The Impact of Climate Change and Military Conflicts on the Safety and Livelihood of Bee Colonies*

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Abstract

Beekeeping is one of the most significant activities in the modern world and is a major contributor to agricultural practices and the wellbeing of the environment due to the services and products made by the bees. Still, bee colonies experience unprecedented challenges propelled by climate changes and military conflicts. The availability of nectar is heavily affected by climate change. Moreover, it affects bees foraging patterns compelling the many species of bees to adapt to the new latitude. Military conflicts impact on beekeeping practices as a direct threat by destroying the hives, uprooting the beekeepers, and poisoning the foraging grounds. Despite this, such issues, including the issue of reporting accuracy can be remedied. Usage of enhanced artificial intelligence tools and satellite analysis can be deployed to solve issues. Such technologies can be instrumental in analyzing environmental transformations due to conflict and its impact on bees and their management to reduce risks. The emerging approaches in the incorporation of technology into beekeeping prove useful in curbing the effect of environmental changes and human disturbances on bees. It is different and almost impossible to over emphasize that steps are warranted to save the bees from both threats and continue with their expansion which is critical in keeping the ecosystem and food security in check.

Keywords

beekeeping, climate change, satellite data, machine learning, automation, biodiversity

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1. Importance of Beekeeping for Pollination and Ecosystem Preservation

Beekeeping, the practice of managing honeybee colonies, is of vital importance to society and the economy (Fig. 1). Honeybees (Apis mellifera) are the primary pollinators for many wild plants and crops, making them crucial for ecosystem stability and agricultural productivity [1,2]. In addition to pollination services, beekeeping also yields valuable products like honey, beeswax, propolis, royal jelly and pollen. There are over 20,500 bee species worldwide, but most research and public attention has focused on the western honeybee, Apis mellifera, due to its extensive use in beekeeping and crop pollination [3–5]. Honey is the most well-known bee product, with an estimated annual global production of 1.85 million tons. It has long been used as a natural sweetener and in traditional medicine for its antibacterial properties [6].

Another important product that could be utilized in the poles would be beeswax as this has a high potential within the cosmetic, candle making, and even food processing industries. The service provided by bees in facilitating pollination is of great value as it helps to optimize and expand ecosystems. About three-quarters of angiosperms are animal-pollinated and bees are the most important pollen-gathering animals. The reproduction of wild flora is achieved by bearing seeds which enhance genetic and ecological diversity of the population [7].

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However, in recent years, there has been growing concern over declines in bee populations globally. While colony losses are not a new phenomenon, the extent and rate of recent declines, particularly of wild bee species, is alarming [2,8]. Anthropogenic factors like habitat loss, pesticide use, climate change, ongoing military actions, chemicals release into the atmosphere and spread of pests and pathogens are considered major drivers of these declines [1]. To mitigate these threats, comprehensive measures are needed to protect natural resources and promote sustainable beekeeping practices.

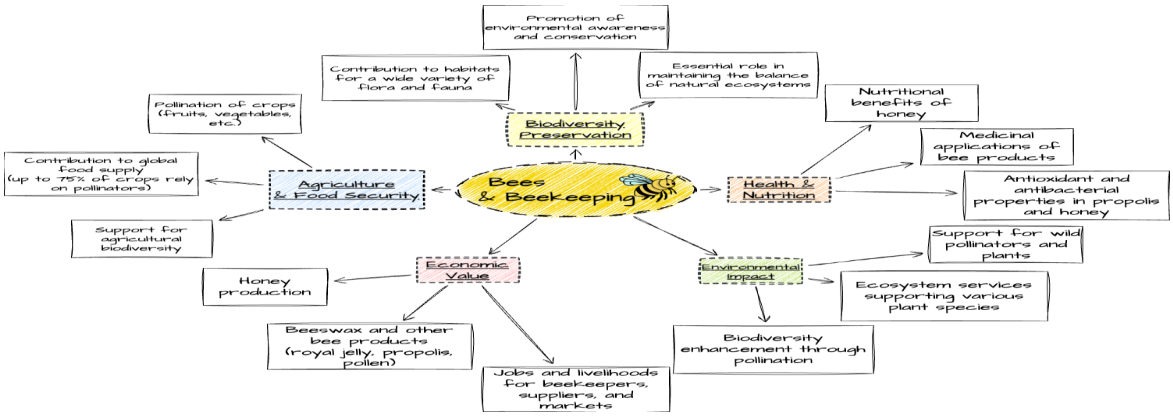

Figure 1: The multifaceted importance of beekeeping: Agriculture, Economy, Environment and health

The decline of wild bee populations remains an alarming issue that deserves the greatest concern and tends to be overlooked. Much like honeybee colonies who are also in decline, there are also wild bees which ought to be given equivalent attention to ensure their non-extinction. Ferocious pollinators such as bumblebees and singular bees, along with managed Apis differ from wild bees. As we are stating in this article, there is a need to give a critical analysis to ensure the problem concerning the disappearance of wild bee population is sufficiently solved. The specific objectives are:

- Assess the major anthropogenic drivers contributing to losses of wild bee populations, including habitat disturbance, climate change, pesticide exposure, and spread of pests and pathogens
- Evaluate how different stressors may interact to impact wild bees at the individual and population levels. Explore a "holobiont" approach considering bees and their microbiomes for understanding environmental effects [10]
- Point out what these critical gaps in our knowledge of wild bee declines are, for instance, the scarcity of toxicological data available on non-Apis species and the limited understanding on the effects on the population level.
- In line with the above, explain the ecological and economic effects of lowering wild bees' population including the disruption of plant pollination systems and the negative effects on the provisioned pollination service for agricultural crops and natural vegetation.
- Emphasize the importance of targeting more attention to wild bees through research, conservation, and policy responses, and propose ways of how it would be possible to slow down the observed decline, including restoring habitats, better management practices, and minimizing the use of pesticides and harmful substances.

This review seeks to highlight a significantly less explored yet more crucial aspect of sustainable bee conservation through the examination of existing works in relation to the causes and consequences of bee and other wildlife depletion. The breadth of possibilities stretches even further considering the intricate interrelations of contributing factors to the issue concerning the well-being

of all bees' kinds and species. But most crucially, the aim remains to generate interest in appealing to such profoundly crucial pollinators and ecosystems that are dependent on them, while taking measures to counteract the collapse in wild bee populations.

2. Impact of Climate Change on Bee Populations, Beekeeping Practices, and Apicultural Products

Climate change affects beekeeping, bees' variability around climatic regions, and the production rate of bee hives. Amid global warming and climate fluctuations, it becomes difficult for bees to settle on the existing conditions. Climate change may lead to the change of the flowering seasons of the plants which call for bees and flowers to be there at the same time, a scenario that may not occur when the flowering times of the plants shift abnormally to the timing of bee emergence. This disparity leads to low honey yields. Climatic changes also impact the number and distribution of the bee species, some cannot survive in a warmer temperature. Due to climate change, many of bee nations are moving to higher altitudes and further north than where they used to reside [11].

Nevertheless, some species might not be such efficient and could cause limited extinction and decline in the pollinators (Table 1) [12]. Finally, in order to stop the effects of climate change on the practice of promotion of the beekeeping culture, it will be necessary to apply all sorts of bee varieties and manage the areas where the particular bees shall be brought to coexist. Following the maximum diversity principle, high diversity in bee species is beneficial in the strengthening of not only the pollination service but also an ecosystem that is primarily aimed at the conservation of bees [13]. On the other side, there is wild bee diversity which can enhance yields hence the necessity to conserve more bee diversity. These bees are more efficient, in the climates that they were chosen for, to facilitate pollination within their ranges.

Table 1
Impact of temperature on Bees

Temperature Range (°C)	Apis Mellifera Activity	Impact on Honey Production
Below 10°C	Minimal to no activity	Low production
10°C – 22°C	Increasing activity, dependent on light	Moderate production
22°C – 25°C	Optimal activity	High production
25°C – 38°C	Activity continues but may decline	High production
Above 38°C	(38°C) Activity declines	Potential decrease in production

The survival of global bee populations and beekeeping is in jeopardy and climate change is the issue at hand. The environmental balance that bees maintain is being greatly altered by the increasing temperatures, new precipitation patterns and increasingly harsher weather. The challenges bees encounter, such as the mismatch between the timing of their flight from colonies and the flowering of plants, lack of water and food sources and colony over stress all worsen. Therefore, to support sustainable beekeeping practices the effects of climate change on bees need to be thoroughly researched and dealt with.

Rising temperatures and unpredictable weather patterns cause bees to adapt more and more which in turn leads to consequences for Climate change that has a direct and unparalleled influence on beekeeping, the geographical and climate range of the bees, and honeybee products [14]. There's

also the problem of the timing when bees emerge not being in sync with flowering plants for bees to pollinate which is caused due to geo climatic changes [15]. This asynchrony, in turn, leads to the disruption of the proportional relationship of two separate events. This disruption results from lower amounts of pollination, less production of honey, and a decrease in the general well-being of the colony [14].

The thermal conditions are also a great factor in determining the existence and the range distribution of bee species. Many bees have a specific temperature and environment where they live in. When the temperatures rise due to climate change, certain bee species are forced to relocate to greater altitudes or farther latitudes to sustain themselves. However, not all species have the ability to adapt and migrate quickly enough, leading to localized extinctions and a loss of pollination services in certain areas [16].

For instance, the European honeybee (Apis mellifera) dominates in temperate climates whereas the hybridization between the species and the Africanized honeybee (Apis mellifera scutellata) does thrive in warmer areas [17]. It is important that this diversity is preserved to ensure the continuity of pollination services in the future considering the impacts of climate change. For pollination services, it is critical to preserve a range of bee species to be able to cope across different climates and landscapes. Changes in weather patterns due to climate change can impact not only the number of bees but also the amount and quality of bee products.

Increased temperatures may modify the modification of the honey's composition with the ant microbial factor thus the honey's market value may depreciate. In addition, the building of the plants and the phenology of the plant in relation to nectar production may compromise the honey amounts produced. Rising temperatures and altered precipitations patterns attributed to climate changes would affect the productive capacity of beekeeping. Therefore, principles of adaptive management in the face of climate change as well as sustainable management need to be emphasized. Such management-oriented practices would include protecting crops from pesticide exposure, monitoring bee health and within-because involvement of various flower sources [18]. Preserving natural habitats and establishing pollinator-friendly landscapes can also help maintain bee diversity and resilience [19].

So, climate change is expected to have very serious effects upon bees, and the activity of beekeeping. Increasing temperature, changing precipitation and increased frequency of storms and droughts are accounting for a mass imbalance in the life of bees. Such analytical studies, along with understanding the particular vulnerabilities of diverse honeybee species, would help in formulating specific and effective bee conservation policies. Beekeepers have to defend adaptive management planning as the best principle to defend colonies and develop their handing off evolution into hibernation. Passive and positive measures have to be taken in order to restore and create biotopes that would appeal to bees and be good for them. As such, one may envisage the consequences of climate change for bees and the prospects for specific kinds of beekeeping in order to increase the effectiveness of the management of system resources and the critical role of bees in ecosystem maintenance.

3. Impact of Military Conflicts on Beekeeping and Bee Populations

Wars and armed conflicts are one of the greatest threats to the practice of beekeeping, the bee population and the bees' products. Wars and armed conflicts are described as the destruction of infrastructure, displacement of population and environmental pollution; all of the above have destructive and enduring consequences to bees and the practice of beekeeping. Among the other opportunities availed at bees due to the warfare are chemical weapons, contamination in the form of heavy metals and loss of proper foraging habitats. It is necessary to rapidly evaluate the characteristics of military conflicts towards bees and to take actions to save such vital pollinators for permanent beekeeping in such areas.

Military conflict is likely to bring about dire impacts on bees and beekeeping, and even result in abusing the bees and their products. Moreover, these effects possess the potential to be enduring as well. With armed conflict, the infrastructure is usually destroyed, there is mass displacement of the

population, and the environment gets polluted, all of this together hinders beekeeping and the survival of bees. During military conflict heavy metals and a variety of other pollutants are released into the atmosphere, and this becomes one of the gravest threats for bees in conflict zones. Chemical contaminants can seep into bee products, such as honey and beeswax and prove to be detrimental for humans and the environment. Several research pieces have been published highlighting that Lead, Cadmium and a range of other toxins are found in honey sourced from countries afflicted by war [20].

Besides the chemical contaminants, chemical warfare is also a great cause of distress for bees in regions engulfed in conflict [21]. Bee populations get obliterated when chemical weapons and other hazardous materials are used during military operations, and that has a devastating influence on them. These chemicals result in an increase in the likelihood of Bee dying, a reduced tendency to search or look for food and impacts the immune system in a negative way [21]. The implications that chemical warfare results in for bees and the overall ecosystem are catastrophic in nature, albeit we do not fully understand the long-term repercussions of such a conflict.

In addition to chemical exposure, other sociocultural and geographical aspects such as bees' limitless accessibility to flowers - which could prove detrimental during a violent military confrontation - must be taken into account too, as these factors can easily strain the ecosystem. Forest degradation, and the use of farmland during a conflict can have brutal consequences in the scope and location where bees gather pollen. Taking into consideration wars in Europe, especially in the territories of Western Balkan, it had been impossible to find and work with local bee colonies due to environmental challenges. Beekeepers usually return alongside armed conflicts and other uncontrolled scenarios, proving to be a problem as well because they tend to forget beekeeping techniques, turning beekeeping and bees into more troubled entities.

On the flipside, narrowly defined military conflicts can lead to increases in bee populations. The example of the Korean War is quite relevant because it involved a no-man's land between two militaries, allowing certain currently endangered species of bees to extend their habitat into the warzone, which became a biodiversity reserve due to the absence of humanity and landmines, creating a biological niche in which bees and other animals thrived [22].

Notwithstanding the conflicting elements induced by military warfare, apiculture practices can equally take part in post war rebuilding and in peace processes. By embedding beekeeping initiatives into humanitarian and development programs, communities can rebuild their agricultural foundations, restore ecological balance, and support the livelihoods of those affected by conflict, thereby strengthening trust and cooperation across previously divided groups. There seems to be a need to formulate conflict sensitive strategies in relation to the protection of bees and sustenance of the beekeeping practice in order to mitigate conflicts effects on this practice and the bee population.

These strategies may include the creation of buffer zones where bees can survive in spite of ongoing military activities, the continuing promotion and improvement of both local and modern best beekeeping practices and educating the masses on the different functions of pollinators in economic development, food security, and cultural preservation. It will also be essential to take measures towards strengthening interstate relations, including international cooperation towards these environmental issues, which cut across borders therefore making it possible to promote respect and co-management of the natural resources in war affected areas.

Furthermore, reaching out to already existing strong networks of beekeepers, researchers, policy makers and non-governmental organizations will be highly critical in ensuring that the best approaches as well as the support. The existing and new monitoring and decision support systems based on modern technology enable reporting and detection of new and expected threats in a timely manner in order to prevent delayed responses and actions. In this way, more sophisticated satellite imaging, predictive modelling with the aid of artificial intelligence as well as automated sensors for hives can all help in the establishment of an early warning system designed to assist local communities in making timely and preventive rather than corrective decisions.

Further, measures have to be put in place to ensure that legal and enforcement mechanisms are effective and deter the deliberate destruction of hives and nesting sites so that the perpetrators are

punished in a suitably harsh manner. Implementing codified prohibitions against the intentional destruction of animal facilities and habitats, while facilitating the proper implementation of procedures and proper support for fair legal adjudication can reduce such actions and enhance confidence in the agencies working to protect the environment and the people. As such, the best interests and concerns of the relevant social and economic stakeholders speaking to protection of bees during wars, are not purely ecological but humanitarian in nature as they relate to food security and economies as well as peoples' cultures who are dependent on these pollinators.

Apiculture presents itself as a melting pot irrespective of socio-political borders, strengthening farming systems and representing a resolve towards the ecosystem's basic web of life even in the time of war. Through developing a vision for a sustainable future and an enabling environment for dialogue and actions, it becomes possible to restore the balance between humanity and the natural environment even in the challenging regions. Such a comprehensive vision that is oriented towards rational government decisions, advanced technologies and multiparty approaches makes it possible to expect that the synergetic sound made by bee hives can mend the wounds of war, allowing people of today and tomorrow to believe that they will prosper.

4. Leveraging Technology for Monitoring and Mitigating Impacts on Bees

Technological improvements such as satellite information, AI, and automation are likely to increase the ability to mitigate the consequences of climate change and military action for bees and beekeeping. Such technologies allow the development of more complex systems for beehive monitoring with alerting, ensuring optimal placement of beehives, and thus enhancing beekeeping effectiveness (Fig. 2). It is worth mentioning that proposed architecture includes both visual detection of bees' well-being, optimal beehive placement algorithms and analysis services to be able to track changes in bee's appearance and availability of harmful diseases. On the other hand, audio service is proposed to track behavioral changes in each hive. A separate monitoring service, using reactive instruments, is able to present to the beekeeper all insights and helpful information about each hive, health and behavior state of bees and alarm about dangerous and unpleasant situations that can put bees at risk. Accordingly, researchers and conservationists are now able to defend against any loss of the bees and their surroundings more effectively. Satellite images and remote sensing techniques aid assessment of the impact of global climate change and wars on the number and the state of the bee colonies. Such technologies make it possible to observe environmental shifts on a wide scale and gather essential information on depletion of habitats, shifts in vegetation, and other elements that are likely to affect bee populations. For instance, satellite-controlled remote sensing can detect variations in land usage and vegetative coverage that are instrumental in foraging strategy to bees.

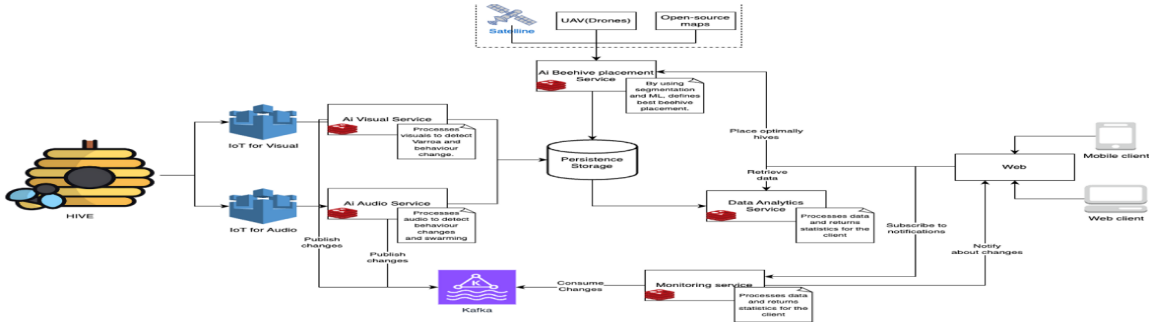

Figure 2: A proposed architecture of the IT solution, designed to improve beekeeping efficiency.

By analyzing environmental data such as satellite images, machine learning and artificial intelligence can be employed to model the reaction of bees towards climate change and war. Such technologies have the capability of identifying shifts and making predictions regarding the colonies of the bees which helps in determining the distribution of plants and their impacts on the native bee

species. AI algorithms are capable of processing large amounts of data allowing them to pinpoint trends and anomalies, consequently making it easier to establish the influence of climate change on the habitats and behavior patterns of the bee population.

The technologies assist in recognizing trends and forecasting future shifts in the colonies of bees, which aids the evaluation of the dispersal of alien species and their consequences on indigenous bee species. The AI algorithms can handle vast volumes of data to identify patterns and anomalies, which can aid in identifying the overall trend of impact of climate change on habitats and behavioral characteristics of the bee populations.

AI has been utilized to track the wellbeing and movements of bees through the evaluation of camera footage along with sensor data attached to hives. This method allows closer and more informative insight regarding bees from a colony level instead of an individual level, thus aiding in formulating and determining what might pose a threat to the health of a bee. As a result, AI can assist in determining both habitat loss and habitat gain which is especially important for conservation.

Integrating automation coupled with digitalization allows for bee population trends in a wider context of global changes such as warfare and climate change to be better understood. With the aid of multifaceted drones, information can be collected to determine and identify events affecting the bee population to help in addressing potential environmental problems. This is extremely useful when aiming to detect threats or develop long-term conservation goals. In this context, predictive analytics are useful in answering the likelihood of a specific species becoming endangered in case of deteriorating global conditions.

Artificial Intelligence especially serves as a great resource in determining environmental and human elements that can threaten bees along with other conservationists. It is also possible to come up with measures targeted at saving particular populations should any irregularities arise.

Automated technologies like electronic monitoring of hives and drones, for example, can greatly improve the evaluation of bee states and activities in real time. With these technologies, different stress-related threatening factors in a bee colony can be identified at the early stage, making it possible to carry out remedial actions, thus ensuring that great loss of the colonies does not occur. With the latest electronic monitoring devices and cameras, conditions within a beehive such as temperature, humidity as well as the levels of bee activity can be monitored wirelessly. These systems collect a stream of data that can be analyzed for abnormalities that may point to imminent threats aimed at bee health [24].

Drones fitted with cameras in addition to sensors can get pictures of hives and the surroundings and detect changes in land use patterns or vegetation in the area that may be detrimental to the survival of bees [24]. There are increasing reports that deep learning models for agricultural field segmentation are helpful in precision beekeeping. Such models can determine the optimal locations for placing beehives by modelling various environmental parameters and forecasting where hives would flourish best [24]. Climate change and military activity effects on global bee populations can also be modelled using deep learning technologies via the usage of time series and satellite imagery which can provide information on how these variables influence bee habitats and even their behaviors [24].

Real-time assessment of the state and actions of a bee colony can be done using automated systems that include electronic monitoring of hives and the use of drones that have a real-time view of hive activities. These devices would assist beekeepers and scientists in monitoring the traces of stress for the colonies, thus enabling loss prevention. It is also worth mentioning the construction of agriculture field segmentation products applying deep learning methods for the purpose of solving tasks in precision beekeeping, such as optimized beehive location [25].

Satellite image analysis and time series data, together with modern technologies such as machine learning and artificial intelligence, can be efficiently utilized in addressing the threats presented by climate change and military activities to the bees. To begin addressing such problems, for example,

there is currently a project that develops a platform that incorporates drones and deep learning techniques with satellite images to monitor bee health and beekeeping in war areas. Such approaches allow global conservation programs to define more accurately what parts of the earth should have their ecology saved.

However, the importance of assuring that bees are sufficiently insulated against the potential military and combat activities and adverse climatic conditions cannot be understated.

As much as technological resolutions are important, it must be acknowledged that factors such as climate change and military missions leave an impact on the populations of bees, which require concurrent efforts managed by researchers, practitioners, and local communities. Strategically beneficial measures are for instance, improving land ecology, creating conservation areas, and raising public awareness about the relevance of bees for economy and biodiversity [24]. This joint approach helps to make sure that the conservation and protection measures are holistic and cover active and ongoing processes.

The combination of modern electronic monitoring and UAV drones, deep learning technologies, drones and UAVs guarantee rapid monitoring and management of bee population in any location. These technologies improve our potential to anticipate stress in bees, properly arrange hives and check the health of bees in different climates. Nevertheless, these successful conservation efforts also require combined action of all interested people to ensure the appropriate use of emerging technologies to safeguard bees and their environment.

5. Conclusion

As a last remark, it needs to be reiterated that beekeeping is very important; it ensures food security to all world citizens, allows for biological diversity, and facilitates various functions of an ecosystem biology. There are crops which need bees, have them as pollinators and yield products, thereby enhancing agricultural productivity and natural ecology's balance. But, alas, bees and the beekeeping business face real obstacles including global warming, military conflicts, and other societal influences. The potential influence of global warming could harm the distribution and dynamics of bee populations, interfere with plant-bee synergies, and, ultimately, lower the output and efficacy of bee related resources. Military conflicts could severely damage the storage and processing of plants, bees or beekeepers. These trends are more vividly illustrated in Ukraine, where such military conflicts have caused systemic and catalytic instability of relations between pollinators, plants and agriculture, highlighting the need for active measures to be taken.

These challenges are abundant, yet they have the capacity to, however, be alleviated by ensuring appropriate technological interventions and the promotion of bee diversity. Existing technologies, especially satellites, usage of modern AI tools, and automation might play a key role and foster the preservation and stability of the beekeeping industry. Such technologies permit operating beekeeping under an expanded framework by enabling timely risk factor recognition and integrating the idea and execution of the information and its processing.

Combat practitioners should also utilize geographic intelligence systems and predictive analytics to undertake regular monitoring. Information which is collected in conflict-affected areas should also be employed to identify threats and efficiently utilize resources while being able to better plan for disaster reversals which is stronger and more adaptive.

For instance, AI assistants can take control of hives by predicting external factors and enhancing certain decision-making processes in a beneficial manner. Integrating these technological approaches with policy initiatives and active societal participation is crucial. Where conventional governance systems might be absent due to the ruptures caused by conflict, the mentioned integration is critical for rehabilitating and creating the necessary economic and ecological foundation for sustainable agricultural practices to exist and be durable.

The preservation of bees and their surroundings in the modern world can only be accomplished by scientists, conservationists and politicians if they cooperate. This involves promoting appropriate

land use policies, establishing national parks and reserves, and fostering appreciation among the public of the ecological and economic worth of bee colonies. Whereas the information obtained from impact evaluation can act as a guideline for national level policy formulation it can also inform specific actions in areas that are most affected so that countries such as Ukraine can benefit from knowledge and technology in restoring their ecosystems.

Most importantly, invasive bee protection and the ecosystem services dependent on them is a shared responsibility. This important species and the global food systems that it sustains must be protected by the beekeeping community, scientists, governmental structures and society as a whole. Such an integrated strategy, coupled with modern scientific innovations, will ensure beekeeping practices and biodiversity conservation in the future. Emphasizing these strategies, especially in today's context where there is great risk of climate change, social or political instability and even wars, is encouraging because it suggests a possibility of collective actions that will help ensure a healthy future for both bees and human beings.

Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT, Grammarly in order to: Grammar and spelling check, and Citation management. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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