Dear Cédric gaucherel,

Your article, entitled A single changing hypernetwork to represent (social-)ecological dynamics, has now been reviewed.

The referees' comments and the recommender's decision are shown below. As you can see, the recommender found your article very interesting but suggests certain revisions.

We shall, in principle, be happy to recommend your article as soon as it has been revised in response to the points raised by the referees.

…

Author's Reply:

Montpellier, January the 8th, 2024

To PCI Network Science Recommender: Prof. Cedric Sueur

Re: Manuscript re-submission

Dear Recommender - Editor,

Attached is our revised research paper for your publication.

We modified the initial version of our paper. This paper now follows the comments of the reviewer. In particular, we shifted both Appendices into the main text at the most appropriate location. We corrected some of the captions and added the suggested references. We also re-edited the whole paper and clarified several explanations.

We are therefore confident that the conceptual and methodological facets of the paper convey general messages for PCI Network Science and would resonate strongly in your publication.

We welcome any questions and comments that you may have.

Sincerely.

Revision round #1

Decision for round #1 : Revision needed

Acceptance under revisions

The manuscript by Gaucherel and colleagues offers an insightful conceptual approach to ecological systems analysis using hypernetworks and Petri nets, emphasizing non-dyadic interactions. Acknowledging the reviewer's concerns, it's essential to highlight that while the paper revisits previously developed concepts by the authors, it aims to contextualize these within ecological systems analysis, a perspective that might be novel for many in the field. To address the critique of lacking new methodological contributions, the **authors could elaborate on** the specific implications and potential applications of these concepts in current ecological research. Clarifying the role of **network visualization** in determining node centrality is crucial to avoid misinterpretation. The authors should consider **integrating the comprehensive explanations from the appendix into the main text**, enhancing the manuscript's accessibility and clarity. Correcting minor typographical errors

and enriching the text with more explicit literature **references** will further strengthen the paper's academic rigor. With these revisions, the manuscript promises to be a valuable guide for researchers in ecological studies exploring the utility of hypernetworks and Petri nets, presenting a clearer view of its practical applications while cautiously delineating the limitations of network visualization in analysis. We look forward to a revised submission for PCI Network Science that addresses these suggestions.

by Cédric Sueur, 01 Jan 2024 08:20

Manuscript: https://doi.org/10.1101/2023.10.30.564699

version: 1

Review by anonymous reviewer 1, 15 Dec 2023 20:15

Gaucherel and colleagues provide a conceptual overview of how hypernetwork approaches coupled with methodologies developed in computer science (e.g., Petri nets) can be used to better describe and analyze the topology and dynamics of ecological systems. Recognizing that many ecological interactions are non-dyadic in nature, hypergraphs that allow for such higher-order interactions are introduced as a useful description of an ecological system. The authors suggest using Petri nets to capture the relationships between ecosystem components (e.g., species, social insect castes) and processes. Thus, each process encompasses a directed hyperedge with the relevant components (represented as nodes) as inputs and outputs. This arrangement naturally leads to a bipartite network conception that can likewise be cast in the form of a hypergraph. This representation can be used to study both short-term flows and long-term topological dynamics.

The paper overall is well-written and interesting. It does not present any new data or analyses, but uses the authors' previous investigations as a case study to explore how hypernetworks and Petri nets can be used to facilitate basic and applied ecological research. I believe the paper will be useful for introducing researchers to these tools and approaches, as well as the types of questions and analyses that they address.

Thank you for this positive appreciation.

The only substantive change that I would suggest is **moving** some of the material in the appendix, particularly L14-43, into the main text. I found the information that it contains to be very helpful in clarifying several points in the paper (e.g., the meaning of the double- vs. single-edged nodes, the meaning of white vs. black arcs, how the transition diagram was constructed). Especially for those readers unfamiliar with the authors' previous work on these topics, integrating this information into the main text will substantially enhance its readability.

Fine, as we do not have limits in paper length, this suggestion has now been followed and the text been clarified. (Both appendices have been located in the main text, for a whole and coherent body of arguments.)

Minor line-by-line comments:

L21: Is 'renewed' the right word here? Novel, perhaps?

Done.

L142: 'representing' is misspelled.

Done.

L167-177: A relevant paper when considering nested network structures, including those that span multiple organization levels, is: Montiglio P.-O. et al., 2020, Behav. Ecol. 31, 279-286.

Thank you for this suggestion (reference now added).

L193-194: As a caveat, it may be useful to note somewhere that the tools available to analyze hypernetworks are still somewhat limited, especially for non-specialist practitioners, relative to those for dyadic, graph-based networks.

Indeed, this is true, although Petri net associated tools and other bipartite graph tools may be used. Actually, our effort was concerning the way we can *handle* such hypergraphs, rather than the description and quantification of hypergraph structures. This comment has now been added.

L273: 'hexagon' is misspelled.

Done.

L277-296: It would be helpful to walk the reader through a few brief examples in plain words that show how Fig. 4 was constructed and how it can be interpreted. For example, what characterizes the state of the initial hexagon? What processes lead to states 14 and 4.

Indeed, good suggestions. The initial state of the system (hexagon) was to be found in the table 1, but we forgot to mention it (now added in the first column and caption). From this initial state, the modelled system may bifurcate in state 4 by following rule R1 ("Reproductives lay eggs", Table 1) or in state 14 by following rule R9 ("workers and reproductives die", Table 1). And so on. We have now added a detailed explanation.

Figure 4: What do the numbers within nodes represent? Are they simply arbitrary labels of different states?

Yes, they are arbitrary identifiers of each state (Fig. 4a) or of structural stabilities (in brackets, Fig. 4b). Now corrected in the main text and figure captions.

Review by Catherine Matias, 31 Dec 2023 16:51

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<u>Review by Catherine Matias reviewer 2</u>

Referee report on manuscript: A single changing hypernetwork to represent (social-)ecological dynamics.
The manuscript aims at proposing a new way of representing ecosystems, through the lens of *evolving* hypergraphs. Quoting the authors, the manuscript does "not present new models and new results, rather than exemplify the proposed concepts with our past basic and applied studies." So it is neither a review of the topic, as the references mainly focus on the authors' own works.
A first part of the manuscript is devoted to introducing the (previously proposed by the authors) concept of Ecological Network (EN), whose main characteristics lies in that its is a comprehensive view of various social-ecological systems acting on shared components (species or other entities). According to the authors, the concept of Ecological Network encompasses approaches such as multilayer, multiplex or multilevel graphs, and goes beyond those concepts as no assumption is

made on the shape of this EN (could be modular, layered, nested or anything else).
From this point, the authors argue that this EN should in fact be replaced by the more general concept of hypergraph, this way including potential higher-order interactions. More specifically, the authors argue that such hypergraph is represented by a Petri net, which is a bipartite representation of any hypergraph.
In a third part, the authors sketch links between this concept (of EN) and the studying of the dynamics of the ecosystem. This part is **not clear to me**. Finally, the authors argue that considering evolving hypernetworks is the promising thing to do, and their framework called EDEN is a way to do that.
In summary, this manuscript is a presentation to Ecologists of previously developed concepts by the same authors. It does not contain any novel methodological contribution, nor apply those to new datasets. It's rather a manifesto for the use of these concepts in studying ecological systems.
Yes, this is perfectly understood, thank you.

Major comments:

• Fig 2: The caption says "When a non-circular representation (b) is allowed, here with an appropriate display algorithm (Kamada and Kawai 1989), certain variables and processes become more central (here, termite workers Wk) and others less central (here, competitors Ac)." Graph visualization is known to be misleading and network statistics may help in quantifying for instance how much a node is "central". This phrasing seems to suggest that visualization makes it possible *to determine the central character of a node*. Later (end of page 8, top of page 9), one can read "With an appropriate graph layout (Fig. 2b), algorithms and graph analyses (Kamada and Kawai 1989), it is possible to produce representations that help in understanding node properties (e.g., whether they influence or are influenced by other nodes) [...]" suggests in the same way that *visualization is sufficient for network analysis*. As the manuscript is aimed at non-specialist, I believe the authors should be more careful and better warn the reader about **potentially naive interpretations**.
Indeed, this is true and we added a comment to avoid misinterpretations.

• Fig 3: It is unfortunate that symbols used in part b) are **not explained**. The authors refer to: "Pommereau et al 2022 for explanations of each symbol indicating how token should circulate in the hypernetwork." This harms understanding and if the aim of this manuscript is not (at least in part) to explain hypergraphs and their usage I do not see what purpose it serves.
Yes, such explanations were to be found in the supplementary materials (Appendix 2). Following the comments of reviewer #1, we have now included both appendices into the main text (and the Fig. 3 caption).

• Fig 4: I don't understand how the objects represented here are relied to Petri nets and the evolving hypernetworks. Again, by remaining too superficial the authors are at risk of not properly conveying their ideas.

Fine, we have now developed this part of the explanation (Appendix 2 inclusion): The main idea is that any (hyper)graph may change according to the arrival and/or removal of any component (node) and process (edge). So, its topology is drastically changing.

Minor comments and typos :

- page 10, line 265: Appendix 1 refers to what? In fact, section “Appendices” mentions the existence of 2 different appendices, which I did not find. On page 12, line 330, there is also a reference to an Appendix 2.

Actually, the first reviewer succeeded to find the appendix link. But you don’t have to worry no, as both appendices have now been inserted into the main text.

- same place: “An EN ecosystem interaction network”. As EN is already short for “ecosystem network”, this should be rephrased.

Done, thank you.

- In the same way, a github link to a software called “ecco” is given, whose exact link with the current manuscript remains unclear.

Clarified, thanks.

We would like here to warmly thank both reviewers and the handling editor for their relevant comments and questions. Best wishes. The authors.