



Research Article

Planting roots: distribution pattern of invasive alien plants in urban habitats of Campobasso (Italy)*

Marco Varricchione^{1,2}, Maria Laura Carranza^{1,2}, Dario Ciaramella¹, Sandra Citterio^{2,3},
Maria Carla de Francesco^{1,2}, Chiara Montagnani^{2,3}, Lucia Antonietta Santoianni¹,
Angela Stanisci^{1,2}

1 Department of Biosciences and Territory, University of Molise, Pesche, Isernia, Italy

2 National Biodiversity Future Center (NBFC), Palermo, Italy

3 Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy

Corresponding author: Lucia Antonietta Santoianni (lucia.santoianni@unimol.it)

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Abstract

Identifying the most widespread or potentially Invasive Alien Plant species (IAPs) and understanding their distribution patterns across urban environments is essential for developing effective management strategies and mitigating their impacts on urban, peri-urban, and natural habitats. This study examines the occurrence and spatial distribution of a set of IAPs along an urbanization gradient and across EUNIS Habitats in a Mediterranean city of Southern Italy (Campobasso). The study was carried out across 14 urban grid cells (500 m × 500 m) reflecting different levels of urbanization. 26 IAP species were surveyed according to a national standardized protocol; for each record, GPS coordinates, cultivated versus spontaneous status, EUNIS Habitat type, and cover area were recorded. The influence of urbanization on IAP richness and occurrence was assessed using Mann–Whitney tests. For species with predominantly spontaneous occurrences (>80%), we analyzed their distribution across EUNIS Habitats and cover area classes.

Grid cells with high cover and patch number of artificial surfaces were associated with significantly greater IAP richness and occurrence values. Slightly more than half of the total records consisted of spontaneously established individuals or populations belonging to ten species, with *Senecio inaequidens*, *Robinia pseudoacacia*, and *Ailanthus altissima* being the most frequent. Transport networks and other hard-surface constructed areas, followed by dry perennial anthropogenic herbaceous vegetation, emerged as the most invaded habitat types. Overall, the findings highlight the need for early detection and prevention efforts targeting “emerging” invasive species that, although currently infrequent, may possess high potential for future expansion.

Keywords

Ailanthus altissima, alien plants, early warning, EUNIS habitats, invasive plants, *Senecio inaequidens*, urban ecosystems, urbanization gradient

Introduction

Cities act as hotspots for alien species (Moro and Castro 2015), and escape from cultivation – for example from common green spaces such as tree-lined avenues, parks, and private gardens – represents a major pathway for the

spread of Invasive Alien Plant species (IAPs) in urban habitats (Pyšek et al. 2011). Planted alien species may overcome dispersal barriers that species with poor dispersal abilities would hardly pass through (Čeplová et al. 2017).

Urban environments contain a broad range of micro-habitats, shelters, and ecological niches, that allow

* Topical Collection: “Role and impact of alien species in plant communities and habitat types”.

many alien plant species to establish and grow (Gentili et al. 2024). Moreover, cities often have high levels of impervious surface coverage, leading to reduced vegetation and, consequently, less competition with native plants (Flores-Reyes et al. 2025). On the other hand, they may provide important ecosystem services such as green air quality improvement, climate regulation, nutrient recycling, and pollination, and they also play a cultural role by providing recreational opportunities for citizens resulting in improved well-being (Buchholz et al. 2015; Campagnaro et al. 2018; Mori et al. 2025). Successful invaders are typically generalist taxa that are often preadapted or highly plastic, enabling them to take root in a wide range of urban habitats (Potgieter et al. 2020).

IAPs may cause a decrease of native biodiversity in cities and directly affect citizens' health and daily activities, contributing to issues such as allergies, higher fire risk, and damage to infrastructure and cultural heritage (Celesti-Grapow and Ricotta 2021; Montagnani et al. 2023).

IAPs may spread from urban to peri-urban, rural, and natural areas (Cadotte et al. 2017; Campagnaro et al. 2022), and they can significantly alter the structure, function, and productivity of natural ecosystems, with a consequent decline of biodiversity in native habitats (Vilà et al. 2011; Pyšek et al. 2012; Lazzaro et al. 2020).

In cities where the interface between urban, rural, and semi-natural areas is particularly narrow, the probability of IAPs spreading from urban environments into natural habitats increases.

Moreover, the restoration and expansion of green areas and infrastructures may enhance the biological permeability of cities, thereby facilitating the dispersal of alien species (Montagnani et al. 2026).

The compilation of inventories that include ecological information on urban green spaces provides valuable insights into ornamental species that are currently invasive or have a high invasion potential, thus enabling prevention measures and targeted interventions (Bartoli et al. 2021; Venturella et al. 2024; de Francesco et al. 2025; Di Gristina et al. 2025; Sarigu et al. 2025; Varricchione et al. 2026).

Identifying the most widespread or potential Invasive Alien Plants and their urban distribution patterns is therefore essential to address management strategies and reduce their impacts in urban and natural habitats (Štajerová et al. 2017; Dana et al. 2019).

For assessing alien plant distribution in urban habitats, the application of the EUNIS Habitat classification system (EEA 2025) may facilitate harmonized ecological assessments and comparative analyses across different urban contexts in Europe (Varricchione et al. 2024; D'Angeli et al. 2026).

A local, but also national and European, strategy is indeed required to the prioritization process and to mitigate the impact of IAPs (Brundu et al. 2020).

In this context, the present study aims to investigate the occurrence and distribution of a pool of 26 IAPs along the urbanization gradient and across urban EUNIS Habitats in a Mediterranean city of Southern Italy (Campobasso).

Target species were selected by Montagnani et al. (2026) for the monitoring of alien plants across Italian cities, based on their invasive status (Galasso et al. 2024), their relevance in Italian urban contexts (Bartoli et al. 2021), and their documented severe impacts on native ecosystems, economy, and human health at both European and global scales (Nentwig et al. 2018).

Moreover, the findings seek to inform effective prevention strategies to mitigate the growing challenge of alien plant invasions.

Material and methods

Study area

The study was carried out in Campobasso, a Mediterranean city in Southern Italy (Fig. 1). The municipality covers an area of 5,611 ha and hosts a population of about 50,000 inhabitants (ISTAT 2022). The urban centre of Campobasso is located at an elevation of 701 m a.s.l., ranging between 422 m a.s.l. and 907 m a.s.l. The area belongs to the Apennine ecoregional province and is characterized by a temperate sub-mediterranean climate (Blasi et al. 2014, 2018), with mean annual temperature of 13.3°C, coldest-month averages between -1°C and 4°C, two months exceeding 20°C, and a mean annual precipitation of 806 mm (Martinelli and Matzarakis 2017; Pesaresi et al. 2017).

In the study area, vegetated man-made habitats (56.8%, EUNIS Habitat V), mainly represented by mixed crops of market gardens and horticulture (11%, V12), large-scale ornamental garden areas (3%, V21), and dry perennial anthropogenic herbaceous vegetation (1.6%, V38), prevail (D'Angeli et al. 2026). Furthermore, 20.5% of the territory includes constructed, industrial, and other artificial habitats (EUNIS Habitat J), in particular composed of buildings of cities, towns, and villages (17.8%, J1), as well as transport networks and other constructed hard-surface areas (2.6%, J4). Moreover, forest and other wooded land (EUNIS Habitat T) encompass 17.8% of the study area, principally consisting of *Quercus frainetto*, *Quercus cerris*, and *Quercus pubescens* subsp. *pubescens* forests (11.1%, T19) and deciduous self-sown forest of non site-native trees (2.4%, T1J) (Varricchione et al. 2024). Finally, a small proportion of the study area is composed of grasslands and lands dominated by forbs, mosses, or lichens (1.3%, EUNIS Habitat R), heathland, scrub and tundra (3.4%, EUNIS Habitat S), and inland habitats with no or little soil and mostly with sparse vegetation (0.1%, EUNIS Habitat U).

Invasive alien plants sampling

Alien species sampling followed the national protocol defined by Montagnani et al. (2026), assessing occurrence records of 26 target IAP species selected for their invasive status and relevance in Italian urban contexts (Suppl. mate-

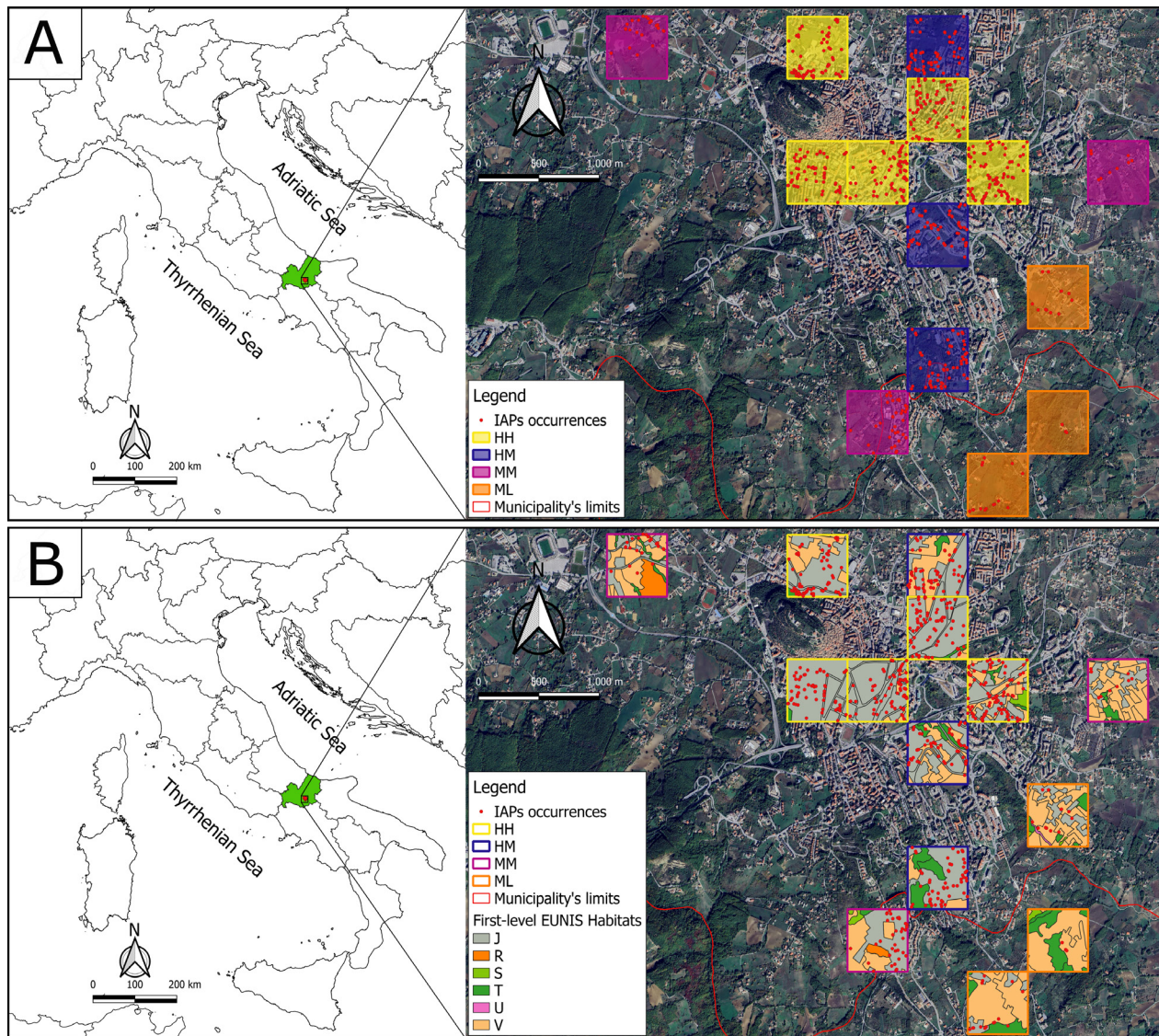


Figure 1. Study area (Campobasso municipality) along with the grid cell types, classified across the urbanization gradient (A) and the first-level EUNIS Habitats (B); HH: high cover (>50%) and high patch number (≥ 20) of artificial surfaces; HM: high cover (>50%) and medium patch number ($5 < x < 20$) of artificial surfaces; MM: medium-low cover (<50%) with medium patch number ($5 < x < 20$) of artificial surfaces; ML: medium-low cover (<50%) with low patch number (≤ 5) of artificial surfaces; J: Constructed, industrial, and other artificial habitats; R: Grasslands and lands dominated by forbs, mosses, or lichens; S: Heathland, scrub, and tundra; T: Forest and other wooded land; U: Inland habitats with no or little soil and mostly with sparse vegetation; V: Vegetated man-made habitats. Red points refer to the occurrences of the target Invasive Alien Plant species recorded during the sampling activities.

rial 1). All selected taxa are classified as invasive in at least one Italian region (Galasso et al. 2024) and present documented impacts on ecosystem structure (e.g., inhibition of growth and regeneration of native species), on urban components (e.g. damage to buildings, infrastructures), or on human health (e.g. allergies), as evidenced by direct observations or published sources (Montagnani et al. 2026).

Surveys were conducted within fourteen 500 m \times 500 m grid cells representing an urbanization gradient, chosen by random stratified method and based on the accessibility.

Each grid cell was classified into urbanization categories based on the composition (proportional cover) and spatial configuration (patch number) of artificial surfaces

within the entire cell area. Both composition and configuration were classified into three levels (H: High, M: Medium, L: Low). This standardized approach allowed the identification of cells referable to four main urbanization categories in the analyzed city:

- HH: High cover (>50%) and high patch number (≥ 20) of artificial surfaces;
- HM: High cover (>50%) and medium patch number ($5 < x < 20$) of artificial surfaces;
- MM: Medium-low cover (<50%) with medium patch number ($5 < x < 20$) of artificial surfaces;
- ML: Medium-low cover (<50%) with low patch number (≤ 5) of artificial surfaces.

Field surveys were carried out during the autumn season, as it corresponds to the main blooming period of most IAPs (de Francesco et al. 2023). To ensure comprehensive detection, it was repeated in spring to record early-flowering alien taxa that may have been absent or undetectable in autumn.

In each grid cell, a team of botanists (from 2 to 4) surveyed all accessible areas and recorded every occurrence of the target species.

For each occurrence record, we collected the geographic coordinates (GPS), noted the local status (i.e., whether the individual/population occurred exclusively under cultivation or also in the wild), the EUNIS Habitat type (Chytrý et al. 2020; EEA 2025) (Table 1), and the cover area according to the following classes: Low: ≤ 1 m²; Medium-low: 1–5 m²; Medium-high: 6–50 m²; High: > 50 m² (Montagnani et al. 2026). Finally, photographs were taken for all recorded occurrences.

The EUNIS habitat classification was derived from the Nature Map of Campobasso (D'Angeli et al. 2026) and from the regional map of Molise (Ceralli et al. 2021). Field surveys allowed the assignment of an additional level of detail based on local environmental characteristics and on the presence of habitat diagnostic species, as reported in the Database of European Vegetation, Habitats, and Flora (Chytrý et al. 2024).

During field surveys, to avoid oversampling, we distinguished occurrences based on the distance between presence cores (adjusted to species-specific dispersal and propagation strategies) and on the type of colonized environment (Montagnani et al. 2026). For example, two records of the same species located in close proximity were treated as separate occurrences when they occurred in different EUNIS habitat types.

Data analysis

We systematically classified all recorded IAPs based on taxonomic family, growth forms, geographic origin (WFO 2025), and invasive status at both the Italian (sensu Galasso et al. 2024) and regional levels (Molise; Portal to the Flora of Italy 2025). Subsequently, for each species, we calculated the percentage of occurrences, expressed as the proportion of the total number of occurrences recorded. We also quantified the percentage of individuals/populations recorded as either cultivated or spontaneous.

Moreover, to assess the potential influence of the urbanization gradient on IAP presence, we compared species richness and the number of occurrences across categories of the grid cells based on the composition and spatial configuration of artificial surfaces. Comparisons were conducted for all target IAPs occurrence records, as

Table 1. List of EUNIS Habitats present in the 14 grid cells in Campobasso, along with their code, name, and description (EEA 2025).

EUNIS Habitat		
Code	Name	Description
J1	Buildings of cities, towns, and villages	Buildings in built-up areas where buildings, roads, and other impermeable surfaces occupy at least 30% of the land. Includes agricultural building complexes where the built area exceeds 1 ha.
J4	Transport networks and other constructed hard-surface areas	Includes roads, car parks, railways, paved footpaths, and hard-surfaced areas of airports, water ports, and recreational areas.
R	Grasslands and lands dominated by forbs, mosses, or lichens	Non-coastal land which is dry or only seasonally wet (with the water table at or above ground level for less than half of the year) with greater than 30% vegetation cover. The vegetation is dominated by grasses and other non-woody plants, including mosses, macrolichens, ferns, sedges, and herbs. Includes semiarid steppes with scattered <i>Artemisia</i> scrub. Includes successional weedy vegetation.
S	Heathland, scrub, and tundra	Non-coastal land which is dry or only seasonally inundated (with the water table at or above ground level for less than half of the year), usually with greater than 30% vegetation cover and with the development of soil.
T1J	Deciduous self-sown forest of non-native trees	Non-planted stands dominated by non-native deciduous tree species such as <i>Acer negundo</i> , <i>Ailanthus altissima</i> , and <i>Robinia pseudoacacia</i> .
U	Inland habitats with no or little soil and mostly with sparse vegetation	Non-coastal habitats on substrates with no or little development of soil, mostly with less than 30% vegetation cover which are dry or only seasonally wet (with the water table at or above ground level for less than half of the year). Habitats which may have a high vegetation cover include crevices of rocks, screes or cliffs, and habitats formed by carpets of moss.
V12	Mixed crops of market gardens and horticulture	Intensive cultivation of vegetables, flowers, and small fruits, usually in alternating strips of different crops. Includes allotments and small-scale market gardens.
V21	Large-scale ornamental garden areas	Cultivated areas of large-scale recreational gardens. The vegetation, usually composed mainly of introduced species or cultivars, can nevertheless include many native plants and supports a varied fauna when not intensively managed.
V211	Park flower beds, arbours, and shrubbery	Plantations of ornamental forbs or shrubs constituting elements of urban parks.
V22	Small-scale ornamental and domestic garden areas	Cultivated areas of ornamental gardens and small parks beside houses or in city squares. Kitchen gardens in the immediate vicinity of dwelling places.
V38	Dry perennial anthropogenic herbaceous vegetation	Stands dominated by perennial herbaceous plants, frequently ruderals, developing on dry abandoned urban or agricultural land, on land that has been reclaimed, on transport networks, or on land used for waste disposal. These stands often replace annual anthropogenic herbaceous vegetation in the course of secondary succession.
V63	Lines of planted trees	More or less continuous lines of trees forming strips within a matrix of grassy or cultivated land or along roads, typically used for shelter or shading.

well as for spontaneous individuals/populations only. Significant differences among categories were evaluated using the Mann-Whitney pairwise post hoc tests for equal medians, with no correction for multiple comparisons.

Finally, we focused on the records occurring as spontaneous individuals/populations of target IAPs. We selected the IAPs with the highest occurrences of spontaneous individuals/populations (defined as those exceeding 80% of total spontaneous occurrences). For these species, to provide insights into potential ecological preferences or suitable conditions for their proliferation in specific urban contexts, we assessed their occurrences across the different EUNIS Habitats and their corresponding cover area classes.

Statistical analyses were performed in the R Statistical Software (v4.4.2, R Core Team 2024) using the “tidyverse” package (Wickham et al. 2019), including “ggplot2” (Wickham 2016), “ggpattern” (FC 2024), and “dplyr” (Wickham et al. 2023) packages.

Results

Our results revealed the presence in the city of Campobasso of 14 of the target 26 urban IAPs, belonging to 11 taxonomic families. Asteraceae family accounts for 28.6% of the total IAPs. The majority of the registered IAPs come from temperate Asia and Northern America (Table 2).

All the recorded species are classified as invasive neophytes (N INV) at national level in Italy. However, only 4 (*Ailanthus altissima*, *Helianthus tuberosus*, *Robinia pseudoacacia*, and *Senecio inaequidens*) are considered N INV in Molise region (Portal to the Flora of Italy 2025), one species (*Artemisia annua*) is naturalized neophytes (N

NAT), and two species (*Acer negundo* and *Ligustrum lucidum*) are casual neophytes (N CAS). For half of the recorded species, the invasion status in Molise region is not available (N/A) (Table 2).

Out of the 634 occurrences of target IAPs, the most frequently observed was *Prunus laurocerasus* (25%, primarily cultivated), followed by *Senecio inaequidens* (23%, entirely spontaneous), *Robinia pseudoacacia* (16%, mainly spontaneous), and *Ailanthus altissima* (11%, mainly spontaneous) (Table 2).

The species richness and occurrence of the investigated pool of IAPs varied along the urbanization gradient. Specifically, grid cells characterized by a high cover and patch number of artificial surfaces (HH and HM) showed significantly higher values of IAP richness (9 vs. 4 species on average, p-value = 0.03) and occurrences (67 vs. 16 on average, p-value = 0.04) compared to grid cells with low cover and patch number of artificial areas (MM and ML; Fig. 2A). Considering only the cultivated individuals/populations of IAPs, the most urbanized grid cell (HH) showed a significantly higher values of IAPs richness (7 vs. 2 on average, p-value = 0.03) and occurrences (36 vs. 5, p-value = 0.03) than the most natural grid cell type (ML; Fig. 2B). A similar trend also emerged when considering only spontaneous individuals/populations of IAPs. The most urbanized grid cell types (HH and HM) had higher spontaneous individuals/populations species richness (5 vs. 2 on average, p-value = 0.04) and occurrences (36 vs. 5 on average, p-value = 0.03) than the most natural grid cell type (ML; Fig. 2C).

With regard to the distribution of occurrences of the selected IAPs across EUNIS Habitats, 33.9% are associated with small-scale ornamental and domestic garden areas (V22), 20.5% with dry perennial anthropogenic

Table 2. List of target Invasive Alien Plants registered in Campobasso city, along with the taxonomic family, growth form, origin area (WFO 2025), status in Italy (Galasso et al. 2024), status in Molise region (Portal to the Flora of Italy 2025), percentage of occurrences relative to the total occurrences, and percentage of occurrences as cultivated or spontaneous individuals/population. The nomenclature conforms to Galasso et al. (2024). P scap: scapose phanerophyte, P caesp: caespitose phanerophyte, P lian: liana phanerophyte, Ch suffr: suffruticose chamaephyte, G rhiz: rhizomatous geophyte, T scap: scapose therophyte, N INV: invasive neophytes, N NAT: naturalized neophytes, N CAS: casual neophytes, N/A: not available.

Species	Taxonomic family	Growth form	Origin	Status in Italy	Status in Molise	Total occurrences (%)	Cultivated occurrences (%)	Spontaneous occurrences (%)
<i>Acer negundo</i>	Sapindaceae	P scap	Northern America	N INV	N CAS	2%	100	0
<i>Ailanthus altissima</i>	Simaroubaceae	P scap	Asia-Temperate	N INV	N INV	11%	5.6	94.4
<i>Artemisia annua</i>	Asteraceae	T scap	Africa, Asia-Temperate, Asia-Tropical	N INV	N NAT	<1%	0	100
<i>Buddleja davidii</i>	Scrophulariaceae	P caesp	Asia-Temperate	N INV	N/A	<1%	33.3	66.7
<i>Helianthus tuberosus</i>	Asteraceae	G rhiz	Northern America	N INV	N INV	2%	15.4	84.6
<i>Ligustrum lucidum</i>	Oleaceae	P scap	Asia-Temperate, Asia-Tropical	N INV	N CAS	7%	95.5	4.6
<i>Lonicera japonica</i>	Caprifoliaceae	P lian	Asia-Temperate	N INV	N/A	1%	40	60
<i>Parthenocissus</i> spp.	Vitaceae	P lian	Northern America	N INV	N/A	6%	55	45
<i>Paulownia tomentosa</i>	Paulowniaceae	P scap	Asia-Temperate	N INV	N/A	<1%	100	0
<i>Prunus laurocerasus</i>	Rosaceae	P caesp	Africa, Asia-Temperate, Europe	N INV	N/A	25%	98.1	1.9
<i>Quercus rubra</i>	Fagaceae	P scap	Northern America	N INV	N/A	1%	100	0
<i>Robinia pseudoacacia</i>	Fabaceae	P scap	Northern America	N INV	N INV	16%	20.2	79.8
<i>Senecio inaequidens</i>	Asteraceae	Ch suffr	Southern Africa	N INV	N INV	23%	0	100
<i>Trachycarpus fortunei</i>	Arecaceae	P scap	Asia-Temperate, Asia-Tropical	N INV	N/A	5%	100	0

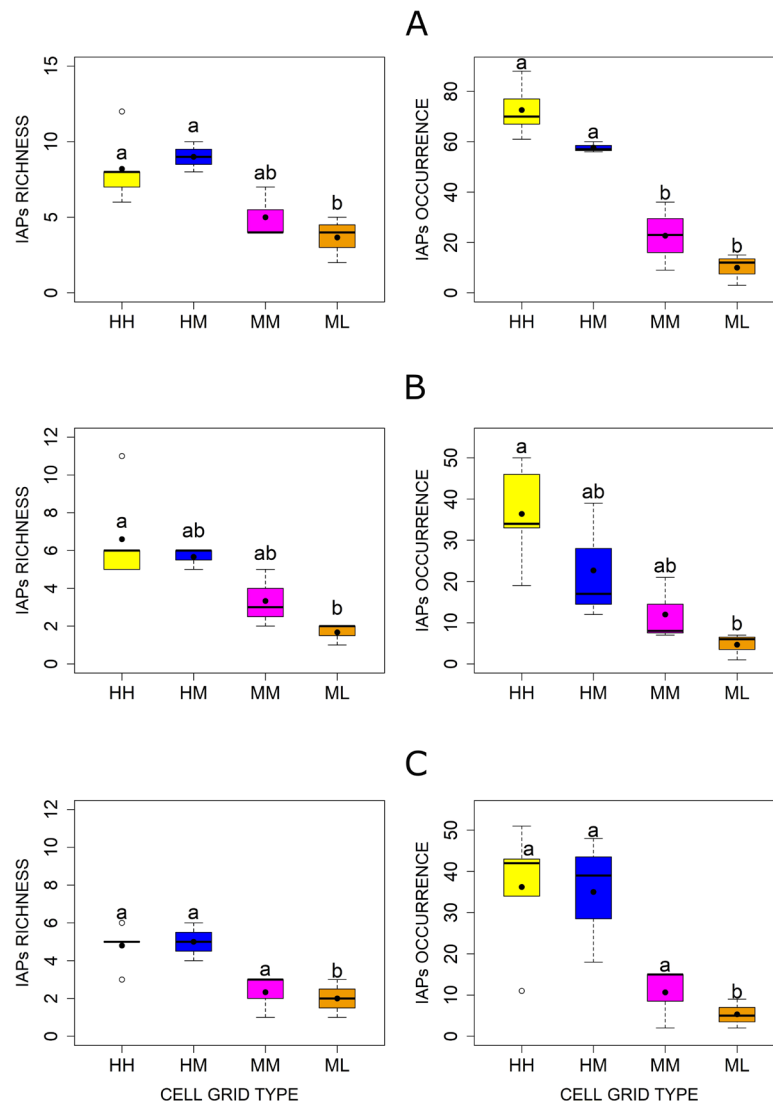


Figure 2. Boxplots comparing richness and number of occurrences of the total recorded target Invasive Alien Plant (IAPs) species (A), of cultivated individuals/populations of target IAPs (B), and of spontaneous individuals/populations of target IAPs (C) across the urbanization gradient (HH: high cover (>50%) and high patch number (≥ 20) of artificial surfaces; HM: high cover (>50%) and medium patch number ($5 < x < 20$) of artificial surfaces; MM: medium-low cover (<50%) with medium patch number ($5 < x < 20$) of artificial surfaces; ML: medium-low cover (<50%) with low patch number (≤ 5) of artificial surfaces). Letters indicate significant differences according to the Mann-Whitney pairwise posthoc tests.

herbaceous vegetation (V38), 20.3% with transport networks and other constructed hard-surface areas (J4), and 11.3% with large-scale ornamental garden areas (V21) (Suppl. material 2). Most occurrences in V21 and V22 involved cultivated individuals/populations, whereas those in V38 and J4 were predominantly spontaneous.

Slightly more than half of the total occurrences of target IAPs (334) consisted of spontaneously established individuals/populations belonging to 10 species. Among these, the majority (>80% of the occurrences) were accounted for *Senecio inaequidens* (44%), *Robinia pseudoacacia* (23.7%), and *Ailanthus altissima* (20.1%) (Fig. 3).

Senecio inaequidens was primarily recorded along the transport networks and other constructed hard-surface areas (J4), followed by the dry perennial anthropogenic herbaceous vegetation (V38). As an herbaceous species, it

generally occurred in small areas, often as single individuals or small individual groups (Fig. 4).

Robinia pseudoacacia mainly occurred in V38, where it occupied large areas and formed dense patches composed of numerous individuals/populations, including mature trees (Fig. 4). Although less common, *Robinia pseudoacacia* also occurred in J4, forming large patches along railway lines, as well as in ornamental and domestic garden areas (V22), where they were mostly represented by small, spontaneously established individuals derived from cultivated trees (Fig. 4).

Ailanthus altissima, by contrast, was more frequent in V38, where it mainly occupied large areas, typically forming small but dense patches. It also occurred in J4, in small areas, and was often represented by isolated or young individuals/populations growing in sidewalk cracks or along road edges (Fig. 4).

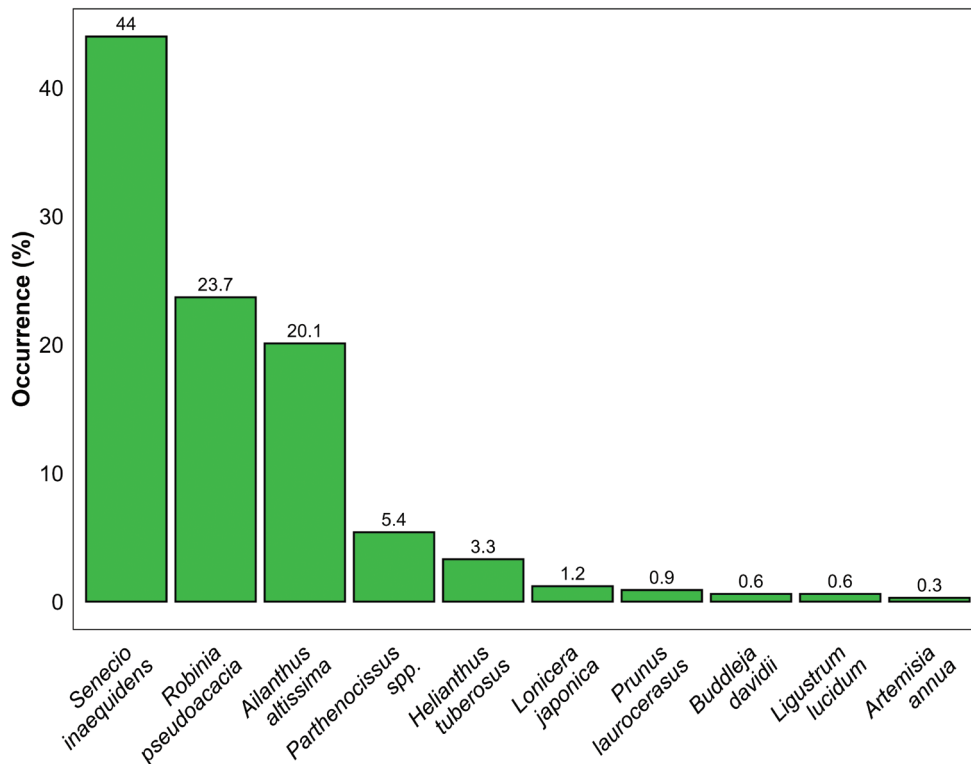


Figure 3. Percentage occurrences of spontaneously established individuals/populations of the target Invasive Alien Plant species recorded in Campobasso (Italy), calculated as the proportion of each species' occurrences relative to the total occurrences of all recorded spontaneous individuals/populations.

Discussion

The findings yield novel insights into how a suite of IAPs is distributed along the urbanization gradient and across EUNIS habitat types in a Mediterranean city.

The target IAPs recorded in Campobasso are mainly woody perennial species, used as ornamental species (Varricchione et al. 2026), in the green furnishing of public and private spaces (Venturella et al. 2024). However, there are also herbaceous species introduced for ornamental and/or food purposes (*Artemisia annua* and *Helianthus tuberosus*) or arrived accidentally (such as *Senecio inaequidens*) (Vacchiano et al. 2013; Quagliani et al. 2025).

Among the target IAPs, the Asteraceae family prevails, in line with the overall composition of non-native flora in Italy (Galasso et al. 2024) and with what was observed in invaded natural habitats (Montecchiari et al. 2020; Viciani et al. 2020; Compagnone et al. 2024) and urban environments (Štajerová et al. 2017; Appalasamy et al. 2020; Ibáñez et al. 2023; Richardson et al. 2025). The native distribution range of the recorded IAPs corresponds to areas with a similar climate to that found in the study area (i.e., the temperate zones of North America, the Asian continent, and, to a lesser extent, the Mediterranean climate areas of South Africa), as recorded for other cities in Southern Europe (Ibáñez et al. 2023; García-Mozo 2024; Sarajlić et al. 2025) and globally (Li et al. 2025; Richardson et al. 2025).

This notable prevalence of American species may indicate a long-standing history of trade and interaction

across multiple geographical regions over several centuries (Arianoutsou et al. 2021), as well as the widespread availability in Europe of habitats analogous to those occupied in their native range (Fristoe et al. 2021; Guarino et al. 2021).

For half of the recorded species, the invasion status in Molise region is currently not available (N/A) (Galasso et al. 2024; Portal to the Flora of Italy 2025). This paper helps to fill this knowledge gap, as for 4 IAPs here are the first documented observations for the region as spontaneously established individuals/populations (Portal to the Flora of Italy 2025). These are *Buddleja davidii*, *Lonicera japonica*, *Parthenocissus* spp., and *Prunus laurocerasus*, already reported in neighboring regions as spontaneous (Galasso et al. 2016; Portal to the Flora of Italy 2025).

Based on the analysis of the urbanization gradient, we observed that the most urbanized grid cells have higher richness and occurrences of target IAPs, as recorded in other cities (Celesti-Grappo et al. 2006; Schmidt et al. 2014; Kalusová et al. 2019; Jogan et al. 2022). Conversely, we observed that IAPs richness/occurrences were lower in most natural grid cells. These findings agree with the assumptions that the most urbanized areas are hotspots for the presence of IAPs (Botham et al. 2009; Kühn et al. 2017; Boscutti et al. 2022) and that the low native vegetation cover coupled with high impervious surface coverage enhance IAPs rooting (Santangelo et al. 2022; Flores-Reyes et al. 2025).

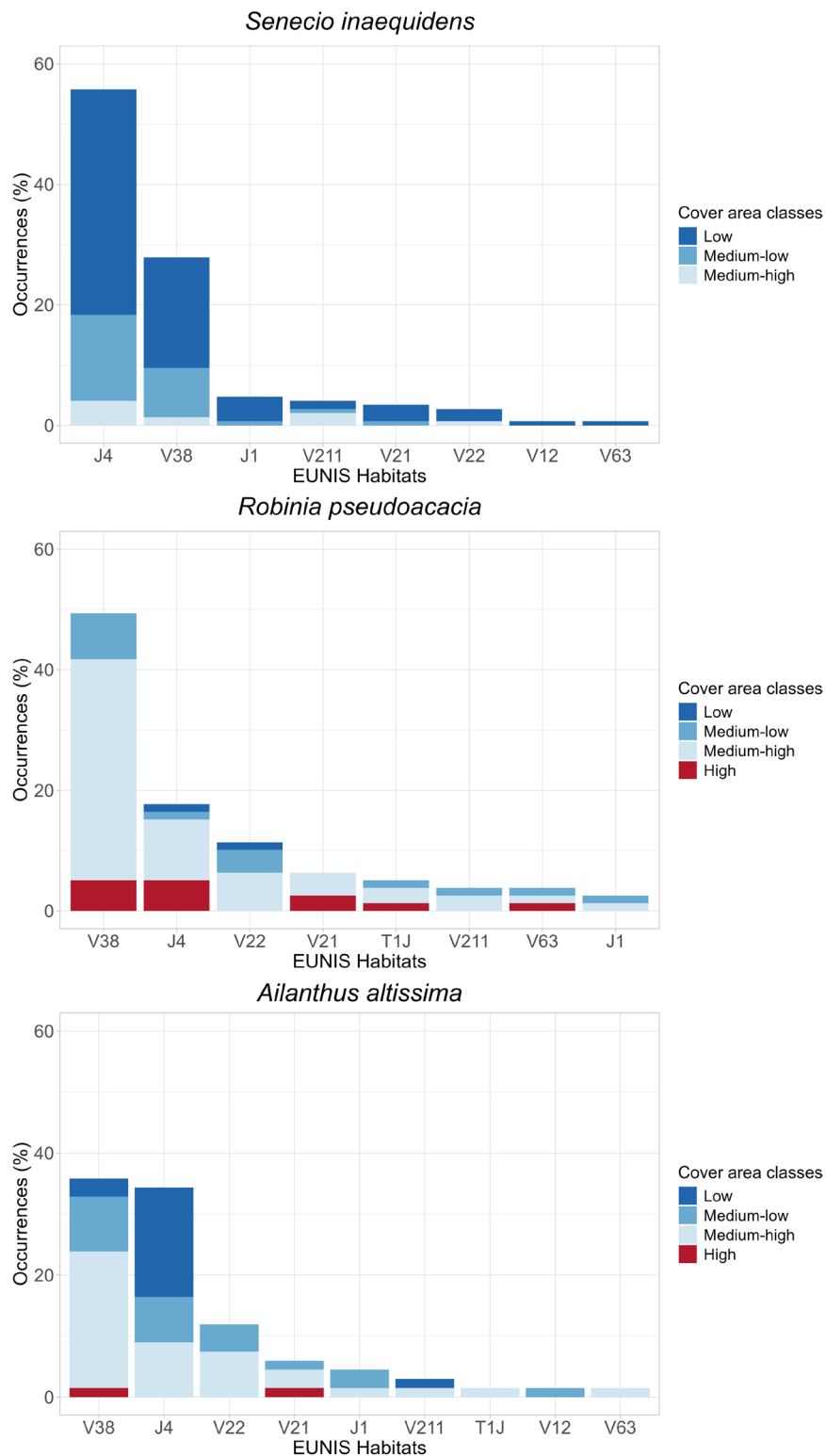


Figure 4. Percentage occurrences and cover area classes (Low: ≤ 1 m²; Medium-low: 1–5 m²; Medium-high: 6–50 m²; High: > 50 m²) of spontaneously established individuals/populations of the three most frequent invasive alien plant species across the different EUNIS Habitats recorded in Campobasso.

Among the target IAPs species spontaneously established, the highest occurrences were accounted by *Senecio inaequidens* (44%), followed by *Robinia pseudoacacia* (23%), and *Ailanthus altissima* (20.1%). These findings partially align with previous records from Milan, Turin, and

Rome, where the most widespread and frequent spontaneous species were *Ailanthus altissima*, *Sorghum halepense*, *Phytolacca americana*, and *Robinia pseudoacacia* (Montagnani et al. 2026). As for *S. inaequidens*, Campobasso is currently the only Italian city in which it showed a high occurrence.

Presumably, other Italian cities in hilly and mountainous areas are experiencing an invasion of this IAP, as its recently documented ability to adapt to progressively higher elevations makes *Senecio inaequidens* one of the most successful neophytes regarding the span of altitude (Bazzato et al. 2024). Further studies should be implemented for updating the distribution of this species in urban and natural habitats.

Regarding the distribution of target IAPs across EUNIS Habitats in the study area, individuals/populations found in cultivation are associated with small-scale ornamental and domestic garden areas (V22) and large-scale ornamental garden areas (V21) (Suppl. material 2). These public and private green spaces are, in fact, the urban areas that host many invasive alien ornamental species, as also observed in other Italian (Bartoli et al. 2021; Venturilla et al. 2024; Di Gristina et al. 2025; Varricchione et al. 2026) and European cities (Jogan et al. 2022; Richardson et al. 2025; Sarajlić et al. 2025). This result highlights the importance of informing public decision-makers responsible for urban green spaces, as well as nursery and horticultural sector operators, about the ecological impacts these species may cause in natural environments (Hulme et al. 2018; Brundu et al. 2020).

In contrast, the pool of IAPs spontaneously established are mainly associated with dry perennial anthropogenic herbaceous vegetation (V38), found in abandoned areas within the city, and with transport networks and other constructed hard-surface areas (J4). These are the primary colonization sites for Invasive Alien Plants in urban environments, as they offer space, resources, and low native species cover (Appalasamy et al. 2020; Boscutti et al. 2022).

Analysing which EUNIS Habitats hosted the most abundant spontaneously growing IAPs (*Senecio inaequidens*, *Robinia pseudoacacia*, *Ailanthus altissima*), it can be noted that the most widespread one, the South African *Senecio inaequidens*, mainly occurred in J4, as also documented in other studies (Bornkamm 2002; Heger and Böhmer 2005; Lenzin et al. 2009). Roadside slopes and residual terrain abutting sidewalk pavement are the most frequently recorded habitats of this species in the study area, as observed in other cities (Ernst 1998; Blanchet et al. 2015; Kocián 2016; Quaglini et al. 2025). However, the species also grows in V38 (i.e., on abandoned areas where ruderal vegetation is established, dominated by perennial species such as *Dittrichia viscosa*, *Scrophularia canina*, and *Hypericum perforatum* (Di Pietro et al. 2017)).

The edges of roads and railway lines represent the ecological corridor that allows rapid dispersal of IAPs both in urban environments and in more natural areas (McDougall et al. 2018; Bhadouria et al. 2025; Brundu et al. 2025). In Central Italy, *Senecio inaequidens* occurrence has been documented up to 985 m a.s.l. and it is invasive in natural grasslands referable to the EUNIS habitats Thermophilous forest fringe of base-rich soils (R51), Trampled xeric grassland with annuals (V34), and Perennial rocky calcareous grassland of subatlantic-submediterranean Europe (R18) (Santoianni et al. 2024, 2025). The species was found at an elevation up to 2575 m a.s.l. in the Western Alps, confirm-

ing its pre-adaptation to mountain conditions (Digital Flora of Aosta Valley 2026). A key factor underlying the invasion success of *Senecio inaequidens* is its high seed dispersal capacity, which enables a rapid colonization of new areas. According to the EICAT (Environmental Impact Classification for Alien Taxa) framework (Vimercati et al. 2022), *Senecio inaequidens* is globally classified as having a moderate impact: it negatively affects native taxa but does not cause local extinctions (Quaglini et al. 2025). However, the species contains highly toxic pyrrolizidine alkaloids, making it hazardous to livestock and potentially other mammals, especially in regions where grazing pressure is high (Dimande et al. 2007; Monty et al. 2008). Moreover, climate change seems to favour its spread in natural habitats (Bazzato et al. 2024).

As regards *Robinia pseudoacacia* and *Ailanthus altissima*, they are mostly related to V38, corresponding to the vegetation stage with pioneer trees of secondary succession developing on dry abandoned urban or agricultural land or on land with man-made ground. This finding was also observed for Milan, Turin, and Rome (Montagnani et al. 2026), where, in response to the urbanization gradient, *Ailanthus altissima* was associated to highly disturbed central areas, while *Robinia pseudoacacia* was found more common in suburban contexts. A recent study analyzing the diversity of Campobasso urban woods and their distribution in relation to the disturbance indicator values (Midolo et al. 2023) and the Ecological Indicator Values for Europe (Dengler et al. 2023), highlighted that these IAPs only occasionally occurred and had low cover in the native urban forests dominated by *Quercus cerris* and *Quercus frainetto* (T19), which represent the potential natural vegetation of the area (Varricchione et al. 2024).

Robinia pseudoacacia forms wooded patches in degraded and vacant urban lots, and it does not seem to threaten urban habitats of conservation relevance. Furthermore, it has a fundamental role in allowing the natural greening of urban areas with degraded, nitrate-rich soil, where native tree species fail to take root (Jim 2013; Gavrilidis et al. 2023; Kato-Noguchi and Kato 2024). *Robinia pseudoacacia* is notable for its ability to thrive in both nutrient-rich and nutrient-poor soils. As a member of the Fabaceae family, it can overcome nitrogen limitations by forming a symbiotic relationship with rhizobia, allowing the tree to fix atmospheric nitrogen (Xiao et al. 2021). In addition, *Robinia pseudoacacia* produces allelochemicals that can suppress the germination, growth, or establishment of neighboring plant species, enhancing its competitive ability (Medina-Villar et al. 2017). This nitrogen-fixing capacity, combined with chemical defences against competitors and resistance to natural enemies, provides a significant advantage in nutrient-poor environments and likely enhances the species' invasiveness, facilitating its successful colonization of challenging habitats (Carl et al. 2018; Kato-Noguchi and Kato 2024). These urban *Robinia pseudoacacia* wooded patches may contribute to some degree to regional biodiversity (Campagnaro et al. 2018) and can play an important ecological role in the local ecological network, especially for arthropod and vertebrate

fauna (Buchholz et al. 2015; Mori et al. 2025). However, it should be pointed out that, along the riverbanks of the region, *Robinia pseudoacacia* is found to be highly invasive and causes a strong negative impact on riparian and lowland forests, with a reduction in the richness of native species and an increase in nitrophilous species in the understory (Varricchione et al. 2024). These findings were also documented in other Italian regions (Fogliata et al. 2021; Fanfarillo et al. 2023; Musarella et al. 2024).

Ailanthus altissima is also abundant in J4, colonizing side slopes along roads and railways. This habitat serves as a natural corridor facilitating the species' dispersal and allowing swift movement both into and out of the city, as reported by Casella and Vurro (2013), Sitzia et al. (2016), and Motti et al. (2021).

Roads are also the gateway for this IAP towards protected areas, as documented by the research made by the Mountain Invasion Research Network (MIREN) (Haider et al. 2022; Santoianni et al. 2024) and the PREVALIEN research project (Lozano et al. 2023; Lozano et al. 2024; Marzioletti et al. 2025).

Ailanthus altissima is a species of Union relevance (European Commission 2019) and its ecological impact in the natural and semi-natural landscape has been documented at national level in several habitats of EU conservation interest (Lazzaro et al. 2020). It causes a decrease in the proportion of native plant species in the understory and an increase in ruderal plant species (Montecchiari et al. 2020; Brooks et al. 2021; Terzi et al. 2021).

Its occurrence in Central Apennine is high in areas where potential natural vegetation has been destroyed by humans, in afforestation, and where there is a recurrent anthropogenic disturbance that alters the soil (Santoianni et al. 2024). In the investigated urban context, it colonizes not only roadside slopes and areas with altered soil and landfills, but also steep rocky slopes and ancient historical sites, as documented in Rome (Celesti-Grapow and Ricotta 2021).

However, further investigations are needed to better understand its dynamics and ecology in Italian natural contexts. The participative science project AilantItaly was recently launched address to these issues (Compagnone et al. 2025).

For management and prevention purposes, the containment of *Senecio inaequidens*, *Robinia pseudoacacia*, and *Ailanthus altissima*, now widespread both in urban and rural landscapes, appears prohibitive in economic terms (Motti et al. 2021). In Italy, *Senecio inaequidens*, *Robinia pseudoacacia*, and *Ailanthus altissima* are also among the most frequent invaders of native plant communities in Natura 2000 sites (Lazzaro et al. 2020). Therefore, the eradication/containment efforts should focus on avoiding a further extensive spread in natural environments, and could be achieved in protected areas where these IAPs threaten the ecological integrity of habitats of conservation relevance (e.g., mountain grasslands (*Senecio inaequidens*), riparian and floodplain forests (*Robinia pseudoacacia*), and open oak forest (*Ailanthus altissima*)), as documented in several studies (e.g. Constán-Nava et al. 2010; Vacchiano et

al. 2013; Sádlo et al. 2017; Nicolescu et al. 2020; Santoianni et al. 2024; Varricchione et al. 2024). As alien species cover decreases with native species cover (Loiola et al. 2018; Anibaba et al. 2023), enhancing the niche-filling of native vegetation in the semi-natural and natural environments could be the most effective and sustainable conservation action.

In the urban context, eradication/containment efforts should be addressed for the conservation of monumental or sacred sites, where several IAPs cause important damages (Celesti-Grapow and Ricotta 2021).

Still, it could be useful to invest in preventing the spread of “emerging” invasive or potentially invasive species that we have documented to be present at low frequencies in natural environments, but that could have the potential for expansion in the coming decades. In particular, on species that are currently casual neophytes in the study region, but which could become invasive in the coming years, as has already happened in other Italian regions (Lazzaro et al. 2020; Viciani et al. 2020; Portal to the Flora of Italy 2025). In our case, these species could be *Acer negundo* and *Ligustrum lucidum*. Moreover, we can consider the species that we documented as spontaneously growing in Campobasso, which are *Buddleja davidii*, *Helianthus tuberosus*, *Lonicera japonica*, *Parthenocissus* spp., and *Prunus laurocerasus*. In addition, there are species that are not yet found self-sown in Campobasso, but they have been documented as present in nature in the nearby regions, such as *Quercus rubra*, *Paulownia tomentosa*, and *Trachycarpus fortunei*.

In detail, *Buddleja davidii*, *Helianthus tuberosus*, *Parthenocissus* spp., *Lonicera japonica*, *Acer negundo*, and *Quercus rubra* could spread to riparian and riverbed habitats, as well as floodplains, as has been observed in other Italian and European areas (Saccone et al. 2013; Montaldi et al. 2024; Alessandrini et al. 2025; Bylak et al. 2025). These emerging invasive plants could show the capacity to rapidly establish and spread within disturbed riparian and anthropogenic environments, enabling them to track habitat instability and expand efficiently along river corridors. Their rapid growth and resource dominance may competitively suppress native vegetation, leading to reduced species richness and altered successional pathways. By reshaping vegetation structure and ground cover, they also have the potential to modify key ecosystem processes with cascading effects on native communities (Richardson et al. 2007; Catford et al. 2012; Deslippe and Veenendaal 2025). Moreover, projections under future climate scenarios indicate an increased likelihood of range expansion, suggesting that their ecological influence could intensify and extend across broader European regions. For example, *Buddleja davidii* can divert pollinators from native species, reducing their visitation rates and potentially impairing native plant reproduction and ecosystem stability (Bylak et al. 2025; Tourbez et al. 2025). As regards *Ligustrum lucidum*, *Prunus laurocerasus*, and *Trachycarpus fortunei*, climate changes can enhance the spread of these evergreen woody species in Mediterranean deciduous oak forests, determining a thermophilization and lauriphilization process of the flora, which is also being observed in

other areas with a temperate climate (Rusterholz et al. 2018; Abrahamczyk et al. 2024; Iseli et al. 2025). By contrast, *Pau-
lownia tomentosa* could colonize open stands of oak forests,
soils rich in debris, and rocky habitats (Essl 2007).

The early warning for these taxa should be shared with
key stakeholders such as nursery companies, urban archi-
tects, agronomists-forestry, citizens, schools, and technical
offices of local authorities (Rainford et al. 2020; Venette et al.
2021). It is necessary to affect the production chain to avoid
their propagation, sale, planting, and cultivation. Further-
more, alternative native species must be identified capable
of providing the same growth and cultivation performance
(Hulme et al. 2018; Clark and Crawford 2025), as well as
aesthetic appreciation, to allow the replacement of invasive
or potentially invasive neophytes (Russo et al. 2025).

One limitation of the present study is the pre-selection
of a nationally defined list of 26 invasive alien species,
which resulted in the exclusion of other invasive alien
species occurring in the study area. This approach was ad-
opted to ensure a standardized sampling framework and
to keep sampling effort manageable, particularly in large
urban areas such as Milan, Rome, and Turin (Montagnani
et al. 2026). Despite this limitation, the study provides a
first overview of the presence and spatial distribution of
a subset of IAPs in the city of Campobasso, and lays the
groundwork for future comparative analyses across the
six Italian cities where data were collected simultaneously
using the same methodology.

Conclusions

Results highlight that, even in inland and medium-small
cities, the pool of investigated IAPs occurs and is either
invasive or potentially invasive. The prevalence of occur-
rences in roadside habitats and urban abandoned areas,
together with the close interface between urban, rural,
and semi-natural environments, makes the landscape po-
tentially permeable to the spread of these IAPs and may
facilitate the outward dispersal of these species from the
city toward areas of higher naturalness.

In the examined area, the South African *Senecio in-
aequidens* emerged as the most prevalent and sponta-
neously established IAP; this species can be harmful in
hill and mountain pastures, especially in a region where
livestock farming is still widespread and oriented toward
high-quality dairy production.

These findings underscore the importance of pre-
venting the spread of the studied IAPs into natural and
semi-natural environments and into the surrounding of
Natura 2000 sites, both near the city and across the re-
gion, through stakeholder engagement, periodic moni-
toring, and targeted containment or eradication measures
aimed at safeguarding conservation-relevant habitats and
grazed or mowed grasslands.

The use of the EUNIS classification can enhance the
comparability of data on invaded urban and natural habi-
tats, facilitating comparative analyses across biogeograph-

ical regions and cities of different sizes, thereby enabling
the identification of common, and consequently more
effective, guidelines for the monitoring, prevention, and
management of IAPs.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

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Author contributions

Marco Varricchione: Conceptualization, Data Curation, Formal
analysis, Investigation, Methodology, Validation, Visualization,
Writing – Original Draft, Writing – Review & Editing. Maria
Laura Carranza: Conceptualization, Funding acquisition, Project
administration, Writing – Review & Editing. Dario Ciarrella:
Data curation, Investigation, Writing – Review & Editing. Sandra
Citterio: Conceptualization, Funding acquisition, Methodology,
Project administration, Writing – Review & Editing. Maria Carla
de Francesco: Data curation, Investigation, Writing – Review &
Editing. Chiara Montagnani: Conceptualization, Funding acqui-
sition, Methodology, Project administration, Writing – Review &
Editing. Lucia Antonietta Santoianni: Data Curation, Formal anal-
ysis, Investigation, Validation, Writing – Original Draft, Writing
– Review & Editing. Angela Stanisci: Conceptualization, Data cu-
ration, Funding acquisition, Project administration, Supervision,
Validation, Writing – Original Draft, Writing – Review & Editing.

Author ORCIDs

Marco Varricchione  <https://orcid.org/0000-0003-4716-6609>
Maria Laura Carranza  <https://orcid.org/0000-0001-5753-890X>
Dario Ciarrella  <https://orcid.org/0000-0003-3646-0546>
Sandra Citterio  <https://orcid.org/0000-0001-5020-1095>
Maria Carla de Francesco  <https://orcid.org/0000-0002-5238-1154>

Chiara Montagnani  <https://orcid.org/0000-0003-2030-2535>
 Lucia Antonietta Santoianni  <https://orcid.org/0009-0008-3486-0769>
 Angela Stanisci  <https://orcid.org/0000-0002-5302-0932>

Data availability

The data underlying this study are available from the corresponding author upon request.

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Supplementary material 1

List of the 26 target Invasive Alien Plants species

Authors: Marco Varricchione, Maria Laura Carranza, Dario Ciarabella, Sandra Citterio, Maria Carla de Francesco, Chiara Montagnani, Lucia Antonietta Santoianni, Angela Stanisci

Data type: docx

Explanation note: List of the 26 target Invasive Alien Plants species (IAPs) along with the taxonomic family and growth form.

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Link: <https://doi.org/10.3897/ved.182200.suppl1>

Supplementary material 2

Percentage of the occurrences of recorded target Invasive Alien Species

Authors: Marco Varricchione, Maria Laura Carranza, Dario Ciarabella, Sandra Citterio, Maria Carla de Francesco, Chiara Montagnani, Lucia Antonietta Santoianni, Angela Stanisci

Data type: docx

Explanation note: Percentage of the occurrences of recorded target Invasive Alien Plant species (IAPs) and of only cultivated and spontaneous individual/population in each EUNIS Habitats (Chytrý et al. 2020; EEA 2025; D'Angeli et al. 2026).

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Link: <https://doi.org/10.3897/ved.182200.suppl2>

Supplementary material 3

Coverage (km²) of first-level EUNIS habitats and Coverage (%) of first-level EUNIS habitats

Authors: Marco Varricchione, Maria Laura Carranza, Dario Ciarabella, Sandra Citterio, Maria Carla de Francesco, Chiara Montagnani, Lucia Antonietta Santoianni, Angela Stanisci

Data type: docx

Explanation note: Coverage (km²) of first-level EUNIS habitats (Chytrý et al. 2020; EEA 2025; D'Angeli et al. 2026) in the four grid cell types. Coverage (%) of first-level EUNIS habitats (Chytrý et al. 2020; EEA 2025; D'Angeli et al. 2026) in the four grid cell types.

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Link: <https://doi.org/10.3897/ved.182200.suppl3>

Supplementary material 4

Distribution maps of the most frequent Invasive Alien Species

Authors: Marco Varricchione, Maria Laura Carranza, Dario Ciarabella, Sandra Citterio, Maria Carla de Francesco, Chiara Montagnani, Lucia Antonietta Santoianni, Angela Stanisci

Data type: docx

Explanation note: Distribution maps of the most frequent Invasive Alien Plant species (IAPs) found in Campobasso (*Ailanthus altissima*, *Prunus laurocerasus*, *Robinia pseudoacacia*, and *Senecio inaequidens*) in the four grid cell types.

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