# Multilayer network model of mutualistic ecosystems: network structure and biodiversity.

Carlos Gracia-Lázaro[1], Laura Hernández[2], Javier Borge-Holthoefer[3], and Yamir Moreno[1,4]

[1]Institute for Biocomputation and Physics of Complex Systems.
[2]Laboratoire de Physique Théorique et Modélisation, UMR CNRS, Université de Cergy-Pontoise, 2 Avenue Adolphe Chauvin,F-95302, Cergy-Pontoise Cedex, France
[3]Qatar Computing Research Institute, Doha, Qatar
[4]Departamento de Física Teórica. University of Zaragoza, 50009 Zaragoza, Spain

Considerable attention is currently being paid to the study of ecological systems, as they often provide valuable services to mankind. A sustainable management of ecosystems as well as a proper assessment of the impact of human activity on them can only be achieved with a good understanding of their properties. *Mutualistic* ecosystems, involve two groups of species that are clearly differentiated, usually animals and plants, who help each other in fulfilling essential biological functions, as in the case of *pollination networks*, where a set of plants is pollinated by the insects that feed from the nectar of their flowers.

Usually they are described by a bipartite network where only vertices of two different kinds (animals and plants) are connected by links that represent the mutualistic interactions. Observed networks show a particular structure called *nestedness*, which implies that the system is composed of *generalists* (species that interact with most species of the other guild) and *specialists* (i.e. species that interact with very few species of the other guild) that mainly interact with generalists.

The origin and the consequences of the nested structure of mutualistic ecosystems as well as the pertinent characterization of such ordering are a matter of strong debate in the ecological community. The relationship between the structure of mutualistic ecosystems and the dynamics that led to this structure is still an open problem. In the seminal paper of May[1], the ecosystem is described by a dynamical linear model, with a random interaction matrix. His results show that a large ecosystem with high conectivity (the connectivity being associated to the complexity of the system) is unstable. Since then, special attention has been paid to the structure of the interaction matrix. Bastolla et. al [2] study a population dynamics model that includes plant-animal mutualistic interactions and animal-animal and plant-plant competing interactions, in mean field approach, except for the weak mutualism regime, where a more realistic mutualistic term is included. They conclude that the nestedness minimizes competition, allowing for an increase of biodiversity. As the parametrization of the studied models is quite arbitrary, it becomes crucial to assess how the obtained results behave face to the variation of these parameters.

In this work we investigate the influence of the network structure on the biodiversity of a mutualistic ecosystem. We study a non-linear population dynamics model and we take the structure of interactions explicitly into account both, in mutualistic and competition terms.

The ecosystem may be treated as a two layers of competing agents, one for plants and another for animals, coupled by the mutualistic interactions. The projection of the bipartite matrix on the animals' or plants' subspaces give the number of counterparts shared by any two given species of the same guild and may be used to model the corresponding competition term.

We study the steady states obtained for real matrices as a function of the intensity of the interactions and we analyse how these states vary with the nestedness of the system while controlling or not for degree distributions. Our results show the existence of a trade-off between the different interactions, so that the largest biodiversity is achieved with a non-trivial combination of mutualism and competition.

[1] R.M. May **238** 413 (1972)

[2] U. Bastolla *et al.* Nature **458**, 1018, (2009).