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Pollinator habitat enhancement through ornamental plants, floral traits and urban green area features for planning biodiversity-friendly cities

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HIGHLIGHTS

- Original data were collected from 7 Italian cities and 43 ornamental plants.
- Ornamentals and green area type varied in how they supported urban pollinators.
- Specific ornamental trait-insect associations indicate that trait variation is key.
- Within green areas, small scale heterogeneity increased pollinators on ornamentals.
- Key role of ornamentals and heterogeneity in urban planning to enhance habitats.

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ABSTRACT

Ornamental plants are chosen for aesthetics or suitability to urban conditions, while their contribution to habitat enhancement is usually not a priority. However, studies have shown that ornamentals could have potential for pollinators. It is a priority to rank ornamental plants, and to understand which floral traits or environmental conditions influence visitation by pollinators, for habitat enhancement and landscape planning. Here, we surveyed ornamental plant–pollinator interactions across seven Italian cities, in May, to quantify relative plant attractiveness in field conditions, elucidate flower trait-pollinator relationships, and assess habitat descriptors or green area type influences. By focusing on plant-pollinator interactions, 43 ornamental plants were ranked for the contribution to both pollinator abundance and species richness, or to specific groups or few insects. Single floral traits positively or negatively associated with specific insect groups: these diverse responses clarify that trait diversity is essential to support heterogeneous urban pollinators. Furthermore, more abundant and species-rich pollinators were found on plants in heterogeneous area conditions, and distinctions emerged across parks,

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historic villas and botanic gardens. Therefore, apart from intrinsic plant features, the design and management of green areas should focus on adequate ornamental plants with diverse floral traits and in heterogeneous habitat contexts, to develop urban green infrastructures for pollinators. Landscape planning and management of green areas could integrate biodiversity-based strategies with priority ornamental plants for pollinator interactions, or use flower traits when lists are not available, to trigger urban ecosystem functionality and enhance habitat quality.

1. Introduction

Plants in urban contexts are crucial elements for society and ecosystems, where plants in urban green areas are often chosen for their aesthetic properties or for their ability to thrive under challenging conditions. In these urban settings, landscape planners, public space designers and private garden owners commonly prioritize visually appealing flowers, typically favoring ornamental, often non-native, plants (Palmersheim et al., 2022). Although primarily selected for aesthetic purposes, ornamental plants sometimes contribute to ecosystem services: shade, habitat, and resources to animals, among others (Biella et al., 2025a; Francini et al., 2022). Therefore, ornamental plants can potentially represent important functional elements in urban ecosystems and for animal biodiversity. For instance, in the context of urban animals, birds may benefit from ornamental vegetation through enhanced foraging opportunities, shelter, and nesting sites (Idilfitri et al., 2014; Magre et al., 2019). In a similar way, urban pollinators obtain resources from flowers of ornamental plants (Honchar & Gnatiuk, 2020). Given the high abundance of ornamental plants in urban green spaces, it is essential to investigate the ecological roles they could play, towards planning strategies that balance human aesthetics and plant and animal diversity (Prokop et al., 2025; Toscano et al., 2025).

Pollinators are fundamental in urban areas for the ecosystem services they provide and contribute to, and therefore they are sometimes the object of specific urban plans to support their diversity (Bellamy et al., 2017; Daniels et al., 2020; Llodrà-Llabrés & Cariñanos, 2022). Pollinators often visit ornamental plants as a source of nutrition and, in fact, ornamental flowers are visited by bees and hoverflies in cities in Italy (Biella et al., 2022) or by hummingbirds in Brazil (Anselmo et al., 2023). A growing number of studies are focusing on this subject: in one, different varieties of the same species were evaluated to assess which one supported pollinators the most (Verweij et al., 2024). In other studies, ornamental species were compared against each other to determine which one is best for pollinators (Garbuzov et al., 2017; Honchar & Gnatiuk, 2020; Salisbury et al., 2025). However, most studies have targeted relatively young plants of mostly woody species kept in pots and in experimental settings, while field studies with established plants in real urban conditions are scarcer. Therefore, there is a need to better characterize how ornamental flora interacts with pollinators in urban conditions.

The potential role of ornamental flora to support pollinators can be appreciated in terms of the quality and the timing of the flower resources they offer (Ranalli et al., 2025): some ornamental plants could provide trophic resources in times when the native flora is not available (Staab et al., 2020; Tasker et al., 2020), or ornamental plants particularly rich in flower resources could support pollinators jointly with the native flora (Salisbury et al., 2015). However, a study analysing the pollen collected by urban honeybees found that only a few ornamental plants were a major pollen source, while many others were discarded (Sponsler et al., 2020). Moreover, marked preferences for specific ornamental plants were noticed when comparing different pollinator groups (Marquardt et al., 2021). In fact, horticulturally-modified varieties with showy flowers can be less attractive to bees because flower resources are not easily accessible (Mach & Potter, 2018). Other traits like corolla depth, colour, nectar composition and floral display area are found to be positively related to the abundance of pollinator groups (Erickson et al., 2022). Therefore, while the literature hints that not all ornamental plants are equally good for pollinators, it is necessary to focus on ranking plants that could contribute to pollinator conservation and habitat enhancement.

Knowledge regarding the extent to which ornamental plants benefit urban pollinators remains limited globally. Moreover, more research is needed to better understand the roles of habitat features and flower traits of ornamentals influencing the variation in pollinator attractiveness. In addition to small scale features and traits, urban areas are composed of green spaces that are heterogeneous in both design and history, and that serve diverse recreational, social and cultural functions. Consequently, different management strategies adopted in different types of green spaces can influence how much biodiversity can be found there. For instance, the use of unmown urban lawns clearly show that when ecosystem-thinking is applied instead of purely aesthetic values, then insect biodiversity increases (Biella et al., 2025b; Rada et al., 2024). Clearly, green spaces of different types may host distinct ornamental plants, which in turn can influence the composition and activity of the pollinator fauna (Silvert et al., 2023). For instance, historic gardens in villas usually feature plants of high aesthetic value: historic villas are usually described as living collections of plants chosen for their aesthetic value, both in Italy as well as elsewhere (Bartoli et al., 2026; Toscano et al., 2017). Botanic gardens host different kinds of plants for education, research, conservation, and aesthetic purposes (Blackmore, 2024). Instead, urban parks usually host plants mostly for shade and decoration (Jim, 2004). Therefore, since the urban flora is planted following different rationales and aims in different urban area types, it is expected that green area features and typology influence the ornamental plant attractivity for pollinators.

In this study, we investigated plant-pollinator interactions with ornamental plants used in several cities across Italy, with the aim to (1) rank established ornamental plants according to their contribution to pollinators in urban areas in the late spring, (2) understand how plant functional traits correlate to different pollinator groups to gain an understanding broader than plant taxonomy, and (3) compare three green area types (i.e., urban park, botanic garden and historic gardens in villas) and explore the role of small-scale habitat features in sustaining pollinator biodiversity via ornamental plants to provide information to landscape planning and local management. The first aim derives from the observation that various purposes lead to sowing different plants in the city, so that pollinators are not always prioritized in the choice: hence, we hypothesized that ornamental flora will differently contribute to pollinator support (Salisbury et al., 2025); moreover, the second aim stems from the hypothesis that specific plant traits would differently influence the flower visitation by distinct pollinator groups probably due to intrinsic insect preferences (Erickson et al., 2022; Verweij et al., 2024); the third aim derives from the hypothesis that habitat conditions will affect flower visitation because of the roles of biotic and environmental factors (Baldock et al., 2019; Neumann et al., 2024), similarly to what has been observed in non-urban contexts (Biella et al., 2025c), that could directly inform future landscape planning and design.

To test these hypotheses, we carried out a specific field campaign across multiple cities and urban contexts, taking Italy as a case study and thanks to the nationwide campaign “Biodiversity Sampling Week” promoted by the National Biodiversity Future Centre in May 2025. Although several studies previously investigated ornamental plants, botanical approaches featured plant diversity and conservation value in botanical gardens or urban parks without considering species interactions (e.g., Bartoli et al., 2026; Toscano et al., 2017). Other studies surveying ornamental flora and pollinators in many parts of the world usually covered a specific type of habitat (e.g. a set of gardens in a city as in Tasker et al., 2020) while here we surveyed and compared different urban habitat contexts. At the same time, our study evaluates the ornamental plants already growing in real urban conditions, while most studies on similar topics, worldwide, focused on potted experimental individuals in *ad-hoc* settings, that may not always recreate the real urban conditions (e.g. Erickson et al., 2021; Sponsler et al., 2020; Verweij et al., 2024). Therefore, the data collection of this study, covering several Italian cities, could show elements relevant to a broader geographical context in the context of urban planning of green infrastructure and local scale green area design and quality.

Within the growing body of literature targeting pollinators and plants in urban landscape planning, from spatial connectivity (Bellamy et al., 2017) to stakeholder engagement (Fischer et al., 2020), from habitat enhancement and urban *microinjections* of biodiversity (Biella et al., 2025a) to policy (Silva et al., 2020), this study could inform landscape and urban planning in several ways. Practically, we highlight the best plants that can be used by green area designers and landscape managers in other regions with compatible climates. In addition, for urban space design, we strengthen the understanding that specific plant traits and habitat features can support pollinator diversity and consequently also the role insects play in the society. Within the existing theories suggesting the integration of ecosystem-thinking to restore biodiversity contribution to the society (Seabrook et al., 2011; Yang et al., 2026), this study provides strong evidence that, in some environmental conditions, ornamental plants could potentially play a role for the ecological quality of urban green infrastructure and also for its connectivity (Minor et al., 2017). Hence, going beyond purely aesthetics ornamentation and instead focusing more on the ecological role in sustaining pollinators in urban ecosystems could lead the way to consider ornamental plants and floral traits as a potential asset in future urban design, planning and management of green spaces aimed at increasing urban biodiversity as claimed by emerging theories (Adedoja & Mallinger, 2024; Biella et al., 2025a; Casanelles-Abella & Egerer, 2026; Ellis et al., 2025; Yang et al., 2026).

2. Methods

2.1. Plant and site choice, sampling

Seven main Italian cities, representing the latitudinal and ecoregional variation of Italy, were included in the survey: Turin, Milan, Sassari, Florence, Siena, Rome, Naples. Ornamental plant species were not selected a priori but were identified during an initial field survey in each study site based on the flowering status, local abundance and accessibility for observation. Local abundance means that plant species were chosen to allow spatial replication of surveys across different plant individuals: this does not necessarily mean that sampling was biased exclusively towards dominant species. Pollinator visitation on adult ornamental flora already growing at the sites was surveyed across three urban habitats (urban park, urban historic garden in villas, and botanical garden): an urban park is a green area where plants are mostly chosen for shade and decoration, a historic garden usually features highly aesthetic vegetation and a botanic garden normally hosts various types of vegetation with several scopes, mostly education and conservation (Bartoli et al., 2026; Blackmore, 2024; Jim, 2004). For each site in each city, we selected between three (occasionally two) and a maximum of six flowering ornamental species, giving priority to plants that occurred in different surrounding contexts. For each plant species, pollinator observations were performed in May 2025 following established field protocols (Biella et al., 2025b): we monitored discrete sampling units (“plots”), defined as either one plant clump (one or two adjacent individuals) or a 1-m^2 area for herbaceous species, and set spatially distinct plots for each 10-min time-observation slot. Each species was surveyed through at least six replicate observation slots within a half-day sampling session, for at least two half-days (i.e., 12–24 replicates per species per site). Data were retrieved by an observer per plot, although different operators could be active at the same site or at different times. Plots were set in sunny conditions, and sampling did not occur under unfavourable weather. During each 10-min period, all insects entering the corolla (“flower visitors”) and contacting the inner parts of the flowers (i.e., collecting flower resources or dusting with pollen or touching the stigma) were recorded and assigned to functional groups: honeybees, bumblebees, other wild bees, syrphid flies, other dipterans (not syrphids), other flying hymenopterans (not bees), butterflies, and beetles. For each group, we quantified (a) abundance of individuals and (b) the morphospecies richness, the latter based on careful evaluations of body features, following previous successful field experiences (Biella et al., 2025b) where insects were sorted to morphospecies based on visible features to distinguish them from each other (e.g. color, size, color pattern, overall appearance, pilosity, etc) without necessarily assigning a taxonomic species name (Hackman et al., 2017).

In addition to pollinator observations, we recorded a set of environmental covariates for each sampling plot by annotating site and plot identities, target plant taxonomic identity, and the land-cover composition within a 20-m radius by means of a visual estimation of the percentage cover of lawn, flowerbeds, trees/shrubs, bare ground, built surfaces, water, and paths/streets, and the number of other flowering species in the vicinity.

The local scale land-cover composition variables were reduced to two main variables with a Principal Component Analysis (PCA, *prcomp* function in R, after log transformation to reduce the effect of overdominant features). This procedure of reducing the initial land cover variables to a set of few variables is ideal to avoid overparameterization. The coordinates of each sampling plot along the PCA ordination axes 1 and 2 were used to generate new variables: PC1 primarily represents the increasing compositional gradient from predominantly flowered greenery (flowerbeds) versus lawn and tree cover, while PC2 captures the decrease in built surfaces (paths, streets, buildings), supplementary information Fig. S1.

2.2. Functional traits of ornamental plants

For each focal plant species, we compiled a set of floral functional traits (Table 1): corolla morphology categorised as disk, tube, or gullet shape based on a similarity to the reference cases by Faegri and van der Pijl (1979); inflorescence (or flower) length and width in cm taken from available data in the literature, where estimates were averaged when multiple sources were available (see Supplementary Text S1); the number of open flowers, and plant height, both of which were measured in the field for each focal plant at each plot and then summed for the flower number and averaged for the height; to measure a floral reward trait, nectar sugar concentration was taken from the available data in the literature (estimates were averaged when multiple sources were available at the species level, otherwise genus-level means were used for unavailable species data; see Supplementary Text S1). We used traits measured in the field and other traits from the literature either when such traits are not variable across plots (e.g. flower shape) or because it was not always possible to collect novel field data for them in our case: however, since field surveys took place on plants in good vegetative conditions without visible signs of difficult growth, we assumed a high adherence between values reported in the literature and those expected in the field.

2.3. Data analysis

The cumulative pollinator abundance or morphospecies richness (of all groups together) were analysed at the plot level for each site and time using Generalized Linear Mixed Models with the *glmmTMB* function in R (Brooks et al., 2017; R Core Team, 2024) with the parameters presented

Table 1
Overview of the plant species included in this study and their flower traits.

Species	Family	Name code in Fig. 1	Number of open flowers per individual (average, measured)	Plant height per individual (cm, average, measured)	Flower shape (literature source)	Inflorescence or flower length (cm, average from literature sources)	Inflorescence or flower width (cm, average from literature sources)	Nectar sugar (% concentration, average from literature sources, species or genus level)
Acanthus mollis L.	Acanthaceae	Ac_moll	6.20	123.73	gullet	35	2	62.14
Acanthus spinosus L.	Acanthaceae	Ac_spin	50.00	150.00	gullet	105	2	63.965
Borago officinalis L.	Boraginaceae	Bo_offi	41.62	68.29	disk	2.15	2.15	39.085
Calendula officinalis L.	Asteraceae	Ca_offi	37.70	75.65	tube	8.75	8.75	52.65
Centranthus ruber (L.) DC.	Valerianaceae	Ce_rube	7375.00	120.00	tube	1.3	1.3	28
Cistus x hybridus/ Cistus x incanus	Cistaceae	Ci_hybr	36.75	70.00	disk	5	5	83.458
Cistus creticus L.	Cistaceae	Ci_cret	35.25	75.83	disk	4.75	4.75	83.458
Delosperma cooperi (Hook. f.) L.Bolus	Aizoaceae	De_coop	33.83	19.17	tube	4	4	55
Deutzia crenata Thunb.	Hydrangeaceae	De_cren	777.78	255.56	disk	2	2	37.464
Digitalis purpurea L.	Plantaginaceae	Di_purp	102.88	120.00	gullet	90	1.25	32.033
Elaeagnus angustifolia L.	Elaeagnaceae	El_angu	300.00	633.33	disk	2	1.5	38.85
Euphorbia platyphyllos L.	Euphorbiaceae	Eu_plat	133.83	87.50	disk	0.45	0.45	13.6
Euryops pectinatus (L.) DC.	Asteraceae	Eu_pect	812.50	130.83	tube	4	4	29.283
Gazania linearis (Rusby) Beauverd	Asteraceae	Ga_line	37.67	31.67	tube	5	5	29.283
Genista aetnensis Raf.	Fabaceae	Ge_aetn	524.10	188.50	gullet	10	4.5	0
Hakea sericea Schrad. & J.C. Wendl.	Proteaceae	Ha_seri	194.58	120.00	disk	4	2	30
Helichrysum italicum (Roth) G.Don	Asteraceae	He_ital	35.58	70.00	tube	0.75	0.75	45
Hydrangea quercifolia Bartr.	Hydrangeaceae	Hy_quer	30.58	199.17	disk	22.85	10.15	16.667
Kolkwitzia amabilis Graebn.	Caprifoliaceae	Ko_amab	311.11	283.33	gullet	8.5	4.5	28
Lantana camara L.	Verbenaceae	La_cama	34.00	124.17	tube	3.5	3.5	20.833
Lavandula dentata L.	Lamiaceae	La_dent	159.15	116.15	tube	8.5	1	31.46
Ligustrum chinense L.	Oleaceae	Li_chin	2395.07	288.07	tube	10	5.5	30
Ligustrum ovalifolium Hassk.	Oleaceae	Li_oval	8757.00	223.13	tube	10	5.5	30
Melaleuca citrina Sol. ex Gaertn.	Myrtaceae	Me_citr	22.17	350.00	gullet	5.5	3.5	10.5
Paeonia lactiflora Pall.	Paeoniaceae	Pa_lact	19.83	70.00	disk	12.5	12.5	23
Papaver croceum Ledeb.	Papaveraceae	Pa_croc	5.00	50.00	disk	8	8	0
Philadelphus coronarius L.	Hydrangeaceae	Ph_coro	224.72	231.51	disk	3	3	41.708
Philadelphus x virginalis	Hydrangeaceae	Ph_xvir	194.40	235.00	disk	3	3	41.708
Phlomis fruticosa L.	Lamiaceae	Ph_frut	875.59	132.22	gullet	30	4	57.42
Pittosporum tobira (Thunb.) W.T. Aiton	Pittosporaceae	Pi_tobi	1316.14	305.71	disk	2	1.5	27.351
Pyracantha koidzumii (Lynes) Bean	Rosaceae	Py_koid	3916.67	90.00	disk	4.5	4.5	22.667

(continued on next page)

Table 1 (*continued*)

Species	Family	Name code in Fig. 1	Number of open flowers per individual (average, measured)	Plant height per individual (cm, average, measured)	Flower shape (literature source)	Inflorescence or flower length (cm, average from literature sources)	Inflorescence or flower width (cm, average from literature sources)	Nectar sugar (% concentration, average from literature sources, species or genus level)
Rosa abietina Gren. & Godr.	Rosaceae	Ro_abie	45.00	127.50	disk	6.5	6.5	18
Rosa x hybrida	Rosaceae	Ro_hybr	283.00	95.00	disk	6.5	6.5	18
Rosa 'iceberg'	Rosaceae	Ro_iceb	32.29	200.00	disk	7.5	7.5	18
Rosa pendulina L.	Rosaceae	Ro_pend	32.78	113.75	disk	5	5	18
Rosa rifiorentissima Franch. & Rochebr. ex Crép.	Rosaceae	Ro_rifi	15.00	113.33	disk	4	4	24
Rosa x damascena	Rosaceae	Ro_xdam	75.67	226.67	disk	5.5	5.5	18
Salvia desoleana Atzei & Picci	Lamiaceae	Sa_deso	180.40	145.67	gullet	20	3.5	39.281
Salvia microphylla Kunth	Lamiaceae	Sa_micr	144.45	60.45	gullet	12.5	2	31.78
Spiraea japonica L.	Rosaceae	Sp_japo	890.00	50.00	disk	4.5	4.5	60
Tagetes erecta L.	Asteraceae	Ta_erec	3.00	20.00	tube	8	8	11.833
Viola lutea Huds.	Violaceae	Vi_lute	10.33	16.67	tube	1.5	1.5	22.66
Westringia fruticosa (Willd.) Druce	Lamiaceae	We_frut	109.60	125.33	gullet	4	2	40.091

below depending on the focus of the analysis.

To address the first aim of ranking plant species contribution to urban pollinators, we performed a regression by including the plant species taxonomic identity, the local environmental and sampling features as predictors to account for local scale environmental variables when comparing plants with each other. In other words, the fixed effects consisted of variables describing the sampling conditions and site characteristics, such as temperature, time of day, the size of the green area, the number of flowering plants (all scaled), and vegetated cover (PC1) and unbuilt cover (PC2) from the PCA variables. Response variables were either the abundance or the morphospecies richness, with a negative binomial error distribution to account for overdispersed count data and two random factors on the intercept, one with the day sampling nested within city and one with operator nested within site. The random effects describe that different cities were not always surveyed on same day for various reasons including feasibility and weather conditions, and, for the second random factor, we accounted for variations generated from different operators being active at different sites, while also not overlapping with the specifications of the first random factor. Predictor significances were tested with a Wald chi-square test (*Anova* function in the package *car* in R, Fox and Weisberg, 2019).

To test if urban green area type influences pollinators, together with sampling conditions and site characteristics, we repeated the above regressions by replacing plant identity with green area type included as fixed effects ("villa", "park", "botanic garden") in the models. While allowing us to focus on area type instead of plant identity, this analysis avoided collinearity especially between area type and plant identity: as clear from the Table S1, in some cases plants were surveyed in one or few green area types. The models included variables such as temperature, time of day, the size of the green area, the number of flowering plants (all scaled) and vegetated (PC1) and unbuilt (PC2) covers. Predictor significances were tested with a Wald chi-square test (*Anova* function in the package *car* in R). To test differences in green area type, a post-hoc test was performed with the *glht* function in R and the Benjamini-Hochberg p-value adjustment (Hothorn et al., 2008). Estimated intercepts for the random effect of the cities were plotted with the confidence intervals retrieved from 1000 bootstrapping with the function *bootMer* in *lme4* package in R.

The relationship between pollinator abundance and floral functional traits was analyzed using a generalized latent variable model (GLLVM) with a negative binomial distribution, with the *gllvm* package in R (Niku et al., 2019, 2025). The multivariate response matrix of pollinator abundances for each sampling plot, in each site and at each time was modelled as a function of floral traits, including the number of flowers in the plant per plot, plant height of the plant per plot, the flower shape (gullet, tube, disk shape), the inflorescence length, the inflorescence width, and the % of sugar concentration in the nectar (all numerical predictors were standardized by scaling), after checking for collinearity with the VIF index. To account for temporal variation in pollinator activity, time of day and air temperature were included as covariates in the latent variable formulation, and two latent variables were fitted to capture residual correlations among pollinator groups not explained by measured traits and environmental covariates. The hierarchical sampling structure was incorporated through random intercepts for city, site, and plant family.

3. Results

In this study, 43 ornamental plant species were surveyed in 7 main Italian cities from 3 main habitats: historic villas, urban parks, botanic gardens (see Supplementary Table S1 for a complete list of plants in each area type and city). The total amount of insects found, summing all plots, were: 476 bumblebee individuals, 2686 honeybees, 2582 other wild bees, 975 hoverflies, 1050 flies, 166 wasps, 99 butterflies, and 1255 beetles belonging to various morphospecies.

Ornamental plants of different taxonomic identity had different roles in shaping the abundance or richness of pollinators, after accounting for local scale environmental factors and sampling (Fig. 1). Plant identity was a significant predictor in the model (Table 2). Some plants did little for pollinators (e.g. *Viola lutea*, *Tagetes erecta*, or *Acanthus mollis*); other plants increased both abundance and richness at the same time as shown, in the plot, by the means estimated from the statistical models of the abundance being nearby to means of the richness in Fig. 1 (e.g. *Pyracantha koidzumii* or *Deutzia crenata*); Other plants increased mostly the abundance while did not increase the richness as given by estimated means being very distanced in the plot (e.g. *Borago officinalis* or *Cistus hybridus*). Other plants only marginally increased abundance or richness (e.g. *Papaver croceum* or *Rosa pendulina)*. In this analysis, plant species identity was a significant predictor, while habitat and sampling variable influences were aligned with what resulted in the analysis below

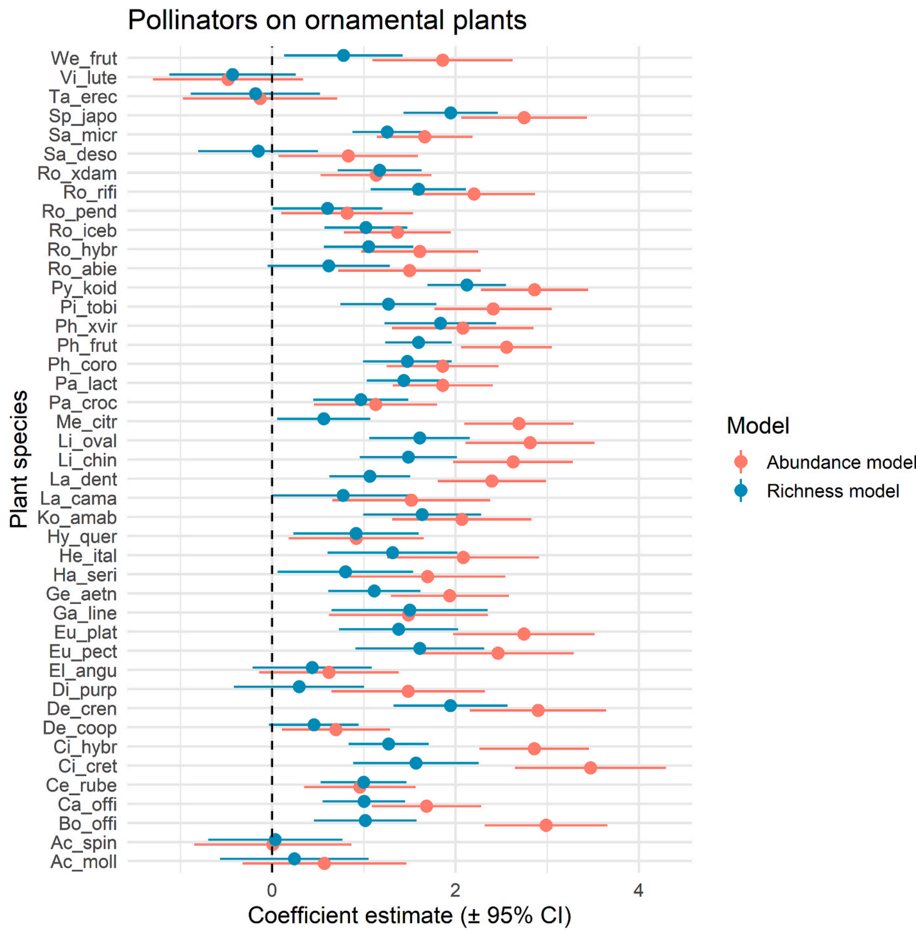

Fig. 1. Ornamental plant contribution to pollinator abundance and species richness (the two colors), the estimated regression coefficients and confidence intervals from a regression model are shown. For each plant, when the estimates are near each other, it means that a plant similarly contributes to both pollinator richness and abundance. Abbreviations are as follows: Ac_moll = *Acanthus mollis*, Ac_spin = *Acanthus spinosus*, Bo_offi = *Borago officinalis*, Ca_offi = *Calendula officinalis*, Ce_rube = *Centranthus ruber*, Ci_cret = *Cistus creticus*, Ci_hybr = *Cistus x hybridus/Cistus x incanus*, De_coop = *Delosperma cooperi*, De_cren = *Deutzia crenata*, Di_purp = *Digitalis purpurea*, El_angu = *Elaeagnus angustifolia*, Eu_pect = *Euphorbia platyphyllos*, Eu_plat = *Euryops pectinatus*, Ga_line = *Gazania linearis*, Ge_aetn = *Genista aetnensis*, Ha_seri = *Hakea sericea*, He_ital = *Helichrysum italicum*, Hy_quer = *Hydrangea quercifolia*, Ko_amab = *Kolkwitzia amabilis*, La_cama = *Lantana camara*, La_dent = *Lavandula dentata*, Li_chin = *Ligustrum chinense*, Li_oval = *Ligustrum ovalifolium*, Me_citr = *Melaleuca citrina*, Pa_croc = *Papaver croceum*, Pa_lact = *Paeonia lactiflora*, Ph_coro = *Philadelphus coronarius*, Ph_frut = *Philadelphus x virginalis*, Ph_xvir = *Phlomis fruticosa*, Pi_tobi = *Pittosporum tobira*, Py_koid = *Pyracantha koidzumii*, Ro_abie = *Rosa abietina*, Ro_hybr = *Rosa x hybrida*, Ro_iceb = *Rosa 'iceberg'*, Ro_pend = *Rosa pendulina*, Ro_rifi = *Rosa rifiorentissima*, Ro_xdam = *Rosa x damascena*, Sa_deso = *Salvia desoleana*, Sa_micr = *Salvia microphylla*, Sp_japo = *Spiraea japonica*, Ta_erec = *Tagetes erecta*, Vi_lute = *Viola lutea*, We_frut = *Westringia fruticosa*.

focusing on the role of habitat conditions (Table 2).

Pollinator groups responded differently to different plant traits, and there was not a single plant trait that increased uniformly all pollinator groups (Fig. 2). Considering the responses of pollinator groups across traits, wild bees were positively and significantly correlated to flower amount, disk-shaped corollas, longer inflorescenses and higher nectar sugar concentration, and with a negative relationship with larger inflorescences. Honeybees benefited from disk- shaped flowers, and longer inflorescences. Bumblebees increased with longer inflorescences but decreased with higher flower number on the plant and gullet flowers. Flies were negatively associated with greater plant height (marginally significant, p value = 0.052), larger inflorescences (marginally significant, p value = 0.061), and higher nectar sugar concentration. Hoverflies decreased with increasing inflorescence length, and nectar sugar concentration. Butterflies were negatively affected by taller plants and tube-shaped flowers. Beetles increased with disk-shaped flowers. Wasps were negatively associated with disk- and gullet-shaped flowers, with larger inflorescences and with higher nectar sugar concentration. Time of sampling did not influence the ordination (latent variable 1: 0.106, p value = 0.26, latent variable 2: 0.004, p value = 0.93), and temperature as well (latent variable 1: - 0.17, p value = 0.93, latent variable 2: 0.003, p value = 0.98).

Pollinator abundance and richness similarly responded to the variables describing sampling and environmental features (Fig. 3, Table 3). For both cases, green area type was a significant or marginally significant predictor, with the villa having significantly fewer pollinators than the other two habitat types. The sampling variable of the air temperature increased pollinator abundances, while the progression in the sampling hour of the day decreased both pollinator abundance and richness. PC1 and PC2 proportionally increased and decreased pollinators, respectively and explained 31.3% and 25.1% of the variability in local land cover across plots (Fig. S1), with negligible differences across cities (Fig. S2). However, area size and the number of flowering species were not significant predictors. Regarding the role of the cities where the study was conducted, the random intercept did not reveal major differences across cities for pollinator abundance and richness (Fig. 3C).

4. Discussion

In this study, we evaluated how ornamental plants influenced urban pollinator biodiversity parameters (abundance and species richness) with the scope of ranking plants for their contribution to habitat

Table 2
Pollinators on ornamental plants. Pollinator regression models in relation to plant species identity, sampling time and air temperature, area size, the flowering species richness, the PC1 and 2 of the local land cover; for each predictor, the estimated coefficients (but for each plant species see figure 1), *Chi squared* and significances from Wald tests (in bold when < 0.05) are indicated.

		Estimated coefficient	Chisq	Df	P value
Abundance	Plant species		667.304	43	**< 0.001**
	Temperature	0.065	2.904	1	0.088
	Time	−0.164	32.843	1	**< 0.001**
	Area size	0.019	0.069	1	0.793
	No. Flowered species	0.009	0.039	1	0.843
	PC1 flowered	0.116	12.486	1	**< 0.001**
	PC2 unbuilt	−0.082	7.023	1	**< 0.01**
Richness	Plant species		458.086	43	**< 0.001**
	Temperature	0.019	0.412	1	0.521
	Time	−0.122	29.162	1	**< 0.001**
	Area size	−0.084	1.833	1	0.176
	No. Flowered species	0.061	2.601	1	0.107
	PC1 flowered	0.064	6.585	1	**< 0.05**
	PC2 unbuilt	−0.022	0.739	1	0.39

enhancement, and to understand the roles played by plant traits and environmental factors at the local scale. We wanted to provide a biodiversity-friendly view to urban planning and green area design that could consider the roles of ornamental plants, their traits and the environments beyond aesthetics. We found important differences among plants commonly used for ornamental purposes, in terms of pollinator support, with influences by habitat features and plant traits in the interaction with specific groups of pollinators. It is important to stress that our study focused on plants used in Italy in urban green areas and flowering in late spring and at the beginning of the summer, but our results could be integrated by existing or future studies from other parts of the world and, possibly, covering more time within the favourable season. Moreover, by using traits and urban habitat variables, we went beyond ranking the ornamental plants useful for pollinators by providing correlates between flower traits and pollinator group: this view on traits could potentially provide a working hypothesis on or even expectations on the role of other plants for pollinators, not directly tested here, that could be tested in future. Nevertheless, our study may not apply to the dynamics of originally ornamental plants that become integrated into natural contexts, as in the case of invasive species introduced for ormanetal purposes (e.g., Tiedeken et al., 2016). Therefore, our results may be considered in the context of urban green areas and ornamental plants that need to be planted by humans, and in the design of urban green areas, gardens, parks, small urban surfaces, with the scope of enhancing habitats and provide support to urban biodiversity (Casanelles-Abella & Egerer, 2026; Ranalli et al., 2025).

When we tested how ornamental plants may enhance pollinator biodiversity, we clearly found different cases. Some ornamental plants increased both pollinator abundance and richness at the same time, while others weakly or did not contribute to them. Intriguingly, some of the tested plants increased pollinator abundance but not their richness, thus showing that they support only a subset of the pollinator community (i.e. many individuals of a few species). Therefore, the ornamental flora, in spite of being a result of an artificial process, resembles natural communities where specialists and generalist plants coexist and share or compete for pollinators (Biella et al., 2017, 2020). A similar conclusion is highlighted in a study from North America, where some garden plants are highly attractive to pollinators while others are much less interesting to them (Lowenstein et al., 2019). Other studies that systematically compared the actual capacity of ornamental plants to support pollinators reached a similar conclusion in many parts of the world, in spite of different geographies and examined species sets (Garbuzov et al., 2015; Verweij et al., 2024). Ornamental cultivars are not always attractive to pollinators and this might depend on the floral traits selected by plant growers (Ricker et al., 2019). This result clarifies that, given the limited availability of space in urban areas, choosing ornamental plants that support not only numerous pollinators but also of different kinds is crucial for enhancing the green area quality in view of sustainable urban development, connectivity and in the context of design, planning, management of the green areas (Seabrook et al., 2011).

To understand why an ornamental plant is or is not attractive to pollinators, we looked for hints from plant traits and local environmental conditions, based on features correlating with pollinator abundance or richness on ornamental plants. Regarding traits, several studies tried to sort out how floral traits could explain the plant performance for attracting pollinators in the context of ornamental flora (Erickson et al., 2022; Wang et al., 2024). Some studies focused on flower rewards, as a study showed that bee visitation among cultivars varied directly with the sugar content and it's accessibility via the corolla tube depth (Verweij et al., 2024). Similarly, another study showed that pollinators preferred cultivars with many flower units (Marquardt et al., 2021), suggesting a key role of rewards. Thus, some ornamental plants could be a valuable nutritional resource for pollinators in urban contexts (Erickson et al., 2021, 2022; Palmersheim et al., 2022). In our analysis, we found that sugar concentration in nectar is especially important for wild bees, but not for other flower-visiting insects, or at least not linearly, which may be interested in other floral cues or reward types. Several insect groups were attracted to plants with longer inflorescens, although some groups did not correlate with showy flower displays (length and width of inflorescence or flowers) and single groups correlated with specific flower shapes. Therefore, the analysis remarks the importance of different flower traits, clearly showing that there is not a plant feature to "rule them all", but that specific pollinator groups were either positively or negatively associated with different sets of floral traits. This is not surprising given that urban pollinators are complex communities with different preferences and life cycles (Erickson et al., 2021, 2022; Wang et al., 2024). Therefore, from our study, results show that ornamental plants with different sets of traits could correlate with the heterogeneous composition of urban pollinator communities. Providing ornamentals with various floral traits is fundamental for the design of green spaces to support pollinators. This view also aligns with the current theories stressing the importance of flower traits into urban design and management (Adedoja & Mallinger, 2024; Llodrà-Llabrés & Cariñanos, 2022) and, more generally, into practical schemes on how to enhance the quality of the urban green infrastructure valuing ornamental plants that could integrate urban spontaneous flora (Ranalli et al., 2025).

The analysis on the effect of environmental features and green area types on pollinator visitation revealed differences between habitat types and their descriptors. However, while differences across cities did not emerge as a relevant aspect in our current analytical framework, it is possible that influences arise from cumulative processes from historical development, urban design strategies across time and latitude, that our sampling design cannot describe. As a future perspective, documenting in more detail the city-level parameters could provide an additional insight into the ornamental plant roles in sustaining pollinators. Nevertheless, we focused on the factors taking place within the green areas, that could provide essential information for future green area design in general, beyond the regionality of the specific cities where our study took place. We found that pollinators were more abundant and species-rich on ornamental plants surrounded by heterogeneous land cover at a small scale, given the positive contribution of both flowerbed cover and sealed surfaces. This is a result with direct implications for urban planning and green space design: making future spaces could take

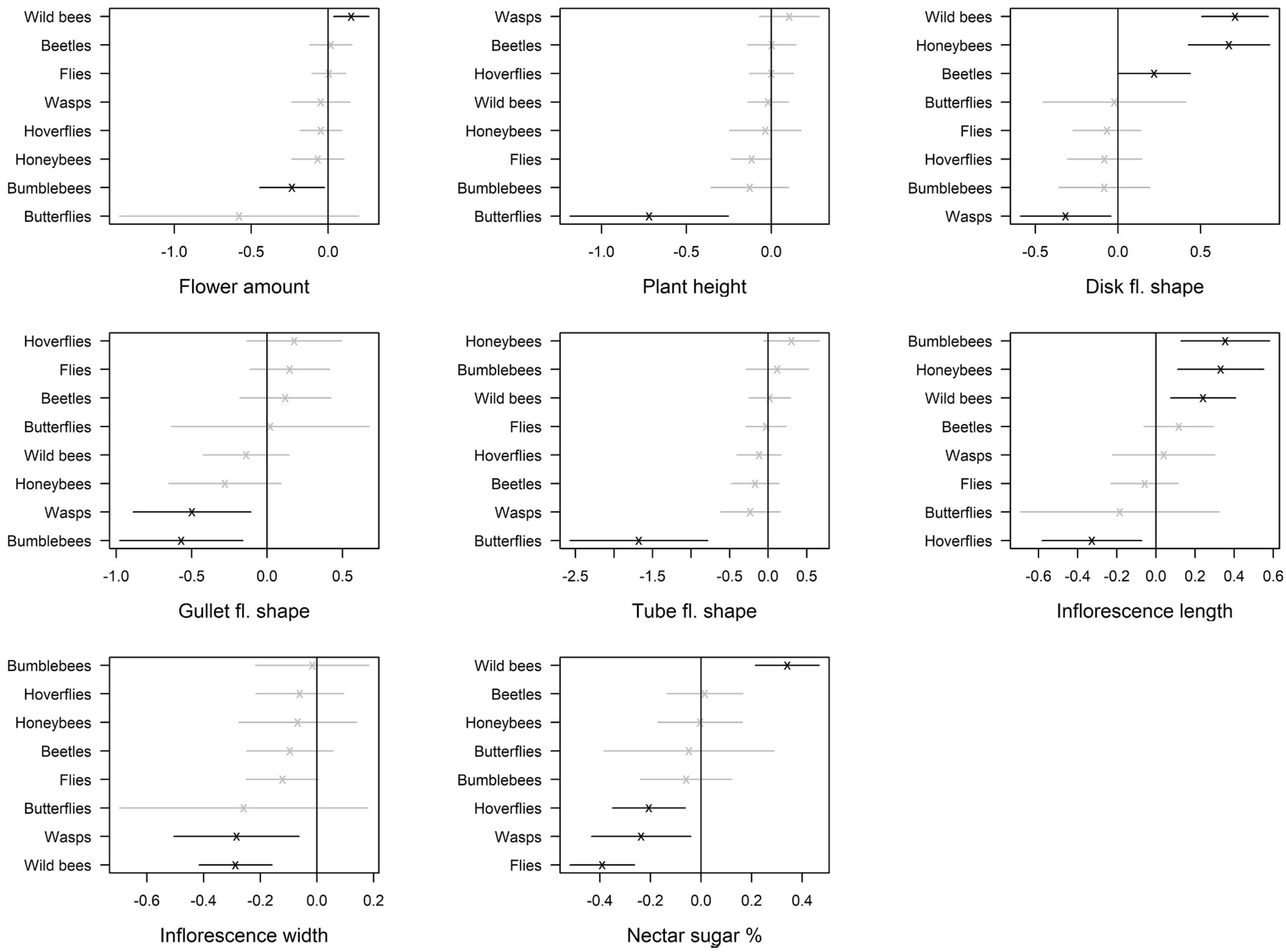

Fig. 2. Pollinator group abundance in relation to ornamental floral traits. Estimated regression coefficients and confidence intervals are plotted after controlling for sampling time and temperature; significant cases are in black, otherwise in light grey.

into account that having heterogeneous small-scale surfaces could enhance pollinators. In fact, previous studies on urban lawns or meadows have shown that habitat features like flower richness or the type and height of herbs are crucial features (Biella et al., 2025b; Biella et al., 2025c; Neumann et al., 2024). Instead, here, by focusing on ornamental plants, we found that the local land cover was fundamental, and therefore the green area small-scale previous design. Similarly to our results, previous studies also described the role of the local share of built-up areas on the variance in urban pollinator visitation (Dylewski et al., 2020). In addition to sealed surfaces, we found that an increased proportion of flowerbeds, instead of mere green surfaces, is also a fundamental feature in the urban green area visitation on ornamental plants. Intriguingly, a recent study explained the increased visitation of pollinators on urban plants with an “oasis effect”, where limited greenspace resources concentrate pollinating insects (Ellis et al., 2025), which would explain the intersecting influence of both greening and sealed land covers on urban ornamental plants. It is important to stress that plant species richness, the abundance of other flowering plants, and the patch size of the plant cluster are other important possible descriptors of habitat heterogeneity that could potentially influence the ornamental plant attractivity to pollinators. From our analyses, it emerges that the small-scale environmental heterogeneity surrounding ornamental plants can support a rich community of insect pollinators in urban areas, in line with previous research (Hosler et al., 2025).

Local habitat conditions could eventually scale up to the level of the entire green area infrastructure, that supports pollinators in different ways. In previous studies, great differences in pollinator biodiversity were found across green area types (Baldock et al., 2019; Dylewski et al., 2019; Threlfall et al., 2015), and therefore it is not surprising that we also recorded distinctions across parks, historic gardens in villas and botanic gardens in the pollinator visitation to urban plants. In the case of this result, crucial information could be taken as reference for future urban planning: Interestingly, the fact that area size was not statistically significant could point to the role of the overall area design and management, rather than the geographical properties of the area alone (Daniels et al., 2020). The fact that historic villas hosted fewer pollinators than the other two green area types could be due to a case of aesthetic design overcoming pollinator awareness, perhaps due to the use of highly aesthetic ornamental plants or intense management of the green cover. The priority to aesthetic values results from the idea of a ‘perfect lawn’, which often precedes the aims of habitat enhancement for biodiversity (Burr et al., 2018), while reducing the frequency of mowing in urban green spaces can sensibly increase insect biodiversity (Biella et al., 2025b; Lerman et al., 2018). To support pollinators and enhance habitats, it is important to shift away from mere aesthetic values and integrate more ecosystem-centered ideas by implementing simple, yet effective, biodiversity-friendly practices in urban green areas (Biella et al., 2025a).

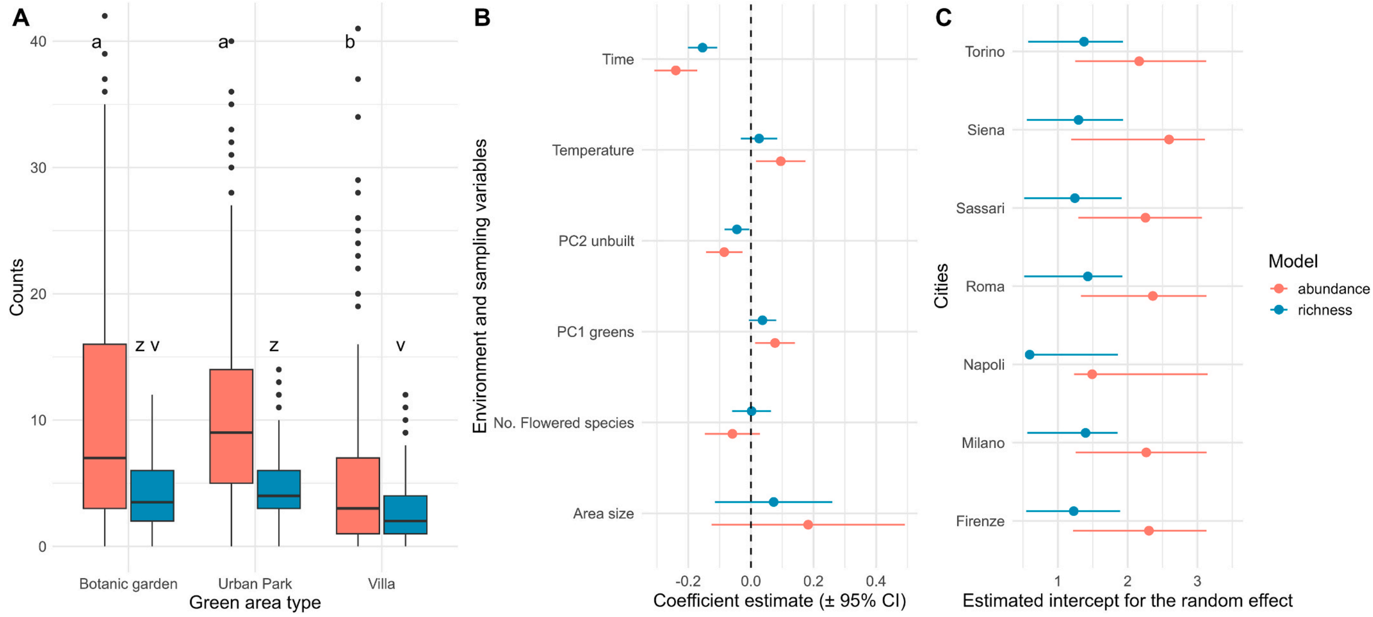

Fig. 3. Pollinator abundance and richness on ornamental plants in relation to (A) three green area types, (B) local environmental features and (C) cities. The variables are a part of the same model but are represented graphically in different plots. In plot (A), boxplots of the raw data are shown and significantly different estimated means are indicated with different letters; in (B) estimated regression coefficients and confidence intervals are shown for the other variables in the model; in (C) estimated intercepts for the random effect of the cities are shown with confidence intervals from bootstrapping.

5. Conclusions

In this study, we described differences between ornamental plants for ranking them for practitioners and urban designers aiming at urban habitat enhancement, and primarily for pollinators. It is important to remark that our study could be relevant at various levels of urban planning, for instance within the existing frameworks attempting the establishment of best practices for the enhancement of multi-taxa urban biodiversity (Biella et al., 2025a), and by means of co-design processes for society engagement, dedicated policies, area prioritization and educational campaigns on pollinators (Ranalli et al., 2025). Key ornamental plants and their trait diversity could also be included into plans increasing connectivity and enhancing habitat quality of suboptimal green areas (Casanelles-Abella & Egerer, 2026). Ornamentals of potential quality could also contribute to realizing schemes mainstreaming biodiversity into urban planning across green spaces and leveraging policy, society and biological needs (Sen & Dhote, 2023). Therefore, ornamentals could be considered essential components of the green infrastructure because they potentially contribute to green connectivity, habitat quality for wildlife and provide benefits to the society (Minor et al., 2017). Our results imply that, in green area planning, design and management, mere aesthetic rationales applied to plants are to be replaced by or integrated with ecosystem-thinking to support biodiversity in cities and their benefits to society.

We showed that some ornamental plants are more effective than others in attracting pollinators, that some plants enhance various kinds of pollinators and that heterogeneous local conditions in the green areas were a key factor for urban pollinators. Hence, landscape designers and green area practitioners could choose the best plants for pollinators and promote a variety of conditions in the local environment instead of homogeneity. However, the set of plants and environmental conditions we tested are mainly relevant to parts of the world where those plants are in use, in turn, the set of plants studied here could be integrated with other studies to cover broader areas and season times. Moreover, since we used plant traits to have a correlative understanding on which plant features contribute to increase pollinators, floral traits could provide a working hypothesis on choosing other ornamentals for pollinator support (Llodrà-Llabrés & Cariñanos, 2022). Specifically, since different plant traits correlated to different pollinator groups, ornamental plants assuring complexity and functional redundancy should be prioritized instead of homogenous plant compositions in a given urban green area, to create sustainable green spaces that will host functionally diverse pollinators and plants (Adedoja & Mallinger, 2024). The findings from our study could also be intersected with other ways to support pollinators: low-intensity management practices on the lawn and urban meadows (Biella et al., 2025b; Moldoveanu et al., 2025), tools for planning urban green spaces in light of increasing pollinators (Graffigna et al., 2025), and ecosystem-thinking in the green space design (Adedoja & Mallinger, 2024; Biella et al., 2025a).

CRediT authorship contribution statement

Paolo Biella: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Giulia Brambilla:** Writing – review & editing, Investigation, Data curation. **Valentina Verduci:** Writing – review & editing, Investigation, Data curation. **Matteo Annessi:** Writing – review & editing, Investigation. **Andrea Beltramini:** Writing – review & editing, Investigation. **Lorenzo Bianco:** Writing – review & editing, Investigation. **Daniele Calabrese:** Writing – review & editing, Investigation. **Francesca Romana Dani:** Writing – review & editing, Methodology. **Marta Depetris:** Writing – review & editing, Investigation. **Andrea Di Giulio:** Writing – review & editing, Methodology. **Andrea Ferrari:** Writing – review & editing, Investigation. **Jessica Frigerio:** Writing – review & editing, Investigation. **Gianni Henson:** Writing – review & editing, Investigation. **Martino Maggioni:** Writing – review & editing, Investigation. **Francesca Martelli:** Writing – review & editing, Investigation. **Oana Catalina Moldoveanu:** Writing – review & editing, Investigation. **Jorge Sanchez Navarro:** Writing – review & editing, Investigation. **Massimo Nepi:** Writing – review & editing, Methodology. **Emily Rose Palm:** Writing – review & editing, Investigation. **Irene Piccini:** Writing – review & editing, Investigation. **Carlo Polidori:** Writing – review & editing, Methodology. **Michelina Pusceddu:** Writing – review & editing, Investigation. **Fausto Ramazzotti:** Writing – review & editing, Investigation. **Enrico Ruzzier:** Writing – review & editing, Investigation. **Alberto Satta:** Writing – review & editing,

Table 3
Pollinators in green area types. Pollinator regression models in relation to green area type, sampling time and air temperature, area size, the flowering species richness, the PC1 and 2 of the local land cover; for each predictor estimated effects, *Chi squared* and significances from Wald chi-square tests (in bold when < 0.05, underlined if marginally significant, that is when p < 0.1) are indicated. Differences between green area types are tested with a post-hoc test.

		Estimated coefficient or difference in log scale	Chi squared	d. f.	P value
Abundance	Type= Botanic garden	0.326	5.710	2	0.058
	Type= Park	0.299			
	Type= Villa	−0.625			
	Type= Botanic garden − Park	0.0273			0.9335
	Type= Botanic garden − Villa	0.9511			0.0432
	Type= Park − Villa	0.9239			0.0432
	Temperature	0.095	5.603	1	**0.018**
	Time	−0.240	47.532	1	**<0.001**
	Area size	0.183	1.350	1	0.245
	No. Flowered species	−0.059	1.731	1	0.188
	PC1 flowered	0.077	5.668	1	**0.017**
	PC2 unbuilt	−0.085	8.308	1	**0.004**
Richness	Type= Botanic garden	0.131	7.3885	2	**0.025**
	Type= Park	0.279			
	Type= Villa	−0.410			
	Type= Botanic garden − Park	−0.147			0.4644
	Type= Botanic garden − Villa	0.542			0.0652
	Type= Park − Villa	0.689			**0.0199**
	Temperature	0.026	0.7867	1	0.375
	Time	−0.155	42.0377	1	**<0.001**
	Area size	0.073	0.5766	1	0.448
	No. Flowered species	0.002	0.0045	1	0.947
	PC1 flowered	0.037	2.7604	1	0.097
	PC2 unbuilt	−0.044	4.9235	1	**0.026**

Investigation. **Giovanni Scopece:** Writing – review & editing, Investigation. **Carla Sorvillo:** Writing – review & editing, Investigation. **Elena Tafi:** Writing – review & editing, Investigation. **Andrea Galimberti:** Writing – review & editing, Investigation, Funding acquisition. **Davide Maggioni:** Writing – review & editing, Investigation. **Massimo Labra:** Writing – review & editing, Funding acquisition, Conceptualization.

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. Supplementary information on the studied plants, sites and local variables

Supplementary information to this article can be found online at https://doi.org/10.1016/j.landurbplan.2026.105757.

Data availability

Data used for this study are available in a public repository at Bicocca Open Archive Research Data, doi: 10.17632/m4k34xsztf.1.

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