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Editorial: Horizons in bee science

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Editorial on the Research Topic
Horizons in bee science

Bees are vital pollinators facing unprecedented pressure from human intervention, including climate change, habitat loss, and introduced parasites (IPBES, 2016; Potts et al., 2010). Recent research is highlighted in 11 publications in the Research Topic "Horizons in Bee Science". Collectively, they emphasize the complex interactions between environmental stressors and bee biology, based on information concerning both social and solitary species. The global importance of these contributions is exemplified by the ~55,000 views and downloads to date (July 2025). Below, we examine the key themes explored in these 11 publications and their implications for advancing our understanding and supporting the well-being of bees.

Bees currently face numerous challenges. Global warming (and resulting thermal stress) negatively impacts both social and solitary species (Acosta et al.; Kevan et al.; Le Conte and Navajas, 2008; Polidori et al.; Soroye et al., 2020; Vilchez-Russell and Rafferty). Honey bees (*Apis mellifera*), the world's most economically important pollinator, are particularly vulnerable to a suite of threats: most notably the parasitic mite *Varroa destructor* and its associated viruses (Francis et al., 2013; Lamas and Evans; Lester; Morfin et al.; Traynor et al., 2020). Studies about bee biology, genetics, interactions between species, and ways to improve their efficiency as an agricultural input (Owen; Anderson and Copeland; Oddie and Dahle; Farina et al.) complement the contributions to this series of articles.

Climate change and bees

Climate-induced heat stress is a growing threat to bee diversity. Solitary bees appear to be particularly vulnerable due to their inability to thermoregulate their nests (Vilchez-Russell and Rafferty). Studies have shown that heat stress reduces survival and adult emergence rates, and alters body size, development time, sex ratios, and diapause in solitary bees. Increasing temperatures can lead to a lack of synchrony between bee emergence and floral resource availability. There is thus a need for habitat management to provide thermal refugia, along with integrated conservation planning that considers climate variability, and species-specific responses and resilience mechanisms.

Acosta et al. propose a methodological framework to identify priority zones for monitoring wild bee species and their response to climate change, using a Brazilian stingless bee, *Melipona fasciculata*, in a case study. They identified three main types of habitat zones for this species using their new methodology: Loss zones – will become unsuitable; Gain zones – will become suitable; and Persistent zones – remain suitable and are best for long-term monitoring. Their approach offers an option for achieving better spatial precision for conservation measures for bees.

Urban Heat Island Effect (UHI) refers to elevated temperatures in urban areas due to human infrastructure such as buildings and roads, particularly affecting ectothermic organisms such as bees (Polidori et al.; Camilo et al., 2025). Temperature increases are generally known to affect bee physiology, reduce foraging efficiency and reproductive success. Not all bees respond in the same way to warming. Specialists and thermosensitive species are at risk of local extinction. UHI can shift flowering times and resource availability in urban areas, leading to mismatches between bees and plants. More comprehensive, multi-scalar research combining urban ecology, thermal biology, and pollination science is needed for informing urban biodiversity planning.

Bumble bee populations are declining globally, with climate warming identified as a key driver (Kevan et al.; Soroye et al., 2020). Bumble bee colonies maintain a remarkably consistent brood rearing temperature across species and biogeographic regions, suggesting limited evolutionary plasticity. They are more susceptible to heat stress than to cold. We know that nest placement and structure significantly affect nest temperatures, but few data exist on thermal gradients and insulation properties in bumble bee nests. There is a need to understand how bumble bee physiology, ecology, and nest architecture affect responses to climate change.

The Varroa mite and its impact on *Apis mellifera*

There is a devastating interplay of honey bees, Varroa mites, and viruses, which is a major cause of colony losses worldwide (Francis et al., 2013; Lamas and Evans). Common beekeeping practices (e.g., splitting colonies, transporting hives) inadvertently facilitate virus and mite dispersal. While miticides help control mites, they do not eliminate circulating viruses, and mite resistance to acaricides is a growing problem. There is a need to understand how management strategies affect bee-mite-virus dynamics. Effective bee health management requires tackling the synergistic threat posed by mites and viruses together, rather than separately.

Varroa infestation reduces honey bee lifespan and exacerbates viral infections by suppressing bee immune responses and increasing virus titers (Morfin et al.). Infestations can lead to colony collapse, if unmanaged. Resistance traits (e.g., Varroa Sensitive Hygiene) have potential for selective breeding programs to promote resistance. Integrative approaches combining genomics, ecology, and behavior could be combined into a multifaceted solution. The complex impact of *Varroa destructor* on honey bee health underscores the need for sustainable, science-based management strategies to mitigate its effects.

Overuse and reliance on acaricides have led to the evolution of resistance in Varroa populations (Lester). Coordinated control management is needed to prevent resistance development. Possible strategies to manage resistance include rotating acaricides with different modes of action and applying treatments only when thresholds are exceeded. Improved monitoring of resistance alleles for resistance patterns is essential. Beekeepers, researchers, and regulators are encouraged to work collaboratively to preserve the efficacy of current treatments.

Advances in bee science and their use in crop pollination

There is much chromosome diversity in bees (superfamily Apoidea), with a wide range of haploid chromosome numbers (n=3-28). Owen showed that chromosome structure and number varies widely among bee species, but a lack of data for many bees makes it difficult to determine relationships among species and how they evolved. Methods for preserving and analyzing chromosomes have improved, including C-banding and FISH techniques, helping advance our understanding of chromosomal rearrangement and evolution. Modern genomic tools can be used to explore adaptive significance and phylogenetic patterns in chromosomal variation (Beye et al., 2006; Christmas et al., 2019; Zayed, 2009).

The microbiota of bees contributes to preservation of stored pollen and honey, inhibition of pathogens, and colony-level disease resistance. Anderson and Copeland conducted a meta-analysis of 35 studies of the microbiota of honey bee hives, finding that bees have a distinct and relatively stable hive microbiota, dominated by aerobic or aerotolerant bacteria, shared across aerobic niches including larva, worker and queen mouthparts, worker crops and hypopharyngeal glands, queen crops and midguts, beebread, royal jelly, and honey. This study points to the need for more research exploring how hive management and climate affect the hive microbiome (Engel et al., 2012), which also should be considered in colony health diagnostics.

Honey bees can rapidly abandon a crop and switch to alternative flowering species depending on nectar and pollen quality (Levin and Anderson, 1970; Wojcik et al., 2018). Farina et al. showed that bees can be trained to associate floral scents with food rewards. Once trained, they visit target crops more frequently, potentially enhancing pollination precision. Continued improvement of automated within-hive conditioning has the potential to make honey bees more effective agents of pollination services. Additional research and adjustments are needed, however, to determine if this system is viable for specific crops.

Conflicts and common ground: unified strategies for pollinator protection

Concern about competition between wild and managed pollinators sometimes leads to conflicts between beekeepers and conservationists (Oddie and Dahle; Prendergast et al.). However, given that honey bees and wild pollinators face common threats, beekeepers can be early detectors of environmental stressors. Fortunately, enlightened beekeepers have increasingly become allies in the advocacy for pollinator-friendly practices. They help promote landscape-scale solutions, such as creating pollinator corridors or pesticide-free zones, and promote floral diversity. Aligned interests between managed and wild pollinators open the door for unified conservation strategies, with beekeepers potentially playing a key role in pollinator protection. This is especially relevant considering that superior fruit set and quality are obtained when wild and managed bees visit the same flowers, showing additive or synergistic effects (Brittain et al., 2013).

Conclusions

A common theme in the contributions to "*Horizons in bee science*" has been to identify pathways for improving conditions, both managed and natural, for these vital pollinators. The next challenges involve prioritizing and implementing these improvements. A coordinated international effort, incorporating changes in management practices, is needed to address the adverse conditions currently confronting bees.

Author contributions

DD: Writing – original draft, Writing – review & editing. PK: Writing – review & editing. VI: Writing – review & editing. PL: Writing – review & editing. SF: Writing – review & editing. MM: Writing – review & editing.

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