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Modelling bee movements to improve pollination

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Pollinators such as bees, flies, butterflies, birds, and bats support a major ecosystem service that sustains most terrestrial plants and animals, including us humans. When foraging on flowers, these animals disperse pollen grains, thereby contributing to the reproduction of about 75 per cent of wild and cultivated plants. Today, the alarming decline of pollinators worldwide threatens this vital ecosystem service, calling for a better understanding and management of plant-pollinator interactions.

In "Bee-Move", we work on developing mechanistic models that will predict the pollination patterns of plants via the movement of pollinators. For this, we have built an interdisciplinary team of bee biologists, electronic engineers, plant ecologists and computer scientists.

Over the past two years, we have developed new experimental tools and protocols to monitor the movements of bees at the scale of landscapes and study their consequences on plant reproduction. We use radars (Figure 1) to track the flight paths of individual bees over several hectares and robotic plants to experimentally manipulate the floral landscape: the density of flowers, the nutritional quality of their nectar and pollen, and some other key characteristics of the environment (Dore *et al.*, 2022). This is immense progress compared to decades of research during which bees were painfully observed by experimenters in the field.

In the next three years, we will use these unique movement data to build computational models capable of simulating bee foraging movements in virtually any kind of environment. These models will predict, with high precision, bee movements, pollen dispersal and, ultimately, plant reproduction patterns. Such a mechanistic approach is entirely novel and holds considerable premises to guide precision agriculture in the context of a pollination crisis by increasing crop yield through favouring the expression of natural behaviour in pollinators.

Pollinators do not move randomly

Although they often look tortuous and complex, the movements of pollinators are not random. More than a century ago, early ethologists such as Charles Darwin and Nico Tinbergen described how bees use visual and spatial memories to navigate (Chittka, 2022). Our recent work using radars to track bee flights shows how pollinators learn to orient in their environment, locate profitable plants, and develop routes to revisit them in an efficient manner (Figure 1). Bumblebees, for instance, use hills, trees and footpaths as landmarks to relocate flowers or their nest (Brebner *et al.*, 2021). When flowers are patchily distributed, bumblebees visit patches in repeated sequences, often using routes minimising overall travel distances as if they were trying to solve a "travelling salesman problem" (Lihoreau *et al.*, 2012).

Models can simulate the movements of pollinators

The detailed analysis of pollinators' movements has revealed a 'navigational toolbox' that bees use to guide their foraging decisions (Lihoreau, 2024). This means we can now build computational models in order to predict their complex movement patterns (Figure 2). For instance, simple algorithms implementing vector learning (i.e. the fact that bees can learn the distance and direction between two points using the position of the sun and possibly other landmarks) can accurately replicate route development and optimisation by bumblebees (Reynolds

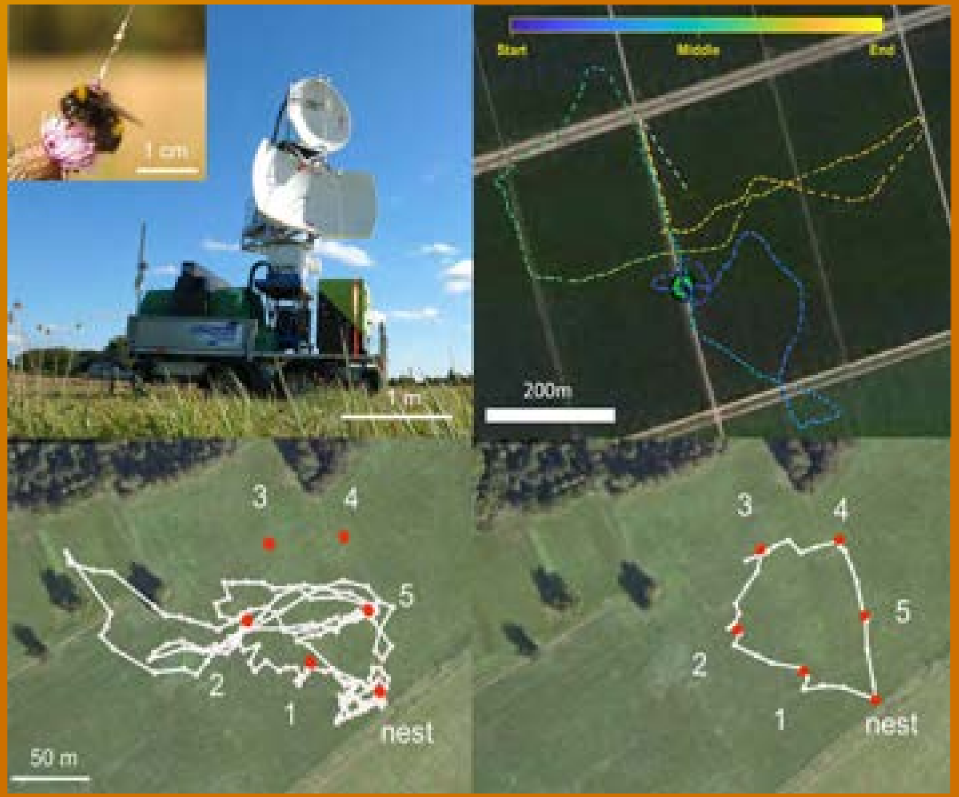

Figure 1: Top left – Bumblebee equipped with a radar transponder and rotating harmonic radar used to track the insects. Photos: Joe Woodgate. Top right: Radar track of a bumblebee following footpaths on the ground (modified from Brebner et al., 2021). Bottom left – Radar track of a bumblebee during its first foraging flight in an array of five feeders (numbers 1–5). Right – Radar track of the same bumblebee after four hours. With experience, the insect developed a near-optimal route to visit the five feeders (modified from Lihoreau et al., 2012).

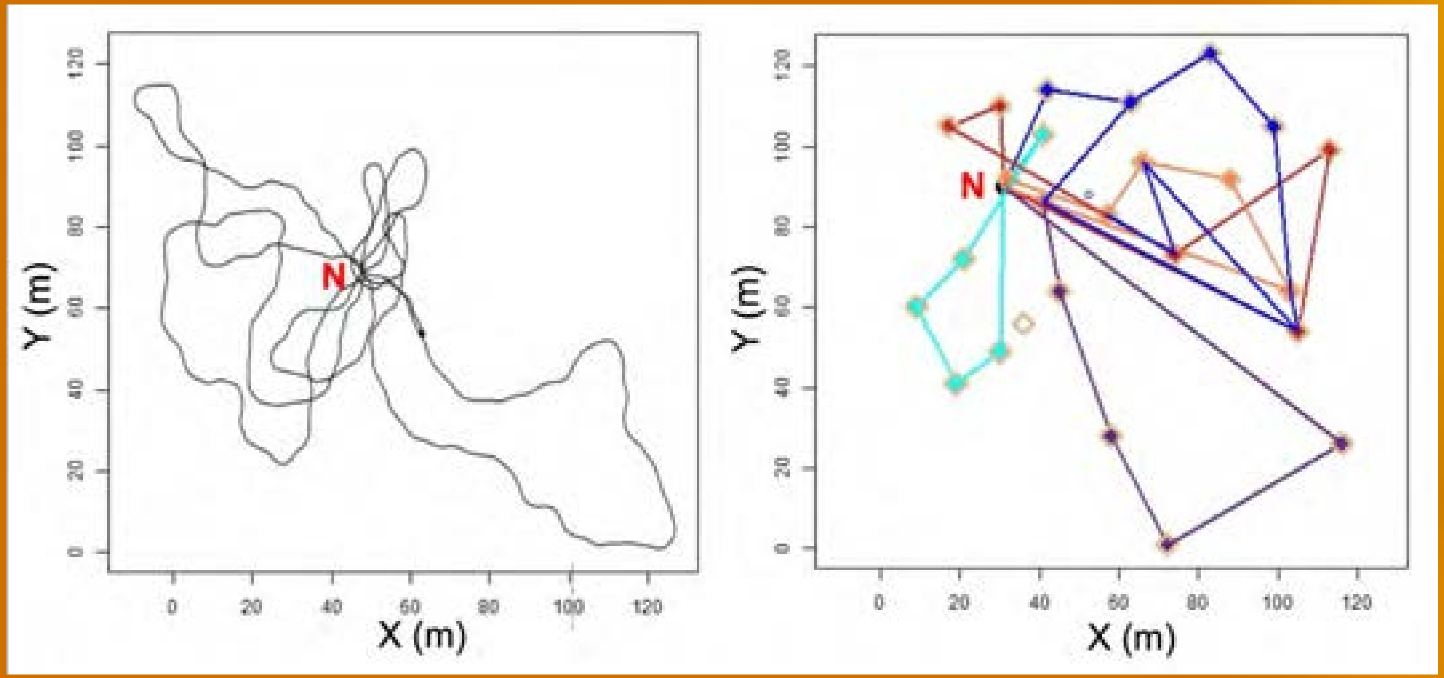

Figure 2: Left – Simulation of search flight by a single bee. In this example, the simulated bee explores its environment by making search loops of varying sizes, starting and ending at its nest (N). Right – Simulation of route development by several bees. In this example, five simulated bees (different colours) learn to concomitantly exploit 20 plants (squares).

et al., 2013). Building on this pioneering work, we are now making predictions about how bees may discover or dismiss specific plants in their environment (Moran *et al.*, 2023) and, in the case of social bees, collectively organise to optimise resource exploitation in the whole plant population (Dubois *et al.*, 2021). Importantly, theory is constantly tested and refined using a tight dialogue between computer simulations and experiments on real bees.

From pollinator movements to precision pollination

Modelling bee movements provides direct access to plant reproduction patterns via pollen dispersal. If we can predict the complex, long-term and non-random patterns of pollen dispersal by bees, it becomes possible to precisely know which plants cross and at which frequency. This means we can anticipate pollination efficiency in a given plant-pollinator community. The power of our mechanistic approach based on bee behaviour (as opposed to statistical models) is that it will generate realistic predictions in any kind of environment, including all scenarios of environmental changes. This is a major step forward, considering the worrying environmental crisis we are facing.

Thus, our models will ultimately constitute unique and powerful tools for precision agriculture. It will be possible, for example, to precisely identify the distribution, diversity (mix of species) and number of pollinators necessary to optimise pollination and food production in a given crop. Improving crop yield through these methods could help farmers compensate for potential losses from transitioning towards more sustainable practices with less (or no) agrochemicals. The very same modelling approach could be used for conservation purposes. Indeed, our models will inform us about pollinator abundance and diversity required for efficient reproduction and maintenance of wild plant populations. They could also provide key information about the plant communities that would better support local populations of endangered pollinators. Thus, better integrating pollinator behaviour into pollination models as we are doing in Bee-Move is not only promising but also an absolutely crucial step forward for a successful ecological transition.

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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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