Peer Community In Ecology

Adaptive harvesting, "fishing down the food web", and regime shifts

Amanda Lynn Caskenette *based on peer reviews by* ***Pierre-Yves HERNVANN*** *and 1 anonymous reviewer*

Eric Tromeur, Nicolas Loeuille (2023) Effects of adaptive harvesting on fishing down processes and resilience changes in predator-prey and tritrophic systems. bioRxiv, ver. 5, peer-reviewed and recommended by Peer Community in Ecology.
https://doi.org/10.1101/290460

Submitted: 03 May 2022, Recommended: 01 March 2023

Cite this recommendation as:
Caskenette, A. (2023) Adaptive harvesting, "fishing down the food web", and regime shifts. *Peer Community in Ecology*, 100417. https://doi.org/10.24072/pci.ecology.100417

Published: 01 March 2023

The mean trophic level of catches in world fisheries has generally declined over the 20th century, a phenomenon called "fishing down the food web" (Pauly et al. 1998). Several mechanisms have been proposed to explain this decline including the collapse of, or decline in, higher trophic level stocks leading to the inclusion of lower trophic level stocks in the fishery. Fishing down the food web may lead to a reduction in the resilience, i.e., the capacity to rebound from change, of the fished community, which is concerning given the necessity of resilience in the face of climate change.

The practice of adaptive harvesting, which involves fishing stocks based on their availability, can also result in a reduction in the average trophic level of a fishery (Branch et al. 2010). Adaptive harvesting, similar to adaptive foraging, can affect the resilience of fisheries. Generally, adaptive foraging acts as a stabilizing force in communities (Valdovinos et al. 2010), however it is not clear how including harvesters as the adaptive foragers will affect the resilience of the system.

Tromeur and Loeuille (2023) analyze the effects of adaptively harvesting a trophic community. Using a system of ordinary differential equations representing a predator-prey model where both species are harvested, the researchers mathematically analyze the impact of increasing fishing effort and adaptive harvesting on the mean trophic level and resilience of the fished community. This is achieved by computing the equilibrium densities and equilibrium allocation of harvest effort. In addition, the researchers numerically evaluate adaptive harvesting in a tri-trophic system (predator, prey, and resource). The study focuses on the effect of adaptively distributing harvest across trophic levels on the mean trophic level of catches, the propensity for regime shifts to occur, the ability to return to equilibrium after a disturbance, and the speed of this return.

The results indicate that adaptive harvesting leads to a decline in the mean trophic level of catches, resulting in "fishing down the food web". Furthermore, the study shows that adaptive harvesting may harm the overall resilience of the system. Similar results were observed numerically in a tri-trophic community.

While adaptive foraging is generally a stabilizing force on communities, the researchers found that adaptive harvesting can destabilize the harvested community. One of the key differences between adaptive foraging models and the model presented here, is that the harvesters do not exhibit population dynamics. This lack of a numerical response by the harvesters to decreasing population sizes of their stocks leads to regime shifts. The realism of a fishery that does not respond numerically to declining stock is debatable, however it is very likely that there will a least be significant delays due to social and economic barriers to leaving the fishery, that will lead to similar results.

This study is not unique in demonstrating the ability of adaptive harvesting to result in "fishing down the food web". As pointed out by the researchers, the same results have been shown with several different model formulations (e.g., age and size structured models). Similarly, this study is not unique to showing that increasing adaptation speeds decreases the resilience of non-linear predator-prey systems by inducing oscillatory behaviours. Much of this can be explained by the destabilising effect of increasing interaction strengths on food webs (McCann et al. 1998).

By employing a straightforward model, the researchers were able to demonstrate that adaptive harvesting, a common strategy employed by fishermen, can result in a decline in the average trophic level of catches, regime shifts, and reduced resilience in the fished community. While previous studies have observed some of these effects, the fact that the current study was able to capture them all with a simple model is notable. This modeling approach can offer insight into the role of human behavior on the complex dynamics observed in fisheries worldwide.

References:

Branch, T. A., R. Watson, E. A. Fulton, S. Jennings, C. R. McGilliard, G. T. Pablico, D. Ricard, et al. 2010. The trophic fingerprint of marine fisheries. Nature 468:431–435. https://doi.org/10.1038/nature09528

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McCann, K., A. Hastings, and G.R. Huxel. 1998. Weak trophic interactions and the balance of nature. Nature 395: 794-798. https://doi.org/10.1038/27427

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres Jr. 1998. Fishing down marine food webs. Science 279:860–86. https://doi.org/10.1126/science.279.5352.860

Valdovinos, F.S., R. Ramos-Jiliberto, L. Garay-Naravez, P. Urbani, and J.A. Dunne. 2010. Consequences of adaptive behaviour for the structure and dynamics of food webs. Ecology Letters 13: 1546-1559. https://doi.org/10.1111/j.1461-0248.2010.01535.x

Reviews

Evaluation round #2

DOI or URL of the preprint: https://doi.org/10.1101/290460
Version of the preprint: 4

Authors' reply, 09 February 2023

Dear Editor,

Thank you very much for identifying these typos in equations 7 and 8. We corrected them in the revised manuscript.

Best regards,

Eric Tromeur and Nicolas Loeuille

Decision by Amanda Lynn Caskenette, posted 04 January 2023, validated 05 January 2023

Clarification required on mean trophic level equation

The paper is greatly improved in terms of the edits made in response to the reviewer comments.

There seems to be, however, an error in equations 7 and 8 (MTLC) that requires correction or clarification before I can recommend this paper.

Should the Y and e_y in the second half of the equation be in the denominator? If not, how is this a mean, what does the Y represent outside of the sum, and why is total effort included twice in the numerator?

I appologize for not catching this in the first round, and for the delay in this response. I am focusing on this equation, as this may be a quick fix, however, I also suggest the authors read through the text again, as there are a few small grammatical errors (e.g. "assumes" not "assume" in line 82, double "the" in line 180) that remain.

I do not think this paper needs to go out the reviewers again if this issue with E7&8 can be corrected.

Amanda

Evaluation round #1

DOI or URL of the preprint: https://doi.org/10.1101/290460

Version of the preprint: 2

Authors' reply, 07 December 2022

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Decision by Amanda Lynn Caskenette, posted 25 July 2022

Merits Revision to Improve Clarity and Thread

This preprint has the potential to provide a clear mathematical representation of how adaptive fishing, depending on fishing effort and the speed at which the fishermen can switch between harvesting predator and prey, can destabilize food webs and lower the mean catch trophic level (i.e. fishing down the food web). The general methods used appear sound and appropriate to tackle the question at hand. There are some issues, however, raised by the reviewers that should be addressed before the pre-print is recommended. The preprint would benefit from some further clarification, and some re-arrangement of the text to increase the readability and to clarify how the models specifically address your question for a wider audience.

Recommendations from reviewers to be included in revision:

1. Clarify the common thread of the manuscript, which should be supported by methods.

2. Plain language summaries and conceptual diagram for what you would expect to see for different model outcomes and what they mean in terms of fishing down the food web, to clarify how the models represent different scenarios for a wider audience.

3. The tri-trophic model best represents the fishing down the food web thread, you should consider including in the main text.

3. More information in the ”Material and Methods” section, moving some from the Results and Appendixes, and filling in some missing information, to increase the ability to reproduce the results.

In addition the reviewers provide many useful specific comments that should be addressed to improve the manuscript.

Reviewed by **Pierre-Yves HERNVANN**, 06 July 2022

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Reviewed by anonymous reviewer 1, 24 June 2022

Broadly the authors set out to do two things. First is to model populations dynamics as a function of different harvesting behaviour (strategies), namely a predator, prey, or mixed fishing approach. The second is to assess the resilliance of these systems based on the different harvesting strategies. And although the objectives are clear I feel that a clear ’take home message’ is missing (or I have struggled to grasp it) - but I think the results seem to suggest that an adaptive fishing strategy (that focuses on harvesting a select group of species based on population trends) is more likely to result in a more ’stable’/resilient system. With the caveat that this will also be strongly inflounced/hampered/modified by economic factors (the return on catch).

My main concern with this manuscript is not very clear/easy to follow which might make it less accessible to more general readers - the paper itself presents a lot of models/conditions that ahve multiple parameters for three different scenarios which means there is a lot of information that needs to be absorbed. I think there would be benefit in potentially trying to phrase some things in ’plain language’ alongside the mathematical derivative (particularly the conditions for stability). This could also be aided by linking to supplementary table 2A at the begining of the results section as it was nice to see all the different conditions presented side-by-side.

Building on this a conceptual figure could be particulalry useful. Although figure 1 (particularly b) are helpful I found myself wishing for a figure that sort of showcased the population dynamics of predator and prey over time under different the harvesting strategies - potentially even showcasing some of the ’tipping points’ as conditions for equilibrium/stability become violated. I feel like this presents a more intuative way to think of population dynamics - although I’m uncertain as to how easy it will be to implement since the total effort also palys a role in shaping these dynamics and adds another layer of complexity.

Is it possible to avoid the use of ’condition 6’ in the text? I find that I have to remind myself of this condition constatly and it might be easier to rater use a ’plain language phrasing’ and link to eq. 6 is parenthesis

Please define \mu (l. 56). It is unclear what predator-to-prey conversion efficiency means.

Results: A subheader after l. 155 to designate the resilience section here migth be nice to break up this section (the preceding section could also be subheader-ed if so desired)

Figure captions/legends. This may be tedious but please rediefine parameters. There are many and it is not always intuitive - this is particulalry the case for figure 2.

Figure 1.b The numbers are discussed in text but I think it would be good to either include a description in the figure caption or to see if these could be inculded on the figure itself.