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Year-round pollinator visitation of ornamental plants in Mediterranean urban parks

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Abstract

1. Many pollinators persist in urban green spaces though these are typically designed to support human recreation rather than for biodiversity conservation. Investigating the role of ornamental plants in supporting pollinators is key to reconciling urban planning and nature conservation.
2. We explored pollinator dynamics and their floral visits to ornamental plants over 12 consecutive months in 15 parks in the Mediterranean city of Seville (Spain).
3. We observed 8422 floral visitors from 155 species in 62 plant taxa (74% non-native). Pollinators were represented by wild bees (42%), honeybees (37%), flies (18%), butterflies (2%) and beetles (1%). Pollinators were present all year round and showed two peaks: first, between late winter and early spring; and second, in early summer for wild bees or early autumn for flies and butterflies.
4. Honeybee visits, but not wild bee, fly or butterfly visits, increased with floral availability per plant taxon. Both native and non-native plants attracted pollinators. However, visitation rates and species richness of each pollinator group varied between native and non-native plants throughout the year.
5. In Mediterranean climates, the combination of native and non-native ornamental plants in city parks can provide flower resources all year round for pollinators to thrive. Urban planners should balance recreation and conservation goals and prioritise non-invasive combinations of native and non-native plants that are valuable to pollinators across all seasons.

KEYWORDS
cities, floral visitors, green spaces, native plants, non-native plants

INTRODUCTION

Despite the global decline of pollinator populations, especially in anthropogenic ecosystems (Bates et al., 2011; Potts et al., 2010), some species persist within cities (Silva et al., 2023). In fact, moderate levels of urbanisation can provide more suitable places for some pollinators compared to agricultural habitats (Wenzel et al., 2020). In cities, pollinators benefit from the resources (e.g., food and nest sites) provided by green areas such as parks, gardens, squares, public walkways, green roofs and courtyards (Baldock et al., 2015). However, although some portion of those floral resources are valuable to pollinators (Garbuzov & Ratnieks, 2014; Rollings & Goulson, 2019), the

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management of ornamental plants in public areas is usually driven by aesthetic and recreational considerations rather than by species conservation objectives (Bolund & Hunhammar, 1999; Kendal et al., 2012). Understanding the dynamics of pollinators visiting ornamental plant species has considerable conservation significance. However, there is limited information on pollinator foraging on ornamental plants, many of which are non-native (Bayón et al., 2021).

Ornamental plants are often selected for their conspicuous flowers, shading provision and tolerance to the local climate, among other factors. Unfortunately, some of these plants may not be attractive to pollinators or their flowering phenology may not match pollinator flight phenology (Garbuzov et al., 2017; Rollings & Goulson, 2019). A large proportion of ornamental plants are non-native species (Mayer et al., 2017; van Kleunen et al., 2018). For instance, Bayón et al. (2021) found that, on average, 82% of the species recorded in urban parks in Spain were non-native, some of which are invasive, meaning that they have the potential to establish and dominate in natural ecosystems causing negative impacts on biodiversity (González-Moreno et al., 2014; Maurel et al., 2016). Moreover, some non-native plants introduced as ornamentals have flowers that are highly attractive to pollinators, become well integrated into the recipient plant–pollinator community and might compete for pollinators with native plants (Vilà et al., 2009). However, it is not well known how pollinator preferences differ between native and non-native plant species in artificial communities such as in urban parks.

Urban pollinators are mostly generalist species, which are usually less sensitive to factors such as landscape fragmentation and the loss of floral and nesting resources (Silva et al., 2021; Wenzel et al., 2020). Therefore, these pollinator species are expected to visit a wide range of ornamental plants, including non-native species (Garbuzov & Ratnieks, 2014; Rollings & Goulson, 2019). However, patterns of visitation are expected to differ for every pollinator taxon examined. Such patterns will depend on intrinsic traits of the plants and pollinators, as well as extrinsic factors of the community (Carvalheiro et al., 2014; Morales & Traveset, 2009; Telles et al., 2017). These factors include phenological overlap, floral abundance relative to other species in the community, and the identity of neighbouring plants (Montero-Castaño & Vilà, 2015; Peralta et al., 2020).

The Mediterranean Basin region is a biodiversity hotspot for insect pollinators (Orr et al., 2021). However, bee diversity in this region is highly endangered by global changes. Urbanisation and climate warming are two of the main factors contributing their local decline (Kantsa et al., 2023). Only a few studies have investigated pollinator persistence in urban Mediterranean parks. The presence of year-around flowers in parks offers the opportunity to investigate their shifting dynamics, which is seldom considered in natural areas where most studies survey pollinators only in spring, when most plants flower.

Here, to understand the importance of ornamental plant species to pollinators over time, we monitored ornamental plant-pollinator interactions over 12 consecutive months in 15 urban parks in the Mediterranean city of Seville (Spain). We aimed to answer the following questions: (1) Which pollinators are present in the parks throughout the year? (2) How do they vary throughout the year? (3) To what extent do the floral visits of different groups of pollinators overlap? (4) Are floral visits related to plant origin (native vs. non-native) and/or floral availability per plant species? Due to mild temperatures in winter and urban plant management (e.g., watering), we expect pollinators to be present in the parks all year round, although they will be more abundant and diverse in spring. We also expect ornamental plant species to play a variable role in supporting different groups of pollinators, based on their feeding needs, and over time. We have no clear prediction about the role of plant origin in supporting pollinators, as existing studies provide contradictory results depending on the plant species examined (Garbuzov & Ratnieks, 2014; Urbanowicz et al., 2020). Finally, we expect floral visits to be dependent on floral availability.

MATERIALS AND METHODS

Study area

The study was conducted in Seville, the fourth largest city in Spain (∼684,000 inhabitants in 2023 across an area of approximately 140 km^2; INE, 2024), located in the southwestern part of the country (Figure 1), between October 2021 and September 2022. The climate is Mediterranean with warm and dry summers and mild winters (mean annual temperature and precipitation are 19.2°C and 539 mm, respectively; AEMET, 2024).

In Seville, there are around 60 recreational green spaces partially scattered throughout the city. In these public green spaces (i.e., parks), a wide variety of ornamental flowering plants, especially tree and shrub species, are cultivated. Some of the most common native species are *Ceratonia siliqua* L. (Fabales: Fabaceae), *Salvia rosmarinus* Spenn. (Lamiales: Lamiaceae) and *Vitex agnus-castus* L. (Lamiales: Lamiaceae), while non-native species include *Citrus* × *aurantium* L. (Sapindales: Rutaceae), *Lagerstroemia indica* L. (Myrtales: Lythraceae) and *Lantana camara* L. (Lamiales: Verbenaceae) (Parques y Jardines; Ayuntamiento de Sevilla, 2024). Due to management practices, warm temperatures throughout the year and differences in flowering phenology among plant species, floral resources are expected to be available nearly year-round.

Sampling design

We selected 15 parks of different sizes (mean $= 0.17$ km^2, range $= 0.003–0.511$ km^2), each containing a minimum of four ornamental flowering tree and shrub species. These parks were, on average, 1.7 km apart (range $= 0.8–2.5$ km), a distance greater than the typical foraging range of most pollinators (Kendall et al., 2022). The parks were located at varying distances from the city edge to the centre (mean $= 1.5$ km, range $= 0.0–3.4$ km) (Figure 1).

We conducted floral visitor (hereafter, pollinator) censuses in each park over 12 consecutive months (October 2021–September

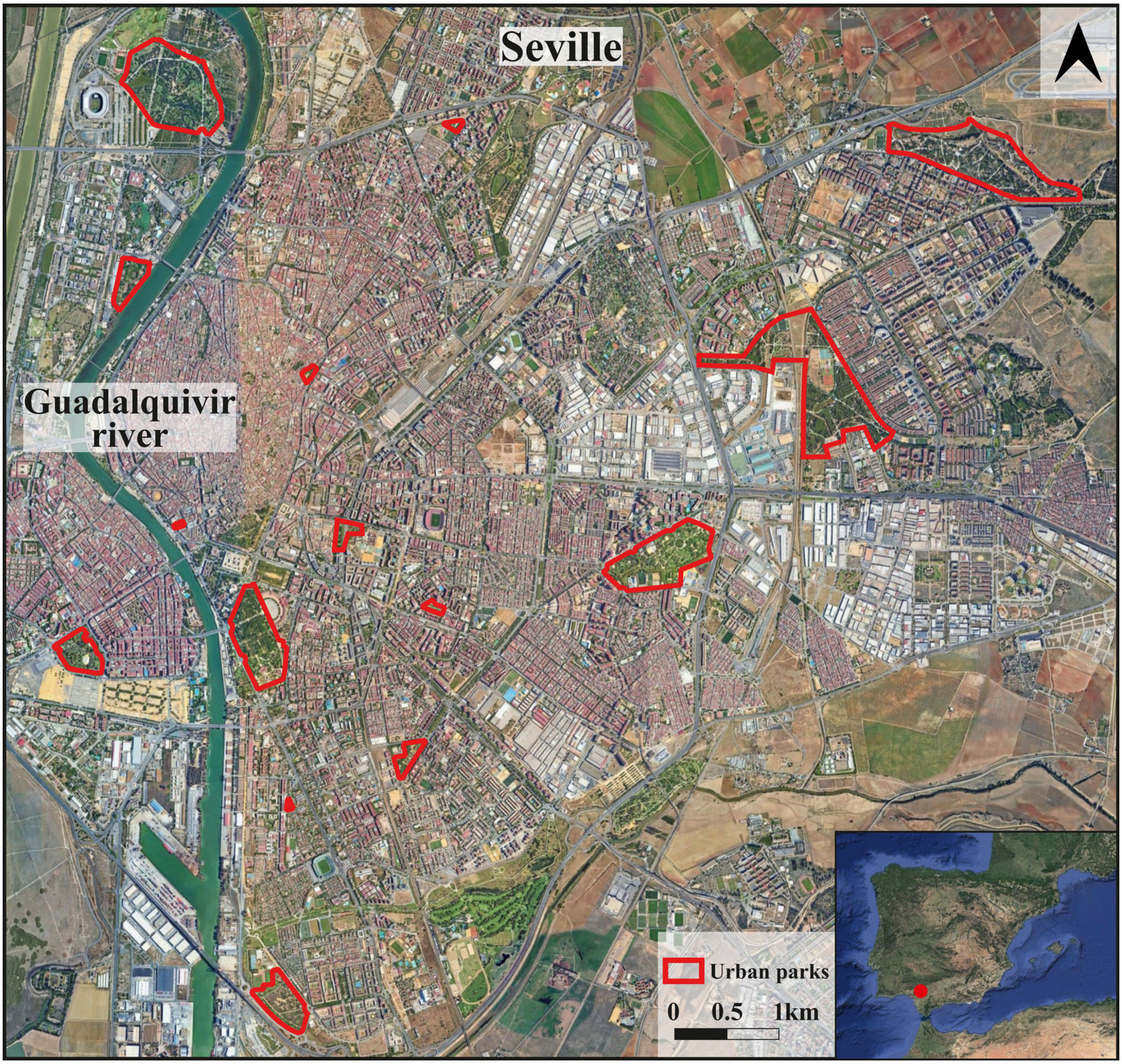


FIGURE 1 Map of the 15 selected parks in the city of Seville, SW Spain. The park names are Jardines de la Buhaira, Jardines del Guadalquivir, Jardines del Valle, Parque Álvaro Diamantino Vellisco, Parque Amate, Parque de Los Bermejales, Parque de los Príncipes, Parque de María Luisa, Parque del Alamillo, Parque del Tamarguillo, Parque Don Miguel Mañara, Parque Federico García Lorca, Parque Infanta Elena, Parque José Celestino Mutis, Parque José María de los Santos.

2022). On average, each park was sampled every 4 weeks, and thus once a month. Between 1 and 6 (mean = 3) randomly selected parks were sampled per day, depending on workload, that is, number of plants surveyed per park. We avoided sampling the same park at the same time slot in consecutive months. In general, the complete monthly sampling of all parks was carried out over the course of one continuous week. Sampling was conducted on sunny, non-windy days, with shade temperatures ranging from 12 to 35°C. All censuses were conducted between 08:45 AM and 7:30 PM.

In each park, we established a fixed 20 m-wide sampling path, which covered the entire area of the park. For the four largest parks (>0.274 km^2), we limited the path to areas with the highest plant diversity, avoiding large extensions of mown areas. The starting point along the sampling path was changed each month. On each sampling day and in each park, we identified all woody ornamental plants in bloom along the path prior to beginning the pollinator censuses. The selected plant species had to meet the following criteria: (a) they were attractive to diurnal pollinators (e.g., we excluded species such as *Hibiscus* L. (Malvales: Malvaceae), *Melia azedarach* L. (Sapindales: Meliaceae) and *Punica granatum* L. (Myrtales: Lythraceae) which are often present in parks but, after a reasonable period of observation (2–3 h), no floral visitors were observed); (b) they were not rare, that is, limited to just a few individuals in a single park; and (c) they allowed for ground-based censuses. Once a plant species met these criteria, we performed two censuses per species, whenever possible at different locations along the sampling path and in a randomised interspecies order to avoid potential biases in temporal and spatial pollinator activity (Zaragoza-Trello et al., 2023). Thereafter, selected species were sampled whenever they were in bloom in any park throughout the year.

During each census, we conducted a 10-min pollinator count per plant, focusing on a 1 m^2 area with the highest flower density. We recorded floral visitors that made contact with any reproductive part of a flower, avoiding double counting. Ants, thrips and other flies and beetles smaller than 3 mm were excluded due to rarity on the flowers. Most specimens were identified visually in the field to the lowest possible taxonomic level. A subset of 629 individuals (7.5% of all observed; see Results) was captured for identification in the laboratory with the help of an expert (co-author Francisco P. Molina). Specimens were captured using aerial nets, stored in a chilled box, and then frozen at -20°C at the end of each sampling day. All specimens are deposited at the Estación Biológica de Doñana (EBD-CSIC). In total, we conducted 774 censuses (20 min each) over 64 days, amounting to 258 sampling hours.

To test whether the plant species were adequately surveyed, we conducted an additional 30-min consecutive observation each month on a single and randomly selected plant species, focusing on 1 m^2 area. We constructed rarefaction curves and found that, in general, almost no new pollinator species were detected after 20 min of observation (Figure S1).

Finally, for each studied ornamental plant species, we estimated floral availability per plant, day and park, by counting receptive (i.e., pollinator-accessible) flowers in five randomly selected 40 cm^2 areas per plant species, distributed along the fixed path. In addition, using the QGIS programme, we estimated the area occupied by each species in each park by mapping their coverage during walking surveys. Then, for each species, we calculated the average number of flowers per m^2 and multiplied this by the estimated area (in m^2) occupied by the plant in the park. In all cases, the maximum length of the parks, and thus the area where flower estimates were conducted, did not exceed a 500 m buffer radius, a typical area of influence for small pollinators according to their flight foraging distances (Kendall et al., 2022). For plants with very small flowers —*Acacia* Mill. (Fabales: Fabaceae) and *Santolina chamaecyparissus* L. (Asterales: Asteraceae)— or bearing aments —*C. siliqua*, *Phytolacca dioica* L. (Caryophyllales: Phytolaccaceae) and *Tamarix* L. (Caryophyllales: Tamaricaceae)— the inflorescence was considered the floral unit.

In total, we sampled 62 plant taxa (74% of which were non-native according to Castroviejo, 2020), with an average of 17 taxa per park (range = 4–29). On average, individual plant taxa were present in 4 parks (range = 1–13). Seventeen plant taxa with cryptic floral traits were grouped at the genus level as there were mixed species and hybrids within and among parks (Table S1). We assumed these taxa were equally attractive to pollinators.

The data set supporting this study has been deposited in the Dryad Digital Repository (Trillo et al., 2026).

Statistical analyses

All statistical analyses were performed in R version 4.2.1 (R Core Team, 2024). We explored general pollinator trends by the following group: bees, flies and butterflies. Beetle data were excluded from analysis due to their low abundance in the parks ($N = 48$ individuals; 0.6% of the total floral visitors observed). For each pollinator group, we assessed the shape of the temporal trend in the average number of floral visits and species richness per plant taxon using generalised additive models (GAMs) implemented with the mgcv package (Wood, 2017). We used negative binomial as the error distribution family and included month as a fixed effect, with plant taxon and park as random effects.

To explore the use of ornamental plants by each pollinator group, we calculated the percentage of floral visits and species richness per plant taxon relative to all plants combined, for each park and month. This approach helped remove bias arising from unbalanced distributions of pollinators and plant taxa among parks. As plants do not flower all year round, and their relative importance to pollinators can therefore vary over time, we grouped months (hereafter, periods) based on overlap in plant taxa flowering phenology. For this purpose, we used the 'vegdist' function with the Jaccard option in the vegan package (Oksanen et al., 2007). We identified four distinct clusters, each comprising three consecutive months: (1) November–January, (2) February–April, (3) May–July and (4) August–October (Figure S2). For each period, we averaged the percentage of floral visits and species richness per plant taxon. Moreover, to reduce potential over- and underestimation of pollinator visits for some plant taxa, we excluded parks with fewer than three censused plants per month and plant taxa with fewer than three censuses per period (same criteria hereafter). For bees, we explored the foraging patterns of wild and managed —*Apis mellifera* Linnaeus, 1758 (Hymenoptera: Apidae)— species separately, as honeybees accounted for nearly half of all bee records. To visualise pollinator use of ornamental plants (in terms of both visits and species richness), we plotted plant-pollinator interaction percentages for each group (i.e., wild bees, honeybees, flies and butterflies; same grouping hereafter) and period using the ggplot2 package (Wickham et al., 2016).

To quantify similarity in the exploitation of floral resources between pollinator groups, we used the Hulbert proportional similarity index (Hurlbert, 1978). This index is calculated as $\mathrm{PS} = \sum_i \min(p_{i,g1}, p_{i,g2})$; where $p_{i,g1}$ is the average percentage of interactions with plant taxon i for pollinators of a particular group and $p_{i,g2}$ is the average percentage of interactions with plant taxon i for another pollinator group. PS values range from 0 (no resource overlap) to 1 (complete resource overlap).

To test whether pollinator visits and species richness per plant taxon were related to floral availability in the park and whether these relationships varied between native and non-native plants, we built generalised linear mixed models (GLMMs) with a negative binomial error distribution (log link) using the package glmmTMB (Brooks et al., 2017) for each pollinator group. For this analysis, we excluded data for *Viburnum* L. (Dipsacales: Viburnaceae), as it included both native and non-native species that could not be reliably distinguished at a glance. Pollinator visits and species richness per plant taxon, park and month were used as response variables. Floral availability (scaled floral units per taxon and park using the 'scale' base function in R), plant origin (native vs. non-native) and period (first, second, third, fourth) were included as fixed effects, while park was included as a random effect. We also included in the models the interaction between plant origin and period. We performed model selection using the MuMIn package (Bartoń, 2022) to generate a set of candidate models ranked by AICc using the dredge function. In all cases, the best models were the more complex ones proposed. We checked the effect of the interaction by post hoc pairwise comparisons within each period using Tukey's adjustment (emmeans package; Lenth, 2025). We evaluated the goodness-of-fit and potential over-dispersion of all models using the package DHARMa (Hartig & Hartig, 2017).

RESULTS

Observed pollinators

In the parks of Seville, over the course of the year, we observed 8422 pollinator visits belonging to 155 species (note that some species were grouped into morphospecies; see Table S2). More than three-quarters (79.2%) of the floral visitors and more than half (56.8%) of the species recorded were hymenopterans. Among these, bee species accounted for 99.3% of the records. The honeybee, *A. mellifera* and the carpenter bee, *Xylocopa violacea* Linnaeus, 1758 (Hymenoptera: Apidae) accounted for 46.8% and 16.4% of the hymenopteran records, respectively (Table S2). We also frequently observed individuals of the genus *Lasioglossum* Curtis, 1833 (Hymenoptera: Halictidae) (11 species; ~9% of records), *Anthidium* Fabricius, 1804 (Hymenoptera: Megachilidae) (2 species; ~8%) and *Megachile* Latreille, 1802 (Hymenoptera: Megachilidae) (5 species; ~6%). In contrast, nearly one-third of hymenopteran species were observed only once (Table S2).

Dipterans were the second most frequently observed pollinator order. Nearly one-fifth (18.1%) of the floral visitors and one-third (33.5%) of the species recorded were flies (Table S2). Among these, the most common species were *Episyrphus balteatus* De Geer, 1776 (Diptera: Syrphidae) (~13% of the dipteran records), *Eristalis similis* Fallén, 1817 (Diptera: Syrphidae) (~12%), *Calliphora vicina* Robineau-Desvoidy, 1830 (Diptera: Calliphoridae) (~11% of records), *Myathropa florea* Linnaeus, 1758 (Diptera: Syrphidae) (~9%) and *Syritta pipiens* Linnaeus, 1758 (Diptera: Syrphidae) (~9%). In contrast, nearly one-fifth of dipteran species were observed only once (Table S2).

Lepidoptera and Coleoptera individuals were also observed in urban parks, albeit more sporadically (Table S2). Butterflies constituted 2.1% of the floral visitors and 6.5% of the recorded species. The most common species were *Vanessa atalanta* Linnaeus, 1758 (Lepidoptera: Nymphalidae) (~38% of the lepidopteran records) and *Pieris*Schrank, 1801 (Lepidoptera: Pieridae) (~28%). Beetles constituted 0.6% of the floral visitors and 3.2% of the recorded species. The most common species were *Oxythyrea funesta* Poda, 1761 (Coleoptera: Scarabaeidae) (~73% of the coleopteran records) and *Heliotaurus ruficollis* subsp. *tangerianus* Escalera, 1922 (Coleoptera: Tenebrionidae) (~21%).

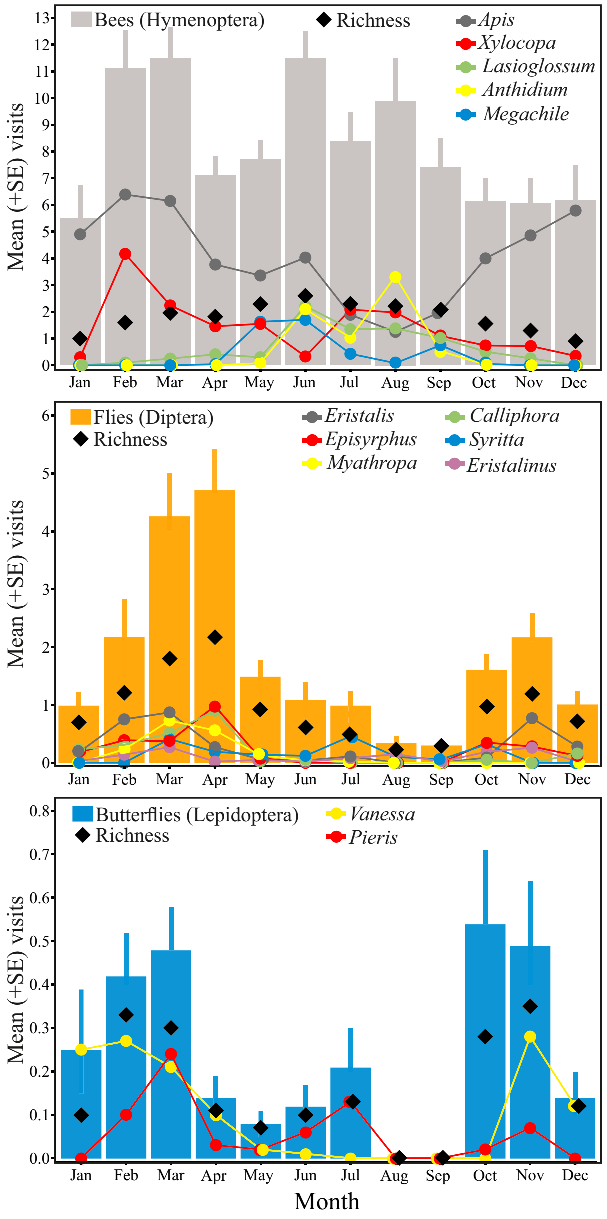


FIGURE 2 Temporal variation in the average number of floral visits and richness of each pollinator group per plant taxa over 12 consecutive months in 15 urban parks in Seville. Pollinator genus that represent more than 5% of the recorded data are also shown. Notice that *y*-axes scales are different for each pollinator group.

Temporal trends

We found significant temporal trends in floral visits and richness for each pollinator group (Figure S3). Bee visits peaked between late winter and early spring, driven, as previously mentioned, by the high

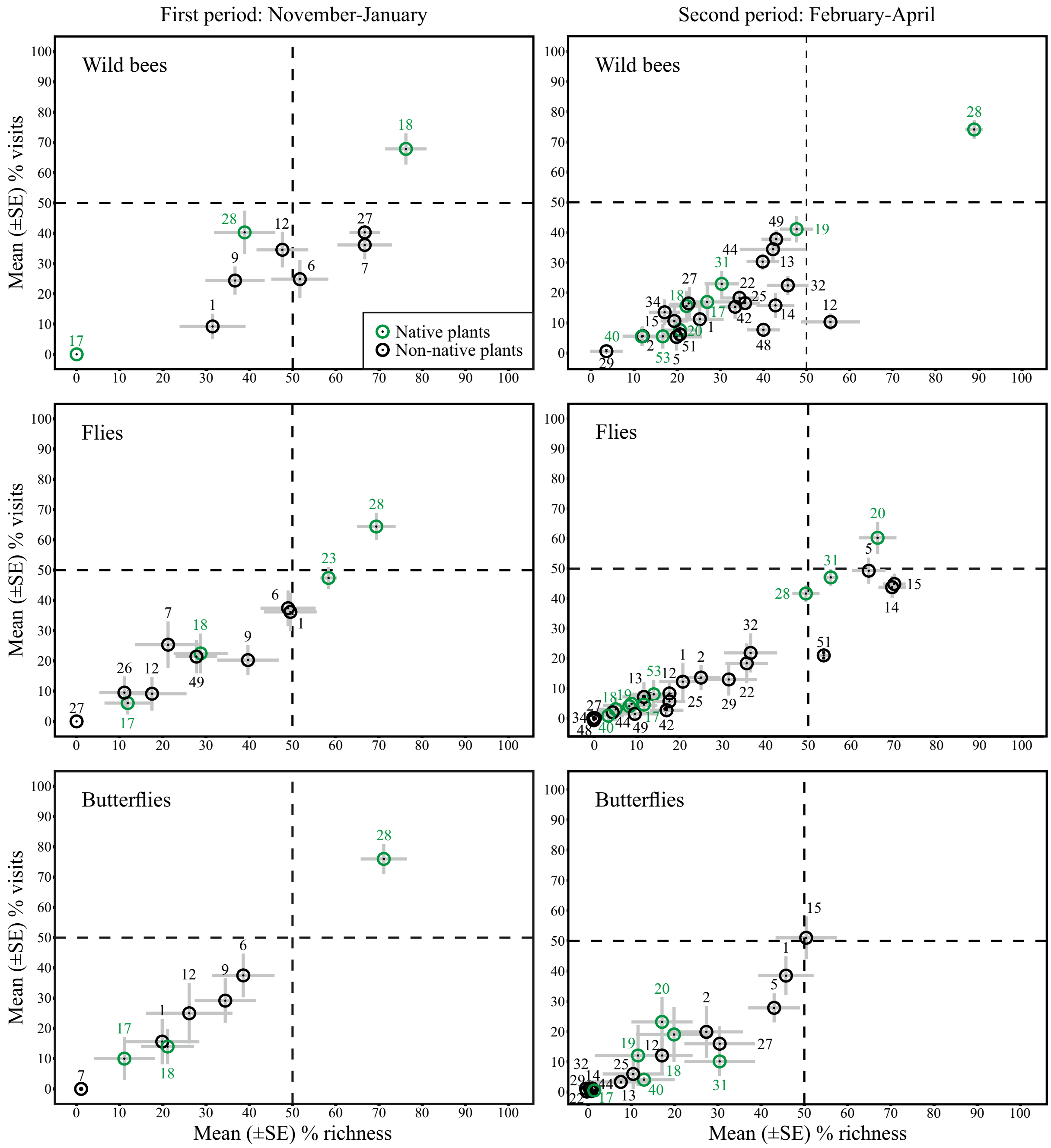


FIGURE 3 Use of ornamental plants by each pollinator group per flowering phenology period. For each plant taxa (see numbers in Table S1 for more details), we calculated the percentage of pollinator species richness (*x*-axis) and the percentage of floral visits (*y*-axis) relative to all plants combined, per park and month. Then, for each period, we averaged species richness and visits per plant taxa. The correlation between floral visits and pollinator richness per plant taxa was positive (*r*: range = 0.75–0.99). Plant taxa in green colour are native and in black are non-native.

abundance of *A. mellifera* and *X. violacea*. The number of visits then declined slightly before peaking again in early summer, driven by the abundance and richness of wild bees, and declined from autumn onward. Correspondingly, bee richness increased from winter to early summer and declined thereafter (Figures 2 and S3). Fly and butterfly visits and richness reached a maximum in early spring and between late winter and early spring, respectively, before declining from late spring to early autumn (Figures 2 and S3).

Floral resource use

Overall, pollinators in the parks benefited from the turnover of flowering plant species throughout the year (Table S1). Accordingly, the role that plant species play in supporting pollinators varied over the four clustered flowering periods (Figures 3 and 4; see Statistical analyses section and Figure S2 for further details). The average number of visited plants was more than twice as high in the second (February–April)

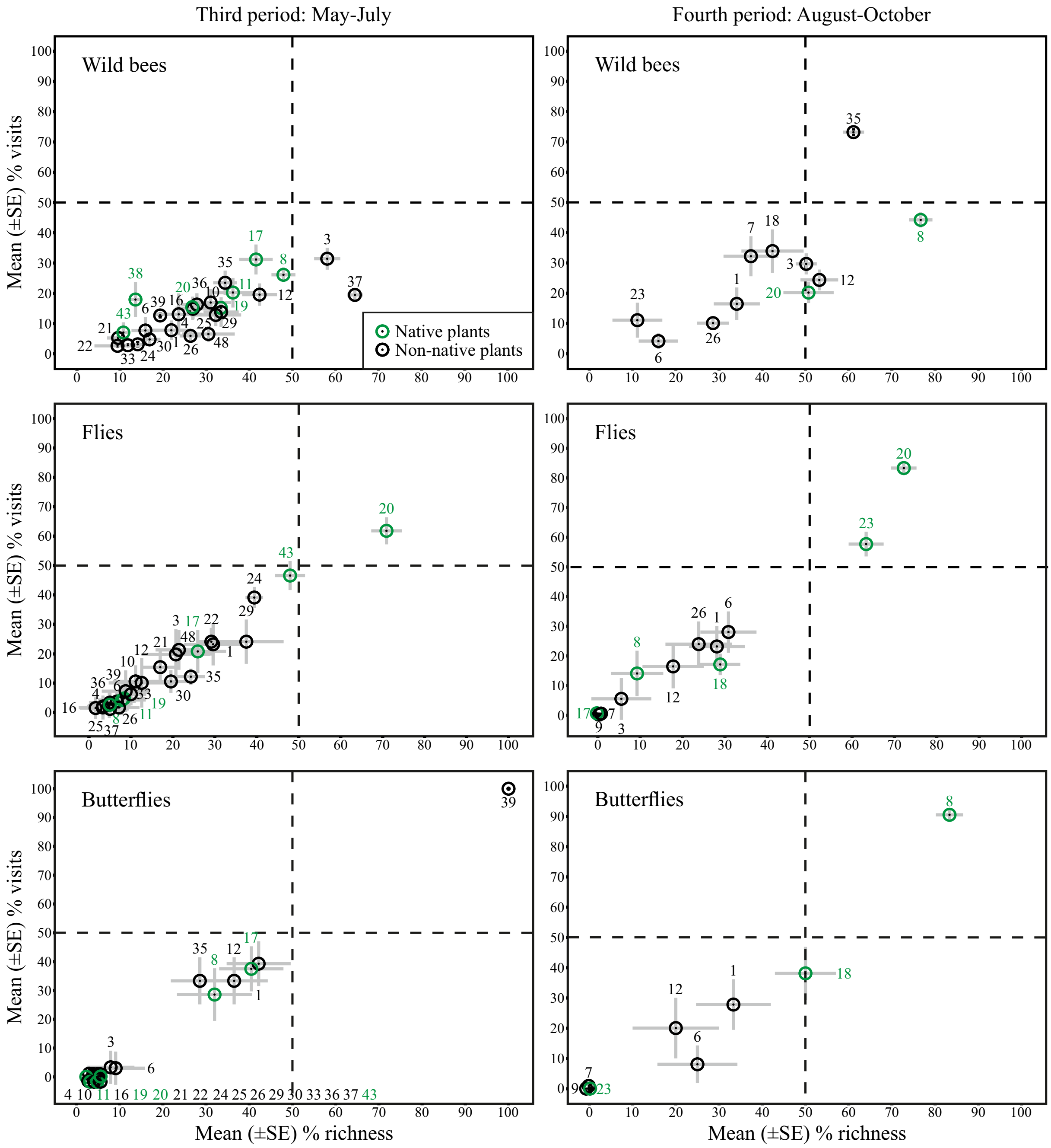


FIGURE 3 (Continued)

and third (May–July) periods (mean = 25) than in the first (November–January) and fourth (August–October) periods (mean = 11), which corresponds with the number of plant taxa flowering in those times (Figures 3 and 4, Table S1).

In general, each pollinator group visited a wide range of plant taxa (Figures 3 and 4, Table S3). There was a strong positive correlation between the number of floral visits and pollinator richness per plant taxon (*r*: range = 0.75–0.99). During the first period, native species such as *Arbutus unedo* L. (Ericales: Ericaceae), *C. siliqua* and *S. rosmarinus* accounted for the highest percentage of pollinator visits and richness per park. In the second period, native taxa such as *A. unedo*, *Crataegus monogyna* Jacq. (Rosales: Rosaceae) and *Tamarix* spp., non-native taxa such as *Photinia serratifolia* (Desf.) Kalkman (Rosales: Rosaceae) and *Pittosporum* Gaertn. (Apiales: Pittosporaceae), and *Viburnum* spp. (which included both native and non-native species) showed the greatest percentage of pollinator visits and richness. In the third period, native taxa such as *S. chamaecyparissus* and *Tamarix* spp., and non-native taxa such as *Koelreuteria paniculata* Laxm. (Sapindales: Sapindaceae), *Lagerstroemia* spp. and *Nandina domestica* Thunb. (Ranunculales: Berberidaceae) exhibited the highest pollinator visitation and richness. During the fourth period, native taxa such as *C. siliqua*, *Tamarix* spp. and *V. agnus-castus*, and non-native

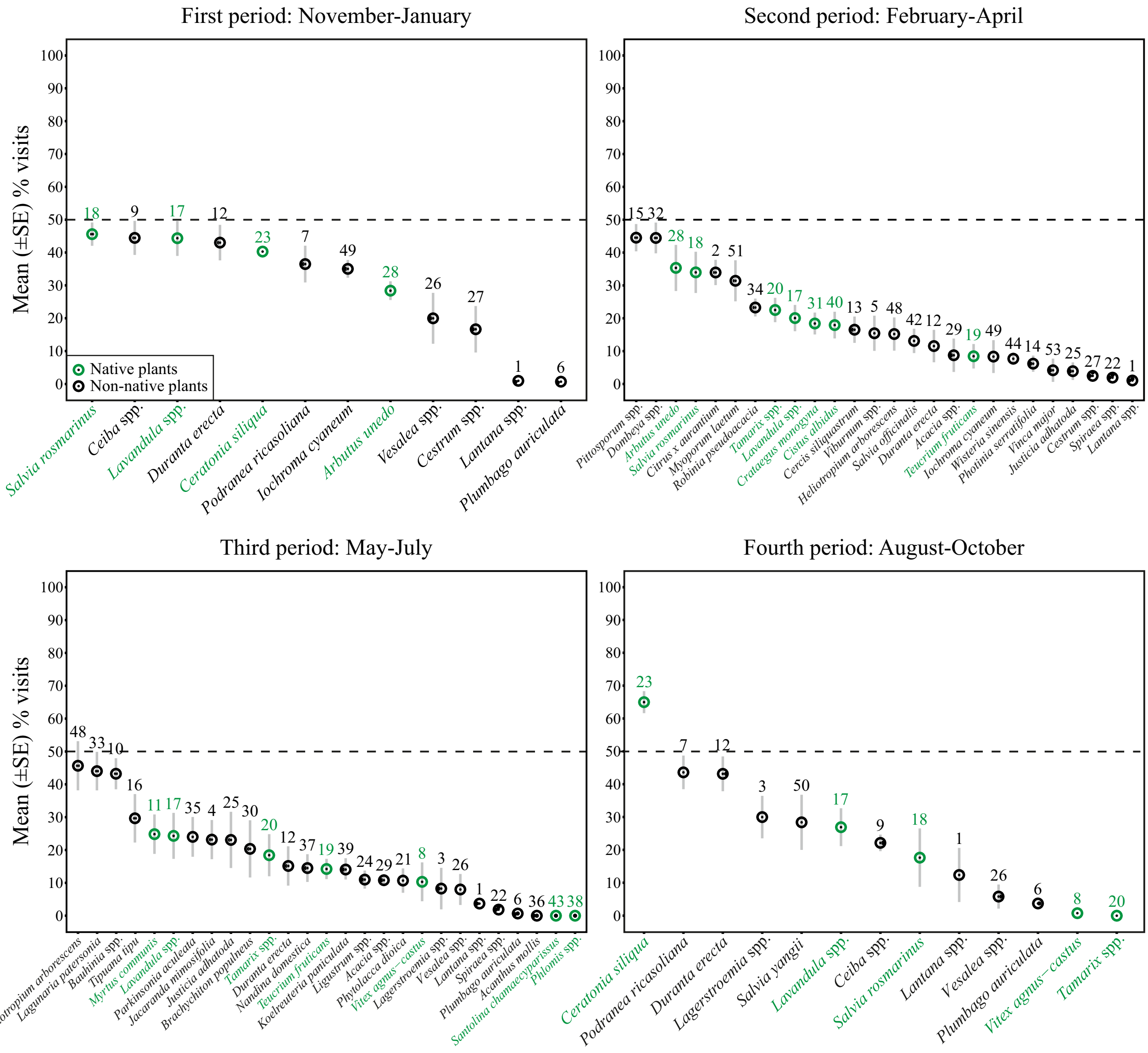


FIGURE 4 Use of ornamental plants by honeybees (*Apis mellifera*) per flowering phenology period. For each plant taxa (see numbers in Table S1 for more details), we calculated the percentage of floral visits (*y*-axis) relative to all plants combined, per park and month. Then, for each period, we averaged visits per plant taxa. Plant names (*x*-axis) linked to their assigned numbers are shown. Plant taxa in green colour are native and in black are non-native.

taxa such as *Parkinsonia aculeata* L. (Fabales: Fabaceae) and *Duranta erecta* L. (Lamiales: Verbenaceae) showed the greatest percentage of pollinator visits and richness.

Similarity in the exploitation of floral resources between pollinator groups

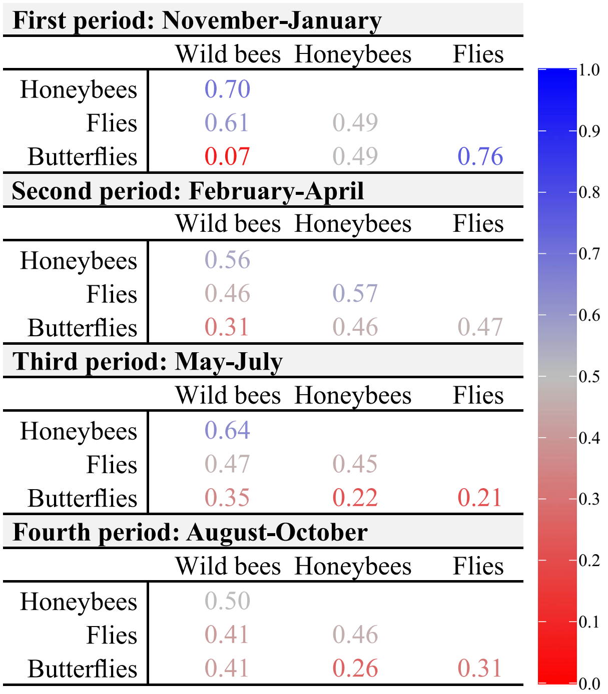
The exploitation of floral resources differed partially between pollinator groups (Figures 3 and 4, Tables 1 and S3). In general, overlap between pollinators was highest during the first period (when few plant taxa were in bloom) and decreased thereafter. Wild bee floral visits largely coincided with those of honeybees across all periods, whereas overlap with flies and butterflies was lower. Similarly, honeybee visits overlapped to a lesser extent with those of flies and butterflies. The overlap between fly and butterfly visits varied greatly between periods (Figure 3, Table 1).

Relationships of floral visits and pollinator richness with floral availability and plant origin

Honeybee visits were positively related to floral availability per taxon, although this effect was only marginally significant (Table 2). In contrast, floral availability had no significant effect on either visits or richness for the other pollinator groups (Table 2).

Plant origin, classified as native or non-native, showed variable effects on floral visits across pollinator group (Table 2). We observed

TABLE 1 Matrix of similarity in the exploitation of floral resources between pollinator groups. We used the Hulbert proportional similarity index, whose values range from 0 (no resource overlap) to 1 (complete resource overlap).



	Wild bees	Honeybees	Flies
First period: November-January			
Honeybees	0.70		
Flies	0.61	0.49	
Butterflies	0.07	0.49	0.76
Second period: February-April			
Honeybees	0.56		
Flies	0.46	0.57	
Butterflies	0.31	0.46	0.47
Third period: May-July			
Honeybees	0.64		
Flies	0.47	0.45	
Butterflies	0.35	0.22	0.21
Fourth period: August-October			
Honeybees	0.50		
Flies	0.41	0.46	
Butterflies	0.41	0.26	0.31

more visits to native plants by honeybees in the first period, wild bees in the third period, flies in the third and fourth periods, and butterflies in the fourth period. In contrast, only flies showed more visits to non-native plants in the second period, while no significant differences between native and non-native plants were observed for the remaining combinations.

Plant origin also had some significant effects on species richness across pollinator groups (Table 2). There was higher richness in native plants for wild bees in the third and fourth periods, and for flies in the third period. Conversely, there was higher richness in non-native plants only for flies in the second period, while no significant differences between native and non-native plants were observed for the remaining combinations.

DISCUSSION

Diversity and temporal trends of pollinators

There was a high diversity of pollinators in Seville's urban parks. Pollinators are commonly found in urban green spaces worldwide, provided they are not highly disturbed (e.g., Baldock et al., 2019; Banaszak-Cibicka et al., 2018; Wenzel et al., 2020). Most of the individuals observed were bees, followed by flies, while butterflies and beetles were poorly represented.

Bees are typically the most frequent group of pollinators in urban green spaces (Silva et al., 2023). Among bees, the managed social honeybee, *A. mellifera*, is the most common species (Hung et al., 2018). Honeybees typically move from hives located in or adjacent to cities to forage in patches with high densities of flowers (Steffan-Dewenter & Kuhn, 2003). In contrast, wild bees (non-honeybees) can benefit from small vegetation patches (Daniels et al., 2020; Vega & Küffer, 2021) and nest, for instance, in bare soil, human-built structures, and cracks and crevices—sites that, to some extent, can be found in urban environments. However, only a few species accounted for the majority of interactions among wild bees. This suggests that some generalist bee species may perform better than specialist species in cities, a pattern commonly observed in other studies (Silva et al., 2023).

Other pollinators such as flies (including hoverflies), butterflies and beetles are less common in urban areas than wild bees (Baldock et al., 2015; Theodorou et al., 2020). Their presence is largely dependent on the availability of specific resources where their larvae can feed and develop. These resources, which are often scarce or absent in cities, include some native plant species, decaying organic material and aquatic habitats, among others (Moquet et al., 2018; Winfree et al., 2011). However, it should be noted that these pollinators are neither as active in visiting flowers as bees nor do they tend to dominate plant-pollinator interactions (Neff & Simpson, 1993; Winfree, 2010), as has also been observed in natural areas around the city of Seville (Magrach et al., 2017).

Pollinator trends varied among groups throughout the year. Among Hymenoptera, honeybees were more abundant between late winter and early spring, while wild bee presence peaked in early summer. Although honeybee hives are not placed in Seville's urban parks, studies show that in natural areas honeybee abundance is linked to the abundance of hives in the surrounding landscape (González-Varo & Vilà, 2017; Trillo et al., 2021). Honeybees are long-distance flyers, and their temporal patterns are likely influenced by the movement of hives between colder to warmer locations. However, we cannot rule out a magnet effect of late-season mass-flowering crops close to the city (Holzschuh et al., 2016). For instance, sunflowers bloom between late spring and early summer, and the high density of crop flowers in the surrounding area could attract honeybees during those months, thereby diluting their abundance in urban parks. In contrast, temporal changes in wild bee composition may reflect differences in species' thermal tolerance optima and limits (Hamblin et al., 2017; Stone, 1993; Zaragoza-Trello et al., 2023). Here, bees from genera such as *Andrena* Fabricius, 1775 (Hymenoptera: Andrenidae) and *Anthophora* Latreille, 1803 (Hymenoptera: Apidae) appeared mainly at the beginning of the year, while smaller bees, such as *Lasioglossum*, *Anthidium* and *Megachile* species, which can tolerate extremely high temperatures (up to 35°C in the shade), were more common from late spring onwards. Similar phenological patterns have been observed in other nearby areas (Molina & Bartomeus, 2019).

Most fly and butterfly species appeared between late winter and early spring, and again in early autumn, while they were absent in mid

TABLE 2 Results of the generalised linear mixed models relating floral visits and species richness of each pollinator group to floral availability per plant taxa, plant origin (native vs. non-native taxa), period (first, second, third, fourth) and the interaction between plant origin and period.

Pollinator group	Model	Terms	Estimate/ratio	SE	*z*-Value/*t*-ratio	*p*-Value
Wild bees	Floral visits	Floral availability	−0.010	0.045	−0.229	0.818
		First period: native vs. non-native	1.21	0.517	0.443	0.657
		Second period: native vs. non-native	1.35	0.299	1.362	0.173
		Third period: native vs. non-native	1.82	0.362	3.028	**0.002****
		Fourth period: native vs. non-native	1.46	0.403	1.385	0.166
	Species richness	Floral availability	0.002	0.032	0.086	0.931
		First period: native vs. non-native	1.00	0.342	0.013	0.990
		Second period: native vs. non-native	1.23	0.188	1.324	0.186
		Third period: native vs. non-native	1.64	0.187	4.312	**<0.001*****
		Fourth period: native vs. non-native	1.46	0.259	2.123	**0.034***
Honeybees	Floral visits	Floral availability	0.137	0.079	1.735	0.082
		First period: native vs. non-native	3.44	1.275	3.330	**<0.001*****
		Second period: native vs. non-native	1.35	0.365	1.098	0.272
		Third period: native vs. non-native	1.05	0.297	0.16	0.873
		Fourth period: native vs. non-native	1.07	0.440	0.163	0.870
Flies	Floral visits	Floral availability	0.124	0.097	1.269	0.204
		First period: native vs. non-native	1.583	0.608	1.196	0.232
		Second period: native vs. non-native	0.543	0.147	−2.257	**0.024***
		Third period: native vs. non-native	2.303	0.689	2.787	**0.005****
		Fourth period: native vs. non-native	2.229	0.908	1.966	**0.049***
	Species richness	Floral availability	0.035	0.063	0.557	0.577
		First period: native vs. non-native	1.25	0.378	0.723	0.470
		Second period: native vs. non-native	0.54	0.115	−2.900	**0.003****
		Third period: native vs. non-native	1.56	0.376	1.849	0.064
		Fourth period: native vs. non-native	1.68	0.568	1.524	0.128
Butterflies	Floral visits	Floral availability	−0.359	0.237	−1.511	0.130
		First period: native vs. non-native	1.896	0.989	1.227	0.220
		Second period: native vs. non-native	0.605	0.229	−1.328	0.185
		Third period: native vs. non-native	0.839	0.524	−0.280	0.779
		Fourth period: native vs. non-native	6.236	3.826	2.983	**0.003****
Butterflies	Species richness	Floral availability	−0.232	0.200	−1.160	0.245
		First period: native vs. non-native	1.080	0.495	0.167	0.867
		Second period: native vs. non-native	0.637	0.222	−1.295	0.196
		Third period: native vs. non-native	1.182	0.657	0.301	0.763
		Fourth period: native vs. non-native	2.283	1.304	1.445	0.149

Note: See Figure 3 for indication of the corresponding months to each period. Significance levels: $^{***}p \leq 0.001$; $^{**}p \leq 0.01$; $^{*}p \leq 0.05$. Values in bold indicate significant results.

and late summer. These groups typically have multiple generations throughout the year (Aak et al., 2011; Richards, 1940). Since adults are usually generalist floral visitors, their presence largely depends on the availability of specific resources needed for larval development. For instance, the larvae of the two most abundant butterflies, *Pieris rapae*/*brassicae* Linnaeus, 1758 (Lepidoptera: Pieridae) and *V. atalanta*, feed primarily on plants in the Brassicaceae and Urticaceae families, respectively (Davis, 1989; Richards, 1940). These ruderal plants grow in urban gardens and along walkways almost year-round, although they are less common in summer—a pattern that mirrors the phenology of the insect adult stages. Another possible and complementary explanation for these peaks of abundance and scarcity could be related to the migratory habits of some fly and butterfly species (e.g., Suchan et al., 2018). Their activity is also related to their phenological sensitivity to seasonal changes in temperature. Summer temperatures in Seville reach 40°C (AEMET, 2024). Many butterfly species advance their flight period as temperatures increase in spring and decline their abundance with hot temperatures in summer (Colom et al., 2022).

Floral resource use and overlap between pollinators

The role that ornamental plant species play in supporting pollinators differed over time. Although we found the flowers of some taxa, such as *Lantana* spp., *Lavandula* L. (Lamiales: Lamiaceae) and *D. erecta*, almost all year round, most taxa flowered for an average of 4 months, mainly between late winter and early summer (i.e., from February to July). During those months, pollinators generally visited a wide range of plants whenever they were available in the parks. In contrast, in months of low resource diversity (i.e., from August to January), we observed that some plants generally had a more prominent role in attracting pollinators. These included the native plants *A. unedo*, *C. siliqua*, *S. rosmarinus*, *Tamarix* spp. and *V. agnus-castus*, as well as the non-native tree *P. aculeata*. The presence of native and non-native pollinator-attractive plants in parks during months with low resource availability may be essential for some species to thrive in urban habitats, as other studies have found (e.g., Staab et al., 2020; Zaninotto et al., 2023).

The exploitation of floral resources differed somewhat between pollinator groups and were dependent on the period. However, in general, wild bee and honeybee floral visits largely coincided. Some differences arose with specific plants such as *Ceiba* Mill. (Malvales: Malvaceae), *Citrus* × *aurantium* and *Pittosporum* spp., which were highly visited by honeybees. One explanation for this behaviour could be the large amount of nectar produced by these species, which attracts honeybees (Seeley, 1997). However, we need to consider that floral resource overlap may vary when compared between pollinator species rather than by groups. Species differences on visitation rates to a particular plant species might depend on demographic traits as well as on morphological traits such as body size and proboscis (Peralta et al., 2020).

Half of the taxa visited by bees were also visited by flies. Some plants like *Brachychiton populneus* (Schott & Endl.) R.Br. (Malvales: Malvaceae), *Viburnum* spp., *Tamarix* spp., *Ligustrum* L. (Lamiales: Oleaceae) and *S. chamaecyparissus* played an important role for flies. In general, some species of Diptera show preferences for plants with high nectar concentrations (Sutherland et al., 1999), yellow and white flower colours (Inouye et al., 2015), large inflorescences and/or flat corollas (Branquart & Hemptinne, 2000). Congruently, the plants most visited by flies have some of those traits.

Finally, Lepidoptera individuals particularly visited plants such as *A. unedo*, *Pittosporum* spp., *K. paniculata* and *V. agnus-castus* throughout the year. Butterflies feed on nectar, and beyond perceiving floral stimuli, their long proboscides allow them to access flowers with deep corollas (Corbet, 2000).

Plant origin and floral availability influence on pollinators

Floral visits and species richness of each pollinator group varied between native and non-native plants throughout the year. Native plants tended to be visited by a higher number and richness of pollinators than non-native plants in certain periods. This disagrees with observations conducted on natural areas where communities dominated by non-native enthomophilous plants compete for pollinators with native plants (Vilà et al., 2009) with negative consequences on their reproduction (Morales & Traveset, 2009). In urban parks, the results have been mixed, with some studies reporting non-native plants to be unattractive to pollinators (Garbuzov et al., 2017) while others showing the opposite (Garbuzov & Ratnieks, 2014). Non-native garden plants can partly substitute for native plants as resources for pollinators when native plants are seasonally scarce (Staab et al., 2020). Differences on the attractiveness of native and non-native ornamental plants to pollinators might depend on differences such as accessibility of nectar reward, pollen quality and mostly on differences in floral availability among species (Potts et al., 2003).

In our study, floral availability had a positive effect on honeybee visits, but not on wild bee, fly or butterfly visits. A preference for flower-rich patches by honeybees, along with their behaviour in communicating the location of such resources within the hive, could explain this pattern, as seen in other studies (González-Varo & Vilà, 2017). Instead, the abundance and richness of the other pollinator groups might be more dependent on other resources such as nesting sites than on flower availability because nest traits and nest environmental conditions requirements vary largely among species (Harmon-Threatt, 2020).

CONCLUSIONS AND RECOMMENDATIONS

Pollinators visiting ornamental plants in urban parks remained diverse throughout the year. To satisfy the full range of floral visitors, highly attractive and complementary plants for different pollinator groups should be cultivated. For instance, the native species *Myrtus communis* L. (Myrtales: Myrtaceae), *Teucrium fruticans* L. (Lamiales: Lamiaceae) and *V. agnus-castus* seem to be excellent plants for wild bees, while *Cistus albidus* L. (Malvales: Cistaceae), *Lavandula* spp. and *S. rosmarinus* are very attractive to honeybees. Similarly, *A. unedo*, *C. monogyna*, *Tamarix* spp. and *Viburnum tinus* L. (Dipsacales: Viburnaceae) would help to satisfy the needs of flies and butterflies.

The selection of non-native ornamental species should be done not only based on their attractiveness to pollinators but also avoiding cultivating those that are invasive (i.e., spread and cause impacts) such as for instance *Acacia* spp., *Lonicera japonica*, *P. aculeata*, *Robinia pseudoacacia*, *Wisteria sinensis* or *Lantana* spp. among many others (Bayón et al., 2022; González-Moreno et al., 2014).

AUTHOR CONTRIBUTIONS

Alejandro Trillo: Conceptualization; investigation; writing – original draft; methodology; formal analysis. **David Ragel-Celdrán:** Methodology; writing – review and editing; investigation. **Curro Molina:** Methodology; writing – review and editing; investigation. **Montserrat Vilà:** Conceptualization; investigation; funding acquisition; writing – review and editing; project administration; supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data are available in the Dryad Digital Repository (DOI: https://doi.org/10.5061/dryad.905qfttzv).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. Rarefaction curves of pollinator richness on plants observed for 30 consecutive minutes and sampled in different month in different urban parks in Seville. In the present study, the censuses lasted 20 min.

Figure S2. Cluster dendrogram: Flowering plant species phenology richness similarity (Jaccard similarity matrix) among months. We grouped the 12 censused months according to their similarity in flowering species and we obtained 4 separate clusters (periods).

Figure S3. Temporal dynamics predicted by the models (GAMs) in the average number of floral visits and species richness of each pollinator group per plant taxa over 12 consecutive months. The adjusted R^2 and the deviance explained of the models are shown. Dashed lines represent the 95% confident intervals. Notice that y-axes scales are different for each graph.

Table S1. List of the ornamental flowering plant taxa censured in 15 urban parks in Seville with indication of the number of parks where the plant taxa was present, the total number of 20 min censuses per plant taxa and their yearly phenology. Plant taxa in green and with asterisk are native taxa.

Table S2. List of the pollinator taxa recorded in 15 urban parks in Seville with indication of the number of parks where the pollinator was observed, the total number of observations and their yearly phenology. C = Coleoptera; D = Diptera; H = Hymenoptera; L = Lepidoptera.

Table S3. Interaction matrix between ornamental plants and pollinators in urban parks of Seville. Only pollinators identified up to family were included. Filled squares are observed interactions.

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