Eigenvector centrality predicts survival in positive-interactions ecosystems

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AGENCIA ESTATAL DE INVESTIGACIÓN

Background:

We find an extraordinary biodiversity on Earth, and one of the main tasks of ecology has been to try to understand it. Since the early works, ecologists have dealt with the following question:

Does understanding how biodiversity is maintained require us to study species interactions or we can assume that species interact randomly?

Recent empirical work has revealed that ecological networks are highly structured[1].
Therefore our question is to what extent the structure of species interactions influences the ecosystem's dynamics.

What we do: we simplify the dynamical model to a replicator equation instead of the typical Lotka-Volterra. We run simulations in several ecological networks to focus on the connections between the structural properties of the nodes (species) and their dynamics (focusing in the behavior of the survival probability as interaction's structure and intensity change)

Methods:

Dynamics

Replicator equation:

average fitness

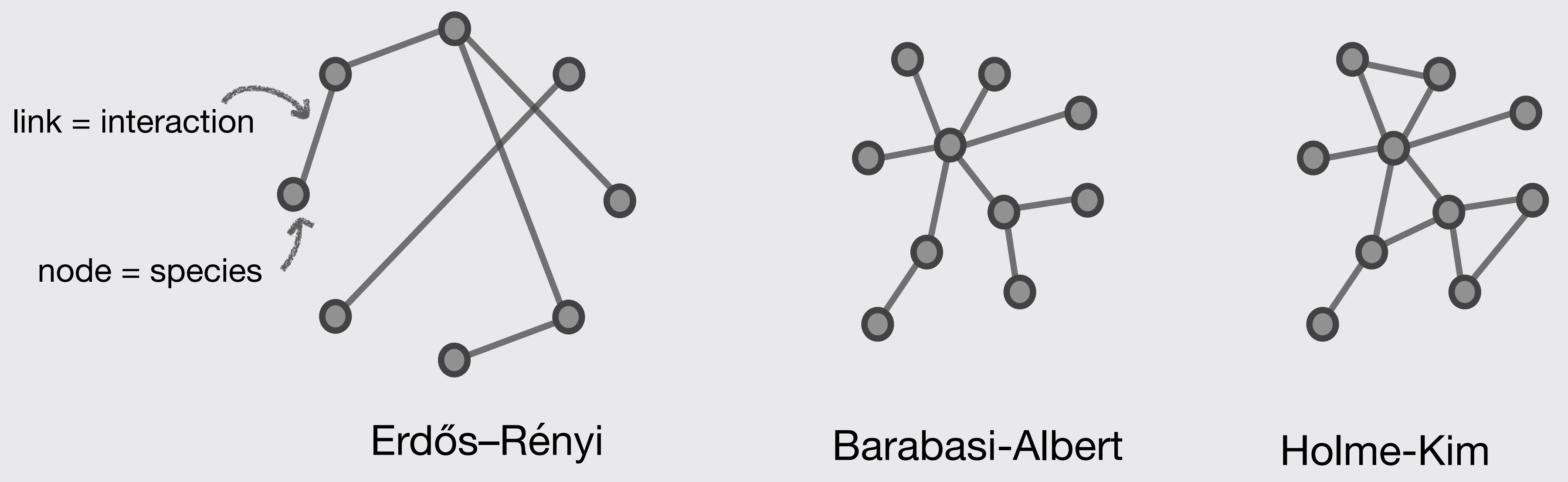
$$\dot{x}_i = x_i \left(\sum A_{ij} x_j - \sum_{ij} x_j A_{ij} x_j \right)$$

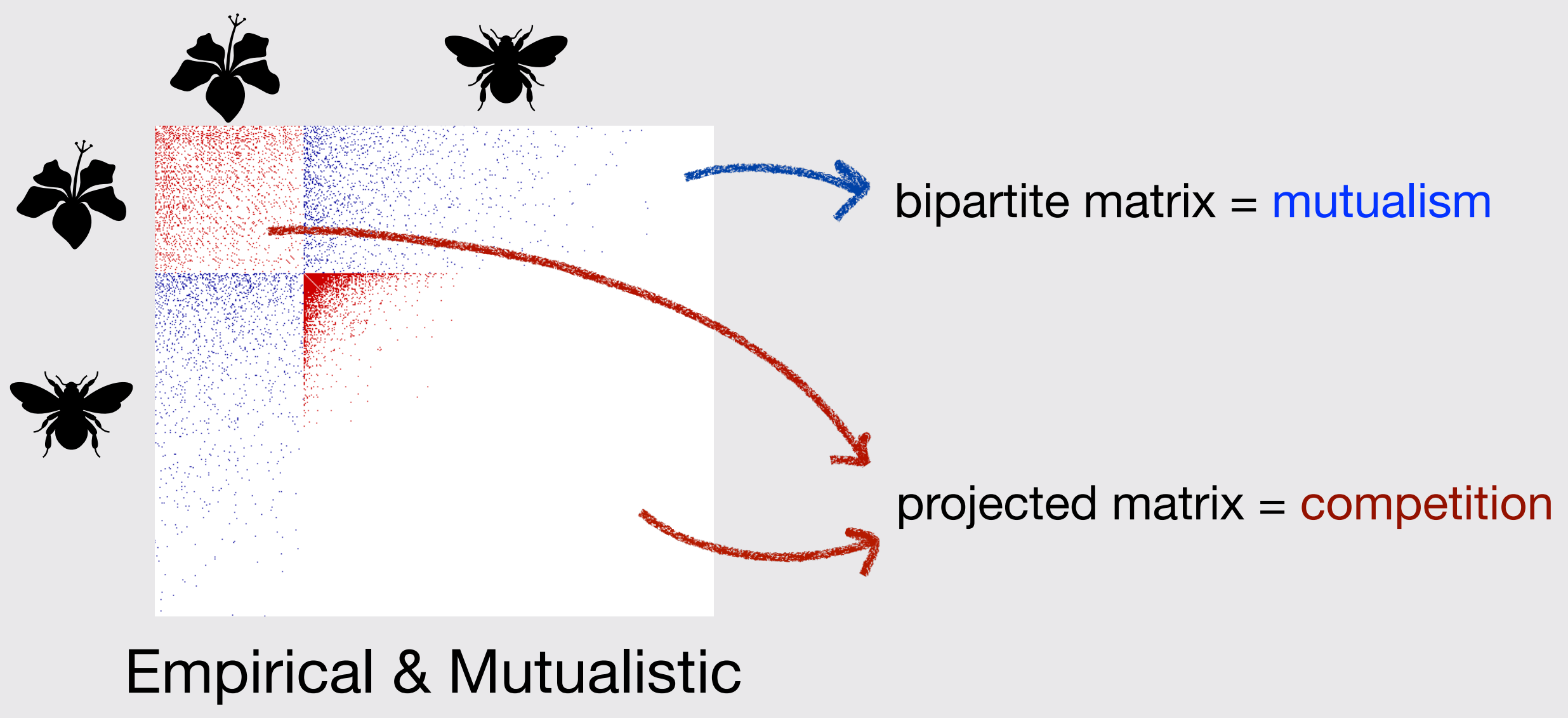
local fitness

$$A_{ij} = \alpha \delta_{ij} \ , \alpha = \text{payoffs (equal for all species)} \begin{cases} > 0 & \text{mutualism} \\ < 0 & \text{competition} \end{cases}$$

✓simpler, less parameters
✓we don't need to consider mutualistic, competitive, … terms separately, but just their joint influence in the form of payoffs
✓equivalence to the Lotka-Volterra equations[2]

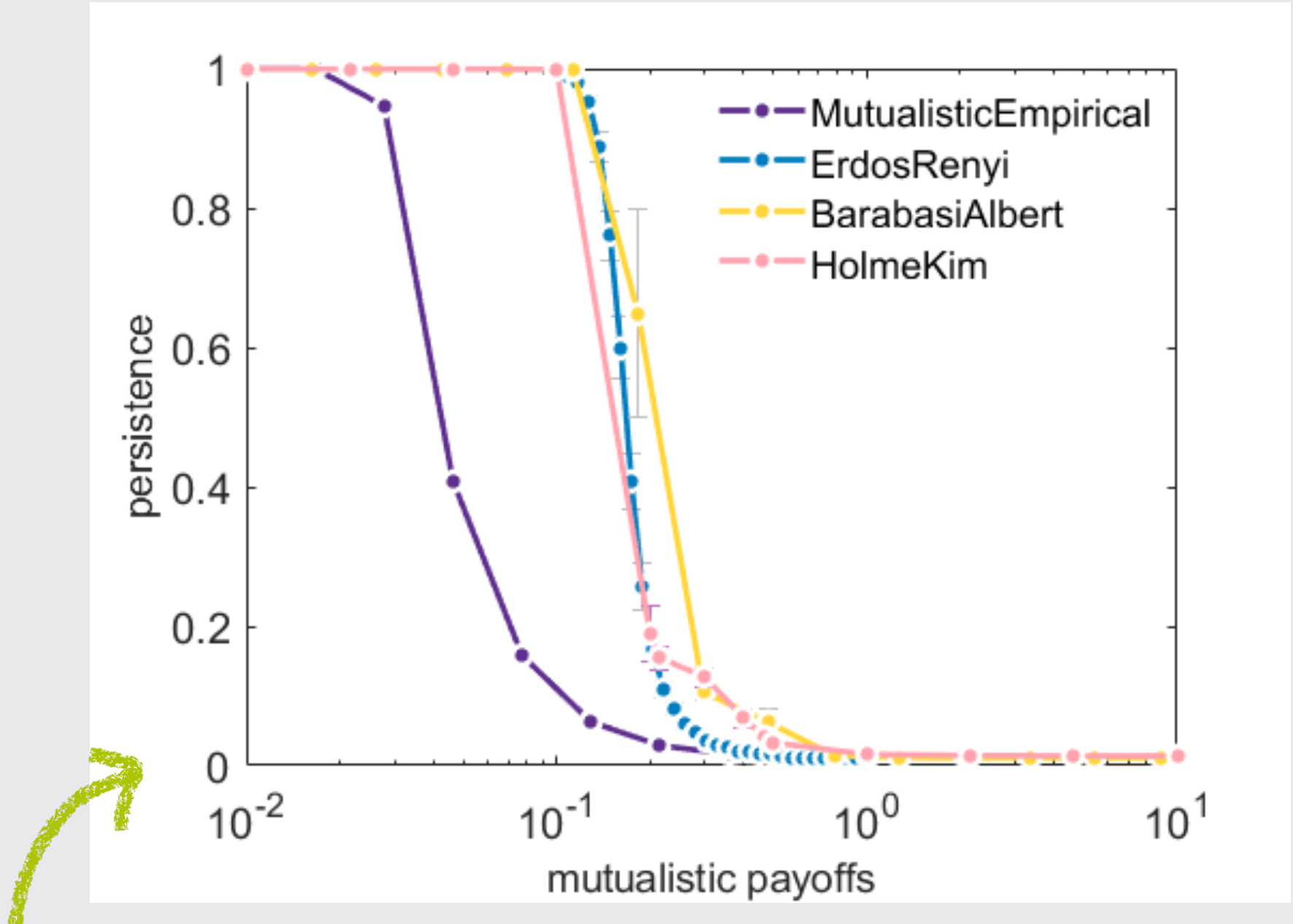
Structure





Results:

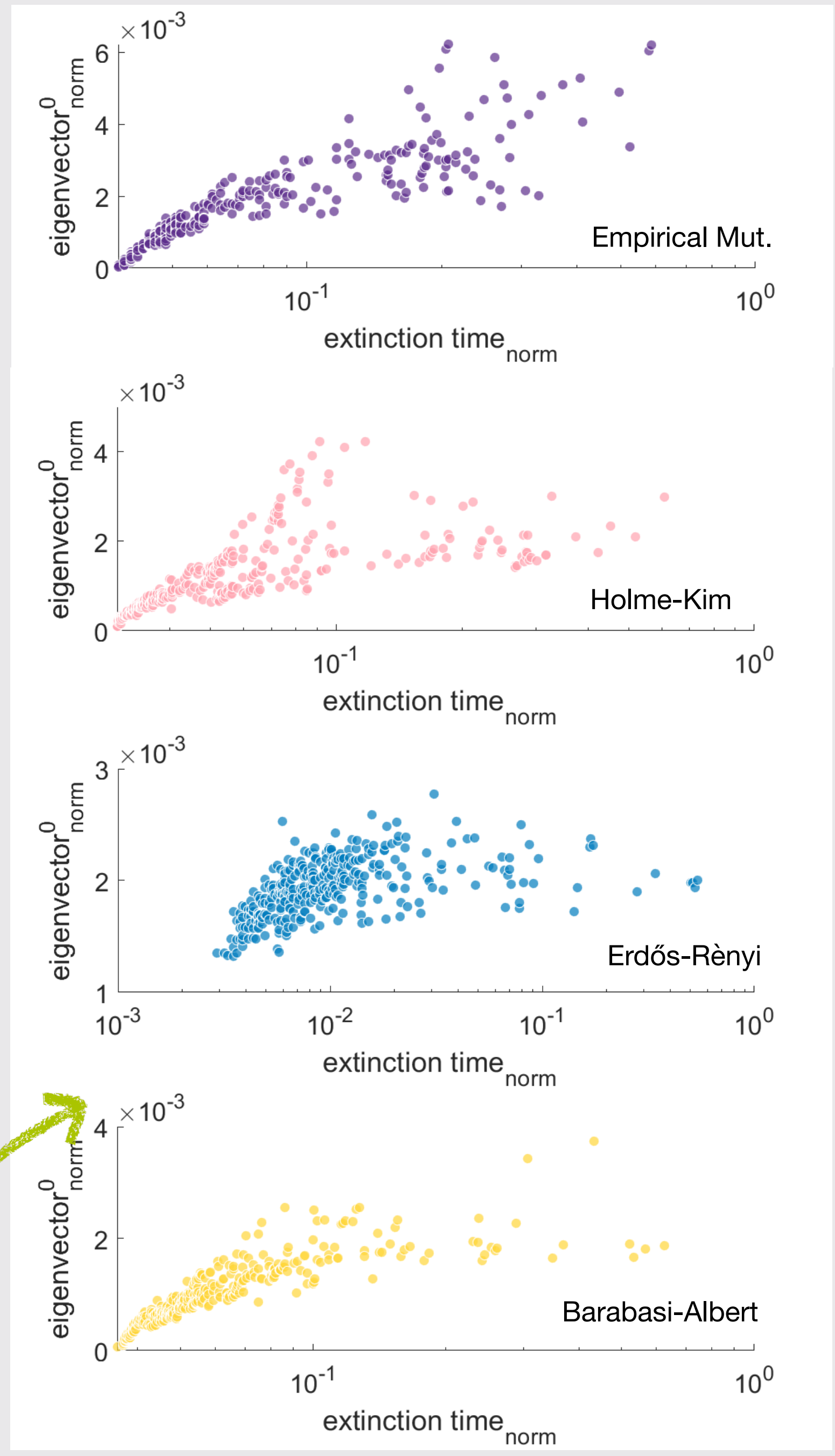
- Positive (mutualistic) payoffs:



A transition occurs from high to very low persistence (the percentage of species that do not become extinct) as we increase the payoff value. The form of this transition is equal for all networks.

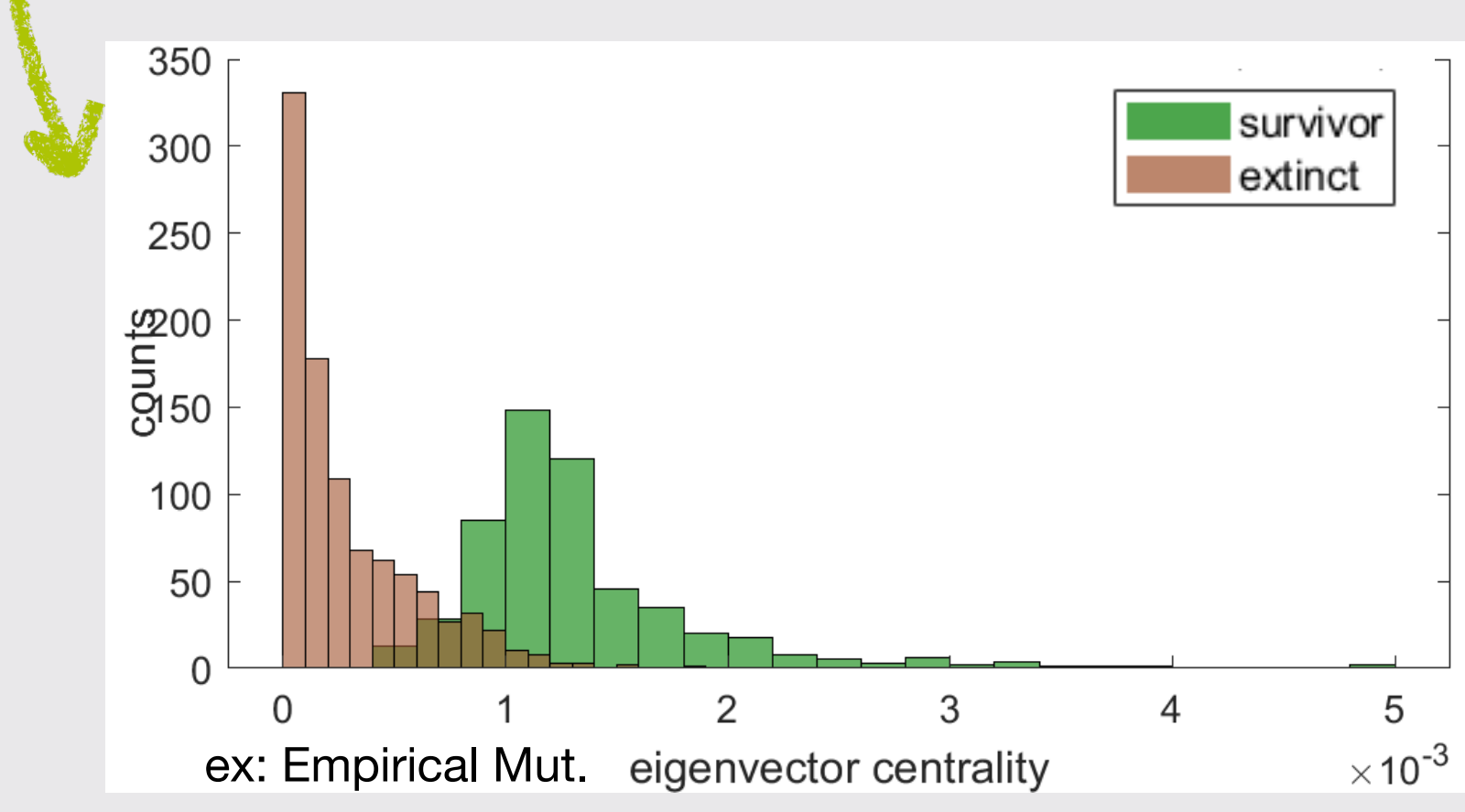
Curiously enough, the main characteristics of each type of network are maintained at the end of the simulation.

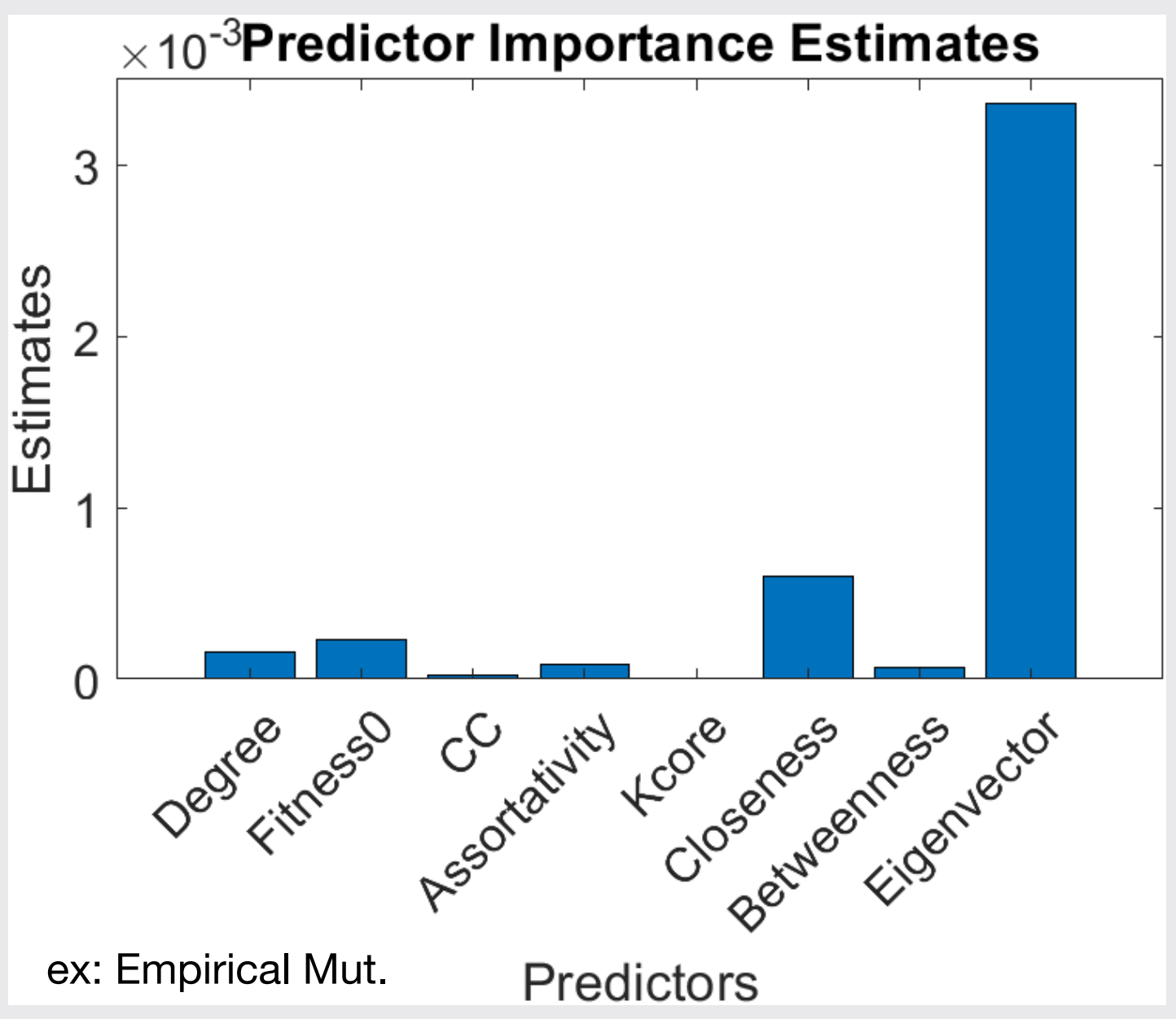
How and why species go extinct?
We have measured several node's properties in relation to survivorship and our results suggest that species with the lowest eigenvector centrality go extinct first.

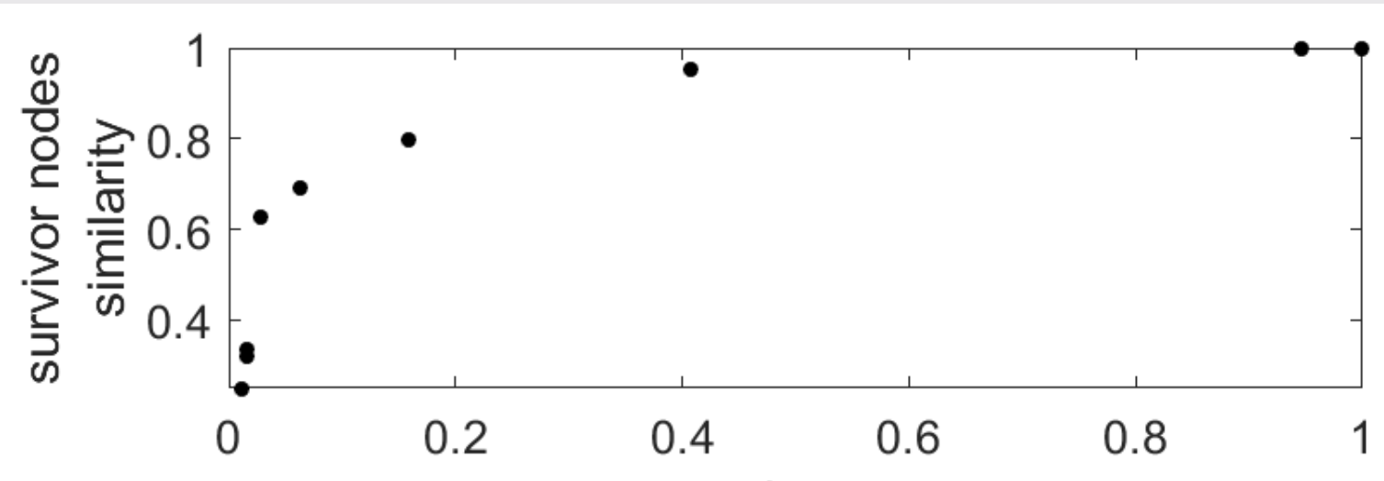


To reinforce our findings, we have used a decision tree to estimate the importance of every node property, obtaining again that eigenvector centrality accounts the better for the survival.

We are able to determine if a species will go extinct with high accuracy just looking at its eigenvector centrality!







Finally, we confirm that the extinction process in the replicator dynamics is similar to a process where species go extinct if they have the lowest eigenvector centrality, by observing that the similarity between the final networks in the two processes is high.

- Negative (competitive) payoffs:

No high persistence is achieved (as in classical results). In this situation, being highly connected is something that causes extinctions.

What we have found:
✓The structure of the neighbours of a species influences its dynamics.
✓With a replicator dynamics and positive payoff, if the species interact mainly positively, it is better to be well connected (as in ordinary life).
✓This fact is accurately captured by the eigenvector centrality of the species at the beginning of the interaction process. It is not characterized by the initial values of other quantifiers such as the degree or the clustering.

[1] PASCUAL, M. & DUNNE, J.A. (eds). *Ecological networks: linking structure to dynamics in food webs*. Oxford Univ. Press (2006)

[2] HOFBAUER, J. & SIGMUND, K. *Evolutionary games and population dynamics.* Cambridge university press, 1998.