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Role of Honeybees in Biodiversity Conservation

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Abstract

Bees are important both ecologically and economically for the ecosystem service role they play as pollinators. Honeybees are pollinators that play a key-role in plant biodiversity conservation and crop production. This unique insect species has been managed in hives by beekeepers for millennia, even though such a peculiar animal production system never resulted in the domestication of the western honeybee. The current widespread decline of insect pollinators could negatively affect human well-being and food production, as many crops rely on animal pollination for the quantity and quality of their yield. The quality of our oxygen, the food we eat, the survival of other species, and several bio-diversity issues are in many ways dependent on the work we do to protect the bees.

Keywords

Honeybee, Biodiversity, Conservation, Sustainability, Nature.

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INTRODUCTION

Biodiversity is the variability among living organisms and is important for all of us. It includes the diversity within and between species, and the diversity of ecosystems [1]. The diversity of ecosystems, species and crop varieties and the genetic diversity are invaluable for the next generations and deserve to be protected. All of us appreciates the aesthetic value of a diverse landscape which provides habitats for a rich variety of animal and plant species. But biodiversity means much more than this. It brings us a multitude of practical benefits, with its contribution to ecosystem services. Take pollination by insects, for example. Worldwide, almost 90 percent of flowering plant species are, at least partly, reliant on the transfer of pollen by insects and other animals. These plants are an essential part of ecosystems, providing food, habitats and other resources for a wide range of other species. Insects are the most important animal pollinator groups, with approximately 70% of angiosperm plants being insect pollinated [2].

Among the pollinating insects, bees are one of the most important and specialized groups [3]. About 15 billion years ago 'Big Bang' happened and universe came into existence. It is said that our earth has originated about 4.6 billion years ago. And thereafter gradually the life on earth came into existence. The evolutionary radiation of bees coincided with the evolutionary radiation of flowering plants [4], and bees occupy an important ecological role as pollinators of a range of flowering plant species. Bees play a crucial role in the complex ecosystems of our planet. Unfortunately, they are under threat. Human-driven change means that present species extinction rates for bees and other pollinators are 100 to 1,000 times higher than normal [5]. The decline in bee numbers is a negative indicator for the future quality of human life and our planet at large.

Beneficial Role of Bees

There are over 20,000 species of bees on our planet. They are essential for pollination, which is vital to all life on Earth. Simply put, plants cannot reproduce if they are not being pollinated [6]. Only when this process is completed can these plants create seeds, grow and provide us with food. While bees are not the only insect pollinators, they are one of the most vital. They are crucial in pollinating wild and managed plants. Bees perform about 80% of all pollination worldwide. They keep our planet's precious ecosystems growing and thriving. Seventy out of the top one hundred food crops humanity grows (providing around 90% of the world's nutrition) are pollinated by bees [7]. This includes many of the fruits, nuts, and vegetables that we depend on for food. Without bees, we would be seriously impeded in our ability to feed humanity.

Bees are taxonomically classified under the insect Order Hymenoptera, along with ants, wasps and sawflies, and are part of the superfamily Apoidea, and clade Anthophilia, with seven recognized families. Although only 50 of the ~ 20 000 described bee species are actively managed by people, the entire clade is important for ecosystem functioning and human well-being. Bees and flowering plants have co-evolved, making bees effective pollinators of a large proportion of flowering plant species. There are perhaps a further ~ 5 000 bee species that are yet to be described [8].

Bees and plants have co-existed since time immemorial. Bees depend for their food on plants: nectar provides them with carbohydrate, while pollen supplies protein [9]. Most bees also depend on plants for shelter. In return, bees help with the vital process of plant reproduction. They cross-pollinate flowers, diversify the genetic background of seed, and help plant species reproduce and survive [10]. Bees can distinguish colors, shapes and scents of flowers. They cannot see red but do perceive ultraviolet light. Bees can reach the concealed nectar in flowers that have intricate structures [11]. Their sense of time means they can accurately visit flowers when nectar is secreted, and pollen grains are produced. Bees have adjusted themselves to evolutionary changes in flowers [12]. They have in turn influenced the evolution of flowers, causing the flowers to become more complex in colour, shape and structure, reducing the number of floral parts, and influencing the production and protection of nectar. Many flowers have complicated ways of providing access to pollen and nectar. These reward pollinating insects but discourage others. The floral structures and the chemical composition of the food are adapted to the senses of certain pollinating insects. Protein-rich pollen and glucose-rich nectar are most sought after by trees [13].

Although bees are not the most diverse group of pollinators (butterflies and moths comprise over 140 000 species), they are the most dominant taxonomic group amongst pollinators; only in the Arctic regions, is another group (flies) more dominant [14]. The ability of bees to transport large numbers of pollen grains on their hairy bodies, reliance on floral resources, and the semi-social or social nature of some species are amongst the characteristics that make bees important and effective pollinators [15,16]. Fifty bee species are managed by people of which around 12 are managed for crop pollination [17]. Bees need a clean and healthy environment. The existence of natural bee colonies is a good indicator of a healthy environment. Individual bees can also be useful in detecting air pollution. India can boast of being a centre of origin of the world's honeybee species. Out of the five honey-producing bee species, four have occurred in India since ancient times. They are also found in the Western Ghats.

1. **Apis dorsata-the rock bee or giant bee:** This wild bee constructs single, huge, vertical wax comb exposed to light. The nest hangs on tall tree branches or towers, or underneath bridges or on rock cliffs. It contributes nearly 75% of total honey production of India. It migrates with the season to seek food and shelter.
2. **Apis florea-the garden bee or little bee:** This wild bee constructs a single, small, vertical comb in bushes exposed to light. It produces small quantities of honey. It also migrates depending upon the availability of food and shelter.
3. **Apis cerana-indica the Indian hive bee:** This hive bee constructs several vertical parallel combs in dark enclosures like hollows in tree trunks or in the ground. It is relatively stationary and can be kept in wooden hives for commercial production of honey and pollination services.
4. **Trigona irridipenis-stingless bee or dammer bee:** Like the hive bee, this wild species occurs in dark enclosures, but it does not construct parallel combs. It builds nests comprising of clusters of cells meant for brood rearing and storage of honey and pollen. These bees are very small-little bigger than mosquitoes.

Upset Balance

Bees are part of the delicate balance in the ecosystem [18]. Human interference can upset this balance and disturb bee populations. On the Mahabaleshwar plateau, for instance, natural honeybee colonies are reduced to dangerously low levels. In the 1950s and 1960s, natural bee colonies were abundant on the plateau; later local beekeepers found it difficult to procure natural

colonies. Deforestation has depleted honey production to such an extent that traders now have to procure honey from other states. What applies to Mahabaleshwar is also the case in many other honey-producing regions in the Western Ghats [19].
Reduced numbers of colonies of Apis cerana, the Indian hive bee, are also due to human interference [20]. In the 1970s, thousands of colonies were lost in an epidemic of a bacterial disease. An exotic species, the European honeybee (*Apis mellifera*) was imported into the Mahabaleshwar region, thereby introducing European foul brood disease. Like the Indian hive bee, the wild migratory species *A. dorsata and A. florea* are also endangered by deforestation and thoughtless honey collection. Crude honey collection methods not only reduce the quality of honey but also damage hives and harm the bee population [21]. The queen is the only fully developed female in the colony. It lays eggs which hatch to increase the population. The workers are the bees seen busily going in and out of the hive carrying food. They are females but are not fully developed sexually. They do not lay eggs. Whether an egg grows into a queen or worker depends on the food given to the larva that hatches from the egg. The drones are male members of the colony. Their sole function is to mate with the queen [20].

Biodiversity Maintenance

Capacity to produce honey, disease resistance, low tendency to abscond or migrate, and mild temper leading to few stings are a few desirable traits the beekeeper seeks in bees. It is possible to breed superior strains of Indian hive bees. Local bee species should be used rather than imported exotic bees which may introduce diseases. Suitable techniques for collecting honey and wax from wild bee species (Apis dorsata, A. florea and Trigona irridipenis) are needed. The Central Bee Research Institute in Pune has been successful to a great extent in this regard. Besides honey, all three species produce wax, pollen, royal jelly and bee venom. These species are immensely important in pollinating flowers. A. dorsata has a longer flight range, while A. florea can work on smaller flowers. Apis indica can be kept for pollination in agricultural or horticultural fields [20].
The potential importance of bees for crop pollination has been highlighted as a particular reason to conserve wild bees and their habitat. [17, 21, 22, 23] More than 90% of the world’s top 107 crops are visited by bees; however, wind- and self-pollinated grasses account for around 60% of global food production and do not require animal pollination [24]. Wild bees contribute an average of USD$3 251 ha^{-1} to the production of insect-pollinated crops, similar to that provided by managed honeybees [23]. A very small number of mostly common wild bee species provide the majority of bee-related crop pollination services [23], and other insects such as flies, wasps, beetles, and butterflies have an important, underemphasized role in crop pollination [25]. Such research has highlighted the danger of exclusively highlighting the importance of bees for crop pollination, to the potential detriment of conserving diversity across the landscape [23, 26]. The wild and managed bees have crucial ecological, economic and social importance including and beyond crop pollination.
Long-standing associations exist across multiple bee species and human societies. Documented ancient bee–people interactions include honey hunting dating back to the Stone Age for the honeybee *Apis mellifera* in Europe, [27], more than 2000 years of keeping the honeybee *Apis cerana* in Asia [28], and beekeeping reaching back to at least pre-Columbian times for stingless bees (*Melipona beechii*) in Mayan Mexico [29]. Bees also appear in many religious scriptures and are found within mythology, cosmology and iconography [17, 27, 29, 30]. Beeswax from culturally significant sugarbag bees (*Tetragonula* spp.) has been used in the production of rock art by Aboriginal peoples in northern Australia for at least 4 000 years [24]. In Greek society, bees are closely linked with the cycle of birth and death and considered an emblem of immortality [31]. “Telling the bees” was a popular tradition in 19th Century New England; it was customary for keepers to inform their bees of any major event such as a birth, death, marriage or long journey [24]. These reciprocal bee–human relationships have historic legacy and are highly important for informing current practices around bee management.
Today, the long-standing mutualistic relationship between bees and people is jeopardised by recent reported declines in bee populations [33]. The loss of managed honeybee colonies [33] and declines in wild bee pollinators [34,35] have been observed. However, much remains undocumented about the conservation status of most bee species [36,37]. The global conservation status of just 483 bee species has been assessed by the IUCN, most of which were ‘data deficient’ [28].
With a decline in bee populations, there has been a surge of research focusing on the drivers of bee decline and the impacts on provisioning ecosystem services [36,39]. Drivers such as habitat loss, pesticide use, the proliferation of parasites, availability and diversity of forage, change in land use and climate, and species competition have all contributed to the reduction in bee populations

[36,40, 41]. These drivers interact in complex ways; for example, market-driven agricultural intensification has limited bees' access to forage resources and at the same time potentially increasing bees' exposure to harmful agrichemicals [42,43]. People can act as a positive influence for ecosystem function through designing bee-friendly policies and contributing to bee conservation approaches [24,44,45]. Acknowledging the plethora of literature addressing the decline in bee populations and the consequences for agriculture, we contend that the ubiquitous importance of bees in connecting the planet and people remains relatively less explored, particularly with regard to broader goals in sustainable development.

Significance of Bees to Sustainable Development

Bees provide a range of ecosystem services that contribute to the wellbeing of people whilst maintaining the planet's life support systems [22,44]. Ecosystem services inherently contribute to achieving global sustainable development [46]. Yet the extent to which bees contribute towards the achievement of the full suite of the sustainable developmental goals (SDGs) has not been explored in detail. Existing research has highlighted the importance of insects in achieving multiple SDGs through the regulation of natural cycles, biological pest control, pollination, seed dispersal, and even as bio-inspiration [22,40,47]. Bee pollination has been identified as directly contributing to food security (SDG2) and biodiversity (SDG15) [47]. However, bees could also contribute to a broader range of SDGs.

We explicitly identify the realized and potential contributions of bees towards achieving the SDGs, presenting evidence to highlight the interconnectedness between bees, people and the planet from an integrated system perspective [48].

The importance of bee pollination for food crops has been widely acknowledged, with growing concern of a global crisis as demand for pollination services continues to outstrip supply, with an associated increase in less diverse, pollinator-dependant agriculture systems [49,50]. In addition to improving the yield of some crops [51,52] bee pollination contributes to enhanced nutritional value (target 2.2) and improved quality and longer shelf life of many fruits and vegetables [53] which could potentially help in reducing food waste resulting from aesthetic imperfections [54].

Less-explored aspects of bee pollination include the contribution to biofuels (SDG7). Despite being self-pollinated, oil seed crops show increased yield when pollinated by bees [55,56]. Research in Mexico on the performance of bees on *Jatropha curcas* found significant improvement in the seed set when the self-pollinated varieties were supported with bee pollination [57]. Canola, another self-pollinating oilseed crop, also shows a positive association between higher yields and bee diversity [55].

Beyond agricultural landscapes, research in urban bee ecology aids understanding of bee dynamics in the cities and informs urban bee conservation initiatives [58,59]. Urban beekeeping strengthens residents' connection to nature [59]. Planting aesthetically pleasing, bee-attractive flowering species in landscape planning can provide forage for bees, and close proximity to such plantings may result in pollination rewards for trees and other species in public green spaces [60]. European honeybees can be used as an indicator species for tracking contaminants and monitoring environmental health in urban areas [61]. In addition, understanding bee forage preference, suitability of habitat and mobility between different habitat types is critical for designing sustainable urban and rural landscapes to optimize pollination benefits as well as support bee health [59].

The contribution of wild and managed bees in pollinating wild plants in natural ecosystems and managed forests (target 15.1) is well-acknowledged [16,26]. The biodiversity found within forests provides a critical range of ecosystem services including water cycle regulation and carbon sequestration [62]. Bee-pollinated plants provide a source of food for wildlife and non-timber forest products for people [26]. For example, Brazil nut trees (*Bertholletia excelsa*) require bee pollination to set their high-value fruit, with much greater productivity in the wild, likely due to low numbers of native bees in plantations [63]. Beekeeping within forest boundaries can support forest conservation alongside rural livelihoods [64,65].

Keeping bees provides opportunities for income diversity with low start-up costs, through diverse products and services including honey, pollen, beeswax, propolis, royal jelly, and pollination services [66]. Initiatives to promote beekeeping and pollination services in Kenya have resulted in livelihood improvements for smallholder farmers through increased farm productivity and an additional income stream [67]. However, in other regions of Africa, constraints to improve livelihoods through bee-related activities have been attributed to a lack of knowledge concerning bee husbandry processes, access to equipment, and training [68]. Vocational education in beekeeping could promote economic opportunities for employment and entrepreneurial enterprise and diversification for Indigenous groups, as well as help empower women including those within traditionally patriarchal societies to promote gender equality [69].

Beekeeping can be an important strategy for livelihood diversification [66], which can directly contribute to an increase in per capita and household income and also allow for enhanced fiscal opportunities (e.g., tourism) and sustained income growth for people in rural areas, irrespective of social and economic status [70]. An initiative for sustainable tourism in Slovenia packages bee-related education and healing experiences with bee products, together with opportunities to create and purchase original crafts using bee products [71]. In Fiji, The Earth Care Agency is working to promote organic honey production on remote islands to provide economic alternatives for indigenous Fijians [72].

In relation to health, honey, bee pollen, propolis, royal jelly, beeswax and bee venom have all been used in traditional and modern medicine [73]. Researchers have identified bioactive properties of honey, propolis and royal jelly which suggest the presence of compounds with antimicrobial, anti-inflammatory, antioxidant, antitumor, and anticancer activities [73]. Honey is used in wound and ulcer care, to enhance oral health, fight gastric disorders, and liver and pancreatic diseases, as well as to promote cardiovascular health [73]. Propolis is used in gynecological care, oral health, dermatology care, and oncology treatments, whilst royal jelly is used in reproductive care, neurodegenerative and aging diseases, and wound healing [74].

Bees have contributed to industry, innovation and infrastructure by inspiring the design and development of a range of structures, devices and algorithms that can benefit sustainable development (target 9b). The honeycomb structure of beehives is often a mainstay in structural engineering [75]. Drawing inspiration from bee anatomy, the medical industry has benefited from innovations such as surgical needles adopted from the design of bee stingers [76]. Bee behavior has inspired complex computer-based search and optimization processes informing a new wave of genetic algorithms [77].

SUMMARY

The decline in global insect populations has attracted the attention of the scientific community, general public and policymakers [17], with heightened public awareness of the importance of bees for pollination. A holistic view of ecosystems including wild and managed bees and humans is necessary to address sustainability challenges [78]. By employing a system approach, we can better understand the interconnections between elements within coupled human–environment systems. We strongly advocate the need for appropriate natural resource management approaches for maintaining sustainable systems as vital for allowing the continued success of bees in their natural role. We summarize the benefits of honeybee in sustaining the biodiversity conservation. We must strive to restore balance and reverse bee decline trajectories if we are to encounter a future in which bees continue to contribute to the sustainable development of society.

REFERENCES

1. Kumar A, Verma AK. Biodiversity loss and its Ecological impact in India. International Journal on Biological Sciences. 2017;8(2):156-60.
2. Schoonhoven LM, Van Loon B, van Loon JJ, Dicke M. Insect-plant biology. Oxford University Press on Demand; 2005.
3. Byrne A, Fitzpatrick Ú. Bee conservation policy at the global, regional and national levels. Apidologie. 2009;40(3):194-210.
4. Cappellari SC, Schaefer H, Davis CC. Evolution: pollen or pollinators—which came first? Current Biology. 2013;23(8): R316-8.
5. Mortelmans J, Kageruka P, Trypanosomiasis Aa, Zaire Tc. Food And Agriculture Organization of The United Nations Rome, 1983.
6. Bekić B, Jeločnik M, Subić J. Honeybee colony collapse disorder (Apis mellifera L.)-Possible causes. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development. 2014;14(2):13-8.
7. Eeraerts M, Smagghe G, Meeus I. Pollinator diversity, floral resources and semi-natural habitat, instead of honeybees and intensive agriculture, enhance pollination service to sweet cherry. Agriculture, Ecosystems & Environment. 2019; 284:106586.
8. Ascher, J.S., and J. Pickering. Discover Life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). 2014.
9. Siegel T. Queen of the Sun: What are the Bees Telling Us?. Clairview Books; 2012.
10. Buchmann SL, Nabhan GP. The forgotten pollinators. Island Press; 2012.
11. Free JB. Effect of flower shapes and nectar guides on the behaviour of foraging honeybees. Behaviour. 1970 Jan 1;37(3-4):269-85.
12. Buchmann SL. The ecology of oil flowers and their bees. Annual Review of Ecology and Systematics. 1987;18(1):343-69.
13. Maloof JE, Inouye DW. Is nectar robbers cheaters or mutualists? Ecology. 2000 Oct;81(10):2651-61.
14. Schiestl FP, Dotterl S. The evolution of floral scent and olfactory preferences in pollinators: coevolution or pre-existing bias. Evolution: International Journal of Organic Evolution. 2012;66(7):2042-55.
15. Ollerton J, Winfree R, Tarrant S. How many flowering plants are pollinated by animals? Oikos. 2011;120(3):321-6.

16. Klein AM, Boreux V, Fornoff F, Mupepele AC, Pufal G. Relevance of wild and managed bees for human well-being. Current Opinion in Insect Science. 2018; 26:82-8.
17. Potts SG, Imperatriz-Fonseca V, Ngo HT, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J, Vanbergen AJ. The assessment report on pollinators, pollination and food production: summary for policymakers. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; 2016a.
18. Nazzi F, Pennacchio F. Disentangling multiple interactions in the hive ecosystem. Trends in parasitology. 2014;30(12):556-61.
19. Jagtap TG. Biodiversity in the Western Ghats: An Information Kit. Worldwide Fund, India and International Institute of Rural Reconstruction. 1994:3-6.
20. Theisen-Jones H, Bienefeld K. The Asian honeybee (Apis cerana) is significantly in decline. Bee World. 2016;93(4):90-7.
21. Tscharntke T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto I, Vandermeer J, Whitbread A. Global food security, biodiversity conservation and the future of agricultural intensification. Biological conservation. 2012 Jul 1;151(1):53-9.
22. Gill RJ, Baldock KC, Brown MJ, Cresswell JE, Dicks LV, Fountain MT, Garratt MP, Gough LA, Heard MS, Holland JM, Ollerton J. Protecting an ecosystem service: approaches to understanding and mitigating threats to wild insect pollinators. Advances in ecological research. 2016 Jan 1;54:135-206.
23. Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, Klein AM, Kremen C, M'gonigle LK, Rader R, Ricketts TH. Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature communications. 2015;6(1):1-9.
24. Patel V, Pauli N, Biggs E, Barbour L, Boruff B. Why bees are critical for achieving sustainable development. Ambio. 2021;50(1):49-59.
25. Rader R, Bartomeus I, Garibaldi LA, Garratt MP, Howlett BG, Winfree R, Cunningham SA, Mayfield MM, Arthur AD, Andersson GK, Bommarco R. Non-bee insects are important contributors to global crop pollination. Proceedings of the National Academy of Sciences. 2016;113(1):146-51.
26. Senapathi D, Biesmeijer JC, Breeze TD, Kleijn D, Potts SG, Carvalheiro LG. Pollinator conservation—the difference between managing for pollination services and preserving pollinator diversity. Current Opinion in Insect Science. 2015; 12:93-101.
27. Roffet-Salque M, Regert M, Evershed RP, Outram AK, Cramp LJ, Decavallas O, Dunne J, Gerbault P, Mileto S, Mirabaud S, Pääkkönen M. Widespread exploitation of the honeybee by early Neolithic farmers. Nature. 2015;527(7577):226-30.
28. Crane E. History of beekeeping with Apis cerana in Asia. The Asiatic hive bee Apciulture, biology, and role in sustainable development in tropical and substropical Asia, ed. PG Kewan. 1995:3-18.
29. Quezada-Euán JJ. The Past, present, and future of meliponiculture in Mexico. InStingless Bees of Mexico 2018:243-269.
30. Fijn N. Sugarbag dreaming: The significance of bees to Yolngu in Arnhem Land, Australia. HUMaNIMALIA. 2014; 6:1–21.
31. Cook AB. The bee in Greek mythology. The Journal of Hellenic Studies. 2013; 15:1–24.
32. Potts, S.G., V. Imperatriz-Fonseca, H.T. Ngo, M.A. Aizen, J.C. Biesmeijer, T.D. Breeze, L.V. Dicks, L.A. Garibaldi. Safeguarding pollinators and their values to human well-being. Nature. 2016b;540: 220–229.
33. Potts SG, Roberts SP, Dean R, Marris G, Brown MA, Jones R, Neumann P, Settele J. Declines of managed honeybees and beekeepers in Europe. Journal of apicultural research. 2010;49(1):15-22.
34. Biesmeijer JC, Roberts SP, Reemer M, Ohlemüller R, Edwards M, Peeters T, Schaffers AP, Potts SG, Kleukers RJ, Thomas CD, Settele J. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science. 2006;313(5785):351-4.
35. Koh I, Lonsdorf EV, Williams NM, Brittain C, Isaacs R, Gibbs J, Ricketts TH. Modeling the status, trends, and impacts of wild bee abundance in the United States. Proceedings of the National Academy of Sciences. 2016;113(1):140-5.
36. Goulson D, Nicholls E, Botías C, Rotheray EL. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science. 2015;347(6229).
37. Jamieson MA, Carper AL, Wilson CJ, Scott VL, Gibbs J. Geographic biases in bee research limits understanding of species distribution and response to anthropogenic disturbance. Frontiers in Ecology and Evolution. 2019; 7:194.
38. The International Union of Conservation of Nature (IUCN) Red List of Threatened Species, Version 2019-3. 2019.
39. Decourtye A, Alaux C, Le Conte Y, Henry M. Toward the protection of bees and pollination under global change: present and future perspectives in a challenging applied science. Current opinion in insect science. 2019; 35:123-31.
40. Sánchez-Bayo F, Wyckhuys KA. Worldwide decline of the entomofauna: A review of its drivers. Biological conservation. 2019; 232:8-27.
41. Wagner DL. Insect declines in the Anthropocene. Annual review of entomology. 2020; 65:457-80.
42. Durant JL. Where have all the flowers gone? Honeybee declines and exclusions from floral resources. Journal of Rural Studies. 2019; 65:161-71.
43. Sanchez-Bayo F, Goka K. Pesticide residues and bees–a risk assessment. PloS one. 2014;9(4): e94482.
44. Matias DM, Leventon J, Rau AL, Borgemeister C, von Wehrden H. A review of ecosystem service benefits from wild bees across social contexts. Ambio. 2017;46(4):456-67.
45. Hill R, Nates-Parra G, Quezada-Euán JJ, Buchori D, LeBuhn G, Maués MM, Pert PL, Kwapong PK, Saeed S, Breslow SJ, da Cunha MC. Biocultural approaches to pollinator conservation. Nature Sustainability. 2019;2(3):214-22.

46. Wood SL, Jones SK, Johnson JA, Brauman KA, Chaplin-Kramer R, Fremier A, Girvetz E, Gordon LJ, Kappel CV, Mandle L, Mulligan M. Distilling the role of ecosystem services in the Sustainable Development Goals. Ecosystem services. 2018; 29:70-82.
47. Dangles O, Casas J. Ecosystem services provided by insects for achieving sustainable development goals. Ecosystem services. 2019; 35:109-15.
48. Stafford-Smith M, Griggs D, Gaffney O, Ullah F, Reyers B, Kanie N, Stigson B, Shrivastava P, Leach M, O'Connell D. Integration: the key to implementing the Sustainable Development Goals. Sustainability science. 2017;12(6):911-9.
49. Aizen MA, Harder LD. The global stock of domesticated honeybees is growing slower than agricultural demand for pollination. Current biology. 2009;19(11):915-8.
50. Aizen MA, Aguiar S, Biesmeijer JC, Garibaldi LA, Inouye DW, Jung C, Martins DJ, Medel R, Morales CL, Ngo H, Pauw A. Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. Global Change Biology. 2019;25(10):3516-27.
51. Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T. Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: biological sciences. 2007;274(1608):303-13.
52. Stein K, Coulibaly D, Stenchly K, Goetze D, Porembski S, Lindner A, Konaté S, Linsenmair EK. Bee pollination increases yield quantity and quality of cash crops in Burkina Faso, West Africa. Scientific Reports. 2017;7(1):1-0.
53. Klatt BK, Holzschuh A, Westphal C, Clough Y, Smit I, Pawelzik E, Tscharntke T. Bee pollination improves crop quality, shelf life and commercial value. Proceedings of the Royal Society B: Biological Sciences. 2014;281(1775):20132440.
54. Gunders D. Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill. Natural Resources Defense Council. 2012; 26:1-26.
55. Halinski R, dos Santos CF, Kaehler TG, Blochtein B. Influence of wild bee diversity on canola crop yields. Sociobiology. 2018.
56. Perrot T, Gaba S, Roncoroni M, Gautier JL, Bretagnolle V. Bees increase oilseed rape yield under real field conditions. Agriculture, Ecosystems & Environment. 2018; 266:39-48.
57. Romero MJ, Quezada-Euán JJ. Pollinators in biofuel agricultural systems: the diversity and performance of bees (Hymenoptera: Apoidea) on Jatropha curcas in Mexico. Apidologie. 2013;44(4):419-29.
58. Hernandez JL, Frankie GW, Thorp RW. Ecology of urban bees: a review of current knowledge and directions for future study. Cities and the Environment (CATE). 2009;2(1):3.
59. Stange E, Barton DN, Rusch G. A closer look at Norway's natural capital-how enhancing urban pollination promotes cultural ecosystem services in Oslo. Reconnecting natural and cultural capital. Contributions from science and policy. 2018.
60. Hausmann SL, Petermann JS, Rolff J. Wild bees as pollinators of city trees. Insect Conservation and Diversity. 2016;9(2):97-107.
61. Zhou X, Taylor MP, Davies PJ, Prasad S. Identifying sources of environmental contamination in European honeybees (Apis mellifera) using trace elements and lead isotopic compositions. Environmental science & technology. 2018;52(3):991-1001.
62. Creed, I.F., and M. van Noordwijk. Forest and water on a changing planet: Vulnerability, adaptation and governance opportunities. A global assessment reports. Vienna: International Union of Forestry Research Organizations. 2018.
63. Cavalcante MC, Oliveira FF, Maués MM, Freitas BM. Pollination requirements and the foraging behavior of potential pollinators of cultivated Brazil nut (Bertholletia excelsa Bonpl.) trees in central Amazon rainforest. Psyche. 2012;2012.
64. Chanthayod S, Zhang W, Chen J. People's perceptions of the benefits of natural beekeeping and its positive outcomes for forest conservation: a case study in Northern Lao PDR. Tropical Conservation Science. 2017; 10:1940082917697260.
65. Mudzengi C, Kapembeza CS, Dahwa E, Taderera L, Moyana S, Zimondi M. Ecological benefits of apiculture on savanna rangelands. Bee World. 2020;97(1):17-20.
66. Bradbear N. Bees and their role in forest livelihoods: a guide to the services provided by bees and the sustainable harvesting, processing and marketing of their products. Non-wood Forest Products. 2009(19).
67. Carroll T, Kinsella J. Livelihood improvement and smallholder beekeeping in Kenya: the unrealised potential. Development in Practice. 2013;23(3):332-45.
68. Minja GS, Nkumilwa TJ. The role of beekeeping on forest conservation and poverty alleviation in Moshi Rural District, Tanzania. European Scientific Journal. 2016;12(23).
69. Mburu PD, Affognon H, Irungu P, Mburu J, Raina S. Gender roles and constraints in beekeeping: A case from Kitui County, Kenya. Bee World. 2017;94(2):54-9.
70. Vinci G, Rapa M, Roscioli F. Sustainable development in rural areas of Mexico through beekeeping. International Journal of Science and Engineering Invention. 2018;4(08):01-to.
71. Arih IK, Korošec TA. Api-tourism: Transforming Slovenia's apicultural traditions into a unique travel experience. WIT Transactions on Ecology and the Environment. 2015; 193:963-74.
72. Matava Fiji Untouched. Community Partnership Kadavu Organic Honey Program. 2019.
73. Easton-Calabria A, Demary KC, Oner NJ. Beyond pollination: Honeybees (Apis mellifera) as zootherapy keystone species. Frontiers in Ecology and Evolution. 2019; 6:161.
74. Pasupuleti VR, Sammugam L, Ramesh N, Gan SH. Honey, propolis, and royal jelly: a comprehensive review of their biological actions and health benefits. Oxidative medicine and cellular longevity. 2017;2017.

75. Zhang Q, Yang X, Li P, Huang G, Feng S, Shen C, Han B, Zhang X, Jin F, Xu F, Lu TJ. Bioinspired engineering of honeycomb structure–Using nature to inspire human innovation. Progress in Materials Science. 2015; 74:332-400.
76. Sahlabadi M, Hutapea P. Novel design of honeybee-inspired needles for percutaneous procedure. Bioinspiration & biomimetics. 2018;13(3):036013.
77. Xing B, Gao WJ. Innovative computational intelligence: a rough guide to 134 clever algorithms. 2014.
78. Saunders ME, Smith TJ, Rader R. Bee conservation: Key role of managed bees. Science. 2018;360(6387):389.