

## 2.9 Electronic beehive monitoring – applications to research

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### Abstract

Electronic bee hive monitoring has evolved in recent years as a result of advances in technology but also as it became apparent that the environmental crisis facing bees called for more data if the problem is to be understood and tackled. Electronic monitoring offers economical and non-intrusive data collection. In this paper it is shown how such data can be used to elucidate the effects that different endogenous and exogenous factors have on honey bee colonies.

**Keywords:** electronic beehive monitoring, hive weight, flight activity, fanning activity, brood temperature

### Introduction

Honey bees are remarkable sentinels of the environment; a single colony can thoroughly sample areas of up to 10km<sup>2</sup>. Assessing the state and dynamics of honey bee colonies in relation to their physical and biological environment (weather, agricultural activity, forage) can uncover the effects on both parts of the plant-pollinator equation. Furthermore, there is a consensus of opinion within the scientific community that more field data are required to help understand the continuing decline in honey bee health.

Most honey bee studies tend to involve frequent physical manipulations for visual assessment as well as sampling the constituents of the nest (honey, bee bread, wax). However, honeybees do not benefit from being disturbed by frequent examinations. Their normal activities are disturbed and occasionally the colonies become weaker potentially biasing results. System described here was developed precisely with the aim to minimise the disruption to honey bee colonies while allowing automation of vital parameter collection, such as bee activity, hive weight, temperature and humidity. Advances in technology which have rendered remote data acquisition and automation a reality, coupled with the steep decline in honey bee welfare as well as a significant rise in public's awareness of honey bee importance in the ecosystem, resulted in the evolution of remote beehive monitoring. Over the recent years a number of beehive monitoring projects have developed sophisticated systems commonly termed as 'smart hives' (Bromenshenk, <http://beealerttechnology.com>; Esaias, <http://hive tool.net>; <http://opensourcesbeehives.net>). In general, smart hives integrate hive weight measurements with hive temperature and humidity sensor readings. What sets our system apart from other monitoring products is the diversity of measurements, acoustics in particular. Most beekeepers relate to different sounds of the beehive so it is no surprise that these have been documented since the classical times.<sup>1,2,3</sup> Possibly the best known pioneer of using acoustics as a tool for bee husbandry is Edward Farrington Woods. A sound engineer by trade, Woods used electronic apparatus to study bee acoustics for over a decade, particularly the changes in sound prior to swarming.<sup>4,5</sup> However, due to limitations in technology, human ear was still needed to interpret the results and a visit to the apiary was still necessary. Building on the Woods' original research we have developed a unique system which combines hive acoustics monitoring with other parameters such as brood temperature, humidity, hive weight and apiary weather conditions. Sounds from a bee colony are monitored and interpreted in relation to other parameters to assess colony behaviour, strength and health. The hive data can be accessed remotely from any internet enabled device in any web browser.

### Methods and materials

All experiments were performed at apiaries located in Italy and UK during seasons of 2013 and 2014. Honey bee colonies in Italy were all housed in 10 frame Dadant-Blatt hives, whereas those in UK were housed in National hives.

## Hardware configuration

Each hive is fitted with a monitor which sends the information to the monitor gateway via low power radio network. The monitor gateway then sends the data via GPRS to the cloud, where the data are stored and can be accessed from any internet enabled device (Figure 1).

### Hive monitor

Hive monitor (Figure 2), fitted above the hive entrance, is designed to measure sound, temperature, relative humidity and movement. Sound is registered using a microphone which is housed within the monitor enclosure and protected from propolisation by bees via the means of an acoustic membrane. Temperature is measured both inside the monitor as well as inside the brood nest using an analogue temperature sensor on a flying lead which is positioned between the frames of brood. During inspection the lead is moved to the side of the hive and then replaced between frames of brood before closing the hive. Similarly, relative humidity of the hive is measured using a humidity sensor on a flying lead which is easily removed and replaced during beehive inspections. Movement is sensed by the accelerometers within the monitor allowing detection of theft or hive displacement. Furthermore, monitors have spare ADC (analog-to-digital-converter) and relay inputs which can support third party CO<sub>2</sub> measurements and bee counters.

### Monitor gateway

In addition to mediating the transmission of data from individual monitors to user interface, monitor gateways are fitted with a weather pack which consists of sun and shade temperature sensors and a self-emptying rain gauge (Figure 2b). Temperature, cloud cover and rainfall at an apiary constitute the meteorological conditions which are crucial when interpreting the data from the monitors. Both bees and plants they visit are directly dependant on the ambient conditions for their activity, thus weather data puts all other data into context.

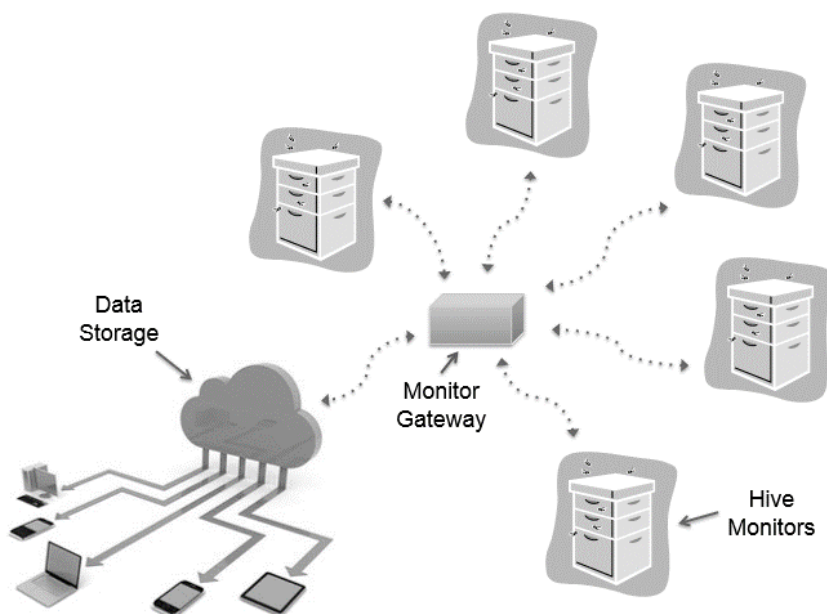


Figure 1 Hardware configuration



**Figure 2a** Hive monitor



**Figure 2b** Monitor gateway and weather pack

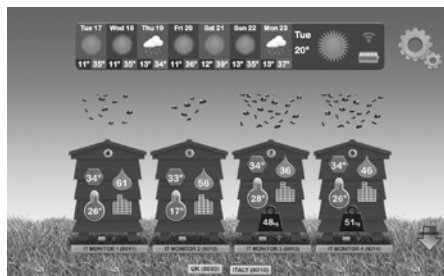
### Hive scales

Hive weight is measured using arnia's hive scales (Figure 3), which feature multiple load cells to allow for measurement of uneven loads. Total scale capacity is 150 kg and minimum sensitivity 100 g. The scale's doughnut shape design allows debris from open mesh floor (OMF) fitted hives to drop through and it does not impede the ventilation through the OMF. Scales are low profile thus not requiring hive stand height adjustment.

All hardware components, monitors, monitor gateway and the scales are powered by alkaline batteries readily available from most shops. Alternatively, they can be powered by solar energy.



**Figure 3** Hive scales



**Figure 4** Graphic User Interface

### User interface

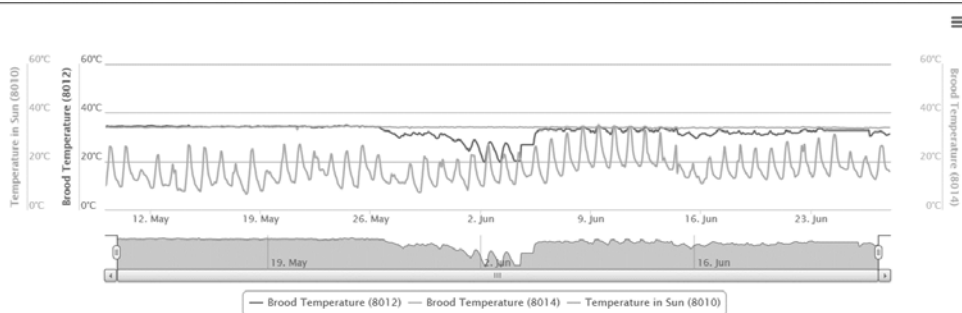
All data collected by monitors are transmitted to the cloud and are accessed via the graphic user interface (GUI) (Figure 4). Once logged into the account the user is presented with the *hive view*, where all the monitored hives can be seen at a glance. From here data can be viewed and downloaded for any time period since the beginning of measurements. Each hive fitted with a monitor displays the sensor information (brood and monitor temperature, relative humidity and weight, if scales are fitted) as an icon. Clicking on any of the icons shows the graphical representation of the data for any given sensor, i.e. the *graph view*. In the graph view it is possible to add any number of other sensor readings whether from the same or different hives, thus allowing visualisation and comparison of the data over time and across the colonies monitored. Activity of the colony is represented by the cloud of bees above the hive. Honey bee activity is further categorised into flight, fanning and hive activity. Current weather as well as last week's weather is displayed in the weather bar at the top of the page. Signal (GPRS) strength and battery power are displayed under the hives. The user is able to set up automated SMS and/or email alerts to inform of theft, hive too humid, broodless, queen started laying, need to add super, honey super full, start and end of nectar flow and extreme weather conditions at apiary.

## Results and discussion

In this section data collected by monitors are presented both as individual parameters as well as different parameter readings compared simultaneously on the same graphs, thus giving a more comprehensive picture of the state of the colony. Readings are related to actual events that occurred within the colony as a result of endogenous or exogenous factors, therefore illustrating the utility of electronic hive monitoring data across a range of scenarios.

### Brood temperature

Honeybees tightly thermos-regulate their brood nest. Any discontinuity in brood temperature indicates a break in the brood cycle. The reasons for this can be seasonal such as swarming or the onset of winter, but a break in the brood can also signify loss of a queen, failing queen or brood diseases. In Figure 5 brood temperature from two monitored hives as well as ambient temperature is depicted. While one colony maintains a stable brood temperature as is expected throughout the active season, the other colony shows a clear and gradual loss of thermo-regulation which then re-stabilises after 11 days. This proved to be a result of swarming and subsequent break in the brood cycle before the new queen mates and starts laying. Re-establishment of net thermo-regulation is a certain indicator or recommencement of laying.



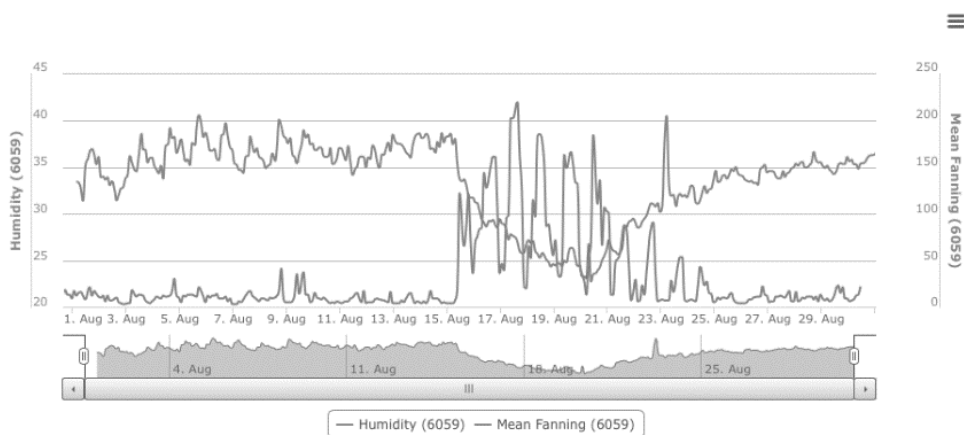
**Figure 5** Ambient and brood temperature from two colonies

Maintenance of nest temperature and other environmental factors at relatively constant levels regardless of external conditions is termed colony homeostasis and is crucial for successful brood rearing, survival of colonies in both cold and hot ambient temperature extremes, early spring initiation of brood rearing and preflight warming of foragers.<sup>6</sup> Any deviances that cannot be explained by seasonal cycles give useful insights into the health of the colony in relation to its environment. For example, colonies becoming broodless can be mapped with changes in land use, PPPs use, in-hive treatments, presence of pest or pathogens or lack of forage. Correlating when queens mate with weather conditions may give an indication how successful the mating was. It is known that unfavourable weather at mating contributes to increased incidence of drone laying queens, thus giving insights into possible causes of colony failure. Overall, nest homeostasis is a potent indicator of colony's state and health particularly when observed in context of exogenous factors.

### Hive humidity

Figure 6 shows relative humidity levels in a colony during the month of August. The ambient temperatures are high and there is little forage available to the bees. In the first two weeks of monitoring the relative humidity is generally stable between 35-40%. On 15<sup>th</sup> of August there is a sudden and sharp decrease in humidity which re-stabilises after about 10 days. This anomaly coincides with the in-hive treatment for *Varroa destructor*. In fact, when fanning activity of the colony is plotted on the same graph it becomes obvious that the decrease in relative humidity is accompanied by a drastic increase in fanning. Fanning activity is a well-defined behaviour of the

bees that occurs in a number of situations: when the nest is too hot bees fan to ventilate the hot air out of the hive, when bees are disturbed, such as following an inspection or during swarm's entry to a new nest, or as in this example following the introduction of a volatile chemical in the hive. The resulting lowered levels of humidity are likely to impact on the brood development.

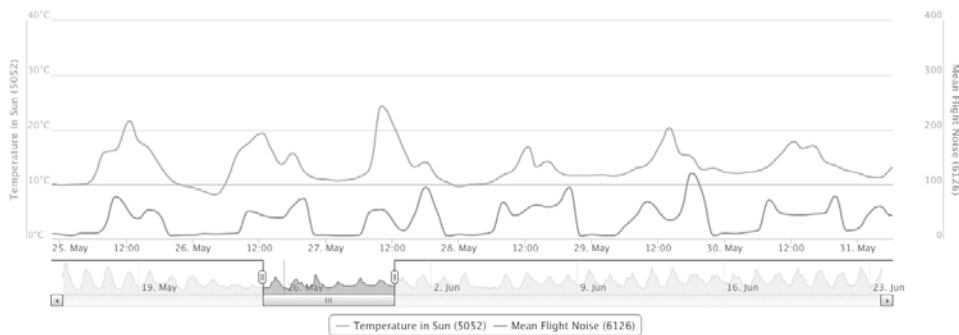


**Figure 6** Relative humidity inside the hive (upper line) and overall fanning activity (lower line)

Humidity of the brood nest is important for the overall fitness of a honeybee colony. Numerous studies have demonstrated that either high or low levels of humidity affect the health of the brood and adult bees, either directly, for example at levels below 50% relative humidity in the brood cells no eggs hatch,<sup>7</sup> this being particularly relevant for small nuclei, or indirectly by favouring the development of pathologies. Thermoregulation and nectar concentration are also intricately linked with humidity levels in the hive.<sup>8</sup> Relative humidity registered by the monitor, depending on the season, is thus a very good measure of the state of the colony. During brood rearing times in a strong colony the humidity levels are relatively stable. Broodless periods are marked by the fluctuations which follow the hive temperature pattern. This is due to the fact that relative humidity is the amount of water held in the air relative to the maximum amount of water that can be held in the air at a given temperature. The warmer the air the more water it can hold thus as the temperature fluctuates so does the relative humidity with it. Finally, winter cluster period is marked by the fluctuations which follow the ambient fluctuations with a 1-2 h lag. Thus, any deviation from these trends is a reason for concern.

### Flight activity

Honey bees diurnal activity is represented in the Figure 7. Data for flight activity can be correlated with ambient temperature to map daily activity patterns, to trend at what temperatures bees start flying in the morning, to uncover whether too high temperatures alter flight patterns. Also from the flight profile it is possible to identify changes in foraging behaviour and playflight behaviour. The latter is a phenomenon that occurs on windless sunny afternoons in which thousands of young bees take orientation flights before becoming foragers. The amount of playflight is directly related to the strength of the colony and queen's laying rate. In Figure 7, first diurnal peak of flight activity is due to foraging bees, which then show a lull in activity during the hottest hours, followed by the mentioned afternoon activity which in big part accounts of the playflight behaviour. From this example it is clear that the flight activity varies greatly throughout the day and for assessment purposes visual inspections may not be sufficient if more than one colony is being observed. Electronic monitoring provides simultaneous readings for any number of colonies, thus eliminating the bias inherently associated with non-simultaneous assessments.

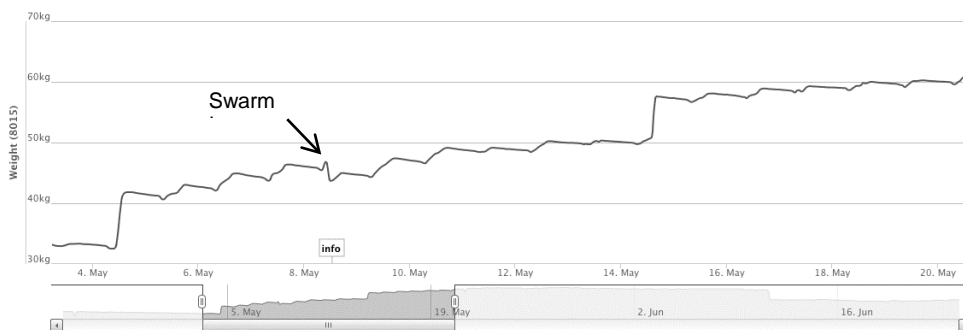


**Figure 7** Daily flight profile (lower line) in relation to ambient temperature (upper line)

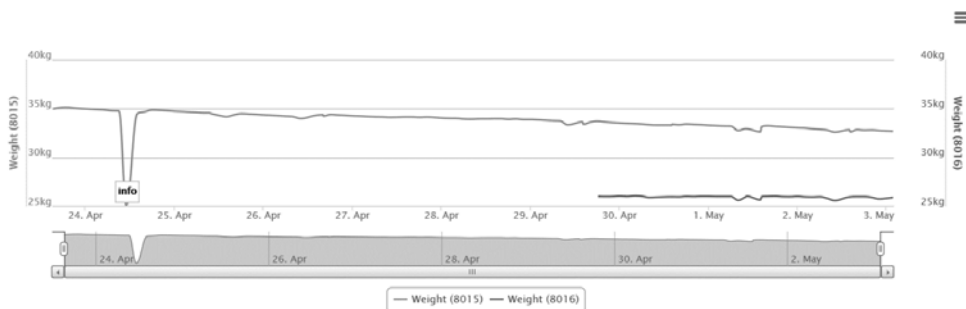
### Weight

Weight of a colony is a very informative parameter that is simple to measure, however it is also the most expensive. During nectar flow, an increase in weight is seen as bees return with nectar, but also the weight drop during the night as the bees process the nectar. This is demonstrated in Figure 7, where addition of honey supers can also be noted as vertical increases in weight.

Weight of a colony is a main biological component as it comprises of adult bee population, brood, honey and pollen stores. It is a measure of colony's strength and productivity. Changes in weight can be correlated with land use, weather conditions and any other exogenous factors to study colony dynamics and behaviour on colony level. Weight data can be used to map nectar flow, as shown in Figure 8, but also can be correlated to the phenological records to map flowering of nectariferous plant species (Esaias, <http://hivetool.net>). This is pertinent for studying the effects of climate change on vegetation and consequences it may have on the honey bee populations, should flowering patterns be altered and plants and their pollinators become unsynchronised. Furthermore, based on the weight data a precise time of swarming can be identified and weight of the swarm calculated. During winter, weight records are useful for identifying if and when supplemental feeding is required.



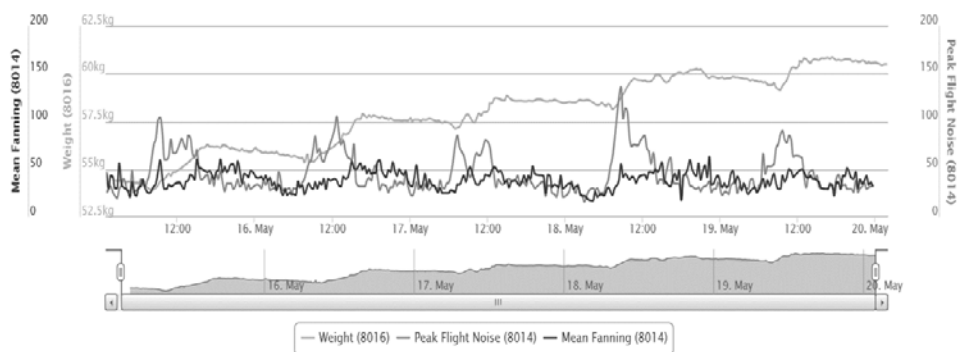
**Figure 8** Colony weight (kg) over a period of Robinia nectar flow.



**Figure 9** Weight as a measure of colony’s metabolism (strong colony upper line, small colony lower line)

During periods of dearth, when no forage is available, consumption of stores reflects the energy required to maintain the colony (Figure 9). The stronger the colony the higher its energy requirements are. This is particularly relevant during wet springs when weather conditions impede foraging and/or nectar production by the plants and a strong healthy colony can perish due to starvation in a short time.

Weight alone offers a wealth of information about the colony, however the ability to combine it with other behavioural parameters such as flight or fanning activity adds another dimension to overall understanding of colony’s dynamics. In Figure 10, weight graph is overlaid with flight and fanning profile showing clearly that increase in flight activity corresponds to increase in weight. Based on this correlation it is possible to assess the foraging efficiency of the colony, not all foraging flights are equally productive, often due to environmental factors such as weather, but also pollution has been shown to decrease the honeybee ability to recognise floral cues.<sup>9</sup> Similarly, increase in fanning activity correlates to decrease in weight as moisture is evaporated from fresh nectar.

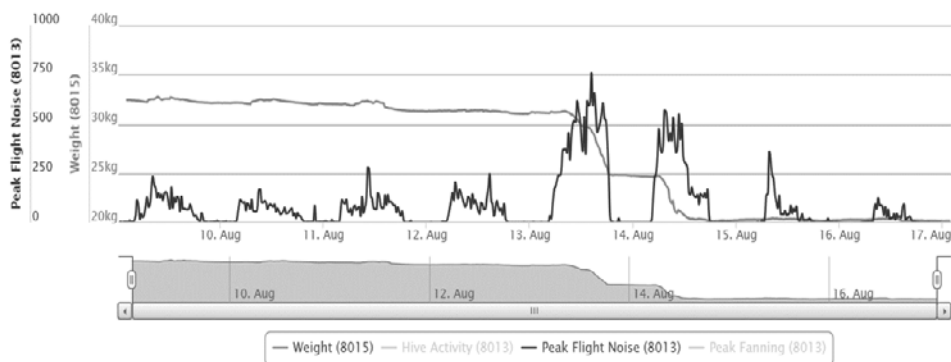


**Figure 10** Weight (stepwise increments) in relation to flight and fanning activity

**‘Black box’**

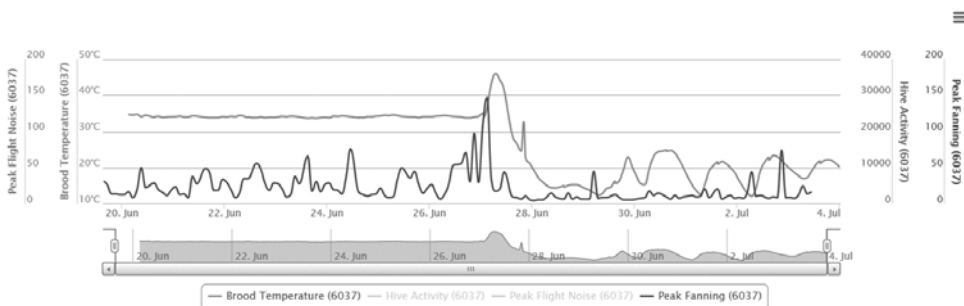
A weak colony during times of dearth can become a victim of robbing by other bees, which if not intervened timely, leads to colony loss. In Figure 11 a typical daily pattern of flight is observed and a gradual decrease in weight until 13<sup>th</sup> of August. Subsequently, the weight decreases rapidly by 11kg over two days and this is reflected in sharp increase in flight activity. This dramatic flight activity however is a record of bees from neighbouring hives robbing the resident colony of its stores in a very short time period and ultimately causing its demise. It is worth noting that without the frequent and continuous data provided by the monitors the cause of colony loss would remain

a guess. A weekly visit to the apiary may have discovered a perished colony but whether the robbing was the cause or the consequence of the demise would not be clear.



**Figure 11** Weight decrease and flight activity during a robbing episode

Another example where a colony was lost and the cause was determined based on the data provided by the monitor is shown in Figure 12. A healthy colony was transported to another apiary and as it was raining on arrival the hive was left in confinement, as this is a common beekeeping practice. Upon beekeepers return the following day it was discovered that all the bees in the hive were dead. Data for that colony were examined and it was shown that the bees died due to heat stress during transportation. Although unfortunate, an interesting feature of this demise was the drastic increase in fanning activity as the colony started to overheat. However, as ventilation was impeded due to confinement during transportation, the fanning did not cool the hive, rather the heat produced by the flight muscles to fan only added to the heat stress. The colony was locked in a positive feedback loop until the temperature reached a fatal 46°C.



**Figure 12** Brood temperature and fanning activity

In both examples of colony losses the data from the monitors were analogous to the in-flight recorder ('black box') of an aircraft. Following an event it was possible to uncover the reasons for colony losses with confidence.

### Conclusion

Electronic bee-hive monitoring has evolved relatively recently as the technology has become available to allow economic, non-intrusive and user-friendly data collection. In this paper it was shown that hive monitors can reliably, frequently, consistently and objectively measure parameters such as hive homeostasis (brood temperature and humidity), bee activity (flight, foraging and fanning acoustics) and productivity (hive weight) as well as meteorological data



These data sets can be triangulated with time of day/season, nectar flows, climate change, changes in land use and practices, pests, pathogens, in-hive treatments, nutrition as well as bee management practices and environmental pollution. On a broader level, electronic hive monitoring enables truly scalable studies, from semi-field trials to full-scale field trials involving hundreds or thousands of colonies across various geographical areas over extended periods, thus facilitating the pooling of diverse sets of data and resources. Furthermore, acquired data which are stored electronically and indefinitely on the cloud, offers the option for retro looking at cause and effect relationships, as a 'black box'. Accumulation of data sets that are objective, automatically managed and scalable can only aid better understanding of multiple factors affecting bee health and how they interrelate.

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