MSc Project Outline

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6 April 2021

Introduction

Co-occurring species that interact together form ecological communities. Biogeography studies species distributions to understand the turnover of species in communities across space and time (Gaston, 2003). However, community composition is not only affected by species turnover, but also interactions turnover (Graham & Weinstein, 2018; Gravel et al., 2019). Thus, ecological networks are useful tools to represent the structure of a community including both species and interactions. Over the past 20 years, ecologists have been investigating the patterns of local interaction networks and their underlying mechanisms.

At first, most research focused on rules driving network assembly and degree distribution. Preferential attachment, a mechanism through which new species tend to interact more with species that have more existing interactions, was suggested to explain the power-law degree distribution and scale-free properties of interaction networks (Amaral et al., 2000; Jordano, Bascompte, & Olesen, 2003; Tylianakis et al., 2018; Watts & Strogatz, 1998). Phenology, morphology and information filtering were additionally suggested to cause truncation of the power-law distribution (Mossa et al., 2002; Olesen et al., 2008).

Investigating structural metrics across networks revealed common structural patterns such as modularity and nestedness (Bascompte et al., 2003; González-Castro et al., 2012; Jordano, Bascompte, & Olesen, 2003). Abundance, species traits (phenology, morphology, phylogeny) and shared diet preferences are believed to drive such structural patterns (Hutchinson, Cagua, & Stouffer, 2017; Jordano, 2016; Pires et al., 2011; Poisot, Stouffer, & Gravel, 2015; Rohr & Bascompte, 2014; Vázquez, Chacoff, & Cagnolo, 2009). However, these approaches often failed to predict pairwise interactions between two species despite correctly inferring structural metrics (Olito & Fox, 2015; Vázquez, Chacoff, & Cagnolo, 2009).

More recently, studies of interactions turnover overcame these limitations using empirical observations and models of pairwise interaction probability (Burkle, Marlin, & Knight, 2013;

Process	References
Partners abundance	Coux et al. (2021), Donoso et al. (2017), García et al. (2014), and Olesen et al. (2008)
Preferential attachment	Amaral et al. (2000), Bramon Mora et al. (2020), Jordano, Bascompte, and Olesen (2003), Olesen et al. (2008), and Tylianakis et al. (2018)
Information filtering	Mossa et al. (2002)
Species traits: phenology, morphology, phylogeny	Burkle, Marlin, and Knight (2013), Coux et al. (2021), Hutchinson, Cagua, and Stouffer (2017), Jordano (2016), Pires and Melo (2020), Rohr and Bascompte (2014), and Rominger et al. (2016)
Interactions fitness: ecological neighbourhood, indirect effects, optimal diet theory, adaptive foraging	Aizen, Sabatino, and Tylianakis (2012), Donoso et al. (2017), Guimarães et al. (2017), Levine et al. (2017), Pires et al. (2011), and Valdovinos et al. (2013)

Table 1 | Processes proposed to determine the existence of pairwise interactions between co-occurring species.

Donoso et al., 2017; Guimarães et al., 2017; Pires & Melo, 2020; Rominger et al., 2016; Tylianakis et al., 2018). Additionally, Bascompte and Stouffer (2009) emphasized in a theoretical review the importance of seasonal dynamics, which were explicitly accounted for in other studies (Bramon Mora et al., 2020; García et al., 2014; Valdovinos et al., 2013).

Altogether, several recurring ecological processes are believed to determine the existence of pairwise interactions at local scale (Tab. 1). Abundance, phenotype, phenology and phylogeny are the most important ones (Vázquez et al., 2009). While the aforementioned mechanisms are species-specific, a growing body of literature suggests that interactions are themselves subjected to traits and fitness variations, that is variation in their rewarding potential. Consequently, ecological neighbourhood, indirect effects and adaptive foraging cause interactions to facilitate or impede each other (Aizen, Sabatino, & Tylianakis, 2012; Donoso et al., 2017; Levine et al., 2017).

However, little is known regarding the consistency of the processes and patterns observed at these local scale at broader scales. It can be questioned whether pairwise interactions observed in one location will tend to exist wherever the involved species co-occur. Fortuna et al. (2020)

showed that the fidelity of interactions at global scale varies depending on the interaction type. Other factors, such as functional group, geographical origin and bioclimatic conditions might also influence the consistency (i.e. predictability at broad scale) of interactions.

Studying the predictability of ecological interactions at a global scale could be insightful as first steps to (i) gain further knowledge on the underlying network wiring mechanisms, (ii) better integrate biogeographical and network ecology models together, and (iii) improve understanding of climate change impacts on ecosystem functioning.

Models at a global scale can rely on limited information, mostly presence data, local static unweighted interaction networks and bioclimatic data. Therefore, there lacks information to discriminate some key processes driving interactions turnover. However, simple phenomenological models can be upgraded to account for more complex processes as data becomes available. Thus, such oversimplified models can be a first step in the direction of a global mechanistic understanding of network wiring.

As highlighted by Fortuna et al. (2020), network ecology often disregards the role of abiotic conditions. Most studies aim at modeling pairwise interactions with prior knowledge of species abundance. Only few studies integrate together questions of bioclimatic suitability and interactions wiring (Graham & Weinstein, 2018; Gravel et al., 2019). Simple phenomenological models of interactions could help bridging the gap between network ecology and biogeography.

A key motive to integrate together models of species occurrence and interactions is predictability. Ecologists thrive to understand the impacts of climate change on the functioning of ecological communities (Parmesan & Yohe, 2003). Integrated models that provide scenarios of community composition changes under different climatic conditions could, in time, prove to be useful tools to achieve this goal.

Project Overview

Overarching research questions

The goal of this project is to use simple phenomenological models to explore the consistency (i.e. predictability) of ecological interactions at broad spatial and temporal scales. The overarching research question is how consistent, loyal, predictable ecological interactions are. The answer to such question will lie somewhere in between perfect fidelity between interaction partner and fully opportunistic, random interactions.

Several different factors might affect the position of species and interactions in this spectrum. Interaction type, functional group, species origin and ubiquity are examples of such factors. Thus, the second objective of this project will be to explore the role and importance of these factors.

Methodological outline

The main challenge of this project lies in the collection, aggregation and analysis of a large amount of data from various sources. The main steps and expected difficulties associated to them are outlined here:

1. **Data collection:** Retrieval of data from various sources. Data include interaction networks across the globe (database: Web of Life, Fortuna, Ortega, and Bascompte, 2014), species occurrence data (GBIF) and bioclimatic variables (WorldClim). A technical issue might be to ensure enough storage space and computing power to download (and subsequently treat) those data.
2. **Data cleaning:** Cleaning the data to ensure sufficient quality is a major challenge when dealing with extensive data sets from various sources (Jetz et al., 2019). In addition to the same technical challenges from data collection, this steps will require to resolve species names, formatting of data, merging data and removing erroneous outliers.
3. **Model design:** Prior to using the data, it will be necessary to build bayesian regression models that can answer the research questions. Definition of weakly informative priors and prior predictive simulations are required to ensure good understanding of the model behaviour.
4. **Model fitting:** This technical step will be challenging in terms of computational power. Depending on the amount of data and the model complexity, it might even be infeasible to run models on local computers with reasonable computing time. In such case, it is possible to resort to high performance clusters (i.e. ETH Euler, Google Compute Engines, etc).
5. **Results interpretation:** Interpreting the model results will require careful exploration of the results via posterior plots, statistics computation and sensitivity analysis.
6. **Manuscript preparation:** The last step will consist in writing a master thesis that provides a complete description of the project and its results. This step will be time consuming as it involves further research, presentation of results and corrections.

Possible extensions

The following list describes some possibilities to extend the project if there is time left:

- Including more data to provide insight on different factors that might affect predictability, such as species trait and phylogeny
- Extending the model to include other types of interactions

Indicative deadline	Tasks
31 April	Discuss/clarify outline, finish data collection, start cleaning
15 May	Finish data cleaning
30 May	Finish model preparation and prior predictive simulations
31 June	Finish data analysis, start interpretation and possible extensions
31 July	Finish all data analysis and results interpretation, start writing
20 August	Finish first draw and start corrections
$\sim$ 25 August	Presentation during lab meeting, get feedback from lab members
10 September	Finish corrections (last days saved as a buffer for corrections)
16 September	**Official final deadline**

Table 2 | Indicative deadlines for the MSc project.

- Improve the model and compare it against alternative model definitions that are based on stronger mechanistic assumptions

Time constraints

Table 2 provides an approximate schedule for the main steps of the project. It is likely that these indicative deadline will change based on the difficulties met during the project. Their goal is to help deciding when to move on or dig deeper to avoid time issues towards the end of the project. It is especially important to keep aside enough time for the writing and correction process, which is a personal weakness.

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