Environmental biases in the study of ecological networks at the planetary scale

Introduction

Ecological networks are a useful way to think about ecological systems in which species or organism interact (Delmas et al. 2018; Poisot, Stouffer, and Kéfi 2016), and recently there has been an explosion of interest in their dynamics across large temporal scales (Baiser et al. 2019; Tylianakis and Morris 2017), especially alongside environmental gradients (Pellissier et al. 2017; Trøjelsgaard and Olesen 2016). As ecosystems and climates are changing rapidly, ecologists realized that networks are at risk or unravelling, being invaded by exotic species that can destabilize them (Magrach et al. 2017; Strong and Leroux 2014), or adopt entirely novel configurations (Hui and Richardson 2019; Guiden et al. 2019). Simulation studies seem to suggest that knowing the shape of the extant network is not sufficient (Thompson and Gonzalez 2017), and that it needs to be supplemented by additional data on species properties, climate, and climate projection.

This renewed interest in ecological networks has prompted several methodological efforts. First, an expansion of the analytical tools to study ecological networks and their variation in space (**REFS**). Second, improvements in large-scale data-collection, through increased adoption of molecular biology tools (**REFS**) and crowd-sourcing of data collection (**REFS**). Finally, a surge in the development of tools that allow to *infer* species interaction (Morales-Castilla et al. 2015) based on limited but complementary data on existing network properties (Stock et al. 2017), species traits (Gravel et al. 2013; Desjardins-Proulx et al. 2017; Brousseau, Gravel, and Tanya Handa 2017; Bartomeus et al. 2016), and environmental conditions (Gravel et al. 2018). These approaches tend to perform well in data-poor environments (Beauchesne et al. 2016), and can be combined through ensemble modeling or model averaging to generate possibly more robust predictions (Pomeranz et al. 2018).

The common goal to these efforts is to facilitate the prediction of network structure, both extant [Poisot, Gravel, et al. (2016); **MARINE FOODWEB**] and future (Albouy et al. 2014), and to appraise its possible variation in response to changes. All of these developments also share the need to be supported by state

of the art data management: novel quantitative tools demand a higher volume of network data; novel collection techniques demand powerful data repositories; novel inference tools demand easier integration between different types of data, including but not limited to interactions, species traits, taxonomy, occurrences, and local bioclimatic conditions.

Poisot, Baiser, et al. (2016) – overview of original DB + updates, **TODO** map of networks + networks over time

- New data
- number and amount of new information
- web API for better data access, and two packages (one in Julia, the other in R) for accessing these data.
- Mangal in its current form offers open network data that is ready to support synthesis at many scales.

Borrett, Moody, and Edelmann (2014) identified network ecology as one of the fastest growing sub-field in the ecological sciences.

Synthesizing ecological data presents important challenges and also some exciting opportunities. Mangal is well suited to offer such opportunities in the study of ecological networks.

- A major challenge to ecological synthesis is generalizing from samples to the behaviour of ecological systems
- two obstacles to such generalizing in ecological systems: data coverage and data quality
  - data coverage: are data collected from every relevant system?
  - data quality: are data fit-for-purpose? Two particular aspects of quality
    * taxonomic resolution
    * sampling effort

Main question, is the data fit for purpose, what can we do and cannot do with it?

Global trends in ecological networks description

Network coverage is accelerating

Networks follow the same scaling
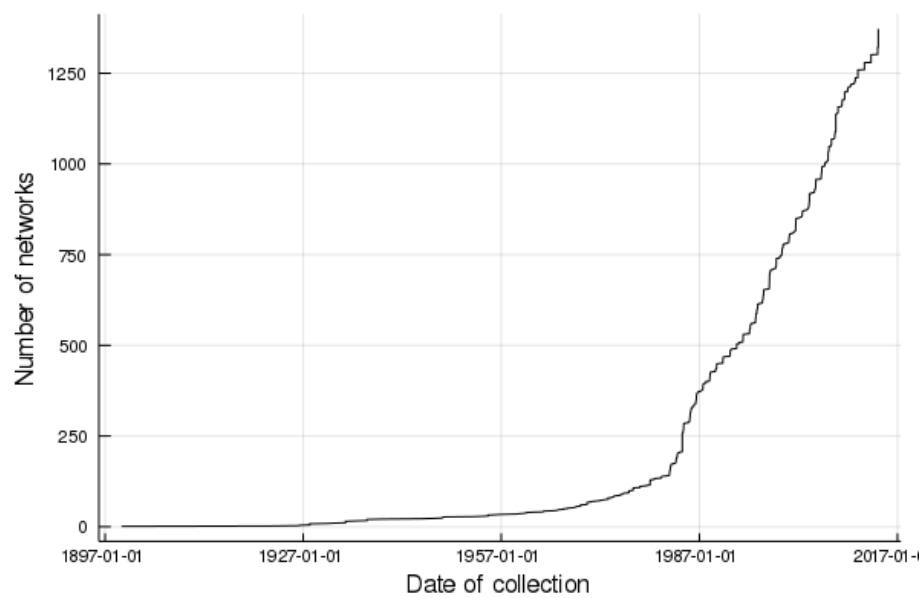
Brose et al. (2004)
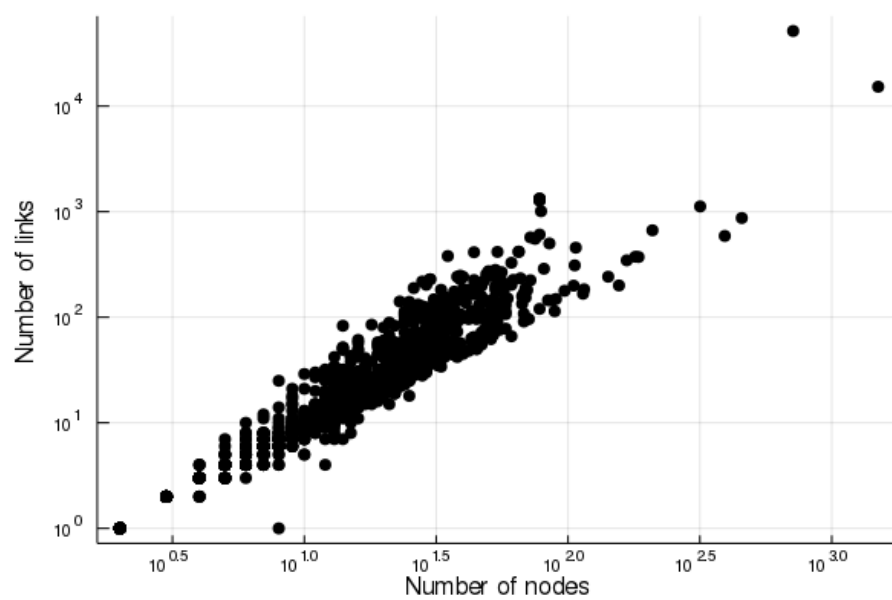
2

Figure 1: fig1

Figure 2: fig1 ref

Different types of networks have been studied in different biomes

Whittaker (1962) suggested that natural communities can be partitioned across biomes, largely defined as a function of their relative precipitation and temperature; in 3, we show that even though networks, overall, capture the diversity of the precipitation/temperature climate well, types of networks have been studied in sub-spaces only. Specifically, parasitism networks have been studied in colder and drier climates; mutualism networks in wetter climates; predation networks display less of a bias.
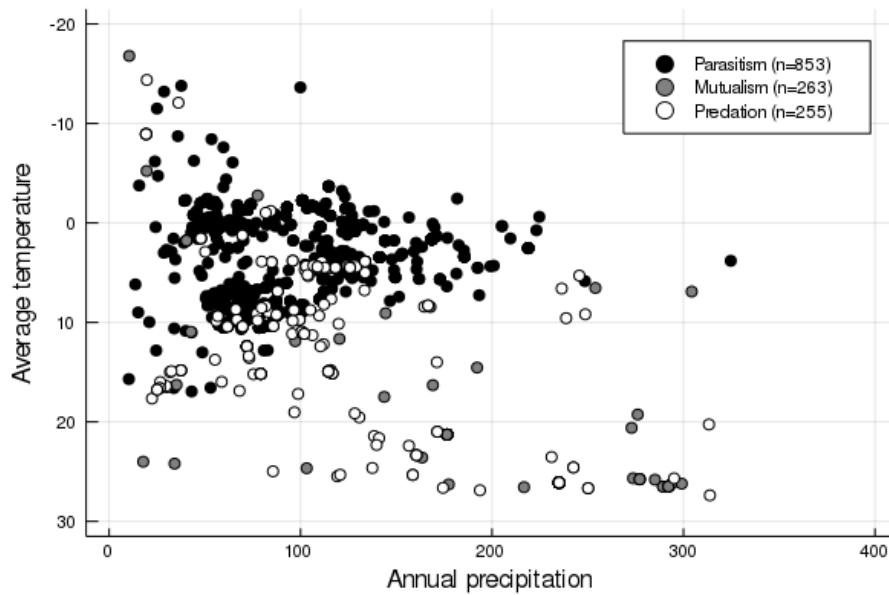

Figure 3: List of networks across biomes

Eccentricity of climate
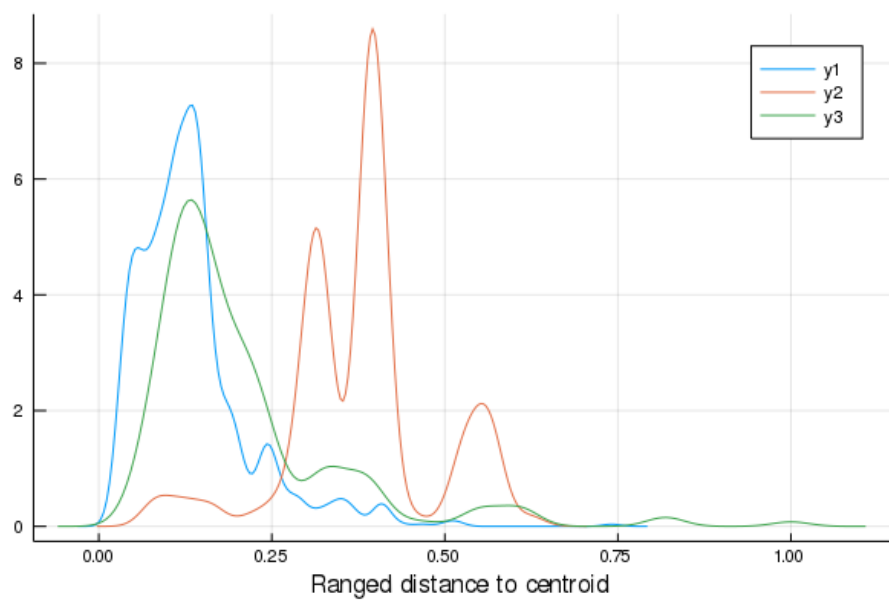
NEED TO FIND A TITLE

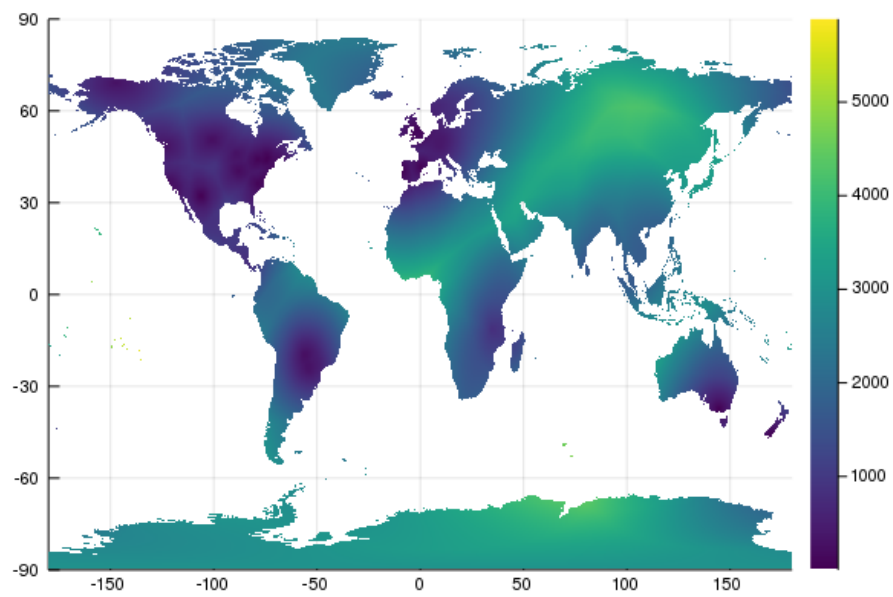Distance issues

Climate analogue
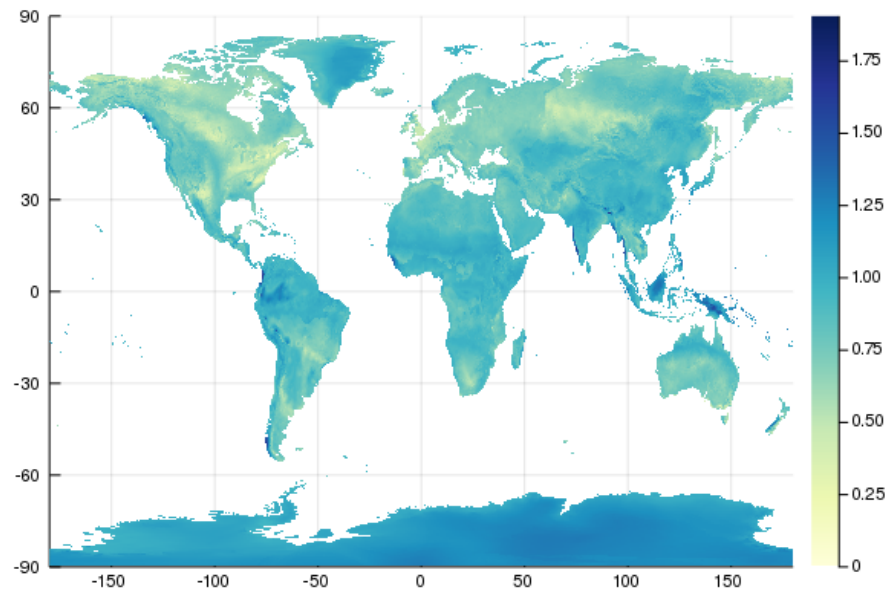
4

Figure 4: tk

Figure 5: tk

5

Figure 6: tk

Conclusions

reducing uncertainty through 'analogues'

When we lack direct observation of a community, often we must resort to the use of 'analog' communities – that is, communities which are similar in space or environment which have been sampled.

- Communities may be similar in at least two ways – close in space, or close in climate
- similarity may result in some (?) similarity in network structure, even if species different.
- Always some uncertainty in such comparisons
- reflects the need for more data gathering, can be used to target efforts

Future of network ecology

Use this spatial gaps for sampling recommendations

more complete analyses

We have only shown some high-level summaries of the data here; many possibilities remain.

more data collection

We have demonstrated the considerable coverage of Mangal; however, our summary also highlights important data-collection needs. In particular, we need better information about (mutualists, desert food webs?)

Active development and data contribution

This is an open-source project: all data and all code supporting this are available on the Mangal project GitHub organization. Our hope is that the success of this project will encourage similar efforts within other parts of the ecological community. In addition, we hope that this project will encourage the recognition of the contribution that software creators make to ecological research.

Data quality: sampling effort and taxonomy

Sampling effort and taxonomic detail are two very challenging but important part of any ecological dataset. The datasets in Mangal represent some of the most detailed studies of ecological networks available. * measures of network structure may be particularly sensitive to the amount of sampling effort * repeat sampling may be necessary to capture a "saturation" of interactions. * we present some visualization of the sampling coverage of Mangal [tk] * High taxonomic resolution is difficult to achieve in ecology, especially depending on the sampling method used (e.g. gut contents vs observations). We present a breakdown of the taxonomic resolution of Mangal. * Ecological networks occur in various kinds, but they are not all equally well sampled. We present a breakdown of the number of parasitic, mutualistic and predator-prey networks sampled in Mangal

References

Albouy, Camille, Laure Velez, Marta Coll, Francesco Colloca, François Le Loc'h, David Mouillot, and Dominique Gravel. 2014. "From Projected Species Distribution to Food-Web Structure Under Climate Change." *Global Change Biology* 20 (3): 730–41. https://doi.org/10.1111/gcb.12467.

Baiser, Benjamin, Dominique Gravel, Alyssa R. Cirtwill, Jennifer A. Dunne, Ashkaan K. Fahimipour, Luis J. Gilarranz, Joshua A. Grochow, et al. 2019. "Ecogeographical Rules and the Macroecology of Food Webs." *Global Ecology and Biogeography* 0 (0). https://doi.org/10.1111/geb.12925.

Bartomeus, Ignasi, Dominique Gravel, Jason M. Tylianakis, Marcelo A. Aizen, Ian A. Dickie, and Maud Bernard-Verdier. 2016. "A Common Framework for Identifying Linkage Rules Across Different Types of Interactions." *Functional Ecology* 30 (12): 1894–1903. https://doi.org/10.1111/1365-2435.12666.

Beauchesne, David, Desjardins-Proulx, Philippe Archambault, and Dominique Gravel. 2016. "Thinking Outside the Box–Predicting Biotic Interactions in Data-Poor Environments." *Vie et Milieu-Life and enVironment* 66 (3-4): 333–42.

Borrett, Stuart R., James Moody, and Achim Edelmann. 2014. "The Rise of Network Ecology: Maps of the Topic Diversity and Scientific Collaboration." *Ecological Modelling* 293 (December): 111–27. https://doi.org/10.1016/j.ecolmodel.2014.02.019.

Brose, Ulrich, Annette Ostling, Kateri Harrison, and Neo D. Martinez. 2004. "Unified Spatial Scaling of Species and Their Trophic Interactions." *Nature* 428 (6979): 167–71. https://doi.org/10.1038/nature02297.

Brousseau, Pierre-Marc, Dominique Gravel, and I. Tanya Handa. 2017. "Trait-Matching and Phylogeny as Predictors of Predator-Prey Interactions Involving Ground Beetles." *Functional Ecology*, July. https://doi.org/10.1111/1365-2435.12943.

Delmas, Eva, Mathilde Besson, Marie-Hélène Brice, Laura A. Burkle, Giulio V. Dalla Riva, Marie-Josée Fortin, Dominique Gravel, et al. 2018. "Analysing Ecological Networks of Species Interactions." *Biological Reviews*, June, 112540. https://doi.org/10.1111/brv.12433.

Desjardins-Proulx, Philippe, Idaline Laigle, Timothée Poisot, and Dominique Gravel. 2017. "Ecological Interactions and the Netflix Problem." *PeerJ* 5 (e3644). https://doi.org/10.7717/peerj.3644.

Gravel, Dominique, Benjamin Baiser, Jennifer A. Dunne, Jens-Peter Kopelke, Neo D. Martinez, Tommi Nyman, Timothée Poisot, et al. 2018. "Bringing Elton and Grinnell Together: A Quantitative Framework to Represent the Biogeography of Ecological Interaction Networks." *Ecography* 0 (0). https://doi.org/10.1111/ecog.04006.

Gravel, Dominique, Timothée Poisot, Camille Albouy, Laure Velez, and David Mouillot. 2013. "Inferring Food Web Structure from Predator-Prey Body Size Relationships." Edited by Robert Freckleton. *Methods in Ecology and Evolution* 4 (11): 1083–90. https://doi.org/10.1111/2041-210X.12103.

Guiden, Peter W., Savannah L. Bartel, Nathan W. Byer, Amy A. Shipley, and John L. Orrock. 2019. "Predator–Prey Interactions in the Anthropocene: Rec-

onciling Multiple Aspects of Novelty." *Trends in Ecology & Evolution* 0 (0). https://doi.org/10.1016/j.tree.2019.02.017.

Hui, Cang, and David M. Richardson. 2019. "How to Invade an Ecological Network." *Trends in Ecology & Evolution* 34 (2): 121–31. https://doi.org/10.1016/j.tree.2018.11.003.

Magrach, Ainhoa, Andrea Holzschuh, Ignasi Bartomeus, Verena Riedinger, Stuart P. M. Roberts, Maj Rundlöf, Ante Vujić, et al. 2017. "Plant-Pollinator Networks in Semi-Natural Grasslands Are Resistant to the Loss of Pollinators During Blooming of Mass-Flowering Crops." *Ecography*, February, n/a–n/a. https://doi.org/10.1111/ecog.02847.

Morales-Castilla, Ignacio, Miguel G. Matias, Dominique Gravel, and Miguel B. Araújo. 2015. "Inferring Biotic Interactions from Proxies." *Trends in Ecology & Evolution*.

Pellissier, Loïc, Camille Albouy, Jordi Bascompte, Nina Farwig, Catherine Graham, Michel Loreau, Maria Alejandra Maglianesi, et al. 2017. "Comparing Species Interaction Networks Along Environmental Gradients." *Biological Reviews of the Cambridge Philosophical Society*, September. https://doi.org/10.1111/brv.12366.

Poisot, Timothée, Benjamin Baiser, Jennifer A. Dunne, Sonia Kéfi, François Massol, Nicolas Mouquet, Tamara N. Romanuk, Daniel B. Stouffer, Spencer A. Wood, and Dominique Gravel. 2016. "Mangal - Making Ecological Network Analysis Simple." *Ecography* 39 (4): 384–90. https://doi.org/10.1111/ecog.00976.

Poisot, Timothée, Dominique Gravel, Shawn Leroux, Spencer A. Wood, Marie-Josée Fortin, Benjamin Baiser, Alyssa R. Cirtwill, Miguel B. Araújo, and Daniel B. Stouffer. 2016. "Synthetic Datasets and Community Tools for the Rapid Testing of Ecological Hypotheses." *Ecography* 39 (4): 402–8. https://doi.org/10.1111/ecog.01941.

Poisot, Timothée, Daniel B. Stouffer, and Sonia Kéfi. 2016. "Describe, Understand and Predict: Why Do We Need Networks in Ecology?" *Functional Ecology* 30 (12): 1878–82. https://doi.org/10.1111/1365-2435.12799.

Pomeranz, Justin PF, Ross M. Thompson, Timothée Poisot, and Jon S. Harding. 2018. "Inferring Predator-Prey Interactions in Food Webs." *Methods in Ecology and Evolution* 0 (ja). https://doi.org/10.1111/2041-210X.13125.

Stock, Michiel, Timothée Poisot, Willem Waegeman, and Bernard De Baets. 2017. "Linear Filtering Reveals False Negatives in Species Interaction Data." *Scientific Reports* 7 (April): 45908. https://doi.org/10.1038/srep45908.

Strong, Justin S., and Shawn J. Leroux. 2014. "Impact of Non-Native Terrestrial Mammals on the Structure of the Terrestrial Mammal Food Web of Newfoundland, Canada." *PLOS ONE* 9 (8): e106264. https://doi.org/10.1371/journal.pone.0106264.

Thompson, Patrick L., and Andrew Gonzalez. 2017. "Dispersal Governs the Reorganization of Ecological Networks Under Environmental Change." *Nature Ecology & Evolution* 1 (May): 0162. https://doi.org/10.1038/s41559-017-0162.

Trøjelsgaard, Kristian, and Jens M. Olesen. 2016. "Ecological Networks in Motion: Micro- and Macroscopic Variability Across Scales." *Functional Ecology* 30 (12): 1926–35. https://doi.org/10.1111/1365-2435.12710.

Tylianakis, Jason M., and Rebecca J. Morris. 2017. "Ecological Networks Across Environmental Gradients." *Annual Review of Ecology, Evolution, and Systematics* 48 (1): 25–48. https://doi.org/10.1146/annurev-ecolsys-110316-022821.

Whittaker, Robert H. 1962. "Classification of Natural Communities." *Botanical Review* 28 (1): 1–239. https://www.jstor.org/stable/4353649.