Bulgarian One Health Journal, *2026, Volume 1, 1* 1-14

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

BEES IN URBAN ECOSYSTEMS: A ONE HEALTH REVIEW OF POLLINATOR BIOLOGY, ENVIRONMENTAL STRESSORS, AND HUMAN-ENVIRONMENT INTERACTIONS

Iliana Ruzhanova-Gospodinova

Faculty of Veterinary Medicine, University of Forestry, Sofia, Bulgaria

iliana_ruzhanova@ltu.bg

Abstract

Bees are indispensable components of terrestrial ecosystems, providing essential pollination services that sustain biodiversity, agricultural productivity, and human wellbeing. In rapidly urbanising landscapes, pollinators are increasingly exposed to interacting anthropogenic stressors, including habitat fragmentation, chemical pollution, climate change, and disease. At the same time, cities offer novel opportunities for pollinator conservation through green infrastructure, responsible management, and public engagement. From a One Health perspective, bees represent a critical nexus linking environmental integrity, animal health, and human systems.

This narrative review synthesises current evidence on bee diversity, biology, and behaviour in urban environments, with particular emphasis on how anthropogenic stressors influence pollinator health and ecosystem services. The ecological and socio-economic importance of pollination, the mechanistic pathways through which urban stressors affect individual bees and colonies, and the role of urban green spaces as refuges and resilience mechanisms were examined. The review further evaluates the opportunities and risks associated with managed honeybees in cities, as it highlights the need for coexistence-oriented approaches that balance apiculture with wild pollinator conservation. A concise case study from Bulgaria illustrates how community-based urban beekeeping initiatives can contribute to One Health objectives when embedded within broader ecological and governance frameworks.

Overall, the review positions urban pollinators as both providers of critical ecosystem services and sensitive bioindicators of environmental change. Protecting bees in cities requires integrated strategies that align urban planning, environmental governance, animal health management, and citizen participation. Such One Health-oriented approaches are essential for building resilient urban ecosystems capable of supporting biodiversity, sustainable food systems, and healthy human populations.

Keywords: *bees; One Health; urban green spaces; anthropogenic stressors; sustainable cities*

1. Introduction: bees as a One Health nexus in urban environments

Bees are among the most important pollinators in terrestrial ecosystems, playing a fundamental role in maintaining plant reproduction, biodiversity, and ecosystem stability. With more than 20,000 described species worldwide, bees exhibit remarkable diversity in morphology, behaviour, and ecological function, ranging from highly social honeybees (*Apis* spp.) to solitary and specialist wild species. Collectively, bees underpin the reproductive success of

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

approximately 87% of flowering plant species and contribute decisively to agricultural productivity, making them indispensable for ecosystem health and food security (Murthy et al., 2025; Hung et al., 2018; 2020; Khalifa et al., 2021; Selamoğlu & Naeem, 2024; Katumo et al., 2022; Klein et al., 2007). From a One Health perspective, bees represent a critical biological link between environmental integrity, animal health, and human societies. Healthy pollinator populations support resilient ecosystems and stable food systems, while their decline signals broader environmental dysfunction. The global economic value of pollination services further underscores the dependence of human systems on pollinator health (Porto et al., 2020; Khalifa et al., 2021). Bees as integrative indicators and service providers within urban One Health systems are represented in Figure 1.

Accelerating urbanisation has profoundly altered landscapes worldwide, reshaping habitats, climate regimes, and species interactions, as urban expansion is frequently associated with habitat loss, fragmentation, pollution, and novel environmental stressors that challenge wildlife survival. Bees are particularly sensitive to these changes due to their reliance on continuous floral resources, nesting substrates, and finely tuned physiological and behavioural adaptations. At the same time, urban green spaces, such as gardens, parks, road verges, and green roofs can function as refuges that sustain diverse pollinator communities when appropriately designed and managed (Baldock et al., 2015; Hall et al., 2017; Rahimi et al., 2022; Braaker et al., 2017; Dromgold et al., 2020; Herrmann et al., 2023; Suni et al., 2022; MacKell et al., 2023).

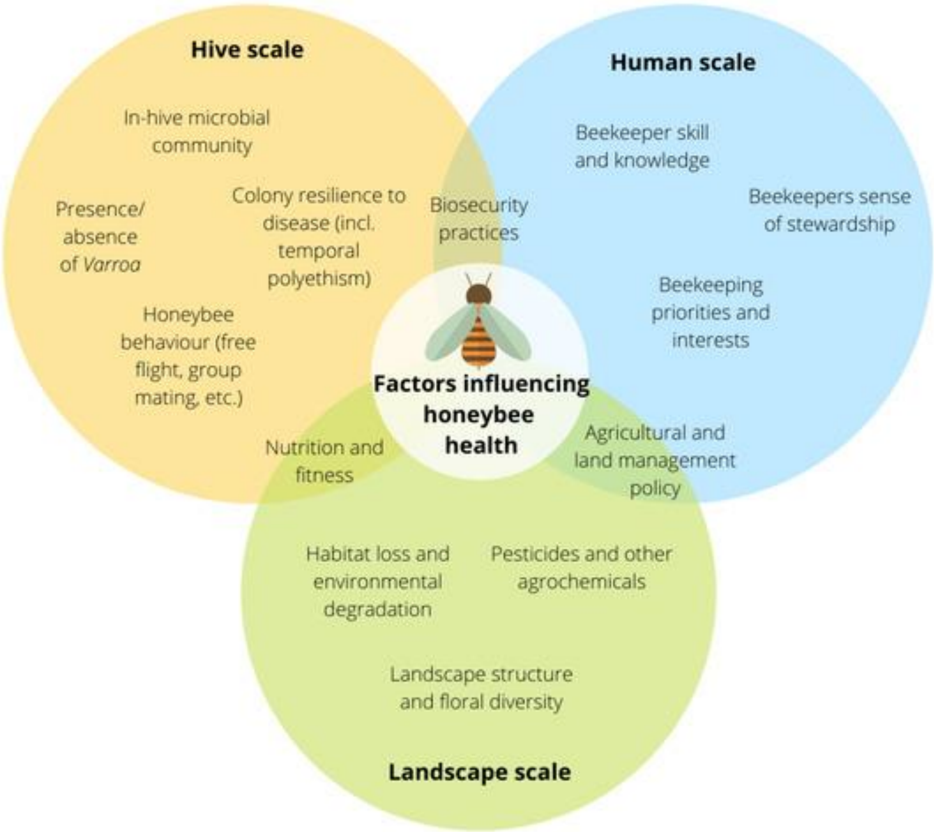

Figure 1. Bees within urban One Health systems.

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

Conceptual framework illustrating interactions between environmental health, animal health, and human wellbeing (Donkersley et al., 2020).

Bee biology and behaviour render pollinators informative sentinel organisms within urban One Health frameworks, as their short life cycles, central place foraging, complex social organisation, and sensitivity to chemical, thermal, and nutritional stressors allow rapid responses to environmental change. Sublethal pesticide exposure, nutritional stress, emerging pathogens, and climate extremes disrupt individual and colony-level function, with cascading effects on ecosystem services (Gérard et al., 2022; Woodcock et al., 2017; Tosi et al., 2017; Paoli & Giurfa, 2024; Zhang et al., 2023; Rahimi & Jung, 2024; Oliveira et al., 2025; Winston, 1987; Seeley, 1995; Robinson, 1992; von Frisch, 1967; Tison & Wright, 2019; Nazzi & Pennacchio, 2014).

Urban beekeeping has emerged as both a conservation-oriented practice and a socio-cultural phenomenon. While managed honeybee colonies may benefit from diverse urban forage and extended flowering seasons, high colony densities can intensify competition with wild pollinators and facilitate disease spillover if not carefully regulated (Bieńkowska et al., 2021; Lorenz & Stark, 2015; Sponsler et al., 2017; Ropars et al., 2019; Goulson et al., 2015). This duality highlights the need for evidence-based approaches that balance managed and wild pollinator health.

By integrating biological, ecological, and socio-environmental evidence, and by including a regional case study from Bulgaria, this article positions urban bees as both beneficiaries and indicators of One Health–oriented urban sustainability strategies. The narrative approach was chosen for its capacity to integrate evidence across ecology, veterinary science, urban planning, and public health, accommodating the conceptual diversity and varied evidence bases that characterise urban One Health research.

2. Bee diversity, biology, and behaviour relevant to urban One Health systems

2.1 Bee diversity and functional guilds in urban environments

Bees constitute one of the most diverse groups of pollinating insects, with more than 20,000 described species worldwide, with a wide range of morphologies, life-history strategies, and ecological roles (Murthy et al., 2025). From a functional perspective, bee communities include highly social species such as honeybees (*Apis* spp.) and bumblebees (*Bombus* spp.), alongside a much larger assemblage of solitary species. This diversity underpins the structure, stability, and resilience of plant–pollinator networks across both natural and anthropogenic landscapes.

Honeybees are highly social insects forming perennial colonies that may comprise tens of thousands of individuals. Their generalist foraging behaviour, sophisticated communication systems, and adaptability to human management have made them the most widely used managed pollinators globally (Hung et al., 2018; Porto et al., 2020; Khalifa et al., 2021). Bumblebees, which form smaller annual colonies, are particularly effective pollinators under cool, cloudy, or low-light conditions and are capable of buzz pollination, a specialised behaviour that enhances pollen release in certain plant taxa (Dyer et al., 2005; Vallejo-Marín,

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

2019). Solitary bees, which represent the majority of bee species, typically nest individually and often exhibit narrower floral preferences, contributing disproportionately to functional complementarity, pollination efficiency, and ecosystem resilience (Murthy et al., 2025; Katumo et al., 2022).

Urban environments act as ecological filters, shaping bee assemblages according to traits such as foraging range, nesting requirements, thermal tolerance, and behavioural flexibility (Baldock et al., 2015; Hall et al., 2017; Rahimi et al., 2022; Braaker et al., 2017; Dromgold et al., 2020; Herrmann et al., 2023; Suni et al., 2022; MacKell et al., 2023). Generalist and cavity-nesting species are often favoured in cities, whereas ground-nesting and specialist species may decline where suitable substrates or host plants are scarce. Nevertheless, when urban green spaces provide diverse, season-long floral resources, cities can support high bee species richness, sometimes comparable to or exceeding that of surrounding agricultural landscapes (Baldock et al., 2015; Hall et al., 2017).

From a One Health perspective, functional diversity among pollinators is not only an ecological asset but a stabilising force for urban food systems, biodiversity maintenance, and ecosystem services that directly and indirectly support human wellbeing. Loss of functional guilds therefore represents a shared risk to environmental integrity, animal health, and human societies.

2.2 Anatomical and physiological adaptations relevant to urban environmental exposure

Bee anatomy and physiology are tightly coupled to ecological function and environmental sensitivity. The tripartite body organisation supports specialised sensory, locomotor, and metabolic functions essential for foraging, communication, thermoregulation, and reproduction (Kane & Faux, 2021). Sensory systems enable bees to process visual, chemical, and mechanical cues, which may be disrupted in urban environments characterised by artificial lighting, pollution, and altered atmospheric conditions (Dyer et al., 2005). The tracheal respiratory system supports high metabolic demands but increases vulnerability to airborne contaminants and thermal extremes. Urban heat island effects and increasing heatwave frequency pose significant thermoregulatory challenges, impairing flight performance, learning, brood development, and survival, particularly in species with narrower thermal tolerance ranges (Gérard et al., 2022; Zhang et al., 2023). The bee nervous system supports spatial memory and associative learning but is highly sensitive to neurotoxic substances. Sublethal exposure to systemic insecticides, particularly neonicotinoids, disrupts sensory processing, learning, and decision-making even at low concentrations (Woodcock et al., 2017; Tosi et al., 2017; Paoli & Giurfa, 2024). These physiological traits position bees at the intersection of environmental exposure and biological response, making them sensitive indicators of urban environmental stress.

2.3 Colony organisation, behavioural plasticity, and vulnerability

Social bees function as integrated superorganisms, in which colony-level performance emerges from coordinated individual behaviour (Winston, 1987; Seeley, 1995). Division of labour within colonies is flexible, allowing adaptive responses to fluctuating environmental conditions (Robinson, 1992). Communication through pheromones, tactile interactions, vibrational cues,

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

and the waggle dance underpins colony efficiency and collective decision-making (von Frisch, 1967; Tison & Wright, 2019). Urban stressors can disrupt these systems: sublethal pesticide exposure impairs learning and communication (Woodcock et al., 2017; Nazzi & Pennacchio, 2014), nutritional stress weakens colony resilience, and parasites such as *Varroa destructor* undermine social cohesion and reproductive stability (Zhang et al., 2023; Rahimi & Jung, 2024; Oliveira et al., 2025).

Although behavioural plasticity enables some colonies to persist in urban environments, chronic exposure to interacting stressors can overwhelm adaptive capacity, leading to reduced pollination services and compromised ecosystem function.

2.4 One Health implications of bee biology in urban systems

Bee diversity, physiology, and behaviour jointly determine both ecological importance and vulnerability in urban environments. Functional diversity enhances pollination stability, while biological sensitivity enables rapid responses to environmental change. Within urban One Health contexts, bees function simultaneously as ecosystem service providers and bioindicators, integrating signals of habitat quality, pollution, climate variability, and disease dynamics across environmental, animal, and human health domains.

3. Ecosystem services and human dependence on bees in urban One Health contexts

Bees provide ecosystem services fundamental to both natural ecosystems and human societies, with pollination representing the most critical contribution. Approximately 87.5% of flowering plant species depend on animal pollinators, with bees playing a dominant role (Hung et al., 2018; Porto et al., 2020; Khalifa et al., 2021; Selamoğlu & Naeem, 2024; Katumo et al., 2022; Klein et al., 2007). Through pollination, bees sustain biodiversity, agricultural productivity, and food system resilience. In agricultural systems, approximately 60% of crop species benefit from animal pollination, which enhances both yield and quality (Porto et al., 2020; Khalifa et al., 2021; Klein et al., 2007). Diverse pollinator assemblages improve fruit set, seed number, and nutritional quality across a wide range of crops, contributing to both food quantity and quality (Hung et al., 2018; Katumo et al., 2022). Without pollinators, global crop production losses would disproportionately affect nutrient-dense foods, with implications for human nutrition and health.

Wild bee diversity plays a crucial role in stabilising pollination services across spatially and temporally variable environments. Functional complementarity among species arising from differences in phenology, foraging behaviour, body size, and environmental tolerance-buffers pollination against environmental variability, particularly in heterogeneous urban and peri-urban landscapes (Katumo et al., 2022; Klein et al., 2007; Baldock et al., 2015; Hall et al., 2017). Diverse pollinator assemblages enhance the reliability and quality of pollination by ensuring service continuity under fluctuating climatic and resource conditions (Hung et al., 2018; Katumo et al., 2022). Conversely, loss of wild pollinator diversity reduces functional redundancy and increases vulnerability of pollination systems to climatic extremes, disease outbreaks, and chemical exposure (Gérard et al., 2022; Woodcock et al., 2017; Tosi et al., 2017; Goulson et al., 2015). Simplified pollinator communities are less resilient to disturbance, resulting in unstable pollination services and increased risk of ecosystem service failure, with

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

downstream consequences for biodiversity conservation, food production, and human wellbeing (Potts et al., 2016; Pywell et al., 2015).

In urban environments, pollination services extend beyond food production. Pollinated vegetation contributes to biodiversity, microclimate regulation, carbon sequestration, and the quality of green spaces, indirectly supporting physical and mental health. Engagement with pollinator-friendly practices also enhances environmental awareness and community cohesion (Hall et al., 2017; Baldock et al., 2015). From a One Health perspective, disruption of pollination services reflects a convergence of environmental degradation, animal health decline, and human vulnerability. Protecting pollinators is therefore integral to maintaining resilient urban ecosystems and sustainable food systems (Potts et al., 2016; Dicks et al., 2016).

4. Anthropogenic stressors affecting bee health in urban One Health systems

Bee populations are exposed to interacting anthropogenic stressors that compromise individual health, colony function, and population persistence. Habitat loss, chemical pollution, pathogens, and climate change act synergistically, amplifying biological effects and undermining ecosystem services. Synergistic interactions among anthropogenic stressors affecting pollinator health and ecosystem services are shown in Figure 2.

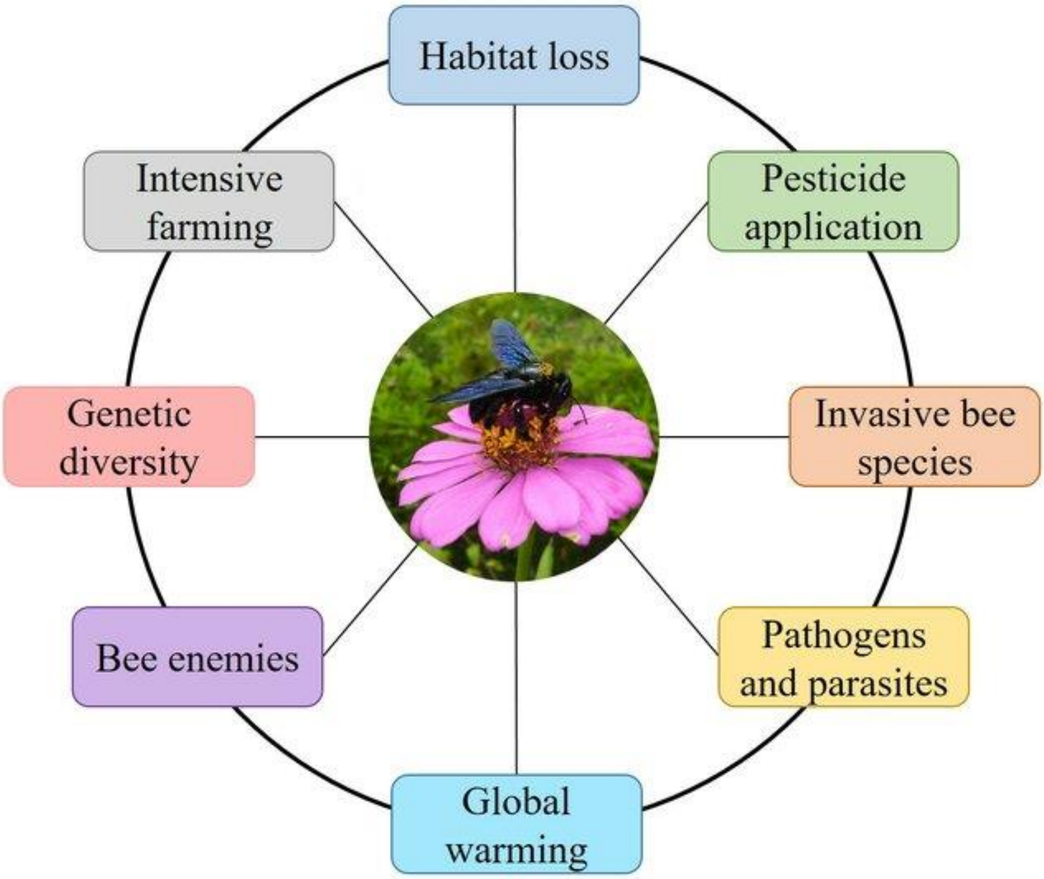

Figure 2. Synergistic anthropogenic stressors affecting bee health and pollination services.

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

Overview of social and solitary bees and their contributions to ecosystem services (Saha et al., 2023).

Habitat fragmentation reduces floral diversity and availability of nesting substrates, leading to chronic nutritional stress that impairs immune function, brood development, and overall colony resilience (Gérard et al., 2022; Rahimi & Jung, 2024; Oliveira et al., 2025). Systemic insecticides such as neonicotinoids cause sublethal neurological, behavioural, and immune impairments in bees even at low concentrations (Woodcock et al., 2017; Tosi et al., 2017; Paoli & Giurfa, 2024). These effects reduce foraging efficiency, learning, communication, and colony performance and interact strongly with nutritional stress, further exacerbating mortality risk (Tosi et al., 2017).

Emerging viral pathogens associated with managed honeybees pose significant spillover risks to wild pollinator populations (Manley et al., 2015; Alger et al., 2019). *Varroa destructor* and associated viruses represent major threats to managed honeybees and facilitate pathogen transmission to wild pollinators through shared floral resources (Zhang et al., 2023; Rahimi & Jung, 2024; Oliveira et al., 2025). Management strategies targeting *Varroa destructor* include both synthetic and natural acaricides, including essential oil–based treatments, which may reduce parasite pressure when applied judiciously (Damiani et al., 2009). Climate change alters flowering phenology, species distributions, and physiological tolerance limits of pollinators, with urban heat island effects intensifying thermal stress and increasing mortality risk, particularly during extreme heat events (Gérard et al., 2022; Zhang et al., 2023).

Interactions among anthropogenic stressors-including habitat loss, chemical exposure, disease, and climate change-destabilise colonies and reduce the reliability of pollination services. These synergistic effects have direct consequences for food security, biodiversity conservation, and human wellbeing, highlighting the systemic nature of pollinator decline within urban One Health contexts (Goulson et al., 2015; Potts et al., 2016).

5. Urban green spaces as pollinator refuges and resilience mechanisms

Urban green infrastructure can mitigate pollinator stressors and enhance ecosystem resilience when appropriately designed and managed. Diverse green spaces-including gardens, parks, road verges, and green roofs-provide floral resources, nesting substrates, and habitat connectivity that support pollinator persistence in cities (Baldock et al., 2015; Hall et al., 2017; Rahimi et al., 2022; Braaker et al., 2017; Dromgold et al., 2020; Herrmann et al., 2023; Suni et al., 2022; MacKell et al., 2023). Season-long floral continuity, prioritisation of native plant species, reduced mowing regimes, and retention of structural habitat elements such as bare ground, dead wood, and heterogeneous vegetation enhance bee diversity, nutritional status, and overall health (Baldock et al., 2015; Hall et al., 2017; Rahimi et al., 2022; Herrmann et al., 2023). Connectivity among green spaces facilitates pollinator movement and gene flow, reducing isolation effects and improving resilience to environmental change (Braaker et al., 2017; Dromgold et al., 2020). Season-long flowering continuity (Figure 3) is a key determinant of pollinator diversity and persistence in urban habitats, including green roofs and other managed green spaces (Baldock et al., 2015).

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 Original article

However, urban green spaces also present trade-offs. Habitat homogenisation, limited spatial extent, and high densities of managed honeybee colonies may intensify competition for floral resources and alter plant–pollinator interactions, particularly in resource-limited environments (MacKell et al., 2023; Ropars et al., 2019). Effective management therefore requires balancing targeted pollinator support with broader biodiversity conservation goals. Within One Health frameworks, pollinator-friendly urban design represents a preventive strategy that strengthens ecosystem services, enhances food system resilience, and contributes indirectly to human physical and mental wellbeing. By integrating ecological function into urban planning, cities can support healthier environments for pollinators and people alike (Potts et al., 2016; Dicks et al., 2016).

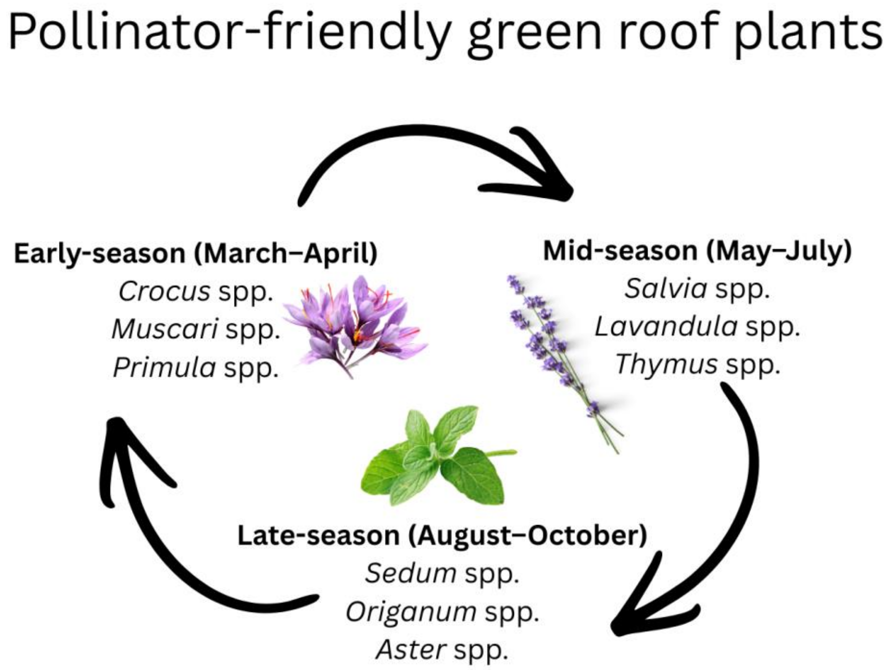

Figure 3. Schematic representation of pollinator-supportive plant groups suitable for urban green roofs. A highlight on flowering continuity and plant functional diversity for urban pollinators. Created based on Baldock et al., 2015.

6. Managed bees in urban environments: opportunities, risks, and coexistence

Urban environments can support productive honeybee colonies due to high floral diversity and extended flowering seasons associated with ornamental plantings and urban heat island effects (Bieńkowska et al., 2021; Lorenz & Stark, 2015; Sponsler et al., 2017). Consequently, urban beekeeping has gained prominence as a practice offering educational, cultural, and ecosystem service benefits (Bieńkowska et al., 2021; Lorenz & Stark, 2015). However, these benefits are contingent upon ecological context, as excessive hive densities may exceed local carrying capacity and generate unintended ecological impacts (MacKell et al., 2023; Ropars et al., 2019; Goulson et al., 2015). High densities of managed honeybee colonies can reduce nectar and pollen availability for wild pollinators and alter plant–pollinator interaction networks, particularly in resource-limited urban green spaces (Ropars et al., 2019; MacKell et al., 2023). In addition, managed colonies may act as reservoirs for parasites and pathogens, facilitating

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 Original article

disease transmission within and between species through shared floral resources (Manley et al., 2015; Alger et al., 2019; Nazzi & Pennacchio, 2014). Urban colonies are further exposed to chemical pollutants and microclimatic extremes, which can exacerbate physiological stress and compromise colony resilience (Woodcock et al., 2017; Zhang et al., 2023).

Colony-level traits such as varroa-sensitive hygiene, combined with targeted and evidence-based control methods, can substantially reduce Varroa destructor pressure and associated viral transmission (Harbo & Harris, 2005; Harris et al., 2010; Jack et al., 2022). Such measures improve honeybee health while lowering disease spillover risk to wild pollinators. Effective coexistence between managed and wild pollinators therefore requires moderated hive densities, robust disease management, integration of beekeeping into pollinator-friendly urban planning, and appropriate regulatory oversight (MacKell et al., 2023; Leung & Reid, 2025; Dicks et al., 2016). Within One Health frameworks, urban beekeeping should prioritise ecological balance and ecosystem integrity over colony proliferation, ensuring that apicultural practices support rather than undermine urban biodiversity and environmental health.

7. Case Study: Urban beekeeping in Bulgaria through a one health lens - The "I Have a Bee" (IHAB) Foundation (https://una.city/nbs/sofia/i-have-bee-organisation)

Urban beekeeping in Bulgaria has developed in parallel with broader European trends in pollinator awareness and citizen engagement. Within this context, the "I Have a Bee" (IHAB) Foundation, established in Bulgaria in 2014, represents a distinctive model of small-scale, hobbyist-oriented urban apiculture. The initiative was designed to make beekeeping accessible to urban residents while prioritising colony welfare, ecological sustainability, and public education.

The IHAB model emerged in response to barriers associated with conventional beekeeping systems, which often require substantial space, technical expertise, and financial investment, making them unsuitable for urban environments. To address these constraints, IHAB developed a compact, low-cost top-bar hive adapted for balconies, small gardens, and terraces. The design emphasises reduced intervention and accommodation of natural bee behaviour, shifting the focus from maximising honey production toward supporting colony health.

In addition to hive design, IHAB promotes education and knowledge exchange through workshops and informal networks, encouraging environmentally responsible practices such as pollinator-friendly planting and reduced chemical use. The initiative has expanded beyond Bulgaria through collaborations with urban beekeeping groups in Europe and North America, demonstrating the transferability of locally developed solutions.

From a One Health perspective, the IHAB Foundation illustrates how community-based approaches can integrate animal health, environmental stewardship, and human participation. By lowering barriers to engagement, the initiative increases public involvement in pollinator conservation while embedding ecological awareness into urban lifestyles. At the same time, the case highlights the importance of moderation and governance in urban beekeeping, as excessive honeybee densities may intensify competition with wild pollinators or increase disease transmission risks.

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 Original article

Overall, the IHAB case study demonstrates that small-scale, education-focused urban beekeeping, when embedded within broader pollinator-friendly urban planning, can contribute positively to One Health objectives. It underscores the value of locally grounded initiatives in supporting resilient urban ecosystems while aligning biodiversity conservation with societal engagement.

8. Conservation strategies and governance through a One Health lens

Safeguarding pollinators in urban environments requires coordinated strategies that address environmental quality, animal health, and human activity simultaneously. Within One Health frameworks, conservation actions must therefore operate across scales-from individual green spaces to city-wide planning and policy governance-while recognising the interdependence of managed and wild pollinator populations (Potts et al., 2016; Dicks et al., 2016). A central pillar of effective conservation is habitat restoration and diversification. Creating and maintaining flower-rich habitats, including wildflower strips, hedgerows, fallows, and urban meadows, increases bee abundance and diversity and enhances pollination services (Pywell et al., 2015; Albrecht et al., 2020; Grab et al., 2018; Kremen et al., 2018). In urban contexts, ensuring season-long floral continuity and prioritising native plant species are particularly important for supporting diverse pollinator guilds and reducing nutritional stress (Baldock et al., 2015; Hall et al., 2017; Rahimi et al., 2022; Herrmann et al., 2023; Suni et al., 2022).

Provision of nesting and overwintering resources is equally critical. Retaining bare ground, dead wood, and structurally diverse vegetation within urban green spaces addresses a key limiting factor for many wild bees. Reduced mowing regimes and the incorporation of semi-natural elements into parks and roadside verges can substantially improve habitat suitability with minimal infrastructural investment (Baldock et al., 2015; Hall et al., 2017; Braaker et al., 2017; Dromgold et al., 2020; Herrmann et al., 2023). Reducing chemical exposure represents a major One Health intervention. Integrated Pest and Pollinator Management (IPPM) approaches extend traditional pest management by explicitly minimising risks to pollinators through monitoring-based interventions, non-chemical controls, targeted application timing, and selection of lower-toxicity compounds (Woodcock et al., 2017; Tosi et al., 2017; Potts et al., 2016). Such approaches benefit not only pollinators but also broader environmental and human health (Dicks et al., 2016; Goulson et al., 2015). Management of managed pollinator health is essential to limit disease pressure and pathogen spillover. Evidence-based control of *Varroa destructor*, including hygienic stock selection and judicious treatment use, improves honeybee health while reducing risks to wild pollinators (Harbo & Harris, 2005; Harris et al., 2010; Jack et al., 2022). Moderating hive densities, particularly in resource-limited urban areas, further reduces ecological conflict and disease transmission risk (MacKell et al., 2023; Ropars et al., 2019;).

Finally, governance, incentives, and monitoring underpin successful conservation. Urban planning policies that integrate pollinator-friendly design, pesticide regulation, support for citizen engagement, and long-term monitoring programs are among the most effective levers for pollinator protection (Potts et al., 2016; Dicks et al., 2016). Within a One Health framework, these measures align biodiversity conservation with public health, food security, and sustainable urban development goals (Katumo et al., 2022; Leung & Reid, 2025).

9. Conclusions and future directions

Bees occupy a central position at the interface of environmental integrity, animal health, and human wellbeing, making them powerful indicators and contributors within urban One Health systems. This review demonstrates that pollinator health in cities is shaped by the interaction of biological traits, anthropogenic stressors, and urban design, with direct consequences for ecosystem services, food security, and societal resilience. Urban environments present a dual reality for bees: they impose significant pressures through habitat fragmentation, chemical exposure, climate stress, and disease, yet also offer opportunities for refuge and intervention through green infrastructure, responsible management, and public engagement. Functional diversity among pollinators, supported by season-long floral resources, nesting substrates, and habitat connectivity, is a key determinant of resilience in these human-dominated landscapes.

From a One Health perspective, pollinator decline is not an isolated conservation issue but a systemic signal of environmental imbalance with cascading effects on human nutrition, economic stability, and ecosystem function. Addressing this challenge requires integrated strategies that align urban planning, environmental governance, animal health management, and community participation.

Future research should prioritise long-term, interdisciplinary studies that link pollinator health to urban environmental quality, human exposure pathways, and climate adaptation. Equally important is the translation of scientific evidence into policy and practice, ensuring that cities are designed and managed as living systems capable of supporting both biodiversity and human health. Protecting pollinators in urban environments is therefore not only an ecological imperative but a foundational component of sustainable and healthy cities.

Acknowledgements

This work was supported by the Erasmus+ Programme of the European Union under project 2024-1-PL01-KA220-HED-000249359: *Buzzing futures: Enhancing entrepreneurship skills and competences in urban beekeeping*. The author gratefully acknowledges Prof. Dr. Petar Antov for his valuable support and encouragement.

References

1. Albrecht, J., Kleijn, D., Williams, N. M., Tschumi, M., Blaauw, B. R., Bommarco, R., … Batáry, P. (2020). The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: A quantitative synthesis. Ecology Letters, 23(10), 1488–1498.
2. Alger, S. A., Burnham, P. A., Boncristiani, H. F., & Brody, A. K. (2019). RNA virus spillover from managed honeybees (Apis mellifera) to wild bumblebees (Bombus spp.). PLOS ONE, 14(6), e0217822.
3. Baldock, K. C., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, L. M., … Memmott, J. (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. Proceedings of the Royal Society B: Biological Sciences, 282(1803), 20142849.
4. Bieńkowska, M., Panasiuk, B., Gerula, D., Wójcik, Ł., Tofilski, A., & Pohorecka, K. (2021). Urban beekeeping: Benefits and risks. Insects, 12(5), 450.

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

5. Braaker, S., Obrist, M. K., Ghazoul, J., & Moretti, M. (2017). Habitat connectivity and local conditions shape taxonomic and functional diversity of arthropods on green roofs. Journal of Animal Ecology, 86(3), 521–531.
6. Damiani, N., Gende, L. B., Bailac, P., Marcangeli, J. A., & Eguaras, M. J. (2009). Acaricidal and insecticidal activity of essential oils on Varroa destructor (Acari: Varroidae) and Apis mellifera (Hymenoptera: Apidae). Parasitology Research, 106(1), 145–152.
7. Dicks, L. V., Viana, B., Bommarco, R., Brosi, B., del Coro Arizmendi, M., Cunningham, S. A., … Potts, S. G. (2016). Ten policies for pollinators. Science, 354(6315), 975–976.
8. Donkersley, P., Elsner-Adams, E., & Maderson, S. (2020). A one-health model for reversing honeybee (Apis mellifera L.) decline. Veterinary Sciences, 7(3), 119.
9. Dromgold, J. R., Threlfall, C. G., Norton, B. A., & Williams, N. S. (2020). Green roof and ground-level invertebrate communities are similar and are driven by building height and landscape context. Journal of Urban Ecology, 6(1), juz024.
10. Dyer, A. G., Neumeyer, C., & Chittka, L. (2005). Honeybee (Apis mellifera) vision can discriminate between and recognise images of human faces. Journal of Experimental Biology, 208(24), 4709–4714.
11. Gérard, M., Amiri, A., Cariou, B., & Baird, E. (2022). Short-term exposure to heatwave-like temperatures affects learning and memory in bumblebees. Global Change Biology, 28(14), 4251–4259.
12. Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science, 347(6229), 1255957.
13. Grab, H., Branstetter, M. G., Amon, N., Urban-Mead, K. R., Park, M. G., Gibbs, J., … Danforth, B. N. (2018). Landscape context shifts the balance of costs and benefits from wildflower borders on multiple ecosystem services. Proceedings of the Royal Society B: Biological Sciences, 285(1880), 20181102.
14. Hall, D. M., Camilo, G. R., Tonietto, R. K., Ollerton, J., Ahrné, K., Arduser, M., Ascher, J. S., Baldock, K. C. R., Fowler, R. A., Frankie, G., Goulson, D., Gunnarsson, B., Hanley, M. E., Jackson, J. I., Langellotto, G., Lowenstein, D., Minor, E. S., Philpott, S. M., Potts, S. G., … Threlfall, C. G. (2017). The city as a refuge for insect pollinators. Conservation Biology, 31(1), 24–29.
15. Harbo, J. R., & Harris, J. W. (2005). Suppressed mite reproduction explained by the behavior of adult bees. Journal of Apicultural Research, 44(1), 21–23.
16. Harris, J. W., Danka, R. G., & Villa, J. D. (2010). Honeybees (Hymenoptera: Apidae) with the trait of varroa sensitive hygiene remove reproductive varroa mites. Annals of the Entomological Society of America, 103(2), 146–152.
17. Herrmann, J., Buchholz, S., & Theodorou, P. (2023). The degree of urbanisation reduces wild bee and butterfly diversity and alters the patterns of flower-visitation in urban dry grasslands. Scientific Reports, 13(1), 2702.
18. Hung, K. L. J., Kingston, J. M., Albrecht, M., Holway, D. A., & Kohn, J. R. (2018). The worldwide importance of honey bees as pollinators in natural habitats. Proceedings of the Royal Society B: Biological Sciences, 285(1870), 20172140.
19. Jack, C. J., Lucas, H. M., McCartney, N. B., & Ellis, J. D. (2022). Assessing repeated oxalic acid vaporization in honeybee colonies for varroa control. Insects, 13(3), 222.
20. Kane, T. R., & Faux, C. M. (Eds.). (2021). Honey bee medicine for the veterinary practitioner. John Wiley & Sons.

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***

21. Katumo, D. M., Liang, H., Ochola, A. C., Lv, M., Wang, Q. F., & Yang, C. F. (2022). Pollinator diversity benefits natural and agricultural ecosystems, environmental health, and human welfare. Plant Diversity, 44(5), 429–435.
22. Khalifa, S. A., Elshafiey, E. H., Shetaia, A. A., El-Wahed, A. A. A., Algethami, A. F., Musharraf, S. G., … El-Seedi, H. R. (2021). Overview of bee pollination and its economic value for crop production. Insects, 12(8), 688.
23. Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B: Biological Sciences, 274(1608), 303–313.
24. Kremen, C., M'Gonigle, L. K., & Ponisio, L. C. (2018). Pollinator community assembly tracks changes in floral resources as restoration progresses. Science, 362(6412), 141–144.
25. Leung, M., & Reid, D. (2025). Reducing risks to native pollinators by introduced bees: A review of Canada's legislation with recommendations for Yukon Territory. Biology, 14(3), 282.
26. Lorenz, S., & Stark, K. (2015). Saving the honeybees in Berlin? A case study of the urban beekeeping boom. Environmental Sociology, 1(2), 116–126.
27. MacKell, S., Elsayed, H., & Colla, S. (2023). Assessing the impacts of urban beehives on wild bees using individual, community, and population-level metrics. Urban Ecosystems, 26(5), 1209–1223.
28. Manley, R., Boots, M., & Wilfert, L. (2015). Emerging viral disease risk to pollinating insects: Ecological, evolutionary and anthropogenic factors. Functional Ecology, 29(3), 341–349.
29. Murthy, J. S. V., Ramakrishna, B. G., Chellappan, M., & Ranjith, M. T. (2025). Perspective chapter: Wild bees–Importance, threats, and conservation challenges. In Insect Conservation-Challenges and Possibilities in a Changing World: Challenges and Possibilities in a Changing World (p. 41).
30. Nazzi, F., & Pennacchio, F. (2014). Disentangling multiple interactions in the hive ecosystem. PLOS Pathogens, 10(10), e1004305.
31. Oliveira, W., Cruz-Neto, O., Silva, J. L., Tabarelli, M., Peres, C. A., & Lopes, A. V. (2025). Climate change will lead to local extinctions and mismatched range contractions disrupting bee-dependent crop pollination. Frontiers in Bee Science, 3, 1510451.
32. Paoli, M., & Giurfa, M. (2024). Pesticides and pollinator brain: How do neonicotinoids affect the central nervous system of bees? European Journal of Neuroscience, 60(8), 5927–5948.
33. Porto, R. G., De Almeida, R. F., Cruz-Neto, O., Tabarelli, M., Viana, B. F., Peres, C. A., & Lopes, A. V. (2020). Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. Food Security, 12(6), 1425–1442.
34. Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V., … Vanbergen, A. J. (2016). Safeguarding pollinators and their values to human well-being. Nature, 540(7632), 220–229.
35. Pywell, R. F., Woodcock, B. A., Campbell, A., Perry, S., Tscheulin, T., Garratt, M. P. D., … Heard, M. S. (2015). Wildlife-friendly farming increases crop yield: Evidence for ecological intensification. Proceedings of the Royal Society B: Biological Sciences, 282(1816), 20151740.
36. Rahimi, E., & Jung, C. (2024). Global trends in climate suitability of bees: Ups and downs in a warming world. Insects, 15(2), 127.

ISSN 3033-0408 https:// DOI 10.59496/20261AH1 ***Original article***
37. Rahimi, E., Barghjelveh, S., & Dong, P. (2022). A review of diversity of bees, the attractiveness of host plants and the effects of landscape variables on bees in urban gardens. Agriculture & Food Security, 11(1), 6.
38. Robinson, G. E. (1992). Division of labor in honeybees. Annual Review of Entomology, 37, 637–665.
39. Ropars, L., Dajoz, I., Fontaine, C., Muratet, A., & Geslin, B. (2019). Wild pollinator activity negatively related to honeybee colony densities in a context of urban beekeeping. PLOS ONE, 14(9), e0222316.
40. Saha, S., Munshi, S. A., & Laskar, N. (2023). Bee pollination: From an ecological and economical perspective. Indian Farming, 73(3), 34–36.
41. Seeley, T. D. (1995). The wisdom of the hive: The social physiology of honeybee colonies. Harvard University Press.
42. Selamoğlu, Z., & Naeem, M. Y. (2024). From flower to food: Honey bees and their role in crop production. Arı ve Arıcılık Teknolojileri Dergisi, 3(2), 56–63.
43. Sponsler, D. B., Matcham, E. G., Lin, C. H., Lanterman, J. L., & Johnson, R. M. (2017). Spatial and taxonomic patterns of honey bee foraging in urban environments. Ecosphere, 8(3), e01754.
44. Suni, S., Hall, E., Bahu, E., & Hayes, H. (2022). Urbanization increases floral specialization of pollinators. Ecology and Evolution, 12(3), e8619.
45. Tison, L., & Wright, G. A. (2019). The influence of neonicotinoids on honey bee communication. Frontiers in Ecology and Evolution, 7, 268.
46. Tosi, S., Nieh, J. C., Sgolastra, F., Cabbri, R., & Medrzycki, P. (2017). Neonicotinoid pesticides and nutritional stress synergistically reduce survival in honey bees. Proceedings of the Royal Society B: Biological Sciences, 284(1869), 20171711.
47. Vallejo-Marín, M. (2019). Buzz pollination: Studying bee vibrations on flowers. New Phytologist, 224(3), 1068–1074.
48. Von Frisch, K. (1967). The dance language and orientation of bees. Harvard University Press.
49. Winston, M. L. (1987). The biology of the honeybee. Harvard University Press.
50. Woodcock, B. A., Bullock, J. M., Shore, R. F., Heard, M. S., Pereira, M. G., Redhead, J., Ridding, L., Dean, H., Sleep, D., Henrys, P., Peyton, J., Hulmes, S., Hulmes, L., Sárospataki, M., Saure, C., Edwards, M., Genersch, E., Knäbe, S., & Pywell, R. F. (2017). Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. Science, 356(6345), 1393–1395.
51. Zhang, C., Wang, X., Kaur, P., & Gan, J. (2023). A critical review on the accumulation of neonicotinoid insecticides in pollen and nectar: Influencing factors and implications for pollinator exposure. Science of the Total Environment, 899, 165670.

1.