# Monitoring Bumblebee Daily Activities Using Microphones

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***ABSTRACT:*** *We present initial results of the study where we used microphones, placed in front of nest boxes, to monitor daily foraging activity of bumblebees. Sound recordings were analyzed using a custom-made computer algorithm which detects flight buzzing sounds coming from arrivals or departures of individual bees. In addition, the algorithm distinguishes between arrivals and departures. We show examples of daily activities for three species (B. pascuorum, B. humilis and B. hypnorum), each was monitored over the course of one day. This paper presents initial results of a longer study where we plan to systematically investigate the activities of bumblebees in various circumstances.*

**Keywords:** Bumblebees, Foraging Activity, Sound Analysis

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## 1. Introduction

Bumblebees (genus *Bombus* from the bee family Apidae) are an important group of wild pollinators. Due to different morphology and lifestyle, when pollinating plants, they are often more effective than honeybees – they are able to go foraging in rainy and cold weather, and in addition, they use a special technique, called buzz-pollination, to extract pollen from plants such as tomatoes. In addition to pollination in the wild, this makes bumblebees important players in greenhouse agriculture.

Pollinator monitoring, as well as monitoring of wild pollinators, is of high interest to agronomists, ecologists, and experts in the field of conservation. In studies of bumblebee activity, currently the most typical approaches are observations and capturing. Capturing is problematic as it includes removal of individuals from the environment. Sometimes, bumblebees are also studied in laboratory conditions, by raising an entire colony in a lab, which typically involves commercially available bumblebee species. One can expect that the behavior in a laboratory is not identical to that in a natural environment. A better approach to controlled studies is introducing the bumblebees into special nest boxes outside. This allows us to monitor them in a near-natural environment.

In this paper, we present the first results of a study where we used microphones to monitor bumblebee daily foraging activities. These activities are important to monitor as they provide a direct insight into pollination service. Using a microphone (recording sounds) is clearly advantageous from personal monitoring (such as in Grad et al. [1]) since it is continuous and allows us to monitor several sites simultaneously (using several microphones). Bumblebee buzzing sounds have been studied before, though with a different focus. Gradišek et al. [2] developed a machine learning based algorithm to recognize individual species and types (queen or worker) of bumblebees based on flight buzzing sound. Heise et al. [3] developed an algorithm to detect bee buzzes from field recordings. In our case, the task was to detect arrivals and departures of bumblebees from the nest boxes (both of which result in buzzes recorded by the microphone), therefore the algorithm was optimized for this task. We discuss the algorithm and show some initial results.

## 2. Materials and Methods

### 2.1 Data Collection

USB stick microphones dB9PRO VR1.0 [4] were used for sound recordings. Each microphone has 8 GB of flash memory, which gives it nominal storage capacity above 90 h. Sound is recorded at 48 kHz with a 192 Kbps bit rate. After each charging, a microphone can record for around 10 h. Microphones were placed in front of nest box entrances in order to record arrivals and departures. In the following, we demonstrate the results for three different bumblebee families, each of them monitored over the course of one day. The details of the investigated families are listed in Table 1. In all cases, the microphones were set around 8 am. For *B. pascuorum*, the microphone kept recording until the battery lasted while for the other two families, on the following day, the microphones were collected around 6pm as the weather deteriorated.

| **Species** | **Date** | **No. of workers** | **Weather** |
|---|---|---|---|
| *B. pascuorum* | 28 May 2018 | 10 | 14 – 28 °C, morning fog, sunny during the day, storms in the evening |
| *B. humilis* | 29 May 2018 | 20 | 16 – 26 °C, morning partially cloudy, light rain after 4pm, heavy rain after 6pm |
| *B. hypnorum* | | 30 | |

Table 1. Bumblebee families studied

### 2.2 Sound Recording Analysis

The flowchart of the algorithm is shown in Figure 1. The algorithm was inspired by that of Heise et al. [3], but simplified in order to work faster as recordings of arrivals and departures in front of a single nest box are typically cleaner than those from a microphone located in the field. Our preliminary analysis was carried out using the Audacity software while a more detailed analysis was done in Matlab, using in-built packages and own code. In each recording, we manually labelled around 10 buzzes at the beginning in order to optimize the thresholds for the algorithm (described in the following). In addition, we manually labelled the entire recording of *B. pascuorum* in order to evaluate the performance of the algorithm.

Preliminary inspection showed that the microphones recorded bumblebee buzzes well, while also recording a series of noises from the environment, such as passing traffic or human speech. Sometimes, these sounds can be louder than the buzzes themselves. The task of our algorithm is therefore to detect loud events and to check whether they are buzzes or noise. For positively identified buzzes, we next determine whether they correspond to arrival or departure of the bumblebee.

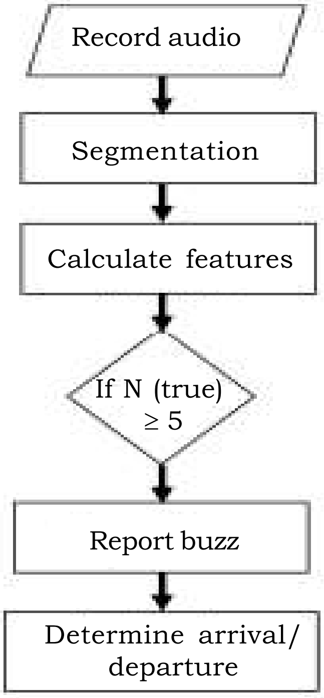

Figure 1. Flowchart of the buzz detecting algorithm

The algorithm is the following:

1. The recording, typically several hours long, is cut to segments of 5 seconds. This length was determined to be sufficiently long to contain the entire event while short enough to contain only a single event.

As the recording is cut into segments, there is a possibility that the cutting occurs in the middle of a buzz. To identify such cases, a special function first checks whether the peak amplitude occurs in the first second of the segment. If it does, it checks the last second of the previous sample, if the peak amplitude occurs in the last second there (indicating that the buzz was cut to two segments). In such cases, both segments are merged into a single segment and the analysis proceeds as described in the following (with only one buzz counted).

2. For each segment, we calculate the Fourier transform of the time-domain signal to obtain the spectra (frequency domain, spectrum amplitude as a function of frequency).

3. For each segment, we calculate seven independent Boolean features that we use to decide whether the segment contains an event or not. In the following, the natural frequencies (the frequency that a bumblebee flaps its wings during flight) are optimized for *B. pascuorum*. For species with significantly different natural frequencies (see [2]), we modify the boundaries. The feature thresholds are set for each family as well, based on some manually inspected events (about 10 – 15 events at the beginning of each recording).

a) We calculate the average amplitude of the segment (which can generally be done either in time or in frequency domain). If the amplitude is larger than a manually determined threshold value, this is a possible event (e.g. true).

b) The natural frequency is f = 180 Hz. We count the number of peaks between 160 and 200 Hz (using the *find peaks* function). If the number of peaks is smaller than the threshold, this is considered a buzz, otherwise we are dealing with noise.

c) We calculate the ratio of average amplitudes around the proposed peak (average amplitude value on the interval 160 – 200 Hz) and below it (60 – 120 Hz). If the ratio is larger than the threshold, this can be a true buzz, otherwise it is likely to be noise.

d) Similar to feature c), we check the ratio of the average amplitude around the proposed peak and above it (220 – 280 Hz).

e) Similar to feature b), we look for a peak at double natural frequency (first harmonic), looking at the interval $(2 * f - 20\,Hz, 2 * f + 20\,Hz)$.

f, g) We follow the same procedure as for features c) and d), just at the frequency of first harmonic and correspondingly higher interval boundaries.

If five or more features return "true", we consider the segment to contain a buzz. This criterion was determined on a series of manually labelled events in order to maximize the accuracy.

Once we know that a segment contains a buzz, we can determine whether it corresponds to arrival or departure. This part is carried out using signal in time domain. Figure 2 shows examples of both events. They are roughly symmetric in shape, which is reasonable given the dynamics of the process. When a bumblebee arrives to the nest box, it is initially far from the microphone and then gets closer – resulting in an increasing signal amplitude. When it lands, it stops buzzing, thus a sharp drop in signal. For departure, the bumblebee starts flying (sharp jump) and then flies away from the microphone (gradual drop in amplitude).

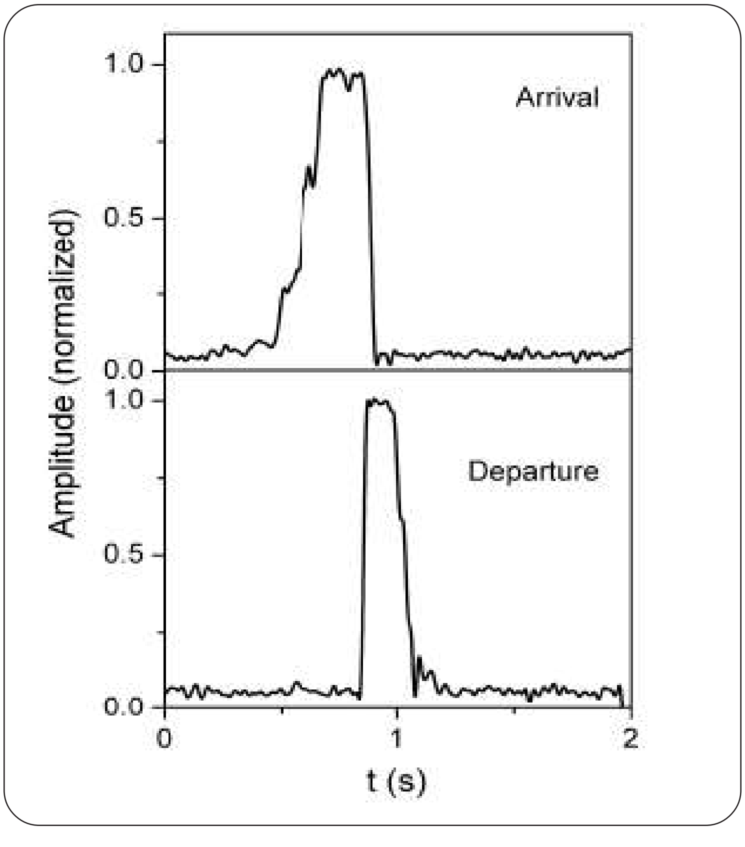

Figure 2. Signal envelope in time domain for arrivals (top) and departures (bottom)

To classify the event as an arrival or a departure, we do the following. First, we calculate the signal envelope and smooth it to reduce the noise. Such envelopes can be seen in Figure 2. Next, we use the *find peaks* function to identify peaks and we calculate the maximum absolute difference between two consecutive peaks. We call this a "drop". Looking at Figure 2, we see that the drop appears at the end of arrival and at the beginning of departure. By integrating the area before and after the drop over a chosen interval, we can determine the arrival or departure.

As each segment has a timestamp, we are able to plot histograms of either arrivals or departures of bumblebees throughout several hours.

### 3. Results and Discussion

Figure 3 shows three histograms for bumblebee departures on a chosen day, on hourly basis.

Figure 3 only shows the number of departures. The numbers for arrivals are very similar, as is to be expected. These three histograms provide a good insight into the daily dynamics of each family. Different species have different foraging habits, for example, *B. pascuorum* were mostly active around noon and in the afternoon while less active in the morning. On the other hand, *B. hypnorum* were more active after 3 pm. Light rain at 4 pm made the *B. humilis* workers stay inside but it did not affect *B. hypnorum*. Of course, as these are initial results on limited datasets, a longer data collection will be required to investigate the dynamics as the family develops over the course of several months.

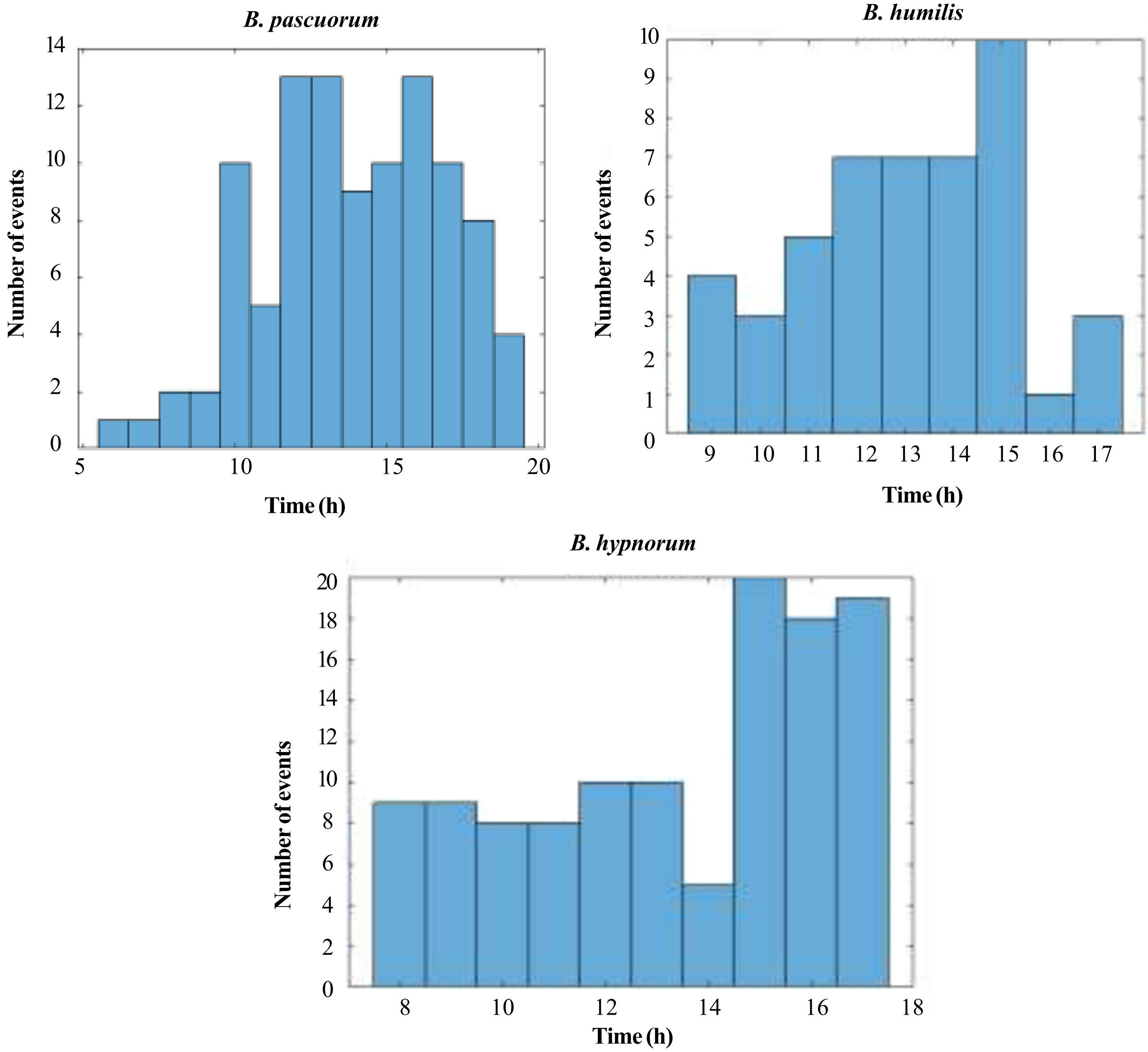

Figure 3. Histograms for number of departures (reflecting daily activity) for three bumblebee families, as described in Table 1

To check the accuracy of the algorithm, we tested it on the manually-labelled recording (*B. pascuorum*). Out of 180 actual events (counting arrivals and departures together, P), our algorithm correctly detected 171 events (*TP*), 9 detected events were not buzzes (*FP*), and 9 events were missed (*FN*). Based on this, we can determine the algorithm sensitivity, $TP / P = TP / (TP + FN) = 0{,}95$ and precision $TP / (TP + FP) = 0{,}95$. Clearly, this estimate is based on a single long recording and may vary for other conditions (different species or different structure of noise).

## 4. Conclusion

We demonstrate that microphones can be used as a simple tool to study bumblebee foraging activity, as opposed to personal monitoring. The algorithm we developed detects potential buzzes and classifies them as either arrivals or departures. Compared to the performance of a human manually labelling the buzzes in the recording, the algorithm works with 95 % sensitivity and 95 % precision, which we consider sufficient for meaningful results. In future, we plan to study several bumblebee families throughout the year to investigate the effects of the weather, temperatures, family size, and other parameters on foraging activity.

## Acknowledgments

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[4] http://db9pro.com/