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Review Article

Anthropogenic Threats to Honeybee Ecology: A Review

Shahnawaz Ahmed

Research Scientist, Institute for Industrial Research and Toxicology, Ghaziabad, Uttar Pradesh, India.

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E-mail Id:
shanu160by2@gmail.com
Orchid Id:
https://orcid.org/0000-0002-8678-4541

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A B S T R A C T

Honeybees (Apis mellifera) play a crucial role in pollinating a wide range of crops, making them vital to global food security. However, honeybee populations have faced numerous challenges due to anthropogenic disturbances in their ecology. This comprehensive review article synthesises current knowledge on the diverse range of threats that honeybees encounter as a result of human activities. The review begins by examining the impact of habitat loss and fragmentation on honeybee foraging and nesting patterns. It highlights the consequences of urbanisation, agricultural expansion, and deforestation, emphasising how these factors have reduced suitable foraging grounds and nesting sites for honeybees. Pesticides and agrochemicals constitute another significant threat to honeybee health and survival. The review explores the effects of neonicotinoids, herbicides, and fungicides on honeybee populations, including sublethal effects on behaviour and colony dynamics. It also discusses the role of genetically modified crops in pesticide exposure. Furthermore, the article delves into the challenges posed by pathogens and diseases, such as Nosema, Varroa destructor mites, and viral infections, and how these factors interact with environmental stressors to weaken honeybee colonies. Climate change and its associated shifts in temperature and precipitation patterns are considered in the context of their impact on honeybee distribution, phenology, and the availability of floral resources. In short, this review underscores the multifaceted nature of anthropogenic threats to honeybees and their ecology. It emphasises the importance of integrated approaches involving habitat conservation, reduced pesticide use, disease management, and climate change mitigation to ensure the long-term survival and well-being of honeybee populations and the critical ecosystem services they provide.

Keywords: Honeybee, Anthropogenic Threats, Invasive Species, Biodiversity Loss, Agro-Chemicals, Conservation

Introduction

This article aims to comprehensively outline and analyse the multifaceted nature of man-made calamities affecting honey bees, with a specific focus on pesticide use, habitat destruction, climate change, and pollution. Through a structured exploration of these calamities and their repercussions on honey bee populations, we aim to educate and raise awareness about the severity of the issue. Honeybees (Apis mellifera) play a pivotal role in the delicate balance of ecosystems and agriculture worldwide. As pollinators, they facilitate the reproduction of countless plant species, including many of the crops that sustain human populations. This review article explores the multifaceted importance of honeybees in both natural ecosystems and agriculture, focusing on the threats posed by anthropological disturbances to their ecological roles. Honeybees are among the most efficient pollinators, contributing to the reproduction of a wide array of crops, such as fruits, vegetables, and nuts.[1] Their role in agriculture is estimated to be worth billions of dollars annually, with one-third of global crop production reliant on animal pollinators, primarily bees.[2] Beyond their agricultural significance, honeybees also contribute to the maintenance of biodiversity by pollinating wild plants. They support the survival of various fauna, from insects to mammals, by enabling the production of fruits, seeds, and nuts upon which many species depend.[3] Honeybees promote ecosystem stability through their pollination services. By enhancing plant reproduction, they help stabilise food webs and ensure a continuous supply of resources for other organisms.[4] The decline of honeybees can disrupt these interactions, potentially leading to ecological imbalances. Honeybee populations exhibit genetic diversity that can be crucial for their adaptation to changing environmental conditions.[5] Anthropological disturbances, such as habitat destruction and pesticide use, can erode this genetic diversity, making honeybees more vulnerable to environmental stressors. The availability of diverse and nutritious crops, supported by honeybee pollination, is essential for global food security. Additionally, honey production and beekeeping activities contribute to the livelihoods of millions of people worldwide.[6] Disruptions in honeybee populations can threaten both food security and economic well-being.

The global decline in honeybee populations has been a matter of concern for scientists, beekeepers, and policymakers. The use of neonicotinoid pesticides has been linked to honeybee population declines. These pesticides can affect bee health, impair foraging behaviour, and weaken colonies. Urbanisation and agricultural expansion have led to habitat loss and reduced forage availability for bees.[7] This can make it more difficult for bees to find the food they need. Honeybees can be susceptible to various diseases and parasites, including varroa mites and nosema, which can weaken and decimate bee colonies. Changes in temperature and weather patterns can impact the availability of flowering plants and disrupt the synchronised timing between bee foraging and flower blooming. Limited access to diverse and nutritious food sources can stress honeybee colonies, making them more vulnerable to other threats. Bees can encounter a range of environmental toxins, including heavy metals and pollutants, which can have negative effects on their health.[8] Large-scale monoculture farming can limit the diversity of available forage plants for bees, making it harder for them to obtain a balanced diet. The international trade of bees for crop pollination can spread diseases and pests among bee populations.

Anthropological disturbances, which refer to human-induced disruptions or alterations of the environment, can have significant impacts on honeybee ecology. These disturbances can affect honeybees directly or indirectly through changes in habitat, forage availability, pesticide exposure, and more. Here, we'll discuss the key ways in which anthropological disturbances influence honeybee ecology and provide references to support these points. Anthropological activities such as urbanisation, deforestation, and land-use changes can lead to the loss and fragmentation of natural habitats for honeybees.[9] This impacts their nesting sites, foraging areas, and overall ability to establish and maintain healthy colonies. Agricultural activities often involve the use of pesticides, which can have harmful effects on honeybees. Pesticides can contaminate the bees' forage, water sources, and hives, leading to bee mortality, impaired reproduction, and behavioural changes.[10] Anthropogenic climate change is altering the distribution and phenology of flowering plants, which directly affects the availability and quality of forage for honeybees. Changes in temperature and weather patterns can also impact the bees' behaviour and life cycles.[11] Human activities, including international trade and travel, have facilitated the introduction of non-native species that can compete with or prey on honeybees, disrupting local ecosystems and affecting honeybee populations.[12] Large-scale agricultural practices, especially monoculture farming, reduce the diversity and abundance of flowering plants essential for honeybee nutrition. Monoculture systems may lack a variety of flowering plants needed for a balanced and nutritious diet.[13]

Habitat Loss and Fragmentation

Urbanisation and agricultural expansion can have significant impacts on honeybee habitats. These changes in land use can lead to habitat loss, reduced forage availability, exposure to pesticides, and increased competition for resources, all of which can negatively affect honeybee populations. As urban areas expand, they often encroach on natural habitats, such as meadows, forests, and wildflower-rich areas. These natural habitats may contain a variety of flowering plants that honeybees rely on for nectar and pollen. The conversion of these areas into buildings, roads, and other infrastructure results in habitat loss for honeybees. Agricultural expansion often involves clearing land for crops or livestock. This process can result in the destruction of diverse ecosystems, including wildflowers and native plants that are essential for honeybee foraging.[14] Urbanisation: In urban areas, manicured lawns and gardens dominated by non-native ornamental plants may not provide sufficient forage for honeybees. Bees require a diverse range of flowering plants throughout the year to meet their nutritional needs. Intensive monoculture farming practices can limit the availability of diverse flowering plants.[6] Large-scale fields planted with a single crop may provide a short period of forage during the crop's flowering season but can be barren for the rest of the year.[8] In urban environments, honeybees may face increased competition for limited forage resources from other bee species and pollinators. When large areas are planted with a single crop, such as almond orchards, bees from multiple hives may be brought in to meet the pollination demand.[7] This can result in intense competition among bee colonies for limited forage during the blooming season.

Consequences of Habitat Loss and Fragmentation

Habitat loss and fragmentation can have significant negative consequences for honeybee populations as well as for pollinators in general. Habitat loss often leads to the destruction of natural forage areas for honeybees. Habitat loss and fragmentation can alter honeybee behaviours and interactions within and outside their colonies. Bees may exhibit changed foraging patterns, flight distances, and mating behaviors. Such alterations can have cascading effects on their ecological roles, such as pollination services and plant interactions.[15] As natural habitats are converted into urban or agricultural landscapes, there are fewer wildflowers and diverse plant species available for bees to feed on. This results in reduced access to nectar and pollen, which are essential food sources for honeybees.[6] Fragmentation of habitats can lead to the isolation of bee populations. Isolated populations are at greater risk of reduced genetic diversity, which can make them more vulnerable to diseases and environmental changes.[16] Fragmented landscapes often mean that honeybee colonies are situated closer to agricultural fields. This proximity can increase their exposure to pesticides and agrochemicals, which can have detrimental effects on bee health and reproductive success.[17] Habitat fragmentation can also reduce the availability of suitable nesting sites for honeybees. This can lead to increased competition among bee colonies for limited nesting resources [6]. The cumulative effects of habitat loss, reduced forage, increased exposure to pesticides, and limited nesting sites can lead to increased stress among honeybee populations. Stressed colonies are more susceptible to diseases and parasites, such as Varroa mites, which can devastate bee colonies.[18] Ultimately, the consequences of habitat loss and fragmentation can lead to a decline in honeybee populations. This decline has broader implications for ecosystems and agriculture, as honeybees play a vital role in pollinating a wide range of crops and wild plants.[19]

Pesticide Exposure

Pesticides can have several adverse effects on honey bees, which are crucial pollinators for many of our food crops and contribute significantly to biodiversity. These effects can harm individual bees, entire colonies, and, ultimately, the broader ecosystem. Pesticides can cause direct mortality in honey bees. Additionally, sublethal doses can affect their foraging behaviour, leading to reduced foraging activity, decreased navigation ability, and disorientation, ultimately affecting their ability to gather food for the colony.[17] Exposure to pesticides, such as neonicotinoids, can impair the learning and memory of honey bees. This can affect tasks crucial for the survival of the colony, such as foraging, navigation, and communication.[20] Pesticides, particularly neonicotinoids and insect growth regulators, can disrupt the hormonal balance and development of honey bees. These disruptions can lead to impaired larval and pupal development, reduced longevity, and altered reproductive capacity.[21,22] Exposure to pesticides can weaken the honey bee's immune system, making them more susceptible to diseases and parasites. Pesticides may suppress the immune response, making it difficult for bees to defend against pathogens.[23]

Pesticides, especially fungicides, can alter the gut microbiota of honey bees. Disruptions in the gut microbiota can affect nutrient digestion, overall health, and resistance to pathogens.[24] Pesticide drift from neighbouring agricultural fields can contaminate bee habitats. Residue accumulation in nectar and pollen can expose honey bees to sublethal doses of pesticides, leading to chronic exposure and long-term effects.[25] Pesticides can adversely affect queen development and reproductive capacity. Exposure during development can lead to malformation or reduced reproductive potential, ultimately impacting colony growth and stability.[26] These adverse effects collectively contribute to the phenomenon known as colony collapse disorder (CCD), where entire honey bee colonies experience rapid and widespread declines. Neonicotinoids can weaken the honeybee's immune system, making them more susceptible to diseases and pathogens. Pesticide exposure may compromise the bees' ability to fight off infections and contribute to the overall decline in honeybee health.[27] Exposure to neonicotinoids can have detrimental effects on overall colony health and survival. Research has shown that prolonged exposure to these pesticides can lead to decreased colony growth, reduced queen production, and, in severe cases, colony collapse.[28] Neonicotinoids can persist in the environment and contaminate nectar, pollen, soil, and water, posing a risk to honeybees and other non-target organisms.[29] It's important to note that while neonicotinoids have been the focus of much research, other pesticides and agricultural chemicals also pose risks to honeybees and pollinators.

The Mode of Action of Pesticides

Pesticides can affect honey bees through various mechanisms, primarily through contact or ingestion. The mode of action depends on the type of pesticide used. Here are the primary ways pesticides impact bees:

- **Neurotoxicity:** Many pesticides, including neonicotinoids and organophosphates, act as neurotoxins. They disrupt the central nervous system of bees, affecting their ability to forage, navigate, and communicate within the hive. This leads to impaired foraging efficiency and can result in colony collapse.[30]
- **Sublethal Effects:** Even sublethal doses of pesticides can have adverse effects on bees. They may not kill bees outright, but they can weaken their immune systems, making them more susceptible to diseases and parasites.[23]
- **Chronic Exposure:** Pesticides may accumulate in the hive through contaminated pollen, nectar, and wax. This chronic exposure can have long-term, detrimental effects on the health andbehaviourr of the entire colony.[31] Pesticides can lead to immediate bee mortality, especially if exposure levels are high. This directly reduces the number of foraging bees and weakens the colony.[32] Those chemicals can affect queen bees' reproductive abilities, leading to a decline in colony strength and resilience.[33] The cumulative impact of pesticide exposure, combined with other stressors, has been linked to CCD, a phenomenon where entire bee colonies mysteriously die off.[34] Pesticide-exposed bees are less efficient pollinators, which can have far-reaching consequences for agriculture andecosystems.[35]

Case Studies: Pesticide-Related Bee Declines

Neonicotinoids and Bee Decline

Neonicotinoids are a class of systemic insecticides widely used in agriculture. Research has linked neonicotinoid exposure to impaired foraging behaviour, reduced colony growth, and increased mortality in honey bees. A notable study by.[36] demonstrated that honey bee exposure to neonicotinoids significantly impairs colony health and survival. The study highlights the urgent need to reevaluate the use of neonicotinoids to protect pollinators. The EU's decision to impose restrictions on neonicotinoid pesticides, including clothianidin and imidacloprid, was based on extensive research. Studies, such as the one conducted by EFSA, provided evidence of the adverse effects of these pesticides on honey bee behavior, reproductive success, and colony survival. The ban highlighted the need for stringent pesticide regulations to protect bee populations.[37]

The decline of honeybee populations, often referred to as colony collapse disorder (CCD), has raised significant concerns worldwide due to its potential impact on global food security and ecosystem health. Among the numerous factors implicated in this decline, neonicotinoid pesticides have emerged as a key anthropogenic threat to honeybee ecology. This case study explores the relationship between neonicotinoids and bee decline, drawing upon scientific evidence and research findings. Neonicotinoids act on the nervous systems of insects, disrupting their neural pathways and leading to paralysis and death. However, the systemic nature of neonicotinoids means that they are absorbed by the entire plant, including its nectar and pollen, making them accessible to foraging honeybees. Numerous studies have demonstrated the adverse effects of neonicotinoids on honey bees.

Toxicology

Research by.[38] found that honeybees exposed to sublethal doses of neonicotinoids exhibited impaired foraging behaviour, reducing their ability to collect nectar and pollen effectively. A study by[39] showed that bees exposed to neonicotinoids had difficulty returning to their hives, which can lead to colony collapse as foragers fail to contribute to the hive.[40] Found that neonicotinoid exposure can lead to decreased colony growth and overwintering success, ultimately contributing to colony losses.[8] It has been demonstrated that even sublethal doses of neonicotinoids can affect bee colonies by reducing their ability to produce new queens and drones.

Regulatory Responses

In 2013, the EU imposed a temporary ban on the use of neonicotinoids on flowering crops that attract bees. This ban was extended in 2018 to cover all outdoor uses. The US Environmental Protection Agency (EPA) issued guidelines in 2019 to restrict the use of certain neonicotinoids. Health Canada initiated a re-evaluation of neonicotinoid pesticides, leading to stricter regulations on their use. The case study highlights the compelling evidence linking neonicotinoid pesticides to the decline of honeybee populations. While the scientific community has made significant strides in understanding this issue, challenges remain in addressing the complex interplay of factors contributing to bee decline. Regulatory actions, such as those taken by the EU, the US, and Canada, underscore the importance of mitigating the risks associated with neonicotinoids.

Imidacloprid and Colony Collapse Disorder (CCD)

Imidacloprid, a neonicotinoid insecticide, gained attention due to its potential role in colony collapse disorder (CCD), a phenomenon characterised by the abrupt disappearance of worker bees from the hive. A study by[41] found detectable levels of imidacloprid in wax and pollen samples from affected colonies, suggesting a potential association. This study underscores the need for cautious pesticide use to mitigate CCD.[40]

While CCD's exact causes are multifaceted, there is mounting evidence linking the neonicotinoid pesticide Imidacloprid to bee colony declines. Imidacloprid is one of the most widely used neonicotinoids, which are systemic insecticides known for their potential environmental impact. Imidacloprid is a neonicotinoid insecticide used to protect a variety of crops from pests. It works by targeting the nervous system of insects, disrupting neural transmission. Its systemic nature means that it can be absorbed by plants and can persist in various plant tissues, including nectar and pollen.

Toxicology

In a pivotal study by[34], it was found that imidacloprid residues were significantly higher in CCD-affected colonies compared to unaffected colonies. A study by[36] demonstrated that even sublethal doses of imidacloprid could impair bee navigation and foraging abilities, potentially contributing to colony collapse. Imidacloprid has sublethal effects on honeybees, including impaired foraging behaviour, reduced brood rearing, and compromised immunity. These effects can weaken the overall health of the colony. It's interaction with other stressors, such as pathogens (e.g., Nosema spp.) and Varroa mites, can exacerbate the negative impact on honeybee colonies. This interaction may lead to a higher susceptibility to CCD. Field observations have shown a correlation between the use of imidacloprid-treated seeds in agriculture and bee population declines in several regions.

Regulatory Responses

The European Union (EU) imposed restrictions on the use of neonicotinoids, including imidacloprid, for certain crops due to concerns about their impact on pollinators. These restrictions were implemented in 2013 and revised in 2018. The U.S. Environmental Protection Agency (EPA) has reviewed the registration of neonicotinoid pesticides, including Imidacloprid, and has implemented label changes and restrictions on some uses to protect pollinators. The case study highlights a growing body of evidence linking imidacloprid exposure to colony collapse disorder in honeybee populations. While more research is needed to fully understand the complex factors contributing to CCD, the precautionary principle has led to regulatory actions in various parts of the world to reduce the use of neonicotinoid pesticides, including Imidacloprid, in order to protect these vital pollinators.

Clothianidin and Sublethal Effects on Bees

Clothianidin, another neonicotinoid, has been associated with sublethal effects on honey bees, impacting their learning and memory capabilities. A study by[39] demonstrated that sublethal clothianidin exposure affects the foraging behaviour and navigation skills of honey bees. These findings emphasise the importance of considering sublethal effects in pesticide risk assessments. A study investigated the effects of imidacloprid, a neonicotinoid pesticide, on bumblebee colonies. It found that exposure to imidacloprid significantly reduced colony growth and queen production .[42] These observations highlighted how even sublethal doses of pesticides can have profound consequences for bee populations. Studies collectively highlight the significant threat that pesticides pose to honey bee populations and, by extension, the ecosystems they support. They underscore the urgency of implementing sustainable agricultural practices and stricter pesticide regulations to mitigate the adverse effects of these chemicals on bee health.

Clothianidin is a neonicotinoid insecticide widely used in modern agriculture to protect crops from various pests. However, concerns have been raised about its sublethal effects on non-target organisms, particularly honeybees (Apis mellifera). This case study aims to analyse the sublethal effects of clothianidin on honeybees, focusing on behavioural changes, foraging patterns, and colony health.[43] It is also a neonicotinoid insecticide that acts on the nervous system of insects by binding to nicotinic acetylcholine receptors. It is highly effective against a wide range of pests and is commonly used as a seed treatment, soil application, or foliar spray.

Toxicity

Numerous studies have demonstrated that exposure to clothianidin can lead to significant behavioural alterations in honeybees. They are such as when bees exposed to sublethal doses of clothianidin exhibit decreased movement and reduced overall activity levels. Clothianidin exposure can negatively impact a honeybee's ability to learn and remember important tasks, such as foraging locations and navigation.[44] Bees exposed to clothianidin may experience difficulties in orientation and navigation, affecting their ability to return to the hive accurately. Honeybees exposed to clothianidin may exhibit changes in foraging preferences, leading them to forage on non-target flowers or even avoid foraging altogether.[8] The pesticide exposure may reduce a honeybee's ability to efficiently forage for nectar and pollen, affecting the overall food supply for the colony. Clothianidin exposure can lead to reduced brood development, affecting the overall growth and vitality of the honeybee colony. Exposure to clothianidin may compromise the honeybee's immune system, making them more susceptible to diseases and infections. Clothianidin, a widely used neonicotinoid insecticide, has been associated with various sublethal effects on honeybees, including altered behaviour, disrupted foraging patterns, and compromised colony health. Understanding these sublethal effects is crucial for implementing responsible pesticide use and developing sustainable agricultural practices that protect both crops and pollinators.

Regulatory Responses

As of 2018, the European Union (EU) had imposed a near-total ban on the outdoor use of neonicotinoid pesticides, including clothianidin. This ban was primarily motivated by concerns about their impact on pollinators. However, there were exceptions for some crops and certain circumstances. United States (EPA) In the United States, the Environmental Protection Agency (EPA) has conducted risk assessments on neonicotinoids, including clothianidin. As of 2021, clothianidin was still registered for use in various crops, but label restrictions and application guidelines had been updated to reduce the risk to pollinators. Various other countries around the world have different approaches to regulating neonicotinoids, with some implementing bans or restrictions on their use in agriculture. Regulatory agencies and researchers continued to conduct studies on the sublethal effects of clothianidin and other neonicotinoids to better understand their impact on bees and other pollinators.

Pollution

The Impact of Air Pollution on Bee Navigation

Air pollution is a pervasive environmental issue, primarily caused by human activities such as industrial emissions, vehicular exhaust, and deforestation. While the detrimental effects of air pollution on human health and the environment are well documented, its impact on bee populations, particularly in terms of navigation, is an emerging concern. [45] Bees play a crucial role in pollination, contributing to the global food supply.[6] This note explores the adverse effects of air pollution on bee navigation, shedding light on the significance of this issue and its broader ecological implications. Bee navigation is a highly developed and intricate skill crucial for their foraging activities. Bees rely on a combination of visual cues, including polarised light patterns, ultraviolet (UV) light, and landmarks, to navigate accurately between their hive and foraging sites.[46] This precise navigation is essential for pollination, as bees need to locate and return to specific flowers to ensure successful pollination.[47] Air pollution consists of a complex mixture of pollutants, including particulate matter (PM), ground-level ozone (O3), nitrogen oxides (NOx), sulphur dioxide (SO2), and volatile organic compounds (VOCs).[48] These pollutants can originate from various sources, including industrial processes, transportation, and agriculture. One of the significant impacts of air pollution on bee navigation is the alteration of visual cues. Particulate matter in the atmosphere can scatter and absorb light, reducing the clarity of polarised light patterns and UV light that bees rely on for orientation.[47] This can lead to navigation errors, causing bees to become disoriented and potentially fail to return to their hives. Air pollutants such as VOCs emitted from anthropogenic sources can disrupt the chemical communication systems of bees. This interference can disrupt foraging patterns and impede a bee's ability to locate nectar sources.[48]

Water Pollution and Contaminated Nectar Sources

Water pollution poses a significant threat to honey bees and their ecosystem, impacting their foraging habits and overall health. Bees rely on water for various essential functions within the hive, including cooling, hydration, and food processing. Moreover, contaminated water sources can lead to toxic nectar, which compromises the quality of honey and the health of the bee population. Pesticides, herbicides, and fertilisers used in agriculture can contaminate nearby water sources through runoff, making these bodies of water hazardous for both bees and their nectar sources.[32] Factories and industrial units often discharge pollutants into rivers and streams, which can contaminate nearby flowering plants and the water used by bees.[49] Improper disposal of household chemicals like cleaning agents, pharmaceuticals, and personal care products can contaminate water sources near residential areas.[50] Bees forage on nectar to produce honey, but if the nectar is contaminated due to polluted water sources, it can result in toxic honey, affecting the health of the hive and potentially harming consumers.[51] Bees may avoid polluted water sources, reducing their access to essential hydration and affecting their ability to forage for nectar and pollen.[52] Continuous exposure to contaminated nectar and water can weaken the immune systems of bees, making them more susceptible to diseases and other environmental stressors.[23] Implementing stringent laws and regulations to protect water sources from pollution is essential. Proper waste disposal, wastewater treatment, and responsible agricultural practices can significantly contribute to mitigating water pollution.[53] Educating communities about the adverse effects of water pollution on honey bees can encourage responsible behaviour and promote better waste management and pollution control.[54] Continued research into developing bee-friendly water sources and designing filtration systems that can remove pollutants from water accessed by bees can be crucial in mitigating this issue.[55] Addressing water pollution and its impact on nectar sources for honey bees is pivotal to ensuring a healthy bee population and sustaining the essential role they play in pollination and ecosystem health.

Plastic pollution and hive contamination

Plastic pollution has become a global environmental concern, affecting various ecosystems, including the delicate balance of honey bee habitats. The presence of plastic debris in bee habitats can have detrimental effects on honey bee colonies and their health. Bees may mistake small plastic particles for food. When plastic debris is present in their foraging areas, bees may collect and ingest it, assuming it to be pollen or nectar. This can lead to gastrointestinal blockages, malnutrition, and even death. Plastic ingestion can weaken bees and make them more susceptible to diseases and predation.[45] Plastic pollution is not limited to bee-foraging areas. Plastic waste can also find its way into beehives, either through bees accidentally carrying plastic fragments back to the hive or through contaminated water sources.[56] Once inside the hive, plastics can disrupt the hive's natural processes and have long-lasting negative effects on bee health.[57] Plastics can release harmful chemicals into the environment, especially when exposed to sunlight. These chemicals, including additives and plasticizers, can leach into the soil and water, potentially contaminating the nectar and pollen that bees collect. When bees consume contaminated resources, it can compromise their immune systems and overall health.[45] Larger plastic items can obstruct the entrances to beehives, making it difficult for bees to enter and exit. This obstruction can disrupt the daily activities of bees, including foraging and communication, and may lead to colony stress.[57] Microplastics, tiny plastic particles smaller than 5mm in size, are of particular concern. They can be found in soil, water, and even air. Bees may inadvertently pick up microplastics when foraging, and these particles can accumulate in their bodies over time, potentially leading to health issues.[56]

Metal pollution

Metal pollution in honey bees is a concerning environmental issue that can have adverse effects on both bee health and the ecosystem. Honey bees can accumulate heavy metals from the environment due to their foraging habits [58]. Researchers have found that bees can collect heavy metals such as lead (Pb), cadmium (Cd), and zinc (Zn) from contaminated flowers and soil.[59] Heavy metal pollution can negatively affect bee health. Studies have shown that exposure to heavy metals can lead to impaired foraging behaviour, reduced lifespan, and weakened immune responses in honey bees.[60] The primary sources of metal pollution in honey bee environments include industrial activities, agricultural practices (e.g., pesticide use and irrigation with contaminated water), and urbanization. Additionally, natural sources such as volcanic activity can also contribute to metal contamination.[61] Researchers use various biomarkers to assess metal pollution in honey bees, including the measurement of metal concentrations in bee tissues (e.g., gut, fat bodies) and the analysis of metal-related enzymes and proteins.[58] These biomarkers help gauge the extent of metal bioaccumulation and its effects on bee physiology.[62]

The Cumulative Impact of Pollution on Bee Health

Pollution, in its various forms, has emerged as a significant threat to bee populations worldwide. While individual instances of pollution may seem manageable, the cumulative impact on bee health can be devastating. This note delves into the multifaceted aspects of pollution and its adverse effects on these vital pollinators.

- **Synergistic Effects:** Different types of pollution often interact, exacerbating their individual effects. For instance, pesticides in combination with air pollution can weaken bee immune systems, making them more susceptible to diseases.[63]
- **Sublethal Effects:** Pollution can have sublethal effects on bees, meaning that it may not directly kill them but can compromise their overall health. These sublethal effects can include reduced foraging efficiency, impaired reproduction, and increased vulnerability to parasites.[64]
- **Long-Term Consequences:** The cumulative impact of pollution can have long-term consequences for bee populations. Weakened and stressed colonies are less likely to survive the challenges of disease, extreme weather events, and habitat loss.[65]

Climate Change

Climate change has a significant impact on honeybee foraging patterns and flowering plant availability. Changes in temperature, precipitation patterns, and overall climatic conditions can affect the timing, abundance, and distribution of flowering plants, which in turn can impact honeybee foraging behaviour and nutrition. Climate change alters the timing of seasons, leading to shifts in the timing of flowering (phenology) of plants. Rising temperatures can advance the onset of spring, causing flowering plants to bloom earlier. Honeybees have evolved their foraging patterns to align with the availability of nectar and pollen from flowering plants. Changes in flowering phenology can disrupt this synchrony, affecting the availability of forage for honeybees.[66] Changes in climate may result in shifts in the distribution and geographic ranges of plant species. Some plants may become more prevalent in certain areas due to changing temperature and precipitation patterns, while others may decline or disappear. These shifts can affect the variety and abundance of forage available to honeybees .[67] Climate change can alter the nutritional composition of nectar and pollen. Changes in temperature and rainfall can influence the concentration of sugars, amino acids, and other essential nutrients in flowers. This altered nutritional quality can impact the health and productivity of honeybee colonies, affecting their ability to sustain the colony and pollination activities.[68] Climate change can lead to more frequent and intense extreme weather events, such as droughts, floods, and storms. These events can damage flowering plants, disrupt honeybee foraging activities, and reduce the availability of forage. The resulting food shortages can have adverse effects on honeybee colonies .[6] Understanding these climate change-induced effects on honeybee foraging patterns and flowering plant availability is crucial for implementing adaptive strategies to support bee populations and maintain pollination services, which are vital for agriculture and ecosystem health.

Effects of Changing Temperatures

Honeybee foraging behavior is influenced by temperature. Warmer temperatures can lead to increased foraging activity, as bees can maintain optimal body temperatures for flight. Conversely, extreme heat can also limit foraging, as it becomes energetically costly for bees to regulate their body temperature while foraging.[69] Temperature plays a critical role in the development and reproduction of honeybees. Higher temperatures generally accelerate the development of honeybee larvae, shortening the time from egg to adult emergence. This can impact the overall population dynamics and productivity of the colony.[70] Winter temperatures are critical for honeybee colonies' survival and overwintering success. Warmer winters may disrupt the bees' ability to enter a proper state of winter dormancy (diapause), potentially leading to increased energy consumption and colony losses.[71] Extreme heat events can lead to heat stress in honeybee colonies. Honeybees employ thermoregulatory behaviours to maintain optimal brood and colony temperatures. However, prolonged exposure to high temperatures can disrupt this thermoregulation and stress the colony.[72] Changing temperatures may alter the geographic distribution of honeybee populations. Bees may adapt to changing climates over time through evolutionary processes, potentially affecting their physiology, behaviour, and life cycles.[73] Understanding the intricate relationship between changing temperatures and honeybee physiology is crucial for developing effective conservation and management strategies to ensure the health and sustainability of honeybee populations, which are vital for pollination and ecosystem health.

Climate Change and Honeybee Declines

Climate change, characterised by rising global temperatures and an increased frequency of extreme weather events, can have detrimental effects on honeybee health. Higher temperatures can stress honeybee colonies and affect their foraging behaviour, flight activity, and overall productivity .[6] Climate change can alter the timing and availability of flowering plants, impacting the synchrony between bees and their food sources. Shifts in floral phenology can lead to a mismatch between the timing of flowering and the presence of bee populations.[74] Climate change-induced droughts can reduce the availability of water sources for honeybees, affecting their ability to maintain hive temperature and humidity, potentially leading to weakened colonies and increased mortality.[75] Climate change can also influence the geographic distribution of plants and subsequently affect honeybee foraging patterns. Bees may need to travel longer distances to find suitable forage, leading to increased energy expenditure and potential nutritional stress.[73] It's important to note that climate change is a complex and multifaceted issue, and its impact on honeybees is influenced by various interacting factors, including habitat loss, pesticide exposure, diseases, and more. Ongoing research is crucial to fully understanding the implications of climate change on honeybee declines and to developing strategies to mitigate these impacts. For the latest and most comprehensive information, please refer to the latest scientific literature and journals in the fields of entomology and climate science.

Invasive Species and Pathogens

The introduction of invasive species is a significant concern for honeybees and other pollinators. Invasive species can outcompete native species for resources such as food, habitat, and nesting sites. Competition for resources can lead to changes in ecosystems and have detrimental effects on local biodiversity, including honeybee populations. The European paper wasp (Polistes dominula) is an invasive species in North America and other regions. It competes with honeybees for nectar and other food sources. They may also prey on honeybees and other pollinators, further impacting their populations.[76] The Asian giant hornet (Vespa mandarinia), also known as the "murder hornet," is an invasive species in North America. They are known to attack and kill honeybees, and they can decimate honeybee colonies. This predation can cause significant disruptions in honeybee populations and honey production.[77] Argentine ants (Linepithema humile) are invasive in many parts of the world. They compete with honeybees for floral resources and may also interfere with the foraging behaviour of honeybees, affecting their ability to collect food.

Invasive plant species can often outcompete native plants for pollinators like honeybees. These plants may produce an abundance of nectar and pollen, attracting honeybees away from native plants. This can disrupt pollination dynamics and impact the reproduction of native plants. For instance, invasive plant species such as purple loosestrife (Lythrum salicaria) and spotted knapweed (Centaurea maculosa) have been known to compete with honeybees for nectar and pollen resources.[78] They may consume or deplete resources that are critical for honeybee survival, such as water sources. For example, invasive fish species like the European carp (Cyprinus carpio) can disrupt aquatic ecosystems by consuming aquatic vegetation that provides habitat for native bee species.[79] Some invasive species can act as vectors for diseases that can harm honeybee populations. For instance, the Varroa destructor mite, which is native to Asia but has become invasive in many parts of the world, can transmit viruses that can devastate honeybee colonies.[80] While some invasive animals, such as certain ant species or other insects, can directly compete with honeybees for food resources or prey upon honeybee colonies, disrupting their foraging and nesting activities[81], Invasive pollinators, such as the European honeybee (Apis mellifera) in regions where it is non-native, can compete with native pollinators, including wild bees, for floral resources. This can have implications for crop pollination, as native bees may be displaced or face increased competition for nectar and pollen resources.[18]

The introduction of invasive species that compete with honeybees for resources can disrupt ecosystems, affect native plant and animal species, and have economic implications, particularly in agriculture, where honeybees are crucial for pollination. Managing and controlling invasive species is essential to mitigating these impacts and protecting honeybee populations and the ecosystems they support. Invasive species can disrupt ecosystems and affect the delicate balance of native flora and fauna .[76] Efforts to mitigate the impact of invasive species on honeybees and other pollinators include monitoring and management strategies to control and eradicate invasive species, habitat restoration for native species, and public awareness campaigns about the importance of protecting native biodiversity. The introduction of invasive species that compete with honeybees for resources can have significant ecological and economic consequences.[80] Invasive species are non-native organisms that, when introduced to a new environment, can outcompete native species for resources like food, water, and habitat. When invasive species compete with honeybees, it can disrupt local ecosystems and impact agriculture and biodiversity. Here are some examples to discuss this issue:

Nosema And Varroa: The Destructor Mites

Pathogens, including Nosema and Varroa destructor mites, can have a significant negative impact on honeybee health. These pathogens can weaken honeybee colonies, reduce their ability to forage for food, and ultimately lead to colony collapse. Nosema is a microsporidian parasite that infects the gut of honeybees. Two species of Nosema are commonly found in honeybees: Nosema apis and Nosema ceranae. Nosema infection damages the lining of the honeybee gut, leading to reduced nutrient absorption. This can result in malnutrition and reduced overall colony health. Infected bees often have a shorter lifespan compared to healthy bees. Diseased bees may spend more time foraging for food due to their reduced nutrient absorption, which can lead to decreased colony productivity.[82] Varroa destructor Mites are external parasites that attach to honeybees and feed on their bodily fluids. They are a major threat to honeybee colonies worldwide. They weaken honeybees by feeding on their hemolymph (a fluid similar to blood). This weakens the bees' immune system and makes them more susceptible to other pathogens. The mites can also physically damage bees by feeding on them and can transmit various viruses while feeding. The mites also reproduce within honeybee brood cells, which can lead to deformed or weakened bees emerging from these cells. If left untreated, varroa infestations can cause significant colony decline and even colony collapse.[80] Both Nosema and Varroa destructor mites are considered major stressors for honeybee populations. They can weaken individual bees and entire colonies, making them more susceptible to other stressors like pesticides and environmental factors. Effective management and control measures are crucial to mitigating the negative impact of these pathogens on honeybee health and overall colony survival.

Nutritional Stress

Monoculture Farming

In monoculture farming, large expanses of land are often planted with a single crop species. This uniformity leads to a significant reduction in floral diversity within the farming landscape. Honeybees rely on a variety of flowering plants for nectar and pollen. When only one type of crop is cultivated over extensive areas, the availability of diverse floral resources decreases.[19] Monoculture crops tend to bloom for a limited period, often synchronously with their growth cycle. After the flowering period of a monoculture crop ends, honeybees lose access to nectar and pollen until the next crop within their foraging range blooms. This can result in periods of food scarcity for honeybee colonies. [83] Different plant species offer varying types and qualities of nectar and pollen. Monoculture farming practices limit the nutritional diversity of forage available to honeybees. This can lead to suboptimal nutrition and health issues in bee populations, as they may not receive a balanced diet with essential nutrients.[84] This farming often involves the heavy use of pesticides, which can have detrimental effects on honeybees. Pesticides can contaminate the nectar and pollen of crops, further limiting the availability of safe and nutritious forage for honeybees.[85] Such farming practices can result in habitat fragmentation, reducing the availability of natural areas with diverse floral resources. This fragmentation can limit honeybees' access to a variety of forage plants that may have otherwise been present in non-agricultural landscapes.[86] In short, we can say that monoculture farming practices can limit honeybees' access to diverse nectar and pollen sources by reducing floral diversity, creating temporal limitations in forage availability, limiting nutritional diversity, exposing bees to pesticides, and contributing to habitat fragmentation. These factors can have adverse effects on honeybee health and contribute to pollinator decline in agricultural landscapes.

Importance of Floral Diversity

Floral diversity is of utmost importance for honeybee nutrition, as it directly influences the availability of diverse and balanced food sources for these crucial pollinators. Different floral species produce nectar and pollen with varying nutrient compositions. A diverse range of flowers provides honeybees with a wider spectrum of nutrients, including carbohydrates, proteins, vitamins, and minerals. This diversity is essential for the bees to obtain a well-rounded and balanced diet.[23] Floral diversity ensures honeybees have access to diverse protein sources. Pollen is the primary source of protein for honeybees, and different plant species offer varying protein levels and amino acid profiles. A lack of protein diversity can lead to nutritional stress in bee colonies.[87] Floral diversity also plays a role in ensuring a consistent food supply throughout the seasons. Bees rely on a succession of blooming flowers to maintain their colonies year-round. A diverse range of flowering plants helps bridge nutritional gaps during different seasons.[6] Various plant species produce phytochemicals and secondary metabolites in their nectar and pollen. These compounds can have health-promoting or protective effects on honeybees, contributing to colony health and resilience.[88] A diverse range of floral resources encourages honeybees to exhibit foraging behaviours that maximise resource collection efficiency. Bees will select flowers based on their nutritional content, which helps optimise their nutrient intake.[89] Floral diversity can contribute to the resilience of honeybee populations by reducing their vulnerability to environmental stressors, such as pesticide exposure or habitat loss. A diverse diet may enhance the bees' ability to withstand such challenges.[90] Thus, floral diversity is essential for honeybee nutrition as it provides a range of nutrients, protein sources, and seasonal stability in their diet. It also contributes to the overall health and resilience of honeybee populations. Conservation efforts aimed at preserving diverse floral habitats are crucial for the well-being of honeybees and the ecosystems they support.

Nutritional Stress Faced by Honeybees

Nutritional stress in honeybees in agricultural landscapes is a significant concern because it can impact the health and survival of bee colonies. Large-scale monoculture farming practices often limit the diversity of available floral resources. Bees rely on a variety of nectar and pollen sources for balanced nutrition.[9] In monoculture settings, bees may have limited access to a diverse diet, leading to nutritional stress. Nutritional stress can vary throughout the year, as different crops bloom at different times. Bees may have access to abundant forage during certain periods but face scarcity during others, potentially leading to imbalances in their diet. The use of pesticides in agriculture can indirectly affect bee nutrition.[91] Pesticides can reduce the availability of nectar and pollen by harming flowering plants. Additionally, pesticide residues in nectar and pollen can be toxic to bees and impact their overall health. The conversion of natural landscapes into agricultural areas reduces the availability of wildflowers and other native plants that are essential for bee nutrition. Loss of natural habitats can limit the diversity of forage sources. Some beekeepers and researchers have explored the use of nutritional supplements, such as sugar water or protein supplements, to provide bees with additional nutrition when natural forage is limited.[92] These supplements can help mitigate nutritional stress, especially during periods of scarcity. Changing climate patterns can affect the timing and availability of flowering plants. Bees may face challenges in synchronising their foraging behaviour with shifting bloom times, which can impact their nutritional intake. Some research has also examined the genetic and physiological adaptations of honeybees to different nutritional conditions.[4] Bees may exhibit preferences for certain types of nectar or pollen, and their ability to digest and utilise different resources can vary.

Human Interventions and Conservation Efforts

Efforts to mitigate anthropological threats to honeybee ecology are crucial for the health and sustainability of honeybee populations. These efforts involve various strategies and actions aimed at reducing or eliminating the negative impacts of human activities on honeybees. Here are some key mitigation efforts to support them.

Pest Management

Promoting IPM practices that minimise pesticide use and encourage the use of less harmful alternatives. This approach is supported by research showing that reduced pesticide exposure benefits honeybee health.[93] Neonicotinoid

Restrictions: banning or restricting the use of neonicotinoid pesticides, which have been linked to honeybee colony declines.[94] Here are some international agencies working to mitigate the exposure to pesticides. Regulatory responses and bans on certain pesticides for the sake of honey bees have been implemented in several countries due to concerns about their impact on bee populations. The decline in honey bee populations has raised concerns globally, leading to regulatory responses and bans on certain pesticides. Here are some examples of regulatory actions and bans related to pesticides for the sake of honey bees: Several regulatory agencies around the world have acted to restrict or ban certain pesticides to protect honey bees and other pollinators.

- **European Food Safety Authority (EFSA):** The EFSA has played a significant role in evaluating the risks associated with pesticides for honey bees and other pollinators. They have recommended restrictions and bans on specific neonicotinoid pesticides, such as clothianidin, imidacloprid, and thiamethoxam, for outdoor use due to their potential harm to bees. These restrictions were enacted under the EU's "Bee Guidance Document."
- **U.S. Environmental Protection Agency (EPA):** The EPA has taken steps to restrict the use of neonicotinoid pesticides, particularly in response to concerns about their impact on pollinators. While not a complete ban, the EPA has imposed limitations on the use of certain neonicotinoid products and required additional label warnings to protect pollinators.
- **Canadian Pest Management Regulatory Agency (PMRA):** The PMRA has implemented restrictions on neonicotinoid pesticides, including clothianidin and thiamethoxam, to protect honey bees and other pollinators. These restrictions include changes to application methods and limitations on use in certain crops.
- **Australian Pesticides and Veterinary Medicines Authority (APVMA):** The APVMA has also evaluated and regulated the use of neonicotinoid pesticides in Australia, considering their potential impact on bees and other pollinators. Regulatory measures have been put in place to mitigate risks.
- **European Union (EU):** The European Union has banned the use of several neonicotinoid pesticides, including clothianidin, imidacloprid, and thiamethoxam, for outdoor use due to their potential harm to pollinators, including honey bees. This ban was implemented in 2013 and has been extended and expanded upon in subsequent years.
- **United Kingdom:** The UK has implemented restrictions on neonicotinoid pesticides, aligning with the restrictions imposed by the EU even after Brexit.
- **India:** India has imposed restrictions on the use of several neonicotinoid pesticides to protect pollinators, including honey bees.
- **New Zealand:** New Zealand has restrictions and guidelines in place for the use of neonicotinoid pesticides, with a focus on minimizing their impact on honey bees and other pollinators.
- **Brazil:** In 2019, Brazil's National Health Surveillance Agency (ANVISA) banned the use of the neonicotinoid pesticide thiamethoxam for the 2019/2020 growing season due to concerns about its impact on bees.

These are just a few examples, and many other countries and regions have also acted to regulate or ban certain pesticides to safeguard honey bees and other pollinators. Keep in mind that pesticide regulations can change over time, so it's essential to stay updated with the latest information from the relevant regulatory agencies and organizations.

Habitat Conservation

Honeybee populations have been facing significant threats in recent years, including habitat loss and degradation. Mitigating these anthropogenic threats to honeybee ecology is crucial for the health of not only honeybee populations but also for the broader ecosystem, as honeybees play a vital role in pollinating many of our crops and wild plants. One of the key strategies to mitigate these threats is habitat conservation. It Encourage individuals, communities, and organisations to plant pollinator-friendly gardens with a variety of native flowering plants. Choose plants that provide nectar and pollen sources throughout the year, creating a continuous food supply for honeybees. And avoid the use of pesticides and herbicides in these gardens to protect bee health.[1] To restore and protect natural habitats such as meadows, prairies, and wildflower fields, which provide essential forage for honeybees. And remove invasive species that can outcompete native plants that are important food sources for bees. Encourage and regulate urban beekeeping to ensure that cities can provide suitable habitats for honeybees and establish guidelines for responsible beekeeping practices in urban areas to prevent conflicts with residents.[6] Support and establish conservation easements and land trusts to protect natural areas from development. These initiatives can preserve honeybee habitats and ensure they remain intact for future generations. It promotes sustainable farming practices that include cover cropping, reduced pesticide use, and maintaining natural vegetation in and around agricultural fields.[2] Farmers create buffer zones of wildflowers and native plants around farmland to provide additional forage for honeybees. Scientists Invest in research to better understand honeybee habitat needs and how to enhance and protect these habitats. And monitor honeybee populations and the health of their habitats to assess the effectiveness of conservation efforts. It is to raise awareness about the importance of honeybees and their habitat conservation among the general public, policymakers, and landowners, and educate people about the role of honeybees in pollination and the consequences of habitat loss.[3] We need to advocate for government policies that support habitat conservation efforts, such as providing incentives for landowners to maintain pollinator-friendly landscapes. These efforts to conserve honeybee habitats are crucial for ensuring the continued health and stability of honeybee populations, which, in turn, helps support food security and biodiversity.

Disease Management

Disease management is a critical effort in mitigating anthropological threats to honeybee ecology. Honeybees (Apis mellifera) are essential pollinators for many crops, and their decline due to various factors, including diseases, can have far-reaching ecological and economic consequences. Varroa mites are one of the most devastating parasites affecting honeybee colonies.[80] They weaken bees by feeding on their hemolymph and transmitting various viruses. Effective management strategies, such as chemical treatments, integrated pest management (IPM) approaches, and breeding for Varroa resistance, have been developed to combat this threat. Nosema is a fungal parasite that infects the digestive tracts of honeybees. It can lead to reduced foraging efficiency and colony losses. Managing nosema infections involves sanitation practices, fumagillin treatments, and genetic selection for resistant bees.[95] Bacterial diseases like American Foulbrood (AFB) and European Foulbrood (EFB) can decimate bee colonies. Management strategies include early detection, quarantine, and destruction of infected hives to prevent the spread of the diseases.[96] Pesticides, including neonicotinoids, have been linked to honeybee health issues. Integrated pest management (IPM) practices promote reduced pesticide use and alternative pest control methods, helping mitigate the impact on honeybee populations.[8] While not a direct disease management approach, preserving natural habitats and providing a diverse range of forage resources helps strengthen bee immunity and resilience to diseases. Maintaining healthy ecosystems supports bee health.[97] Providing education and training to beekeepers on best management practices, disease identification, and appropriate treatment methods is crucial to preventing, detecting, and managing diseases effectively.[98] Continued research on bee diseases, their epidemiology, and the impact of anthropological factors on disease dynamics is essential. Regular monitoring of bee populations and disease prevalence helps in understanding disease trends and making informed management decisions.[99] By implementing these disease management strategies and incorporating research-based approaches, we can work towards mitigating the anthropological threats to honeybee ecology and safeguarding their vital role in pollination and ecosystem health.

Education and Public Awareness

Mitigating anthropological threats to honeybee ecology involves a multi-faceted approach, and education and public awareness are crucial components. Anthropological threats primarily stem from human activities and can include pesticide use, habitat loss, monoculture farming, climate change, and the introduction of invasive species. Education and public awareness efforts can help address these threats, including some educational programmes such as teaching integrated honeybee ecology and the importance of pollinators into school curricula at various levels.[100] Educate students on the role of honeybees in ecosystems, agriculture, and biodiversity. Organise workshops, seminars, and webinars to educate farmers, beekeepers, policymakers, and the general public about honeybee ecology, their significance, and the threats they face. Develop online courses, videos, and interactive platforms to provide accessible and comprehensive information about honeybee ecology and conservation measures. Various public awareness campaigns may be helpful. Utilising television, radio, newspapers, and social media to disseminate information about the importance of honeybees, their declining populations, and actions that individuals and communities can take to support their conservation. Engage in community events, fairs, and exhibitions to raise awareness about honeybee conservation. Offer demonstrations and interactive activities to illustrate the crucial role honeybees play in our food systems.[85] Partner with non-governmental organisations and conservation groups to reach a wider audience and coordinate awareness campaigns effectively. Citizen Science Initiatives such as Bee Monitoring Programmes to Encourage citizens to participate in bee monitoring programmes, providing valuable data on honeybee populations and distribution and contributing to research efforts. Community Gardens and Bee-Friendly Planting: to encourage individuals and communities to plant bee-friendly gardens and create habitats that support pollinators, educating them on the importance of diversifying plant species. Policy advocacy and lobbying Conducting advocacy workshops can help train sessions to educate stakeholders and interested individuals on policy issues affecting honeybee ecology.[4] Empower them to advocate for policies that promote honeybee conservation and sustainable farming practices. And Engagement with policymakers to advocate for regulations that promote responsible pesticide use, habitat preservation, and sustainable agriculture, with a focus on honeybee protection. Collaborate with agricultural organisations to educate farmers on sustainable and bee-friendly farming practices that minimise the use of harmful pesticides and support honeybee habitats. Establish certification programmes for bee-friendly agricultural products, encouraging farmers to adopt practices that protect honeybee populations and their ecosystems.

Research and Innovation

Research and innovation play a crucial role in mitigating anthropological threats to honeybee ecology. Honeybees are essential pollinators that contribute to the global food supply and ecosystem health. However, they face numerous challenges, including habitat loss, pesticide exposure, disease, and climate change. To address these threats, scientists, researchers, and innovators have been working on various strategies and solutions. As Researchers are developing alternative pest control methods and encouraging the use of environmentally friendly pesticides. For instance, neonicotinoid pesticides have been linked to honeybee declines, and studies like "Agricultural landscape and pesticide effects on honeybee biological traits by Henry, M. et al. (2012) have highlighted these concerns.[38] Innovative approaches like the use of biological control agents, such as beneficial insects, to combat pests in agricultural settings are being explored .[101] Biological Control for Honey Bee Pathogens. Efforts to restore and enhance bee-friendly habitats, such as wildflower meadows and native plant gardens, can provide honeybees with diverse foraging resources. Research like "The conservation of native bees: are organic farming and planting wildflowers enough?" by Morandin et al. (2006) emphasises the importance of such initiatives .[102] Innovative technologies like remote sensing and GIS (geographic information systems) are being used to identify suitable locations for habitat restoration.[90]"Agricultural landscapes and pollinator conservation in Kenya" Research into honeybee diseases, such as Nosema and Varroa mites, is ongoing. Studies like "Varroa destructor: A Complex Parasite, Crippling Honey Bees Worldwide" by Rosenkranz et. al. (2010) delve into the impact of Varroa mites on honeybee health.[80] Innovations in genetic breeding and breeding programmes for disease-resistant honeybee populations are being explored.[103] "A Selective Sweep in the Varroa Destructor Mite Is a Potential Barrier to Host Adaptation in Its European Honeybee Host".

Research is focused on understanding how climate change affects honeybee distribution and behavior. Studies like "Climate change impacts on bumblebees converge across continents by Kerr et. al. (2015) highlight these concerns.[73] Innovations include the development of climate-smart agriculture practices that can help mitigate the effects of climate change on honeybee populations.[100]"Safeguarding pollinators and their values for human well-being" Engaging the public in beekeeping and citizen science initiatives can help raise awareness and gather valuable data. The "Great Sunflower Project" is an example of a citizen science effort focused on pollinators. Innovative educational tools and programmes are being developed to promote bee-friendly practices and increase public knowledge about honeybee ecology.[104] "The Bee SmartTM School Garden Kit: Impact and Implications for Bee Literacy" Researchers are developing technologies like remote hive monitoring and sensor networks to track hive health and behaviour in real-time.[105] "The Internet of Bees: Adding Sensors to Monitor Honey Bee Colonies" Innovations in diagnostic tools for detecting bee diseases and parasites are helping beekeepers and scientists identify issues early,[106] "Viruses of Honeybees"). These research and innovation efforts are essential for mitigating anthropological threats to honeybee ecology and ensuring the long-term survival of these vital pollinators. Technological Advances: Supporting research and innovation to develop technologies that aid beekeepers in hive management and monitoring bee health.[69] Investigating honeybee genomics to better understand their biology and potential genetic factors contributing to their health. Efforts to mitigate anthropological threats to honeybee ecology require collaboration among governments, researchers, beekeepers, and the general public. These actions are essential for the continued pollination services that honeybees provide and for safeguarding the global food supply.

Habitat Restoration and Conservation

Honeybees (Apis mellifera) play a crucial role in pollination and ecosystem health, making their conservation and habitat restoration essential for maintaining biodiversity and supporting agriculture. Anthropogenic threats such as habitat loss, pesticide exposure, climate change, and invasive species are significant challenges for honeybee ecology. Habitat restoration and conservation efforts can help mitigate these threats and promote a healthier environment for honeybees. Such as: Habitat Restoration and Creation by Planting Native Flowers and Vegetation: Restoring and creating habitats with diverse native flowers and vegetation can provide forage and nesting resources for honeybees. Native plants are adapted to the local ecosystem and can support a more robust and resilient honeybee population.[107] Preserving wild areas by conserving natural landscapes, such as forests, meadows, and wetlands, helps maintain healthy ecosystems and provides essential foraging areas and nesting sites for honeybees.[108] Integrated Pest Management (IPM) is another strategy to minimise pesticide use, and using bee-friendly alternatives can significantly reduce the exposure of honeybees to harmful chemicals .[41] Establishing habitats that are resilient to climate change and can support honeybees under changing environmental conditions is vital for long-term conservation efforts.[109] Raising awareness about the importance of honeybees and involving local communities in conservation efforts can lead to more support and engagement in habitat restoration initiatives.[6] By implementing these strategies and referencing the suggested articles, conservationists, policymakers, and individuals can contribute to the preservation of honeybee ecology, ensuring their continued contribution to pollination and ecosystem health.

Supporting Beekeepers

Supporting beekeepers is a crucial effort in mitigating anthropological threats to honeybee ecology. Honeybees play a vital role in pollinating a wide variety of crops and plants, contributing to global food security and biodiversity. However, honeybee populations have been declining in recent years due to various anthropogenic factors, including pesticide use, habitat loss, climate change, and the spread of diseases and pests.[41] Here are some key ways in which supporting beekeepers can help address these threats: by Encouraging beekeepers to adopt sustainable practices such as integrated pest management (IPM) and organic beekeeping can reduce the reliance on chemical pesticides that harm honeybees and other pollinators.[6] Offering training and educational resources to beekeepers can help them better understand bee health, disease prevention, and colony management techniques, ultimately leading to healthier honeybee colonies. Funding research into honeybee health, genetics, and breeding programmes can lead to the development of more resilient bee populations that are better equipped to withstand environmental stressors. Implementing practices to maintain clean hives and monitoring for diseases can help prevent the spread of pathogens that can devastate bee colonies. Beekeepers can work to preserve and create diverse forage habitats for honeybees, ensuring they have access to a variety of pollen and nectar sources throughout the year.[10] Collaborating with farmers and policymakers to implement measures that reduce pesticide exposure, such as using alternative pest control methods or adopting bee-friendly farming practices, Advocating for regulations that protect honeybees, such as banning or restricting the use of harmful pesticides, can significantly reduce anthropological threats.[19] Providing financial incentives or subsidies to beekeepers can help offset the costs associated with hive management and bee health initiatives. Implementing monitoring programmes to track honeybee populations, diseases, and environmental factors can help identify threats early and inform conservation efforts.[99] Engaging local communities in beekeeping and pollinator conservation initiatives can raise awareness and foster a sense of responsibility for honeybee health. Supporting beekeepers is a multifaceted approach that requires collaboration between beekeepers, scientists, policymakers, and the broader community. By addressing the anthropological threats to honeybee ecology through these measures, we can help safeguard honeybee populations and the critical ecosystem services they provide.

Policy and Regulation

Mitigating anthropological threats to honeybee ecology requires a comprehensive approach involving policy and regulation. Anthropological threats include habitat loss, pesticide exposure, climate change, invasive species, and diseases. Effective policies and regulations should aim to protect honeybee habitats, reduce pesticide use, promote sustainable agricultural practices, and enhance bee health. It is to implement policies to protect and restore natural habitats for honeybees, ensure adequate forage and nesting sites, and Encourage the planting of diverse native plants that support honeybee forage and nesting habitats.[10] Enforce stricter regulations on pesticide use, especially neonicotinoids and other harmful insecticides, to reduce their impact on honeybee health. Promote integrated pest management (IPM) practices to minimise pesticide usage and encourage alternative, eco-friendly pest control methods.[110] Encourage and incentivize farmers to adopt sustainable agricultural practices that minimise negative impacts on honeybees and other pollinators. Promote organic farming, agroforestry, and diversified crop rotations to enhance ecosystem resilience and support pollinator populations.[92] Develop educational campaigns to raise public awareness about the importance of honeybees and the threats they face, encouraging responsible actions to protect them. Collaborate with schools and community organisations to integrate bee ecology and conservation into curricula and community activities.[13] Fund and support research on honeybee diseases and parasites to develop effective disease management strategies. Implement regulations for beekeepers to monitor and manage disease and pest infestations, promoting biosecurity measures to prevent disease spread.[111] By integrating these policy and regulation efforts, we can work towards safeguarding honeybee ecology and, in turn, support global food security and biodiversity.

Climate Change Mitigation

Climate change poses significant threats to honeybee ecology, including altered foraging patterns, increased susceptibility to diseases and pests, and habitat loss. Mitigating these threats is crucial to ensuring the survival of honeybee populations, which are essential for pollinating many of our food crops and maintaining biodiversity. Some efforts may mitigate anthropological threats to honeybee ecology, such as reductions in greenhouse gas emissions as Climate change is primarily driven by the release of greenhouse gases into the atmosphere. Efforts to mitigate climate change through the reduction of emissions from human activities, such as burning fossil fuels and deforestation, can indirectly benefit honeybee populations. This includes transitioning to clean energy sources, improving energy efficiency, and reforestation efforts.[112] Promoting sustainable agriculture practices can help reduce the impact of climate change on honeybees.

Practices such as organic farming, reduced pesticide use, and crop rotation can enhance bee-friendly habitats and reduce exposure to harmful chemicals.[41] Restoring natural habitats and planting pollinator-friendly native plants can provide essential forage resources for honeybees. Creating wildflower meadows and hedgerows and maintaining diverse landscapes can help honeybees thrive in changing climates.[113] Continuous monitoring of honeybee populations and research into their behaviour, genetics, and response to changing climates are essential. This knowledge can inform conservation efforts and help breed honeybee varieties that are more resilient to environmental stressors.[6] Beekeepers can implement climate-resilient practices such as providing shade and water sources for their colonies during heatwaves, insulating hives in cold weather, and monitoring for signs of stress or disease.[114] Raising awareness about the importance of honeybees and their role in pollination is crucial. Encouraging individuals and communities to act to protect honeybees and their habitats can contribute to their conservation.[115] Governments can enact policies and regulations to protect honeybee habitats and reduce the use of pesticides harmful to pollinators. In the European Union, for example, neonicotinoid pesticides were banned due to their detrimental effects on bees.[116] Climate change and honeybee health are global issues, and international cooperation is vital. Collaborative efforts can include sharing best practices, research findings, and strategies for mitigating the impacts of climate change on honeybees.[19] By addressing climate change and its associated threats, we can contribute to the long-term survival and health of honeybee populations. These efforts are not only essential for honeybees but also for the overall health and sustainability of ecosystems and agricultural systems worldwide.

International Collaboration and Awareness

Encouraging international collaboration and information sharing on honeybee research, conservation strategies, and best practices to address threats on a global scale. Efforts to mitigate anthropological threats to honeybee ecology require a multi-faceted approach involving collaboration between governments, researchers, beekeepers, farmers, and the public. Ongoing monitoring, research, and adaptation of strategies are essential to effectively protecting honeybees and their vital role in ecosystems and agriculture. International collaboration and awareness are crucial components of efforts to mitigate anthropological threats to honeybee ecology. Honeybees play a vital role in global agriculture by pollinating a significant portion of our food crops, making their well-being essential for food security and ecosystem stability. However, honeybee populations worldwide have been declining due to a combination of factors, many of which are related to human activities. To address these threats effectively, it is imperative to work together on a global scale.

Pesticides, particularly neonicotinoids, have been linked to honeybee population declines. International collaboration involves sharing research findings, developing common guidelines, and coordinating efforts to regulate and reduce the use of harmful pesticides. The European Union, for example, banned certain neonicotinoids in 2018, a move that spurred discussions and actions in other countries .[10] The loss of natural habitats due to urbanisation and agriculture intensification is a significant threat to honeybees. International awareness campaigns can educate the public and policymakers about the importance of preserving wildflower-rich habitats and promoting sustainable land-use practices.[117] Collaboration can also facilitate cross-border efforts to restore pollinator-friendly landscapes. Honeybees face various diseases and pests that can decimate colonies. International collaboration is essential for sharing research on disease management strategies, monitoring the spread of diseases, and implementing coordinated efforts to control them.[38] Organisations like the World Beekeeping Association can serve as hubs for information exchange.[6] Climate change disrupts the natural cycles of flowering plants and can affect the availability of forage for honeybees. International agreements, such as the Paris Agreement, address climate change on a global scale, emphasising the need to reduce greenhouse gas emissions and adapt to climate-related challenges, which indirectly benefit honeybee ecosystems.[41] Maintaining genetic diversity in honeybee populations is vital for their resilience against environmental stressors. International collaboration can help in sharing breeding programmes and genetic resources to develop honeybee strains that are more resistant to diseases and environmental changes.[118] Raising public awareness is essential to garnering support for honeybee conservation efforts. International organisations and governments can work together to launch global awareness campaigns to educate the public about the importance of honeybees and the threats they face. International collaboration promotes the sharing of research findings, data, and best practices.[117] This collaborative approach allows scientists from different countries to work together to understand honeybee ecology better and develop effective conservation strategies.[38] International organisations like the United Nations and its specialised agencies, such as the Food and Agriculture Organisation (FAO), can play a pivotal role in developing global policies and guidelines to protect honeybee populations. International collaboration and awareness are essential to address the complex and interconnected challenges facing honeybee ecology. By working together, nations can develop more effective strategies to protect honeybees and ensure the sustainability of our food supply and ecosystems.

Promoting Sustainable Agriculture and Habitat Restoration

Promoting sustainable agriculture and habitat restoration is crucial for conserving biodiversity, maintaining ecosystem services, and addressing various environmental challenges. Many initiatives and organizations around the world are actively working towards these goals.

- **The United Nations Sustainable Development Goals (SDGs):** The SDGs include several targets related to sustainable agriculture and habitat restoration. For instance, Goal 2 focuses on ending hunger, achieving food security, improving nutrition, and promoting sustainable agriculture. Goal 15 aims to protect, restore, and promote sustainable use of terrestrial ecosystems, including forests.
- **The Convention on Biological Diversity (CBD):** CBD is an international treaty dedicated to conserving biodiversity. The Aichi Biodiversity Targets, adopted under CBD, include targets related to habitat restoration and sustainable agriculture.
- **The Sustainable Agriculture Network (SAN):** SAN is a global network of organizations promoting sustainable agriculture practices, including organic farming, fair labor practices, and the conservation of ecosystems.
- **The Global Environment Facility (GEF):** GEF provides funding and support for projects that aim to protect biodiversity, restore habitats, and promote sustainable agriculture.
- **The Nature Conservancy:** This organization works on various initiatives related to habitat restoration, sustainable agriculture, and protecting natural areas. They collaborate with governments, communities, and businesses.
- **The World Wildlife Fund (WWF):** WWF engages in projects around the world to promote sustainable agriculture and habitat restoration, with a focus on protecting endangered species.
- **The Rainforest Alliance:** This organization certifies sustainable agricultural practices and works to conserve biodiversity in tropical regions.
- **The United Nations Food and Agriculture Organization (FAO):** FAO supports sustainable agriculture through various programs and initiatives, including the promotion of agroecological practices.

Local and National Conservation Organizations

Many countries have their own conservation organizations and initiatives focused on sustainable agriculture and habitat restoration. For example, the National Wildlife Federation in the United States works on habitat restoration and conservation efforts. Reference: National Wildlife Federation. Promoting sustainable agriculture and habitat restoration is essential for maintaining biodiversity, conserving natural resources, and ensuring food security. Various initiatives and organizations around the world are actively working toward these goals.

- **The Sustainable Agriculture Research and Education (SARE) Program:** SARE is a U.S. Department of Agriculture (USDA) program that promotes sustainable farming practices through research and education.
- **The World Agroforestry Centre (ICRAF):** ICRAF works on agroforestry and sustainable land management to restore ecosystems and improve agricultural practices.
- **The Sustainable Agriculture Initiative (SAI) Platform:** SAI Platform is a global initiative that brings together organizations to promote sustainable agriculture practices in the food and beverage industry.
- **The United Nations Environment Program (UNEP) - Billion Tree Campaign:** UNEP's Billion Tree Campaign aims to combat deforestation and restore forests by planting billions of trees worldwide.
- **The Nature Conservancy's Agriculture Program:** The Nature Conservancy works with farmers and landowners to implement sustainable agriculture practices that benefit both nature and people.
- **The United Nations' Decade on Ecosystem Restoration (2021-2030):** The UN has declared this decade as the Decade on Ecosystem Restoration, with a focus on restoring degraded ecosystems, including agricultural lands.
- **The Organic Farming Research Foundation (OFRF):** OFRF supports and promotes organic farming practices through research and education.
- **The Global Ever Greening Alliance:** This alliance focuses on promoting practices like agroforestry, reforestation, and land restoration to combat desertification and improve land productivity.

These initiatives and organizations play a crucial role in advancing sustainable agriculture and habitat restoration by conducting research, implementing best practices, and raising awareness about the importance of balancing agricultural production with conservation efforts. They contribute to a more sustainable and resilient agricultural and environmental future

Future Research Directions

There were several gaps in our understanding of honey bees and areas requiring further research. It's important to note that scientific research is continuously evolving, and new studies may have emerged since then. Here are some key areas where further research is needed, such as colony collapse disorder (CCD), Although CCD garnered significant attention, the exact causes of this phenomenon were not completely understood. Researchers were investigating various factors, including pesticide exposure, pathogens, poor nutrition, and stressors, but more comprehensive and long-term studies were needed to pinpoint the primary causes and potential interactions among them.[41] The effects of pesticides, especially neonicotinoids, on honey bee health and behaviour require continued investigation. Understanding the sublethal effects of pesticides and how they interact with other stressors is crucial for developing sustainable agricultural practices.[8] The availability and quality of forage plants for honey bees is a critical factor in their health and survival. Research on the impact of land use changes, monoculture agriculture, and urbanisation on honey bee forage and nutrition was ongoing.[92] Climate change can disrupt honey bee foraging patterns and affect the timing of flowering plants. Research into how climate change impacts honey bee behaviour and distribution, as well as strategies for adaptation, is essential.[119] Understanding the genetic basis of honey bee disease resistance and the selective breeding of resistant honey bee populations was an area of ongoing research.[120] Developing comprehensive monitoring programmes to track honey bee health and population dynamics at regional and global scales was crucial for understanding trends and identifying emerging threats.[100] Research into sustainable farming practices that support honey bee and pollinator health, such as habitat restoration, crop diversification, and reduced pesticide usage, was ongoing.[121] Understanding the long-term impacts of beekeeping practices, such as migratory beekeeping and supplemental feeding, on honey bee populations and colony health was an area of interest .[41] These areas represent some of the gaps in honey bee research as of 2021. Given the critical role honey bees play in pollination and food production, ongoing research is vital to protect and support honey bee populations in the face of various threats. Researchers continue to work on these and related topics to expand our knowledge of honey bees and improve their conservation.

Several innovative solutions and technologies have been proposed or developed to help conserve honeybees. Nevertheless, there may have been further advancements and developments in bee conservation since that time, so I would like to recommend checking the most recent scientific literature and conservation initiatives for the latest information, such as implementing precision agriculture techniques to reduce the use of pesticides and herbicides while maintaining crop yields. Promoting pollinator-friendly farming practices such as creating wildflower strips and hedgerows.[122] Using sensors and data analytics to monitor hive conditions, including temperature, humidity, and disease outbreaks. These technologies can help beekeepers take timely actions to prevent hive losses.[123] Studying the honeybee genome to understand genetic factors that contribute to resilience against diseases and environmental stressors. This information can inform breeding programmes for more robust honeybee colonies[124] Developing and using biopesticides and natural predators to control pests that affect honeybee colonies reduces the need for chemical pesticides.[91] Engaging citizen scientists to monitor bee populations and health, contributing to data collection and research efforts. Promoting hive sharing programmes where individuals or organisations maintain beehives helps increase bee populations.[125] and last but not least, encouraging the planting of gardens with diverse, bee-friendly plants to provide forage and habitat for bees.[126] These are just a few examples of potential solutions and technologies for honeybee conservation. Advancements in research and technology continue to play a vital role in understanding and addressing the challenges facing honeybee populations.

Interdisciplinary Research

Interdisciplinary research is crucial for gaining a comprehensive understanding of honeybee ecology, as it allows scientists from different fields to combine their expertise and approaches to study the complex interactions within honeybee colonies and their broader ecological context. Interdisciplinary research involving entomologists, behavioural ecologists, physiologists, and geneticists can provide insights into honeybee behaviour, physiology, and genetics. Understanding aspects such as foraging behaviour, communication, reproductive strategies, and immune responses is vital for comprehending how honeybee colonies function and adapt to their environment.[127] Ecologists, environmental scientists, and toxicologists can shed light on the influence of environmental factors such as pesticides, climate change, and habitat loss on honeybee health and populations. This knowledge is crucial for developing effective conservation and management strategies.[6] Collaboration between ecologists, agronomists, and economists can evaluate the contribution of honeybees to pollination and, consequently, agricultural productivity. Understanding the economic and ecological value of honeybee pollination helps in making informed decisions about sustainable agricultural practices.[93] The teamwork of microbiologists, veterinarians, and entomologists is critical for studying honeybee diseases and pathogens. This interdisciplinary approach can lead to the development of strategies for disease management and prevention, ultimately promoting honeybee health.[111] Integration of expertise from engineers, data scientists, and mathematicians can lead to the development of advanced technologies, such as remote sensing and tracking devices, and innovative data analysis techniques. These tools enable researchers to gather and analyse large-scale data to better understand honeybee behaviour, movement, and environmental interactions.[56]

Interdisciplinary research is crucial in understanding honeybee ecology because honeybee behaviour, health, and overall ecology are complex and multifaceted. A holistic approach that combines insights from various scientific disciplines can provide a more comprehensive understanding of honeybee ecology. Here are some key points highlighting the importance of interdisciplinary research in this context. Since Honeybee colonies interact with a wide range of biotic and abiotic factors, including plants, other pollinators, pathogens, pesticides, and environmental conditions. Understanding these complex interactions requires expertise from multiple fields such as biology, entomology, botany, and ecology.[19] Honeybees are essential pollinators for many crops, contributing significantly to agricultural productivity. Interdisciplinary research is needed to study how honeybee ecology influences crop yield and food security.[9] The health of honeybee colonies is influenced by factors like pathogens, pesticides, nutrition, and genetics. Collaborative research between biologists, veterinarians, and chemists is crucial to understanding the dynamics of honeybee diseases and developing effective management strategies.[111] Honeybee behavior, including foraging, navigation, and communication, is influenced by a combination of genetic, physiological, and environmental factors. Insights from fields like behavioural ecology, neurobiology, and genetics are essential to unravelling the intricacies of honeybee behaviour.[127] Understanding how honeybees respond to changes in their environment, including urbanisation and climate change, requires input from ecologists, climatologists, and urban planners.[128] Interdisciplinary research informs conservation efforts and policy decisions related to honeybee management and protection. Collaboration between scientists, policymakers, and stakeholders is essential for effective conservation strategies.[6] Honeybee ecology is a multifaceted field, and interdisciplinary research is necessary to gain a comprehensive understanding of honeybee behaviour, health, and their role in ecosystems and agriculture. Collaboration among experts from various disciplines is key to addressing the challenges facing honeybees and ensuring their continued contribution to pollination and biodiversity.

Conclusion

Honeybees play a crucial role in pollinating a wide range of crops and are integral to global food security. However, they face numerous stressors, both natural and human-induced, that are impacting their health and survival. The extensive use of neonicotinoid and other pesticides has been linked to bee mortality and colony collapse disorder. Regulations and alternative pest management strategies are essential to mitigating this threat. Urbanisation, agriculture, and land-use changes have led to the loss of foraging habitats and nesting sites for honeybees. Conservation efforts and habitat restoration are vital to addressing this issue. Changes in climate patterns affect bee foraging and plant phenology, potentially disrupting the timing and availability of food sources. Adapting beekeeping practices and promoting climate mitigation measures are necessary. Honeybees are susceptible to various diseases, including nosema and varroa mites. Integrated pest management and genetic breeding for resistance are critical to bee health. Poor nutrition due to monoculture farming and limited floral diversity can weaken honeybee colonies. Promoting diverse forage sources and sustainable agriculture is essential. The global trade in bees and bee products can introduce diseases and pests to new regions. Strong biosecurity measures are needed to prevent the spread of these threats. Ongoing research is essential to monitor and understand emerging threats to honeybee ecology, including the potential impacts of new technologies and pollutants. The preservation of honeybee populations and their vital role in pollination requires a holistic approach involving cooperation among scientists, beekeepers, policymakers, and the public. Efforts to mitigate anthropogenic threats, conserve habitats, promote sustainable agriculture, and support research will be crucial in ensuring the continued well-being of honeybee populations and the ecosystems they support.

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Disclosure of conflict of interest

The author of this article declares that he has no conflicts of interest that could potentially influence the results or interpretations presented herein.

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