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Enhancing pollination ecosystem service in urban green areas: An opportunity for the conservation of pollinators

Joana Llodrà-Llabrés [a], Paloma Cariñanos [b,c,*]

[a] Department of Ecology. University of Granada, Spain
[b] Department of Botany. University of Granada, Spain
[c] Andalusian Institute for Earth System Research (IISTA-CEAMA), University of Granada, Spain

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ABSTRACT

The rapid growing urbanization is one of the main threats to urban biodiversity and the ecosystem services (ES) that they provide. Pollination is one of the most affected ES in urban areas mainly due to the decline in urban green areas (UGAs) and other factors derived from urbanization itself. Considering this and the already existing global pollinator crisis, the aim of this work is the evaluation of urban green infrastructure as an opportunity for pollinator conservation. For that purpose, the ornamental vegetation of a medium-sized Mediterranean city (Granada, south-eastern Spain) was determined. The floral origin, phenology and floral traits of the conforming species and the pollinator species that they attract were analysed. Additionally, NMDS analysis were performed in order to determine if the "Pollination Syndromes" are a useful tool to actually predict the pollinator group attracted to a certain plant species. It was found that UGAs have huge potential for pollinator conservation as the major part of its ornamental species have an entomophilic pollination strategy. However, there is an imbalance in the availability of flower resources throughout the year. Hence, the addition of species flowering out of the main flowering season would be advisable in order to get a continuous supply of floral resources for pollinators. A current disproportion in the potentially attracted pollinator groups was also found out, being bees the predominantly attracted ones. However, results showed that the "Pollination Syndromes" are a tool with limitations at the moment and needs to be used with considerations. Thus, the specific plant-pollinator relationship should be determined through field work in each case-study. Further studies considering key factors such as urban connectivity and fragmentation would be desirable to ensure a comprehensive management for urban pollinators.

1. Introduction

Population is concentrating in cities at an accelerated rate. In 2018, 55.3 % of the world's human population lived in cities, and by 2030 it is expected to raise by up to 60 %, as well as an expansion of urban areas and an increase in the number of megacities during this period (United Nations, 2019). Urban development requires an increase in land use in urban and peri-urban areas, degrading green areas and affecting ecosystem quality and residents' life quality (Breuste et al., 2015). Rapid urban growth is a threat to all living beings that inhabit it as the original ecosystem and its particular conditions are modified (McKinney, 2008).

Urban ecosystems represent less than 3 % of the land surface. However, it has global impacts through emissions accumulation and resources use and demand (Grimm et al., 2008). Resources used in cities are, in major part, produced outside them as their Ecosystem Services (ES) production is limited despite a high demand for them (Balzan et al., 2018). This implies that a certain connection between cities and natural ecosystems must be maintained (Gómez-Baggethun et al., 2013). In this situation, urban green infrastructure (UGI), defined as a strategically planned network of natural and semi-natural areas, together with other environmental elements designed and managed with the aim of providing ES and increasing connectivity between urban and peri-urban environments is paramount (European Comission, 2013). UGI is mainly formed by any urban green areas (UGAs), such as parks, forests, tree-lined streets, green roofs and cemeteries (Breuste et al., 2015). An increase in UGI would increase the provision of ES in cities (Balzan et al., 2018), such as air quality, water and local climate regulation (Millenium Ecosystem Assessment, 2005) and the maintenance of urban

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* Corresponding author at: Department of Botany, University of Granada, Spain.
E-mail addresses: joanallodra@ugr.es (J. Llodrà-Llabrés), palomacg@ugr.es (P. Cariñanos).

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biodiversity (Bennett and Lovell, 2019). Urban residents especially demand cultural ES to the detriment of provisioning and regulating ones (Herrero-Jáuregui et al., 2019), despite the latter being particularly important.

Pollination is a regulation ES that performs essential functions resulting in a benefit to humans, as it produces essential resources for them and contributes to their well-being. Animals are the pollinating agent for almost 90 % of wild floral species and 35 % of the world's agricultural production depends on it, with a huge associated market value (IPBES, 2016). However, pollination is one of the most harmed ES due to urbanization, as insect and plant communities and their interactions are modified (Theodorou et al., 2017). The altered biotic and abiotic conditions in the urban microclimate compared to the surrounding non-urbanised area (Williams et al., 2015), together with the deliberate introduction of new species (Williams et al., 2009), forest loss and soil sealing derived from urban sprawl (Ferreira et al., 2020), result in a decrease in plant resources altering biotic interactions, such as the pollination process. Worldwide, pollinator abundance is declining (Millenium Ecosystem Assessment, 2005) and 16.5 % of vertebrate pollinators are threatened with extinction and up to 40% of bees, the most abundant pollinator group, are threatened (IPBES, 2016). Although not all pollinator groups are affected uniformly, general effects of urbanization on certain insect behavioral traits have been identified (Wenzel et al., 2020).

Pollinators are motile organisms that depend on local conditions but also on the conditions of their full dispersion area (Kremen et al., 2007). These conditions vary widely at very small scales in cities (Matteson et al., 2013) due to their heterogeneity in floral resources (Baldock et al., 2019; Matteson et al., 2013), ground cover and associated insect communities (Matteson et al., 2013).

The main threats to pollinators currently include: (a) pesticide use (Menon and Mohanraj, 2018), (b) increasing parasitism due to urbanization on *Bombus* spp. (Theodorou et al., 2016) and *Apis* spp. (Fortel et al., 2014), (c) climate change that affects insects and host plants phenology, although the effect magnitude depends on the thermal tolerance of each taxon (Baldock, 2020), and (d) urbanization causing habitat loss and fragmentation, introduction of exotic species, particular climatic conditions and urban pollution (Harrison and Winfree, 2015). Urban ecosystems represent homogenizing and selective forces of biotic communities, altering the behaviour, physiology and morphology of organisms, hence those species best adapted to these conditions become predominant (Grimm et al., 2008).

Urbanization affects urban vegetation, altering plant-pollinator interactions. Urban flora species more resistant and tolerant to urban environmental stress become more abundant and the floral community standardizes (Williams et al., 2015). The most common species in the urban environment are spontaneously growing herbaceous plants in unmanaged sites, and ornamentals, mainly exotics (Lowenstein and Minor, 2016). The floral community ultimately found in a city depends on four main filters defined in Williams et al. (2009): (a) habitat transformation and (b) fragmentation, (c) particular conditions with high pollution and urban heat island (UHI) effect, and (d) human preferences whereby species with attributes considered as attractive are preferred. Certain characteristics are over-represented in the urban environment, such as autogamous and self-pollinating species and unspecialized floral morphotypes (Desaegher et al., 2019), mainly with large flowers, as their pollination is favoured in the urban ecosystem (Irwin et al., 2018). Urban plants phenology may also be impacted by urbanization. The flowering period is extended as floral senescence is delayed (Li et al., 2020). However, the magnitude of this effect will vary according to (a) the flowering time; (b) growth form, with spring-flowering and woody perennial species being more affected than summer-flowering and herbaceous annual ones (Li et al., 2020); and (c) the climate of the region, with these changes being more noticeable in cold climate regions than in those with temperate climates (Li et al., 2019). The location of the vegetation in cities is also altered, as anthropogenic activities in different UGAs benefit some species somewhere while excluding them somewhere else (Piano et al., 2020), making selective forces in cities non-random (Williams et al., 2009).

In the face of the accelerated decline in pollinators abundance and diversity and growth of urban areas, cities should be considered as an opportunity for pollinator conservation, as the resources required for pollinators are not necessarily reduced (Lowenstein et al., 2014). UGAs present a beneficial vegetation concentration for pollinators abundance and diversity and their pollination function, although their spatial disposition is a key factor for pollinators movement, diversity and density (Hennig and Ghazoul, 2012).

The aim of this work is to evaluate the potential of urban green spaces for the conservation and attraction of pollinators and for the improvement of the Pollination Ecosystem Service. This study was carried out in a Mediterranean medium-sized city, which will allow both the analysis of the pollination attributes of a large number of plant species distributed throughout this bioclimatic region, as well as the suitable measures in UGAs aimed at the conservation of pollinator biodiversity in urban environments with similar environmental characteristics.

2. Methodology

2.1. Description of the study area

The study was carried out in the city of Granada (Andalusia, Spain), located in the southeast of the Iberian Peninsula (37° 11 'N, 3° 35' W; 738 m a.s.l.) (Fig. 1) occupying a surface area of 88.02 km^2 and with a population of 233,648 inhabitants (National Statistics Institute, 2020). Granada has a continental Mediterranean climate with an average annual temperature of 15.1 °C and average annual precipitation of 357 mm for the period 1971–2000 (AEMET, 2018).

The city of Granada has high levels of atmospheric pollution, exceeding the limits established by the European Directive 2008/50/CE for atmospheric pollutants of particulate matter with an aerodynamic diameter under 10 μm (PM_{10}), NO_2 and ozone. The main sources of pollutant particle emissions in Granada are traffic and heating systems, especially in winter and autumn. The topography of the city favors thermal inversions and weak winds that favor the accumulation of atmospheric pollutants (Casquero-Vera et al., 2019).

The city of Granada has 363 green areas (300 with a surface area under 5000 m^2 and 63 with a greater area) covering a total area of 1141,884.7 m^2, which represents a surface area of 4.9 m^2 of green areas per inhabitant (Delgado-Capel and Cariñanos, 2020). For this study, 40 UGAs distributed throughout the urban matrix have been considered. The list of plant species that grow in them was obtained from the inventories available from the Granada City Council's Park and Garden Service (https://www.granada.org/inet/warboles.nsf), as well as on-site visits made to some spaces for which no prior information was available as they have been created recently. According to the most recent data from the Granada City Council's Park and Garden Service, there are approximately 40,000 trees, among which a few ones stand out: *Platanus* x *hispanica* Mill. ex Münchh, *Ulmus* spp., *Acer* spp., *Cupressus* spp., *Citrus* x *aurantium* L., *Populus* spp., *Phoenix* spp., *Washingtonia filifera* (Lindl.) H. Wendl., *Robinia pseudoacacia* L., *Melia azederach* L. and *Ligustrum* spp. (Cariñanos et al., 2016, 2020). The main attributes of the UGAs considered are presented in Table 1.

The particular climatic characteristics of the urban area of Granada may favor the presence of shrub and herbaceous plants of diverse origin and hardiness zones (Cariñanos et al., 2016), both in public and private parks and gardens. In addition, the peri-urban environment of the city has two ecosystems of interest for this study: La Vega, in the south and southwest of the city, in which multifunctional crops systems are carried out (Puente Asuero, 2013), and the Sierra Nevada National Park, an outstanding biodiversity hot-spot due to the important floristic diversity and vegetation units because of its particular bioclimatic and biogeographic characteristics (Lorite, 2001).

Fig. 1. Geographic location of Granada (Andalucia, Spain).

Table 1
List of UGA of Granada analyzed in the current study with their respective attributes.

Urban Green Area	Typology of green infrastructure	Number of plant species	Surface (m^2)	Urban Green Area	Typology of green infrastructure	Number of plant species	Surface (m^2)
Avenida Constitución	Tree-lined street	21	11695	Joaquina Eguaras	Garden	18	7110
Calle Antonio Dalmases	Tree-lined street	1	3111	Lancha del Genil	Garden	3	1500
Calle Doctor López Font	Tree-lined street	10	1750	Mesón del Toledano	Tree-lined street	1	300
Calle Montijo Squares	Tree-lined street	8	838	Parque Bola de Oro	Park	4	5913
Calle Peñuelas	Tree-lined street	1	780	Parque García Lorca	Park	30	71500
Calle Profesor Dalmau	Tree-lined street	2	3945	Parque García-Arrabal	Park	35	32070
Campo del Príncipe	Park	20	4855	Plaza Albert Einstein	Square	3	11600
Carmen de los Mártires	Garden	95	70000	Plaza Bib-Rambla	Square	2	3730
Cuarto Real de Santo Domingo	Historical garden	38	7455	Plaza de Fontiveros	Square	21	451
El Barranquillo	Huerto urbano	8	1000	Plaza de Gracia	Square	12	1674
Emperador Carlos V	Garden	10	20000	Plaza de la Concordia	Square	16	5856
Facultad de Ciencias	Garden	80	44470	Plaza de la Trinidad	Square	18	3377
Fuente Nueva	Garden	51	19600	Plaza de los Lobos	Square	15	2207
Glorieta Arabial	Flowerbed	18	3160	Plaza de Toros	Square	2	19336
Gran Vía	Tree-lined street	1 predominant	12186	Plaza del Campillo	Square	1	6000
Hospital Real	Garden	55	15050	Plaza Emilio Herrera	Square	4	1000
Iznajar Almanjayar	Park	3	1285	Plaza Isabel la Católica	Square	3	1238
Jardín Botánico	Botanical garden	42	2850	Plaza Nueva	Square	5	3534
Jardines del Salón y Bomba	Garden	62	8085	Rotonda de Neptuno	Flowerbed	18	7900
Jardines del Triunfo	Garden	18	15000	Tierno Galván	Garden	6	1000

2.2. Characterization of plant traits

For each plant species present in the UGAs of the city, the region of origin, the flowering period and the pollination strategy (anemophily, entomophily or ambophily, that is, the simultaneous occurrence of both strategies) were determined (Faegri and van der Pijl, 1979). As insects are the most important pollinator group in the region of Spain (Rosado Gordón et al., 2013), this study will focus on biotic pollination, mainly entomophily. Hence, for insect-attracting species (enthomophilous and ambophilous) the floral syndrome and legitimate pollinator group were also determined through specialized references (Fenster et al., 2004; Rosas-Guerrero et al., 2014).

Pollinators are divided into functional groups being each one attracted by a set of specific combinations of floral characteristics. Each of these attracting combinations is known as "pollination syndrome" (Fenster et al., 2004). Based on the classification established by Faegri and van der Pijl (1979) there are 11 pollination syndromes (Dellinger, 2020) determined, mainly, by the time of floral anthesis, presence and type of smell, presence of nectar, color, size and floral morphology (see Appendix Tab. S1).

The floral characters here determined were shape, symmetry (actinomorphic or zygomorphic) and floral orientation (pendent, upright or horizontal), anther position (enclosed or exposed), anthesis time (diurnal or nocturnal), presence or absence of smell, type of smell (sweet, fruity, fresh, musky, sour or decaying), floral color, presence or absence of nectar, volume of nectar and presence of nectar lines on the corolla. The selection of these characters was based on the methodology used by Ollerton et al. (2009) skipping the character of the floral size and width and length of the floral tube, since the individuals present in cities are usually ornamental varieties with chosen attributes (Garbuzov and Ratnieks, 2014).

2.3. Statistical analysis

The statistical analysis was divided into two parts: (1) detection of overlaps between the theoretical attracting floral syndromes for each pollinator group, and (2) validation of the coincidence between referenced described pollinators and the expected ones from flower syndromes for each plant species. The ultimate goal of the second part is to find out if a plant species can be chosen based on its floral syndromes when it is needed to attract a concrete pollinator group.

The statistical analysis was carried out using a table of absence (indicated with a 0) and presence (indicated with a 1) of each floral character obtaining the different combinations that make up the theoretical pollination syndromes of each pollinator group. An NMDS (Non-Metric Multidimensional Scaling) statistical analysis was performed using the Sorensen index based on the Bray-Curtis distance (Ollerton et al., 2009). Consecutive analyzes were conducted with between 2 and 4 dimensions, choosing the one with the lowest stress value, thus achieving a better graphic representation. The analysis was performed using functions of the vegan package of the Rstudio 1.2.5033 software. Pollination syndromes of bats and small mammals were not considered in the analysis, as they are non-existent pollinators in the study area.

For the second part of the analysis, only those species with existing referenced information on their pollinators and floral syndromes were taken into account. Ten NMDS analysis were carried out, one for each group of plant species pollinated by the same pollinator group. A table with the characters of the analyzed species was created following the same pattern as in the first part. For each species one row was added for each existing possible combination between characters. When information about a character was missing, it was indicated as absence (0), since the NMDS analysis does not allow the presence of blank spaces. In order to reduce the sample size of each analysis, the group of flies was divided into flies and syrphids, as syrphids have a prominent role as pollinators within the dipterans and among non-bee insects (Doyle et al., 2020). The group of bees was divided into bees and bumblebees, since both groups present behavioral differences both in the buzzing properties that facilitate pollen release (De Luca et al., 2014), and in the existence of marked species-specific components that some flowers present to increase the ratio of stigmal contact (Woodcock et al., 2013). The group of bees includes solitary and honey bees. Although solitary bees have been widely reported to have a higher pollination efficiency than honey bees, their visitation rate is generally lower than that of the latter ones (Eeraerts et al., 2020), which would outweigh their higher pollination performance. If a species was observed to have more than one pollinator group, it was considered in as many groups as reported pollinators.

3. Results and discussion

3.1. Floral composition of public UGA of Granada

A total of 40 green areas in Granada (listed in Table S1) were considered for this study. Considered green areas cover an area of 434,461 m^2, 38.0 % of the city surface was analysed. Based on the information provided by the Granada City Council's Park and Garden Service and the on-site inventories, a list of 215 plant species was obtained. These species belong to 83 botanical families, with the families Rosaceae, Cupressaceae, Leguminosae and Pinaceae being the best represented with 9.77 %, 7.44 %, 6.51 % and 6.01 %, respectively.

Regarding the pollination strategy, it was determined that 58.60% of the species (126 species) are entomophilous; 34.42 % of the species (74 species), anemophilous; and 6.97 % of the species (15 species), ambophilous, which means that 65.57 % of the species are a potential resource for pollinators. The families with the highest number of entomophilous species are Rosaceae, Leguminosae, Caprifoliaceae and Labiatae, with 16.67 %, 10.32 %, 4.76 % and 3.97 %, respectively. Among the species with anemophilous pollination, the families with the highest number of species are Cupressaceae, Pinaceae, Salicaceae and Fagaceae, with 21.62 %; 17.57 %; 8.11 % and 5.41 % of the total number of species with this pollination strategy.

Some studies have revealed that the main function of UGAs in Granada is the improvement of citizens well-being by providing spaces for socialising, relaxing or exercising (Adinolfi et al., 2014), which is corroborated by the main families present in such areas, with a high aesthetic value usually incorporated as ornamentals in flower beds, low hedges or thematic collections (i.e. rose gardens, aromatic plants) (Franco et al., 2006). In contrast, tree-lined streets are often dominated by gymnosperms or broad-leaved deciduous plants with high ecological plasticity and adapted to urban microclimate conditions (Pauleit et al., 2002). Although there may be diversity in the pollination strategy of this group, anemophily is the main strategy of such over-represented genera in urban areas such as *Platanus, Cupressus, Quercus, Acer* or *Pinus* (Pauleit et al., 2002). Their role as pollination ES suppliers is minimised, being more relevant their disservice as sources of allergen emission (Cariñanos et al., 2021, 2016).

Besides ornamental species purposely introduced in cities, spontaneously growing vegetation, which can represent up to 67 % of the vegetation present in Mediterranean cities (Salinitro et al., 2018), should be also considered as potential resources for pollinators (Lowenstein and Minor, 2016). Unfortunately, it is often scarcely considered. In Granada, only one district has been examined for spontaneous vegetation: the Albaycín district. 161 plant taxa belonging to 48 botanical families were present, being the Compositae family the best represented (unpublished data), coinciding with the predominant spontaneous vegetation of other European cities (Salinitro et al., 2018). The families Poaceae, Cruciferae and Leguminosae are also widely represented in the Albaycín (unpublished data), which are important families among the Mediterranean flora (Bosch et al., 1997).

Although the public urban green surface is the main resource for pollinators to consider, in the case of this ES of pollination private green spaces are also of importance (Baldock, 2020) and should be considered.

Often, the study of the plant composition in these spaces is difficult. However, in Granada, it is worth noting the presence of a type of traditional dwelling known as "Carmen" (from the Arabic karm, "vineyard"), of Nazari origin, where a green space, garden and orchard are annexed to the house (Seco de Lucena Paredes, 1992). They usually contain a panel plant species linked to the Hispano-Muslim garden tradition (Tito Rojo and Casares Porcel, 2011), with abundance of aromatic species such as jasmine (*Jasminum* spp.), the night-heron (*Cestrum nocturnum*) or the myrtle (*Myrtus communis*), species with showy flowers, fruit trees for food production, and species that attract fauna (Kugel, 2001).

Regarding the origin of the ornamental species of Granada, 81.72 % of them are original from only four geographical areas, three of them of remote origin: Asian, American and Euro-Siberian regions, with 25.48 %, 15.87 % and 15.38 %, respectively;one native: Mediterranean region, for 22.12 % of the species.

The percentage of alien ornamental species present in Granada and their predominant origins are in line with that of other European cities where it exceeds 50 % (Salinitro et al., 2018; Staffolani et al., 2011). However, alien species may potentially behave as invasive species and threaten native ecosystems. In European cities, the invasive potential of species varies according to the geographical origin, being highest in European species, followed by American and, finally, Asian species (Ceplová et al., 2017). Regarding this, today it is possible to know the invasiveness potential of many ornamental plants so that they can be avoided or controlled if they are already present (Bayón and Vilá, 2019). In this way, and with adequate handling and management techniques, alien species offer an opportunity to provide additional floral resources during reduced flowering periods of native species (Salisbury et al., 2015).

The flowering period of the analyzed species is shown in Fig. 2. That of the species relevant to pollinators (entomophilous and ambophilous species)) extends throughout the year with its peak in April, May and June, when 50 %, 59.96 % and 56.62 % of the species bloom, respectively, which is characteristic of the Mediterranean climate (Castro-Díez and Montserrat-Marti, 1998). The scarcity of floral resources among ornamental flora in winter and autumn (between October and February, specifically) in Granada is due to the Mediterranean climate, which favours a period of plant growth in winter and a period of flowering in spring, concentrated in March and May. Although Mediterranean species as a whole can provide floral resources throughout the year, they are diminished between October and February (Petanidou and Lamborn, 2005).

This imbalance in flowering times is a widespread situation, as cities are often dominated by a few plant species, concentrating their flowering in a reduced time span and producing an imbalance in the availability of floral resources at different times of the year (Santamour, 2002); Cariñanos and Casares-Porcel, 2011). This may be because urban green areas are designed mainly according to aesthetic criteria and species that are easy to manage are chosen (Sikora et al., 2020), reducing the plant diversity in the urban environment. However, as a general trend, an increase in the number of species has been observed with urbanization (Matteson and Langellotto, 2011), contributing to pollinator diversity maintenance (Salisbury et al., 2015; Wenzel et al., 2020). However, not all additions will do, as in some cases a greater preference of native pollinators for native species than for exotic species has been observed in highly urbanised environments (Buchholz and Kowarik, 2019). A continuous availability of floral resources over time is essential for pollinator survival and activity (Dylewski et al., 2019), which can be achieved by planting different species with sequential flowering or species with a long flowering period (Aleixo et al., 2014).

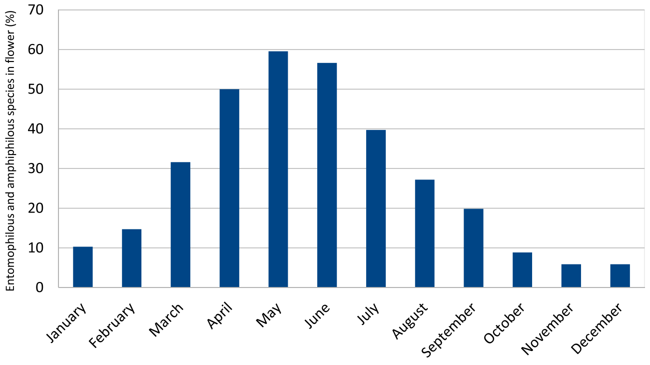


Fig. 2. Percentage of entomophilous and ambiphilousspecies in flower along the year in Granada.

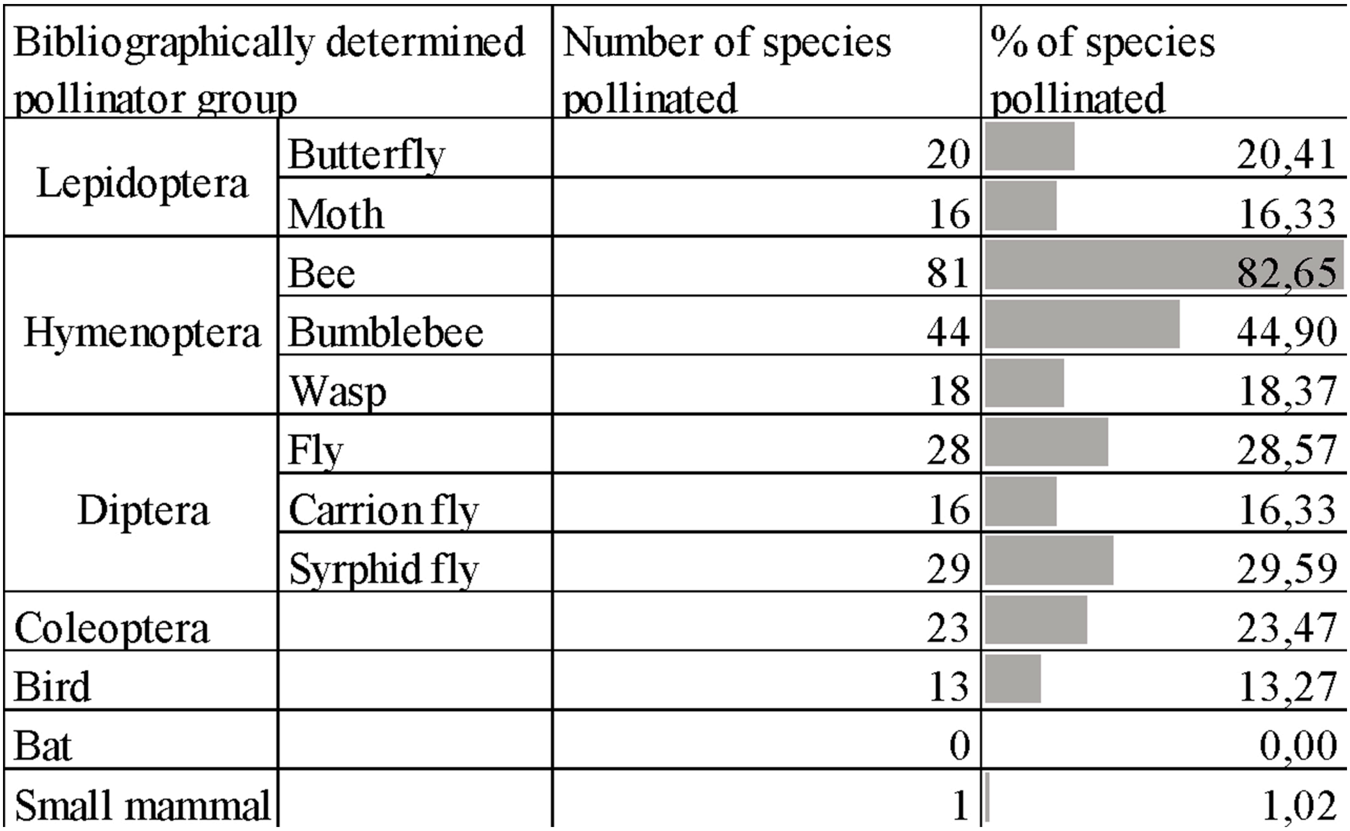
3.2. *Pollinator groups potentially attracted to the ornamental vegetation of Granada*

Information on the potential pollinators was obtained for 97 out of the 141 entomophilous and ambophilous species in the green areas of Granada. Only 22 showed pollination by a single pollinator group. The remaining 75 species may be pollinated by more than one group, indicating a mostly generalist pollination. In Mediterranean cities and temperate climates, plant-pollinator interactions are mostly generalist (Bosch et al., 1997). In contrast, in tropical climates these interactions are mainly specialized (Rosas-Guerrero et al., 2014), as, for example, in Brazil where only 3.11% of species are pollinated by more than one pollinator group (Aleixo et al., 2014).

Among pollinator groups, Hymenoptera stand out: bees, which pollinate 82.65 % of the species, followed by bumblebees, which pollinate 44.90% of the species (Table 2). Within Hymenoptera, even if at a great distance from the pollination role of bees and bumblebees, wasps are responsible for the pollination of around 19 % of the species, which is not trivial. Although wasp pollinating function has long been neglected they are important ES-providers, among which their role as pollinators stand out (Brock et al., 2021) Diptera, including syrphids and flies, also stand out pollinating 58.16 % of the species. Bats and small mammals are the least relevant pollinators in the studied area, pollinating one and none of the species, respectively. These results highlight the relevance of bees as main pollinators in urban areas. Honey bees and, if to a lesser extent, bumblebees can sometimes act as secondary pollinators of ornithophilous species in cases where the legitimate pollinator is absent, as in the cases of two species present in Granada: *Phormium tenax* J.R.Forst. & G.Forst. (Howell and Jesson, 2013) and *Campsis radicans* (L.) Seem. (Kolodziejska-Degórska and Zych, 2006). However, where on-site pollinator inventories have been carried out, results vary broadly. Thus, in certain Mediterranean ecosystems, such as high mountain and arid habitats, ants can bet important pollinators, (Gómez et al., 1996). In European cities with temperate climate, bees are more abundant than lepidoptera and syrphids in urban parks (Dylewski et al., 2019). In a tropical-climate city, bees are the most abundant pollinator group, but birds and butterflies are also relevant, while beetles are scarce (Aleixo et al., 2014).

In relation to the effects of urbanization, Hymenopterans are reported to be the least affected pollinator group (Deguines et al., 2016; Theodorou et al., 2020), while butterflies may be affected the most (Dylewski et al., 2019). This could be due to a higher resilience of Hymenoptera to the specific conditions of the urban ecosystem than other groups, or to a lower resilience to the rural ecosystem as they are more sensitive to pesticides (Theodorou et al., 2020). They have lower requirements than other groups, depending only on food resources (nectar and pollen) and nesting sites (Dylewski et al., 2020). In contrast, Syrphidae and Lepidoptera interact with vegetation in a more complex way and have different requirements at different life stages that may not be present at the same time in the same environment (Dylewski et al., 2019).

Table 2
Number and percentage of vegetal species potentially pollinated by the different pollinator groups.



Bibliographically determined pollinator group		Number of species pollinated	% of species pollinated
Lepidoptera	Butterfly	20	20,41
	Moth	16	16,33
Hymenoptera	Bee	81	82,65
	Bumblebee	44	44,90
	Wasp	18	18,37
Diptera	Fly	28	28,57
	Carrion fly	16	16,33
	Syrphid fly	29	29,59
Coleoptera		23	23,47
Bird		13	13,27
Bat		0	0,00
Small mammal		1	1,02

3.3. *Statistical analysis – actual pollinator prediction through floral syndromes*

The results of the NMDS analysis of the ideal flower syndromes are shown in Fig. 3. The lowest stress levels were obtained by using 4 dimensions, obtaining a stress value of 0.087 and $R^2 = 0.946$, representing the data faithfully.

The ideal floral syndromes for pollinators of wasps, flies and moths differ from the others. Those of bees and butterflies are completely overlapping with each other and partially overlapping with those of birds, a similar situation to that of carrion flies and beetles.

The lowest stress levels were obtained with 4 dimensions for all the groups (see Appendix Fig. 2–11) for the second part of the statistical analysis.

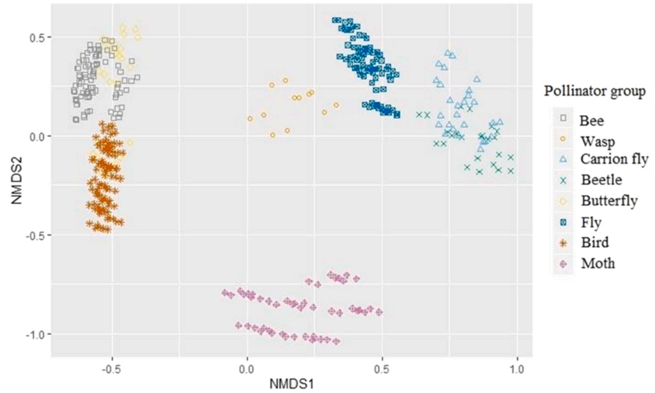


Fig. 3. Representation of the NMDS analysis of the ideal pollination syndromes of each pollinator group.

Among the considered plant species, only 21 (21.65 % of the species) showed an actual floral syndrome significantly correlated with the ideal floral syndrome of their observed pollinators. None of the species pollinated by bees (stress = 0.109, $R^2 = 0.904$), bumblebees (stress = 0.099, $R^2 = 0.924$), butterflies (stress = 0.097, $R^2 = 0.932$), birds (stress = 0.096, $R^2 = 0.932$) and moths (stress = 0.097, $R^2 = 0.933$) have floral syndromes that are within the NMDS space of their respective pollinator group.

Among wasp-pollinated species (stress = 0.095, $R^2 = 0.936$), only *Callistemon citrinus* (Curtis) Skeels fell within the ideal NMDS space of wasps. In the case of Calliphoridae (stress = 0.091, $R^2 = 0.941$), two species fell within the ideal NMDS space: *Prunus laurocerasus* L. and *Magnolia grandiflora* L. These two species, besides *Ailanthus altissima* (Mill.) Swingle fell within the ideal NMDS space of Coleoptera (stress = 0.097, $R^2 = 0.933$). Flies (stress = 0.095, $R^2 = 0.934$) and syrphids (stress = 0.098, $R^2 = 0.930$) have the highest number of species within the ideal NMDS space. There were 9 fly-pollinated species: *Ilex aquifolium* L., *Hedera helix* L., *Buxus sempervirens* L., *Acacia dealbata* Link, *Rhamnus alaternus* L., *Ruta graveolens* L., *Valeriana officinalis* L., *Acer pseudoplatanus* L. and *Acer granatense* Boiss. For syrphids, there were 13 species: *Schinus molle* L., *Hedera helix* L., *Viburnum opulus* L., *Cornus sanguinea* L., *Alliaria petiolata* (M. Bieb.) Cavara & Grande, *Salvia officinalis* L., *Acacia dealbata* Link, *Spartium junceum* L., *Valeriana officinalis* L., *Tilia cordata* Mill., *Tilia* x *europaea* L. and *Ilex aquifolium* L.

The low correlation percentage between present and ideal floral syndromes of the respective pollinator group (22%) suggests that the use of floral syndromes for the selection of plant species for attracting a particular pollinator group would not be the best tool. However, the lack of information on certain traits, such as odor or nectar volume, in most species could have biased the results. Ollerton et al. (2009) found out that floral syndromes could be used, albeit with caution, as a correlation percentage of 30% was obtained. Other studies such as Rosas-Guerrero et al. (2014) validate floral syndromes as a tool, although with reservations. By now, there are limitations to make generalizations about floral syndromes such as the lack of a common standardized database where such information is available, the large instra-specific variations of certain characters (E-Vojtkó et al., 2020), the use in cities of garden varieties with characters that differ from natural varieties (Garbuzov et al., 2017) or the different floral display depending on climatic and/or edaphic conditions (Rollings and Goulson, 2019).

Lastly, it should not be overlooked that the greatest flow of pollinators into city boundaries comes from peri-urban environments, which allows, in addition exchangement between communities (Banaszak-Cibicka et al., 2016). Maintaining the quality of peri-urban habitats and ruderal areas inside and outside the urban boundary is also essential for the conservation of pollinators such as bees (Martins et al., 2017). In the case of Granada, the areas of the Vega and Sierra Nevada are crucial parts of the corridors between the rural and urban ecosystems that should be maintained in a favorable state and be included in any plan for the ecological configuration and urban planning of the city. This would be interesting for potential further studies, as one of the most necessary measures in this regard is to increase the areas that can potentially perform as corridors in the city, which actually represent 2.8% of the UGI of the city (Delgado-Capel and Cariñanos, 2020). However, key factors such as the ecological configuration of the landscape, connectivity and fragmentation, are often not considered when creating urban planning schemes (Hersperger et al., 2020). Having specific information on this subject could contribute to shifting the current trends in urban planning. Nevertheless, strategic plans must be context-specific as each city has specific cultural, social, environmental and institutional contexts (Hersperger et al., 2020). Different UGAs differ in plant composition, management and use (Bennett and Lovell, 2019), and should be managed accordingly.

4. Conclusions

This work has highlighted that although the urban environment constitutes a threat to pollinators, a detailed analysis of the characteristics of urban green spaces can show up the measures necessary for these spaces to perform as conservation niches of pollinators. The achieved results highlight that the characterization of the flora constituting UGI, and the identification of their origin, flowering period, floral syndromes and specific pollinators allows the design of specific actions to reinforce the pollination ES. In this sense, it has been possible to identify the species with the most attractive floral syndromes for generalist pollinators such as bees, as well as the periods of the year in which it is necessary to reinforce the floral resources availability in the city.

Our results have revealed that greater diversity in terms of pollination strategies and species origin increases the provisioning resources for pollinators. In this sense, the spontaneous flora and the flora that make up the private green spaces can also be considered as available resources, reinforcing the deficit that may occur in certain periods of the year if only the public green area is considered. The review of the main groups of pollinators potentially attracted by the floral resources of the city have revealed that bees (honey and solitary bees), bumblebees, syrphids and flies are the main groups, with bees standing out above all of them. Butterflies, on the other hand, are the most affected group by the increase in urbanization. Regarding the use of pollination syndromes to predict the specific pollination groups, acceptable results have only been shown for flies and syrphids, probably due to the large intra-specific variations of the characters of the ornamental flora species.

On the whole, it can be concluded that with adequate planning, design and management measures for urban vegetation, UGAs can reinforce their role as resource provision areas for pollinators, and therefore, enhance the Pollination Ecosystem Service in urban environments and their associated benefits.

CRediT authorship contribution statement

Joana Llodrà-Llabrés: Conceptualization, Methodology, Formal analysis, Writing – origina draft. **Paloma Cariñanos González:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2022.127621.

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