BEEKEEPING DEVELOPMENT FOR SUSTAINABLE PRODUCTION, ENVIRONMENTAL MONITORING AND ENVIRONMENTAL THREATS

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ABSTRACT:

Apiculture, which is the practice of beekeeping, plays a crucial role in sustainable agriculture. Bees and other pollinators are essential for the reproduction and production of many crops and plants. They contribute to the pollination of fruits, vegetables, nuts, and seeds, which directly impacts crop yield and quality. Apiculture is not only about harvesting products but also about the welfare and conservation of bees. Beekeepers play a critical role in monitoring and managing the health of honeybee colonies. They strive to prevent and control diseases and pests that can affect bees, such as Varroa mites and certain bacterial infections. Responsible beekeeping practices focus on ensuring adequate food sources, minimizing stress on the bees, and providing suitable hive conditions. Apiculture contributes to sustainable agriculture in several ways. The pollination services provided by bees support the productivity and diversity of plant species, benefiting ecosystems and agricultural systems. Beekeepers often maintain diverse forage areas with a variety of flowering plants to provide bees with a rich and continuous source of nectar and pollen. Furthermore, beekeeping can contribute to local economies, rural development, and environmental conservation by promoting biodiversity, creating employment opportunities, and generating income through the sale of bee-related products.In recent years, there has been increased attention to the conservation of pollinators and the promotion of sustainable beekeeping practices. Efforts are underway to protect and restore natural habitats, reduce pesticide use, and educate beekeepers and the general public about the importance of bees and their role in food production. Apiculture combines tradition, science, and environmental stewardship, making it a fascinating and significant practice that intersects with agriculture, ecology, and human well-being. It provides a connection to nature, a source of valuable products, and a means to support sustainable and resilient food systems.

KEYWORDS:

Apiary, Apiculture, Bee, Bee Keeping, Bee maintenance, Honeybee, pollen, foraging, Hive, Biodiversity, Colony, Comb, Sustainable, Swarming

BACKGROUND:

Bees are a fundamental part of ecosystems. They play a major role in maintaining biodiversity, ensuring the survival of many plants, ensuring forest regeneration, sustainability and adaptation to climate change and improving the quantity and quality of agricultural production systems. In fact, close to 75 percent of the world's crops producing fruits and seeds for human consumption depend, at least in part, on pollinators for sustained production, yield and quality. Beekeeping, also called apiculture, refers to all activities concerned with the practical management of social bee species. Beekeeping is different from honey-hunting, which involves "plundering wild nests of honeybees to obtain crops of honey and beeswax". For thousands of years, we have known that honey can be obtained much more easily and conveniently if bees are encouraged to nest inside a man-made hive (Food and Agriculture Organization of the United Nations [FAO], 2009). Depending on the type of hive and the species and subspecies of bee, it is also possible to manage the colony to some extent. In many rural areas of the world, beekeeping is a widespread activity, with thousands of small-scale beekeepers depending on bees for their livelihoods. Social bees can provide humans with valuable hive products (honey, wax, propolis, pollen, royal jelly, queen bees and swarms) and services (pollination, apitherapy, apitourism and environmental monitoring) and play other important economic, cultural and social roles. Several species (and subspecies) of bee are kept across the world: in Europe, America and West Asia, Western honeybees are standard (*Apis mellifera*), while in East and South Asia, beekeepers keep the indigenous Eastern or Asiatic honeybee (*Apis cerana*). In the tropics, other species of social bee such as stingless bees (Melipona) are kept, mainly for honey production. Meanwhile, bumblebees (Bombus) are kept for their pollination services all over the world. Other species are kept in some areas (e.g. *Apis dorsata* and *Apis laboriosa* in Nepal and India, and *Apis florea* and *Apis andreniformis* in Southwest Asia). These guidelines aim to make beekeeping more sustainable by providing useful information and suggestions for proper management of bees around the world, which can then be applied to project development and implementation.

INTRODUCTION:

Apiculture can provide livelihoods or a source of income for many rural areas and small farms. Modern apiculture is shifting towards a farming system that is more sustainable and respectful of indigenous bees. But sustainable apiculture requires good knowledge (and training) on the proper management of bees to optimize the natural systems and resources that beekeepers rely on. Furthermore, state-of the-art technologies and innovations may strongly enhance beekeeping activities. Bees are vital to the health of the environment. Their pollination activity supports biodiversity, making it the most important agro-environmental service. In fact, the value of bee pollination is estimated to be 30–50 times greater than the value of hive products such as wax and honey. In fact, close to 75 percent of the world's crops producing fruits and seeds for human consumption depend, at least in part, on pollinators for sustained production, yield and quality with an estimated 10 percent of the total economic value of agricultural output for human food dependent on insect pollination. Unfortunately, external stressors frequently interfere with bee productivity and services. These include land-use changes, disease and pests, indiscriminate use of chemicals (veterinary medicines and/or pesticides), climate change, spread of monocultures, globalization (which implies the introduction of invasive species of pathogens), and poor management practices. All of these stressors affect not only bee health, but also the quality and quantity of bee products and services provided by the bees, reducing both income for beekeepers and the positive effect of bees on the environment.

Sustainable beekeeping helps to:

- reduce rural poverty
- increase resilience of small-scale beekeepers
- obtain high-quality products
- maintain environmental biodiversity and crop productions through pollination.

In other words, sustainable beekeeping will help to achieve the United Nations Sustainable Development Goals (SDGs). A sustainable approach, including proper procedures that beekeepers should follow to obtain high quality and quantity of bee products (live bees, honey, pollen, wax, propolis, royal jelly, etc.) are described in detail. Of course, beekeeping practices vary depending on the type of bee (*Apis mellifera spp*., *Apis cerana spp*., *Melipona spp.* or stingless bees, and Bombus spp. or bumblebees), the geographical area and the kind of beekeeping practised (the most relevant technical specifications are provided for beehives and feeding).

Good beekeeping practices and the pillars for sustainable production

Pollination: Bees are responsible for pollinating a significant portion of our food crops. By transferring pollen from the male part of the flower to the female part, bees facilitate fertilization and seed formation. This process is critical for the production of fruits and seeds, ensuring genetic diversity and crop yield.

Biodiversity: Beekeeping promotes biodiversity by providing habitats for bees and other pollinators. By creating suitable environments, such as beehives or nesting sites, beekeepers support the growth and survival of pollinators. This helps maintain a healthy ecosystem and supports the overall balance of biodiversity in agricultural landscapes.

Ecosystem Services: Bees provide valuable ecosystem services beyond pollination. They contribute to the maintenance and preservation of ecosystems by pollinating wild plants, which are essential for the survival of various animal species. Bees also help improve soil health and nutrient cycling through their role in the pollination of flowering cover crops.

Honey Production: Beekeeping is primarily associated with honey production, which is a sustainable and renewable food source. Honey is a natural sweetener that can replace artificial sweeteners and contribute to a healthier diet. Local honey production also reduces the need for long-distance transportation and promotes food self-sufficiency.

Soil fertility: Beeswax and propolis, produced by bees, have beneficial properties that can be used in organic farming and sustainable agriculture. These natural substances can enhance soil fertility, act as a natural fertilizer, and contribute to the overall health of the soil.

Crop diversification: Beekeeping can encourage crop diversification, as certain crops benefit greatly from bee pollination. Farmers may choose to cultivate bee-friendly crops or integrate flowering plants in their fields to attract bees, thereby improving the overall ecological balance of their agricultural systems.

Sustainable honey production: Honey is a natural sweetener and food source produced by bees. Beekeepers can follow sustainable practices, such as harvesting honey in moderation and leaving enough honey for the bees to feed on during winter. Responsible honey production ensures the well-being of bee colonies and maintains a sustainable supply of honey.

Education and awareness: Beekeeping can serve as an educational tool to raise awareness about the importance of bees and their role in sustainable agriculture. By teaching about beekeeping practices and their positive impact on the environment, beekeepers can inspire others to adopt sustainable farming practices and conservation efforts.

Beeswax and Other Products: Beekeeping also yields beeswax, propolis, royal jelly, and pollen, which have numerous applications. Beeswax is used in candles, cosmetics, and food products, while propolis and royal jelly are sought-after for their medicinal properties. These products offer additional economic opportunities for beekeepers.

Beekeeping is concerned with the practical management of social bee species, often within farming systems, and significantly contributes to food and nutrition security, poverty alleviation and economic growth. An innovative, sustainable, integrative approach that considers all steps of the beekeeping value chain, from ensuring a sustainable floral resource base and breeding bees, to harvesting hive products and enhancing bee services (mainly pollination services), is critical to sustainable beekeeping enterprise development. The main pillars to consider for sustainable beekeeping are the environment, genetics, practices, and education and extension services. Environment: The external environment, including environmental parameters and biodiversity, constitute the "external" factors that may influence aspects such as foraging activity, availability of flowering plants, physical stressors and ultimately, the products and the services provided by bees. These external factors include the natural environment (climate conditions). The quality and quantity of nectar and pollen sources and the diversity of the plants available to bees are fundamental to the success of beekeeping systems and are, in some cases, able to be influenced and managed by human interventions. Genetics: Bee genetics are a critical factor for production, health, and sustainability of beekeeping systems. Other than choosing local bees that can cope with the natural and managed environment, certain characteristics can be improved by breeding activities. For this reason, the conservation of indigenous bee species and local genetic diversity is important to the long-term viability of bee species and beekeeping enterprises. Locally adapted stock may also be better suited to specific environmental pressures and so more productive and sustainable in these environmental systems than introduced bee species or genotypes. In most cases, autochthonous bees should be favoured over allochthonous species. Practices: These include all the beekeeping activities carried out to manage bees for a particular outcome (such as honey production, conservation or pollination services), including appropriate housing, the application of technologies and innovations, good beekeeping practices (GBPs) and biosecurity measures in beekeeping (BMBs). Used in combination, these practices are fundamental to resilient and productive beekeeping systems. GBPs are all those general activities that beekeepers apply in on-apiary production for optimal health of humans, bees and the environment. They are the basis for application of the BMBs, which include all those operational activities implemented by beekeepers to reduce the risk of introduction and spread of specific bee disease agents. Education and extension: These services are fundamental to improving beekeepers' skills on sustainability, helping them to acquire appropriate knowledge and technical skills on GBPs. Effective and ongoing training activities and extension are important to uptake and success in beekeeping systems and can also provide opportunities for beekeepers to build partnerships with researchers, extension units and other relevant authorities to strengthen the honey value chain and collectively answer the sector's new challenges. In conclusion, an impactful approach to beekeeping should consider all these pillars to ensure the development of a sustainable, resilient and competitive apicultural sector which will allow beekeepers to improve the productivity, profitability and sustainability of their enterprises. In this way, the beekeeping sector can become more resilient to shock, seasonality, and stressors, provide income-generating opportunities without exacerbating environmental degradation, enhance crop production, and become more efficient in providing profitable bee products and services.

Beekeeping development: integration of knowledge

Every project must ensure environmental, financial and social sustainability, and the bees and their hives are only one part of the story. Correct situation analysis and a good understanding of markets and trade are crucial in using apiculture to move people out of chronic poverty.

CONCERNING BEES

Use only local species or subspecies of bees and learn about local bee biology and behaviour. Honeybees naturally live inside tree cavities, or in beekeepers' hives. The commonly used species is *Apis mellifera*, which occurs naturally in the north of the Arctic Circle, and throughout Europe, the Middle East and Africa. This bee has been introduced worldwide, and is now found almost everywhere. There are many different subspecies with different characteristics that enable them to survive across widely varying climates, from -20 °C in European winter to 40 °C in the Middle East. That said, wherever there are flowering plants, there are bees, and many other bee species produce honey, beeswax and propolis (as discussed in later chapters), on which people build livelihoods. Many developing nations are in tropical regions of the world, and tropical bees have biology and behaviour hugely different from bees that have evolved to live in regions with temperate climates. As such, apicultural techniques that work well in industrialized nations in temperate climates are not necessarily well suited to tropical climates and remote rural areas. Bees live freely in nature; they cannot be contained like other animals, and feed and mate freely. Never introduce bees from another region – this is how honeybee parasites (like Varroa) and viruses have spread in recent years. Because bees mate naturally in the wild, there is no point in introducing bees since it needs to be done continuously, year after year, which is not sustainable beekeeping. It also interferes with native bee populations that have evolved to thrive in local conditions. However, because people make money from selling bees and extolling one type over another, much unnecessary and damaging trade and movement of bees takes place. If you are confused or unsure about the information available locally, contact a reliable organization like Apimondia for impartial advice.

SITUATION ANALYSIS

Beekeeping is commonplace in poor rural communities worldwide where it is a resilient, sustainable and low-risk activity. However, people and apiculture are not the same everywhere, and subsistence beekeeping does not necessarily create wealth. Try to identify the true constraints, if any, that existing local beekeepers are facing. Accept that long-lasting development takes time, and be prepared to invest in training so that skills are available in the long term. A truly sustainable beekeeping project will build on local beekeeping skills, expertise and resources, and provide training and follow-up support for at least two years. It will be necessary to make decisions concerning the delivery of training and follow-up support. For example, for Bees for Development's projects in Ethiopia, a model of lead beekeepers and followers works well. Elsewhere, more formal training delivered by local skilled beekeepers has worked better than a model of master beekeepers who are expected to pass skills to new beekeepers; this has proved highly effective in Ghana. It is important to find the best model for each context, which will depend upon several local factors including cultural norms, the social fabric of village life, prevailing beekeeping skills, and transport resources.

SCALE AND EFFICIENCY

Beekeepers need business skills to weigh up the implications of direct costs, selling prices, indirect costs and volume. Enterprise analysis has revealed that focusing on volume as opposed to price per kg, which is the usual approach, can be key to increasing total yearly income from an apiary. Projects should invest in building the competent business skills of beekeepers.

TECHNOLOGY

Many governments implement plans for the modernization of agriculture, and a plan for the modernization of apiculture is also a good idea. There have been many interventions that primarily seek to change the types of hives that beekeepers are using, in the belief that this will lead automatically to more honey, better-quality honey and increased productivity. While it is expected that changing technology will result in poverty alleviation, there has been little evaluation of the change these interventions have achieved. Where the expected change has not occurred, too often it is it blamed upon insufficient training, the weather or another variable, without questioning whether attempting to change technology is indeed the correct approach. Projects focused on provision of equipment are most profitable for the businesses making and delivering equipment, and consultants providing teaching on their use with bees in the consultant's own world region. Many African nations (such as Ethiopia, Tanzania and Zambia) are successfully exporting high-quality honey and/or beeswax to be sold within the EU and other world markets, and meeting the world's strictest criteria for these products. Every drop of this honey and beeswax is harvested from local-style hives, which are the gold standard in simple, cost-effective, natural and sustainable beekeeping. Frame hives like the Langstroth hive, which was patented by the Rev Langstroth in 1852, are sometimes referred to as "modern" hives in Africa. However, it is their low-cost, easy-to-make, widely available and efficient local-style hives that should bear this name. We now understand that the reason large populations of healthy honeybees are still prevalent in Africa is the widespread prevalence of simple, natural beekeeping in simple, cylindrical beehives. Logs, reeds, grass and clay are the typical materials used to make local-style beehives. The usual design is a cylinder, which offers honeybees an attractive nest space. With no movable parts, the bees fix their combs to the walls of the cylinder. Tried and tested over many years, these types of hives are shown to function efficiently, and because these hives are made from locally available, natural resources, they are cheap and accessible to even the poorest people. Poor farmers are widely encouraged to commercialize to increase their incomes and many people assume that commercialization calls for a change in technology. The abandonment of simple local hives is encouraged in favour of so-called "modern" hives. This kind of intervention results from insufficient analysis of the situation and is often an inappropriate approach. Cost benefit analyses sometimes show that a beekeeper can pay back the cost of a frame hive after a few years, but these forecasts are rarely based on actual field data. Svensson (2002) reports on the failure of beekeeping projects developed on the basis of poor analysis and false projections. Even if a beekeeper can pay back after four years, for example, they do not have the money to invest in the first place and are forced into a debt situation. In a paper describing the producer-owned company North Western Bee Products in Zambia, Wainwright (2002) reported that "it would be difficult to manage the African bees in these hives. Most importantly, the high capital cost of the hives would burden the beekeeper with debts would be unable to repay." Conversely, giving out free hives is never sustainable either. Beekeeping projects have become popular with donors and non-governmental organizations (NGOs), and for good reason. However, the demands and expectations of donor-funded projects drive NGOs to design projects with visible and measurable outputs. It is easy to draw up a budget for a certain number of hives and once delivered, they can be photographed and counted, helping the NGO to prove that it has implemented the project as planned. It is much harder to see and measure a new skill or a new market link. Spending money on hives also pushes up the costs of projects without increasing complexity of design or delivery. For implementing organizations surviving on a percentage overhead of total project costs, simple yet expensive projects are attractive. However, development projects often wrongly assume that “modern” hives will help people earn more money from beekeeping. When considering quality, honeybees living in frame hives and those living in local-style hives are identical, feeding on the same flora, in the same place, making the same products. What differs are the harvesting and post-harvest handling methods. Some beekeepers using local-style hives harvest carelessly and offer low-quality products to the market. However, closer analysis shows that the market in which they sell accepts the standard of their products, and beekeepers have no experience of different market requirements. This is a valid and useful area for project intervention. Because beeswax is recycled in frame hives, the overall harvest from frame hives constitutes more honey and less beeswax than is obtained from local-style hives. However, beeswax is a useful product and in many ways an easier product to store and sell than honey. It is also currently in high demand on the world market. Recycling comb has no economic benefit when there is significant income to be generated through the sale of beeswax, and foundation is either expensive or not available. One beekeeper in Uganda said, “I was advised to provide foundation for my bees because then they can spend more energy making honey, and I can get more honey more quickly for selling.” His neighbour replied, “All bees need wax comb. If I have to provide foundation, I have to take money out of my pocket to buy it; I would rather the bees made it for themselves for free.” Furthermore, while frame hives enable combs to be inspected and placed back in the hive, tropical bees are often quick to abscond when manipulated. Frame hives also enable combs to be replaced following the extraction of honey, using a centrifugal extractor, but because centrifuges are expensive and may only be used perhaps once or twice a year, they must be stored and shared at a central location. This means boxes full of frames must be transported to the processing centre on foot or by bicycle, an expensive, time-consuming and dusty exercise.

MARKETS AND TRADE

Before beginning any intervention, do all that you can to understand the local market system. Once your project begins, build a supporting environment and listen to beekeepers, evaluating and recording progress. Commercialization of beekeeping means achieving scale and efficiency. True production costs must be calculated to ensure profitability. Local-style hives are more profitable than frame hives because they are so cheap to produce, and despite assumptions and statements, there is no evidence that frame-hive beekeepers in sub-Saharan Africa harvest greater total volumes of honey than beekeepers using large numbers of local-style hives. Markets that are accessible, rewarding, reliable and fair will encourage beekeepers to invest more in beekeeping. Supply chain problems are very typical in poor nations and stem from poor market information and linkages, lack of working capital, lack of containers, low investment and poor communication. Projects should therefore focus their efforts on tackling these problems.

HARVESTING AND HANDLING FOR QUALITY

Any beekeeper who follows simple, good practices can produce high-quality honey, packaged and labelled as required by supermarkets. All projects should invest in training beekeepers and collection-centre staff on the correct methods of harvesting from any type of hive, record-keeping so that product traceability is made possible, and correct post-harvest handling and storage.

Bees and the environment:

Bees depend heavily on the environment. It has a direct impact on not only bees' products but also their health. The bee colony sources food from its environment and, in return, contributes to the function and health of the environment through vital pollination. At the same time, bees and hive products can be strongly affected by pollutants present in the environment. For these reasons, beekeepers should always carefully consider where they place their bees. Excluding cases where bees are used to monitor the environment, it is in the beekeeper's best interests to choose the best possible environment for the hive. Proper hive–environment management requires skills that go beyond bee management and often involves forming partnerships with other stakeholders in wider landscape management.

ENVIRONMENTAL INPUTS

The environment with which bees interact can be considered on different levels, from the regional level to the local level, and the inputs are more evident the closer they are to the hive. Some inputs depend on how far the bees travel and are therefore limited by their maximum flight distance, which is about 3 km from the apiary. Some inputs depend on how far the bees travel and are therefore limited by their maximum flight distance, which is about 3 km from the apiary. The impact of climate on hives is linked not only to the regional climate but also its physical features and the microclimate where the hive is located. Physical features include the topography of the terrain, its orientation and the structure of the surrounding vegetation. These determine the hive's exposure to the sun, shade, wind, humidity and frost, and create a local microclimate which impacts the hive's functioning – even its ability to survive. Depending on the regional climate, these local characteristics will have a more or less important role in mitigating adverse climate effects. With respect to the use of different types of chemicals as part of the agriculture practice, honeybees and other pollinators are not the target insects, but they are the recipients of all the direct and indirect effects of them. These types of chemicals/ pesticides include insecticides, acaricides, fungicides, herbicides and antibiotics and their effects on bees start from acute poisoning and instant death of adult bees and developing forms, to the chronic and fatal effects which are various and sometimes very unfavorable and difficult to quantify. Intensive agriculture practice usually requires higher quantities of pesticides to be used. However, in the last decades we see a tendency for reducing the total amounts of the chemicals used, still honeybee losses are increasing due to the use of the new families of more toxic insecticides (e.g. the neonicotinoids). The impact of pesticides on pollinators is vast, clear, and increasingly well documented. Honeybees' and other pollinators' decline, driven by pesticides, poses serious threats to the environment, ecosystems, and to human health. The richness of the surrounding vegetation is also crucial because bees must be able to find their vital nutritional resources (nectar, pollen, honeydew, water etc.). These resources must be available in sufficient diversity, quality and quantity throughout the bee season (which may be with or without wintering) to ensure the survival and reproduction of the colony. Bees will find plenty of nectar (for their sugar needs) in certain flowers and plenty of pollen (for their protein needs) in others. Depending on the time of year and the specific functions to be carried out in the colony (such as feeding the brood, building up stocks or increasing the workers' longevity), the bees' needs can differ and therefore require different, sometimes specific, plant species. However, each flower has a given flowering season and cannot meet the needs of the bees over the entire prospecting period. Bees must therefore be able to find plants with staggered flowering, at a distance accessible from their hive, throughout their period of need. This staggered flowering will also be of interest to the beekeeper, who will be able to collect honey that has a distinctive flavour and characteristics due to the specific flowers involved. Because of all these factors, the environment must be sufficiently biodiverse within natural and semi-natural areas, and agricultural landscapes must have varied cultivation, ideally mixed with surrounding natural areas for forage.

HOW BEES CONTRIBUTE TO THE ENVIRONMENT

Bees' fundamental contribution to the environment is pollination of flowers. Many flowering plants, including wild species and many food crops, are pollinated by bees. It is estimated that approximately 80 percent of all flowering plant species are specialized for pollination by animals – mostly insects. As bees collect nectar and pollen from flowers, they transfer pollen from the male part of the flower to the female part, which enables the flower to produce fruit (fructification). Fruit production is essential for the reproduction, and therefore for the renewal and sustainability, of terrestrial natural ecosystems. When fruits produce new plants or are consumed, they ensure the functionality of the ecosystem. By moving from flower to flower, bees also allow for cross-pollination of flowers, which promotes genetic diffusion and plant diversity. This genetic diversity is also a source of functionality and resilience in ecosystems. For some flowers, cross-fertilization with other individual plants is even obligatory and makes bees all the more indispensable. Honeybees have been shown to have a significant effect on the pollination of flowering crops. Not only do they increase agricultural yields by increasing the proportion of pollinated flowers and, therefore, fruits and seeds, but they also improve the quality of fruits and seeds by the way they pollinate flowers or inflorescences (this has been proven for strawberries and cocoa). As pollination declines, beekeepers are increasingly being asked to position beehives near fields and are being paid for this service. It should be noted that on a global scale, the economic value of pollination (for natural ecosystems as well as for food security and livelihoods) is estimated to be far greater than the economic value of bee products. Nevertheless, bee products are often the source of the beekeeper's motivation and contribute to food security, health, income and other local services. Bees and their products can also participate in the food chain of their environment. Bee reserves can undergo predatory assaults (from both larger animals and insects) and bees themselves can be eaten by birds, hornets or parasites, for instance.

ENVIRONMENTAL THREATS

The climate has an influence on both bees and the vegetation on which they depend. It affects the physiology and activity of bees and those of vegetation (namely diversity, production and phenology). Climate change can cause flowering to shift over time, and reduce the period of nectar and pollen availability for bees. This situation can become critical – especially if the number and variety of species is reduced – with shorter flowering periods, longer gaps between flowering periods and insufficient products in terms of quality and quantity. The clearing of natural areas rich in flowering plants (from herbs to trees) around or within agricultural landscapes, reduced crop diversity and increased plot sizes all reduce biodiversity and thus the availability of satisfactory resources for bees, causing pollinator and bee decline. Chemical treatments and overuse or improper use of pesticides also reduce diversity and in some cases are even directly implicated in bee mortality. The same is true for invasive species that alter biodiversity and bee diseases (e.g. varroosis, Aethinosis, nosemosis), both of which are consequences of globalization. Honeybees can also have a negative influence on their environment. The honeybee has the advantage of being a generalist, which means that it can use nectar and pollen from a large number of flowers of different plant species. Some local bees or wild pollinators, on the other hand, are more particular or less adaptable. A reduction in plant resource diversity can either cause their host plant to disappear, or increase competition between pollinators for their host plant. In many cases or on certain plants wild pollinators have been found to provide better pollination services than honeybees. For some flowers, honeybees are not the most suitable insects for pollination and can even damage the reproductive organs, compromising fructification. There are also cases where the mass arrival of honeybees leads to competition with wild bees and aggressive behaviour. For all of these reasons, beekeepers must make careful and balanced decisions about where they place their hives.

HOW TO OPTIMIZE THE ENVIRONMENT FOR BEES AND OTHER POLLINATORS

As highlighted, the availability of resources in the environment is crucial for bees. This is also true for wild pollinators, which use the landscape for forage but also for nesting sites. The availability of environmental resources relies not only on the richness of habitats in the surrounding landscape but also on the connectivity between these habitats. Fragmentation in the landscape, which isolates habitats, has a negative effect on pollinators because it restricts their movement. Pollinators benefit from pollination-friendly landscape management practices such as intercropping and nectar-rich crop provision, as well as hedgerows or other larger natural or semi-natural regions, especially when diverse natural habitats are otherwise limited and isolated in plant production systems. Meanwhile, it is very useful (though difficult) to evaluate pollinator diversity and abundance in the landscape, learn about their biology, tutilize and integrate potential indigenous local knowledge, and monitor their populations over time. Thankfully, resources exist to help determine populations, establish monitoring protocols, and manage landscapes sustainably with an eye towards increasing pollinator health and provision. In cases where foreign bees are introduced into an environment, the number of colonies is increased or there is a mass arrival of bees, these evaluation and monitoring protocols and tools are even more important and should be obligatory to prevent environmental degradation. User-friendly monitoring tools exist for both managed pollinators (e.g. Hivelog, HiveTracks) and wild pollinators. Beekeepers are important stakeholders in the environment and can play a major role in landscape management.

Through their regular observation of nature, their knowledge, their contact with other stakeholders, their legitimacy with shared benefits from their bees and partnerships, and awareness-raising, they can improve the environment and convince others to contribute as well. Many different actors can help manage the landscape, including beekeepers, farmers, pastoralists, foresters, local and indigenous knowledge holders, watershed managers, and scientists. At the landscape level, it is recommended to maintain and promote some of the key components on which pollinators depend and ensure connections between them, especially to prevent the creation of long distances without favourable habitats. This can be achieved by creating natural areas with native vegetation with dense and diverse flowering plants to serve as nectaries. In agricultural and urban landscapes, natural areas can develop along streams, around or within fields or inhabited areas with hedges, trees and uncultivated areas or woods. Pollinators may also benefit from the interactions between agroecosystems and weed management when agricultural systems are managed with an ecological approach. Many pollinators depend heavily on forests for nesting and forage, and the extent of forests in a landscape impacts pollination services for many wild plants and crops. Maintaining and promoting landscape heterogeneity and patchiness with small plots of varied vegetation is also recommended, using varied management that takes into account ground-nesting bees and flowering periods. This increases the diversity and connectivity of flower and pollinator nesting resources and habitats. It is important to ensure that ecosystems remain functional across all seasons, especially where honeybees are moved seasonally, so that pollination services are properly maintained. In farming, in addition to these landscape practices, heterogeneity and connectivity in particular can be promoted within fields by combining spatial diversity and temporal diversity. Spatial diversity can be achieved by growing diverse crops distributed between plots of limited size, with varied agricultural practices to create diversity in vegetation, flowers and soil. Temporal diversity can be achieved by growing crops that flower at different times, with staggered mowing or harvesting and intermediate flowering crops. In forestry, forest management can restore degraded forests, improve spatial and temporal heterogeneity in tree communities and habitats, and have significant effects on pollinator abundance and diversity. Heterogeneity can be promoted through selective logging, thinning or coppicing; regulated mowing or grazing, or prescribed burning, keeping a mosaic of burned and unburned areas. Keeping dead standing and lying wood in forests and ensuring sufficient bare ground can particularly benefit cavity-nesting and ground-nesting bees. Bees are amazing creatures not only because of their organization and their collective intelligence, but also because they provide an essential service to nature and humans through pollination. Keeping bees provides food and income as well as pleasure for many beekeepers. However, beekeeping must integrate bees with the environment for the benefit of both if it is to be sustainable. Beekeepers need to be aware of the environment and the impacts their managed bees can have locally. They have a responsibility to ensure that their honeybee colonies do not harm the environment, and to adapt their practices so as not to disrupt its natural balance and ensure sustainability. They have the capacity to intervene in landscape management and improve the environment, promoting biodiversity which benefits bees, other pollinators and nature in general. From the other side, farmers need also to be aware and alert of the detrimental effects the pesticides and all the chemicals products used in the environment have on bees. The ministries of all countries must ensure that pesticides coming in to the market have no harmful effects on human health or animal health as well as no unacceptable effects on the environment. Beekeepers, farmers and other stakeholders together with policy makers should act responsibly to protect biodiversity, the quality of the environment and increase the level of protection for bees. That will be probably the only way to ensure food security for the future generations.

Environmental monitoring with honeybee colonies

Humans need to assess environmental health and possible environmental changes over time. They fulfil this need with chemical, physical, chemico-physical, electronic and biological assessments. Generally, environmental pollution is monitored at pre-determined points, fixed automatic monitoring stations, or mobile stations. In the case of air pollution control units, the system directly measures the concentrations of pollutants in air samples taken from the atmosphere: when the threshold levels of certain pollutants established by law are exceeded in one or more locations, measures are taken to limit these emissions. However, this type of monitoring has serious limitations as automatic control units have high purchase and maintenance costs. It should also be noted that quantifying the concentrations of individual pollutants alone does not paint a global picture of environmental degradation, as the various substances present can act synergistically, amplifying their effects on living organisms. Biological indicators allow these synergistic interactions to be taken into account and in some cases, reveal the presence of substances illegally released into the environment. Due to their biological, morphological, physiological and ethological characteristics, bees are considered reliable bioindicators of environmental pollution (for example, pesticides, polyaromatic hydrocarbons, heavy metals and radionuclides). Bees can be classed as mobile sensors: during foraging activities, foraging bees move tirelessly over an area of about 30 km2 (3 km from the hive), sampling all natural resources – vegetation, soil, water and the air. Moreover, their hair is particularly good at retaining the materials of the different natural resources they come into contact with. Considering that a healthy honeybee hive may contain approximately 8 000 foragers and that each honeybee, during the productive season, visits a thousand flowers a day, a colony of bees makes approximately 8 million microwithdrawals every day, without considering the transport of water, which on hot days can even reach a few litres. Bees detect and reveal contaminants in the environment in which they live in two ways: directly, through extensive mortality, as in the case of insecticides or other pesticides, and indirectly, through the presence of pollutant residues on and inside their bodies or in hive products (honey, pollen, wax, propolis and royal jelly). Bees can be used as biological indicators of the quality of the environment. Environmental monitoring with honeybee colonies involves the colony being used as a biosampling tool to detect environmental contaminants. For optimal usage of honeybees as a biosampling tool, their possibilities and limitations must be considered. The basic method of using honeybee colonies for biomonitoring of the environment is to have the foragers collect the contaminants as biosamples, bringing them into the hive, and to subsequently invasively or non-invasively sample the colony for target contaminants Honeybee colonies biosample the environment as they forage for food. Along with pollen, nectar, water and propolis, contaminants present in flowers are collected unintentionally. Contaminants on leaves and in water sources can also be collected in a similar manner, alongside honeydew, extrafloral nectar and water collection. Contaminants end up in flowers and on leaves through airborne deposition, drift, direct spraying, and via uptake of systemic pesticides. Contaminants in flowers manifest themselves in many ways: loose particles can attach to the flowers, lipophilic contaminants can bind to the wax layer of pollen, and other contaminants can disperse or dissolve in nectar, honeydew and guttation fluid. Nectar and pollen foragers behave differently. Nectar foragers mainly pick up the contaminants in the nectar but particles in the flowers and on leaves also stick to their hair. This cohort barely grooms itself during foraging, leaving plenty of pollen and possible contaminants in their hair and on their feet. Dissolved and dispersed contaminants in the nectar are transported in their honey stomachs. Depending on the particle size, contaminants may be filtered out into their proventriculi and end up in their faeces. Pollen foragers, however, groom themselves continuously to brush off all the pollen and the contaminant particles in their pollen baskets. Nevertheless, some pollen and contaminants remain in their hair and on their feet. Not all flowers are both suitable nectar and pollen plants. Based on the annual nectar and pollen need and given the fact that the maximum weight of pollen and nectar collected per flight is about the same, there are approximately five times more nectar foragers than pollen foragers. Additionally, there is always a cohort of scout bees looking for new food sources, bringing in nectar and pollen and possibly contaminants. Therefore, it is obvious that nectar and pollen foragers may forage around different plants and carry different contaminants on different locations inside and on their bodies.

Lastly, all the foods that are collected – and therefore the contaminants – are brought into the hive. Nectar is partly stored in the cells and partly consumed directly by the foragers and the hive bees. It is also fed to the pupae. Some of the dissolved contaminants can bind to the beeswax in the cells. Part of the stored nectar is turned into honey. This nectar is passed around the colony in a process called "trophallaxis". Pollen is brought to cells directly by the pollen foragers. In the colony, all these pathways combine and are completed with the additional exchange of particles trapped in the hairs, via physical contact and auto- and allogrooming, resulting in the dissemination of nectar, pollen and contaminants to every single bee in the colony within a day. To gain insight from the colony, be it regarding food sources or contaminants, the colony is sampled. The sampling methods depend on the target material being examined. Sampling methods must involve taking great care at all times to ensure that target contaminants are collected properly. Two prerequisites for monitoring studies involving the sampling of honeybee colonies are that disturbance of the colony is minimized to keep the biomonitoring tool intact and that the methods used are robust. Sampling of the honeybee colony is carried out either invasively (at the expense of the colony) or non-invasively. Aside from the ethical issues concerning killing honeybees or taking their food, invasive sampling also disturbs the delicate balance between disruption and alteration of the test system, and its natural buffer capacity for the bee colony. Furthermore, bee samples – especially those taken from the flight entrance – are very difficult to standardize due to their inhomogeneous distribution and significant variations in the contaminant load. In-hive bee sampling overcomes this problem as contaminants are distributed among all the bees, but in this case, the sample size is critical. If the sample size is too low, this can result in non-detectable contamination concentrations. If it is too high, it will disturb the monitoring tool. The application of passive samplers overcomes these sampling issues. Passive samplers physically or chemically bind the molecules that pass by or through the sampler without impacting the environment. The first generation of passive samplers used in honeybee studies were in tubes placed outside the hive entrance, so that as bees entered and left the hive, they would leave part of the pollen and contaminant load in this passive sampler. The disadvantage of passive samplers placed outside the hive is that they are exposed to the elements, which could affect their binding and contact capacity. Furthermore, the passive samples and contact are limited to the bees entering and leaving the hive. In-hive passive samplers are not exposed to these climatic variations as in-hive conditions are relatively constant. All bees in a colony carry a portion of all the particles circulating in the colony and the amount present in an individual bee is often undetectable, but since bees are continuously moving around the colony, in-hive passive samplers – for example, the APIStrip in a bee lane – will be touched by numerous bees during their exposure period. The longer the period, the more contacts will be made with the samplers. Studies with plant pathogens and pollen revealed that particles entering the colony once will be diminished significantly in the two weeks after they are introduced, due to dilution, because of the influx of newborn bees and the natural mortality of old bees. Therefore, in addition to the correct sampling method and tools, time is a significant factor in using honeybee colonies for biomonitoring. There are several ways to use honeybee colonies for biomonitoring, as presented above, and the general best practice for this activity is to follow a strict protocol that ensures a uniform “sample to data” route. This requires proper sample collection, conditions, storage, size, coding and code handling, shipment, analysis, recording, and archiving. This should all be based on good laboratory practice, particularly the traceability of samples from sampling up to the presentation of the final data and the persons responsible along this route. The final product of biomonitoring and subsequent invasive or non-invasive sampling of honeybee colonies depends on the matrix and the study objective. The data generated are colony data that must be “translated” into data on environmental conditions. Invasive sampling particularly requires thorough consideration of the consequences as well as where to sample, how to sample and how large the sample size should be. Certain biomonitoring equipment is already available, such as the previously mentioned APIStrips and pollen traps. A prerequisite for biomonitoring is that biomonitoring tools the honeybee colony must not be affected or agitated by the biomonitoring equipment. To sample pollen, use a pollen trap. No specific beekeeping equipment is required for invasive sampling.

CONCLUSION

The field of research into translating honeybee colony biomonitoring data into data on environmental conditions is relatively new and needs to be further developed. There are several variables that you should consider if you are looking to use bees and/or hive products to study contaminants:

• Meteorological events: Meterological events, such as rain and wind, can clean up the atmosphere or transfer contaminants to other natural resources.

• Seasonality: The nectar flow, which varies throughout the seasons, may or may not dilute the contaminants, and bees – which are opportunistic insects – tend not to circulate in strong nectar areas.

• Botanical origin of honey: Open flowers are far more exposed to contaminants than closed flowers as nectar is generally more protected by the corolla of closed flowers.

Chemico-physical characteristics of the pollutants being studied: The concentration of pollutants in hive products differs depending on their fat or water solubility (for example, pesticides are easier to find in beeswax than in honey). Project planners that would like to use honeybees for biomonitoring purposes should note that long-term biomonitoring programmes, in addition to increasing scientific knowledge, provide crucial information for environmental policies and should therefore be considered fundamental components of economic policies.

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