EIP-AGRI Focus Group

Bee health and sustainable beekeeping

MINIPAPER 05: Monitoring

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1. Introduction

Honeybees are highly influenced by environmental conditions and quality, beekeepers' management practices, socio-economic conditions and policies adopted for cropping and land use. The beekeeping sector lacks suitable tools for risk assessment and decision making which can be used by relevant stakeholders (e.g. beekeepers, risk assessors, policymakers). To support management decisions for the beekeeping sector multiple types of variables must be monitored.

The aim of this minipaper is to summarise which variables can be collected
(i) by beekeepers or other personnel manually,
(ii) by remote sensors automatically, and
(iii) using GIS or existing/proposed networking systems.

We described the relevance of monitoring each variable in terms of bee health and beekeeping success. The main goal is to propose a path towards the identification and validation of best management practices, to subsequently integrate into a novel system supporting right decisions of beekeepers and relevant stakeholders.

2. Dissertation

Emerging and existing apiary management strategies called **precision beekeeping** (PB) are based on the monitoring of individual bee colonies to minimize resource consumption and maximize the productivity of bees. Tools used in PB are called also "smart hive" - a hive that can tell you about itself (usually hive weight, temperature, humidity, sounds, images). Smart hive is a progressive step towards building an "intelligent hive". Rather than just transmitting data about the current state of the hive, the intelligent hive would be able to tell you what the hive needs to perform better than it does today. It would take all of the data collected from a smart hive, combine it with knowledge of best management practices and data from thousands of other hives, risk maps using GIS and use machine learning and artificial intelligence techniques to optimize colony health, production, and pollination performance.

In some EU countries proper systems of hive registration exist, in some not. Unreliable data are collected by officials not specialized in beekeeping. Beekeepers are not motivated to up-date registers. Most beekeepers have very poor records of their beekeeping operations. Even for those who kept records,

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the data would still need to be digitised and shared. Probably only "automated" systems, collecting data from many hives, will work properly.

The data collection process in PB can be classified into two groups:

- apiary-level parameters (meteorological parameters and video observation);
- colony-level parameters (weight, temperature, humidity, gas content, sound, vibration, the number of incoming/outgoing bees, the number of bees in the hive entrance area etc.).

The causes that influence honeybee colony health are multiple and may be subdivided into 5 categories, all susceptible to be monitored:

- climate change and variability;
- change in land use and fragmentation of the landscape;
- chemical exposure;
- diseases and biological agents.
- beekeeping practices;

The variables that influence the health of bee colonies can be analysed from the general to the particular, for example moving from a global scale, to a regional or local scale, and finally apiary scale. In this transit, there are different actors and responsibility, as well as different possibilities of intervention for their solutions, summarised in Table 1.

Table 1: Factors that influence honeybee colony health, the main actors, and possibility of mitigation through intervention, rated from low (+) to high (+++)

SCALE	FACTORS	MAIN ACTORS	INTERVENTION
Global	(1) climate change and variability	Human being	+
Regional	(2) change in land use and fragmentation of the landscape (3) chemical exposure (mainly agricultural) (4) diseases and biological agents (across apiaries)	Society Land owners Companies Farmers, Industry	++
Apiary	(3) chemical exposure (beekeeping treatments) (4) diseases and biological agents (within an apiary) (5) beekeeping practices	Beekeepers	+++

Implementation of PB can be split into three phases: data collection, data analysis and application. EFSA (2016) has proposed a hierarchical framework for the definition of the health status of a honey bee colony, including "colony attributes", "external drivers", and "colony outputs", which could be monitored by PB (EFSA, 2016).

Colony attributes include:

- Demography of the colony (DEM), including brood extension, adult number and bee mortality.
- Behaviour and physiology (BEH), including foraging disruption, atypical behaviour.
- Queen (QUE) presence and performance.
- In-hive products (IHP): amount of honey and beebread in colony.
- Contamination (CON): chemical residues in honey, beebread and beeswax.

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- Disease, infection and infestation (DII), including presence and abundance of parasites, bacteria and viruses.

Each attribute is composed by a set of indicators (i.e. variables) that could be directly measured.

External drivers include:

- Resource Providing Unit (RPU): land cover, land use, nectar and pollen availability and quality characterising landscape within 3 km around the hive.
- Environmental drivers (ENV): factors related to weather and climate influencing bee colony status (precipitation, humidity, temperature), chemical contamination including pesticides, electromagnetic pollution.
- Beekeeping management practices (BMP) include variables like hobby or professional, conventional or organic etc.

Colony outputs include:

- Pollination services provided by the colony.
- Products harvested by the beekeeper, the hive rental service and the live honeybees extracted from the colony.

According to the declaration of cooperation on "A smart and sustainable digital future for European agriculture and rural areas" signed by representatives of 25 European countries in April 2019, technologies such as artificial intelligence, robotics, block chain, high performance computing, the Internet of Things and 5G have the potential to make farming more efficient, productive and sustainable.

Relevant EU projects (web pages presented in the Annex):

H2020 (big projects – more than 7 million € each):

- POSHBEE: Pan-European assessment, monitoring and mitigation of stressors on the health of bees (2018-2023). **http://poshbee.eu**
- B-GOOD: Giving Beekeeping Guidance by computational assisted decision-making (2019-2023). **https://b-good-project.eu/**
- HIVEOPOLIS: Futuristic beehives for a smart metropolis (2019-2024). **https://www.hiveopolis.eu/**

H2020 (projects with budget between 1 - 2 million € each):

- BPRACTICES New indicators and on-farm practices to improve honeybee health in the *Aethina tumida* in Europe (2017-2020). **http://www.izslt.it/bpractices/**
- SAMS: International Partnership on Innovation in Smart Apiculture Management Services (2018-2020). **https://sams-project.eu/**
- IOBEE: Beehive health IoT application to fight Honey Bee Colony Mortality (2017-2020) **http://io-bee.eu**

H2020 (small projects with budget ca. 0,05 million € each acting in year 2019):

- WARMHIVE: Smart thermotherapy solution for *Varroa* mite treatment. **https://cordis.europa.eu/project/id/836015**
- BEEHOME: Automated beekeeping platform powered by AI that increases honey production by 50%, reduces labour use by 90%, and reduces colony loss by 80%. **https://cordis.europa.eu/project/id/854754**
- FOG: Frequency protector generator for honeybees. **https://cordis.europa.eu/project/id/836486**

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Several Digital Innovation Hubs and EIP Operational Groups (https://ec.europa.eu/eip/agriculture/en/eip-agri-projects) exist as well, for example the ones on the list below. Main past project was **FP7** SWARMONITOR: Development of a tool for effective diagnostic monitoring of honeybee colonies.
EIP-AGRI Operational Groups (funded under the Rural Development programmes, measure 16)

- BeeScanning 2.0 - monitoring a biological system
- Remote beehive monitoring, a new opportunity for nomadic beekeeping (NOMADI-App)
- PICA: Innovative Platform for beekeeping

Other on-going initiatives:

- COLOSS (Prevention of honeybee COlony LOSSes) honeybee research association. https://coloss.org/core-projects/colony-losses-monitoring/
- Apimondia working group "Standardization of data on bees and beekeeping". https://www.apimondia.com/en/activities/working-groups
- BeeXML project: Exchanging Data about Bees and Beekeeping. http://beexml.org/

Global list of scientific/educational projects, open source and commercial projects on beehive monitoring is listed at the www.hiveeyes.org and www.colonymonitoring.com web pages.

Existing tools:

PB Monitoring approaches that are already widely used and relatively cheap:

- **Weight monitoring** of the colony can be used to identify (i) occurrence of nectar flow during the foraging season; (ii) consumption of food during non-foraging periods; (iii) the occurrence of swarming events through a decrease in the hive weight; (iv) estimation of the number of foragers. Measuring the weight of the colony can be done by automated or manual scales.
- Bee **colony temperature** measurements using various methods including: (i) Manual temperature measurements by different loggers; (ii) Wired sensor networks; (iii) Wireless sensor networks; (iv) Infrared imaging. Temperature data can help to identify colony states as (i) death; (ii) swarming; (iii) brood rearing; (iv) broodless state.

Tools available but not widely applied:

Audio signals and audio processing techniques to estimate bee behaviour. Many devices and methods have been developed for sound analysis but not widely applied because of the complexity of sound interpretation. Systems for **gas concentration** (carbon dioxide) and **forager traffic** (counters, RFID) are also tested.

Companies:

Current sensing and other components available as well as list of companies offering electronic colony monitoring systems are summarised at the hiveeyes.org and colonymonitoring.com pages. Examples of companies operating in Europe: BeeLabel, OpenHiveScale or Optibee from France, ApisProtect (Ireland), APiSTech (Portugal), Arnia (England), Beeing and Melixa from Italy, Pollenity (Bulgaria), Save-bees (Greece), XLogBee (Croatia), Wolf Hive Scale (Germany) BeeKing (Latvia) or Beescanning (Sweden).

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Some vendors of colony monitoring system design their products specifically for commercial beekeepers, f. e. **ApisProtect** and **Beehero**. Links to the web presentations of named companies/consortiums are listed at the References.

Examples of state-of-the-art of research/practice

External drivers:

- Resources (RPU): **BeeHero** project - tracking and optimizing pollination and **BeeScape** project -maps the landscape around the apiary.
- Environment (ENV): effects of temperature and precipitation on honeybee winter mortality - Switanek *et al.*, 2017.
- Beekeeping management practices (BMP): BMP implemented in Europe and its influence on honeybee colony health – Sperandio *et al.*, 2019.

Colony variables:

- Queen (QUE): SMARTBEE project, future sensors based on vibrations or brood temperature signals from hive – Cejrowski *et al.*, 2018.
- In-hive products (IHP): weight monitoring by electronic scales or using ripe honey detectors (colonymonitoring.com).
- Contamination (CON): environmental monitoring of bee food and bee products, e.g. Tosi *et al.* 2018; Manning *et al.*, 2018; Sánchez-Bayo *et al.*, 2019; POSHBEE project and several citizen science initiative projects.
- Disease-infection-infestation (DII): **COLOSS** Monitoring Group – winter mortality via standardised questionnaires, several disease-related risk factors evaluations, e.g. Morawetz *et al.*, 2019.
- Demography (DEM): **COLOSS** Monitoring Group – winter mortality via standardised questionnaires; model of honeybee colony population – Khoury *et al.*, 2011.
- Behaviour (BEH): e.g. Siviter *et al.*, 2018, landing board activity sensors (colonymonitoring.com).

Examples of national monitoring projects covering both external and internal drivers:
Italy: ApeNet - monitoring project (2009-2010) - Porrini *et al.*, 2016.
Italy: BeeNet - monitoring project (2011-2014).
Spain: Environmental evaluation of pesticides by means of biomonitoring stations with *Apis mellifera* colonies. Extramadura, 2007.
Spain: Development and starting of network of biomonitoring stations with *Apis mellifera* colonies to evaluate urban pollution at real time in Cordoba City. 2008-2011.
Germany: (**DeBiMo**) German bee monitoring project. – Genersch *et al.*, 2010.

3. Research needs

The development of **decision support systems** is suggested to be a mid-term task. In the long term, specific DSS-controlled electronic devices should be developed to enable new functionalities for PB. This will be a "shift" from "smart" to "intelligent" hive. "Intelligent" hive would be able to do:

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- Monitor the hive for signs of trouble and send alerts before trouble hits.
- Monitor regional and national trends in real time and adjust for how those trends might affect your bees.
- Suggest ways to improve your production, pollination, or bee health.
- Prescribe the best management practices customized for a particular hive in a particular place at a particular time.
- Pre-emptively suggest treatments before trouble manifests.
- Identify the treatments most likely to succeed given your hive characteristics, current environmental conditions, and history.

Data from many beekeepers are necessary, need to be transcribed digitally, shared, and converted to a standard format that could be combined with data from other beekeepers in other micro-climates with different genetic stock and conditions. Integration of Data Collection, Machine Learning, and Best Management Practices into an Intelligent Apiary Management System is needed. Researchers will be willing to share datasets from previous projects if there will be motivation (f. e. indexed scientific journal specialised in datasets publishing). Data from automated systems should be supplemented by surveys, questionnaires and data collection at the field level, which opens the doors for CS (citizen science) projects. Projects incorporating external drivers (nectar/pollen sources, weather/climate conditions and beekeeping management practices) with colony variables could bring interesting outputs.

4. Ideas for innovations

There are opportunities for companies to differentiate themselves by addressing different segments of the beekeeping market, e.g. backyard beekeepers, small honey producers, large honey producers, pollination providers, packaged bee producers, queen breeders, and researchers will each have a need for monitoring devices adapted to their specific circumstances.

From practical point of view, a colony monitoring device should tell beekeepers:

- What is the approximate level of *Varroa* in the colony?
- Is the colony queenright? Is the queen there? Is she healthy? Is she the mated queen I introduced?

Other parameters are for now in the eyes of beekeepers less important. However, sensors allowing precise feeding, time for honey harvest, presence and levels of *Varroa*, interpreting bees pheromone communications, detecting nectar scents and other hive odours and predicting swarm mood needs to be designed or improved.

Another inspiration from practice includes:

- Systems of precise apiary feeding/predicting of nectar flow.
- Definition of optimal hive/livestock density for different regions/landscapes.
- Use a beehives/bee products as biomonitoring networks to inform society about pollution and environmental quality via Citizen Science projects.

Further research needs coming from practice, ideas for EIP AGRI operational groups and other proposals for innovation can be found at the final report of the focus group, available at the FG webpage **https://ec.europa.eu/eip/agriculture/en/focus-groups/bee-health-and-sustainable-beekeeping**

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5. Conclusions

One third of the existing honeybee colonies die each year and beekeepers would gladly pay for monitoring devices that reduce their losses by a significant amount. Modern technologies enable beekeepers to remotely monitor brood health, honey production, cluster size and location, stores in hive, and many colony activities such as swarming and robbing.

Currently the field of hive monitoring devices and systems is wide open. Few entrepreneurs provide colony monitoring devices or systems that are low cost, reliable, and useful. There are some sensors not actually available on the market, or they are not designed for beehives. These sensors would monitor the level of liquid feed, detect when supers were full, measure the quality of honey, detect the presence and levels of *Varroa*, detect bees pheromone communications, detect nectar scents and other hive odours, monitor the level of carbon dioxide, and sense the hive's ventilation processes.

The details of the devices that sense, transmit, analyse, report and store colony health data in a robust, economical and useful manner will continue to evolve as the industry matures and beekeepers come to understand the value of their monitoring systems. Hives and their products can be used for pollution and environmental quality biomonitoring, which can be possibly used for environmental evaluation of CAP measures adopted.

6. References

Articles

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ZACEPINS, A. *et al*. 2015. Challenges in the development of Precision Beekeeping. *Biosystems Engineering*, 130: 60-71. doi: 10.1016/j.biosystemseng.2014.12.001.

Project web presentation

BEEXML: Exchanging Data about Bees and Beekeeping **http://beexml.org**

BEEWISE: Autonomous beehive **https://www.beewise.ag**

B-GOOD: Giving Beekeeping Guidance by computational assisted decision-making **https://b-good-project.eu/**

BPRACTICES New indicators and on-farm practices to improve honeybee health in the *Aethina tumida* in Europe **http://www.izslt.it/bpractices/**

HIVEOPOLIS: Futuristic beehives for a smart metropolis **https://www.hiveopolis.eu/**

IOBEE: Fighting Honey-Bee Colony Mortality through IoT **http://io-bee.eu**

POSHBEE: Pan-European assessment, monitoring and mitigation of stressors on the health of bees. **http://poshbee.eu**

SAMS: Smart apiculture management services **https://sams-project.eu**

SWARMONITOR: Development of a tool for effective diagnostic monitoring of honey bee colonies **https://cordis.europa.eu/project/rcn/105847/factsheet/en**

The World Bee Project Global Hive Network **http://worldbeeproject.org**

Remote hive monitoring existing tools

ApisProtect	**https://www.apisprotect.com**
ApiSTech	**https://apistech.eu**
Arnia	**https://www.arnia.co.uk**

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BeeHero	https://www.beehero.io
BeeKing	https://beeking.eu
Beeing	https://beeing.it
BeeLabel	https://www.label-abeille.org
BeeScape	https://beescape.org
BeeScanning	https://beescanning.com
Beewatch	http://beewatch.de
BeeWise	https://www.icko-apiculture.com/beewise.html
Hiveeyes	https://hiveeyes.org
Melixa	http://melixa.eu
OpenHiveScale	http://www.openhivescale.org
Optibee	http://www.optibee.fr
Pollenity	https://pollenity.com
SaveBees	http://www.save-bees.com
Wolf Hive Scale	https://www.wolf-waagen.de
XLog	http://www.xlogbeescale.com

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