Peer Community In
Network Science

The Dawn of Dynamic Hypergraph Modelling in Ecology

Cédric Sueur *based on peer reviews by* ***Catherine Matias*** *and 1 anonymous reviewer*

Cedric Gaucherel, Maximilien Cosme, Camille Nous, Franck Pommereau (2023) A single changing hypernetwork to represent (social-)ecological dynamics. bioRxiv, ver. 3, peer-reviewed and recommended by Peer Community in Network Science.
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The study of Gaucherel et al. (2024) represents a groundbreaking shift in the field of ecosystem representation and management (DeFries and Nagendra 2017), offering a comprehensive and innovative approach that emphasises the importance of dynamic and complex models to accurately understand and preserve our ecosystems.

At the heart of this pioneering work is the introduction of advanced representational methods such as interaction networks and hypergraphs (Bretto 2013; Golubski et al. 2016), which mark a significant departure from traditional static models. These novel representations are adept at capturing the intricate, multi-component interactions within ecosystems, thereby providing a much more nuanced and interconnected view of ecological systems.

This approach is particularly innovative as it moves beyond the simplicity of previous models, offering a dynamic, fluid, and interconnected perspective of ecological dynamics that is more reflective of the real-world complexity of these systems. Furthermore, the study proposes the integration of social networks with ecological ones (Sosa et al. 2021; Sueur 2023), acknowledging the profound impact that human activities have on natural systems (Afana 2021; Elmqvist et al. 2021; Pelé et al. 2021). This interdisciplinary approach is pioneering in its attempt to bridge the gap between social and ecological studies, underscoring the interconnectedness of natural and human systems and highlighting the need for a holistic approach to ecosystem management (Stokols et al. 2013; Stone-Jovicich 2015).

The significance of the study lies not only in its methodological innovations but also in the implications it holds for the field of ecology and environmental management. By employing these advanced methodologies, the study provides a more thorough understanding of ecosystems. By considering a wide range of components and their interactions, these models offer insights into the complex dynamics of ecosystems, which are crucial for developing effective conservation and management strategies. This comprehensive approach is particularly important in an era where ecosystems are increasingly threatened by a variety of factors, including climate change, habitat destruction, and pollution (Mantyka-pringle et al. 2012; Trathan et al. 2015).

Additionally, the dynamic nature of the proposed models, especially the use of hypergraphs, facilitates the adaptive management of ecosystems. By accurately representing the changing interactions and components within these systems, these models enable managers and policymakers to respond more effectively to ecological changes, ensuring that conservation efforts are both effective and timely (Ascough Ii et al. 2008; Fischer et al. 2009; McKinley et al. 2017). Moreover, the advanced modelling techniques proposed by the study have the potential to significantly improve predictive capabilities regarding ecosystem dynamics. Understanding the complex interactions and the long-term dynamics of ecosystems allows for better anticipation of future changes and challenges, a crucial aspect in a rapidly changing world where ecosystems are under constant threat.

In conclusion, this study marks a significant advancement in the field of ecological representation and management. Its innovative approach in utilising complex models like hypergraphs and integrating social and ecological networks provides a more comprehensive, dynamic, and nuanced understanding of ecosystems. Such innovations are crucial in an era of rapid environmental change and increasing anthropogenic pressures.

By enhancing our ability to understand, predict, and manage ecosystem dynamics, this study lays the groundwork for more effective conservation strategies and ecosystem management practices. It underscores the need for a holistic approach to understanding and preserving our natural world, recognising the intricate and interconnected nature of ecosystems and the pivotal role humans play within them.

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Reviews

Evaluation round #1

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Version of the preprint: 1

Authors' reply, 15 January 2024

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.

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Decision by Cédric Sueur, posted 01 January 2024, validated 03 January 2024

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.

Reviewed by anonymous reviewer 1, 15 December 2023

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.

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.

Minor line-by-line comments:

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

L142: 'representing' is misspelled.

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.

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.

L273: 'hexagon' is misspelled.

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.

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

Reviewed by Catherine Matias, 31 December 2023

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