Review of PhD thesis by David Beauchesne

The overall objective of the thesis is to evaluate the cumulative effects of climate change and human activities on ecological communities, with a focus on the role of ecological interactions in mediating the effects of multiple stressors throughout food webs. This is an important goal that addresses a critical gap in our understanding of how to predict the responses of and manage ecosystems under multiple stressors. Despite the importance of ecological interactions in structuring communities, they have been largely ignored by current approaches to measure cumulative effects on communities, on the grounds of conceptual and computational complexity. This thesis represents a huge step forward in tackling this gap. In general, I found the thesis exceedingly well written, both in French and in English, and I have appreciated the care taken to produce the final output.

The thesis comprises 7 main sections: a review-style introduction, five empirical chapters (Articles 1-5), and a General Discussion.

The **Introduction** provides a concise overview of the major issues considered in the thesis. The candidate demonstrates an excellent understanding of the issues, expresses them clearly with no serious omissions of key papers, and builds a cogent argument that identifies the critical gap addressed by the thesis.

Article 1 is in review in a very good journal, *Ecology Letters*. In this chapter, the candidate develops a conceptual framework to link community structure and pathways of stressor effects to individual species responses to single stressors, and then scales these responses back up to the community level to understand the sensitivity of communities that vary in structure to the combined effects of multiple stressors. The conceptual model on its own would be worthy of publication in a high-impact journal, but the candidate goes even further and tests it using a population dynamic model focused on the Saint Lawrence system food web. This chapter was a mammoth undertaking that represents a very significant advance on previous work. I was excited to read it! The model seems to uncover some important generalities: apex predators seem to be particularly sensitive to and negatively affected by multiple stressor effects, as are omnivorous species. Species sensitivity is modulated by community structure, and overlooking species interactions underestimates the effects of multiple stressors.

The chapter did raise some questions. For example, I wonder to what extent the sensitivity of apex predators is a mathematical inevitability since these species should invariably involved in the highest number of indirect ecological interactions. At least, this should be the case for generalist predators such as those encountered in the Saint Lawrence. I also wondered whether the simple positive vs negative nature of the trophic amplification metric might inherently make it difficult to observe simple additive effects of multiple stressors (where trophic amplification should be exactly zero). These questions, which I'm looking forward to discussing with the candidate, should not detract from the novelty and importance of this thoughtful contribution that will undoubtedly inspire many research groups.

Article 2 was published in Vie et Milieu in 2016. The goal of this chapter was to combine empirically described trophic interactions, obtained from a global database, with taxonomic relatedness to predict interactions in data-deficient ecosystems. The premise is that species for which data exist might serve as surrogates for related species lacking data. The idea is then put to the test against known interactions among species from the Gulf of St Lawrence. The machine-learning algorithm developed proves to be quite accurate at predicting trophic interactions on the basis of taxonomic proximity. The caveats (e.g., the extent to which taxonomy reflects phylogeny) are discussed honestly. It is clear that with further

refinements, such as the use of phylogeny, this algorithm can be a useful tool to generate additional trophic data to feed into the framework developed in Article 1.

Article 3 reviews the state of knowledge regarding cumulative impacts in the Gulf of Saint Lawrence and the challenges to their evaluation. This review was published in Le Naturaliste Canadien in 2016. The review is clear and concise. The five challenges identified spell out mainly research needs and priorities. Such calls for more research always make me wonder about the trade-off between getting more data and acting more quickly with imperfect information.

Article 4 brings together spatially explicit information on 22 drivers of environmental change in the Saint Lawrence system and identifies areas of high cumulative exposure and intensity. Not surprisingly, coastal areas show some of the highest cumulative exposure and intensity, but so do the estuary and the Anticosti Gyre. Few areas in the Saint Lawrence are free of drivers, which is an important message to disseminate. I would have like to see some discussion of two implicit assumptions of the study: first, that drivers interact additively to produce cumulative effects, and second, that spatial co-occurrence also means temporal co-occurrence. This paper was published in Frontiers in Marine Science in 2020. An outcome of the paper is a valuable, publicly available platform for shared information on factors affecting marine and coastal environments.

Article 5 examines the extent to which ecological interactions can amplify cumulative effects in marine ecosystems. Driver data from Article 4 are combined with the approach from Article 1 to provide an in-depth study of the role of species interactions in generating cumulative effects, both for whole networks and for individual species. Some of the conclusions repeat those of Article 4, e.g. most of the Saint Lawrence experiences multiple stressors, but the most important conclusion is profound: when species interactions are considered, the total cumulative effects on individual species are generally greater than when these interactions are ignored. The extent of the difference depends in part on species characteristics and community structure. New indirect and sometimes non-intuitive sources of stress on species can be identified by considering ecological interactions, which has important implications for management. This paper will undoubtedly become the cornerstone of a shift in perspective in multiple stressor/cumulative assessment research.

The **General Discussion** does a great job of weaving together the findings and conclusions of all articles and putting them in the larger context of natural resource management, of discussing honestly some of the limitations of the work, and of casting a eye to what we will need in the future to manage marine ecosystems in a holistic way.

Overall statement. Taken together, the findings of this thesis have pushed forward significantly our understanding of the role of ecological interactions in mediating the cumulative effects of multiple stressors on marine ecosystems. The thesis is accepted.

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