Living systems are highly integrated, with a multitude of levels of organization, from molecular and intra-cellular scales to ecosystems. Complex organisms are themselves consortia of macro- and micro-organisms, which work together with their host to build the individual. Yet, each of these organisms can function and evolve in the short term according to its own logic, possibly in conflict with other higher or lower levels, or with other time scales. The once common idea among evolutionists that natural selection results in organisms perfectly adapted to their environment is now severely undermined. Not only because, as the Red Queen explains to Alice, one has to run relentlessly to keep its place in a changing environment, or because past evolutionary history and chance constrain the possibilities of present adaptation, but also because different levels of selection have interests that are generally difficult to reconcile.

Multi-scale coevolution resets classical questions in evolutionary biology

One example, of particular interest is the question of the source of heritable variations. The phenotype of organisms in a population is influenced not only by variations in their nuclear and mitochondrial genomes, the dynamics of which is the object of population genetics, but also more and more patently by the consortium of microbes and genetic elements that constitute its microbiome and virome. The hologenome designates this complex assembly of genetic materials, which obey different rules of transmission and different evolutionary strategies. The ability of symbionts to manipulate host phenotypes or to interfere with each other influences the evolutionary dynamics of all players in ways that are yet poorly understood. In addition, new questions arise, such as the importance of co-adaptation in these systems and their consequences in maintaining cohesive biological systems.

› **Symbiosis: a response to and a source of divergent selection**

Using a variety of approaches combining experimental evolution, genomic, functional, phenotypic and behavioral data, we aim to test whether symbiosis facilitates diversification and to characterize the underlying microevolutionary processes.

› **Ecological networks of horizontal gene transfer**

We develop original methods to detect gene transfer and we investigate the factors that influence the routes of gene transfers among microbes but also among insects.

› **The interplay between symbiosis, infection and immunity and its evolutionary consequences**

We try to understand the intimate interaction of hosts with pathogens, symbionts and transposable elements and how it affects the extended phenotype of the host.

› **Transgenerational inheritance and environment changes**

We try to decipher the molecular mechanisms that underlie rapid adaptation to environment and to test for transgenerational inheritance of fitness traits.

› **Intragenomic conflicts and demography**

We are developing models to test whether changes in the demography of the host affect the dynamics of transposable elements.

› **The determinism of phenotypic convergence**

We study the genomic basis of convergent phenotypic evolution in particular in the case of animals and plants adaptation to increasing temperature and decreasing water.

› **Reconciling the tree of life**

We develop phylogenetic methods for “reconciling” gene/species or host/symbiont histories and use these methods to explore the bulk of extinct or undescribed species and the history of association of symbiotic microbes with their hosts.

Integrating methods

The methods we use to tackle the questions raised by multi-scale co-evolution extend from theory, modelling and simulation to big data analysis, lab (notably on insects), and to a lesser extent, field activities.

Implication of research, responsibility of researchers and citizen sciences

From our research (some of which have immediate consequences in health, agriculture and ecology) and our concerns about the responsibility of scientists in society, we are committed to promote an “implicative” research. The implicative position means that we try to work on the link between science and society, not only through a one-way communication, applying or explaining our science, but also favoring early discussions on research projects, that may influence our research directions.