HONEYBEE IN ECOSYSTEM: STUDY OF THEIR ECOLOGICAL ROLES AND ENVIRONMENTAL INTERACTION

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Abstract
Honeybees are necessary for maintaining agricultural yield and balance in the environment. In this review article the classification of honeybees, their habitats and distribution in the geographical regions are being explored. Honeybees have a crucial role in the natural process of pollination and facilitates plants in reproduction and long-term soil fertility. Honeybees also have a key role in maintaining food chains and they also affect both wild territory and conserved areas. Biotic components like pests, pathogens and abiotic components like pesticides, cold effect the functioning, longevity and health of honeybees. Honeybees are also known as natural bioindicators as they are defensive to contaminants, fertilizers, pesticides and habitat loss. Decline in overall population of honeybees brought about chain reactions of environmental impacts due to different factors like use of agrochemicals, habitat degradation, climate change and diseases. Such limitations call attention to the critical requirement for protection efforts by risking balance of environment, species richness and agricultural yield. Impactful protecting efforts include tracking population of honeybees, their well-being, habitat rehabilitation and using renewable agricultural practices. In this study ecological behavior of honeybees and their interactions with environment is reviewed here which also emphasizes subjects for future consideration to assure their protection.

1. INTRODUCTION:

Honeybees specifically *Apis mellifera* play a crucial role in the maintaining stability of ecosystem. Being pollinators, honeybees assist the reproduction of unlimited plant species, consisting of many crops that support human populations (Ahmed, 2023). Whereas pollination in agro ecosystems may increase crop production and quality managing rising food needs (Papa et al., 2022).

The diversity of wild bee species illustrated in Fig.01 reflect difference in their physical properties like size, flighting behavior and ability to survive in extreme weather conditions can assure effective pollination (Weissmann et al., 2021). Over 75% of the world's crops are supported by pollinators (Reilly et al., 2024). Pollination in most crop systems is accomplished by a mix of wild insects, mostly wild bees, and controlled honeybees (Reilly et al., 2024). The products obtained from honeybee is another service performed by honeybees for the mankind and help to maintain the balance in the natural environment (Papa et al., 2022).

Worker bees act as environmental indicators as they unintentionally gather and accumulate toxic nectar and pollen from plants that reveal the degree of chemical contamination in their immediate surroundings (Selamoğlu & Naeem, 2024). Because of their exceptional significance, honeybees have garnered a lot of attention and sparked a lot of research due to severe and unexplained honeybee colony losses that have been reported to be progressively increasing recently (Genersch, 2010).

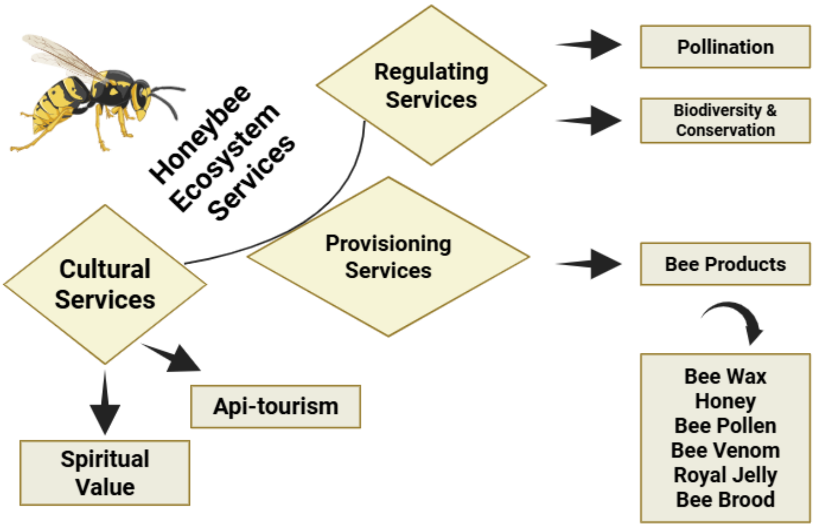

Fig. 01. Ecological services provided by honeybees

2. Taxonomy and Specie Diversity of Honeybees:

As members of the family Apidae and order Hymenoptera, honeybees go through a complete metamorphosis throughout their entire cycle. Because of their distinct physical and behavioural characteristics, they are very successful pollinators. Studies have distinguished 26 subspecies based on variations in morphology, behavior, and geographic range (Yadav et al., 2017).

India has a wide diversity of honeybees, particularly those belonging to the Apidae family, many of which are vital to both commercial and natural beekeeping. *Apis dorsata*, *A. cerana*, *A. florea*, and stingless bees are examples of naturally occurring species however, *A. mellifera* was brought from Europe and is commonly raised for honey production together with A. cerana (Srinivasan & Haran, 2023).

While *A. dorsata, A. laboriosa*, and *A. florea* are primarily found in tropical and subtropical regions of South and Southeast Asia. Clearly different from their natural habitats, *Apis cerana* favors tropical to temperate regions in Southeast Asia and the Indian subcontinent (Yadav et al., 2017).

3. Habitat and Geographic Distribution of Honeybees:

Honeybees belong to the Apis genus, which has different geographic distributions depending on their habitat and environmental needs. While some honeybee subspecies thrive in adaptable and varied environments, others thrive in very specialized environments and habitats. For example, the giant honeybee lives in South Asia, specifically in regions such as Pakistan, where studies indicate that just about 23% of the region under study should be suitable environments according to both field study and climate modeling systems. Suitable environments for the giant honeybee will, according to such studies, be reduced and will probably be elevated further towards the higher elevations of the region by the mid- to late-21st century, as predicted by (Khan et al., 2025).

The Himalayan giant honeybee lives primarily at the foothills and mountainous regions of the Himalayas, specifically in India, China, Myanmar, Laos, and Vietnam, and prefers subtropical broadleaf forests at higher elevations. Current models of their distribution suggest that their range might extend slightly further east and west than originally described, as suggested by (Otis et al., 2024).

The various species under the Apis genus are known to show varying elevation ranges and habitat preferences, which are mostly dependent on environmental factors such as climate and topography. In Asia's highlands, *Apis laboriosa* tends to be found within elevation ranges of between 500 m up to more than 3000 m, where they are found within broadleaf and mixed forests where seasonal changes in temperature and cold are known environmental factors for consideration (Otis et al., 2024).

In Pakistan, *Apis dorsata* tends to be found within lower to mid-elevation range habitats where temperature and rainfall changes are predictive factors for consideration. However, under projected climate change, *Apis dorsata* tends to shift to higher elevation ranges, particularly by 2070, where emissions of greenhouse gases are set to continue rising (Khan et al., 2025). This shows that each honeybee species tends to respond uniquely to changes in elevation ranges.

Aside from the giants in Asia, other species such as the Western honeybee (*Apis mellifera*) are found on different continents. While certain constituent of the Western honeybee shows regional variations, studies suggest that the climate affects the geographical distribution of such species. Moreover, it is expected that due to environmental changes, the habitat suitability of these species will vary in different time periods (Saleem, 2025).

Although it has already been proven that honeybees such as A. mellifera can survive in different habitats within different continents such as Africa, Europe, and Asia, the rise in temperature and changes in rain patterns will affect the regions they can survive in. This phenomenon is not only true among *A. mellifera* populations but is wide-ranging to other such honeybees as *A. cerana, A. florea, and A. dorsata*. Such studies carried out by conducting surveys and modeling have also shown how diversity in habitat, annual floral supply, and landscape structure affect the distribution of honeybees. For example, recent surveys carried out in agroforestry and agricultural landscapes of Punjab, Pakistan, revealed that *A. dorsata* and *A. cerana* occupy different districts and landscape types. A. dorsata was found to be more common in sub-mountainous regions, whereas *A. Florea* was found to be common in other districts (Bashir et al., 2023).

Such observations illustrate how different species of honeybees occupy different regions within a similar geographical location due to microhabitat conditions, diversity in flora, and climate.

4. Honeybees as a Pollinator:

Honeybees (*Apis mellifera*) are known to make a very crucial contribution to pollination, which will then be reflected in an increase in seeds. With this, it is evident that when experiments were done on *Brassica carinata*, there were obvious seeds in the crops that were pollinated by honeybees compared to those that were not. This highlights a very crucial contribution by these bees. (Desha & Dubale, 2023). The mechanism of cross pollination is illustrated in Fig.02.

Apart from domesticated flora, honeybees are observed to pollinate other native flora, albeit to varying degrees of success. Honeybees are known to pollinate a variety of native flowers. However, their contribution to reproduction would depend on the native flora and habitat conditions, as confirmed by (Shakoori & Salmanpour 2024). This, therefore, indicates that although honeybees do contribute to pollination activities, other environmental factors do come into play. The activity of honeybees may impact on the structure of the entire network of plants and other pollinators. Observational studies have revealed that honeybee activity impacts these networks. However, the activity of honeybees did not influence the behavior of wild pollinators in specific habitats (Worthy et al., 2023).

The implication is that the impact of honeybee activity is double-edged: through direct and indirect effects. Nevertheless, honeybees do not ensure effective pollination for all plant species. For instance, studies carried out by scientists on orchids reveal how these honeybees, considered an invasive species, do not pollinate these plants effectively, rather acting as pollen consumers themselves, according to (Scaccabarozzi et al., 2024). This again indicates how the pollination service of honeybees varies with different plant species and how their ecological role is not always beneficial, as it sometimes turns out to be a challenge.

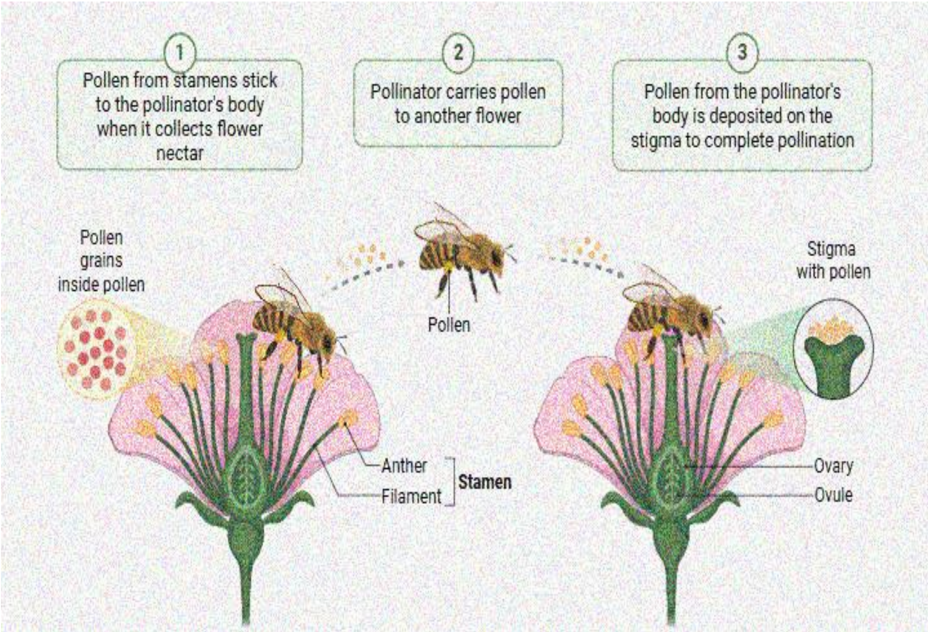

Fig. 02. Cross pollination done by honeybee in flowering plant

5. Importance of Honeybee in Food Chain:

5.1. Pollination & Ecosystem Services

Honeybees, which include *Apis mellifera*, are arguably the most important little workers in nature. Their movement from one flower to another translates into assisting plants to reproduce, which maintains the balance in nature (Seddik & AbbasAli, 2025). Various plant species entirely depend on bees to reproduce seeds and fruits, which later feed other insect species, as well as bird life and others. As we look at the role played by bees in agriculture, we can clearly see how important they are to crop production, which gets to our tables due to their role in its quality. The plants would certainly not thrive without such hardworking teams, and eventually, almost all plant and animal species would be affected, ranging from smaller bugs to larger animal species (Ferenczi et al., 2023).

5.2. Agricultural Productivity and Food Security

Honeybees in the field are the best friends any farmer can have. They contribute greatly to the increased productivity of agricultural crops, ensuring they are more productive and fruitful. For instance, studies were carried out in the semi-arid regions of Egypt, which revealed the need for these bees in the production of faba beans, since the bees were related to the increased quantity and quality of seeds produced (Seddik & AbbasAli, 2025).

5.3. Biodiversity & Ecosystem Connections

Not only do honeybees assist in the improvement of crops; they are vital to the maintenance of the balance of nature. They contribute to the survival of various plant types through pollination. They travel over long distances, thus linking isolated plant populations. This results in diversity. It is not just cropping improvement that honeybees are responsible for; they are also the link to the survival of wild plant populations. This ensures the stability of food chains. Without honeybees, food chains are broken, plant populations are reduced, and the balance of nature is upset (Kaya et al., 2026).

6. Interaction of Honeybees with Biotic and Abiotic Factors

In some past decades the number of studies using specie distribution model has increased. To identify the areas which are suitable habitats by linking species occurrence data with environmental factors. These models help us a lot. Biotic factors are directly involved in distribution models. These biotic factors involve the resource related and interactive variable which are connected to niche concept. But those types of variables that do not have interactions are called Stenopaeic variables. These are also related to Grinnelian niche. For instance, the spatial scale of biotic factors plays an important role when it is used an explanatory variable. The seasonal lifecycle of a perennial colony is presented in Fig.03. There is still limited evidence. Biotic factors are often excluded because they are influenced by interaction with the species being modeled. (Huang, E. & Marshall, L. 2024).

Invasive species have frequently been identified as one of the main biological catalysts for biodiversity loss and have, in various instances, increased the effects of global climatic change. Changes in habitats resulting from land use, environmental pollution, and climatic change frequently make habitats unsuitable for indigenous species and provide invasive species with a competitive advantage. It has been proposed that habitat disturbances may impact indigenous and alien species differently, but it has been difficult to separate the interactive effects of species and environmental conditions. Invasive species may dominate indigenous species, forcing them out of their habitats, resulting in local extinctions. However, other studies show no significant effects of alien species introduction on indigenous species. The inconsistent data obtained from various studies emphasize the need to separate abiotic and biotic filters in explaining species coexistence. Two primary hypotheses describe the effects of pressure from the environment and species interaction on the co-occurrence of indigenous and alien species at the same trophic level. Competitive relaxation is one hypothesis which implies that co-occurrence is more likely in species-rich environments with low levels of competition, since the total species density is likely to be boosted. (Cifuentes, M. C., & Castro, S. A. 2023).

For an organism to thrive and reproduce, appropriate environmental conditions must be present. Also, the response of an organism to all these factors is liable to influence the population dynamics. There are some seasons in the environment; therefore, it is expected that various stages of an organism's life may have greatly varying environmental conditions. As a result, the importance of environmental factors, such as temperature and climate, and biotic factors, such as food and competition, may vary over the lifespan of an organism. For example, extreme abiotic factors, such as mild winters or strong summer weather, may be significant to certain stages of an organism's life; on the other hand, certain stages may have a more important biotic component. As a result, there is a need to understand the varying responses of the stages of an organism's life to the impacts of both the abiotic and biotic factors; nevertheless, the findings of most studies ignore the varying impacts (Ogilvie, J. E., & Caradonna, P. J. 2022).

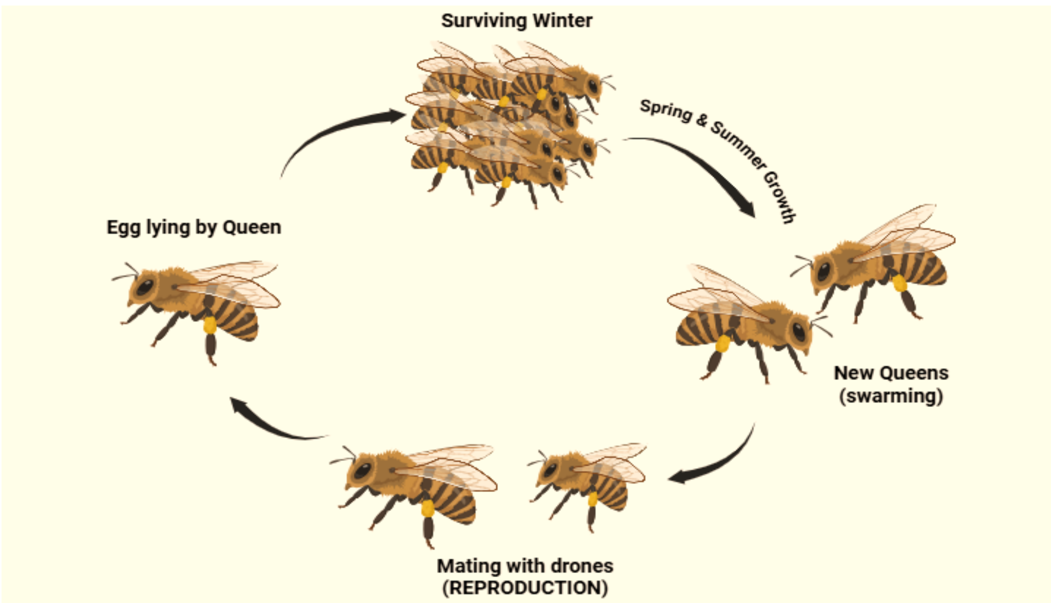

Fig. 03. Honeybee life cycle

6.1. Effect of Biotic Factors on Honeybee Health:

About 29 various diseases and pests have been identified to cause the loss of honeybee colonies on a yearly basis around the globe. Quantitatively significant biological risks include parasitic Varroa destructor mites, microsporidian pathogens like *Nosema apis* and the more virulent *Nosema ceranae*, fungal pathogens. Other significant honeybee pests include amoebas like Malpighamoeba mellificae, spiroplasma diseases, septicemia-causing pathogens, the small hive beetle Aethina tumida, as well as honeybee wax moths of the family Pyralidae. (Nevo, B et al., 2019).

Among the Varroa species, the Varroa mite is considered one of the biggest threats to the health of honeybees. Since its introduction to Europe in the mid-20th century, and then to North America in the 1980s, the Varroa mite has cost honeybees dearly, spreading all over the world, apart from Australia and some isolated locations. Varroa destructor results in significant losses across Canada and various European countries every year, and it has been identified as one of the major reasons behind the decline of bee population especially in countries like Europe and North America. (Radoslav, G., & Hristov, P. 2019).

6.2. Effect of Abiotic Factors on Honeybee Health:

It has been widely discussed that the reproductive toxicity of different agrochemicals to honeybee queens and drones directly influence colony growth and long-term survival. In most cases, queens' mate multiple times, but such exposure to neonicotinoids can impair queens by damaging their ovaries and by reducing the amount and quality of sperm stored in the spermatheca, which impairs reproductive success. The queens may suffer from physiological disturbances, including a decrease in pheromone attractiveness to worker bees and disturbance in gene expression related to antioxidant defense, immunity, and development. These disturbances weaken the ability of the queen to regulate and maintain colony stability. Major environmental stressors affecting honeybees are summarized in Fig.04. Moreover, such a negative impact of exposure to the agrochemical impairs drone health by depressing sperm quality and viability, further compromising successful reproduction within the colony. (Wang, K., & Ji, T. 2024).

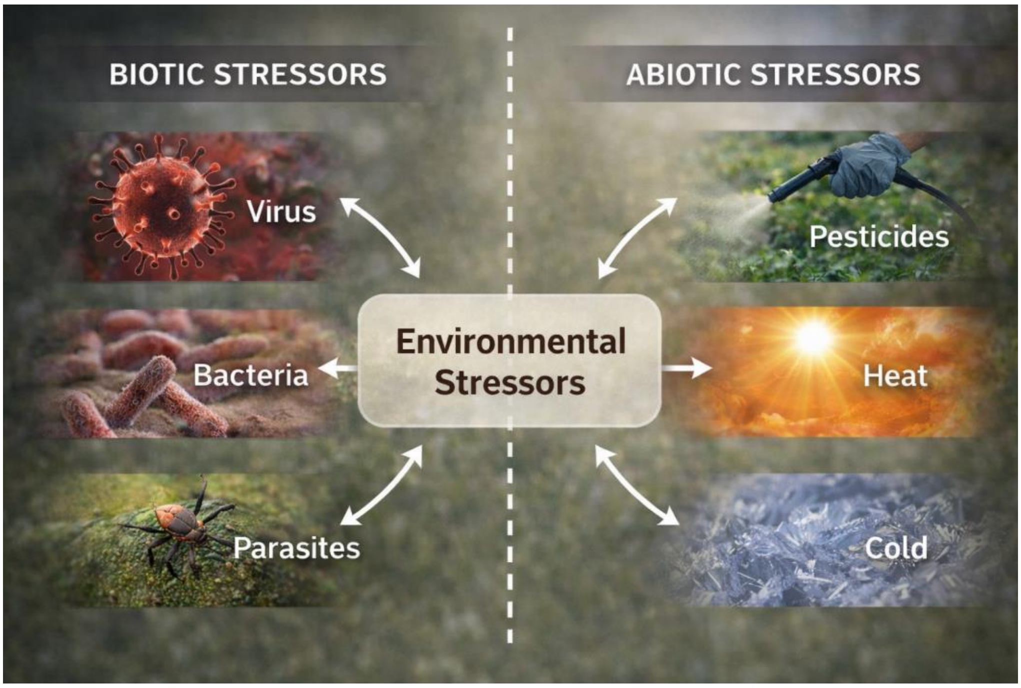

Fig. 04. Major environmental stressors affecting honeybees

7. Honeybees as bioindicators of Environmental change

Human activities are significantly impacting the atmosphere, oceans, and land globally in different ways. These impacts of human activities are frequently observed in agricultural systems, where modifications of abiotic conditions may disrupt microbial communities, vegetation, fauna, and diseases, leading to consequences for human health, food security, and biodiversity .For coping with the problems faced due to global environmental changes, it has been suggested that different mitigation measures need to be taken into consideration in order to ensure the productivity and sustainability of agriculture. For example, the promotion of organic farming practices indicates land management changes, whereas the preference of wind-pollinated crops in place of flowering crops indicates the development of less sensitive agriculture (Quigley, T. P., & Harwood, G. H. 2019). The bioindicator role of honeybees is depicted in Fig.05.

The role and application of bio-indicators can be effectively explained with the example of a honeybee, an insect that has been the focus of my research and my teams over the past twenty years or so. The use of bees as bio-indicators is not a novel idea. Even in 1935, J. Svoboda (Crane, 1984) suggested the potential use of such an approach to obtain valuable information on the impact of industrial activities on the environment in a particular region. Twenty-five years later, Svoboda and his team successfully applied the bee approach to communicate the increasing amounts of the radio-isotope Strontium-90 in the environment due to nuclear tests carried out in the atmosphere (Celli, G., & Maccagnani, B. 2003). The bioindicator use of honeybees can further be utilized for the surveillance of the environment in urban waste treatment plant facilities, particularly in ecological or sensitive environments, such as the Campania region of Italy. The waste-to-energy plant near the city of Acerra is in an interzone between the countryside and industrial areas. It has been in operation since 2009, has an installed capacity of 107.5 MWe, and is certified as per ISO 9001, ISO 14001, EMAS, and ISO 4500.The facility uses three units of a combustion line, where residual municipal waste, consisting of unsorted solid waste subject to pretreatment at the Caivano S.T.I.R. Waste shredding, sifting, and packaging plant in Campania, is used. Recognized as one of the most technologically advanced plants in Europe, it was built with cutting-edge technology to guarantee effective environmental protection measures. (Crispino, G., & Amorena, M. 2024).

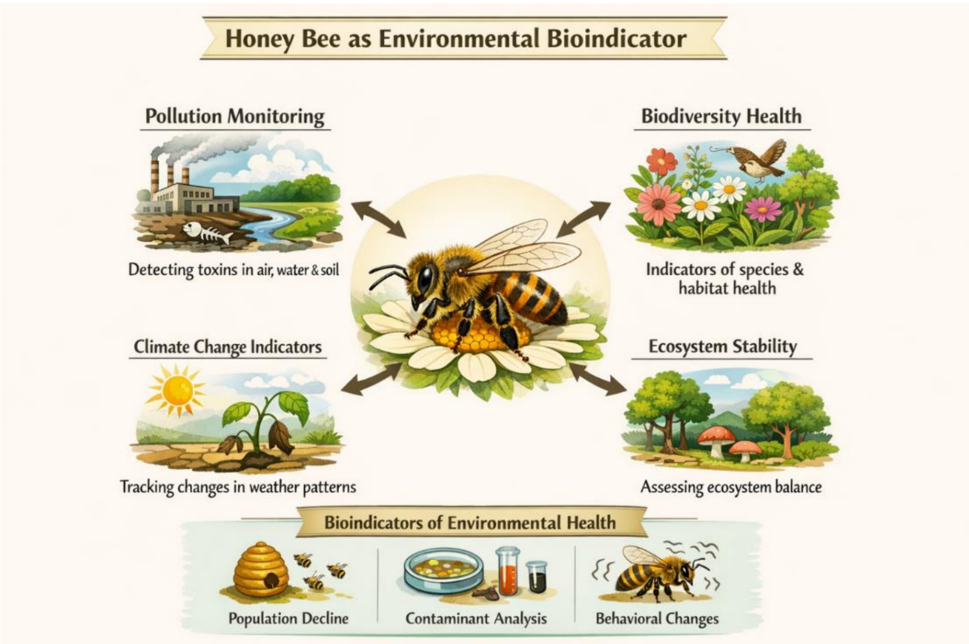

Fig. 05. Honeybees as bioindicator of environmental health

8. Impact of Environmental Stressors on Honeybee

Honeybees play a vital role in pollinating both natural vegetation and agriculture crops, making them one of the most valuable contributors to global food production and biodiversity. Among pollinators *Apis mellifera* stands out for its enormous economic importance, of dollars annually to agriculture worldwide.

However in recent decades alarming declines in both wild and managed be populations have been reported across many regions research so just that no single causes responsible for these losses instead be decline results from a complex combination of factors bees are continuously exposed to harmful pesticides mixture as well as growing range of parasites add infectious diseases some of which or spreading due to human activities and global trade additional pressures such as habitat destruction climate change poor beekeeping practices and reduced floral diversity further weaken bee populations. Together these stressors interact and intensify one another making it difficult to identify exact causes and increasing the vulnerability of bees to collapse (Havard et al., 2020). Colony collapse Disorder due to environmental stressors is shown in Fig.06.

Honeybees *Apis mellifera* are the backbone of the agricultural pollination in North America and essential for maintaining crop productivity. Your lord's colony size enables efficient pollination of the cross vast areas, especially when beekeepers move hives to forms for commercial pollination. In the United States the beekeeping industry realizes heavily on pollination services for crops such as almonds, apples, berries and cucurbits. To meet this demand, colonies are transported over long distances for much of the year. This repeated movement often places bees in large monoculture environments increasing their exposure to pesticides and disease-causing agents. At the same time, limited access to diverse pollen weakens their nutrition. Continuous relocation also disturbs foraging behavior, creating stress that increases vulnerability to parasites, diseases and conditions like Colony Collapse Disorder (Simone-Finstrom et al., 2016).

When stress is sustained for a long period, it eventually drains the body. This implies that stress can weaken the immunological system, disrupt the metabolism, and influence cognitive abilities such as learning and memory, all happening within bees and other bodies. This leads to exhaustion, making the body more susceptible to different types of diseases. At the cellular level, the body responds to stress by initiating defense mechanisms, such as antioxidant and heat shock response, for survival. These defense mechanisms occur when organisms or bodies are subjected to extreme chemical environments. Even though it is important for bodies to have these mechanisms, it is not applicable to the above physiological points (Even, Devaud, & Barron, 2012).

Looking at habitat conditions, future research needs to investigate how environmental and biological stressors influence bee groups across different areas.Existing evidence indicates that reduction in floral diversity and quantity restricts food supply, which negatively affects bee populations.

For this reason, it is necessary to analyze influences that evaluate direct factors like habitat links, environmental disturbances, and invasive species while maintaining constant floral resources (Belsky & Joshi, 2019)

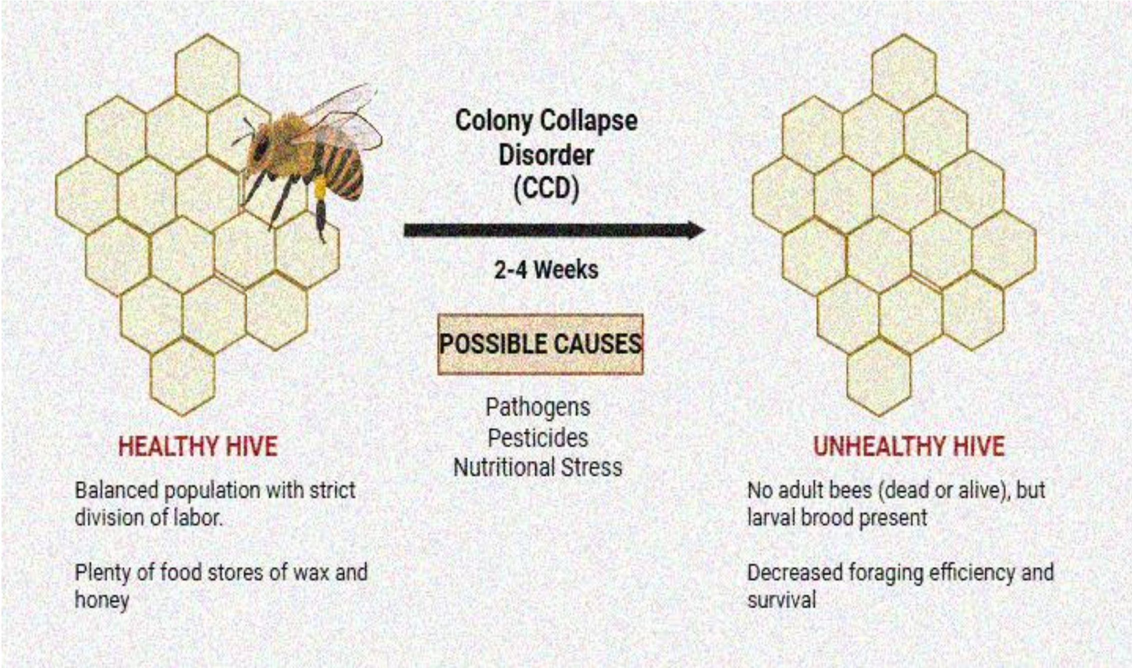

Fig. 06. Colony Collapse Disorder in honeybees

9. Ecological Consequences of Honeybee Decline

Honeybees are small insects, but their work is very powerful. They help plants grow by spreading Pollens from one flower to another without bee plants would fail to reproduce because many animals and humans depend upon these plants for food. If there become slow crops and wild plants cannot grow properly. Formers especially need bees because many agricultural crops rely on them. The decreasing pollinators such as honeybees, butterflies and bumblebees have already harmed farming in western countries. These and other insects not only help plants reproduce but also contribute to better soil conditions. Continuing loss of these pollinators could lead to a serious reduction in plant life and overall biodiversity. (Paudel et al., 2019).

Pollinators do much more than help plants reproduce. They not only help crops grow but also make them healthier and more productive. Without enough pollinators, fertilization becomes efficient, leading to fewer fruits and weaker harvests. Each year globally their services are valued at billions of dollars annually, and nearly one - tenth of the world's food supply realizes them. Bees and other pollinating insects are very important for Indian agriculture. Because natural bee numbers have decreased in Apple regions, Formers have started hiring *Apis mellifera* Colonies to support crop production. Production of mustard in Rajasthan and cardamom in Kerala has also declined. These losses directly impact farmers' income and increase stress on the country's food supply. (Sadafale et al., 2025)

In many regions, one of the most effective pollinators is *Apis cerana cerana*. These bees greatly support crop fertilization and fruit production. If these bees are not present, pollination services may reduce by almost half. Losing the species could result in the loss of nearly half of population activities with apple orchards being hit in the hardest. (Kortsch et al., 2024)

10. Conservation of Honeybees

Many wild bees are very good at pollinating crops. Dead trees and strong plant stems are important homes for wild bees. Keeping natural woody materials around orchards helps these bees survive and multiply. Studies also show that having many different flowering plants increases the number and variety of nesting bees. To attract bees, it's important to have a variety of native plants because many bees choose specific plant types. Some species nest in soft rotting logs, above the ground. They use natural materials like leaves, mud, oil or tiny stones to complete their nests. Modern orchard management like herbicides and moving often removes these safe spots. Keeping dry stems through winter gives pollinators a safe place to live. (Kline et al., 2023)

To protect the Russian honeybee *Apis mellifera* for the long-term specific breeding and conservation planning or required to evaluate their genetics. Selective Queen rearing combined with genetic testing strengthens colonies while keeping their natural traits. Isolated meeting stations stop imported bees from mixing with local populations. Protecting and expanding areas around apiaries helps maintain natural habitats and the native gene pool. Collaboration with global breeding programs brings experts is an improved method. System for distributing means can help protect natives and boost commercial honey protection. Effective communication allows the sharing of valuable knowledge. Increasing the number of pure blood colonies reduces hybrid bees from mixing with the local population. (Frunze et al., 2025).

11. Conclusion:

Pollination by honeybees is vital for ecological balance. This supports life not only by helping crops grow but also through their relationships with plants, animals, and the environment. Ecosystems rely on honeybees for pollination of food chains and environmental interactions. Losing them can disturb nature and negatively affect productivity. Honeybees face rising risks due to climate change and pollution. Conserving them helps maintain ecological balance and make honeybee conservation a global responsibility. Pollution and climate change or stressing honeybee populations. Ensuring their survival is vital for stable ecosystems making honeybee conservation a global responsibility protecting honeybees is protecting life itself.

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