajski lug (Delač et al., 2023), Tuškanac (Essert et al., 2023), and Jelenovac (Justić et al., 2020) show very similar patterns. A higher proportion of therophytes was recorded at Mihaljevac and Borongajski lug, indicating a stronger degree of anthropogenic influence at these sites. In Mihaljevac, this pattern can be partly attributed to the sampling focus on the roundabout area, with only limited inclusion of the adjacent forest habitat.

Table 3 Comparison of number of life forms of invasive plant species between Mihaljevac tram roundabout and other locations in Zagreb

Tablica 3. Usporedba broja životnih oblika invazivnih biljaka tramvajskog okretišta Mihaljevac s drugim lokacijama u Zagrebu

Life form	Mihaljevac	Dotrščina (Budisavljević et al., 2017)	Tuškanac (Essert et al., 2023)	Jakuševac (Bekavac et al., 2024)	Jelenovac (Justić et al., 2020)	Borongajski lug (Delač et al., 2023)
Geophytes	1	1	0	4	1	2
Hemicryptophytes	4	4	3	5	5	5
Phanerophytes	3	1	3	4	3	4
Therophytes	4	2	1	3	3	4
Nanophanerophytes	0	0	0	1	0	0

In our study in Bundek Park, we recorded 10 invasive plant species . The densest populations were observed for *Artemisia verlotiorum* and *Parthenocissus quinquefolia*. Most invasive species were found near lakes, along paths and playgrounds, and in neglected roadside areas, whereas intensively managed green spaces were free from invasive flora.

Similar findings were reported for Silesia and Ursynów parks in the Czech Republic, where invasive species were almost entirely absent from areas under regular management, such as mowing and removal of undergrowth (Fortuna-Antoszkiewicz et al., 2018).

Compared with Jarun and Savica, both remnants of former Sava River branches, Bundek Park supports fewer invasive species, which can largely be attributed to its smaller surface area. *Lepidium virginicum* was the only species recorded exclusively at Bundek, while the remaining invasive species were also found at Jarun and Savica (Alegro et al., 2013; Vuković et al., 2013). The invasive flora of Bundek was dominated by hemicryptophytes, followed by phanerophytes and therophytes (Table 4), indicating relatively open and moderately dry habitats. In contrast, the dominance of therophytes at Jarun and Savica reflects the expansion of ruderal habitats and the spread of weedy and invasive species. Overall, these findings suggest that Bundek Park is either less exposed to anthropogenic disturbance or exhibits greater ecosystem stability.

Table 4 Comparison of number of life forms of invasive plant species between Bundek park and other locations in Zagreb

Tablica 4. Usporedba broja životnih oblika invazivnih biljnih vrsta parka Bundek s drugim lokacijama u Zagrebu

Life forms	Bundek	Jarun (Vuković et al., 2013)	Savica (Alegro et al., 2013)
Geophytes	1	6	3
Hemicryptophytes	5	2	5
Phanerophytes	2	3	4
Therophytes	2	13	13
Hydrophytes	0	1	0

In Stupnički lug, six invasive plant species were recorded, with *Solidago gigantea* being the most abundant. Dense populations were confined to the forest margins, while no invasive species were detected within the forest. A similar distribution pattern was reported for the Kalnik forest area, where *S. gigantea* occupied open, sunny habitats and gradually disappeared as canopy cover increased (Horvat and Franjić, 2016).

The low presence of invasive species within the forest can be attributed to strong competition from native tree species (Keškić, 2020; Rauš et al., 1987) and limited human intervention. Bekavac et al. (2024) emphasize that such habitats present substantial barriers to the establishment of invasive species. Comparable conditions were observed in the neglected Czech Wielgie Park, where only one invasive species was recorded, occupying a fully sun-exposed and water-accessible site (Fortuna-Antoszkiewicz et al., 2018).

In marginal areas of Stupnički lug, *Robinia pseudoacacia* occurred sporadically in association with native tree species, but no dense stands were observed. According to Fortuna-Antoszkiewicz et al. (2018), woody invasive species tend to form clusters in open habitats, while herbaceous invasives primarily colonize open, sun-exposed areas along transport routes, a pattern also evident at this site. The spread of invasive species into protected areas is a particularly sensitive issue, as management options are limited and human intervention must remain minimal (Hall et al., 2022).

In the abandoned agricultural areas of Donji Stupnik, nine invasive plant species were recorded. The most abundant were *Erigeron annuus* ssp. *strigosus*, *Ambrosia artemisiifolia*, and *Solidago gigantea*. Dense populations were primarily associated with degraded and neglected habitats, but were also observed on agricultural land and meadows.

Soil degradation accompanied by dense stands of *E. annuus* ssp. *strigosus* was particularly evident along heavily trafficked roads and near logistics facilities. According to Song et al. (2018), mowing promotes the spread of this species, which may explain its localized dominance. This site also supported the largest populations of *A. artemisiifolia*, particularly within cultivated fields. Knolmajer et al. (2024) reported that populations growing on managed agricultural surfaces produce the highest quantities of pollen and seeds. The species is commonly dispersed by humans through contaminated seed material or agricultural machinery, which likely facilitated its introduction and spread at this site.

4. CONCLUSION

The results of this study confirm that urban environments are more heavily exposed to invasive plant species than less disturbed semi-natural habitats. This is primarily due to increased habitat heterogeneity, higher levels of human accessibility, and frequent disturbance. Across all sites, invasive species were most strongly associated with areas under pronounced anthropogenic impact and in varying stages of neglect, irrespective of habitat type.

In contrast, Stupnički lug remained largely free of invasive flora, owing to dense forest vegetation and reduced human impact. Although the study encompassed only a limited parts of the Zagreb area and a relatively small number of invasive species, clear differences in floristic composition between urban, suburban, and semi-natural habitats were evident. These findings underscore the importance of targeted monitoring and management strategies for invasive plant species in urban and peri-urban landscapes.

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