Lifting the veil on evolution from terrestrial to water walking insect

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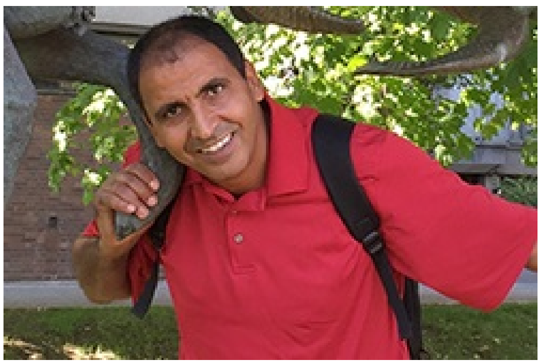

Credit: CORDIS

Anyone who has seen a lake or a small pond will have witnessed the evolutionary marvel of those curious insects that run over water with no trouble whatsoever, as if it were solid ground. An EU project is allowing ENS de Lyon to investigate the genetics behind this capacity.

Heteroptera and Gerromorpha, two species of semi-aquatic insects, are dominating water surfaces worldwide and have become somewhat of a scientific curiosity. To understand this adaptation—these insects are none other than evolutions of their terrestrial counterparts—integrative studies combining evolutionary developmental biology and evolutionary ecology are needed.

The WATER WALKING (Developmental genetics and adaptive bases of a major ecological transition - How to walk on water!) project is trying to achieve just that. Abderrahman Khila, group leader at ENS de Lyon, has been developing a multi-level approach to study how the interplay between developmental genetic pathways and the ecological environment can drive morphological evolution such as that observed in semi-aquatic insects.

Why is it so difficult to integrate evolutionary developmental biology with evolutionary ecology?

We need tools and we need a good ecological context at the same time. Current standard models (Drosophila, mice, zebrafish, etc.) offer great tools but lack the ecological context. Natural models, which are usually chosen because of a specific ecological context, have not been established for a routine use of sophisticated tools, such as transgenesis or genetics.

How can the study of semi-aquatic insects help overcome these problems?

Semi-aquatic insects pose a particularly interesting set of biological problems that enables us to address questions related to species adaptation and diversification. Moreover, these insects have proven quite amenable in terms of the transfer of certain genetic tools: It makes it possible to address these questions in a detailed and integrative manner, that is, combining developmental genetics with ecology and evolution.

One striking aspect of the biology of this group of insects is their capacity to occupy water surface as a new habitat (their ancestors were terrestrial) and therefore acquire new ecological opportunities. Accompanying this transition is a large set of conspicuous phenotypes such as increased leg length, reversal of relative leg length plan (second legs are the longest in water striders, whereas in most insects third legs are the longest) as well as the way they generate movement on the fluid substrate. They also exhibit an array of sexually relevant phenomena such as spectacular dimorphisms and phenotypic plasticity often driven by conflict between genres.

This, along with the tools we were able to establish, made a big difference in integrating ecology, evolution, and developmental genetics.

How did you proceed to study these insects?

I was invited to join an effort to study the genetic basis of sexual conflict in the water strider by Prof. Locke Rowe (University of Toronto) in collaboration with Prof. Ehab Abouheif (McGill University, Montreal). My first condition then was that we try to test some basic techniques, which worked very well. It worked so well that I decided to build the rest of my career on this system.

What are the main things you have learnt so far?

Water striders generate movement on water using a highly efficient trick: they have evolved elongated second legs with a paddle shape that act as oars. The right and left second legs move in a simultaneous sculling motion through the water just like oars on a rowing boat.

The first question we asked ourselves is, how do such morphological and function modifications evolve? We found that a Hox gene called Ultrabithorax (Ubx; conserved from invertebrates to humans) changed its spatial and temporal expression and that these changes shape the second legs into the way they look. What was really surprising is that this gene makes second legs long but makes the third legs short, which results in the characteristic morphology of water striders. We found that these opposing roles of the gene are mediated through differences in the amount of Ubx protein that each leg has. More specifically, at low dose—the case of the second legs—Ubx promotes growth, but at high dose—the case of third legs—Ubx suppresses growth.

As we wondered how it is that differences in dose can result in opposing effects on the growth of the legs, we found that genes that are regulated by Ubx responded differently to its levels. We discovered, for the first time, that an ancient immune system protein (important for antigen processing and presentation in humans) called gilt is now controlled by Ubx. At a low dose of Ubx (second legs) gilt is expressed and contributes to lengthening the leg. At a high dose of Ubx (third leg) gilt expression is entirely shut down contributing to keeping that leg shorter.

In addition to locomotion on fluid, we found that the shape of water striders' legs is under selection from predators striking from underneath the fluid, such as fish. This work allows us to understand how selection (requirement for locomotion on fluid substrates as well as predation) can shape animal morphology through changes in a pre-existing developmental programme and also through the emergence of new genetic interactions.

What do you still need to do before the end of the project?

There are several projects that are still in motion. The first tries to understand how these animals acquired the ability to maintain their body weight on water whilst most others would drown. Small hairs on their legs allow for the trapping of air and thus forming a cushion between the leg and the water surface. We would like to understand how the shape and the density of these hairs are established during development.

Another important project addresses the question of how evolutionary novelties emerge. Some species specialise in fast running water and have evolved a propeller on the tip of their second legs; a sort of fan. We found that this novelty emerged through the emergence of a new gene by duplication. This is exciting because the general agreement is that novelties can emerge by re-using pre-existing genes.

A final project deals with sexual selection. A species of water-walking insects exhibits a spectacular polymorphism in the males in terms of leg length; some males have short legs (females too) but others have extremely long legs. We now know that leg length is important for male combat to acquire females and that males with longer legs often win. We are trying to understand how such spectacular phenotypic plasticity can evolve both from an ecological and developmental perspective.

Besides the integration of two disciplines, what do you think could be the main benefits of your research?

The integration per se is not the main goal. The goal is to understand how diversity comes to be and what factors contribute to it. The answers to this important question have been scattered and truncated because fields of study (such as developmental biology, ecology, population genetics etc.) are not sufficiently cross fertilising. By integrating them, we hope to bring a more comprehensive understanding of diversity in general.

More information: Project website: cordis.europa.eu/project/rcn/189963_en.html

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