

Advances in Honeybee and Their Biological and Environmental Threats

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1. Introduction

Honeybees (*Apis mellifera*) play a fundamental role in both natural and agricultural ecosystems through the pollination services they provide, contributing substantially to global biodiversity, crop production, food security, and ecosystem stability [1,2]. However, their health and survival are increasingly threatened by a combination of biological and environmental stressors. Among the most pressing challenges are emerging and re-emerging pathogens, parasites, invasive alien species, resistance to control measures, pesticide exposure, habitat degradation, nutritional stress, and climate change [3–5]. Acting simultaneously, these stressors contribute to significant colony losses in many regions of the world, highlighting the urgent need for multidisciplinary research to better understand their interactions and develop sustainable mitigation strategies [6,7].

The Special Issue, Advances in Honeybee and Their Biological and Environmental Threats, brings together original research that addresses these complex challenges from complementary perspectives. The contributions explore honeybee health, colony management, urban and rural ecology, pathogen dynamics, environmental pollution, bee products, and advances in molecular diagnostics, providing new insights into the factors that influence honeybee resilience and productivity.

Beyond their ecological and economic importance, honeybees also represent valuable bioindicators of environmental quality. Their foraging behavior, colony performance, and bee products can provide important information on ecosystem health, environmental contamination, and landscape quality, making them effective sentinels for monitoring environmental change [8,9].

The aim of this Special Issue is to advance current knowledge on the biological and environmental threats affecting managed honeybees, feral colonies, and wild pollinators while encouraging innovative approaches for their conservation and sustainable management. By integrating studies from diverse scientific disciplines, this collection contributes to a broader understanding of the challenges facing pollinators and highlights emerging opportunities to protect bee health and the essential ecosystem services they provide.

2. An Overview of Published Articles

Gerula et al. [contribution 1] compared the performance of honeybee colonies kept in urban and rural (agricultural) environments across five regions of Poland. Researchers evaluated colony overwintering, spring development, colony strength, swarming, honey production, and *Varroa destructor* infestation in apiaries located in five cities and five nearby villages. All colonies were managed under standardized conditions using *Apis*



Received: 3 July 2026

Accepted: 28 July 2026

Published: 5 August 2026

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mellifera carnica queens and Dadant hives. Urban colonies showed significantly faster brood development in spring, which was associated with higher Varroa infestation levels later in summer. Honey production was higher in some urban apiaries, but this advantage depended strongly on regional differences and local forage availability rather than the urban environment alone. Most measured traits, including honey yield, varied significantly among regions, highlighting the importance of local environmental conditions. Differences between study years in overwintering success, spring brood production, and summer colony strength suggest that weather also played an important role. Overall, the results indicate that urban environments can sustain productive honeybee colonies, but colony performance is shaped by a combination of habitat, regional forage resources, parasite pressure, and annual climatic variation.

Sorvillo et al. [contribution 2] investigated the potential spillover of honeybee pathogens to wild pollinators in urban green spaces in Milan, Italy, over a two-year monitoring period. As urbanization creates fragmented habitats such as parks and gardens, managed honeybees (*A. mellifera*) and wild pollinators increasingly share floral resources, creating opportunities for pathogen transmission. The researchers examined pathogen dynamics within these shared foraging environments and confirmed widespread transmission of RNA viruses between managed and wild bee populations. Among the viruses detected, Acute Bee Paralysis Virus (ABPV) showed the highest prevalence in both sampling years, indicating its major role in pathogen circulation in urban ecosystems. The findings reinforce concerns that urban green areas, while valuable for pollinator conservation, can also facilitate disease spread through increased contact among different pollinator species. The authors highlight the importance of continuous monitoring and integrated management strategies to reduce pathogen spillover risks and support the health and conservation of both managed and wild pollinator communities.

In this study, Gerula and Gabka [contribution 3] evaluated whether urban landscapes provide nectar resources for honeybee colonies comparable to those found in rural environments. Over two years (2021–2022), researchers monitored changes in hive weight in paired urban and rural apiaries across five locations in Poland to estimate nectar collection, foraging duration, and weight loss. Land cover within a 3 km radius of each apiary was analyzed using Sentinel-2 satellite imagery, identifying eight landscape categories, including urban areas, agricultural land, forests, grasslands, wetlands, and water bodies. The results showed no significant difference in the total amount of nectar collected by urban and rural colonies. However, urban colonies experienced significantly more foraging days, suggesting a longer or more continuous availability of floral resources. No individual land cover type was significantly associated with nectar yield, and landscape gradients identified through multivariate analyses did not affect nectar collection. Overall, the findings indicate that diverse urban environments can support honeybee foraging as effectively as rural areas, provided that a continuous and diverse supply of nectar-producing plants is maintained.

Glevitzky et al. [contribution 4] assessed the potential of honey as a bioindicator of environmental pollution by comparing honey collected near former mining sites with honey from protected areas in Romania. Researchers analyzed the physicochemical properties, heavy metal concentrations, bioactive compounds, and antimicrobial activity of the samples. Honey from protected areas contained higher levels of phenolic compounds and flavonoids and showed stronger antibacterial and antifungal activity. In contrast, honey from former mining areas had significantly higher concentrations of heavy metals, particularly lead (Pb), cadmium (Cd), and iron (Fe), indicating persistent contamination from historical mining activities. Elevated levels of copper (Cu) and zinc (Zn) were also detected. The antimicrobial properties of the honey were evaluated against a broad range of bacterial

and fungal pathogens, with honey from protected sites consistently demonstrating greater inhibitory activity. The results confirm that the geographical origin and surrounding environmental conditions strongly influence honey quality and composition. Overall, the study demonstrates that honey is an effective natural bioindicator of environmental contamination while also reflecting differences in its nutritional and therapeutic value.

How the age and sex of grafted larvae, as well as the timing of royal jelly (RJ) collection, influence royal jelly yield and quality have been examined by Kanelis et al. [contribution 5]. Using strong *A. mellifera* colonies, researchers grafted first-, second-, and third-day larvae and collected RJ 24, 48, and 72 h after grafting. They also compared the use of worker and drone larvae. The physicochemical properties of the RJ, including moisture, protein, sugar, and 10-hydroxy-2-decanoic acid (10-HDA) content, were analyzed. Royal jelly yield increased significantly with collection time, reaching its highest level after 72 h. Protein content gradually decreased, while moisture content increased over time, whereas sugar concentration and 10-HDA remained stable. Grafting second-day larvae produced the highest RJ yield without affecting its chemical composition. In addition, the sex of the grafted larvae had no significant effect on either the quantity or quality of the royal jelly. These findings provide practical guidance for optimizing royal jelly production while maintaining product quality and supporting efficient queen-rearing practices.

Bordin et al. [contribution 6] present the first comprehensive molecular and metagenomic characterization of the microbiome of the Italian honeybee (*A. mellifera*). Researchers analyzed samples from 20 apiaries across Italy using molecular diagnostics and next-generation sequencing (NGS) to identify beneficial, commensal, and pathogenic microorganisms associated with honeybee colonies. Molecular screening detected important parasites, including *Vairimorpha ceranae*, *Lotmaria passim*, and *Crithidia mellificae*, as well as several major honeybee viruses, including Sacbrood virus (SBV), Black Queen Cell virus (BQCV), Deformed Wing virus (DWV), Chronic Bee Paralysis virus (CBPV), and Acute Bee Paralysis virus (ABPV). Bacterial community analysis revealed a microbiota dominated by the beneficial genera *Lactobacillus*, *Gilliamella*, and *Snodgrassella*. Virome analysis also identified viruses not previously reported in Italy, including Apis rhabdovirus (ARV-1 and ARV-2), Bee Macula-like virus (BeeMLV), and Lake Sinai virus (LSV). The study provides a detailed overview of the Italian honeybee microbiome and virome, improving understanding of bee health and offering valuable tools for epidemiological surveillance, disease monitoring, and the development of more effective diagnostic methods.

3. Conclusions

The articles collected in this Special Issue provide a comprehensive overview of current advances in honeybee research, spanning urban ecology, pollinator health, environmental monitoring, apicultural management, and emerging molecular tools. Together, they demonstrate how honeybees continue to serve not only as essential pollinators but also as valuable indicators of ecosystem health and environmental change.

Several contributions highlight the growing importance of urban environments for beekeeping. The studies by Gerula et al. [contribution 1] and Gerula and Gąbka [contribution 3] show that, under appropriate conditions, cities can support productive honeybee colonies with nectar resources comparable to those found in rural landscapes. However, these benefits are strongly influenced by local forage availability, regional environmental conditions, climatic variability, and parasite pressure, emphasizing that successful urban beekeeping requires careful management rather than relying solely on the urban setting.

The increasing interaction between managed honeybees and wild pollinators is addressed by Sorvillo et al. [contribution 2], whose findings underline the need to consider urban green spaces not only as biodiversity refuges but also as potential hotspots for

pathogen transmission. Their work reinforces the importance of integrated disease surveillance and coordinated management strategies to safeguard pollinator communities.

Environmental quality is another recurring theme. Glevitzky et al. [contribution 4] demonstrate that honey is an effective bioindicator of environmental contamination, reflecting both historical pollution and the ecological conditions surrounding apiaries. Their results further illustrate how environmental quality directly influences the nutritional and antimicrobial properties of bee products.

From a practical beekeeping perspective, Kanelis et al. [contribution 5] provide valuable evidence-based recommendations for optimizing royal jelly production, showing that production efficiency can be improved without compromising product quality. Such findings contribute directly to the sustainability and profitability of modern apiculture.

Finally, Bordin et al. [contribution 6] illustrate the transformative role of molecular diagnostics and metagenomics in honeybee health research. Their comprehensive characterization of the Italian honeybee microbiome and virome expands current knowledge of beneficial and pathogenic microorganisms, providing a valuable foundation for improved disease surveillance, epidemiological studies, and future precision management of honeybee colonies.

Collectively, the studies published in this Special Issue emphasize that honeybee health and productivity result from complex interactions among environmental conditions, landscape composition, pathogens, colony management, and microbial communities. Addressing these interconnected factors will require multidisciplinary approaches that integrate ecology, microbiology, environmental sciences, molecular biology, and apicultural practice. As global challenges such as urbanization, habitat alteration, climate change, and emerging diseases continue to affect pollinators, the knowledge generated by these contributions provides an important scientific basis for developing sustainable beekeeping practices, protecting pollinator biodiversity, and maintaining the essential ecosystem services upon which agriculture and natural ecosystems depend.

Author Contributions: M.B. and F.M.: writing—original draft preparation; review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were not required for these studies because honeybees (invertebrates) are not covered by any specific legislation.

Conflicts of Interest: The authors declare no conflicts of interest.

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