Final Report
Ecology and Evolution of Mimicry in a Changing World
[EcoEvoMimic]

Outline of the project

The EcoEvoMimic project explored how the evolution of mimicry in animals evolved, and how contemporary global change may influence these mimetic relationship. I took as my study system the hoverflies (harmless, pollinating insects) as "mimics", and the stinging bees and wasps that they so closely resemble as "models". A variety of these insects are shown on the right (five are venomous, seven are harmless) to illustrate the concept. Using a variety of different approaches, including long-term datasets of recorded insects over the past century, field studies of wild bird behaviour, and psychological studies using humans to explore animal behaviour, I quantified the consequences of global change for the ecology and evolution of these two groups of insects. Specifically, I was interested in the ecological concept of "decoupling", whereby two or more organisms that are reliant upon one another no long occur together. Such an effect is possible when plants flower before their pollinators have emerged in Spring, or birds lay try to rear chicks after their caterpillar food has already turned into moths or butterflies. The same is theoretically possible in species that mimic one another, but this has not yet been evaluated. Below, I outline the key results from the project:

Key Finding 1: Hoverflies are responding strongly to climate change

An underlying assumption of the project involved the responses of different groups of insects to climate change. If all aspects of the natural world reacted to climate change in the same way then the links between organisms (predators and prey, plants and pollinators) would remain intact. However, if interacting species moved to different locations or occurred at different times of year then there is the potential for decoupling. Using 50 years of citizen science data and 30 years of standardised recording, I demonstrated that the hoverflies are emerging earlier in the year in response to climate change, and that this rate of change is substantially more rapid than that of the plants that they pollinate. The agreement between these two datasets provides substantial support to the central finding, which occurs on a scale that is difficult to quantify. I was also able to make extensive use of laboratory studies which measured development times in different hoverfly species under different temperatures. However, there was no evidence that species that respond strongly to temperature in the laboratory also respond strongly in the field. The main conclusion from this part of the work is that, while we know that there is a strong response from natural populations of hoverflies to the changing climate, the mechanism underpinning that response remains elusive. The work was published in the journal Ecography (Hassall *et al.*, 2016).

Key Finding 2: Climate change "decouples" models and mimics

Following on from the finding that hoverflies were responding rapidly to climate change, I tested for the potential effects of this change on their relationships with stinging wasps and bees. A central hypothesis in the EcoEvoMimic project stated that the changes in the timing of emergence of mimics and their models would influence how bird predators learned to distinguish harmless from harmful insects.

The primary method to study these made use of a novel application of virtual reality to animal behaviour experiments. While working with wild birds is the preferred way to see how nature really responds to these kinds of questions, we can gain insight by using humans as a proxy for animal learning. I recruited 45 participants to play a game in which they had to play the part of birds foraging. Participants scored points if they "ate" the harmless insects (mimics) with which they were presented, but lost points if they ate the defended prey (models). I varied the order of the presentation such that sometimes participants saw the model first, sometimes the mimic first, and sometimes the order was randomised. The results showed that the mimics benefit most from a random pattern of occurrence which seems to confuse our human predators. Meanwhile the models benefit from emerging first, as this allows them to educate the predators. The predators themselves also performed worst when the images were randomised, and performed best when the models occurred first.

A component of the project was designed to evaluate this in the field using wild birds by varying the order of presentation of pastry "prey" that were painted in different colours. Some of those prey contained a bitter-tasting chemical that the birds could learn to avoid (equivalent to the stinging bees and wasps) and others were plain pastry (equivalent to the harmless hoverflies). However, despite running the project for two weeks across nine sites, this ambitious experiment proved not to be sufficient to capture the variability across the different locations.

Additional findings

Through the fellowship, I have had the opportunity explore related topics that were not part of the core mission of the EcoEvoMimic project. First, I showed, by recording the sounds that mimics and models make when attached, that acoustic mimicry (the imitation of sounds) also occurs in this group (Moore & Hassall, 2016). However, there is little evidence that it deters predators in field experiments. Second, I have shown that the timing of emergence of urban dragonflies shows a very small response to the "urban heat island" (the warmer temperatures found in cities) compared to the response to wider climate change (Villalobos-Jimenez & Hassall, in press). My other work that has carried on during the fellowship has continued to explore wider issues of global change and biodiversity, with studies showing that urban ponds can be biodiversity reservoirs in cities (Hill *et al.*, 2016), that climate change and invasive species interact to determine future impacts on freshwater ecosystems (Kenna *et al.*, 2016) and that climate change may alter rates of aging with implications for an endangered freshwater mussel (Hassall *et al.*, 2017).

Ongoing and future work

In addition to the projects that have already been completed as part of the EcoEvoMimic project, I am currently running or planning a series of follow-up studies. This includes an online experiment to evaluate the similarity between many types of mimic and model (which can be found here: http://www.mimicryexperiment.net/. I am also trialling the application of mimicry theory in the design of citizen science and pollinator monitoring techniques, using the insights derived from my work on bee, wasp, and hoverfly ecology to inform conservation monitoring and management.

Website: The project website can be found at http://ecoevomimic.christopherhassall.com/ and will be updated to contain links to materials produced and used during the project.

References

Hassall C, Amaro R, Ondina P, Outeiro A, Cordero-Rivera A, San Miguel E (2017) Population-level variation in senescence suggests an important role for temperature in an endangered mollusc. Journal of Zoology, **302**, 32-40.

Hassall C, Owen J, Gilbert F (2016) Phenological shifts in hoverflies (Diptera: Syrphidae): linking measurement and mechanism. Ecography, n/a-n/a.

Hill MJ, Biggs J, Thornhill I *et al.* (2016) Urban ponds as an aquatic biodiversity resource in modified landscapes. Global Change Biology.

Kenna D, Fincham WNW, Dunn AM, Brown LE, Hassall C (2016) Antagonistic effects of biological invasion and environmental warming on detritus processing in freshwater ecosystems. Oecologia, 1-12.

Moore CD, Hassall C (2016) A bee or not a bee: an experimental test of acoustic mimicry by hoverflies. Behavioral Ecology, **27**, 1767-1774.

Villalobos-Jimenez GJ, Hassall C (in press) Effects of the urban heat island on the phenology of Odonata in London, UK. International Journal of Biometeorology.