

The biological interpretation of probabilistic food webs

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1: Community ecologists are increasingly thinking probabilistically when it comes to food webs and other ecological networks. Assuredly, the benefits of representing ecological interactions as probabilistic events (e.g., how likely are species to interact?) instead of binary objects (e.g., do species interact?) are numerous, from a better assessment of the spatiotemporal variation of trophic interactions to an increase capacity to reconstruct networks from sparse data. However, probabilities need to be used with caution when working with species interactions. Indeed, depending on the system at hand and the method used to build probabilistic networks, probabilities can have different interpretations that imply different ways to manipulate them. At the core of these differences lie the distinction between assessing the likelihood that two groups of individuals *can* interact and the likelihood that they *will* interact. This impacts the spatial, temporal, and taxonomic scaling of interaction probabilities, thus enlightening the need to properly define them in their ecological context. Published data on probabilistic species interactions are poorly documented in the literature, which impedes our ability to use them appropriately. With these challenges in mind, we propose a general approach to thinking about probabilities in regards to ecological interactions, with a strong focus on food webs, and call for better definitions and conceptualizations of probabilistic ecological networks, both at the local and regional scales.

1 Introduction

2 Cataloging species interactions across space is a gargantuan task. At the core of this challenge lies the
3 spatiotemporal variability of ecological networks (Poisot *et al.* 2015), which makes documenting the
4 location and timing of interactions difficult. Indeed, it is not sufficient to know if two species have the
5 biological capacity to interact to infer the realization of this interaction at a specific time and space. Taking
6 food webs as an example, a predator and its potential prey must first co-occur on the same territory in
7 order for a trophic interaction to take place. They must then cross paths, which can happen only if their
8 relative abundances in the ecosystem is high enough and their phenology matches. Finally, the interaction
9 occurs only if the predator has a desire to consume its prey and is able to capture and ingest it.

10 Environmental (e.g. temperature and presence of shelters) and biological (e.g. physiological state of both
11 individuals and availability of other prey species) factors contribute to this variability by impacting species
12 co-occurrence and the realization of their interactions. In this context, it is unsurprising that
13 computational methods are being developed in ecology to help alleviate the colossal sampling efforts
14 required to document species interactions across time and space (Strydom *et al.* 2021).

15 The recognition of the variability of species interactions and the emergence of numerical methods have
16 led ecologists to rethink their representation of ecological networks, slowly moving from a binary to a
17 probabilistic view of species interactions (**Poisot2016StrProa?**). This has several benefits. For example,
18 probabilities represent the limit of our knowledge about species interactions and can indicate the expected
19 frequency of two species interacting with each other. They are also very helpful in predictive models when
20 modeling the spatial distribution and temporal variability of ecological networks, generating new
21 ecological data, and identifying priority sampling locations.

22 However, representing species interactions probabilistically can also be challenging. Beyond
23 methodological difficulties in estimating these numbers, there are important conceptual challenges in
24 defining what we mean by “probability of interactions.” Because this ecological representation is still in its
25 infancy, there is no clear definition found in the literature. In this contribution, we outline different ways
26 to define and interpret interactions probabilities in network ecology and propose an approach to thinking
27 about them. These definitions mostly depend on the study system (e.g. local network or metaweb) and on
28 the method used to generate them. We show that different definitions can have different ecological
29 implications, especially related to spatial, temporal, and taxonomic scaling. Although we will focus on

30 food webs, our observations and advice can be applied to all types of ecological networks, from
31 plant-pollinator to host-parasite networks. Overall, we argue that probabilities should be better
32 documented, defined mathematically, and used with caution when describing species interactions.

33 **Definitions and interpretations**

34 **Overview of interaction probabilities**

35 How are interaction probabilities defined in the literature? It might not be as intuitive as one would think.

- 36 • There is a big difference in how we interpret the probability that two species *can* interact (metaweb)
37 and the probability that they *will* interact (realized networks).
- 38 • Interaction probabilities can be used to describe Boolean interactions (e.g., the probability that two
39 species interact) and weighted interactions (e.g., the probability distribution of the amount of energy
40 flow between two species).
- 41 • In many studies, it is not obvious if authors use interaction scores or probabilities (in the latter case,
42 it is rarely specified what these probabilities truly represent).

43 **Probabilistic metawebs**

44 What does a probability in the context of a metaweb mean?

- 45 • It means the probability that two taxa can interact, regardless of biological plasticity, environmental
46 variability, or co-occurrence.
- 47 • One observation is enough to set this probability to one.
- 48 • Can we turn this into a local network realisation that is also probabilistic and intuitive?

49 **Papers: (Strydom2022FooWeb?)**

50 **Probabilistic local networks**

51 What does a probability in the context of a local network mean? A cautionary tale of how we define
52 probabilities.

- It means the probability that two taxa will interact at a given location.
- What do we mean by saying that two taxa will interact? We usually mean that at least one individual from one group will interact with (e.g., predate) at least one other individual from the other group.
- The probability is conditional on the environmental and local abundance contexts.
- We should expect a certain number of interactions to be realized depending on the probability value. This number depends on the number of trials, which also depends on the ecological context (e.g., environmental conditions, scale) in which probabilities were estimated. This is in contrast with probabilities in metawebs.

Scaling

Spatial and temporal scales

How do interaction probabilities scale spatially and temporally?

- Why do probabilistic local food webs scale with area and time but not probabilistic metawebs?
- In metawebs, interaction probabilities do not scale with space and time because they depend solely on the biological capacity of two species to interact.
- In local food webs, interaction probabilities scale with space and time because there are more opportunities of interactions (e.g., more environmental conditions) in a larger area and longer time period.
- What are some network area relationships in probabilistic local food webs?
- We know that local networks can inform regional networks. However, can regional networks inform local networks?

Figure: Empirical example of the association between the number of interactions in realized local food webs and the number of interactions in the corresponding species subnetworks of regional networks. We should expect the interaction to be linear below the 1:1 line.

Papers: there might be something in these McLeod *et al.* (2020); (McLeod2021SamAsy?); (Wood2015EffSpa?)

78 **Taxonomic scale**

79 How do interaction probabilities scale taxonomically?

- 80 • There are different biological interpretations of probabilities in food webs at the individual level and
81 at higher taxonomic levels.
- 82 • How does the scaling up of the nodes from an individual to population to any higher taxonomic
83 group change our interpretation of interaction probabilities? How does the aggregation change our
84 interpretation?
- 85 • How is it similar and different to spatial and temporal scaling? Basically, all kinds of scaling are just
86 different ways to aggregate individuals or nodes.

87 **Figure:** Conceptual figure of how a scale up of the nodes from an individual to a population to any higher
88 taxonomic group change our interpretation of the probability of interaction.

89 **Concluding remarks**

90 Here we present some advice moving forward.

- 91 • What can we learn from other systems/fields (e.g., social networks, probabilistic graph theory)?
- 92 • What even are probabilities? What is the probability that we will ever know the answer to that?
- 93 • Be careful of how we define probabilities. Be sure to be explicit about these things. Be sure to specify
94 the type of interaction, the spatial, temporal, and taxonomic scale when presenting new data on
95 interaction probabilities. We need better metadata documentation.
- 96 • Be careful to use and manipulate interaction probabilities properly depending on how they were
97 defined and obtained. Different interpretations imply different scaling, and thus different ways to
98 manipulate these numbers.
- 99 • Maybe mention thinking about a workflow to predict probabilistic local food webs from probabilistic
100 metawebs.

101 **References**

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