Convocatoria AEET-SIBECOL de ayudas a proyectos de investigación ERC en ecología (10ª ed., 2020)

1. Datos de identificación.

Título de la propuesta	**Advancing the biogeography of ecological networks: NETMAP**
Categoría	**Ganando independencia**
Nombre y apellidos del Beneficiario	**David García Callejas**
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2. Memoria Técnica. Actividades y resultados de investigación

2.1. Introducción (Planteamiento, objetivos y justificación)

Introduction

Understanding the drivers behind the distribution of biodiversity on Earth is one of the fundamental challenges in ecology. The geographical variation of species interactions, and its underlying mechanisms, are as important as the study of species distributions, but have been historically much less studied. In the NETMAP project I will study the geographical variability of different types of species interactions, to understand whether a common set of mechanisms influences the variability of different interaction types or, on the contrary, different interaction networks show idiosyncratic responses to large-scale environmental gradients. I will compile an unprecedented database of spatially referenced ecological networks, including food webs, plant-herbivore, plant-pollinator, and plant-seed disperser networks. I will evaluate their variability on a global scale (e.g. across latitudinal or primary productivity gradients, and across gradients ofhuman pressure) and use null models to assess the significance of the relationships obtained. This project, developed in collaboration with Dr. Sonia Kéfi, will be the first comparative biogeographical study of ecological interaction networks on a global scale. As such, it will advance our knowledge on large-scale drivers of community structure across different types of ecological interactions.

Scientific background

The distribution of species and their interactions are subject to environmental, biotic, and spatial drivers (Poisot et al. 2017). Historically, the variability of species interactions across large spatial or environmental gradients has received much less attention than that of species distributions. However, there is increasing evidence that the distributions of species interactions are as much subject to environmental variability as species distributions (Schleuning et al. 2012, Tylianakis & Morris 2017, Poisot et al. 2017). Studies with different model systems are still too specific to distill general trends, but there already exist examples on plant-gall-parasitoid interactions (Gravel et al. 2018), tetrapod food webs (Braga et al. 2019), or ant-tree interactions (Dáttilo & Vasconcelos 2019), among others. Despite these advances, we are still lacking an overarching understanding of how different types of ecological interactions comparatively respond to large-scale drivers. Recent insights from intertidal communities (Lurgi et al. 2020) or agricultural fields (Shinohara et al. 2019) point to contrasting environmental or land-use effects over different types of interactions, but studies with larger scope and quantitative hypotheses to test are needed. Such approach would provide novel insights on the structure of multiple-interactions communities, and therefore on the dynamics and stability of such complex communities.

Objectives

The main research objective of the NETMAP project is to understand how large-scale environmental and anthropogenic drivers influence the spatial variability of different types of ecological interactions. This entails two specific objectives:

O1. Compilation of a spatially-explicit database of ecological networks, focusing on four distinct types of ecological interactions on terrestrial systems: predator-prey, plant herbivore, plant-pollinator, and plant-seed disperser. This information will be complemented by the environmental context associated to each community, and by including an index of human pressure at the spatial extent of each study.

O2. Quantify the comparative response of different types of ecological networks to a common set of large-scale gradients. I will analyze how the interaction networks compiled in O1 respond to different drivers, including an overarching latitudinal gradient, species richness, primary productivity, or human pressure gradients. This will be assessed through specific null models, and will identify potentially convergent or divergent responses across interaction types.

2.2. Descripción de la ejecución- Metodología

O1. Compilation and standardization of ecological networks

O1.1 Compilation of raw network data

This step involved searching the literature and existing databases for datasets of ecological networks that contain, at least, the following information:

- list of taxa and their direct interactions, either in presence/absence or in any quantitative measure
- spatial location of the community (latitude and longitude)
- type of interaction(s) recorded
- Year(s) of sampling

Furthermore, the search was limited to observational studies, to avoid potential biases introduced by experimental manipulations.

O1.2 Data homogeneization

The raw information from different sources, as expected, comes in different formats. These need to be standardized in order to analyze them. I collated all gathered networks into a dataset of the following format:

- List of links, with columns:
network_id, *node_from*, *node_to*, *link_type*

- List of nodes, with columns:
node_id, *taxonomy_name*, *taxonomy_rank*

- List of networks, with columns:
network_id, *original_id*, *network_db*, *network_interaction*, *network_year*, *network_lat*, *network_lon*, *network_topology_type*, *network_spatial_type*

With these data structures, it is straightforward to subset networks according to any parameter of interest, or to perform node-level analyses. The raw network information was complemented with information on habitat type (from Jung *et al.* (2020)), human pressure index (from Venter *et al.* (2016)), and environmental variables (from Fick & Hijmans (2017)). These parameters were obtained at 1km spatial resolution given the spatial coordinates of each network.

O2 Global structural patterns of ecological networks

O2.1 Structural characterization of ecological networks

The first analysis of the study is the characterization of the structure of the compiled networks. This first step is independent of spatial factors and serves as a baseline for establishing differences between networks of different interaction types. First, a series of metrics that capture relevant structural properties are selected. These metrics must be applicable to unipartite and bipartite binary networks. Second, dimensionality reduction methods are applied to uncover the distribution of networks across the structural metrics. In particular, with the help from Dr. Kéfi and a collaborator from his group, Ismaël Lajaaiti, we will apply a novel dimensionality reduction method particularly suited to network structural metrics, UMAP (Botella *et al.* 2022).

Network structure is highly influenced by richness or connectance, which prevents meaningful comparisons of raw structural values between networks of different size. We therefore applied a null model analyses to standardize structural metrics. In particular, for each compiled network, we obtained 100 replicates with randomized links, and calculated each structural metric for each of these replicates. The z-score of each metric for the observed network with respect to the distribution of randomized networks can be in most cases used to compare networks (e.g. Pellissier *et al.* (2018)).

O2.2 Relationships with environmental and human pressure gradients

This objective follows O2.1, and will consist of statistical analyses relating structural properties of the different networks to latitudinal, environmental, and human pressure gradients, likely using generalized mixed models accounting for spatial auto-correlation.

2.3. Resultados obtenidos (cumplimiento de objetivos)

O1. Database of ecological networks

I collected and standardized, up to July 2022, a total of 3019 networks. Of these, 668 are food webs, i.e. consumer-resource networks, 882 host-parasite ones, 450 are plant-frugivore networks, 957 are plant-pollinator networks, and a further 62 do not have a specified type of interaction, so will be discarded. The spatial distribution of the valid networks is shown in Fig. 1.

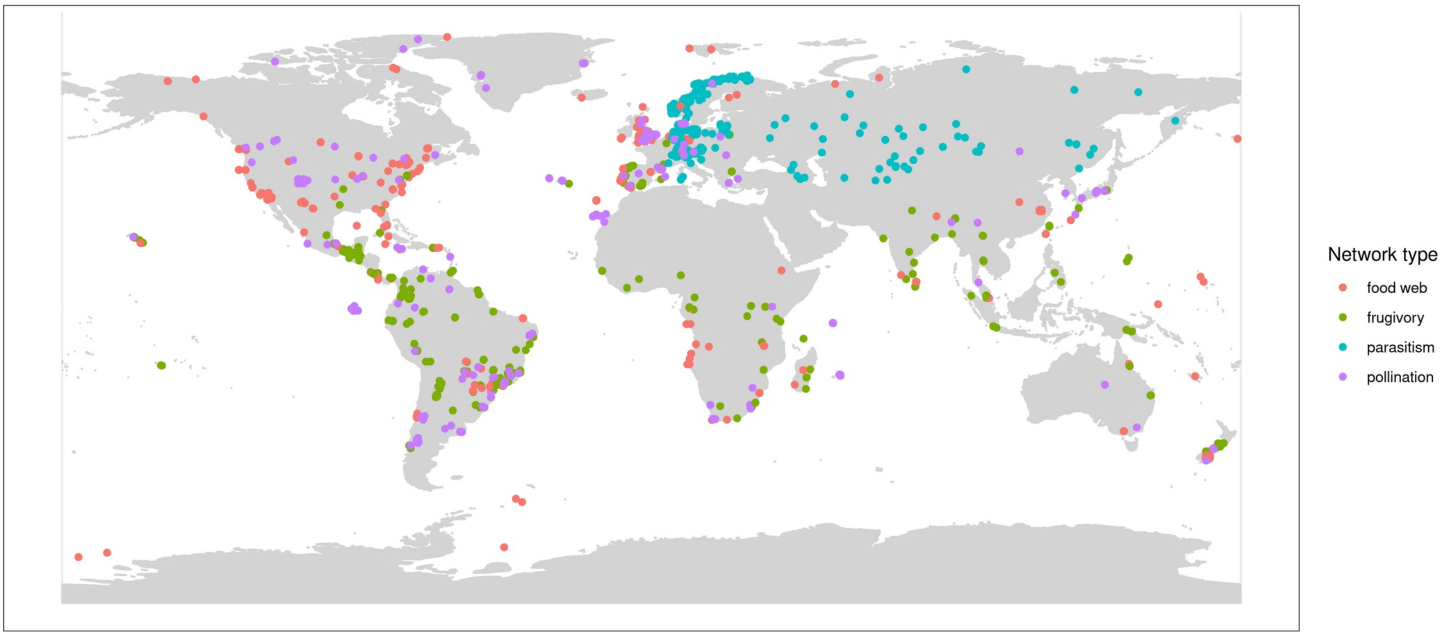

Figure 1: Spatial distribution of networks compiled up to 07/2022

The collected database will be made publicly available upon publication of the study via an online data repository (Zenodo).

The structure of the networks displays differences in some metrics across interaction types, but also higher homogeneity than expected (Fig. 2). The metrics analyzed so far will be complemented with metrics for niche overlap among species in the networks, and with metrics on average specialization/generality.

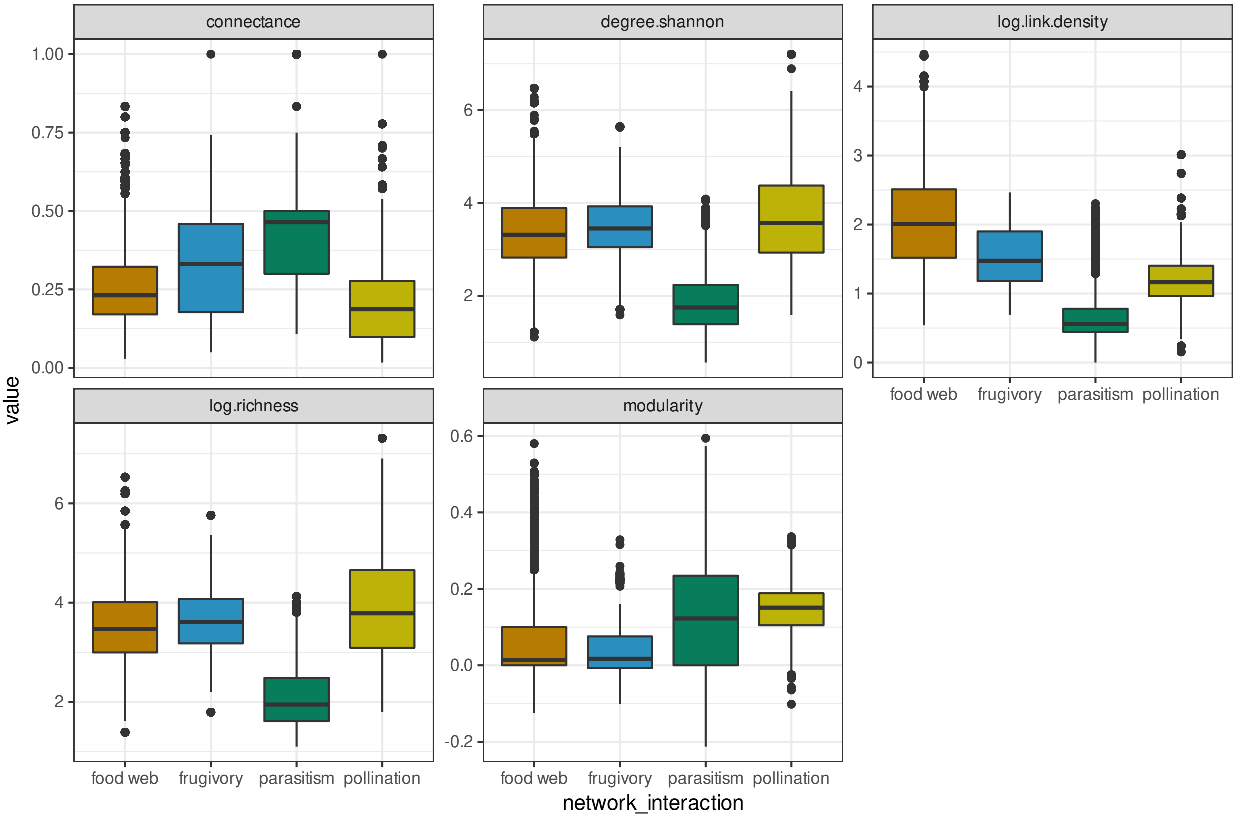

Figure 2: Structural metrics analyzed for the different types of interaction networks. Connectance refers to the ratio of observed/potential links in a given network; degree.shannon is the heterogeneity of the degree distribution, quantified as the Shannon index; log.link.density is the logarithm of the number of links per species; log.richness is the logarithm of the number of species in the network; modularity is measured as recently proposed by Farage *et al.* (2021).

A preliminary analysis of dimensionality reduction shows that plant-frugivore networks tend to be structurally different than plant-pollinator ones. Host-parasite networks are structurally quite diverse, and This analysis is, on this fist step, performed separately for bipartite and unipartite networks, hence the two separate comparisons.

I am currently working on these analyses and outlining the relationship with environmental and human pressure variables.

2.4. Conclusiones y valoración de la ejecución

The time frame for this project was interrupted by the COVID-19 pandemic, but in the end, it allowed me to collect a high number of ecological networks before going to Montpellier to work on their analyses with Dr. Kéfi and her group. We already have a methodological "pipeline" to keep adding networks, and to generate structural metrics, a robust null model, and to distill the groupings according to the structural metrics selected. In that regard, the stay at the group of Dr. Kéfi has been extremely valuable, as I have been directly exposed to their methodologies of analysis, in terms of structure and dynamics of networks of different interaction types. I have directly learned the use of novel techniques, such as UMAP, and discussed the most appropriate types of null models to use in a global study such as this one.

To summarize, I have learned new methodologies that will be of use in future studies, and novel ways of analyzing ecological networks, as well as generated further connections with researchers at the CNRS and the University of Montpellier.

Given the short timeframe of the stay, the outcome is highly positive, and the remaining analyses and writing of the manuscript will be done in collaboration with Dr. Kéfi and Ismaël Lajaaiti, including a prospective visit to Montpellier in February 2022 funded by Dr. Kéfi.

2.5. Publicaciones resultantes

García-Callejas, D., Lajaaiti, I., Thébault, E., Kéfi, S. (In preparation)

2.6 Referencias

Botella, C., Dray, S., Matias, C., Miele, V. & Thuiller, W. (2022). An appraisal of graph embeddings for comparing trophic network architectures. *Methods in Ecology and Evolution*, 13, 203–216.

Farage, C., Edler, D., Eklöf, A., Rosvall, M. & Pilosof, S. (2021). Identifying flow modules in ecological networks using Infomap. *Methods in Ecology and Evolution*, 12, 778–786.

Fick, S.E. & Hijmans, R.J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37, 4302–4315.

Jung, M., Dahal, P.R., Butchart, S.H.M., Donald, P.F., De Lamo, X., Lesiv, M., *et al.* (2020). A global map of terrestrial habitat types. *Sci Data*, 7, 256.

Pellissier, L., Albouy, C., Bascompte, J., Farwig, N., Graham, C., Loreau, M., *et al.* (2018). Comparing species interaction networks along environmental gradients. *Biol Rev*, 93, 785–800.

Venter, O., Sanderson, E.W., Magrach, A., Allan, J.R., Beher, J., Jones, K.R., *et al.* (2016). Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. *Nat Commun*, 7, 12558.

3. **Informe de gastos del proyecto.** Relación de partidas de gastos y sus importes. Se deberán aportar justificantes originales de los pagos realizados (tickets, recibos o facturas).

Expenditures:

- 1 Laptop computer: 1199€
- Accommodation in Montpellier for 1 month: 1348,38€

Firmado por GARCIA CALLEJAS JOSE DAVID - 31729479J en fecha 18/08/2022 con un certificado emitido por AC FNMT Usuarios

Fdo: David García Callejas

en Sevilla, a 18 de Agosto de 2022