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The global challenge of improving bee protection and health

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Agriculture is heavily reliant on insects for food production. In fact, at least a third of all crops rely on pollination (Klein et al., 2007). Paradoxically, as agriculture becomes more intensive and the need for pollinators increases, modern agricultural practices also reduce bee populations through application of pesticides and intensive land use (Klein et al., 2007; Aizen and Harder, 2009; Gallai et al., 2009). This increased demand and concurrent declining bee health have led to a 'pollination crisis' (Holden, 2006; Goulson et al., 2015). Bee diseases and pests have become a major limiting factor in the effort to provide the large numbers of strong honey bee colonies that are now required, greatly increasing costs for beekeepers and hive rental fees for farmers (Genersch, 2010; Traynor et al., 2020).

Besides honey bees, there are over 20,000 other bee species (Engel et al., 2020). The non-*Apis* bees are often wonderfully diverse in form and function, worthy of conservation and preservation in their own right. For example, the re-discovery of Wallace's Giant Bee, *Megachile pluto*, or the Dodo of the bee world, provides new challenges for conservation (Vereecken, 2018). The contribution of many non-*Apis* bees to pollination is substantial, though often much less appreciated. Additionally, the interaction of other bee species and honey bees can have synergistic benefits for pollination services, resulting in higher fruit-set and productivity (Brittain et al., 2013).

In this article we briefly review the major stressors and health issues for bees. Improving the protection and health of honey bees, and the many thousands of other bee species, is a major global challenge and is the goal for this journal section.

Major stressors and mortality factors for honey bees

Western honey bee colony losses vary widely year-to-year, but are generally becoming worse. Annual honey bee colony loss surveys show considerable variation in temporal and spatial rates of colony loss as well as in the contributing factors. *Varroa destructor* mites and the viruses these parasites spread are now considered the greatest contributor to these losses, though queen problems, a lack of natural food sources, and new pests also play substantial roles (Brown et al., 2016; Stahlmann-Brown et al., 2022).

Modern agriculture and human transformation of much of the landscape have greatly impacted both honey bees and the numerous species of solitary and social bees around the globe. A "web of stressors can act indirectly, in association, or synergistically", negatively affecting bee health (Goulson et al., 2015; Steinhauer et al., 2018). These stressors vary around the globe, changing over time, which was highlighted in a recent study that demonstrated both a dramatic decline in honey bee lifespan and an associated decline in the average amount of honey production per colony each year over the last five decades in the USA

(Nearman and vanEngelsdorp, 2022). Understanding and untangling this web of stressors to reduce colony losses and improve honey bee health remains a substantial challenge. Pronouncements of a 'colony collapse syndrome' and 'pollinator declines' go hand-in-hand with conclusions that the world is experiencing insect declines that result from multiple anthropogenic pressures that often interact (Goulson et al., 2015; Goulson, 2019). Contributing factors include land-use intensification, with habitat loss to agriculture and urban development, the spread of invasive species and diseases, and pesticides (Cox-Foster et al., 2007; Vanbergen et al., 2013; Goulson et al., 2015).

Until recently, the types of agricultural chemicals that were considered dangerous for bees were mainly restricted to insecticides. Fungicides have generally been deemed safe for use on flowering crops when bees are present. Unfortunately, their negative impacts on bee health are becoming increasingly evident, both through mortality of commensal microorganisms (Yoder et al., 2013; Motta et al., 2018) and direct effects on bee metabolism, including mitochondrial respiratory inhibition (Nicodemo et al., 2020).

Climate change is affecting bee populations worldwide, with predicted increasing losses of vital pollinators (Giannini et al., 2012). Widespread decline of bumble bees on various continents due to such changes has already been well documented (Soroye et al., 2020). Climate change could also result in range expansion of invasive species that affect bees, such as the small hive beetle (*Aethina tumida*) (Cornelissen et al., 2019).

Considerable geographic differences in the predominant stress factors have been reported. Honey bee populations in Brazil and other regions of Latin America experience different rates of loss from a diverse array of factors, when compared to North America, Europe, and Asia (De La Rúa et al., 2009; Cornman et al., 2012; Maggi et al., 2016). In regions where Africanized bees predominate, the Varroa mite is not a major cause of bee mortality and treatment is normally not needed (De Jong et al., 1982; Moretto et al., 1991; Dias de Freitas et al., 2022). Pesticides have been cited as the main mortality factor for honey bees and other bees in Brazil (Castilhos et al., 2019). Approaches to protect honey bees in these regions therefore would be different from what is necessary in Europe and North America. In the Middle East and Asia, other challenges to honey bee health are emerging. For example, the parasitic mite *Tropilaelaps mercedesae* and related species are continuing to spread (Chantawannakul et al., 2018). Originally a parasite of the Asian giant honey bee, *Tropilaelaps* spp. are now associated with colony losses in Western honey bees and are a major potential threat for bees in other regions of the world. In some countries, such as China, sacbrood virus is a key problem (Ai et al., 2012), and chronic bee paralysis virus is cited as a serious emerging threat to honey bees in England and Wales (Budge et al., 2020). It is clear that invasive species, including mites and small hive beetles, as well as the many different bee virus genotypes and their international movement, can become major issues for honey bee health.

The future consequences of these stressors and consequent pollinator declines are predicted to be dire. Potts et al. (2010) concluded that these "pollinator declines can result in loss of pollination services, which have important negative ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, wider ecosystem stability, crop production, food security and human welfare".

Protection and health of other bee species

Other eusocial and solitary bees suffer both similar and different challenges. Bees have experienced reductions in species diversity and richness, as part of and along with the decline of entire arthropod communities (Potts et al., 2010; Goulson et al., 2015). These declines are a problem in their own right, but also impact on agricultural production as a diverse bee community can provide pollination or biological insurance when honey bee populations decline (Winfree et al., 2007).

Some of the best available data on the challenges that non-*Apis* bee pollinators face comes from studies of bumble bees. Bumble bee species in Europe have experienced substantial range contractions and frequent localized extinction, with four species having gone extinct (Goulson et al., 2015). Similarly in North and South America, there has been a decline and range contraction in native bumble bee populations (Cameron and Sadd, 2020). Many of the contributors to honey bee colony losses also affect bumble bees (Goulson, 2019). The relationship between disease in honey bees and bumble bees is often positive and strong (Furst et al., 2014; McMahon et al., 2015; Cameron and Sadd, 2020; Piot et al., 2022). The same factors of habitat loss, pathogens, invasive species, climate change, and pesticides that affect honey bees, can negatively impact bumble bee health (Cameron and Sadd, 2020) and many other bee species. In another example of the vulnerability of other bee species, social stingless bees depend heavily on associated microorganisms for their nutrition, metabolism, and survival (Menezes et al., 2015; Paludo et al., 2019). As in honey bees, fungicides used in agriculture can impact the microorganisms that these native pollinators require for their survival. Nevertheless, since they are more easily monitored, honey bees can serve as sentinels for detecting mortality factors that also affect native bees (Wood et al., 2020).

The health problems of other bee species often, however, can contrast with those in honey bees. Stingless bee colonies in Brazil experience various different mechanisms of loss (Freitas et al., 2009; Dias de Freitas et al., 2022). The increasing popularity of many of the hundreds of species of social stingless bees found in subtropical and subtropical regions of the world and the resulting intensive management of the colonies, both for pollination and for producing honey, has resulted in new disease and pest problems that require study (Menezes et al., 2009; Toledo-Hernández et al., 2022). In addition, pesticides sometimes affect solitary or non-*Apis* bees to a greater extent than honey bees. For example, in a Swedish study, neonicotinoids negatively affected solitary and bumble bee species but had no observed effect on honey bees (Rundlof et al., 2015). Consequently, we cannot always manage honey bee and non-*Apis* species with the same broad strategies.

It is worth noting that efforts to enhance introduced bee populations might come at the expense of negatively impacting native bees (Iwasaki and Hogendoorn, 2021). Not only can honey bees or bumble bees that are introduced for commercial purposes transmit disease to native bees (McMahon et al., 2015; Cameron and Sadd, 2020), they are often highly competitive. This competition can negatively affect native pollinators and the plants they pollinate (Geslin et al., 2017). Thus, in some areas there may well be a tension or a dilemma concerning introduced honey bees or bumble bees. Will our efforts to enhance honey bee supplies come at the cost of native bees and other pollinators? Nevertheless, the premise that introduced honey bees will typically negatively impact native bees and consequently pollination services is controversial and has proven not to always to be the case (Moritz et al., 2005). When Africanized bees advanced north from Brazil and became the main type of honey bee in Central America, there were similar concerns. However, coffee production increased significantly throughout this region with their arrival, and there appeared to be a benefit from increased activity of honey bees in synergy with native bee pollinators (Roubik, 2002).

The continuing challenges for bee protection and health

To meet the increasing demand for strong hives to pollinate crops, beekeepers have been obliged to spend considerably more on treatments for bee diseases and pests, such as foulbrood and Varroa mites (Baylis et al., 2021). Throughout much of the world, without such treatments, it is considered impossible to keep Western honey bee colonies alive. Compounding this problem, Varroa populations are increasingly showing resistance to acaricides, resulting in bee losses (Traynor et al., 2020). There is a need for alternative pest control options. New options that are being considered include gene silencing or RNAi approaches (Garbian et al., 2012; Leonard et al., 2020), and even genetic modification of bee gut bacteria (Moran and Sloan, 2015) and Varroa (Faber et al., 2021).

We need means to combat starvation and bee diet issues, especially as the effects of parasites and pathogens can be compounded by poor nutrition (Dolezal and Toth, 2018). To meet the heightened demand for bees in recent years, beekeepers have considerably increased their investment in protein diet supplements, including diet additives that purportedly help keep bees healthy (De Jong et al., 2009; Brodschneider and Crailsheim, 2010; Turcatto et al., 2018; Noordyke and Ellis, 2021; Ricigliano et al., 2022). As an additional input in the effort to improve bee health, probiotics for bees have recently become available (Dharampal et al., 2019; Borges et al., 2021), which makes sense given the ubiquity and apparent benefits of bacterial associates found in nectar, pollen, bee guts, and their stored food (Anderson et al., 2013), though their utility has not yet been proven.

Ideally, beekeepers would prefer to have bees that do not require chemical and other control measures to keep their colonies alive and productive. Besides simplifying management and avoiding the costs for such controls, honey bee products that are not contaminated by disease and pest control chemicals are considerably more valuable and acceptable for the market. However, throughout much of the world, efforts to breed bees for resistance to major bee pests, such as the Varroa mite (Büchler et al., 2010; Rinderer et al., 2010), are yet to provide consistently viable alternatives that can be widely applied for commercial and hobby beekeeping (von Virag et al., 2022), even though some local populations of European bees have demonstrated the ability to survive Varroa infestations without the need for acaricides or other treatment options (Seeley, 2007; de Mattos et al., 2016; Oddie et al., 2018). Also, Africanized bees in Brazil and various other regions of Latin America normally do not require any chemical controls for Varroa (De Jong, 1996; Rosenkranz, 1999; Martin and Medina, 2004; Tibatá et al., 2021). Studies of these examples of naturally occurring tolerance or resistance to Varroa infestations could be useful to help find alternatives that will work for beekeeping worldwide.

Many challenges remain for improving bee health. Protecting bees will require a joint effort by beekeepers, scientists, and public institutions, to help ensure that the bees will continue to prosper and provide us and nature with their essential services. It is our hope and goal that the 'Bee Protection and Health' section of the new journal "Frontiers in Bee Science" will be a productive vehicle to help focus on bee protection, so that bees can continue their vital roles in ecosystems and agriculture around the globe.

Author contributions

DD and PL wrote, revised, and approved the final version of this article. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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