How do bees move across the landscapes?

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How do bees manage to locate flowers? And how do they move between them?

These are fundamentally important questions for biologists aiming at better understanding the basic behaviour of pollinators. Addressing these gaps of knowledge is also critical for sustainable development, to protect our ecosystems, economies and food security. When foraging for nectar, pollinators, such as bees, transfer pollen between flowers. In doing so, they mediate the reproduction of plants on which most animals rely—herbivores, of course, but also predators that consume them, and the predators of predators etc.

As humans, most of our alimentation is based on fruits, vegetables, and animals that depend on pollination. It has been estimated that insect pollinators contribute to more than 75 per cent of the reproduction of wild and cultivated plants, a service worth several hundred billion euros a year for food production worldwide.

Over recent years, however, the widespread decline of pollinators associated with our impact on ecosystems has generated considerable public debate and concern. The risk that we may soon be facing a pollination crisis in which crop yields would begin to fall because of inadequate pollination and food demand increases has made the study of plant-pollinator interactions an absolute priority.

In particular, despite thousands of years of domestication and more than a century of academic research on bee behaviour, how bees move and disperse pollen across landscapes remains largely mysterious. If we could understand patterns of pollen dispersal by bees, and thus know which plants cross and at which frequency, we could predict the pollination efficiency in a given plant-pollinator community. We could also selectively and efficiently promote pollination for conservation or agricultural purposes.

Linking bee movements to plant reproduction

The ERC project "Bee-Move" brings together an interdisciplinary team of bee biologists, radar scientists, computer scientists and plant ecologists. The team will monitor the spatial movement patterns of bees in the field and experimentally study their consequences on plant reproduction.

The ultimate aim of Bee-Move is to produce a mechanistic model capable of simulating bee movements and pollination success for any given environment. Our team will test the hypothesis that different types of pollinators will have different influences on pollination. For instance, bumblebees, that tend to wander around and forage we , may promote higher levels of plant outbreeding than honey bees that actively recruit nestmates for mass exploitation of blooming resources. Both types of pollinators are expected to be complementary.

The challenge of tracking bees in the field

The first challenge of Bee-Move is to develop a tracking system to monitor bee movements. Direct observations of bee foraging patterns in the field have always been difficult and thus limited to small spatial scales within the field of view of an experimenter.

While it is relatively easy to spot a bee on a flower, it is generally much more challenging to follow that same bee during its complete foraging journey, starting and ending at its nest. It is even more problematic to follow the flight trajectories of that bee repeatedly to study how they develop with time, under the influence of learning, and interactions with the other bees around.

Such detailed investigation of bee behaviour in the field requires monitoring multiple (hundreds), small (<2 cm), and fast-flying (20 km/h) individuals, interacting over several kilometres (<10 kms) during consecutive days or weeks. This is out of reach with current technologies. At best, automated systems have been used to record the 2D flights of single bees carrying a large transponder within 700 m, or the visitation sequences by microchipped individuals at target locations with no information on their trajectories. These hard-technological limitations are the main reason why all the basic questions, previously outlined, about how bees move and forage are still unanswered.

The promises of millimetre wave radars

In Bee-Move, we will develop a new type of tracking system based on millimetre wave radars to automatically monitor the 3D movements of hundreds of bees simultaneously in areas of several square kilometres. Our recent utilisation of such radars to monitor the movements of humans and farm animals such as sheep and pigs (Henry *et al.*, 2019; Dore *et al.*, 2021) gives us good reasons to think we will succeed.

Without going much into details, these types of radars surround us in our everyday life. For instance, modern cars are equipped with radars in the back to advertise obstacles when moving backwards. These radars are made of antenna arrays that transmit an electromagnetic signal. The echo signal backscattered by objects in the environment (e.g. another car) is perceived backed by the radar through its receiving antenna arrays. In this radar sensing approach, the object of interest (the target) has an electromagnetic signature that can be remotely detected without

Figure 1: Radar-based tracking system to study bee movements. Left: complete system with radar, support and rotating reflector. Right: system without radar. Photo credit: Tamara Gomez-Moracho.

having to use tags or transponders. Transmitting the electromagnetic signals in all directions through the fast rotation of a reflector can give information about the azimuth, elevation and range of the target and thus be used for 3D tracking over time (Figure 1).

As a first step, we recently managed to use millimetre wave radars to track bumblebees collecting sucrose solution on a feeder in the field (Dore *et al.* 2020). With this system, we recorded the flight path of several bumblebees simultaneously (Figure 1), but also similarly sized insects, such as honey bees and hornets. We are currently working on different solutions to increase the volume of interrogation by this tracking system. Combining signals from multiple radars is one possibility (Figure 2). Our short-term aim is to cover volumes of several hundred cubic metres to study ecologically relevant foraging distances for the bees.

Robotic meadows: towards a new framework to study bees in the field

With this radar-based tracking system, we will develop a new kind of behavioural study with bees in the field. In the coming year, we will deploy radars in experimental fields in order to monitor bee movements across much larger areas. We will then acquire unique data about bees' interactions and collective foraging patterns at unprecedented spatial and temporal scales. This was not possible before.

To precisely manipulate the environment of the bees, we will combine this tracking system with 'smart flowers' on which bees could forage. These robotic flowers will recognise the bees individually once landed on them and selectively give them access (or not) to a controlled amount of nectar and/or pollen. Spreading many of these robotic flowers in the field will create an artificial meadow in which we will continuously record the flight paths of bees (with the radars) and the information about food collection (with the flowers).

This will enable us to study the behavioural responses of bees following manipulations of the environment, such as changes in flower densities, spatial

Figure 2: Left: Bumblebees (Bombus terrestris) collecting sucrose solution on a feeder in the field. Photo credit: Tamara Gomez-Moracho. Right: 3D trajectories of bumblebees flying around the feeder. The tracks were obtained with two radars placed on each side of the feeder.

arrangements, and reward qualities, that will simulate real ecological scenarios. We will compare the spatial foraging patterns of the solo foraging bumblebees and the mass foraging honey bees. Each of these experiments will bring new fundamental knowledge about pollinator foraging behaviour. This will also set the stage for future studies investigating the consequences of all these behaviours on real plants, as planned in the second step of Bee-Move. But this is another story.

References

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PROJECT NAME
Bee-Move

PROJECT SUMMARY

The ERC Consolidator Grant "Pollination ecology: how do bees move across the landscape and fashion plant reproduction (Bee-Move)" aims to link the study of bee spatial foraging patterns in the field with pollen dispersal and plant reproduction success. It will identify key mechanisms of pollination on which we could act for ecological, economic or public health issues.

PROJECT PARTNERS
Bee-Move is based at the Research Center on Animal Cognition (CRCA-CBI), in collaboration with the Laboratory for Analysis and Architecture of Systems (LAAS-CNRS). Both research institutes are located at the University of Toulouse III, France.

PROJECT LEAD PROFILE
Dr Mathieu Lihoreau is a cognitive ecologist, specialised in bee behaviour. He graduated at the University of Rennes 1 and worked as a postdoc in the UK and Australia. He is currently a CNRS group leader at the CRCA-CBI. In 2020 he received the ERC Consolidator Grant Bee-Move to study bee movements and their impact on pollination.

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