A Scoping Review: The Value of Urban Bee Research to Urban Planning

Master Thesis
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24-02-2023
Abstract
Bees are relevant for several Sustainable Development Goals, most relevant of which is pollination. However, biodiversity rates have dropped sharply over the past decades, in part due to land use change. Contrarily, some research points towards cities as hotspots for bees. Taken together, it is unclear how bees respond to landscape characteristics. Therefore, a scoping review has been conducted in this work. To be included in this review, publications were required to be primary research and to include an urban weighing component regarding bees. The analysis was divided over four domains, including landscape characteristics and habitat characteristics. The results showed that natural areas are most important for bee biodiversity conservation, though urban areas still have advantages agricultural and rural areas. Moreover, habitat characteristics, especially floral characteristics, strongly correlate with bee biodiversity. Based on this work it is advised to maintain natural areas, improve on floral characteristics, increase area size of green areas, and focus on habitat characteristics for bee conservation.

Layman’s summary
Bees are important for most of global pollination, thus adding to food security. Unfortunately, over the last decades, bee biodiversity has dropped sharply. One of the major reasons for this has been change of land use, which affects natural landscape where bees mainly reside. However, recent research has also pointed to cities as a hotspot for bees. Because of this ambiguity, a scoping review has been conducted. This type of review aims to assess the research field without assessing the quality of individual articles. Research articles that were related urban bee ecology were included in this review. Within this work, articles are categorized over four domains, including landscape characteristics and local habitat characteristics. It becomes clear that natural areas are more valuable for bees since biodiversity levels are higher. Notably, urban areas sometimes score better than agricultural and rural areas. Furthermore, plant biodiversity also positively influences bee biodiversity. Based on this work, it is advised to maintain natural areas and improve the size of green areas overall. Additionally, improving on plant biodiversity and other local habitat characteristics adds to bee biodiversity.
Introduction

Internationally, cities are making steps towards becoming bee inclusive (Marshman & Knezevic, 2021). Enhancing bee biodiversity is especially interesting for cities due to the perceived paradox of the city as a refuge for bees and the city as driver of land-use change and fragmentation (Glaum et al., 2017; Hall et al., 2017; Harrison & Winfree, 2015). Humans depend on bees for most of global pollination, an ecosystem service of major relevance to food security, but bees also contribute to other Sustainable Development Goals (Patel et al., 2021; Willmer et al., 2017). Unfortunately, there is no panacea for increasing urban bee biodiversity, and methods are therefore often limited to basic steps, such as increasing floral abundance and richness (Threlfall et al., 2017; Turo & Gardiner, 2019). Within urban bee ecology, a relatively new field, research is taken up that must aid bee conservation in the city (Hernandez et al., 2009). Going beyond floral measures, urban bee ecology may inform urban planning for the design of inherently bee-friendly cities.

To counter the effects of urbanization within the city’s perimeter, it must be clear what the effects of urbanization and urban areas are on bee biodiversity. Evidently, cities act as a filter to bees resulting in urban “winners and losers” (Banaszak-Cibicka & Żmihorski, 2012). Beyond biodiversity indices, cities also influence the traits of bees that are frequently encountered (Buchholz & Egerer, 2020). Which bee traits are functionally relevant within urban bee ecology is not set in stone; some researchers include more bee traits than others or may order traits differently. For example, Williams et al. (2010) distinguish body size (continuous), nesting behaviour (2 options), nest construction (2 options), trophic specialization (lecty, diet; 2 options) and sociality (2 options). They exclude cleptoparasites because some of their traits are determined by their host. Contrarily, Twerd & Banaszak-Cibicka (2019) note body size (3 options), nesting behaviour (3 options), trophic specialization (2 options) and sociality (3 options, including cleptoparasitic). Other researchers may also include tongue length, emergence during the bee season and temperature breadth (Ayers et al., 2021; Buchholz & Egerer, 2020).

Another aspect of bees that is often mentioned is the native status of bees, which could be treated as a trait. Due to the abundance of exotic, ornamental plants in urban areas, exotic bees are also attracted to urban areas (e.g., Molumby & Przybylowicz, 2012; Salisbury et al., 2015). Furthermore, urban beekeeping is becoming increasingly popular (M. Egerer & Kowarik, 2020). Consequently, the proportion of exotic bees in cities, specifically honeybees is relatively high. Though not all honeybees are managed by beekeepers (Youngsteadt et al., 2015), some researchers prefer to exclude Apis mellifera L. altogether (e.g., Buchholz et al., 2020; Choate et al., 2018; Kammerer et al., 2021). For other bees, the city’s geography would determine whether a bee is exotic or not.

For cities to become bee inclusive, it is important to find out how the city filters bee communities and how to counter this filter. There are numerous researchers hypothesizing on measures that need to be taken to balance out bee communities, also regarding specific traits (Buchholz & Egerer, 2020; Ferrari & Polidori, 2022). For example, below-ground nesting bees need bare soil to nest, so are theoretically negatively affected by impervious surfaces (Fortel et al., 2014; Matteson et al., 2008). However, not all traits are predicted easily, and research literature is contradictory on this matter (Buchholz & Egerer, 2020). For example, large bees are expected to be advantaged, as their size allows them to forage further. The downside of this is that larger bees also require more energy and it remains disputed which effect is stronger (Ferrari & Polidori, 2022). Consequently, it may be difficult for cities to plan for bee biodiversity. This paper will therefore attempt to answer the following question: How do bees respond to urban landscape characteristics?
Against this background, we conduct a scoping literature review in accordance with Arksey & O’Malley (2007), to summarize and disseminate research findings in aid of municipalities and thus to inform urban planning. With said goal, it is also possible to investigate gaps between research topics and practice. Four perspectives will be taken regarding bee biodiversity, namely urban environment, local urban habitat, green roofs, and housing. The former three are clear themes from research literature and are at the cross section of urban planning and urban bee ecology. Though relatively new to mix, green roofs are already fully taken up in such research (Rahimi et al., 2022). Bee housing is also included, due to its accessibility as a measure to cities (MacIvor & Packer, 2015; Rahimi et al., 2021). In this review, honeybees will also be included as they are undeniably part of the city’s bee composition.

1. Methodology

A scoping review was conducted to investigate how bees are affected by urban environments, at both the local and the landscape scale. The review is conducted following the following subsequent steps (table 1).

1.1 Data gathering

Scopus and Web of Science were used to identify a list of articles related to the topic. The literature search was applied in both search engines, for their elaborate range of interdisciplinary research. The articles were retrieved at the beginning of December 2022. No articles were excluded based on their publication date. The initial query produced a collection of 2179 articles, 782 of which were excluded immediately for being duplicates. The search query used in Scopus, is as follows: "TITLE-ABS-KEY ( bee OR apidae AND urban* OR city OR roof AND NOT algorithm )". Its functional equivalent was used in Web of Science. After use of these search engines, all subsequent steps were performed in Google Sheets (click here).

<table>
<thead>
<tr>
<th>Steps</th>
<th>Procedure</th>
<th>Accepted articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Data gathering</td>
<td>Web of Science and Scopus search, through the following search string: &quot;TITLE-ABS-KEY ( bee OR apidae AND urban* OR city OR roof AND NOT algorithm )&quot;</td>
<td>1397</td>
</tr>
<tr>
<td>2. Data screening &amp; cleaning</td>
<td>Title reading with the following criteria: - Are bees involved? - Is an urban component present?</td>
<td>834</td>
</tr>
<tr>
<td></td>
<td>Abstract reading with the following criteria: - Is the urban component weighed? - Are bees researched for aspects related to their ability to pollinate?</td>
<td>499</td>
</tr>
<tr>
<td>3. Data scoping</td>
<td>All available full texts were downloaded.</td>
<td>460</td>
</tr>
<tr>
<td>4. Article appraisal &amp; analysis</td>
<td>Full text reading using the criteria from step 3.</td>
<td>276</td>
</tr>
</tbody>
</table>

Table 1. Methodological steps of the literature review.

1.2 Data screening and cleaning

The remaining 1397 articles were screened in three steps, with each step getting closer to the overarching research question. In this manner, questionable article titles and abstracts were treated with caution and not immediately excluded. Articles were screened for their relationship to bees and urban form during title reading. Consequently, for all research perspectives, an urban component was present. In the subsequent step, abstracts were read for the presence of an urban weighing and
aspects that would influence bee’s ability to pollinate, thus excluding research focussed on bees as biomarkers. Urban weighing involves an empirical step such as comparison between two locations or along an urban gradient to determine the effect of the urban environment, or otherwise various urban habitats.

1.3 Data scoping

In preparation of full text reading, 39 texts were not fully available. This left 460 out of 499 texts available for the final step.

1.4 Article appraisal & analysis

During data extraction, the steps of data screening on abstracts were now applied to full texts. Through this process, another 183 out of 460 articles were eliminated. Articles that involved more than only bee species were also included, on the condition that results on bees could be distinguished from the data. The remaining data were chartered into subtopics and were used for critical analysis. Chartering of the 276 articles was performed using four analytical themes: landscape characterization, habitat characterization, green roofs, and housing. The results were clustered among six themes determined a priori: biodiversity & survival, native status, size, sociality, nesting, and lecty. During data collection, results were clustered when insufficient results were obtained for multiple specific factors, but their combination would not lose specificity to said factors. For example, all developments that occur in and around the colony are clustered in colony dynamics. This includes but is not limited to thermoregulation, colony weight (biomass), brood production and sexual offspring production, since each of these factors shed light on the state of the colony. Pollen collection includes the ability of bees to collect pollen, including their diversity, abundance, but also plant pollination success. Other factors that were clustered are parasitism, varroa load and the honeybee effect and urban environment. This effect encompasses a proven difference in bee composition by cause of honeybees. For biodiversity indices, composition and evenness are clustered under diversity and density is clustered with abundance. For all articles, the following information was also noted: goal, species, output measures, geography and if present, policy recommendations.

Landscape radii are commonly between 200 and 1500 meters, often derived from foraging distances of the bee in question. Habitat characteristics are determined in a smaller area, e.g., a plot of 100 m². In papers that do not research habitat characteristics, these areas are usually also included. Consequently, in articles concerning landscape characterization, habitat characteristics are often included. For landscape characterization, urban areas were compared to other habitats which include natural, agriculture, suburban and rural categorization. Articles were consistently followed in their categorization. Alternatives to categorization, such as %impervious surface, were also followed consistently. These were clustered as general urban comparisons. Some articles contained comparisons between multiple areas (e.g., urban versus agricultural and urban versus natural). These were both entered separately, as these domains are also analysed separately.

For habitat characterization, factors influencing bee traits and three biodiversity outcomes (abundance, richness, alpha diversity) were determined both before and during the data extraction. Factors determined beforehand were floral factors (richness, abundance, diversity), isolation, area size, native status of vegetation, buildings and ecomanagement. Additionally, several habitat types were included. During analysis, only factors that contained at least 3 hits were included.
2. Results
After data gathering and careful selection of articles, 276 articles were analysed for various properties. These include bee species, geography, and properties related to landscape characterization, habitat characterization, green roofs, and housing.

The most investigated species concerned *A. mellifera* (51), in part due to papers on the relationship between apiaries and their location. However, most articles (162) considered entire bee communities, in aim of providing a comprehensive overview of the species found in urban and non-urban areas. Furthermore, articles focussed specifically on bees with certain traits (13), stingless bees (18), *Bombus spp.* (51), wild bees (16) and native bees (6). In the latter two, *A. mellifera* is specifically excluded (or assumed to be). These articles did not concern apiaries. Excluding *A. mellifera*, 47 articles were on one species and 10 articles were on multiple specific species not bound by traits or genus. Notably, for further analysis of the results, all species are pooled.

With 112 articles, most papers were based on research performed in the North America. The USA produced most papers (95). Europe produced close to the same amount (105) with most papers from Germany (25), England (16), Poland (14) and France (13). In South America, 21 of 24 papers were from Brazil and Australia produced 16 of 17 articles in Oceania. 5 papers concerning multiple countries were produced in Europe, whereas 1 paper on multiple countries was produced in Asia. Like other recently published review studies (e.g., Brant et al., 2022; Prendergast, Dixon, et al., 2022), it is evident research efforts are focussed on developed countries found in North America, Western Europe, and Australia.

225 out of 276 articles concerned the urban environment, followed by 78 on habitat characterization. Only 8 articles were produced on green roofs and 5 articles were produced on housing. Therefore, no analysis was performed on these themes.

2.1 Landscape characterization
Within urban environment, 147 articles mentioned results on biodiversity measures in general whereas 124 (partly overlapping) articles mentioned specific traits affected by the urban environment. 28 articles mentioned effects of urban characteristics on (relative) abundance on exotic bees. Between 32 and 46 mentions were made on each trait. Following authors’ definitions there were 71 comparisons found between urban and natural areas, 32 between urban and rural, 23 between urban and agricultural and 16 between urban and suburban. In total, there were 129 points of comparison for general measures (table 2). In papers on landscape characterization often no hypothesis is given for the reason behind the differences between various habitats. However, where possible more insights are shared.

Natural areas are more suited for bees compared to urban areas, though the results are moderately contradictive (table 2). The negative results generally outweigh the positive and neutral results, especially for abundance. Consequently, abundance is generally higher in natural areas, for example for *Bombus* species (Schochet et al., 2016). The same pattern is visible for richness and diversity, each of which is generally higher in natural areas. Notably, the number of positive and neutral results for these biodiversity indices is relatively high, demonstrating its overall inconclusiveness. Diversity of collected pollen, a measure that serves as a proxy for sufficient floral resources, is better or unaffected in respectively 1 or 2 cases. Despite this discrepancy, the difference between natural and urban areas explicitly favours the former.

In contrast to the urban to natural comparison, the urban to agricultural comparison shows a distinction between abundance and richness of bees. Abundance is unaffected, as shown by a 1 to 4
positive to neutral ratio. Contrarily, richness is higher in urban areas, deduced from 4 articles with positive remarks, versus 1 neutral remarks. The higher bee richness could reflect the more diverse supply of food and possibly nesting locations (Baldock et al., 2015; Theodorou et al., 2017). Diversity is lower in urban areas, though authors of both articles expect intensification of agriculture would negatively affect diversity (Christman et al., 2022; Harrison et al., 2018a). Pollen collection is also higher in urban areas (Alburaki et al., 2018; Brodschneider et al., 2021; Renaud et al., 2022). Conclusively, urban areas are likely more suited for bees than agricultural areas.

Due to only few comparisons between urban and suburban areas, no strongly convincing correlations are found. For bee abundance, richness, and diversity there are relatively many neutral mentions, up to 50% per index. In rural areas, abundance is evidently lower than in urban areas, with 6 positives to 2 negative notices. Richness, however, is met with various results as there are 2 remarks for each type of result. It can be concluded that rural areas contain less bees but a similar number of bee species, compared to urban areas.

<table>
<thead>
<tr>
<th></th>
<th>Natural</th>
<th>Agricultural</th>
<th>Suburban</th>
<th>Rural</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ - /</td>
<td>+ - /</td>
<td>+ - /</td>
<td>+ - /</td>
<td>+ - /</td>
</tr>
<tr>
<td>Abundance</td>
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<td>1 0 4</td>
<td>1 1 2</td>
<td>6 2 0</td>
<td>9 20 13</td>
</tr>
<tr>
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<td>4 0 1</td>
<td>1 1 2</td>
<td>2 2 2</td>
<td>7 17 11</td>
</tr>
<tr>
<td>Diversity</td>
<td>1 9 7</td>
<td>0 1 1</td>
<td>1 2 4</td>
<td>2 3 2</td>
<td>5 8 10</td>
</tr>
<tr>
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<td>0 1 0</td>
<td>0 0 0</td>
<td>0 1 1</td>
<td>0 0 0</td>
</tr>
<tr>
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<td>3 1 0</td>
<td>0 0 0</td>
<td>1 2 1</td>
<td>2 1 0</td>
</tr>
<tr>
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<td>2 0 0</td>
<td>1 2 4</td>
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<td>1 0 0</td>
<td>2 4 2</td>
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<td>0 2 0</td>
<td>0 2 0</td>
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<tr>
<td>Pesticide Use</td>
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<td>1 0 0</td>
<td>0 0 1</td>
<td>0 1 0</td>
<td>0 0 0</td>
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<tr>
<td>Varroa Load</td>
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<td>1 1 0</td>
<td>0 1 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
</tbody>
</table>

Table 2. Number of remarks on biodiversity indices and other measures for habitat comparisons and general comparisons. “+” = Urban better than …; “−” = Urban worse than…; “=” = No significant difference between urban and … The colours indicate the weight of the number of remarks, relative to its habitat or column. Gray green indicates no remarks, light orange indicates between 0% and 5%, dark orange indicates between 5% and 10%, yellow indicates between 10% and 15%, light-green indicates between 15% and 20%, dark-green indicates 20% or higher.

Finally, based on papers using general urban measurements making use of %impervious or other urban gradients, there is a trend in which more urban areas show lower bee abundance and richness. Notably, the number of studies that found positive or neutral results is also high. Positive effects are sometimes attributed to a more diverse landscape (M. H. Egerer et al., 2017; Martins et al., 2017) though the opposite also has been found (Janvier et al., 2022). Diversity, however, is met with less negative results (8), showing diversity can be somewhat maintained in urban areas.

Furthermore, pollen collection appears to be higher in more urban areas, though only with 2 positive versus 1 negative remark. Parasitism is characterized by diverging results, making it difficult to draw any conclusion. Colony dynamics appears to be unaffected by urban landscape characteristics, with 4
neutral remarks, against 1 positive and 2 negative remarks. The honeybee effect, a direct influence of the presence of honeybees on bee composition, is noted 9 times.

The urban environment strongly affected some bee traits and the proportion of native bees. Urban areas contained more exotic bees in 20 out of 27 cases. Out of these cases, half were seen in the USA, 5 in Oceania and 3 in Europe. For the remaining 6 cases, 3 remarks were made of urban form leading to less exotic bees and 4 cases of the native status being unaffected. Not all researchers exclude honeybees, making urban beekeeping a cause for more exotic bees (Carré et al., 2009; Casanelles-Abella et al., 2022; McCune et al., 2020). Otherwise, ornamental and exotic plants may also increase exotic bee species (Casanelles-Abella et al., 2022; McCune et al., 2020; Sivakoff et al., 2018; Threlfall et al., 2015; Wilson & Jamieson, 2019).

Bee size is unaffected by urban form in a third of the notices, whereas 20 papers show that bees become smaller. In 10 papers the contrary is seen, and bees become larger. It is hypothesized that small bees are advantaged since smaller bees need less resources (Banaszak-Cibicka & Zmihiorski, 2012; Fortel et al., 2014). At the same time, large bees would be favoured due to their ability to cover longer foraging ranges (Bennett & Lovell, 2019; Ropars et al., 2019). With factors that may benefit small and large bees differently, no conclusion can be drawn on how urban environments affect bee size. This conclusion is further supported by the relatively high number (16) of neutral articles.

Urban form generally favours cavity-nesting bees, with close to half (17) of papers showing their abundance rising. However, a fourth (11) of articles mentions more ground-nesting bees found in urban areas and another fourth (11) shows nesting preference to be unaffected. A major reason for ground-nesting bees to be disadvantaged is the lack of nesting surface in urban areas (Fortel et al., 2014; Pereira et al., 2021; Threlfall et al., 2015). On the contrary, cavity-nesting bees can nest in (abandoned) buildings or other urban cavities (Hamblin et al., 2018; Pardee & Philpott, 2014; Zanette et al., 2005).

Trophic specialization is lower in urban areas with a 21 out of 32 articles noting more polylectic bees in urban areas. They are generally less sensitive to urbanization, but also do not depend on specific flower species for their foraging (Choate et al., 2018; Fetridge et al., 2008; Geppert et al., 2023). Wray & Elle (2015) note that these primarily concern A. mellifera, Bombus spp. and solitary cavity nesters. Oligolectic bees are seen in 4 cases and 7 papers mention lecty to be unaffected. Larger cities would generally contain more exotic and ornamental plants, therefore limiting resources for oligolectic bees (Ferrari & Polidori, 2022).

Finally, in more than half (17) of the cases, urban form leads to more eusocial bees, versus a quarter of cases (8) that show urban areas contain more solitary bees. Another 5 articles show neutral results. However, there are no strong theories on why which bee is advantaged (Carper et al., 2014; Cohen, Egerer, et al., 2022; Guenat et al., 2019).

Out of 276 articles, there were 39 articles that investigated both urban form and habitat characterization, 33 of which noted biodiversity indices. Of these articles, 8 made the remark that landscape factors are not significantly relevant, but habitat characteristics are. Each of these articles notes that habitat characteristics are significantly relevant, whereas landscape characteristics are not, when combined into the same model. This hints at habitat characteristics acting as a substitute for landscape characteristics.
2.2 Habitat Characterization

On articles discussing habitat characterization affecting bees, there were 138 mentions of biodiversity indices, 131 of which concerning abundance, richness, and diversity. Abundance of bees is primarily increased through floral abundance, area size and floral richness in said order. The two former causes are generally predicted to be relevant, as they increase the chance at successful foraging. Floral richness is related to flowering plant species (Kearns & Oliveras, 2009) and was sometimes also related to bee species richness (Griffiths-Lee et al., 2022; Theodorou et al., 2020). It is probable that floral richness increases bee abundance through bee species richness. Floral additions, through either pathway, remain a safe and consistent way of increasing bee abundance. Few remarks are also made of the positive effects of ecomanagement. This may be expected since less mowing allows for higher abundance of native plants.

Positive effects on species richness can also be found in floral abundance, floral richness, and area size, though interestingly, there are also three remarks that indicate no richness effect by area size (table 3). Possibly, this is due to the small size of the habitats investigated (Gunnarsson & Federsel, 2014; Loyola & Martins, 2011). Isolation and exotic vegetation negatively affect richness, remarked by 2 notions each. Isolation of areas decreases the total area available to support bees, thus limiting especially species that smaller species (Banaszak-Cibicka et al., 2016). Additionally, isolation enlarges the competition between the honeybee and wild bees, favouring the former (Plascencia & Philpott, 2017). Similarly, exotic vegetation is generally less attractive to native bees, thus reducing their richness (Molumby & Przybylowicz, 2012; Zhang et al., 2022).

Alpha diversity is positively affected by floral richness, floral diversity, area size, and ecomanagement. Most likely, this is due the same reasons as given above for abundance and richness. Notably, floral abundance is noted for both increasing and decreasing diversity, as determined by 2 mentions for both. One of its negative remarks points towards a possible interaction with honeybees (Plascencia & Philpott, 2017). Similar to abundance and richness, isolation also negatively affects diversity, with (relatively) most negative remarks.

There were 39 notices of traits affected by habitat characteristics and 10 notices of the native status. Native bees are negatively affected by exotic vegetation, as they increase competition by exotic bees (Molumby & Przybylowicz, 2012; Threlfall et al., 2017) and are less suited to the needs of native bees (Potter & Mach, 2022; Salisbury et al., 2015).

Relatively less notions of traits were made in habitat characterization papers, compared to papers on urban form, with between 4 and 16 remarks on a total of 78 articles. Consequently, no results are drawn on bee size or sociality. Buildings in the proximity generally favour above-ground nesting bees, a direct consequence of less area available for ground-nesting and more nesting sites for cavity-nesting bees (Lanner et al., 2020; Zanette et al., 2005). Though lecty has most remarks, they are divided over many unrelated causes. Only area size appears to be affected diet, with polylectic bees gaining advantage in larger areas. This also fits with their most suited habitat, the park, which is generally larger than other habitats. Residential parks, on the other hand, benefit oligolectic bees, possibly due to a higher plant species richness (Sirohi et al., 2022).
Table 3. Number of remarks for bee traits, native status and biodiversity indices for several habitat factors and habitat types. The colours indicate the weight of the number of remarks, relative to its habitat or column. Gray green indicates no remarks, light-orange indicates between 0% and 4%, dark-orange indicates between 4% and 8%, yellow indicates between 8% and 16%, light-green indicates between 16% and 32%, dark-green indicates 32% or higher.
3. Discussion

In this scoping review, the outcomes of 276 articles have been extracted to determine the effects of urban form and other relevant characteristics in urban areas on bees. Scoping reviews are limited in thoroughness due to their superficiality; unlike systematic reviews, articles are not assessed for their methods but rather, are valued in a broad context. Furthermore, interactions between factors have not been included in this work, due to the two-dimensional way of working that spreadsheets allow. However, various articles noted interactions, for example between habitat and urban form (Muratet & Fontaine, 2015; Sivakoff et al., 2018), season and urban form (Twerd et al., 2021) and management and urban form (Guenat et al., 2019).

Within urban form, urban degree is mostly measured through percentage impervious surface or other urban gradients such as human population density. However, urban degree is not fixed on such measures. To perform urban weighing, areas of various urban degrees are compared. However, in one paper two areas with two relatively low percentages of impervious surface may be compared, whereas in another, two high percentages may be compared. Possibly, this is also the reason for the relatively high number of neutral remarks for general comparisons (table 2).

Some articles compare three degrees of urbanization, though often based on the categorization of urban, suburban, and rural areas (Amado De Santis & Chacoff, 2020; Banaszak-Cibicka & Żmihorski, 2020; Łoś et al., 2020) or otherwise from inner to outer city (Hülsmann et al., 2015; Theodorou et al., 2022). Though resulting in a more complete picture, clear distinctions between urban, suburban, and rural areas are vital for assessing the effect of urban form on bees. Similarly, rural and agricultural areas may well be used interchangeably for agricultural areas, due to the low human population density in found agricultural areas.

Instead, in this work habitats are set off against an urban counterpart. A common thought among researchers is that low degrees of urban form increase biodiversity, whereas higher degrees do not (Ferrari & Polidori, 2022). Due to the binary approach of this work, such a thought can only be supported by the comparison of urban and suburban areas. However, remarks on suburban areas do not show such a trend. Naturally, it is also not visible from the generic metric of urban form.

A different proxy for urban form that may be useful for bee biodiversity is temperature. Due to the urban heat island effect, higher temperatures are seen in areas with higher urban degrees and therefore it acts as a proxy. Articles that show temperature is relevant to bee biodiversity and filtering, are clustered under urban environment. However, only few researchers refer to temperature as a driving force (Geppert et al., 2023; Hamblin et al., 2018; Kammerer et al., 2021). Notably, their papers are recent and may prove useful in conservation of bee biodiversity. As pointed out by Banaszak-Cibicka (2014), an increase in temperature results in an emigration up north of Mediterranean bees. Consequently, a different composition in urban areas may well be the consequence of migrating bees, instead of being a consequence by urbanization. Notably, sunlight is also generally accepted to be a major predictor of bees (Everaars et al., 2011; Matteson & Langellotto, 2010; Williams & Winfree, 2013).

3.1 Are cities friendly or hostile environments for bees?

In their review, Prendergast et al. (2022) notes that abundance is often higher in urban areas whereas richness is lower, compared to natural areas. That is not the case in this review, but rather, both abundance, richness and diversity are lower in urban areas. However, richness is higher in urban areas, compared to agricultural and rural areas, and so is abundance compared to rural areas.
Most likely, this difference is due to the higher diversity of habitats found in the urban landscape. The negative effects of urban areas are also found in the general comparisons, highlighting many more negative remarks than positive remarks (table 1). This is further supported by the positive relationship between floral diversity and bee diversity (table 2). In conclusion, urban areas are relatively hostile environments for bees, though especially compared to natural areas.

Traits are clearly affected by urban form. Also, remarks on bee composition are most likely also related traits since some traits are convincingly advantaged in urban areas. However, within this work there appears to be no consistent way in which specific traits are advantaged or disadvantaged. Most clearly, urban areas contain more exotic bees and with a close second, urban form also benefits generalist bees. Though less evident, urban areas favour smaller, more social, and cavity-nesting bees, though the number of neutral remarks on size and nesting type is high. Notably, research that includes honeybees, which are generally dominant in urban environments, all traits are likely skewed towards honeybees. The honeybee is a small, social, cavity-nesting, and generalist bee. These traits are also advantaged in urban areas, hindering the assessment of what traits are favoured in urban areas beyond honeybees. With regard to the earlier conclusion, it appears urban areas are selectively hostile to bees, thus acting as a filter.

3.2 Opportunities for urban habitats for bees
Nonetheless, urban areas may host high numbers of bees of various species. Their biodiversity can be supported through various methods, as deduced by the results on habitat characterization. The recommendations are not placed in order and are supported by several research articles found in table 3.

Focus on habitat characteristics rather than on landscape characteristics or habitat types for bee conservation. Several articles show that habitat type is not relevant to biodiversity indices. Rather, landscape characteristics and habitat types may hint at where higher biodiversity of bees can be found. Notably, habitat characteristics do indeed make up habitats. For example, an area with high floral richness and abundance is more likely to be an unmanaged natural area than a highly urbanized area. Focussing on improving habitat characteristics also allows practitioners to include urban areas in their work. Giving attention solely to landscape characteristics does not aid in bee diversity, which is the primary goal of urban bee ecology.

Secondly, maintaining natural areas is an important measure to be taken to protect bee biodiversity. Natural areas are hotspots for bees, that have no dependency on urban or otherwise developed areas. Notably, natural areas are more suited for bees than urban areas are. This way bee biodiversity is maintained, while giving time to cities to make their cities more bee friendly. Natural areas close to urban areas may populate cities in the future.

Measures for making cities more bee friendly are found in habitat characteristics. Undoubtedly, increasing floral richness and floral abundance also positively affects bee abundance, richness, and diversity (see also 3.2). Notably, improving on these aspects is a relatively easy and cheap way of nurturing bee biodiversity. Moreover, applying stakeholder involvement in conservation practices may increase their effectiveness, especially when greenery is involved, and is therefore advocated (Brom et al., 2022; Hall et al., 2017; Kristine Braman & Griffin, 2022). Citizen science may further involvement and research goals, while simultaneously engage citizens when simple floral measures may prove effective.

Furthermore, efforts that reduce the proportion of exotic bees in urban areas may lower competition for native bees. Promoting native vegetation, specifically vegetation that suits oligolectic species may
advantage native bees. This applies to both public areas and private lands, though for the latter forms of encouragements would be necessary. Honeybees are a major competitor in urban areas, in part due to beekeeping. Limiting beekeeping would prove effective in limiting competition of exotic species. However, interventions may affect commercial parties and hobbyists, thereby also giving negative side-effects.

Finally, increasing the size of green areas has proven to be an effective measure to promote bee biodiversity overall. In this review, it has come to light that area size is related to bee abundance, richness, and diversity. It may be particularly difficult in dense cities to carry out this measure, due to a lack of space. In such cases, connecting existing green spaces may be valuable first steps. Nevertheless, in line with the second recommendation, (near-)natural areas are priceless for the maintenance of bee biodiversity. Efforts must therefore be made to increase green area size.

<table>
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<tr>
<th>#</th>
<th>Recommendation</th>
<th>Supporting articles</th>
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<tr>
<td>1.</td>
<td>Focus on habitat characteristics</td>
<td>Antonini et al., 2013; Felderhoff et al., 2022; Gerner &amp; Sargent, 2022; Kearns &amp; Oliveras, 2009; Matteson &amp; Langellotto, 2010; Pardee &amp; Philpott, 2014; Persson et al., 2022; Williams &amp; Winfree, 2013</td>
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<td>2.</td>
<td>Maintain natural areas</td>
<td>Abbate et al., 2019; Banaszak-Cibicka, 2014; Cándido et al., 2018; Clermont et al., 2015; Collado et al., 2019; de Matos Barbosa et al., 2022; Fetridge et al., 2008; Harrison et al., 2018a, 2018b, 2019; Hisamatsu &amp; Yamane, 2006; Hung et al., 2017, 2019; Maher et al., 2022; Marín et al., 2020; Mráz et al., 2021; Neil et al., 2014; Prendergast, Tomlinson, et al., 2022; Prendergast &amp; Ollerton, 2021; Razo-León et al., 2018; Renaud et al., 2022; Schochet et al., 2016; Shrestha et al., 2021; Simla et al., 2022; Verboven et al., 2014; Wayo et al., 2020; Wray &amp; Elle, 2015; Yasrebi-de Kom et al., 2019</td>
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| 3. | Promote floral richness and abundance                | **Floral richness:** Felderhoff et al., 2022; Gerner & Sargent, 2022; Griffiths-Lee et al., 2022; Lanner et al., 2020; Lowenstein et al., 2014; Matteson & Langellotto, 2010; Novotny et al., 2021; Pardee & Philpott, 2014; Persson et al., 2022; Quistberg et al., 2016; Stewart et al., 2018; Theodorou et al., 2020; Wilson & Jamieson, 2019  
**Floral abundance:** Ahrné et al., 2009; Alves & Gaglianone, 2021; Bennett & Lovell, 2014; Berthon et al., 2021; Clos et al., 2020; Daniels et al., 2020; Gerner & Sargent, 2022; Hennig & Ghazoul, 2012; Kanduth et al., 2021; Lanner et al., 2020; Makinson et al., 2017; Matteson & Langellotto, 2010; McDougall et al., 2022; Novotny et al., 2021; Pardee & Philpott, 2014; Persson et al., 2022; Quistberg et al., 2016; Stewart et al., 2018; Threlfall et al., 2015; Williams & Winfree, 2013; Zanette et al., 2005 |
| 4. | Plant native vegetation and otherwise limit honeybees | Casanelles-Abella et al., 2022; Martins et al., 2017; McCune et al., 2020; Meeus et al., 2021; Molumby & Przybyłowicz, 2012; Patenković et al., 2022; Plascencia & Philpott, 2017; Potter & Mach, 2022; Prendergast et al., 2021; Ropars et al., 2019; Salisbury et al., 2015; Threlfall et al., 2015; Weissmann et al., 2021 |
| 5. | Increase the size of green areas                    | Cándido et al., 2021; Cohen, Ponisio, et al., 2022; Hennig & Ghazoul, 2012; Lozier et al., 2020; Makinson et al., 2017; Matteson & Langellotto, 2010; McCune et al., 2020; Micholap et al., 2017; Muratet & Fontaine, 2015; Nemesio & Silveira, 2007; Quistberg et al., 2016; Stewart et al., 2018; Turo et al., 2021; Zanette et al., 2005 |
3.3 Literature gaps and directions for future research

Looking at the geography of the conducted research, it becomes immediately clear that disproportionately few articles from Africa, Asia and South America are available. Moreover, the ecology of these areas is different from that of the western world. Combined, it becomes evident that research from North America, Europe and Australia cannot be directly projected onto these areas. As such, to make conservation practices relevant locally, future research must also involve these areas.

Another major gap in research that becomes clear from this work, concerns the effect on urban areas on species turnover. Despite researching multiple areas for comparison, turnover is often unmentioned. In this review, it was noted only six times. Since urban areas are generally seen as filters to bees, beta diversity should be deemed as an important index for its complete understanding.

Additionally, there were too few papers on bee housing and green roofs to perform include these. More research on these topics would allow for systematic analysis of their effects. Since bee housing is an accessible manner of increasing bee biodiversity, it would be valuable to determine their effectiveness.

Furthermore, the many zeros found in both tables indicate research gaps, though not all zeros or low numbers indicate directions for future research. This includes research on the effect of habitat type on biodiversity, as there is already much literature available on local habitat characteristics. Insights into these characteristics can also be applied to all habitat types. Consequently, further deepening the relevance of local habitat characteristics at the expense of research into habitat types will likely prove more valuable. Further low number that do indicate research gaps, involve how traits are affected by local habitat characteristics. Through said research, the urban filter can be scrutinized, and bee conservation can be specified. This would be supported by going further than floral indices, with inclusion of local plant composition that advantage native bees (Filipiak, 2019; Nichols et al., 2019).

Despite these research gaps, it is evident that governments must not wait for future research before making interventions. Waiting for the filling of research gaps would only postpone the restoration of bee biodiversity. Most recommendations given are clear-cut and immediate action would therefore be most suited.
References


Wild pollinator activity negatively related to honey bee colony densities in urban context. *PLoS ONE, 14*(9). https://doi.org/10.1371/journal.pone.0222316


