PhD thesis proposal

Exploring the Key Links in Trophic Networks

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The loss of biodiversity threatens ecosystem stability, resilience, and the services ecosystems provide to humans. Conservation efforts have primarily focused on protecting species individually, often overlooking the complex web of interactions that bind species into functioning communities. In these intricate networks, disturbances can trigger cascading effects, leading to secondary extinctions. Food webs — representations of species and their trophic interactions — offer a promising framework for understanding and predicting ecosystem responses to perturbations. While they integrate information on both species and their interactions, current food web approaches do not explicitly evaluate the importance of interactions. However, trophic interactions are the links by which perturbations spread. The distribution and the magnitude of trophic interactions in food webs are key factors determining the stability of food webs and their ability to cope with perturbations. Moreover, multiple perturbations related to global change (light pollution, temperature increase, artificial noise,...) will alter the magnitude or presence of an interspecific interaction with profound consequences for communities. We propose to reposition existing approaches aiming at detecting key interactions in complex networks to food webs. By doing so, we aim to refine the PageRank-based characterization of species within communities, offering a more robust framework for understanding how ecosystems respond to perturbations and how to best preserve them. This project offers a novel perspective by shifting the focus from species-level conservation to the identification of key trophic interactions, providing a more nuanced understanding of ecosystem dynamics and resilience, which is crucial for developing more effective conservation strategies in the face of global environmental changes.

In this regard, a recent study, conducted in collaboration between the theoretical physics group at the Institut UTINAM and a researcher from the German Centre for Integrative Biodiversity Research (iDiv, Leipzig), proposed an innovative method for quantifying the importance of species within these trophic networks, particularly in predator-prey relationships. This novel approach not only analyzes the species themselves but also investigates their roles within a broader system.

The proposed PhD project builds on this work and aims to extend this methodology to evaluate the significance of trophic links within these networks. The goal is to understand, beyond individual species, how interactions between them—such as predator-prey relationships or competition networks—affect the stability and resilience of ecosystems. The primary objective of this project will be to develop new tools and algorithms to quantify the contribution of different trophic links to the overall network, taking into account multiple factors such as network structure, energy fluxes, and ecological dynamics.

The PhD candidate will begin by acquiring an in-depth understanding of the algorithm used to quantify the importance of links in a trophic network. This algorithm, based on Markov chains, calculates eigenvector centrality, a key indicator for assessing the influence of each link on the overall dynamics of the network. This initial stage involves mastering the mathematical and algorithmic foundations of the approach before extending and adapting it to new contexts. Once this understanding is in place, the candidate will develop a sensitivity analysis algorithm, using compiled languages such as Fortran or C++, or an interpreted language like Python. This algorithm will measure the impact of modifications to trophic links on the overall network dynamics, focusing on indirect effects and cascading consequences.

Additionally, the candidate may be involved in exploring the dynamic aspects of predator-prey relationships, particularly by studying the stability of fixed points in these systems. This includes analyzing how trophic interactions can evolve over time and how these changes may affect the long-term stability of ecosystems. A part of the work will also involve developing mathematical models and simulations to test various hypotheses about the resilience and robustness of trophic networks in response to disturbances, whether natural or human-induced. Throughout the project, the candidate will also broaden his/her knowledge in theoretical ecology, a discipline that seeks to understand the fundamental principles governing ecological interactions and ecosystem structure. This experience will allow him/her to become familiar with key concepts in ecological modeling, such as dynamic equilibria, coexistence theories, and diversity models, and apply them to contemporary ecological challenges. The candidate will thus develop a holistic view of ecology, combining advanced mathematical tools with a deep understanding of biological and ecological processes.

Reference:

[1] Identifying important species in meta-communities G. Rollin, S. Kortsch, J. Lages, B. Gauzens, Methods in Ecology and Evolution 15, 1601-1703 (2024) https://doi.org/10.1111/2041-210X.14384