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Avenues towards reconciling wild and managed bee proponents

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Bees are crucial for food security and biodiversity. However, managed bees are increasingly considered drivers of wild bee declines, leading to stakeholder conflicts and restrictive policies. We propose avenues to reconcile wild and managed bee proponents and point out knowledge gaps that hinder the development of evidence-based policies.

Negative impacts of managed bees: a growing concern based on circumstantial scientific evidence

Integrating biodiversity conservation with food security for a growing world population represents a major challenge. Three quarters of the world's crops are dependent on pollinators, and their cropped area is expanding. Consequently, reliance on pollinators, especially managed and wild bees, is increasing [1]. Among Earth's 20 000+ wild bee species, many are declining, threatening biodiversity and leading to pollination deficits [2,3]. To mitigate pollination deficits, 19 bee species can currently be managed and transported where and when required to promote crop pollination [4].

Establishing and maintaining high densities of managed bees raises concerns about their impacts on wild bee populations [5]. In recent decades, a growing number of studies have investigated whether competition for floral and nesting resources with managed bees and pathogen transmission negatively impact wild bees [5,6], often fueling conflicts among beekeepers, farmers, conservationists, and scientists [7]. Despite more than 200 scientific papers addressing managed bee–wild bee interactions, and 66% concluding that there are potential risks to wild bees, evidence remains circumstantial, contextual, and does not include long-term and population-level assessments [5]. Insufficient knowledge of the circumstances in which interactions amongst bees become detrimental can lead to inaccurate risk assessments and potentially to ecological or economic harm. Nevertheless, due to increasing pressure from stakeholders, and despite the low degree of confidence in available data, policy-makers have begun to ban managed bees from conservation areas or cities [8], a trend that is likely to increase. Ensuring contextually optimal trade-offs between conservation and socioeconomic priorities is key for bee policies (Box 1) and necessitates rapid and coordinated action to facilitate the co-creation of solutions by stakeholders. Here, we propose research avenues to generate the knowledge required to assess the risks associated with bee management and to develop effective policies. Furthermore, we highlight challenges and list currently actionable levers to mitigate conflicts.

Challenges towards effective conflict resolution

Measuring long-term and population-level effects of managed and wild bee interactions

Enhancing our knowledge about the effects of managed bees on wild bees requires an assessment of conservation-relevant parameters that is currently lacking. These parameters include population size and genetic diversity, which are crucial to the long-term sustainability of populations but are extremely resource-intensive or impossible to assess using classical methods based on counting bees. By comparison, genetic methods require relatively small sample sizes, provide information on genetic diversity, population demography [10], and on pathogen prevalence, loads, and transmission. The possibility of collecting bee environmental (e)DNA also provides another potential noninvasive method to assess these. The recent development of genomic tools to analyze historic samples also allows screening of museum specimens to reveal fluctuations in genetic diversity and demography over time. Such data can link variation in bee management intensity or other stressors to wild bee population sizes over time, contributing to the assessment of their respective effects and to possible mitigation measures. The need for molecular approaches is highlighted as a goal of the CBD COP15 Global Biodiversity Framework: 'Genetic diversity within populations of wild and domesticated species is maintained, safeguarding their adaptive potential'.

Assessing the impact of pathogens

While pathogen transmission between managed and wild bees is increasingly considered a threat, which pathogens compromise wild bees, to what extent, Box 1. The importance of contextualization in bee policies

Ecological contexts include interactions among biologically diverse bee species and their impacts on ecosystems. Socioeconomic aspects include pollination demand, beekeeping profitability, food security needs, and livelihood goals. A crucial aspect for contextualizing bee-oriented policies is the interplay between land-cover types and the endemism of managed species. In many regions of the world, crop pollination relies on non-native managed bees. In agricultural landscapes, where pollination is mainly a necessary economic service, the introduction of managed non-native bees to fill pollination deficits can be acceptable. However, in urban, semi-natural, and natural habitats, where pollination is mainly an ecological service, negative interactions with native bees can be less acceptable, as arguments about economic losses are irrelevant. Developing management techniques for local populations of native bee species could be a viable alternative to introducing non-native bees [4]. In the native ranges of managed bee species, policy-making is more complex than in the non-native range [9]. Although they are naturally occurring, their management can lead to unnaturally high densities, with potential negative consequences for wild conspecifics or other pollinators. Whether it is desirable, or indeed possible, to regulate native managed bee densities according to local carrying capacities and pollination requirements should be further considered.

and in which contexts they are impacted, remain unclear, especially for interspecific transmission (e.g., [6]). Identifying these contexts is crucial to accurately determine the risks associated with bee management. Molecular detection and phylogeny to assess transmission patterns combined with experimental work to test the impact of pathogens will guide the development of policies to regulate the localization and densities of managed bees at levels appropriate to ensure the conservation of wild bee populations.

Before such data become available, pre-emptive measures known to reduce pathogen loads in managed bees (e.g., therapeutic treatments), and thus potential transmission to wild bees, should be implemented more consistently [11] or better enforced [2]. Identifying the obstacles to implementation and enforcement of good practices through socioeconomic studies is required. In parallel, maintaining or restoring diverse communities of plants and pollinators in ecosystems can reduce the risks associated with pathogen transmission through partitioning of foraging niches [12].

Quantifying ecosystem carrying capacities to mitigate competition

The intensity of competition between organisms is modulated by resource availability and quality. Ecosystem carrying capacities, resource niche overlaps, and their temporal dynamics will, therefore, influence how bee species interact. Increasing carrying capacities to reduce competition can be achieved through measures such as floral enhancements (e.g., flower strips, hedgerows) promoted by the European Union (EU) Common Agricultural Policy or the US Farm Bill (e.g., programs of the Natural Resources Conservation Service of the US Department of Agriculture) [13]. Pollinator-friendly enhancements of agricultural landscapes can also decrease natural and human-driven displacement of managed bees, thereby decreasing the spatial range of potential impacts.

Despite our ability to increase resources locally, tools are lacking to estimate ecosystem carrying capacities to match resource availability with local wild and managed bee community requirements. Where increasing floral resources is impractical, knowing the carrying capacity of ecosystems is imperative for making informed adjustments to managed bee densities [14]. Deterministic models incorporating resource availability – as well as spatiotemporal resource requirements and use by local pollinator assemblages – are promising tools to estimate the degree of competition and the effectiveness of mitigation measures. However, multidisciplinary projects are required to generate the pertinent data to optimize such models.

Evaluating the impacts on a broader diversity of wild bee species

Most research on the impacts of bee competition and pathogen transmission has focused on a restricted number of model species that are easy to manage or to find in the wild (e.g., buff-tailed bumble bees *Bombus terrestris*, European orchard bees *Osmia cornuta*; [5]). The resulting narrow range of life-history traits considered in those studies limits our ability to provide broad predictions for diverse native pollinator communities. Developing methods to study other wild bee species will decrease reliance on these few umbrella species. Moreover, the effects of interspecific competition or pathogen spillover on wild bees are frequently tested using managed populations of these species. A concern with these tests is that a managed population can be genetically and/or phenotypically different to local wild conspecifics, and thus does not represent the natural situation. Studying wild populations of bees is more challenging but can be facilitated by genetic approaches, for example, using eDNA to quantify effective population sizes and monitor pathogens [10].

Fostering the co-creation of policies

Due to differing values, motivations, understandings, and expectations, different stakeholder groups (e.g., farmers, beekeepers, conservationists) have diverse and sometimes contradictory views on the management of pollinators, and on their contributions to livelihoods and wider society. Recognizing these views during a co-creation process, and placing them within the current knowledge base on interactions between bees, is key to the development of evidence-based policies that consider local ecological and socioeconomic contexts and decrease conflicts [9] (Figure 1). The simultaneous consideration of a multitude of factors is an essential but

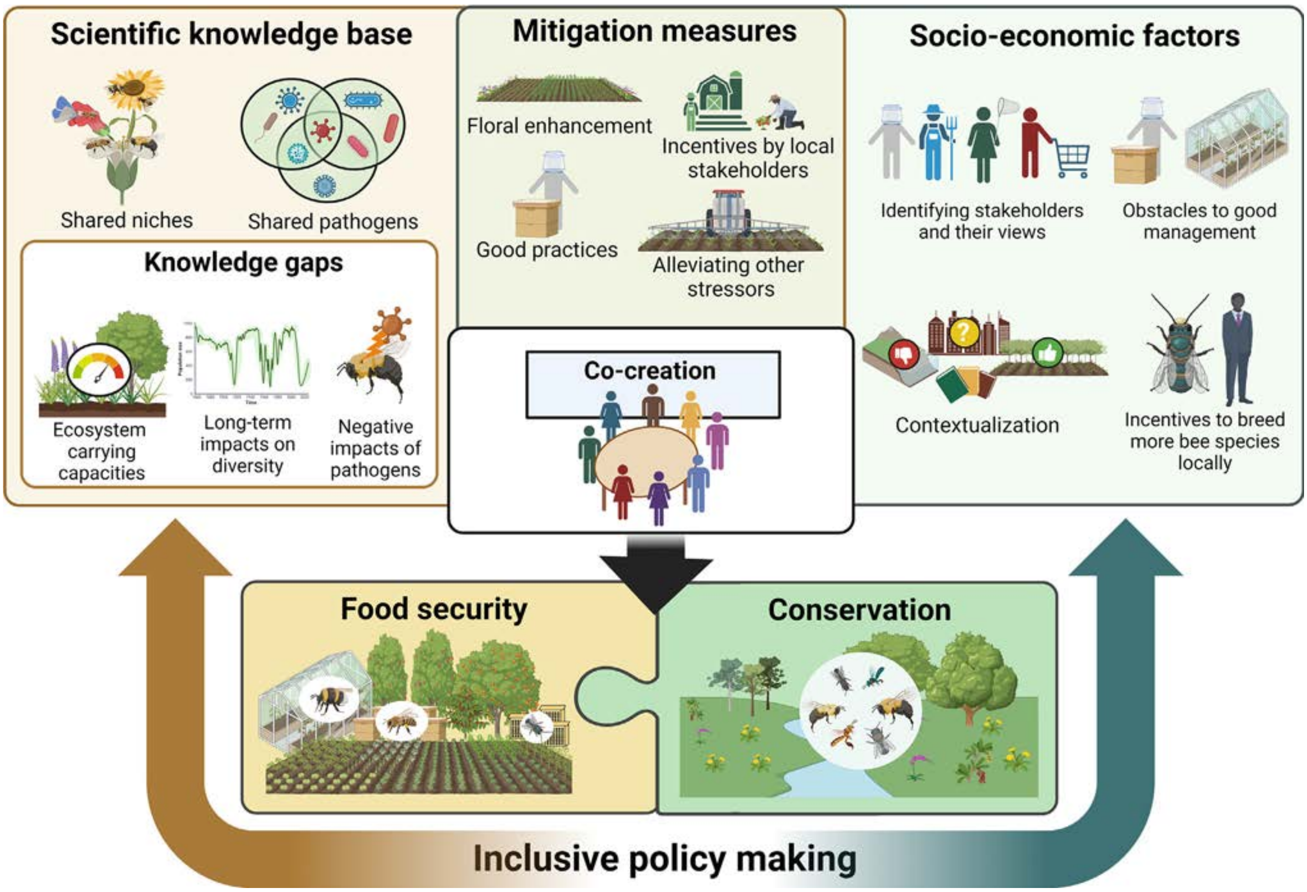

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Figure 1. Guidelines towards inclusive bee policy-making. Inclusive policy-making to better integrate food security and conservation needs can be developed by taking into account both available and missing knowledge in a co-creation process considering socioeconomic factors. Figure created with Biorender.com.

challenging task that requires an inclusive approach [7,9]. To enable this, key wild and managed bee proponents should be provided opportunities to co-create policies through stakeholder consultations and multi-actor knowledge synthesis [e.g., The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)] during which win–win solutions can be elaborated to federate both parties towards a common goal. In addition to national policies, a variety of incentives driven by local or national stakeholders (such as beekeeper associations, wild bee conservation societies, and grower groups) have great potential to foster such co-creation and reduce trade-offs resulting from conflicting goals.

Unity for managed and wild bees

In the context of pollinator declines and increasing reliance on managed bees for crop pollination, actual and perceived negative interactions between managed and wild bees will inevitably lead to escalating conflicts. Habitat loss and climate change that alter floral resource diversity and availability will likely exacerbate these issues. Evidence-based policies to integrate conservation and food security requirements are, therefore, urgently needed. To develop such policies and move beyond precautionary principles, we suggest that more emphasis be placed on identifying the general contexts in which managed bees impact wild bees and the importance of these impacts in relation to other bee stressors. A recent global expert assessment ranked pollinator management and associated pathogens lower than land cover, land configuration, land management, pesticide use, and climate change as drivers of pollinator declines in terms of importance and confidence level [15]. Obtaining greater confidence in the risks posed by managed bees to wild bees and other pollinators will allow effective allocation of resources towards policy-making and implementation. International scientific collaborations and interdisciplinary initiatives involving all stakeholders are key to co-create effective and context-relevant policies to reconcile food security and conservation of wild bees.

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Declaration of interests

The authors have no interests to declare.

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