High-order *vs.* structured interactions in competitive ecosystems

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Ecological systems present a remarkably robust biodiversity, for which ecologists have proposed several mechanisms. This emergent property is being explained theoretically in terms of interacting species models on one part, and immigration and speciation models on the other [1]. In fact, simple dynamical models of competitors can produce a stable persistence when high-order interactions are considered, in which the interaction between two species is modulated by one or more other species [2]. Without this assumption, species densities fluctuate through time. The evolution of the density of one of the species is therefore proposed to depend on the outcome of the competition among them [1].

Even if the model does not consider the single effect of every individual of a given species on every individual of the others, it yields convergence to equilibrium. However, this deterministic-approximation approach ignores that single individuals can interact in diverse ways with multiple partners, whose identity can change not only with time but also with location. Here we propose a spatial model, in which each cell of a square lattice is occupied by an individual of a certain species. This representation provides a different context to test whether the structure of the ecosystem and the spatial distribution of individuals may be other candidates for the maintenance of biodiversity. At each time step, a random individual dies and only two neighbours compete to fill the gap, namely, we do not consider high-order interactions. Neighbours are chosen among surrounding cells upon a tuneable radius.

We have observed that the extension of the individual's neighbourhood plays an important stabilizing role. When the neighbourhood comprises neighbours up to a distance radius r of four, the system exhibits coexistence, and fluctuations around the equilibrium densities decrease with radius, Fig. 1. If the neighbourhood radius is larger, we obtain wider amplitude fluctuations similar to those of the dynamical model where no high-order interactions are considered. The method used to choose the neighbourhood can be generalised in terms of the Laplace transform, where the probability of being chosen decrease with the distance from the dead cell. In this new scenario we also find that, when the probability of choosing remote neighbours is negligible, the regime has little fluctuations in densities equilibrium. However, if the system is embedded in a random network, only wide fluctuations appear regardless of neighbourhood's size. Thus inclusion of a regular spatial structure in competitive network models can stabilise dynamics, making species fluctuations decrease and allowing coexistence.

Moreover, our model also allows us to study processes taking place in these systems such as the spatial redistribution of species. Lattice-based models exhibit similar power-law scalings in the geometry of clusters, including communities sizes [3], Fig. 2. In particular, it has been suggested that deviations from power laws are a symptom of instability [4]. Numerical confirmation of these results will be additionally presented, at which different neighbourhood radii will be considered.

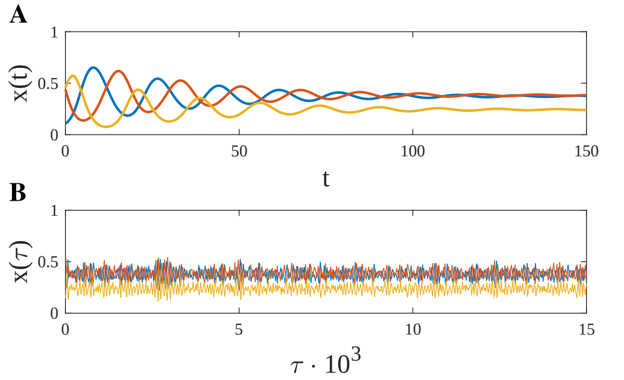

Fig. 1. (a) Reproduction of density evolution for a 3-species ecosystem in [1] with 3-order interactions. (b) Dynamics of our lattice-based model with $r = 3$ in a 100×100 lattice.

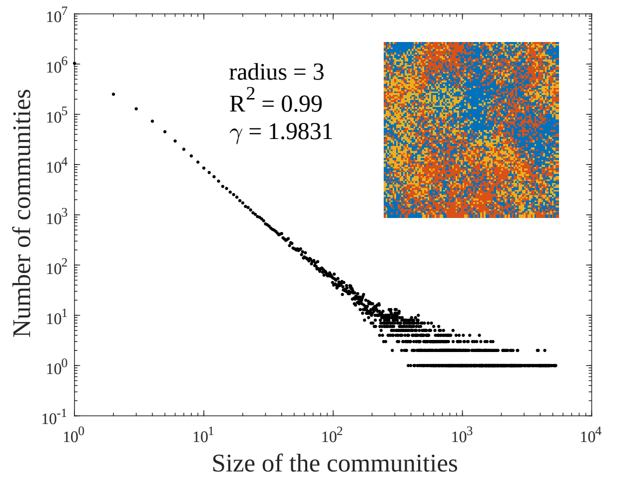

Fig. 2. Power law fit of the stable regime of Fig. 1 (b). Insert is a snapshot of the system at the end of the simulation.

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