computers and electronics in agriculture 64 (2008) 72–77

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/compag

Monitoring of swarming sounds in bee hives for early detection of the swarming period

S. Ferrari[a], M. Silva[b], M. Guarino[a,*], D. Berckmans[b]

[a] *Dipartimento di Scienze e Tecnologie Veterinarie per la Sicurezza Alimentare, Facoltà di Medicina Veterinaria, Universita degli Studi di Milano, Via Celoria 10, 20133 Milano, Italy*

[b] *Measure, Model and Manage Bioresponse (M3-BIORES), Department of Biosystems, Katholieke Universiteit Leuven, Kasteelpark Arenberg 30, 3001 Heverlee, Belgium*

ARTICLE INFO

Keywords:
Bee
Frequency
Hive
Honey loss
Sounds
Swarming
Temperature

ABSTRACT

Beekeeping, known as one of the oldest forms of agriculture, in its complexity requires control for honey production with what modern technology can offer. Honey is included in animal production implying that farmers have interest in big productions according to the best blooming time, the presence of parasites, the genetic strain of his bees and the swarming periods of the honeybees (queen and her workers leaving the hive).

This last fact has a big economic interest for the beekeeper as swarming means honey loss since bees start collecting the honey to migrate. Here for a method that enables the prediction of the swarming is required to prevent the queen from leaving the hives. In this experiment an acoustic method based on labelling of sounds is proposed to predict the swarming period. Three hives were monitored during 270 h. The microphones were sited inside the hives together with a temperature and humidity sensor. The sounds were recorded with a sample rate of 2 kHz, and analyzed via Matlab and Cool Edit Pro. During this period 9 swarming activities occurred. Swarming is indicated by an increase in the power spectral density at about 110 Hz; approaching to swarm the sound augmented in amplitude and frequency to 300 Hz, occasionally a rapid change occurred from 150 Hz to 500 Hz. Another finding indicating the initiation of a swarming period is the raise in temperature from 33 °C to 35 °C until the actual time of swarming when the temperature starts dropping to 32 °C. With more activity, ventilation from bee wings causes drop of temperature. Less information comes from the correlation between sound and humidity since this parameter is too much influenced by the external conditions and no significant variation occurred according to a swarm. This increase of temperature, together with the changes in acoustical features of the sound recorded in the hive, may be used as a predictor for swarming of the bees to reduce honey loss.

* *Corresponding author*. Tel.: +39 02 503 17927.
E-mail addresses: Sara.Ferrari@unimi.it (S. Ferrari), Mitchell.Silva@biw.kuleuven.be (M. Silva), Marcella.Guarino@unimi.it (M. Guarino), Daniel.Berckmans@biw.kuleuven.be (D. Berckmans).
0168-1699/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.compag.2008.05.010

1. Introduction

Beekeeping is known to be one of the oldest forms of agriculture: Publius Vergilius Maro (Mantova, 15 October 70 a.C.—Brindisi, 21 September 19 a.C.) in his Georgicon wrote about the art of beekeeping, therefore this discipline has progressed gradually together with human agricultural knowledge and technologies and its complexity implies modern technology control for a bigger honey production. Beekeeping is agriculture sector with rural development functions, for honey and hive's goods production and the maintenance of ecological balance. To improve production and marketing of apiculture products, program protocols should be drawn up comprising technical assistance, control of varroassis, rationalization of transhumance, management of hive restocking in the Community and co-operation on research programs between partners.

Honey is an animal production and the farmer has interest in big productions according to the best blooming time, the presence of parasites, the genetic strain and the swarming periods of the honeybees.

Swarming represents the natural way a honey bee colony uses to reproduce. Swarming normally occurs in strong populous colonies and chiefly from spring to early summer. The preparations for lift-off takes almost 1 month (Lindauer, 1955). About 10 days prior to leaving the hive, the bee workers engorge themselves honey (36 mg for each bee) and nearly cease normal flight activity; few hours before swarming, some workers become 'excited' and "begin running back and forth in waves, buzzing to excite the other workers" (Winston, 1987). This last fact has a big economic and managerial interest for the beekeeper as swarming means bee and honey loss.

Three factors that are connected with swarming are the brood and adult bee population (as related to space within the hive), the amount and distribution of available queen pheromone and the hive environment. All these factors are related to be a combination of sounds, temperature and humidity of the hive system itself. Beekeepers must take responsibility for their swarms since control of swarming involves more extensive manipulation and rather critical timing. Several scientists widely worked to predict swarming moments by individuating the main factors that could lead a hive to swarm. Early studies attribute the cause of swarming to the amount of food in the hive. Morland (1930) argued that swarming was the result of too many young nurse bees that produced too much brood food. In order to reduce the amount of food, queen rearing began, which led to swarming. Another group of scientists believed that the crowding of adult workers and limited space for food rearing resulted in swarming (Demuth, 1921; Winston, 1987). There is, however, no sufficient evidence to support these hypotheses (Winston, 1987). Other investigations (Simpson, 1958; Winston et al., 1980; Lensky and Slabezki, 1981) found a multifactor relationship between swarming and several within-colony demographic factors such as colony size, brood hive congestion, worker age distribution and reduced transmission of queen substances. Seeley and Heinrich (1980) considered the temperature of the system before lift-off. Camazine and Visscher (1999) and Lewis and Schneider (2000) studied their communication by vibration signals and dances and other researchers considered sound (Woods, 1959; Vancata, 1995; Wenner, 1962; Esch, 1967). None of these factors alone are found to initiate swarming (Winston, 1987). This analysis will consider the anamnesis of the hives, the sound, the external and internal temperature and relative humidity.

By understanding how to best predict swarming, beekeeping will be improved, more enjoyable and profitable.

A method that enables the prediction of the swarming is proposed to prevent the queen from leaving the hives by using sound analysis.

By referring to sound data collected in hives during the swarming seasons we can study the sound features correlated with the activity of the insects, temperature and humidity of the hive ecosystem.

The aim of the study will to build up an early swarming monitoring system that will inform the beekeeper about the trends of his hives and manage them only in critical moments when necessary, avoiding loss of honey.

2. Materials and methods

In this experiment an acoustical method based on sound analysis for classification is proposed to identify the swarming period of the Italian Honey Bee *Apis Mellifera Ligustica*. Three hives were monitored with sound, humidity and temperature during 270 h continuous recording in May 2006 in the beekeeping experimental farm from the University of Milan (Fig. 1). The beekeeper did not remove the newborn queen cells to allow as much as possible recording of swarms sounds; this practice is in reality the most common method to avoid swarming but it requires lot of management. The recording devices consisted of three omnidirectional microphone (ECM 3005, Monacor) with frequency response from 50 Hz to 16,000 Hz connected to a pc.

The recorded signal was digitalized with a soundcard soundscape SS88IO-3 with 8 channels at 16 bits and a sampling rate of 2 kHz. Pre-amplifiers were also used that allowed the regulation of the sensors for the signal inputs or control the sound signal itself and avoid saturation.

For monitoring the temperature and relative humidity "HOBO" data loggers were used (HOBO Temperature/RH Smart Sensor H08-007-02, the sampling occurred every 3 min or 0.0056 Hz).

Both the sensors (microphone and HOBO) were covered by a special net against propolisation from the bees which usually cover every external body entering in the hive with Propolis.

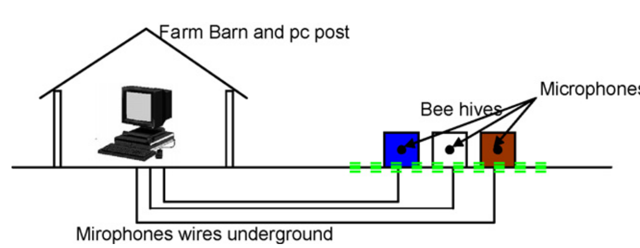
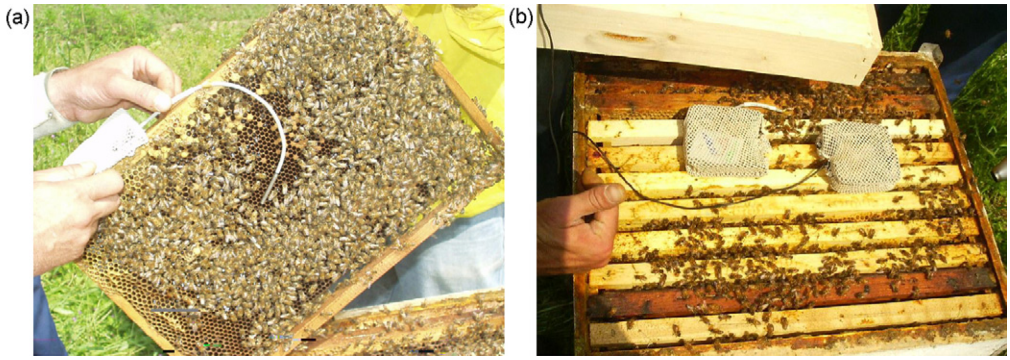


Fig. 1 – Set up for the sperimentation in the University farm.



Picture 1 – Sensors positioning; (a) position of the sensor for humidity and temperature detection inside the hive in between the looms, (b) position of the microphone and Hobo over the looms in the hive.

Sensors were placed on top of hive's looms under the cover as is shown in Picture 1a and b.

For recording the sounds and the manual labelling Adobe Audition 1.5 was used while signal processing operations were made with Matlab 7.1.

Our work consisted in monitoring the sound activity of the bees together with internal and external temperature and humidity variation. The synchronization between the pc clock and the data loggers' clock has been important to compare the dynamic changes of the signals.

The first step in the analysis was to filter the sound signal to get rid off all the environmental noise disturbing the "bee frequencies" we were interested in.

Therefore, a Butterworth filter (6th order Band pass filter) was applied to the sound signal, with cut-off frequencies 100 Hz and 2000 Hz.

After filtering the different sound signals, sound and HOBO data were synchronized. Starting from the time of the swarming in the audio files we went up with manual labelling and hobo data table to the relative humidity and temperature correlated to the events. An example of the output data from hobo sensor is shown in Table 1.

By listening the audio files and manually dividing sounds in classes we could investigate sounds features class by class. The procedure is named "labelling" and it is done also with the aid of the analysis of the sound spectrogram in both time and frequency domain.

Table 1 – Example of exported datas from Hobo sensor software including the date, the time, relative humidity and temperature of the samples

Date; time	Uncomp RH (%)	Temperature (°C)
05/04/06; 14:30:00.0	34.7	23.63
05/04/06; 14:32:30.0	35	24.01
05/04/06; 14:35:00.0	34.4	23.24
05/04/06; 14:37:30.0	34.4	23.24
05/04/06; 14:40:00.0	35.9	22.86
05/04/06; 14:42:30.0	41.4	22.48
05/04/06; 14:45:00.0	46.5	21.71
05/04/06; 14:47:30.0	46.4	21.33

Frequency and amplitude variation have been investigated (via Matlab and Adobe Audition) for night and day activity together with swarming sounds (Fig. 2).

3. Results

Nine swarming activities occurred during the recordings which were detected both from sound and visual analysis of the observer in situ at the right moment.

Swarms occurred always in daylight time and preferentially in the hottest hours. The duration of a swarm (moment from which the bees started to excite until they leave the hive) cannot be considered as a standard parameter to discriminate

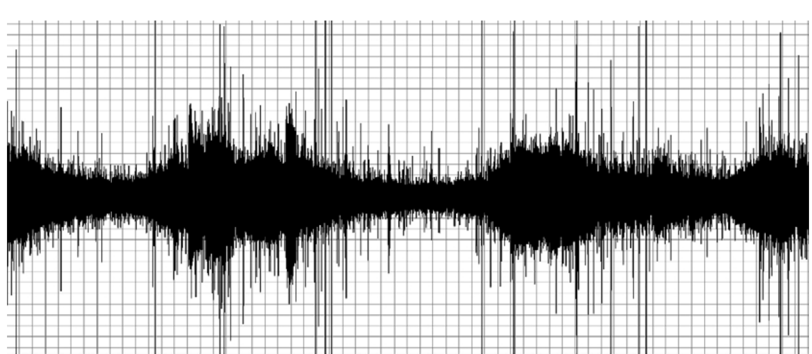


Fig. 2 – Spectrogram of hive noise from a 3 days continuous recording, the variation in amplitude of the signal stands for the day/night activity or the swarms.

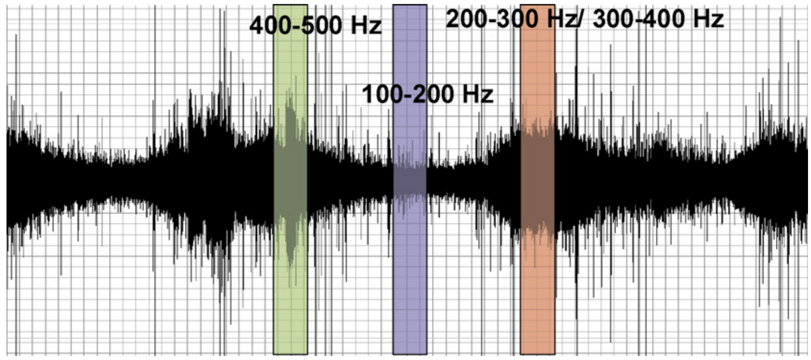


Fig. 3 – Manual labelling of three characteristics and repeatable events extracted from the audio files. Swarming event (green), activity during night (blue), and activity during day (red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 2 – Length of nine swarms detected with average and standard deviation of these values

	nr	Duration [min]
Swarm	1	51.16
Swarm	2	23.3
Swarm	3	28.12
Swarm	4	45.46
Swarm	5	16.28
Swarm	6	43
Swarm	7	38
Swarm	8	13.53
Swarm	9	56.23
Average		35.0 ± 15.3 [min]

the sounds from the others since they had wide range in length lasting from 13.53 min to 56.23 min ($\mu = 35$ min; D.S. = 15.3 min) (Table 2).

Analysing the sound recorded we reach interesting information about the activity of bees especially in relation to

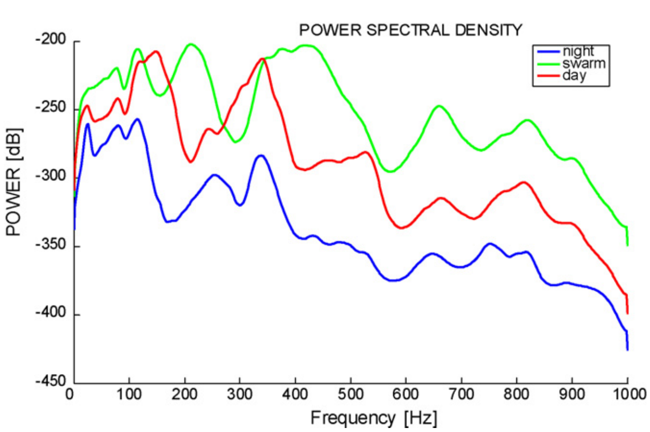


Fig. 4 – Values of frequency (x) and amplitude (y) of a swarming sound (green) compared to night (blue) and day time (red) activity. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

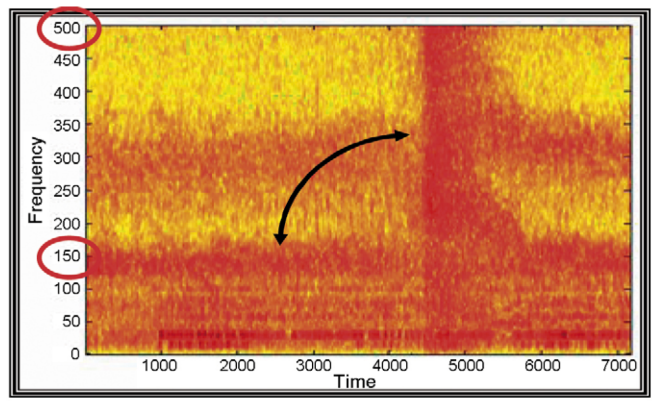


Fig. 5 – Spectrogram of a swarming sound in frequency domain, the arrow indicates the rapid change in frequency accompanying the swarming moment. The maximum energy content of the sound signal is represented in dark red color. The jump goes from 150 Hz up to 500 Hz. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

- the status of the colony (contingent swarming, normal activity);
- moment of the day (night and day trend).

These variations are shown in Fig. 3 where some specific events have been detected and marked with the corresponding fundamental frequency. The same figure shows the spectrograms of the sound recording during night, day and swarming. At night time, the general amplitude is much lower compared with the sound during normal day activity. It can be seen that the peak frequencies occur around the same frequency bands. When comparing the swarming sound frequencies, the main difference is the shift of about 150–250 Hz and 350–450 Hz. More energy content in higher frequencies in swarms compared to bees normal activity. The analysis lead over the values of frequency and amplitude of the whole sound data collected show us a clear increase of both parameters in swarming sounds comparing to the other sounds (Fig. 4).

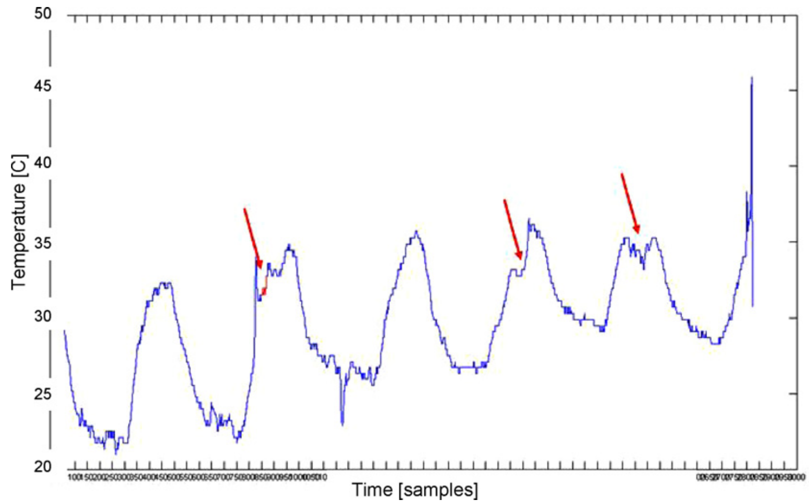


Fig. 6 – Variation of the temperature (Y) in time domain (X). Red arrows indicates drop temperature preceding the swarming moment. The line oscillation stands for the night/day alternance.

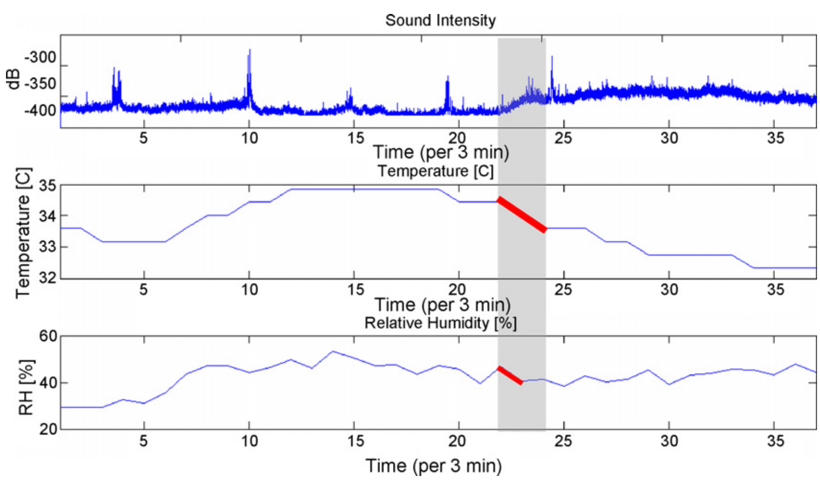


Fig. 7 – Correlation of the three parameters investigated. Top view shows the intensity of sound increasing at swarm, the middle one the decreasing in temperature and the bottom view the drop of humidity associated to a swarm.

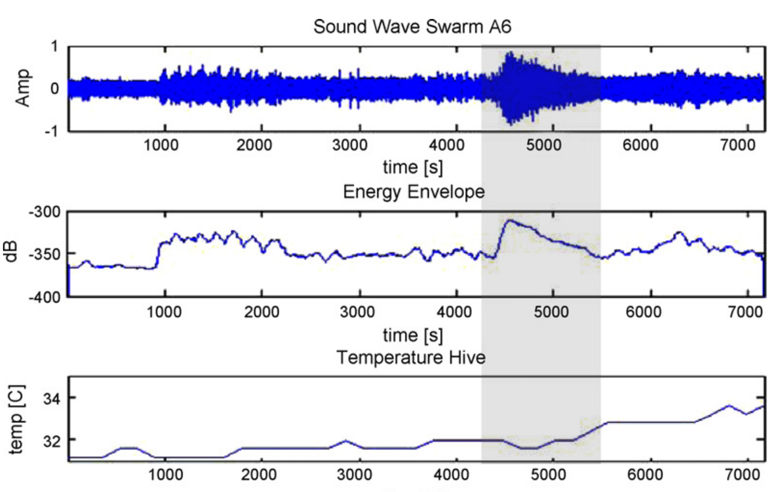


Fig. 8 – Plot of the correlation between sound and temperature. Top view shows the intensity of the sound spectrum in time domain, the middle one is the energy envelope (the shape of a sound distinguishable from other) and the bottom shows the drop of temperature associated to a swarm.

In Fig. 5 the transition form normal bee activity to swarming is shown, it can be seen that dominant frequency bands (50–150 Hz and 250–350 Hz) are broadened and there is an excitation over the entire frequency reaching values over 500 Hz. The frequencies of sounds in a beehive can be summarized as peaks of 25–150 Hz for activity at night time, peaks of 100/150–300 Hz at day time and peaks of 500–600 Hz during swarming.

Therefore, the frequency domain of a bee hive sound can be a clear tool to evaluate the approaching to a certain phenomenon since a rapid increase of energy peaks in the highest frequencies is present at swarming and allow us to make a clear distinction of the swarming sound in between all the other sounds. There seems also to be a relation between sound intensity and temperature in the hive together with climatic variations occurring during the day. A decrease in temperature in the previous minutes before the lift-off from 35 °C to 33 °C until the actual time of swarming when temperature starts dropping again to 32 C (Figs. 6–8) is found; a possible explanation for this observation is the ventilation phenomenon which consists in a rapid flitting of bees wings to reach a muscle temperature which is around about 35 °C for lift-off (Seeley and Tautz, 2001).

Before swarming we also observe a decrease in relative humidity due also probably to the phenomenon of ventilations but more improving has to be done on humidity since this parameter is strongly influenced by the external relative humidity and by the day hour.

4. Conclusions and discussion

In this project 270 h of sound recording was done in bee hives together with the recordings of temperature and humidity. The aim was to investigate the changes in sound characteristics and the relation with changes in temperature and humidity. It could be seen that with increase of activity, as seen at swarming moments, the frequency content shifts from about the range of 100–300 Hz to a higher frequency range of 500 Hz to 600 Hz. This is caused by the intense flitting of the wings, which causes drop of temperature from 35 °C to 33 °C. This shift in frequency together with the temperature drop might used as a prediction for swarming, enabling the prevention of it to assure less honey loss. As temperature alone might be related too much to climatic changes, the combination with sound analysis will be able to identify the moment prior to swarming.

A following step in this research is to integrate the sound recordings together with the environmental variables, and to link this with an on-line analysis system that is able to alarm the beekeepers to take action.

Bioacoustics, by analysing the characteristics of sounds, helps in ethologic and productive recognition by labelling of animals status.

REFERENCES

Camazine, S., Visscher, P.K., 1999. House haunting by honey bee swarms: collective decisions and individual behaviour. Insects Soc. 46, 348–360.

Demuth, G.S., 1921. Swarm Control. Farmers bulletin. U.S Department of Agriculture 1198, pp. 1–28.

Esch, H., 1967. The sounds produced by swarming honey bees. Z. Vergl. Physiol. 56, 408–441.

Lensky, Y., Slabezki, Y., 1981. The inhibiting effect of queen bee (apis mellifera) foot print pherormone on the construction of swarming queen cups. J. Insect Physiol. 66, 185–193.

Lewis, L.A., Schneider, S.S., 2000. The modulation of worker behavior by the vibration signal during house hunting in swarms of the honeybee, *Apis mellifera*. Behav. Ecol. Sociobiol. 48 (2), 154–164.

Lindauer, M., 1955. Schwarmbienen auf Wohnungssuehe. Z. Vergl. Physiol. 37 (203), 324.

Morland, D., 1930. On the causes of swarming in the honeybee: an examination of brood food theory. Ann. Appl. Biol. 17, 137–147.

Seeley, T., Heinrich, B., 1980. Regulation of the temperature in the nests of social insects. In: Insect Thermoregulation. John Wiley, New York.

Seeley, T.D., Tautz, J., 2001. Worker piping in honey bee swarms and its role in preparing for liftoff. J. Comp. Physiol. A 187, 667–676.

Simpson, J., 1958. The factors which cause colonies of *Apis Mellifera* to swarm. Insects Soc. 5, 77–95.

Wenner, A.M., 1962. Sound production during the waggle dance of the honeybee. Anim. Behav. 10, 79–95.

Winston, M.L., 1987. The Biology of the Honey Bee. Harvard University Press.

Winston, M.L., Taylor, O.R., Otis, G.W., 1980. Swarming, colony growth patterns, and bee management. Am. Bee J. 120, 826–830.