A review of diversity of bees, the attractiveness of host plants and the effects of landscape variables on bees in urban gardens

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Abstract

Background: The world’s growing population and growing need for food have increased attention to urban agriculture around the world. Most crops grown in urban environments need bees for pollination. However, little is known about bee populations in urban areas and little attention has been paid to the function of these pollinators in cities. Therefore, studying the ecology of pollinating bees in urban gardens and green roofs contributes greatly to urban agriculture. In this study, the results of 87 articles related to the presence of bees in gardens and urban farms were summarized in three general sections. The first part deals with issues, such as the diversity of bees in urban gardens, dominant species in these areas, their nesting type, origin, specialty, and sociality. The second part examines the attractiveness of host plants in urban gardens and farms and their origin for bees. The third section examines the effects of landscape and local variables effects on the presence of bees in urban farms and gardens.

Results: Our data showed that urban environments, especially urban gardens, contain a high diversity of bees, which honeybees and bumblebees are the most dominant species in these environments. The results of the second part showed that native plants were more attractive to bees than non-native plants. In the third section, most studies have shown the negative role of urbanization on the presence of bees. On the other hand, many studies have shown that the presence of green spaces or other farms and gardens around the studied gardens have a positive effect on the presence of pollinators.

Conclusion: Urban environments have a high diversity of plants and bees that provides a good opportunity to increase agricultural production in these environments. Planting native plants and creating artificial nests for solitary bees and bumblebees can help attract more bees to urban environments. Converting lawns into floral resources or carrying out agricultural activities around green spaces can also effectively help to increase agricultural production in the city.

Keywords: Urban agriculture, Urban gardens, Green roofs, Bees, Pollination

Introduction

Urban areas now account for more than half of the world’s population [80]. The United Nations estimates that by 2050, 68 percent of the world’s population will live in cities, with rapid urbanization growing in low-income countries [70]. The expansion of cities threatens biodiversity and reduces agricultural lands [52]. The world’s growing population and growing need for food have increased attention to urban agriculture around the world [69]. In recent years, attention to urban gardens, urban agriculture, and roof agriculture has increased. Urban agriculture does not have a specific definition and includes a wide range of agricultural activities within cities. Types

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of urban agriculture include home gardens, allotment growing, community gardens, commercial, vertical agriculture, rooftop gardening [71]. The crops grown in these gardens contribute to urban sustainability and food security [13]. Urban agriculture positively affects the local environment, including improving air quality, increasing carbon stabilization rates, reducing urban heat islands, and reducing runoff-related water pollution [53]. Reducing the food supply chain as a result of urban agriculture is another advantage of this type of agriculture [86].

Many crops are grown in the city, such as cucumbers, tomatoes, watermelons, strawberries, peppers, and eggplants that require a pollination process to produce the crop [65]. Pollination is a vital ecosystem service not only in natural ecosystems but also in cities [94]. However, little is known about bee populations in urban areas and little attention has been paid to the function of these pollinators in cities. With the growth of urban agriculture, the role of bees in helping to produce food in cities has become more prominent. Some studies claim that urban farms and gardens are short of pollinators, and to increase agricultural production on urban farms, we need to increase the supply of pollination services in cities by creating new flowering sources around urban farms. For example, To increase the supply of pollination to support urban farms in Chicago, Davis et al. [14] propose two scenarios based on the conversion of turf-grass flora resources. (1) If the goal is to improve the pollination supply for home gardens, the best strategy is to convert the turf-grass throughout the urban landscape into floral sources. (2) If the goal is to increase the pollination supply for urban farms, the best strategy is to convert turf-grass to floral resources that are located within a radius of 250 m from urban farms.

Others suggest a companion planting strategy to attract pollinators to farms and urban gardens. Companion planting is a traditional method of planting different flowering plants in the proximity of cultivating crops to attract pollinators [37]. For example, Griffiths-Lee et al. [37] planted a borage plant next to a strawberry crop based on a companion planting strategy. They used the borage plant to attract pollinators to the strawberry farms. This increased the production of strawberries by 32%. Someone Pereira-Peixoto et al. [77] also examined the behavior of bees in isolated urban gardens and gardens adjacent to rapeseed crops. They found that the bees’ abundance in gardens adjacent to the rapeseed plant was higher than in isolated gardens in the city. In the gardens bordering the rapeseed crop, during the mass flowering of the rapeseed crop, a spillover from the gardens to the rapeseed was observed, which could increase the yield of the rapeseed crop. Langellotto et al. [49] also claim that in farms near urban gardens, 30 to 50 percent of the bees in the gardens go to the farms for pollination. However, Matsuoka et al. [63] cultivated several plant species with sodium plants and did not observe any positive effect of the companion planting strategy in attracting pollinators.

Bees are thought to be moving between gardens and farms, helping to increase crop production. However, many studies have shown that the relationship between urban agriculture and bees is more complex than we think because, bees are unable to fly long distances, and reports indicate that they usually fly less than 1,000 Meters. For example, Hofmann et al. [41] examined flight distances of four specialist species and two general species of Osmiini bees (Megachilidae). They found that females flew an average of 73 to 121 m and males 59 to 100 m. In addition, even if farms and urban gardens are adjacent, we should not expect bees to visit all of these farms. For example, based on the mark-recapture method of Bombus impatiens species, Matteson and Langellotto [65] found that 45% of these species were found in the same gardens that were marked, implying that the bumblebees did not move between the gardens and remained inside the original garden. O’Connell et al. [74] showed that although many crops were grown around ornamental plants, B. vosnesenskii visited ornamental plants more than the crops. Therefore, bee food preferences affect their role in the pollination of agricultural products in and around gardens.

These studies show that the strategy of adding flowering plants to urban gardens or around farms is not always a good solution, because if the added flowers provide bees with better quality resources, agricultural products will receive fewer visits. It seems that better management of gardens and urban farms is needed to understand the relationships between bees and these areas. In this regard, the following questions should be answered (1) What is the diversity of bees in urban areas, especially in gardens and urban farms. We need to know in detail about the dominant species in the urban gardens, in particular, their nesting type, and determine whether they are native, general, and social. (2) What is the relationship between host plants and pollinating bees? In particular, their attractiveness to bees according to origin. (3) How do landscape and local variables around urban gardens affect the presence of bees? Answering these questions can help us determine the best strategy to increase the pollination supply in gardens and urban farms. We believe that to answer these questions, the relevant studies that have been published so far need to be reviewed and their results summarized. Then, based on the insights that these studies give us, we will be able to guess the optimal strategy to increase the urban agricultural products by bees.
Methods
We searched for published studies using the ISI Web of Science. We conducted our search from 1990 to 2021 using the following search string: (pollinator* OR pollination* OR bee*) AND (urban garden* OR urban agriculture* OR green roofs*). The final data set included studies from 1990 to 2021. Nearly 900 articles were obtained, leaving 280 unique articles after the duplicate articles were removed. We were only looking for articles that examined the relationship between bees and urban agriculture. Therefore, we selected studies that would help our knowledge to increase the production of agricultural products (edible or ornamental) by bees (native or non-native). After reviewing the titles and abstracts of the articles, 87 articles remained that were related to our goals, and we recorded the most important results of these articles. We divided the results of these studies into three general sections. The first part deals with issues, such as the diversity of bees in urban gardens, the dominant species in these areas, their nesting type, origin, specialty, and sociality. The second part examines the diversity of host plants in urban gardens and farms, their origin, and attractiveness for bees. The third section examines the effects of landscape and local variables on the presence of bees in urban farms and gardens (Table 1).

Bee diversity in urban gardens
To better management of urban gardens, we need to have an overview of pollinators within these areas. Although the presence of bees in urban gardens depends on various factors such as location and climate of the city, the landscape around the gardens, the type, and origin of host plants, the use of pesticides, identifying bees in urban gardens can be a great help in managing these gardens. Various studies have investigated the diversity and species richness of bees in urban, suburban, and natural environments that the details of their results are beyond the scope of this study. However, many of these studies have shown that the diversity of bees within cities is in some cases greater than in natural areas, and generally emphasize the high diversity of bees and their population composition within cities, and sometimes cities, especially city gardens, are referred to as bee hotspots [4, 94].

Table 2 shows the number and family details of bees recorded in urban gardens and green roofs. This table details 45 studies, most of which were conducted in the United States (60%). Most of these studies have focused on urban gardens, and only six studies (13%) have examined the diversity of bees on green roofs. The number of bees recorded in urban gardens is between 10 to 200 species and on green roofs between 5 to 326 species. Most of the recorded species belong to 5 families of Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, so that 53% of the studies have reported these families in their investigations.

Dominant bees in urban gardens
Identifying the dominant species in urban environments, especially in urban gardens, helps us in managing these gardens, because by creating artificial nests, we can attract more populations of these species to the gardens. Some studies have identified dominant species in their studied gardens. Details of these studies are provided in Table 2. This table shows the nesting type, origin, sociality, generality, and the scientific name of the most dominant species recorded in urban environments. This table presents 31 studies, most of which were conducted in the United States (51%). These studies show that bees that live in urban environments are mostly above-ground nesting and a small percentage (12%) of these species nest in the soil. Non-native species are also found to a significant extent (29%) in urban environments, most of which are composed of honeybees.

Bumblebees, honeybees, and stingless bees are social. Therefore, studies that have reported the predominance of these species in their studies have also shown a high proportion of social bees in urban gardens. According to Table 2, the most dominant species in urban environments is the honeybees (38%) followed by bumblebees (19%). Although some studies have shown that honeybees negatively affect the presence of wild bees due to the competitive process and do not recommend beekeeping in the cities [82], other studies have shown that the number of honeybees is positively correlated to bumblebees [39] and does not appear to compete with bumblebees or other wild bees [32, 47].

The attractiveness of the host plant for bees
Numerous studies have focused on the attractiveness of different plants in attracting pollinators, and the results of these studies are provided in different lists. Looking at these lists, we find that a large number of native and non-native plant species have been introduced to attract pollinators. However, there are many criticisms of these lists. For example, Garbuzov and Ratnieks [31] examined the strengths and weaknesses of the 15 list of introduced plants for attracting pollinators, stating that these lists have little overlap in terms of the different plants they introduce. Contrary to popular belief, limited species are effective in attracting pollinators, and there are several studies to support this claim. For example, Garbuzov and Ratnieks [33] tested 228 varieties of the Aster plant to measure their attractiveness for bees. They showed that only a small fraction of the varieties of this genus were highly attractive to pollinators. Table 3 shows a list of
| References | Country     | Garden           | No. Species | Family                                                                 |
|------------|-------------|------------------|-------------|----------------------------------------------------------------------|
| [27]       | USA         | Urban garden     | 76          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 23 genera |
| [101]      | USA         | Urban garden     | 32          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 17 genera |
| [21]       | USA         | Urban garden     | 110         | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [64]       | USA         | Urban garden     | 54          | –                                                                   |
| [25]       | USA         | Urban garden     | 82          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 28 genera |
| [26]       | USA         | Urban garden     | 68          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 26 genera |
| [97]       | USA         | Green roof       | 63          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 23 genera |
| [66]       | USA         | Urban garden     | 45          | –                                                                   |
| [85]       | Sweden      | Urban garden     | 28          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 8 genera |
| [56]       | USA         | Urban garden     | 37          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [9]        | Switzerland | Green roof       | 126         | –                                                                   |
| [77]       | Germany     | Urban garden     | 20          | 2 families (=Colletidae, Megachilidae)                               |
| [75]       | USA         | Urban garden     | 66          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [67]       | Argentina   | Urban garden     | 66          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 32 genera |
| [58]       | Canada      | Green roof       | 17          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [54]       | USA         | Urban garden     | 20          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [96]       | Australia   | Urban garden     | 19          | 4 families (=Apidae, Colletidae, Halictidae and Megachilidae)         |
| [59]       | Canada      | Green roof       | 11          | 2 families (=Colletidae, Megachilidae), 5 genera                     |
| [6]        | Poland      | Urban garden     | 104         | –                                                                   |
| [81]       | USA         | Urban garden     | 55          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [51]       | USA         | Urban garden     | 96          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [36]       | USA         | Urban garden     | 10          | *Bombus* spp.                                                        |
| [60]       | Australia   | Urban garden     | 21          | 4 families (=Apidae, Colletidae, Halictidae, Megachilidae)            |
| [23]       | USA         | Urban garden     | 18          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [78]       | USA         | Urban garden     | 43          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [73]       | Canada      | Urban garden     | 200         | 6 bee families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae and Melittidae) |
| [42]       | Asia, Europe, and North America | Green roof | 326 | *Apidae* |
| [87]       | Philippine  | Urban garden     | 14          | 2 families (=Apidae and Halictidae), 6 genera                        |
| [57]       | USA         | Urban garden     | 29          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 23 genera |
| [91]       | USA         | Urban garden     | 98          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [47]       | Austria     | Green roof       | 90          | 19 genera                                                            |
| [2]        | USA         | Urban garden     | 17          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 13 genera |
| [22]       | USA         | Urban garden     | 14          | 4 families (=Andrenidae, Colletidae, Halictidae, Megachilidae)         |
| [38]       | Ghana       | Urban garden     | 167         | 4 families (=Apidae, Colletidae, Halictidae, Megachilidae)            |
| [7]        | USA         | Urban garden     | 75          | 3 families (=Apidae, Halictidae, Megachilidae)                        |
| [11]       | USA         | Urban garden     | 57          | 19 genera                                                            |
| [5]        | USA         | Urban garden     | 172         | 6 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, Melittidae), 44 genera |
| [76]       | Switzerland | Green roof       | 5           | *Halictidae*                                                         |
| [20]       | USA         | Urban garden     | 49          | 4 families (=Apidae, Colletidae, Halictidae, Megachilidae)            |
| [8]        | USA         | Urban–rural      | 81          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 23 genera |
| [50]       | Austria     | Urban garden     | 113         | 22 genera                                                            |
| [15]       | Argentina   | Urban garden     | 73          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae) |
| [92]       | Germany     | Urban garden     | 117         | –                                                                   |
| [88]       | India       | Urban garden     | 39          | 3 families (=Apidae, Halictidae, Megachilidae)                        |
| [3]        | USA         | Urban garden     | 20          | 5 families (=Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae), 17 genera |
| [12]       | USA         | Urban garden     | 15          | 4 families (=Andrenidae, Apidae, Colletidae, Halictidae), 14 genera |
attractive plants for bees in urban gardens. These plants have been suggested by 23 studies, most of which have been done in the United States (39%).

**Native vs. non-native host plants**

It is claimed that the presence of native and non-native bees in gardens is primarily related to the host plant [6]. One of the factors that affect the attraction of bees in urban gardens is the origin of the host plant, which some studies have found that native plants are more effective in attracting pollinators than non-native ones. However, some studies claim that non-native plants attract more bees and others claim that the simultaneous presence of native and non-native plants in urban gardens attracts more bumblebees than those whose non-native species are predominant [84]. Staab et al. [92] state that the visit of bees to native and non-native plants depends on their flowering season. After the flowering season in non-native plants, bees’ visits decrease and they will shift to native plants. Regardless of the origin of the studied plants, plant height also has a positive effect on bees’ visiting rate [17].

Table 4 shows the attractiveness of the plants in urban gardens for bees according to plant origin. This table presents 16 studies, 44% of which found that bees are more attracted to native plants. Others have found that non-native plants are more attractive to bees than native plants (38%). Few studies have shown that there is no difference in the attractiveness of native and non-native plants for bees (18%).

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**Table 2** Nesting type, origin, sociality, generality, and the scientific name of the most dominant species recorded in urban environments

| References | Country | Nesting    | Origin   | Sociality | Generality | Species           |
|------------|---------|------------|----------|-----------|------------|-------------------|
| [27]       | USA     | Above-ground | Native   | Solitary  | General    | Apidae            |
| [21]       | USA     | Soil       | Native   | Social    | General    | Halictidae        |
| [64]       | USA     | Above-ground | Non-native | Social   | General    | Hylaeus leptoccephalus |
| [65]       | USA     | Above-ground | Native   | Social    | General    | Bumblebees        |
| [25]       | USA     | Above-ground | Non-native | Social   | General    | Honeybees         |
| [26]       | USA     | Above-ground | Native   | Solitary  | General    | Megachilidae      |
| [97]       | USA     | Above-ground | Native   | Social    | General    | Halictus virescens |
| [72]       | Egypt   | Above-ground | Non-native | Social   | General    | Honeybees         |
| [58]       | Canada  | Above-ground | Native   | Social    | General    | Bumblebees        |
| [96]       | Australia | Above-ground | Non-native | Social   | General    | Honeybees         |
| [54]       | USA     | Above-ground | Native   | Social    | General    | Bombus impatiens  |
| [67]       | Argentina | Above-ground | Native   | Social    | General    | Plebeia droryana  |
| [34]       | UK      | Above-ground | Native   | Social    | General    | Honeybees         |
| [33]       | UK      | Above-ground | Native   | Social    | General    | Honeybees         |
| [95]       | Germany | Above-ground | Native   | Social    | General    | Bumblebees        |
| [51]       | USA     | Soil       | Native   | Solitary  | General    | Lasioglossum ilinoensis |
| [29]       | UK      | Above-ground | Non-native | Social   | General    | Honeybees         |
| [78]       | USA     | Above-ground | Non-native | Social   | General    | Halictidae        |
| [73]       | Canada  | Soil       | Native   | Social    | General    | Apis cerana       |
| [87]       | Philippine | Above-ground | Non-native | Social   | General    | Bombus griseocollis |
| [2]        | USA     | Above-ground | Native   | Social    | General    | Honeybees         |
| [7]        | USA     | Above-ground | Native   | Social    | General    | Bumblebees        |
| [83]       | UK      | Above-ground | Native   | Social    | General    | Honeybees         |
| [22]       | USA     | Above-ground | Non-native | Social   | General    | Honeybees         |
| [5]        | USA     | Soil       | Native   | Social    | General    | Lasioglossum coactum |
| [4]        | UK      | Above-ground | Native   | Social    | General    | Bumblebees        |
| [35]       | Canada  | Above-ground | Non-native | Social   | General    | Honeybees         |
| [62]       | Germany | Above-ground | Native   | Social    | General    | Bumblebees        |
| [8]        | USA     | Above-ground | Native   | Social    | General    | Halictus tripartitus |
| [92]       | Germany | Above-ground | Native   | Social    | General    | Honeybees         |
| [99]       | USA     | Above-ground | Native   | Social    | General    | Honeybees         |
Landscape and Local features effects

Many studies have examined the effect of landscape features on the presence of bees at both the local and landscape levels. Local variables include garden size, variety, and density of host plants, plant origin, type of agricultural products, roof height, etc. Some studies suggest that only local variables affect the presence of bees in the gardens and that the variables of the landscape or the features around these gardens have no effect. Some studies have found that increasing the richness and density of floral resources inside the gardens attracts pollinators to the gardens. At the landscape level, variables such as the percentage of impervious surfaces, traffic, the presence of other gardens, parks, forest patches, the density of buildings are usually measured. Most of the studies have focused on the role of the percentage of impervious surfaces as an indicator of urbanization.

Table 5 shows a list of studies that have examined the effects of local and landscape features and on the presence of bees in urban gardens and green roofs. The results of these studies have been obtained at distances of 50 to 1000 m from the gardens. This table presents 44 studies, most of which have been conducted in the United States (47%). The urbanization column shows the type of impact of impervious surfaces around the gardens. Studies that have not examined the effects of urbanization are shown by “-” and those that have not found a relationship between bee presence and urbanization were considered.

Table 3 Attractive plant species for bees in urban environments

| References | Country | Garden          | Attractive species                                      |
|------------|---------|-----------------|--------------------------------------------------------|
| [25]       | USA     | Urban garden    | Asteraceae, and Lamiaceae                              |
| [66]       | USA     | Urban garden    | Ornamental plants                                      |
| [72]       | Egypt   | Urban garden    | Achillea santolina, Chenopodium album, Beta vulgaris, Foeniculum vulgare |
| [30]       | UK      | Urban garden    | Borago officinalis, Lavandula * intermedia 'Grosso'    |
| [34]       | UK      | Urban garden    | Sedum, Origanum                                        |
| [33]       | UK      | Urban garden    | Aster                                                   |
| [29]       | UK      | Urban garden    | Iberis, Alstromeria, Tradescantia                      |
| [2]        | USA     | Urban garden    | Asclepias tuberosa and A. fascicularis                 |
| [91]       | USA     | Urban garden    | Harvestable crops and ornamental flowers                |
| [87]       | Philippine | Urban garden     | Bidens pilosa (Asteraceae) and Brassica rapa (Brassicaceae) |
| [4]        | UK      | Urban garden    | Cirsium arvense, Taraxacum agg, Rubus fruticosus agg, Ranunculus repens |
| [83]       | UK      | Urban garden    | Calamintha nepeta, Helium autumnale, and Geranium rozanne |
| [55]       | USA     | Urban garden    | Non-native, perennial, ornamental                      |
| [45]       | Poland  | Urban garden    | Lonicera                                               |
| [19]       | France  | Urban garden    | H. maximum, C. jacea, L. comiculatus                   |
| [17]       | USA     | Urban garden    | Borago, Phacelia, milkweed                             |
| [99]       | USA     | Urban garden    | Asclepias curassavica                                  |
| [43]       | Ukraine | Urban garden    | Rheinanthus vernalis, Echium vulgaris, Cirsium arvense, Trifolium pratensis, |
| [90]       | Poland  | Urban garden    | Asteraceae, Fabaceae, and Lamiaceae                    |
| [93]       | Australia | Urban garden       | Brassica rapa and Ocimum basilicum                     |
| [100]      | USA     | Urban garden    | Ruderal plant                                          |
| [62]       | Germany | Urban garden    | Bidens ssp., Coreopsis ssp. and Euphorbia hypericifolia |
| [3]        | USA     | Urban garden    | A. incarnate, A. tuberosa                              |
Table 5: The effects of urbanization and local variables on the presence of bees in urban gardens and green roofs

| References | Country        | Garden   | Urbanization | Key result                                                                 |
|------------|----------------|----------|--------------|-----------------------------------------------------------------------------|
| [1]        | Sweden         | Urban garden | Negative     | Local variables were more important than landscape variables                |
| [66]       | USA            | Urban garden | –            | Adding wild native species to the garden did not attract pollinators        |
| [85]       | Sweden         | Urban garden | Negative     | Seed set for C. persicifolia decreased with urbanization                     |
| [97]       | USA            | Green roof  | Negative     | Green spaces around green roofs increased bee abundance                     |
| [102]      | USA            | Urban garden | Negative     | Bombus and Megachile were affected by local variables                       |
| [9]        | Switzerland    | Green roof | Negative     | Green roof size has no effects on bee populations                           |
| [39]       | Sweden         | Urban garden | –            | Garden size does not affect pollinator populations                          |
| [98]       | Belgium        | Urban garden | Negative     | Bumblebee visiting rate decreased with the increasing amount of green space around gardens |
| [84]       | UK             | Urban garden | –            | Regardless of the origin, the increase in flowers attracts bumblebees     |
| [54]       | USA            | Urban garden | –            | In-garden flowers have a positive effect on coneflower pollination          |
| [30]       | UK             | Urban garden | –            | Garden size does not affect pollinator populations                          |
| [33]       | UK             | Urban garden | –            | Garden size does not affect pollinator populations                          |
| [79]       | USA            | Urban garden | Neutral      | Garden size does not affect pollinator populations                          |
| [96]       | Australia      | Urban garden | Negative     | Colletidae were almost absent from residential landscapes                   |
| [59]       | Canada         | Green roof  | Negative     | Roof height reduced brood cells                                             |
| [81]       | USA            | Urban garden | Negative     | Garden size positively affected small bees                                  |
| [28]       | Canada         | Urban garden | –            | Garden size does not affect pollinator populations                          |
| [16]       | USA            | Urban garden | Negative     | Urbanization is associated with reduced flower visitor richness             |
| [6]        | Poland         | Urban garden | Negative     | The presence of a large green patch around the gardens has a positive effect on bee presence |
| [95]       | Germany        | Urban garden | Positive     | Local variables were strongly related to flower visitation rates           |
| [60]       | Australia      | Urban garden | Neutral      | Local and landscape variables were not associated with bees' populations   |
| [24]       | UK             | Urban garden | Neutral      | Bumblebees were negatively correlated with areas cultivated for vegetables |
| [36]       | USA            | Urban garden | Negative     | Diversity and abundance of Bombus spp. Decreased with urbanization         |
| [48]       | USA            | Urban garden | Negative     | Bees were positively associated with distance to the city center           |
| [23]       | USA            | Urban garden | Neutral      | Visits to one species increased with urbanization but visits to others decreased |
| [78]       | USA            | Urban garden | Negative     | The diversity of bees decrease with increasing flower abundance            |
| [47]       | Austria        | Green roof  | –            | Roof height did not affect bee communities                                  |
| [87]       | Philippine     | Urban garden | Negative     | Home gardens surrounded by woody habitats showed higher bee richness       |
| [91]       | USA            | Urban garden | Positive     | The presence of green spaces around the gardens positively affected bees   |
| [11]       | USA            | Urban garden | Negative     | Canopy cover within gardens negatively affected bee abundance              |
| [7]        | USA            | Urban garden | Neutral      | Garden size positively affected small bees                                  |
| [44]       | China          | Urban garden | Negative     | Urbanization negatively affected Gentiana dahunica                         |
| [38]       | Ghana          | Urban garden | Neutral      | Fewer cavity-nesting bees were found in urban than in rural areas          |
| [52]       | France         | Urban garden | Negative     | Gardens surrounded by other gardens showed higher bee richness           |
| [22]       | USA            | Urban garden | Neutral      | Positive effect on non-native species but negative on native species      |
| [5]        | USA            | Urban garden | Negative     | Natural cover around gardens increases bee richness                         |
| [68]       | USA            | Urban garden | Negative     | Suburban landscapes are suboptimal for B. impatiens                       |
| [50]       | Austria        | Urban garden | Neutral      | Flower abundance was the most important factor as a local variable         |
| [18]       | Argentina      | Green roof  | Negative     | Street cover in the landscape negatively affected total richness           |
| [8]        | USA            | Urban–rural | Negative     | Urban areas negatively impact bee communities                              |
| [61]       | Mexico         | Urban garden | Neutral      | Floral visitor abundance was influenced by habitat type and season        |
| [20]       | USA            | Urban garden | Positive     | Barren lands around gardens negatively affected bee populations           |
| [12]       | USA            | Urban garden | Neutral      | Bee abundance and richness did not change with increasing floral resources |
| [74]       | USA            | Urban garden | Positive     | The percent urban cover positively affected B. vosnesenskii                |
neutral. Half of these studies have reported the negative effects of urbanization on the presence of bees. Few of these studies (9%) have found positive effects and 22% have found no relationship between urbanization and the presence of bees in urban gardens and green roofs.

Conclusion
In this study, the results of 87 articles related to the presence of bees in gardens and urban farms were summarized in three general sections. In the first part of the results, our data showed that urban environments, and especially urban gardens, contain a high diversity of bees, which provides a good opportunity for urban agriculture. Most studies have emphasized the greater abundance and diversity of bees in ground-level gardens than green roofs. This result may be due to the cultivation of Sedum monoculture or the high height of buildings that are more prone to wind than short buildings. Therefore, planting native plants with greater diversity for green roofs than sedum monoculture is recommended to attract bees [97].

One important result was that bumblebees and honeybees have been identified as the dominant species in urban gardens by most studies. This result can help a lot in managing urban gardens and increasing the pollination supply, because by recognizing the habitat needs of these species, a significant percentage of pollinating bees can be attracted to farms and urban gardens. Most studies showed that native bees make up a larger population than non-native bees in urban gardens. Since few studies have examined the competition between honeybees as a non-native species (for example in North America) and native bees, we are not able to reach a definite conclusion in this regard. Therefore, the strategy of increasing the bee population in urban environments by establishing beehives is facing major challenges, and more studies are needed in this field.

Most studies claimed that the identified bees were of general and social species. Urban environments are different from natural environments and provide difficult conditions for the presence of specialist species. Air and noise pollution, the effects of urban heat islands, urban microclimate, traffic, and the lack of suitable host plants for specialist species have caused cities to accommodate general species that one of the most important of which is honeybees. Therefore, in the strategy of increasing floral resources in gardens, it is necessary to avoid planting flower species that need specialist bees for pollination. Honeybees and bumblebees, previously mentioned as common species in urban gardens, are part of the above-ground nesting [7]. On the other hand, about 70% of solitary bees nest in the ground [25], which are less present in urban environments. Therefore, to attract bees, more attention should be focused on the habitat and nesting needs of above-ground nesting. Our data showed that the diversity of host plants had a significant effect on the presence of pollinators in farms and urban gardens so that native plants were more attractive to bees than non-native plants.

Related studies on the effect of landscape and local variables on the presence of bees in farms and urban gardens showed that urbanization negatively affects the presence of bees in urban gardens. Some studies have shown that the presence of green spaces or other farms and gardens around the studied gardens have a positive effect on the presence of pollinators. Therefore, the strategy of converting lawns into floral resources or carrying out agricultural activities around green spaces can effectively help to increase agricultural production in the city.

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References
1. Ahnne K, Bengtsson J, Elmqvist T. Bumble bees (Bombus spp) along a gradient of increasing urbanization. PLoS ONE. 2009;4(5):e5574.
2. Baker AM, Potter DA. Colonization and usage of eight milkweed (Asclepias) species by monarch butterflies and bees in urban garden settings. J Insect Conserv. 2018;22(5):405–18.
3. Baker AM, Redmond CT, Malcolm SB, Potter DA. Suitability of native milkweed (Asclepias) species versus cultivars for supporting monarch butterflies and bees in urban gardens. PeerJ. 2020;8:e9823.
4. Baldock KC, Goddard MA, Hicks DM, Kunin WE, Mitschunas N, Morse H, Osgathorpe LM, Potts SG, Robertson KM, Scott AV. A systems
approach reveals urban pollinator hotspots and conservation opportunities. Nat Ecol Evol. 2019;3(3):363–73.

5. Ballare KM, Neff JL, Ruppel R, Jha S. Multi-scalar drivers of biodiversity. Local management mediates wild bee community response to regional urbanization. Ecol Appl. 2019;29(3):e01869.

6. Banaszak-Cibicka W, Ryghtyska H, Dylewska L. Features of urban green space favourable for large and diverse bee populations (Hymenoptera: Apoidea: Apiformes). Urban For Urban Green. 2016;20:448–52.

7. Bennett AB, Lovell S. Landscape and local site variables differentially influence pollinators and pollination services in urban agricultural sites. PLoS ONE. 2019;14(2):e0212034.

8. Birdshire KR, Carper AL, Briles CE. Bee community response to local and landscape factors along an urban-rural gradient. Urban Ecosyst. 2020;23:689–702.

9. Braaker S, Ghazoul J, Obrist M, Moretti M. Habitat connectivity shapes urban arthropod communities: the key role of green roofs. Ecology. 2014;95(4):1010–21.

10. Buchholz S, Kowarik I. Urbanization modulates plant–pollinator interactions in invasive vs. native plant species. Sci Rep. 2019;9(1):1–9.

11. Burdine JD, McCluney KE. Interactive effects of urbanization and local habitat characteristics influence bee communities and flower visitation rates. Oecologia. 2019;190(4):713–23.

12. Cohen H, Philpott SM, Liere H, Lin BB, Jha S. The relationship between pollinator community and pollination services is mediated by floral abundance in urban landscapes. Urban Ecosyst. 2021;24(2):275–90.

13. Colasanti KJ, Hamm MW, Litjens CM. The city as an “agricultural powerhouse”? Perspectives on expanding urban agriculture from Detroit, Michigan. Urban Geogr. 2012;33(3):348–69.

14. Davis AJ, Lonsdorf EV, Shienk CR, Martinez KC, Taylor JR, Lovell ST, Minor ES. Enhancing pollination supply in an urban ecosystem through landscape modifications. Landsc Urban Plan. 2017;162:157–66.

15. De Santis AA, Chacoff N. Urbanization affects composition but not richness of flower visitors in the Yungas of Argentina. Neotrop Entomol. 2020;49(4):568–77.

16. Deguenes N, Julliard R, De Flores M, Fontaine C. Functional homogenization of flower visitor communities with urbanization. Ecol Evol. 2016;6(7):1967–76.

17. Diblee AC, Drummond FA, Stack LB. Plant origin and other attributes influence pollinators and pollination services in invasive vs. native plant species. Sci Rep. 2019;9(1):1–9.

18. Domínguez MVS, González E, Fabián D, Salvo A, Fenoglio MS. Habitat characteristics influence pollinators and pollination services along an urban-rural gradient. Urban Ecosyst. 2020;23:689–702.

19. Dusza Y, Kraepiel Y, Abbadie L, Barot S, Fico G, Lupi D. A botanic garden as a tool to combine public perception of nature and life-science investigations on native/exotic plants interactions with local pollinators. PLoS ONE. 2020;15(2):e0228965.

20. Egerer M, Cecala JM, Cohen H. Wild bee conservation within urban arthropod communities: the key role of green roofs. Ecology. 2014;95(4):1010–21.

21. Fetridge ED, Ascher JS, Langellotto GA. The bee fauna of residential gardens in a suburb of New York City (Hymenoptera: Apoidea). Ann Entomol Soc Am. 2008;101(6):1067–77.

22. Fitch G, Wilson CJ, Glaum P, Vaidya C, Jamieson MA. Does the effect of floral neighborhood on pollinator visitation. Oecologia. 2015;185(4):713–23.

23. Fitch GM. Urbanization-mediated context dependence in the effect of floral neighborhood on pollinator visitation. Oecologia. 2017;185(4):713–23.

24. Foster G, Wilson CJ, Glaum P, Vaidya C, Jamieson MA. Does the effect of floral neighborhood on pollinator visitation. Oecologia. 2017;185(4):713–23.

25. Foster G, Wilson CJ, Glaum P, Vaidya C, Jamieson MA. Does the effect of floral neighborhood on pollinator visitation. Oecologia. 2017;185(4):713–23.

26. Frankie GW, Thorp RW, Pawelek JC, Hernandez J, Coville R. Urban bee diversity in a small residential garden in northern California. J Hymenopt Res. 2009;18(2):368–79.

27. Frankie GW, Thorp RW, Schindler M, Hernandez J, Erter B, Rizzardi M. Ecological patterns of bees and their host ornamental flowers in two northern California cities. J Kansas Entomol Soc. 2005;78(3):227–46.

28. Fukase J, Simons A. Increased pollinator activity in urban gardens with more native flora. Appl Ecol Environ Res. 2016;14(1):297–310.

29. Garbuco M, Alton K, Ratnieks FL. Most ornamental plants on sale in garden centres are unattractive to flower-visiting insects. PeerJ. 2017:e3066.

30. Garbuco M, Madsen A, Ratnieks FL. Patch size has no effect on insect visitation rate per unit area in garden-scale flower patches. Acta Oecologica. 2015;62:53–74.

31. Garbuco M, Ratnieks FL. Listmania: the strengths and weaknesses of lists of garden plants to help pollinators. Bioscience. 2014;64(1):1019–26.

32. Garbuco M, Ratnieks FL. Quantifying variation among garden plants in attractiveness to bees and other flower-visiting insects. Funct Ecol. 2014;28(2):364–74.

33. Garbuco M, Ratnieks FL. Using the British national collection of asters to compare the attractiveness of 228 varieties to flower-visiting insects. Environ Entomol. 2015;44(3):638–46.

34. Garbuco M, Samuelsson EE, Ratnieks FL. Survey of insect visitation of ornamental flowers in Southover Grange garden, Lewes, U.K. Insect Sci. 2015;22(5):700–5.

35. Guanavietti M, Giuliani C, Boff S, Fico G, Lupi D. A botanic garden as a tool to combine public perception of nature and life-science investigations on native/exotic plants interactions with local pollinators. PLoS ONE. 2020;15(2):e0228965.

36. Glaum P, Simao M-C, Vaidya C, Fitch G, Ullinanco B. Big city Bombus: using natural history and land-use history to find significant environmental drivers in bumble-bee declines in urban development. R Soc Open Sci. 2017;4(5):170156.

37. Griffiths-Lee J, Nicholls E, Goulson D. Companion planting to attract pollinators increases the yield and quality of strawberry fruit in gardens and allotments. Ecol Entomol. 2020;45(5):1025–34.

38. Guent S, Kunin WE, Dougill AJ, Dallimer M. Effects of urbanisation and management practices on pollinators in tropical Africa. J Appl Ecol. 2019;56(1):214–24.

39. Gunnarsson B, Feddersel LM. Bumblebees in the city: abundance, species richness and diversity in two urban habitats. J Insect Conserv. 2014;18(6):1185–91.

40. Hangstob AD. Does the introduced bumblebee, Bombus terrestris (Apidae), prefer flowers of introduced or native plants in Australia? Aust J Zool. 2005;53(1):29–34.

41. Hofmann MM, Fleischmann A, Renner SS. Foraging distances in six species of solitary bees with body lengths of 6 to 15 mm, inferred from individual tagging, suggest 150 m-rule-of-thumb for flower strip distances. J Hymenopt Res. 2020;77:105.

42. Hofmann MM, Renner SS. Bee species recorded between 1992 and 2017 from green roofs in Asia, Europe, and North America, with key characteristics and open research questions. Apidologie. 2018;49(3):307–13.

43. Honchar HY. Diversity and trophic relationships of functional groups of bumblebees (Hymenoptera: Apidae, Bombus Latreille, 1802) in urban Habitats. Psych E J Entomol. 2020. https://doi.org/10.1155/2020/5182146.

44. Hou Q-Z, Pang X, Wang Y-P, Sun K, Jia L-Y, Zhang S-H, Li Q-X. Urbanization threaten the pollination of Gentiana dahurica. Sci Rep. 2019;9(1):1–9.

45. Jachula J, Denisow B, Stralkowska-Abremek M. Floral reward and insect visitors in six ornamental Lonicera species—plants suitable for urban bee-friendly gardens. Urban For Urban Green. 2019;44:126390.

46. Koyama A, Egawa C, Taki H, Yasuda M, Kanzaki N, Ide T, Okabe K. Non-native plants are a seasonal pollen source for native honeybees in suburban ecosystems. Urban Ecosyst. 2018;21(3):429–46.

47. Llaguki E, Burdine JD, McCluney KE. Urbanization alters communities of flying arthropods in parks and gardens of a medium-sized city. PeerJ. 2017;5:e3620.


49. Langellotto GA, Melathopoulos A, Messer I, Anderson A, McClintock N, Costner L. Garden pollinators and the potential for ecosystem service flow to urban and peri-urban agriculture. Sustainability. 2018;10(6):2047.

50. Lanner J, Kratschmer S, Petrović B, Gaulhofer F, Meimberg H, Pachinger L. City dwelling wild bees: how communal gardens promote species richness. Urban Ecosyst. 2020;23(2):271–88.

51. Levé M, Baudry E, Bessa-Gomes C. Domestic gardens as favorable pollinator habitats in impervious landscapes. Sci Total Environ. 2019;647:20–30.

52. Lovell ST. Multifunctional urban agriculture for sustainable land use planning in the United States. Sustainability. 2010;2(8):2499–522.

53. Lowenstein DM, Matteson KC. Diversity of wild bees supports pollination services in an urbanized landscape. Oecologia. 2013;170(3):811–21.

54. Lowenstein DM, Matteson KC, Minor ES. Evaluating the dependence of urban pollinators on ornamental, non-native, and weedy/floral resources. Urban Ecosyst. 2019;22(2):293–302.

55. Marín L, Martínez-Sánchez ME, Sagot R, Navarrete D, Morales H. Floral visitors in urban gardens and natural areas: diversity and interaction networks in a neotropical urban landscape. Basic Appl Ecol. 2020;43:3–15.

56. Mach BM, Potter DA. Quantifying bee assemblages and attractiveness of flowering woody landscape plants for urban pollinator conservation. PLoS ONE. 2018;13(12):e0208428.

57. MacIvor JS, Rutten A, Salehi B. Exotics on exotics: pollen analysis of urban bee visits to Sedum on a green roof. Urban Ecosyst. 2015;18(2):419–30.

58. MacIvor JS. Building height matters: nesting activity of bees and wasps on vegetated roofs. Israel J Ecol Evol. 2016;62(1–2):88–96.

59. Makinson JC, Threlfall CG, Latty T. Bee-friendly community gardens: Impact of environmental variables on the richness and abundance of exotic and native bees. Urban Ecosyst. 2017;20(2):463–76.

60. Marin L, Martinez-Sanchez ME, Sagot R, Navarrete D, Morales H. Floral visitors in urban gardens and natural areas: diversity and interaction networks in a neotropical urban landscape. Basic Appl Ecol. 2020;43:3–15.

61. Marquardt M, Kienbaum L, Kretschmer LA, Penell A, Schweikert K, Fleischmann A. High honeybee abundances reduce wild bee abundances on flowers in the city of Munich. Oecologia. 2021;195(3):658–67.

62. Potter A, LeBuhn G. Pollination service to urban agriculture in San Francisco, CA. Urban Ecosyst. 2015;18(3):885–93.

63. Prospects WU. The 2014 Revision, Highlights (ST/ESA/SER.A/352). 2014.

64. Quistberg RD, Bichler P, Philpott SM. Landscape and local correlates of bee abundance and species richness in urban gardens. Environ Entomol. 2016;45(3):592–601.

65. Renner SS, Graf MS, Hentschel KE, Fleischmann A. High honeybee abundances reduce wild bee abundances on flowers in the city of Munich. Oecologia. 2021;195(3):825–31.

66. Rollings R, Goulson D. Quantifying the attractiveness of garden flowers for pollinators. J Insect Conserv. 2019;23(5):803–17.

67. Schröter J, Lüthig M, Schweikert K, Fleischmann A. Woody habitats promote pollinators and complexity of plant–pollinator interactions in home gardens located in rice terraces of the Philippine Cordilleras. Paddy Water Environ., 2018;16(2):253–63.

68. Sanyé-Mengual E, Cerón-Palma J, Olivier-Sola J, Montero JJ, Riera-deville J. Environmental analysis of the logistics of agricultural products from roof top greenhouses in Mediterranean urban areas. J Sci Food Agric. 2013;93(1):100–9.

69. Shivalingaswamy TM, Udayakumar A, Gopinath K, Anjanappa R. Non-Apis bee diversity in an experimental pollinator garden in Bengaluru–a Silicon Valley of India. Sociobiology. 2020;67(4):2602–6.

70. Sikora A, Michalop P, Kelm M. Flowering plants preferred by bumblebees (Bombus Latr.) in the botanical garden of medicinal plants in Wrocław. J Appl Sci. 2016;60(2):59.

71. Sikora A, Michalop P, Sikora M. What kind of flowering plants are attractive for bumblebees in urban green areas? Urban For Urban Green. 2020;48:126546.

72. Shivalingaswamy TM, Udayakumar A, Gupta A, Anjanappa R. Non-Apis bee diversity in an experimental pollinator garden in Bengaluru–a Silicon Valley of India. Sociobiology. 2020;67(4):593–8.

73. Sikora A, Michalop P, Kelm M. Flowering plants preferred by bumblebees (Bombus Latr.) in the botanical garden of medicinal plants in Wrocław. J Appl Sci. 2016;60(2):59.
94. Theodorou P, Radzevičiūtė R, Lentendu G, Kahnt B, Husemann M, Bleidorn C, Settele J, Schweiger O, Grosse I, Wubet T. Urban areas as hotspots for bees and pollination but not a panacea for all insects. Nat Commun. 2020;11(1):1–13.
95. Theodorou P, Radzevičiūtė R, Settele J, Schweiger O, Murray TE, Paxton RJ. Pollination services enhanced with urbanization despite increasing pollinator parasitism. Proc R Soc B Biol Sci. 2016;283(1833):20160561.
96. Threlfall CG, Walker K, Williams NS, Hahs AK, Mata L, Stork N, Livesley SJ. The conservation value of urban green space habitats for Australian native bee communities. Biol Cons. 2015;187:240–8.
97. Torietto R, Fant J, Ascher J, Ellis K, Larkin D. A comparison of bee communities of Chicago green roofs, parks and prairies. Landsc Urban Plan. 2011;103(1):102–8.
98. Verboven HA, Aertsen W, Brys R, Hermy M. Pollination and seed set of an obligatory outcrossing plant in an urban–peri-urban gradient. Perspect Plant Ecol Evol Syst. 2014;16(3):121–31.
99. Warren ML, Kram KE, Theiss KE. Characterizing the nectar microbiome of the non-native tropical milkweed Asclepias curassavica, in an urban environment. PLoS ONE. 2020;15(9):e0237561.
100. Wijesinghe E, Minor ES, Karunarathne I, Yakandawala K. Relative attractiveness of ruderals and ornamental plants to flower-visiting insects in a tropical anthropogenic landscape. Urban For Urban Green. 2020;51:126657.
101. Wojcik VA, Frankie GW, Thorp RW, Hernandez JL. Seasonality in bees and their floral resource plants at a constructed urban bee habitat in Berkeley, California. J Kansas Entomol Soc. 2008;81(1):15–28.
102. Wojcik VA, McBride JR. Common factors influence bee foraging in urban and wildland landscapes. Urban Ecosyst. 2012;15(3):581–98.

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