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Seasonal variation in floral resource use by a hover fly (*Melangyna*) (Diptera: Syrphidae) and the western honey bee (*Apis mellifera*) (Hymenoptera: Apidae) in an urban setting

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Concerns about the impacts of introduced honey bees (*Apis mellifera* L.) on native insects and pollination services are prevalent. These impacts may be more pronounced on urban greenspaces, yet research on the use of abundant winter-flowering plants, such as *Acacia* spp. and *Grevillea* spp., in subtropical ecosystems is limited. Our study investigated the seasonal use of floral resources by honey bees and native hover flies (*Melangyna* indet.) in urban greenspaces of varying urbanization levels in Sydney, Australia. We found both insect groups use similar plants, with honey bees having a higher number of interactions with plants in general, but *Melangyna* interacting with more plant species during some seasons. Particularly in autumn and winter, when native plants flower, *Melangyna* had more interactions and visited more plant species than honey bees. The overlap in floral resources used by both was higher than expected in various urbanization levels during spring and autumn. This suggests that *Melangyna* may play a significant role in pollination during autumn and winter, especially in highly urbanized sites. The observed differences in floral resource utilization and seasonal variations indicate that the potential effects of introduced *A. mellifera* on native pollinators like *Melangyna* may be difficult to quantify given the high number of variables and complexity of the system. Our findings underscore the importance of considering seasonal patterns and multispecies interactions in studies on the impact of introduced species on native biodiversity.

Keywords: floral visitors, foraging behavior, sustainable cities, urban biodiversity, urban ecology

Introduction

Insects play a critical role in maintaining biodiversity, providing ecosystem services such as nutrient recycling, pest control, and pollination (Noriega et al. 2018). While urbanization poses numerous threats to biodiversity (Czech et al. 2000), most research on the topic has focused on the negative impacts on wildlife (Grimm et al. 2008, McDonald et al.2020). However, urban environments also offer unique opportunities to study ecological processes such as competition (Spotswood et al. 2021), adaptation, and evolution (Johnson and Munshi-South 2017, Rivkin et al. 2019). Urban greenspaces, encompassing natural, seminatural, and artificial ecological communities within or around cities (Cilliers et al. 2013), serve as vital refugia for biodiversity worldwide (Aronson et al. 2014, Beninde et al. 2015). Research on urban biodiversity has examined how insects respond to the pressures of urbanization, and findings reveal that different taxa respond in unique ways to urban attributes at both local and landscape scales (McIntyre 2000, Lequerica Tamara et al. 2021). For example, in a study conducted in the same region where our study takes place, Hymenoptera species richness was positively related to proportion of greenspace, while Diptera species richness was negatively related to proportion of greenspace (Lequerica Tamara et al. 2021), suggesting that a more detailed study of these taxa may be needed to understand what drives their species richness locally in urban contexts.

Urbanisation has multidimensional impacts on local and landscape scales that affect insect communities, particularly through the replacement of natural habitats with built infrastructure and the creation of greenspaces that differ in their ability to support insect biodiversity (Bowler et al. 2025). These complex and varied impacts on insect communities across taxonomic groups, functional roles, and ecosystems suggest that a multidimensional approach to quantifying urban environments is necessary (Vaz et al. 2023). For example, proportion of greenspace, human population density, and greenspace area are all proxies for urbanization at the landscape scale (Lequerica Tamara et al. 2021, Persson et al. 2020), although they measure different aspects of urbanization. Increase in human population density is the stronger driver for urban growth (Bhatta 2010), and it is a widely used proxy for urbanization. Furthermore, human population density and greenspace area have a strong correlation in our study area both in buffers with a 1 km ($R^2 = 0.76$) and 2 km ($R^2 = 0.67$) radii (Lequerica Tamara et al. 2021), and multiple Australian studies have used human population density to investigate the relationships between urbanization and insect communities (Lequerica Tamara et al. 2021, 2023, Persson et al. 2020). Understanding how urbanization influences pollinator interactions require studying taxa across varying levels of human population density, particularly important floral visitors like the western honey bee (*Apis mellifera* L.) (Hymenoptera: Apidae) and hover flies (Diptera: Syrphidae).

The western honey bee, domesticated over 4,000 yr ago, has become one of the world's most widespread and abundant insects (Goulson 2003) and an important pollinator (Klein et al. 2007). It thrives in Mediterranean habitats across Asia, North America, South America, and Australia, pollinating at least 35 of the 107 most crucial crops for human consumption (Klein et al. 2007) from both domesticated hives and feral colonies (Goulson 2003). The species' waggle dance, a method of communicating resource locations, leads to higher concentrations of honey bees on fewer floral resources (Seeley 1983). Given their abundance and spread, honey bees could potentially compete with native insect pollinators (Paini 2004). Therefore, understanding its use of floral resources across seasons in urban areas is important, as it may guide effective greenspace management.

Hover flies are among the most speciose fly families in the world with more than 6,300 species worldwide (Skevington et al. 2019). Most species of hover flies are known to be generalist flower visitors and are considered important pollinators in many natural and agricultural systems (Thompson and Rotheray 1998, Larson et al. 2001). Many hover fly species are also present in urban areas and are recognized as important floral visitors of several native plant species, including threatened ones, especially during winter (Boyd et al. 2011, Dunn et al. 2020, Lequerica Tamara et al. 2023).

Concerns about the potential impact of introduced honey bees on native floral visitors (Klein et al. 2007) have prompted the study of such interactions both in general (Paini 2004) and in specific systems, such as crops (Lindström et al. 2016, Mallinger et al. 2017), and urban greenspaces (Egerer and Kowarik 2020, McCune et al. 2020, Prendergast et al. 2021, Weissmann et al. 2021, MacInnis et al. 2023, MacKell et al. 2023). Of the studies exploring the general relationship between honey bees and native bees, a majority only assessed resource overlap, visitation rates, or resource harvesting, without considering other conditions for competition such as resource limitation and negative impact on survivorship (eg Pyke and Balzer 1985, Wills et al. 1990, Bailey 1993, Paton 1996, Gross and Mackay 1998, but see Paini 2004 for a review). Therefore, these studies only suggest correlative evidence in the use of floral resources between honey bees and native bees (Paini 2004). Of the remaining studies that included direct measurements of survival, fecundity, or population density, some found no negative effects of honey bees on native bees (Schwarz et al. 1992, Spessa 1999), while one concluded that honey bees had a negative impact on the populations of *Exoneura asimillima* (Hymenoptera: Apidae) (Sugden and Pyke 1991).

In the context of urban environments, urban beekeeping of honey bee hives has gained popularity worldwide, leading to a surge in the number of honeybees in urban landscapes (Lorenz and Stark 2015, Egerer and Kowarik 2020, MacInnis et al. 2023). This urban-specific increase has led to an increased number of studies that explore the effects of honey bees on native bees in urban greenspaces. While some of these urban-focused studies found no evidence of competition (McCune et al. 2020, Prendergast et al. 2021), they underscored the complexity of these interactions. Factors such as time of the year, habitat type, native bee guild, urban heat island, floral resource diversity and abundance, and the density of *A. mellifera* were all identified as influencing the impact on native bees (McCune et al. 2020, Prendergast et al. 2021). Nevertheless, urban honey bee abundance has been found to have a negative relationship with pollen availability, wild bee species richness (MacInnis et al. 2023, MacKell et al. 2023) and wild bee abundance (Weissmann et al. 2021).

Despite the importance of dipterans as pollinators, there is a knowledge gap about potential competition for floral resources between honey bees and hover flies, as most studies focus on the relationship between honey bees and native bees (Mallinger et al. 2017). There is a growing trend in cities striving to become more bee-inclusive (Knezevic and Marshman 2021), but other important floral visitors, such as hover flies, may also be considered. Both honey bees and hover flies have the ability to remain active in relatively colder environments (Kearns 1992, Hingston and Quillan 2000, Woyke et al. 2003, Lefebvre et al. 2018, McCabe et al. 2019, Montoya et al. 2021). Hover files of the genus *Melangyna* Verrall, 1901 are distributed across the Holarctic, as well as in New Guinea, and Australia, with at least 4 species occurring in Australia (Vockeroth 1969). Australian *Melangyna* can remain active during the entire year in geographic areas with mild winters and winter-flowering plants (Lequerica Tamara et al. 2023) and possibly migrate from colder to milder climates regions during the winter (Finch and Cook 2020).

It is important to understand how honey bees and *Melangyna* use floral resources during different seasons in urban greenspaces, because these taxa may play a more important role in pollination, especially winter-flowering plants, than previously reported in literature (Lequerica Tamara et al. 2023). Additionally, understanding if increasing urbanization levels affect the overlap in the use of floral resources between honey bees and *Melangyna* is important, because this may have consequences for the conservation of hoverfly diversity in urban greenspaces.

In this study, we investigated the use of floral resources by native hover flies and honey bees in urban greenspaces across multiple seasons. The first aim of this study was to examine how honey bees and *Melangyna* interact with floral resources in urban greenspaces during different seasons. We predicted that honey bees would have more interactions with more species of plants in the warmer seasons, and that *Melangyna* would have more interactions with more species of plants during the colder months. This prediction was based on the higher abundance and diversity of hover flies in Sydney, Australia during winter, as reported in (Lequerica Tamara et al. 2023). The second aim of this study was to determine if there is an overlap between floral resources used by honey bees and floral resources used by *Melangyna* in urban greenspaces with varying urbanization levels, as measured by human population density. In the urban greenspaces studied, hover flies in the genus complex *Melangyna* are the most abundant (see Methodology for a detailed explanation for the treatment of *Melangyna* as a genus complex). We hypothesized that overlap in the use of floral resources by honey bees and *Melangyna* indet. will be lower than expected by chance within seasons and urban greenspaces with different urbanization levels. We based our prediction that honey bees and *Melangyna* indet. were expected to use floral resources dissimilarly on the differences in social structures between honey bees and *Melangyna* indet. The ability to advertise resources to hive members is reflected in a higher number of individuals visiting the same resource. On the contrary, flies in the *Melangyna* indet. are solitary foragers, and so they are not expected to congregate in high numbers around floral resources (Rotheray and Gilbert 2011). Finally, we predicted a higher overlap of floral resources in sites with greater urbanization, because these sites are expected to have fewer floral resources concentrated in smaller areas, leading to higher competition of floral visitors for these limited resources.

Materials and Methods

Sample Design and Site Selection

This study was conducted within Sydney, Australia, which has a human population of 5.2 million people (Australian Bureau of Statistics 2021), and a humid subtropical climate (Köppen classification system) characterized by mild winters and hot summers (Kottek et al. 2006).

We randomly selected 6 quadrats in each of 5 urbanization levels, resulting in a total of 30 quadrats (Supplementary Fig. S1). We chose one urban greenspace with an area between 0.5 and 118 ha within each quadrat, for a total of 30 sampling sites. To generate the 5 urbanization levels, we estimated the human population density by using the "ABS Census of Population and Housing: Mesh Block Counts" digital map layer (ABS 2016), which provides information related to the resident population and dwelling counts from the 2016 Australian population census. We projected this layer onto the Map Grid of Australia 1994 (MGA94) in QGIS (QGIS Development Team 2021) and generated a human population density heatmap of Sydney using a grid of square quadrats measuring 0.01 Decimal Degrees (DD) by 0.01 DD (0.0001 DD^2 quadrats), overlaid on the metropolitan area of Sydney.

We calculated the relative population density per cell by dividing the absolute population density of each quadrat by the population of the most densely populated quadrat (2,533 persons). Finally, we used the Jenks natural breaks optimization method in QGIS 3.14 ($n = 5$ bins, $\mu = 5.5$, $\sigma = 15.5$) (QGIS Development Team 2021) to divide the population density scores into 5 categories of relative human population density. We used these 5 categories of relative human population density as a proxy for urbanization levels.

On the initial visit to each site, we established a 100-m sampling transect by following walking paths when available. For sites without paths, we defined the 100-m transect as the transitable path adjacent to the most vegetated area. Subsequently, we surveyed the interactions of honey bees and hover flies with plants along each transect.

Honey Bee and Hover Fly Survey

We conducted visits to each of the 30 sites, one in each season from winter 2019 until autumn 2020. Sampling of honey bees and hover flies was conducted between 9:00 AM and 6:00 PM on week days with favorable conditions (ie sunny or partly cloudy days, winds below 30 km/h, chance of rain below 50%, and a minimum daytime temperature above 10 °C). Visits to sites were randomized spatially and temporally during the 3-month period of each season, so that a maximum of 2 sites were visited per day per season. During a 20-min walk along a 100-m transect, we recorded all interactions between insects and plants within 2.5 m of the transect line. An interaction between an insect and a plant was defined by either an insect making contact with the plant (flowers and vegetative parts) or by hover flies hovering immediately above the plant at a distance ≤10 cm for more than 2 s. We identified the plant species in situ, or by photographing specimens if not identifiable in the field. The New South Wales Flora Online system (PlantNET 2021) was used to identify all plants to the species level. Insects were captured with a sweep net and each specimen was transferred to an individual vial. The timer was paused between the time the insect was first seen and the time it was secured in the vial and notes on the interaction were taken, at which time the insect survey and the timer were resumed. If the insect escaped and could not be identified in situ, a morphological description of the specimen was produced and recorded.

We identified all collected hover flies to species level, except for 3 specimens whose genera could not be determined and were treated as "morphospecies". Specimens were identified with the help of Andrew Young and by using a series of dichotomous keys that were compiled and/or rewritten by F. Christian Thompson, which are not published, but widely circulated (Thompson 2011). Overall, 16 species of hover flies were identified, but 15 of these species of hover flies had too few interactions, so they were excluded from the analyses. Only honey bees and hover flies within the genus *Melangyna* were used in the analyses. However, we could not identify hover flies within the genus *Melangyna* indet. to the species level, because this entire genus is a complex consisting of at least 4 subgenera (Vockeroth 1969) whose phylogenetic relationships remain unresolved, indicating a need for taxonomic revision (Mengual et al. 2023). Therefore, the 3 species within the genus *Melangyna* (subgenus *Austrosyphus*) with potential to occur in the study area (*M. collatus* Walker; *M. jacksoni* Bigot; and *M. viridiceps* Macquart) are treated as *Melangyna* indet. throughout this paper. All specimens were pinned and are currently housed at our university (Table 1).

Statistical Analyses

Honey Bees and Melangyna indet. Interactions with Plants

We created a matrix with all the interactions between the floral resources and floral visitors discriminating by season (eg winter, spring, summer, autumn), site identity (ie name of each site), and urbanization levels (measured as categories of human population density, eg 1: lowest, 2: low, 3: medium, 4: high, and 5: highest). Each row in the matrix represented a floral resource, and each column represented an insect. The value in each cell represented the "strength" of the interaction, such that a higher number of interactions per site between one species of insect and one species of plant had a greater "strength". We used the "plotweb" function in the "*Bipartite*" package for R to produce interaction networks and webs between all the sampled insects (ie honey bees and *Melangyna* indet.) and the plants with which the insects interacted for each season (Dormann et al. 2008). Additionally, we produced interaction webs specifically for honey bees and *Melangyna* indet. and the plants they were observed interacting with during each season. Finally, we tallied the total number of interactions observed for each type of floral visitor, as well as the number of plants each floral visitor was observed interacting with during each season.

We tested if the number of interactions between the sampled insects and plants were higher in winter by using generalized linear

Table 1. Species of insect floral visitors and the number of interactions observed between each species of insect and plants

Type of insect	Insect species	*N* interactions recorded	% total interactions recorded
Honey bee	*Apis mellifera*	366	55%
Hover fly	*Melangyna* indet.	213	32%
	Simosyrphus grandicornis (Macquart)	27	4%
	‘morphospecies 5’	7	1%
	Episyrphus glaber Wright	6	1%
	Episyrphus viridaureus (Wiedemann)	5	<1%
	Sphaerophoria sp. (Lepeletier & Serville)	5	<1%
	‘morphospecies 4’	3	<1%
	Betasyrphus serarius (Wiedemann)	2	<1%
	Eristalinus punctulatus (Macquart)	2	<1%
	Australis copiosa (Walker)	2	<1%
	Allograpta sp. Osten Sacken	1	<1%
	Eupeodes confrater (Wiedemann)	1	<1%
	Meliscaeva sp. (Zetterstedt)	1	<1%
	‘morphospecies 13’	1	<1%
	Triglyphus sp. Loew	1	<1%
	Xanthandrus agrolas (Walker)	1	<1%

mixed models (GLMM). To evaluate the effect of season and insect species on the response variable “number of interactions”, we deployed the “glmmTMB” function for zero-inflated models in the “*glmmTMB*” package for R (Brooks et al. 2017). We used “site identity” (n = 30) as a random effect to account for the multiseason sampling at each site. Finally, we used the “*ggplot2*” package for R to create boxplots (Wickham 2016).

Floral Resource Overlap between Honey Bees and Melangyna indet.

We compiled a database of all observations from the dominant floral interactors to determine if the overlap between the floral resources used by honey bees and those used by *Melangyna* indet. varied by season and urban greenspaces with different urbanization levels. The database contained all the interactions between the floral visitors and the floral resources they used, and was organized by season, urbanization levels, and site. Each row represented a floral visiting interaction, each column was a floral resource, and the value corresponded to the strength of the interaction. The goal was to determine if there was an overlap between the floral resources used by the 2 species in urban greenspaces with varying urbanization levels.

To generate a null model of hypothetical interactions, we used the observed pool of floral resources (ie those in which we observed honey bees and *Melangyna* indet. interacting within each site) to create 1,000 random iterations of the interactions between hypothetical insect pairs and the plants for site per season. We then computed the Morisita–Horn (M–H) dissimilarity indices for the observed insect–plant interactions (ie honey bees and *Melangyna* indet.) and for the hypothetical insect–plant interactions (ie 1,000 iterations generated by the null model), in all sites for every season. We used the “vegdist” function in the “*Vegan*” package for R (Oksanen et al. 2016) to compute the M–H dissimilarity indices. The M–H dissimilarity index is a metric that compares the proportion of all honey bees associated to each plant species to the proportion of all *Melangyna* indet. associated to each plant species (Barwell et al. 2015, Roswell et al. 2019). This index ranges from 0 (maximum resource overlap) to 1 (minimum resource overlap) and is tolerant to under-sampling and uneven sample size between groups (Barwell et al. 2015).

We tested the hypothesis that the observed overlap between the floral resources used by *A. mellifera* and those used by *Melangyna* indet. are lower than what is expected by chance within seasons and urban greenspaces with different urbanization levels. A one-sided $\alpha = 0.05$ was used to test the hypothesis. We compared the observed M–H dissimilarity value with 1,000 simulated dissimilarities: if the observed M–H dissimilarity value was higher than 950 of the 1,000 simulated dissimilarities, we concluded that there was a significant difference between the observed resource overlap and the resource overlap expected by chance.

Results

We observed a total of 664 interactions between target insects and plants. The majority of these (586 interactions, 88% of total) involved honey bees or *Melangyna* indet. (Table 1). The remaining interactions (78 interactions, 12% of total) were attributed to 15 species of hover flies (Table 1) but were insufficient to calculate dissimilarity indices, and consequently, were excluded from the insect–plant networks and statistical analyses.

Specifically, we documented 586 interactions between our target insect groups (honey bees and *Melangyna* indet.) and 178 species of plants across 30 urban green spaces between winter 2019 and autumn 2020 (Table 1 and Supplementary Figs. S2 to S5). Honey bees had the highest number (n = 373, 64%) of interactions with 78 species of plants, followed by *Melangyna* indet. (n = 213, 36%) interactions with 100 species of plants. The plants with which we observed the insects interact more often were *Allocasuarina diminuta* L.A.S. Johnson (62 interactions), *Acacia floribunda* (Vent.) Willd. (42 interactions), and *Leucopogon ericoides* (Sm.) R.Br. (32 interactions).

Honey Bees and *Melangyna* indet.—Plant Interactions

During winter, honey bees had significantly higher number of interactions (195 interactions with plants), compared to *Melangyna* indet. (126 interactions with plants) ($Z = 2.623$, $df_{RESID.} = 710$, $P < 0.001$) (Fig. 2), but honey bees interacted with fewer plant species (22 species) compared to *Melangyna* indet. (35 species of plants) (Fig. 1A). The plants most frequently interacted with by honey bees were *A. diminuta* (54 interactions) and *A. floribunda* (36 interactions), whereas for *Melangyna* indet. they were *Grevillea banksii* R. Br. (15 interactions) and *Acacia hamiltoniana* Maiden (13 interactions).

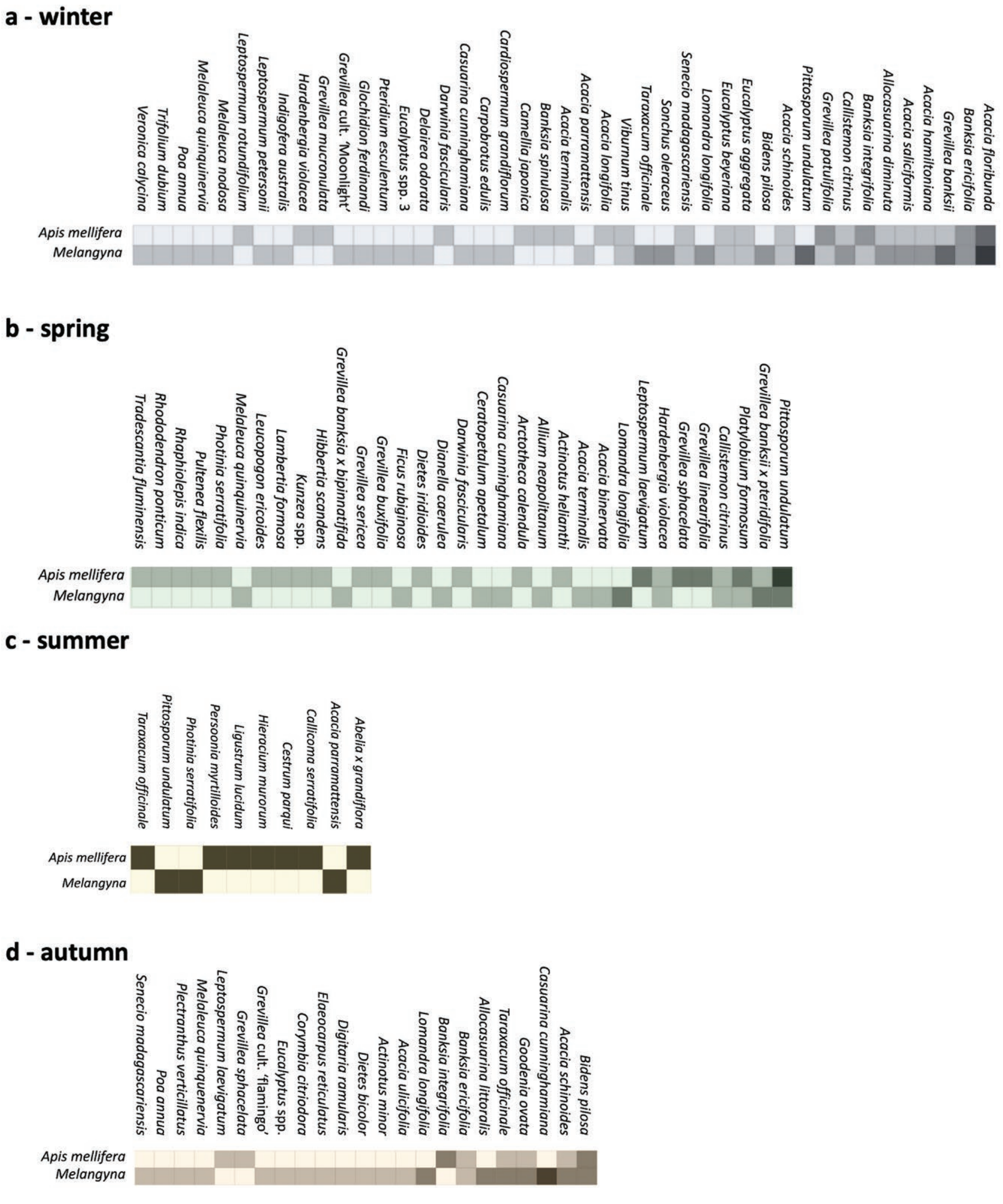

Fig. 1. Interaction webs between insects (left) and plants (top); the shade of color denotes the strength of the interaction relative to the total number of interactions for the season, such that darker boxes represent more interactions; plants are ordered by increasing number of interactions (from left to right), such that the last plant to the right had the highest number of interactions with the insect in the first row. A) Winter: *Melangyna* indet. (126 interactions), honey bees (195 interactions); B) spring: honey bees (115 interactions), *Melangyna* indet. (29 interactions); C) summer: honey bees (10 interactions), *Melangyna* indet. (3 interactions); D) autumn: *Melangyna* indet. (55 interactions), honey bees (50 interactions).

During summer, the number of interactions between insects and plants was lower than in winter ($P < 0.001$), spring ($P < 0.001$), and autumn ($P < 0.001$) (Fig. 2; Table 2). Honey bees had more interactions (10 interactions) with more species of plants (7 species) than *Melangyna* indet., which had 3 interactions with 3 species of plants (Fig. 1C). The plant with which honey bees had most

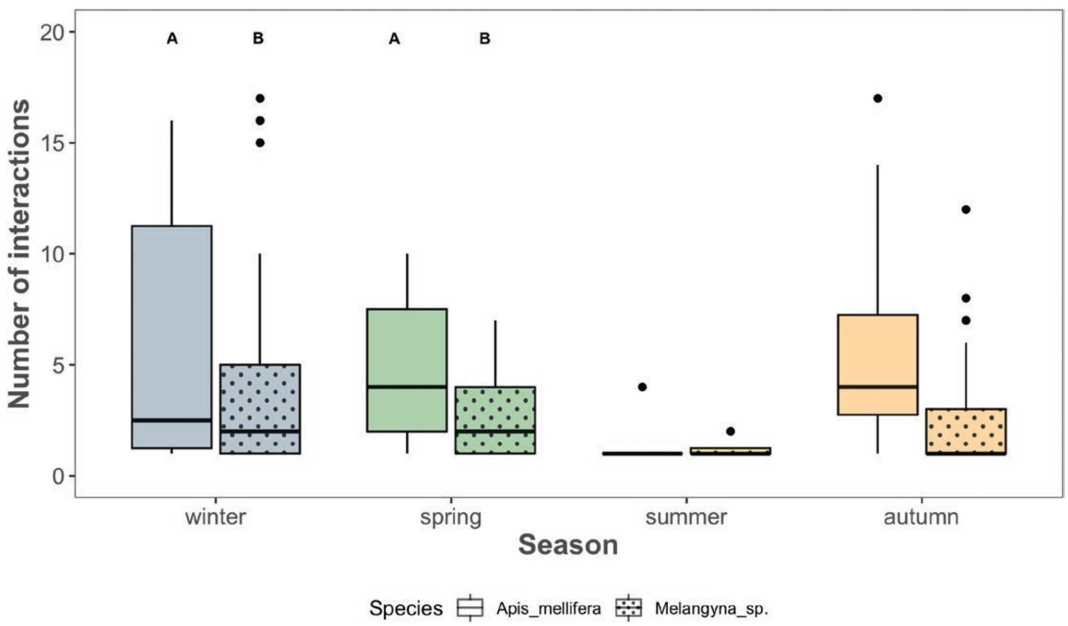

Fig. 2. Box plots showing the number of interactions between honey bees (*Apis mellifera*) and plants (plain boxes) and between *Melangyna* indet. and plants (dotted boxes) among seasons. The number of interactions between insects and plants was lower in summer than in winter ($P < 0.001$), spring ($P < 0.001$), and autumn ($P < 0.001$). *Melangyna* indet. had fewer interactions than *Honey bees* in winter ($P = 0.015$) and spring ($P < 0.001$) (Table A3, Supplementary materials). Uppercase letters denote statistically significant differences of the number of interactions between insects in the same season.

interactions was *Ligustrum lucidum* Aiton (4 interactions). The interactions observed in summer between honey bees and other plants had a frequency of 1. *Melangyna* indet. interacted with each of the 3 species of plants only once during summer.

During autumn, honey bees had fewer interactions (50 interactions) with a smaller number of plant species (8 species), compared to *Melangyna* indet., which had 55 interactions with 20 plant species (Fig. 1D). Honey bees had the most interactions with *Banksia ericifolia* (17 interactions) and *Acacia schinoides* (14 interactions), while *Melangyna* indet. had the most interactions with *Casuarina cunninghamiana* Miq. (11 interactions) and *Grevillea* "Flamingo" (8 interactions).

Floral Resource Overlap between Honey Bees and *Melangyna* indet.

During spring, we observed that the M–H dissimilarity index between honey bees and *Melangyna* indet. was higher than expected by chance in sites with lowest ($P_{OBS} > Z = 0.029$), high ($P_{OBS} > Z = 0.01$), and highest ($P_{OBS} > Z = 0.01$) urbanization levels (Fig. 3; Table 2). On sites with lowest and high urbanization levels, honey bees had more observed interactions with plants ($N_{LOWEST\text{-}A.mellifera} = 56$) and ($N_{HIGH\text{-}A.mellifera} = 7$) than Melangyna indet. ($N_{LOWEST\text{-}Melangyna} = 6$) and ($N_{HIGH\text{-}Melangyna} = 0$), respectively. Inversely, on sites with the highest urbanization levels, honey bees had fewer observed interactions ($N_{HIGHEST\text{-}A.mellifera} = 8$) than *Melangyna* indet. ($N_{HIGHEST\text{-}Melangyna} = 14$).

During winter, the observed M–H dissimilarity index between honey bees and *Melangyna* indet. was within the expected range in all sites (Fig. 3; Table 2).

During autumn, the observed M–H dissimilarity index between honey bees and *Melangyna* indet. was higher than expected by chance in sites with medium ($P_{OBS} > Z = 0.01$) and highest ($P_{OBS} > Z = 0.01$) urbanization levels (Fig. 3; Table 2). On sites with medium urbanization level, honey bees had fewer observed interactions ($N_{MEDIUM\text{-}A.mellifera} = 1$) than *Melangyna* indet. ($N_{MEDIUM\text{-}Melangyna} = 11$). Although on sites with highest urbanization level both groups had the same number of observed interactions with plants ($N_{HIGHEST\text{-}A.mellifera} = 3$; $N_{HIGHEST\text{-}Melangyna} = 3$), *A. mellifera* interacted with 1 species of plant (*B. integrifolia*), while *Melangyna* indet. interacted with 2 (*Acacia ulicifolia* and *Allocasuarina litoralis*).

In summer, not enough observations were made to calculate M–H dissimilarity index between honey bees and *Melangyna* indet.

Discussion

Our study revealed that while honey bees and *Melangyna* indet. use similar plants during different seasons, they did so in different ways. In general, honey bees had more interactions with plants, suggesting that this species of insect was locally abundant. Conversely, *Melangyna* indet. interacted with more species of plants, especially during winter, suggesting that this genus complex is more abundant during the colder months. Specifically, during spring and autumn (in sites with lowest, high, and highest, and sites with medium and highest urbanization levels, respectively) the floral resources used by honey bees and *Melangyna* indet. had less overlap than would be expected between 2 hypothetical floral visitors if given the exact same pool of floral resources.

It is possible that the higher number of interactions observed for honey bees is indicative of its greater local abundance compared to *Melangyna* indet.; however, we acknowledge that we have not directly quantified the local populations of either species in this study. For example, honey bees predominantly interacted with *A. diminuta* and *A. floribunda* in winter, *L. ericoides* in spring, and *B. ericifolia* in autumn. During 3 of these 4 observation events, *Melangyna* indet. was also seen using the same floral resource as honey bees but in much lower numbers. The social nature of honey bees allows them to communicate the location and characteristics of floral resources to other foragers within the hive, leading to a higher number of individuals congregating on specific floral resources (Beekman and Ratnieks 2000, Grüter and Farina 2009). Previous research has

Table 2. Mean values for the observed M–H dissimilarity index (representing the observed floral resource overlap between honey bee and *Melangyna* indet., shaded rows) and mean values (with standard deviations) for the M–H dissimilarity indices calculated for the null mode (representing floral resource overlap between 1,000 pairs of hypothetical floral visitors given the observed pool of floral resources, clear rows)—during winter, spring, and autumn, and in 5 urbanization levels

		Urbanisation levels (Human population density)				
Season	Value	1 (lowest)	2 (low)	3 (medium)	4 (high)	5 (highest)
Winter						
	Observed M–H	0.444 (n = 5)	0.654 (n = 3)	0.640 (n = 3)	0.400 (n = 1)	0.667 (n = 1)
	Null model M–H	0.479 (sd = 0.116)	0.632 (sd = 0.19)	0.653 (sd = 0.187)	0.522 (sd = 0.234)	0.587 (sd = 0.279)
	Pr ($M–H_{OBS} > Z$)	0.40	0.56	0.48	0.31	0.58
Spring						
	Observed M–H	**0.822 (n = 1)**	NA	0.600 (n = 1)	**0.600 (n = 1)**	**1.000 (n = 2)**
	Null model M–H	0.441 (sd = 0.159)	NA	0.537 (sd = 0.169)	0.380 (sd = 0.177)	0.592 (sd = 0.224)
	Pr ($M–H_{OBS} > Z$)	**0.03**	NA	0.64	**0.01**	**0.01**
Autumn						
	Observed M–H	0.778 (n = 1)	0.556 (n = 1)	**1.000 (n = 1)**	0.517 (n = 1)	**1.000 (n = 1)**
	Null model M–H	0.528 (sd = 0.204)	0.667 (sd = 0.254)	0.824 (sd = 0.254)	0.758 (sd = 0.279)	0.602 (sd = 0.394)
	Pr ($M–H_{OBS} > Z$)	0.12	0.34	**0.01**	0.23	**0.01**

A M–H dissimilarity index value of 1 represents complete overlap between the floral resources used by the pair of species, and a M–H dissimilarity index value of 0 means no overlap. Observed M–H values that are higher than expected by chance, as identified by null model tests, are indicated in bold Pr ($M–H_{OBS} > Z$). Sample size represented by n.

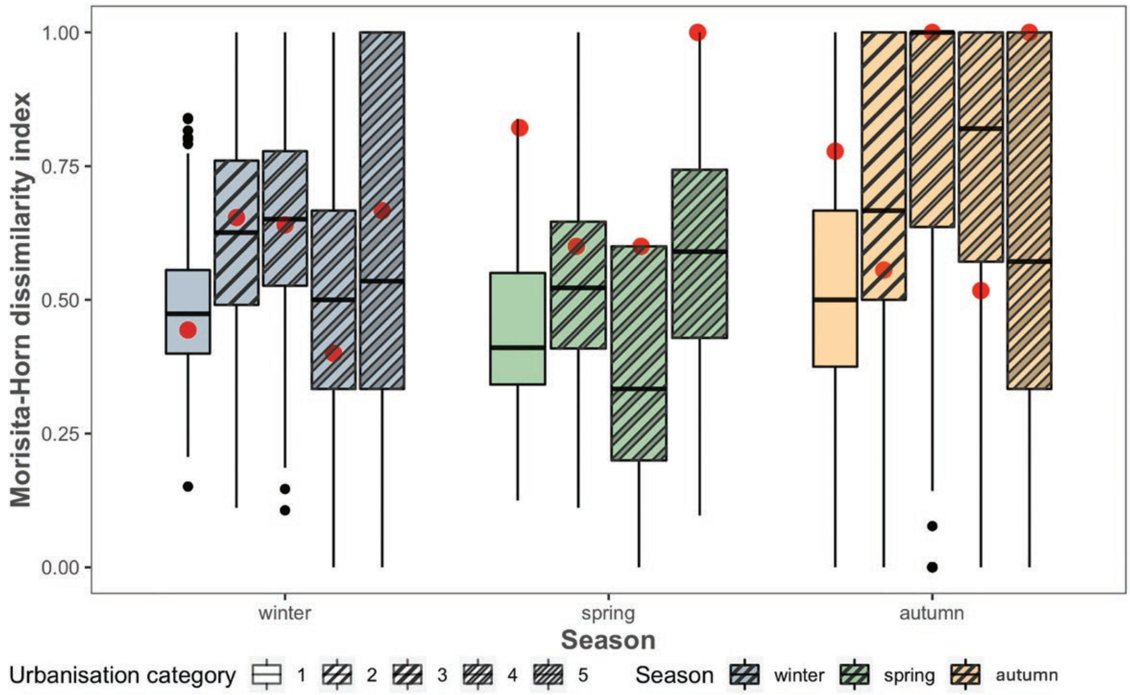

Fig. 3. Graph contrasting the observed values (bigger dots) for the M–H dissimilarity index calculated for the interactions between honey bees-plants and *Melangyna* indet.-plants, and the M–H values derived from a null model with 1,000 random permutations between (box plots). A M–H dissimilarity index value of 1 represents maximally dissimilar use of resources (ie no overlap in the use of floral resources), while a value of 0 represents a complete overlap in the use of resources, between the compared groups (ie observed M–H values and null-model values). The density of diagonal stripes in box plots represents urbanization levels (measured as human population density), such that higher density of diagonal stripes represents greater urbanization (thus higher human population density). The number of insect–plant interactions during summer was too low for an estimation of the M–H dissimilarity index between honey bees and *Melangyna* indet., thus the absence of box plots for this season.

reported honey bees as an introduced floral visitor and potential pollinator of both native (Paton 1993, Gross 2001, Lomov et al. 2010) and exotic plants (Simpson et al. 2005, Chapman and Oldroyd 2020). By interacting more frequently with fewer species of plants, honey bees may play a role in the pollination of the more common species of plants in urban greenspaces.

On the other hand, *Melangyna* indet. is a group of solitary visitors, and there is no evidence that individual hover flies can communicate resource locations with their conspecifics. This difference in the ability to congregate around specific floral resources might explain why *Melangyna* indet. had fewer interactions with plants than honey bees during winter, spring, and summer. Interestingly, although *Melangyna* indet. had fewer interactions with plants than *A. mellifera,* it interacted with more plant species during autumn and winter. By using a wider range of floral resources across the greenspace, *Melangyna* indet. may play an important role in the pollination of less common or conspicuous species of plants in urban greenspaces during the colder months. It is also plausible that different species within the *Melangyna* indet. were visiting distinct flowers during winter. Assessing this is not currently possible due to the profound morphological similarities and the paucity in the understanding of this group. This highlights the urgency that the revision of the genus *Melangyna* calls for.

Our study design examined how varying urbanization levels influence plant use by honey bees and *Melangyna* indet. Revealing distinct patterns across the urban gradient. During spring, honey bees interacted more with plants at both the lowest and high levels of urbanization. This pattern could be explained by the presence of vegetation remnants or urban forests with undetected feral honey bee hives at the least urbanized sites, explaining the high number of honey bees compared to *Melangyna* indet. At highly urbanized sites, managed hives from urban beekeeping could explain higher numbers, but it is not possible to detect this with the human population density design used in our study. In contrast, *Melangyna* indet. had more interactions with plants on sites with the highest urbanization level supporting previous findings that dipterans are more abundant in highly urbanized areas (Lequerica Tamara et al. 2021).

Urbanisation creates diverse pressures on insect communities beyond habitat loss (Vaz et al. 2023). These pressures lead to complex dynamics among insects, and human activities influence these dynamics through several mechanisms. For example, the replacement of natural habitats with built infrastructure reduce and fragment foraging areas (Bowler et al. 2025) while the introduction of ornamental species may favor certain floral visitors (Berthon et al. 2021). Additionally, urban management practices such as mowing and pesticide use affect insect groups differently (Vaz et al. 2023). The interaction among these factors may play an important role in explaining the seasonal differences observed in our study. For example, more resilient species like honey bees may benefit from some of these factors in times of the year during which we observed more floral resource overlap, such as spring and autumn.

While human population density served as a proxy for urbanization, we acknowledge its limitations with this approach. We used "human population density" as a surrogate for 2 main reasons; it correlates strongly with vegetated area in our study region ($R^2 = 0.76$ at 1 km radius; $R^2 = 0.67$ at 2 km radius) (Lequerica Tamara et al. 2021); and it also captures multiple dimensions of urbanization relating to infrastructure density. Nevertheless, this approach may not translate to other studies as population may not correspond directly to changes in available greenspace, where quantification of management actions to or addition of new urban greenspaces may produce better predictors of insect diversity and abundance.

Acknowledging variations in air temperature and different stages in the life cycles of *A. mellifera* and *Melangyna* indet. throughout the year is important in determining the causes of floral resource overlap between these insects across seasons. *Melangyna* indet. might undergo a quiescent period or be in an immature stage during summer, followed by the emergence of adults in early autumn, and a peak population size in winter (Soleyman-Nezhadiyan 1996, Rotheray and Gilbert 2011). Our study found that during autumn, honey bees had fewer interactions with fewer species of plants than *Melangyna* indet., in sites with medium and highest urbanization levels. This aligns with our suggestion that the local population size of *Melangyna* indet. starts increasing with the start of autumn and the emergence of adults triggered by shorter day lengths and cooler air temperature (averages ranging between 11.6 and 24.8 °C in March, April, and May [Australian Bureau of Meteorology 2022]). Similarly, honey bees forage activity increases as air temperatures drop into the optimal range for peak hive activity (between 18 and 20 °C) (Woyke et al. 2003) for longer periods during the day. Sites with higher urbanization levels might have had a higher concentration of native and exotic flowers in smaller areas, which could support local populations of floral visitors (Berthon et al. 2021) such as *Melangyna* indet. Quantifying flower abundance and concentration in future studies would determine whether relative flower abundance has implications for floral visitation in urban greenspaces.

Notably, out of the 586 observed insects–plant interactions (ie *A. mellifera* and *Melangyna* indet.), 52 interactions (9%) were singletons, ie a single observation of an interaction with that plant species. Although this amount of singleton observations suggests that the number of repeat observations per site used in our study may not have been optimal, previous studies suggest that floral visitor abundance in Australian urban greenspaces may not be as high as in northern hemisphere systems (Threlfall et al. 2015). To account for this, we implemented a survey methodology that allowed us to capture as many insect–plant interactions as possible across different urbanization levels for 1 yr. Thus, we have decided to keep these singletons for the computation of M–H dissimilarity indices, to observe how the use of floral resources overlapped between these 2 groups of insects. Nevertheless, future studies of floral visitors in Australian urban greenspaces could benefit from having larger sample sizes, for example by increasing the number of surveys per site.

Despite several studies examining the potential negative impacts of honey bees on the populations of native floral visitors in Australia, the available evidence is inconclusive, although coexistence and resource overlap may be plausible. For example, some of these studies have been hindered by confounding factors or flawed interpretation (Matthews 1984, Hopper 1987, Pyke 1990), while others have shown no evidence of negative impacts (Schwarz et al. 1992, Huryn 1997, Spessa 1999), with some suggesting negative impacts (Sugden and Pyke 1991, Prendergast et al. 2021, Weissmann et al. 2021, MacInnis et al. 2023, MacKell et al. 2023). However, it is important to note that these results should be interpreted with caution, as they may not be generalizable as they are nuanced and may depend on local contexts (Paini 2004, Chapman and Oldroyd 2020).

While there was minor overlap in resource use, it is difficult to determine if floral resources were limited and being depleted by honey bees or *Melangyna* indet. The conditions under which a floral resource, such as nectar or pollen, becomes limiting may be unpredictable and occur over short periods of time (Spessa 1999). There is a growing body of evidence that shows that plants may control nectar production, and even adjust its secretions (reabsorb or stop production in absence of consumers or increase it when consumers become available) (Heil 2011). Thus, it is possible that nectar does not represent a limiting floral resource for either of the floral visitor taxa in this study. Although pollen was not quantified in this study, none of the flowers bearing anthers with exposed pollen seemed to be depleted of this resource after visitation by honey bees or *Melangyna* indet. (personal observation). Understanding if nectar and pollen are limiting resources is an essential element to assess whether honey bees have a negative impact on native floral visitors, including *Melangyna* indet. The development of more efficient and reliable quantification methods for pollen and nectar are needed to advance this field (Wäckers et al. 2007).

It is important to consider that our study included interactions of insects with flowers but also with vegetative parts and hovering in proximity (<10 cm) of the plants. Although the *Melangyna* visiting flowers were likely foraging for floral resources, those found on vegetative parts could have been resting and those hovering near the plants could have been females looking for suitable oviposition sites (Soleyman-Nezhadiyan 1996) or males waiting for a mating opportunity (Rotheray and Gilbert 2011). Limiting interactions to floral visits may provide a more accurate representation of the resource overlap between floral visitors.

Our study provides valuable insights into the floral visitation dynamics of honey bees and *Melangyna* indet. in urban greenspaces of one large, subtropical metropolitan area, contributing to the broader understanding of urban biodiversity conservation and management. As cities continue to expand, maintaining healthy and diverse plant populations becomes essential for supporting urban pollinators and ecosystem resilience. By identifying specific plant species frequently visited by *A. mellifera* and *Melangyna* indet., our findings can inform targeted planting strategies in urban greenspaces to enhance pollinator-friendly habitats and minimize competition between pollinator species for floral resources. Additionally, understanding the differential resource use patterns of these floral visitors can guide urban planning efforts aimed at preserving and promoting native pollinator populations. Further research in this field, incorporating factors such as nectar and pollen availability, having larger insect–plant interaction pools, and urban habitat characteristics, will be crucial for developing comprehensive strategies to support pollinator conservation in urban environments.

Supplementary material

Supplementary material is available at *Journal of Insect Science* online.

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Author contributions

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Conflict of interest. None of the authors have a conflict of interest.

Data availability

Our data are publicly available from the University of Sydney eScholarship Repository (https://ses.library.usyd.edu.au).

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