

Plant traits in a 300-year-old urban forest: insights for plant conservation in compact cities

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Abstract

As urbanization accelerates worldwide, reconciling urban growth with biodiversity conservation has become increasingly urgent. Urban forests offer a promising solution by supporting biodiversity and mitigating the negative impacts of urbanization. Historic urban forests, such as the Royal Park of Portici (Naples, Italy), founded in 1738, offer a unique opportunity to assess the long-term contribution of these green spaces to urban biodiversity. In the present study we investigated the role of the Royal Park in supporting urban plant diversity, focusing on the functional traits of species that use the Royal Park as a refuge versus those that disperse into the surrounding urban matrix. We recorded vegetative, pollination and dispersal traits and tested if specific traits were associated with species found exclusively in the Royal Park or in both the Royal Park and urban matrix. The results showed that annual plants with generalist pollination and animal-mediated dispersal strategies thrive in the urban matrix, while perennial species with specialized pollination are restricted to less disturbed areas such as the Royal Park. Urban forests can serve as critical refugia for species and as species sources for nearby green spaces. To maximize their ecological function, efforts should prioritize improving connectivity, reducing environmental stress, and minimizing human disturbance, particularly for species with specific ecological requirements.

Key words: green space; plant traits; urban biodiversity; urban forest; urban planning

Introduction

As urbanization is currently the fastest-growing form of land use worldwide (Lin and Fuller 2013), there is an increasing need for sustainable urban planning based on a sound ecological knowledge of urban biodiversity, which is essential for maintaining ecosystem functions and improving human well-being (Sandifer et al. 2015, Taylor and Hochuli 2015, Reyes-Riveros et al. 2021, Pinto et al. 2022).

Across large urban areas, some are often defined as compact, namely a type of densely built-up area that leads to intensification of space use, higher residential density, centralization of services and scarcity of urban green spaces (hereafter UGS; Sushinsky et al. 2013, Balzan et al. 2021), which mostly include spaces to promote public use (e.g. public parks and urban forests) or small remnants of marginal land (e.g. traffic island flower beds). In compact cities, the ecological impacts of urbanization are locally intense and lead to the complete loss and fragmentation of natural and semi-natural habitats (Parris 2016) as they are replaced by impervious surfaces. In compact cities spaces for plant and animal species are usually very small, isolated and interspersed with an urban matrix of unsuitable habitats and physical barriers (built-up and paved surfaces; Melero et al. 2020). These act as filters and hinder the spread of species by reducing landscape connectivity (Sushinsky et al. 2013). Additionally, the

few remaining UGS of the compact cities are also exposed to high levels of environmental stress and human disturbance (Davies et al. 2008, Jenks and Jones 2010).

Among the environmental stressors and human disturbances associated with compact urban development, high heat retention has been shown to affect species through a warmer climate (urban heat island effect, Deilami et al. 2018). UGS tend to be drier, more nutrient-rich, and more alkaline due to the deposition of nutrients from the air (de Barros Ruas et al. 2022). They also have higher levels of localized disturbance due to high management intensity and human trampling (Liu et al. 2023). The unique environmental conditions that prevail in urban areas lead to a reduction in species richness and changes in their relative abundance (Knapp et al. 2017, Oliveira et al. 2020) which in turn can trigger changes in biotic interactions that lead to further species loss (Olden 2006, Baiser et al. 2012).

Nevertheless, UGS serve as refugia for species and facilitate ecological connectivity by enabling the movement of species through fragmented landscapes (Zhao et al. 2022, Lorenzato et al. 2024, Berger et al. 2024). In addition, UGS provide diverse Nature's Contributions to People (NCPs; Mattana et al. 2022) that are critical to human well-being by mitigating the effects of urban heat, reducing noise pollution, improving air quality and carbon sequestration and increasing aesthetic values, all of which contribute to healthier and more sustainable living (Godefroid and

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Koedam 2007, Lin and Fuller 2013, Evans et al. 2017, Threlfall et al. 2017, Filazzola et al. 2019). For all these reasons, UGS are increasingly recognized as a form of investment in Nature-Based Solutions (NBS) to address pressing global challenges such as biodiversity loss and the climate crisis (Nesshöver et al. 2017) and to meet human needs.

Among UGS, urban forests are advocated as NBS to improve urban biodiversity and mitigate the negative impacts of urbanization on human well-being (Threlfall et al. 2017, Filazzola et al. 2019). The concept of urban forest was first introduced in North America in 1894 (Coke 1894) and transferred to Europe in the 1980s (Konijnendijk et al. 2006). While the forested landscapes of earlier centuries often had utilitarian or aesthetic functions, today's urban forests are purposefully planned and managed to achieve specific ecological and social objectives. In the European context, this includes the integration of trees and wooded areas in different urban spaces such as parks, streets, private gardens and marginal land, to enhance biodiversity, provide ecosystem services and promote human well-being. Among the characteristics of urban forests, their age has been shown to play a crucial role in their current biodiversity and benefits to society (Nagendra and Gopal 2011). It has been shown that the older the urban forests are, the greater the biodiversity supported and thus the ecosystem services provided (Ma et al. 2023). In this context, historic urban forests can provide an opportunity to assess their long-term contribution to urban biodiversity. Unfortunately, there are few examples of historic urban forests that still exist today (Johnson and Handel 2016, Milecka et al. 2019).

The Royal Park of Portici, in southern Italy, on the coast of the Gulf of Naples, is one of them. The Royal Park was founded in 1738 and was originally intended for leisure and hunting and was located on the edge of the urban area. Over time, however, the Royal Park was integrated into the urban area as the city expanded, so that today it is considered part of the urban area and has evolved from a private recreational and hunting forest into a public space. Portici is a compact Mediterranean city that is closely linked to the large conurbation of Naples and has a high population density. The Royal Park of Portici is therefore a unique example of a long-established forest within a compact Mediterranean city, making it an ideal case study for investigating the contribution of an ancient urban forest to biodiversity.

In light of these considerations, the aim of this study was to evaluate the contribution of the Royal Park to biodiversity by analysing its role as a refuge for plant species and as a possible source of plant species for the UGS scattered in the urban matrix. We focused on plant species because they are the fundamental component of green spaces, as they determine their structural characteristics and are the basis for the conservation of animal species in the urban environment (Andrade et al. 2023). Nowadays, studies on plant species in urban areas are mainly assessed from a functional perspective to investigate either conservation (e.g. Hostetler et al. 2011) or effectiveness in providing ecosystem services (e.g. Andrade et al. 2023). Indeed, the analysis of functional traits has been shown to be better suited to capture species response to urbanization, while taxonomic diversity may mask general patterns of ecological strategies (Dolan et al. 2017, de Barros Ruas et al. 2022). In this study, we specifically compared the functional traits of plants exclusive to the Royal Park with those of species that live both outside and inside the Park, not only to determine the contribution of an ancient urban forest to plant diversity, but also to determine the functional identity of species that use the Royal Park as a refuge and those that can disperse in the UGS scattered in the built environment. In addition,

this study aims to provide insights that support the achievement of several UN Sustainable Development Goals (SDGs) by advancing knowledge and practical solutions, particularly for Good Health and Well-being (SDG 3), Sustainable Cities and Communities (SDG 11), Climate Action (SDG 13) and Life on Land (SDG 15).

Materials and methods

Study site

Portici is a municipality of Naples (southern Italy) which extends over an area of 4.60 km² (ISTAT 2012) from the Tyrrhenian Sea (Gulf of Naples) to the south-western slope of the Somma-Vesuvius volcano (90 metres above sea level). It is characterized by a Mediterranean climate (summer period of drought which lasts from late May to August). The warm season runs from June to September with average temperatures over 30°C in July and August. Average annual temperature of the last 16 years (2006–21) has been 17.2°C and average annual precipitation has been 847 mm/year. The rainiest month is November (average rainfall: 102 mm) and average of consecutive number of days without rain during the year is 19 (ISTAT 2023). With 55 765 inhabitants (ISTAT 2012) and 12 110 inhabitants/km², it is currently the second most densely populated municipality in Italy. The high population density is reflected in a very compact urban development, in which green spaces account for <2% of the area of the city. The most important green space of the city is the Royal Park of Portici, which extends upwards from the sea and is surrounded by built-up and paved surfaces. It is a historic example of an urban forest, as in 1738 the King of Naples, Charles of Bourbon, and his wife Maria Amelia decided to create it to enjoy the beauty of the natural landscape around their residence. Since the forest was intended to harbour natural vegetation, particularly for hunting, a large holm oak wood was planted by transporting the soil layer and by bringing in *Quercus ilex* L. plants from Sicily (Stinca and Motti 2009; Fig. 1a).

The Royal Park is currently divided into two parts: The upper part (36 ha, called 'Gussone Park'), managed by the University of Naples Federico II, and the lower part (almost 10 ha), managed by the local administration (Fig. 1b). It is dominated by a mixed Mediterranean holm oak forest (*Q. ilex*) with *Fraxinus ornus* L. and *Celtis australis* L. and a rich shrub layer characterised by *Sambucus nigra* L., *Laurus nobilis* L., *Rhamnus alaternus* L. and *Cytistus villosus* Pourr., as well as several clearings with herbaceous vegetation. The level of disturbance is very low, and management is minimal (mowing and tillage are rare) and mainly focussed on research activities.

In addition to the Royal Park, there are several other UGS in Portici, including public parks and private gardens. However, they are very small (on average <0.2 km²) and isolated in the urban matrix (average distance 400 m). These sites share common characteristics, such as the dominance of the herbaceous layer (although trees are often present) and a high level of anthropogenic disturbance in the form of management (frequent mowing) and trampling.

Data collection

At the beginning of 2023, we surveyed all UGS of Portici and identified those that were either free or accessible on request. In total, there were 16 out of 19 spaces that could be surveyed, in addition to the Royal Park (Fig. 2).

An inventory of spontaneously occurring angiosperm species was drawn up for each site as part of three surveys carried out at



Figure 1. Historic image showing the Royal Park in the first phase of its construction (a; ‘The slopes of Vesuvius from Portici with a view of the Bourbon Palace’, 1783–1784, by Giovan Battista Lusieri) and contemporary photograph of the Royal Park of Portici and the surrounding city (b; Google Earth).

each site between March and September 2023 in order to take into account species that develop at different times of the year. Pteridophytes and gymnosperms were excluded due to their rarity. Species nomenclature follows [Pignatti et al. \(2017\)](#) and sub-species were considered at the species level.

For each species recorded, we collected vegetative, pollination and dispersal traits ([Table 1](#)), considering two vegetative traits (i.e. life cycle, perennating organs), six pollination traits (i.e. pollination strategy, floral symmetry, floral size, floral tube length, inflorescence type, flower colour), and three dispersal traits (i.e. dispersal strategy, fruit size, seed size). The traits were collected from different sources (i.e. [Kühn et al. 2004](#), [Perez-Harguindeguy et al. 2013](#), [Stefanaki et al. 2015](#), [Pignatti et al. 2017](#); [Table 1](#)). The list of plant species, their occurrence in the Royal Park and in UGS in the surrounding urban matrix as well as their traits can be found in Supporting Data S1.

Data analysis

To investigate whether different plant traits were associated with species occurring exclusively in the Royal Park or with species occurring in both the Royal Park and in the UGS in the urban

matrix, we performed a Pearson’s Chi-square test of independence with simulated p-value (based on 9,999 randomizations) for each plant trait with Bonferroni-adjusted post hoc tests in case of the significance of the Chi-square tests (function `chisq.posthoc.test`, `chisq.posthoc.test` R package; [Beasley and Schumacker 1995](#), [Agresti 2007](#)). Considering that the Chi-Square test of independence is used to determine whether there is a significant association between two nominal (categorical) variables ([McHugh 2013](#)), we compared the frequency of each trait type and the two species groups, without performing intra-group comparisons. All statistical analyses were performed using R ([R Core Team 2024](#)).

Results

Overall, the list of recorded taxa included 395 species belonging to 254 genera and 81 families, all living in the Royal Park. Among them, 318 species (belonging to 222 genera and 75 families) occurred only in the Royal Park, while 77 species (belonging to 65 genera and 31 families) occurred both in the Royal Park and the UGS in the urban matrix. We did not consider plant species that



Figure 2. Map of the study site. The Royal Park of Portici is outlined in yellow, while the other surveyed UGS in the urban matrix are represented by blue dots.

occurred exclusively in the UGS in the urban matrix and not in the Royal Park (Supporting Data S1). Among the shared species, *Asteraceae* was the most represented family, followed by *Fabaceae*. In contrast, the species exclusive to the Royal Park were dominated by *Poaceae*, followed by *Fabaceae*, reflecting distinct taxonomic patterns between the two groups.

Among the 11 plant traits analysed, Pearson's Chi-square test of independence (with simulated p-values) showed significant variation in the frequency of occurrence for five traits between the two groups (i.e. species that occur exclusively in the Royal Park or with species that occur both in the Royal Park and in the UGS in the urban matrix): life cycle, perennating organs, floral symmetry, tube length, and dispersal strategy (Table 2).

Specifically, species with a perennial life cycle and species with hidden perennating organs were more frequently associated than expected (i.e. the observed frequencies are significantly higher than what would be predicted under the null hypothesis of independence in the Chi-square test) with plant species occurring exclusively in the Royal Park (Table 2; Fig. 3a and b), while annual plant species and plant species producing seeds as perennating organs were more frequently than expected associated with plant species that occur both in the Royal Park and in the UGS in the urban matrix (Table 2; Fig. 3a and b). For pollination traits, plant species with flowers exhibiting bilateral symmetry and a long corolla tube were associated more frequently than expected with plant species occurring exclusively in the Royal Park (Table 2; Fig. 3c and d), while plant species with flowers exhibiting radial symmetry were associated more frequently than expected with plant species that occur in both the Royal Park and the UGS in the urban matrix (Table 2; Fig. 3c). Finally,

for dispersal strategies, epizoochory was associated more frequently than expected with plant species that occur both in the Royal Park and in the UGS in the urban matrix (Table 2; Fig. 3e).

Among the plant species present both in the Royal Park and in the UGS in the urban matrix, *Daucus carota* L., *Galium aparine* L., *Torilis arvensis* (Huds.) Link, *Tribulus terrestris* L., and *Urospermum picroides* (L.) Scop. ex F.W.Schmidt exhibited a combination of plant traits associated with plants that can disperse in the urban matrix and establish in UGS, i.e. annual plants with seeds as perennating organs, with flowers showing radial symmetry and a short corolla tube, and epizoochory as a dispersal strategy. Conversely, among plant species exclusive to the Royal Park and showing the combination of plant traits less adapted to the urban environment (i.e. perennials with hidden perennating organs and flowers with bilateral symmetry and long corolla tube) were *Anacamptis coriophora* (L.) R.M.Bateman, Pridgeon & M.W.Chase, *A. morio* (L.) R.M.Bateman, Pridgeon & M.W.Chase, *Arum italicum* Mill., *Epipactis microphylla* (Ehrh.) Sw., *Limodorum abortivum* (L.) Sw., *Spiranthes spiralis* (L.) Chevall and *Serapias lingua* L.

Discussion

The differences in plant functional traits between species exclusive to the Royal Park and those also occurring in the UGS in the urban matrix indicate a strong ecological segregation driven by urbanization. The two groups differed not only in species composition but also in functional strategies, indicating different ecological filters operating in the two environments. Only 19.5% of the total species pool was shared between the Royal Park and the UGS in the urban matrix, and these shared species mostly

Table 1. Traits used to characterize the plant species found in the study site.^a

Trait category	Trait type	Traits levels	Description	References
Vegetative traits	Life cycle	Annual/Biennial	Plant dies at the end of its first growing season after producing seed/or grows vegetatively the first season, then flowers in the second to produce seed.	Raunkiaer 1934, Ellenberg and Müller-Dombois 1967, Whittaker 1975, Klotz et al. 2002, Perez-Harguindeguy et al. 2013, Pignatti et al. 2017
		Perennial	The individual survives for at least three growing seasons.	
		Hidden	Perennating tissue under the ground surface (e.g. bulbs, bulbils)	
	Perennating organs (relation of the perennating tissue to the ground surface)	Basal	Perennating tissue on the ground surface (0–2 cm)	
		Exposed	Perennating tissue above the surface	
Pollination traits	Pollination strategy	Seeds	Seeds as perennating tissue	Petanidou 1991, Klotz et al. 2002, Petanidou and Lamborn 2005, Stefanaki et al. 2015, Pignatti et al. 2017, pers. obs.
		Entomophily	Plants pollinated by insects	
		Anemophily	Plants pollinated by wind	
		Mixed strategy	–	
	Floral symmetry	Radial	Several axes of symmetry	
		Bilateral	One ax of symmetry	
	Floral size	Small	<2 cm	
		Medium	2–10 cm	
		Large	>10 cm	
	Tube length	Short	<4 mm	
		Medium	4–10 mm	
		Long	>10 mm	
	Inflorescence type	Isolated flower	Any type of inflorescence with up to five concurrently functional (open) flowers	
		Spherical inflor.	Aggregations of flowers arising on a flat or spherical surface of the inflorescence (heads, umbels, corymbs)	
		Cylindrical inflor.	Aggregation of flowers arising along a cylindrical surface of the inflorescence (spikes, racemes, panicles)	
Flower colour	White	Dominant colour of the corolla (for each single colour variable)		
	Blue			
	Red			
	Yellow			
	Green			
Dispersal traits	Dispersal strategy	Double coulored	Seed dispersed by wind or without external vectors	Klotz et al. 2002, Pignatti et al. 2017, pers. obs.
		Anemo/Autochory		
		Epizoochory		
	Endozoochory	Seeds dispersed by animals through ingestion and subsequent defecation		
		Fruit size	Small	
	Seed size	Medium	5–20 mm	
		Large	>20 mm	
		Small	<2 mm	
		Medium	2–10 mm	
	Large	>10 mm		

^a The size classes of seeds were selected after a field survey to determine the minimum, maximum and average sizes from which we formed the categories. The assigned value denotes the diameter in the case of circular shapes, the length in the case of elongated shapes and the average between length and width when seeds and fruits were irregular or different from the previous ones.

exhibited traits indicative of ecological generalization, such as annual or biennial life cycles, zoochorous dispersal mechanisms and generalist pollination systems. In contrast, species restricted to the Royal Park were mainly characterized by perennial life cycles, hidden perennating organs (e.g. rhizomes, bulbs), and specialized pollination strategies, reflecting adaptation to more stable and less disturbed conditions. The observed trait patterns support the interpretation that urbanization acts as a selective

force that promotes the persistence of species adapted to disturbance, while filtering out those that require long-term habitat continuity.

UGS in the urban matrix are generally characterized by a high level of human disturbance, which can occur regularly in the form of management (Paudel and States 2023) and/or short-term and occasional trampling (Pescott and Stewart 2014). Human disturbance represents a filtering factor that can select species

according to their functional traits (Khan et al. 2023). Annual species with high growth rates have been shown to perform better under human disturbance as they can complete their life cycle between disturbance events. In addition, in the Mediterranean climate most of the precipitation falls in winter and the summers have little or no rainfall. Vegetation regularly experiences both seasonal and inter-annual droughts, which are exacerbated by impervious urban surfaces (Miller et al. 2022). Drought resistance strategies in plants include the annual life cycle, because species spend the drought period as seed rather than as adult organisms. For annual plants that rely on animal pollination, ensuring

pollinator visitation is therefore crucial. In highly disturbed urban areas, this can be best achieved by species with flowers having a high degree of generalization for different pollinator species and guilds. Such generalization is often revealed by the floral morphology, where open disc flowers are accessible to a wide range of pollinators (Westerkamp and Classen-Bockhoff 2007), consequently increasing the likelihood of pollination events. In urban environments, this high degree of generalization is even more important as both plant and pollinator species are selectively filtered based on their life history traits, resulting in less predictable pollination visits (Theodorou et al. 2020, Gathof et al. 2022).

Interestingly, among dispersal strategies, epizoochory (i.e. involuntary dispersal mediated by animals via the body surface) was significantly associated with plant species that can disperse in the urban matrix and establish in UGS. This is in some ways surprising, as the dispersal processes of animal-dependent plants are thought to be disproportionately affected by urbanization, as many animals avoid cities or restrict their movements within the urban environment (Gelmi-Candusso and Hämäläinen 2019). However, this dispersal strategy also includes human-mediated dispersal, which is an important mechanism in urban environments (Czarnecka et al. 2013). In comparison with the urban matrix, the Royal Park is relatively little visited by humans. Surely human-mediated seed dispersal is a ubiquitous phenomenon in cities (Bullock et al. 2018) and, according to our results, perhaps the most important factor for the connectivity of green spaces in the urban environment.

Table 2. Results of Pearson's Chi-square test of independence with simulated P-value (based on 9999 randomizations) to test the association between the frequency of each trait in the two groups of species. Bold indicates significant results.

Trait group	Trait	Chi Square statistic	d.f.	P-value
Vegetative traits	Life cycle	7.441	1	0.006
	Perennating organs	18.344	3	<0.001
Pollination traits	Pollination strategy	0.695	2	0.706
	Floral symmetry	7.636	1	0.005
	Floral size	3.928	2	0.143
	Tube length	7.186	2	0.027
	Inflorescence type	3.482	2	0.175
	Flower colour	4.765	5	0.445
Dispersal traits	Dispersal strategy	13.209	2	0.001
	Fruit size	1.065	2	0.587
	Seed size	3.365	2	0.185

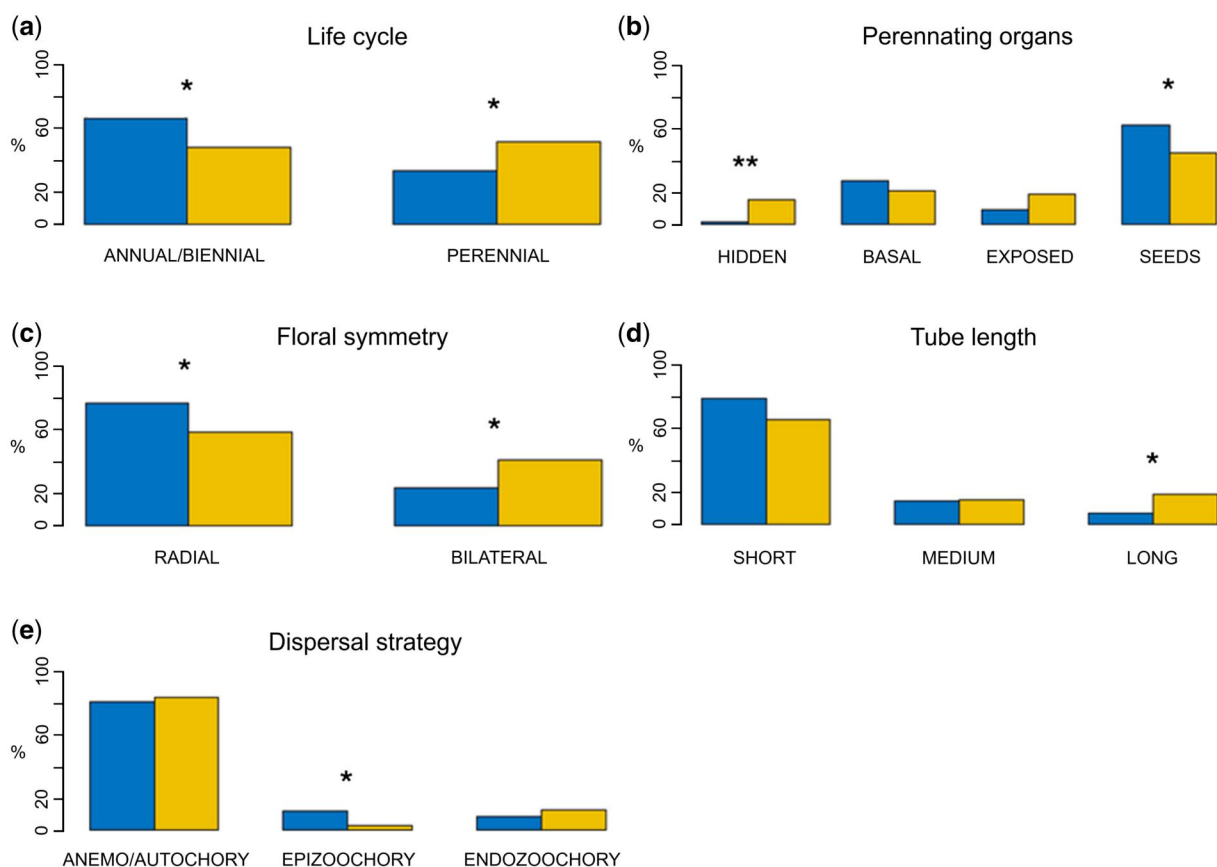


Figure 3. Proportion of plant species per trait within each of the two analysed groups. Trait types displayed are: (a) life cycle, (b) perennating organs, (c) floral symmetry, (d) tube length, and (e) dispersal strategy. Yellow bars represent plant species occurring exclusively in the Royal Park, while blue bars represent plant species that occurred both in the Royal Park and in the UGS in the urban matrix. Significant associations are marked with an asterisk for a P-value <.05 and with two asterisks for a P-value <.01.

Conversely, plant species that are exclusive to Royal Park have functional traits that are associated with stable environmental conditions. These exclusive species are mainly perennial plants with hidden perennating organs (e.g. bulbs). Although such functional type of plants can also thrive in highly disturbed habitats (Del Vecchio et al. 2016), they are particularly common in old forests such as those in the Royal Park (Wulf 2003, Jabs-Sobocińska et al. 2022). In our study, their widespread absence in the UGS in the urban matrix is probably due to their limited dispersal ability and low seed bank persistence (Jabs-Sobocińska et al. 2022), which prevents their return to newly established UGS. In addition, plant species exclusive to the Royal Park showed more than expected flowers with bilateral symmetry and/or a very deep corolla (e.g. tubular or bell-shaped flowers). Complex floral traits, such as bilateral symmetry and long corolla tubes, often correspond to specialized pollination strategies. These specialized plants usually require very evolved pollinators that can handle flowers with complex morphology, such as bumblebees, which are among the species most affected by urbanization (Theodorou et al. 2020). Their absence may therefore result in specialized plants being unable to maintain their populations in UGS exposed to high levels of environmental stress and human disturbance, ultimately highlighting potential indirect effects of urbanization on the pool of plant species that can thrive in UGS.

Functional diversity of plants is associated with the provision of more ecosystem services and thus with a better quality of life for citizens (Díaz et al. 2007). Species with functional traits that are better adapted to urbanization, such as annual plants with generalist pollination and human-mediated dispersal, should be favoured in the creation of self-sustaining UGS, because they are less affected by urbanization. On the other hand, species with functional traits less adapted to urbanization might need to be supported to improve the functional diversity of plants in the urban environment. To improve the functional diversity of plants in compact cities, environmental conditions must be created that meet the physiological and ecological requirements of plant species that are more vulnerable to environmental stress and human disturbance associated with the urban environment. This could be achieved through the planting of urban forests where environmental stress and human disturbance should be minimised (such as the Royal Park of Portici).

Urban forests are an effective solution for conserving biodiversity in compact cities and mitigating the effects of dense urban development (Threlfall et al. 2017). Our findings suggest that historic parks can serve as refugia for species of conservation concern. In Portici, 318 of the 395 species identified occurred exclusively in the Royal Park, including rare or endangered species (Stinca and Motti 2009), such as *Serapias lingua* L., *Allium neapolitanum* Cirillo, *A. roseum* L., *A. triquetrum* L., *Ampelodesmos mauritanicus* (Poir.) T.Durand & Schinz, and *Bellevallia romana* (L.) Sweet., which are included in national Red Lists (Glasnović et al. 2024, Lončarević et al. 2024). However, the limited space and poor ecological connectivity with the urban matrix limit the role of the Royal Park in promoting biodiversity in disturbed urban areas. Less than 20% of the species in the Royal Park were shared with other UGS, mostly species that are widespread and have traits typical of species found in other compact cities (Celesti-Grapow and Blasi 1998, de Barros Ruas et al. 2022), reflecting the global trend towards biotic homogenization in cities (McKinney 2006, Delgado-Baquerizo et al. 2021, Lokatis and Jeschke 2022).

In conclusion, urban forests can serve not only as refugia for species with specific ecological needs, but also as a source of

species for surrounding UGS in the urban matrix. However, to maximize their ecological function as a source of species, it is important to improve connectivity with the urban matrix and facilitate the dispersal and establishment of species throughout the city. This requires minimizing environmental stressors and human disturbance, especially to reduce the impact on plant species with specific ecological requirements. Maximizing the ecological function of UGS would in turn also improve ecosystem services, especially those related to biodiversity, such as pollination, climate regulation and aesthetic and recreational value. Integrating ecosystem services into urban planning can ultimately make cities more sustainable and support the achievement of the UN SDGs Good Health and Well-being (SDG 3), Sustainable Cities and Communities (SDG 11), Climate Action (SDG 13) and Life on Land (SDG 15).

Author contributions

Rosario Rummo (Conceptualization [supporting], Formal analysis [equal], Investigation [lead], Writing—original draft [equal]), Edy Fantinato (Conceptualization [equal], Formal analysis [lead], Supervision [equal], Writing—original draft [equal]), and Giovanna Aronne (Conceptualization [lead], Investigation [equal], Supervision [equal], Writing—original draft [equal])

Supplementary data

Supplementary data are available at JUECOL online.

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Data availability

Data available within the article and in [Supplementary Data 1](#).

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