*Supplementary information*

# A global expert assessment on the role of beehive acoustic-based honeybee (*Apis* spp.) (Apidae; Hymenoptera) colony monitoring

**Supplementary Table S1:** Summary of the experts' comments compiled during round 2 for the question asked in a questionnaire (*Please write comments below on the importance of factors in perspective of their monitoring via honeybee colony acoustics*). References cited are merely those that were referred by the experts during peer reviewing process.

| **Factors** | **Compiled experts' comments** | **% level of agreement** | | |
|---|---|---|---|---|
| | | **Agree** | **Disagree** | **Neutral** |
| Chemicals | • Honeybees are likely to report chemical compounds in beehive through sound. In addition, compounds outside the beehive can also be monitored by beehive sound.<br>• Beehive sound can recognize chemical compounds only when the concentration is high enough for honeybees, if the level of the compound is very low, the colony may not be aware of it.<br>• Bees are sensitive to chemicals, such as queen pheromone. Other non-endogenesis ones, such as pesticides, may be mixed with pheromone to disturb their sense to those they used for chemical communication. Thus, I guess that bees can be able to respond in beehive sound differently. | 80 | 20 | 0 |

| | | | | |
|---|---|---|---|---|
| Colony health | • Beehive sound can partly reflect the health condition of the colony, for example, to detect presence of pest infection, and to detect the absence of queen.<br>• Some diseases may cause specific odor. Bees may use these odors as cues to signal to their nest-mates to remove them.<br>• Communication in a colony is varied, and when a queen is lost, the sound of a colony is markedly different from that of a normal colony. But more experiments are needed to see if there is a significant difference in the sounds of bees under other conditions.<br>• Acoustic check of a colony can be the determination of the colony health as a global parameter but such conclusions could be obtained if further researches are conducted in this area. | 80 | 0 | 20 |
| Spatiotemporal patterns | • Dancer bees have ability to tell about the flight distance to their nest-mates acoustically ((Spangler 1991)Spangler 1991, Eskov 2019) but whether colony acoustics can indicate spatial patterns is not clear yet.<br>• Limited evidence exist thus require further work by researchers to explore in this area in the future. | 80 | 0 | 20 |
| Food availability | • Beehive sound has a potential as an alternative method to assess and monitor plant nectar and atmospheric pollutants.<br>• They may use sound to signal to their nest-mates for nectar quality but more research is needed in this area.<br>• Given the relation between food quality and vibrations or sounds produced by honey bees, it should be possible to monitor food availability. However, microphones in this case need to be rather sensible to capture the vibrations produced by the foragers. | 80 | 0 | 20 |

| | | | | |
|---|---|---|---|---|
| Population size | • Acoustic properties of a hives' soundscape can be examined to determine population size of a honeybee colony.<br>• A large colony will emit a strong sound and vice versa but to understand how exactly the properties of colony sound change in relation to varying number of bees, need additional investigation. | 60 | 0 | 40 |
| Predator attack | • We can see the potential of predator attacks via colony sound.<br>• Whether a honeybee colony convey a message about threat to their nest-mates, it may depend on size of predator, and species of that colony.<br>• Louder "stop signals" may be captured more easily. Predator attack, at least in Asian species (*Apis cerana*), has been shown to result in audible sounds of different quality. In case *A. mellifera* shows similar tendencies, it should be able to monitor predator attacks bioacoustically. | 80 | 0 | 20 |
| Colony states | • To recognize two classes, bee colonies during honey collection, and colonies after total cessation of honey harvest, the estimates of the power spectrum density of bee noise act as an important and the most reliable classification features (Shostak and Prodeus 2019). | 60 | 0 | 40 |

**Supplementary Table S2:** An information on percent number of experts exhibiting their confidence for acoustical monitoring of various factors at different levels of confidence.

| **Factors** | **% confidence at different confidence levels** | | | **% unknown** |
|---|---|---|---|---|
| | *High* | *Medium* | *Low* | |
| Colony health | 70 | 30 | 0 | 9 |
| Swarming | 80 | 20 | 0 | 9 |
| Pests and pathogens | 62.5 | 37.5 | 0 | 27 |
| Predators attack | 70 | 20 | 10 | 9 |
| Pesticides | 50 | 37.5 | 12.5 | 27 |
| Weather condition | 28.57 | 71.42 | 0 | 36 |
| Environmental pollution | 55.55 | 33.33 | 11.11 | 18 |
| Land cover | 0 | 50 | 50 | 63 |
| Land management | 0 | 50 | 50 | 63 |
| Food availability | 37.5 | 50 | 12.5 | 27 |
| Spatiotemporal patterns | 28.57 | 42.85 | 28.57 | 36 |

## Chi-Square Analysis

**Supplementary Table S3:** Crosstabulation of the experts' rating on importance and confidence regarding monitoring of multiple factors through beehive colony acoustics.

| | | **Confidence on factors** | | | **Total** |
|---|---|---|---|---|---|
| | | **low** | **medium** | **high** | |
| **Importance of factors** | **little important** | 1 | 0 | 0 | 1 |
| | **not important** | 1 | 2 | 1 | 4 |
| | **very important** | 1 | 2 | 3 | 6 |
| **Total** | | 3 | 4 | 4 | 11 |

**Supplementary Table S4:** Chi-Square Coefficient

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| **Pearson Chi-Square** | 8.590[a] | 4 | .043 |
| **Likelihood Ratio** | 5.527 | 4 | .033 |
| **Linear-by-Linear Association** | 1.984 | 1 | .152 |
| **N of Valid Cases** | 11 | | |

a. 9 cells (100.0%) have an expected count of less than 5. The minimum expected count is .27.

**Supplementary Table S5:** Symmetric Measures for the strength of a relationship

| | Value |
|---|---|
| **Phi** | .571 |
| **Cramer's V** | .404 |

The output tables of results comprised three tables, Table 3 is the cross-tabulation table of both variables that produced the linear and positive relationship between the importance and confidence of experts regarding acoustic monitoring of factors via beehive colony acoustics. Table 4 is the chi-square coefficient table that identified the value of the chi-square coefficient as 8.590 and the p-value is 0.043 which is less than the significant value of .05. Hence, we conclude that there is a statistically significant and positive association of experts' rating on importance and confidence regarding all the factors. In other words, as the importance of acoustically monitoring various factors increases in experts' opinion, their level of confidence to monitor these factors also increases. The third table (5) of symmetry measures explained this association concerning Phi as a very strong positive association with the value in between the 0.40 to 0.69 and Cramer's V as a medium positive association with the value in between the 0.4 to 0.5 among these variables.

## References


Eskov, E. 2019. The origin and organization of the bee colony *Apis mellifera* L. Cambridge Scholars Publishing.

Shostak, S., and A. Prodeus. 2019. Classification of the bee colony condition using spectral features. Pages 737-740 *in* 2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T). IEEE.

Spangler HG (1991) Do honey bees encode distance information into the wing vibrations of the waggle dance? Journal of insect behavior 4:15-20