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PP-305 [Beekeeping Technology and Quality]

Translating bee-collected signals into ecosystem indicators

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INTRODUCTION

Biodiversity loss, climate change, and pollution are accelerating ecosystem decline, yet monitoring remains sparse and expensive. Honeybees (Apis mellifera) naturally sample their environment through foraging, making each hive a potential ecological sensor. Advances in AI, edge computing, and low-cost connectivity now enable real-time audio and video analysis at hives, transforming them into scalable biodiversity observatories. This approach extends beyond colony management: it provides a novel tool to detect ecosystem stressors, guide restoration, and support biodiversity recovery.

OBJECTIVES

Develop science-based indicators that translate bee-derived observations into quantitative measures of biodiversity, habitat quality, and environmental stress. While digital monitoring cannot fully capture biological complexity, it can generate efficient and interpretable proxies. The goal is to build a digital platform that reliably identifies these indicators, communicates them in a stakeholder-relevant format, and ultimately triggers informed ecological action.

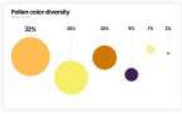
METHODS

Beehives (Apis mellifera) were equipped with multi-modal sensors (weight, temperature, humidity, audio, video). Core sensors recorded every 1–5 minutes, while audio/video were summarized at 15–60 minute intervals. Continuous data were evaluated against literature-based thresholds and indices, translating bee-derived signals into standardized environmental indicators. Metrics were aggregated across hives at the apiary level and organized from specific measures to broader ecological themes. To contextualize trends, indicators were complemented with beekeeper/farmer observations and external datasets (e.g., weather, registries).

RESULTS 1: Beehive data to environmental indicators

Pollen diversity

Foragers collect pollen across 500–700 ha daily, serving as natural botanical samplers. Computer vision classifies pollen pellet colours into groups, and the Shannon Index is applied to these groups to measure diversity. Colour variety has been validated as a proxy for floral species richness (Conti et al., 2016). In diverse landscapes, ~6 pollen types are detected per day (Brodschneider et al., 2021). Lower values indicate dominance by few floral sources (e.g., monocultures), while higher values reflect species-rich, balanced communities.

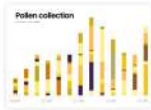


Bird diversity

Birds are attracted to hives, where their calls are recorded and classified by automated recognition. Weekly species detections are used to calculate a Shannon diversity index as an indicator of bird diversity. As established bioindicators, birds reflect habitat structure, pollution, and resource availability (Gregory & van Strien, 2010). Increasing scores signal recovery of ecological complexity and complement pollen-based diversity.

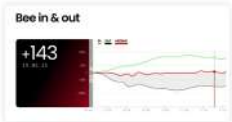
Food access

Continuity of nectar and pollen supply is tracked through hive weight (nectar, corrected for non-nectar changes) and pollen inflow. Signals are normalized to colony activity, ensuring declines reflect true environmental shortages. A benchmark-based score indicates food access: stable values mean sufficient resources, while drops point to flowering gaps or habitat degradation. Reduced food access weakens colonies, limits pollinators, and lowers plant reproduction, with cascading effects on yields and ecosystem stability (Maggi et al., 2023; Potts et al., 2016).



Toxicity

AI counters track abnormal forager losses by comparing outgoing and returning bees. EFSA (2013) defines >10% daily mortality at the colony level as acute toxicity, with smaller but persistent deviations indicating chronic effects. Adapting these thresholds to forager mortality allows daily rates to indicate area toxicity risk. Because bees transport contaminants in nectar, pollen, and water, forager mortality serves as a sensitive bioassay for detecting pesticide or pollution events in real time (Girotti et al., 2020; Mair et al., 2023).



Invasive species and diseases

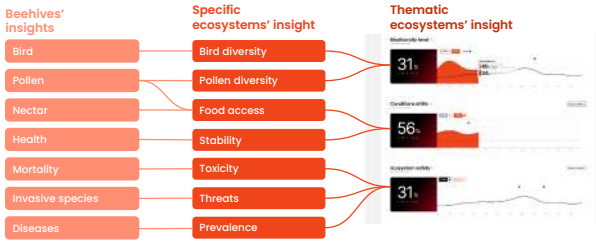
This indicator captures emerging biological threats to pollinators by combining automated detections (e.g. Asian hornet, Nosema, Deformed wing virus) with manual field inputs. Risk is scored along two axes: richness (number of different stressors) and persistence (duration of detection). These dimensions were chosen because both breadth and continuity of pressure shape ecological impact. Invasive species and diseases are well-documented drivers of pollinator decline and ecosystem instability (Helen E. et al., 2024). Persistent or rising scores denote escalating ecological risk.

Environmental stability

Colonies maintain brood areas at 33–36 °C with < ±1 °C daily variance (Stabentheiner et al., 2010; Minaud et al., 2024). Continuous temperature data are expressed as a thermoregulation score, where deviations may result from climate extremes, human activity, colony health, or poor management. Chronic deficits observed despite good beekeeping are strong indicators of environmental stress. This metric links colony health with the environment's capacity to sustain stable life processes.

RESULTS 2: Specific to thematic indicators

Standardised indicators targeting specific environmental aspects were combined into broader categories to improve monitoring and interpretation. Pollen and bird diversity were aggregated into a biodiversity indicator reflecting species presence. Food access and stability metrics were merged into a habitat quality indicator that assesses resource continuity and species viability. Invasive species, diseases, and toxicity were integrated into a safety score highlighting environmental threats. Together, these composite indicators provide continuous insights into ecosystem dynamics. Although they do not capture all species, drivers, or stressors, they deliver actionable signals that support rapid responses to major challenges, allow progress to be tracked, and guide restoration efforts.



DISCUSSION & CONCLUSION

Bee-derived indicators offer quantitative, literature-anchored measures of ecosystem state. They support:

- Standardised assessment of diversity, resource continuity, stability, and stress.
- Detection of abrupt events (e.g., toxicity spikes) and sustained pressures.
- Cross-site and temporal comparison using defined thresholds and normalization.
- Aggregation of specific insights into thematic summaries for broader interpretation and higher-level monitoring.

These results can complement existing ecological monitoring and reporting practices.

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PP-305 [Beekeeping Technology and Quality]
Honeybees, edge computing & AI, the connected hive journey continues beyond beekeeping

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Beefutures

IOT technologies applied to apiculture celebrate close to 20 years old anniversary. Two decades later, bees are still dying at an accelerated pace, and managing bees digitally has not yet delivered its promises.

The fight with the varroa mite continues, new enemies keep coming, our agriculture model has not fundamentally changed, and human living space keeps expanding... in the meantime, the globe´s temperature continues breaking new records and disturbing Nature and life each year more profoundly.

What if the promise of technology is not about managing honeybees more efficiently but helping us decode the reasons for the bee decline and the impact of environmental stressors on ecosystem health and biodiversity?

The technology has evolved massively for the just last 5 years; with the emergence of AI and more powerful computers, new doors are opening to monitor and comprehend the world of bees and their interaction with the environment.
Processing video and audio in real time on a small computer was not within reach 10 years ago, today it is. Powered with solar energy and connecting to cellular networks, now even accessible in remote locations, monitoring bee traffic from the entrance of a hive, listening to the surrounding of a hive, following the health of bee colonies and their response to climate incidents and human actions becomes possible at scale.
With spatially diverse and continuous data, a new era of ecosystem and biodiversity monitoring and reporting seems possible with honeybees. Data sampled from hives can now extend beyond just the bees, providing insight into floral abundance and diversity, surrounding birds diversity, pollinator pathogens and invasive species prevalence. Every apiary can become a monitoring station of the local ecosystem's health and biodiversity, empowering us to understand the macro and local challenges. New insights can help develop new rehabilitation strategies and assist growers and food brands in the journey towards regenerative agriculture.