MATTERS ARISING
https://doi.org/10.1038/s41559-021-01481-5

nature ecology & evolution

Check for updates

Empirical pressure-response relations can benefit assessment of safe operating spaces

Steven J. Lade[1,2] ✉, Lan Wang-Erlandsson[1], Arie Staal[3] and Juan C. Rocha[1]

ARISING FROM H. Hillebrand et al. *Nature Ecology & Evolution* https://doi.org/10.1038/s41559-020-1256-9 (2020).

In a recent study, Hillebrand et al.[1] tested ecosystem pressure-response data from multiple meta-analyses for multimodality and changing variance, both indicators of 'tipping point' thresholds that lead to discontinuous responses such as regime shifts. They found that such thresholds were difficult to detect and argued that threshold and safe operating space concepts are therefore not suitable for environmental management and policy. We find the results of their analysis, however, to be consistent with the current scientific understanding of thresholds that (1) many ecosystems have thresholds that lead to non-linear dynamics such as regime shifts and (2) awareness of the risks associated with such thresholds can help inform environmental management, even when the positions of these thresholds are uncertain. We then discuss (3) how safe operating space concepts relate to threshold concepts. In fact, (4) the approach of Hillebrand et al. could strengthen the empirical basis for assessments of safe operating spaces. We now elaborate on these four points.

There is extensive experimental and observational evidence of threshold dynamics, such as regime shifts, in a variety of ecosystems[2–5]. That the analysis by Hillebrand et al. did not find thresholds does not invalidate this evidence of threshold dynamics. As Hillebrand et al. found in the analysis of their own model-generated data, both variations in threshold locations between cases and observation noise can obscure thresholds in datasets that aggregate responses across cases. The position of a potential threshold in a single case may even change over time due to the confluence of multiple drivers[6] or stochastic variability. Differences between the temporal[7,8] and spatial[2] scales on which a threshold occurs and on which it is observed may also obscure their observation. While there is extensive ex-post evidence of thresholds in specific cases, and despite extensive work on early warning signal methods[9], we agree that variations in thresholds can make it challenging to detect or predict the location of a threshold in a specific case.

Even in the absence of precise information on threshold location, awareness of the risks associated with potential thresholds can promote risk-averse decision-making and promote collaboration, especially when dependence on a public good is high[10]. For example, knowledge of the existence of a threshold was sufficient for extractors of a resource to avoid that threshold in behavioural experiments[11] and for climate negotiators to cooperate[12]. Multiple evidence bases[13], such as modelling, past experience from other ecosystems or traditional ecological knowledge can help reduce uncertainty in the likely position of a threshold; however, residual uncertainty is an unavoidable feature of environmental management. Management that ignores even partial evidence of thresholds could risk potentially damaging and irreversible consequences in the misguided expectation that the ecosystem will recover[14].

Hillebrand et al. argue that if thresholds cannot be detected using their method, safe operating space approaches are also not useful. Safe operating spaces and similar approaches, such as sustainability boundaries[15], limits to acceptable change[16] and tolerable windows[17], denote acceptable levels of human perturbations to biophysical processes, which may or may not be defined based on threshold dynamics or threshold positions. 'Acceptable' can, for instance, be based on historical variability in state, experimentally measured levels of ecosystem services, a sustainable level of extraction[18] or expert judgements about acceptable levels of change[19]. In systems with known threshold or other non-linear dynamics[1], safe operating spaces could also be set at precautionary distances from the potential threshold range or pressure levels that trigger the non-linear dynamics.

Meta-meta-analyses of the type performed by Hillebrand et al., while they cannot detect thresholds, could instead help define aggregate-scale safe operating spaces. Pressure-response relations aggregated across multiple cases, derived from the meta-analyses that Hillebrand et al. identified, could help set levels of pressure where levels of response typically become unacceptable at the biome scale, for example, in the response of carbon storage to biodiversity loss[20]. These types of analyses could also help infer appropriate limits in cases where insufficient data are available to inform ecosystem management, alongside other considerations, such as normative values and the specific social-ecological context of each case.

To conclude, we are confident that the accumulated evidence of thresholds in ecosystems is valid and that appropriate application of safe operating space concepts is useful in environmental management and governance. At the same time, we thank Hillebrand et al. for their important methodological advance of systematically studying meta-analyses of ecosystem pressure-response relations. A diverse methodological toolkit is necessary to support the continued development, understanding and application of thresholds and safe operating space concepts.

Received: 2 December 2020; Accepted: 5 May 2021;
Published online: 3 June 2021

References

1. Hillebrand, H. et al. Thresholds for ecological responses to global change do not emerge from empirical data. *Nat. Ecol. Evol.* **4**, 1502–1509 (2020).
2. Biggs, R. O., Peterson, G. D. & Rocha, J. C. C. The Regime Shifts Database: a framework for analyzing regime shifts in social-ecological systems. *Ecol. Soc.* **23**, 9 (2018).

[1]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden. [2]Fenner School of Environment & Society, Australian National University, Canberra, Australian Capital Territory, Australia. [3]Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, the Netherlands. ✉e-mail: steven.lade@su.se

3. Diaz, R. J. & Rosenberg, R. Spreading dead zones and consequences for marine ecosystems. *Science* **321**, 926–929 (2008).
4. Walker, B. & Meyers, J. A. Thresholds in ecological and social–ecological systems: a developing database. *Ecol. Soc.* **9**, 3 (2004).
5. Hirota, M., Holmgren, M., Van Nes, E. H. & Scheffer, M. Global resilience of tropical forest and savanna to critical transitions. *Science* **334**, 232–235 (2011).
6. Scheffer, M. et al. Creating a safe operating space for iconic ecosystems. *Science* **347**, 1317–1319 (2015).
7. Eppinga, M. B. et al. Long-term transients help explain regime shifts in consumer-renewable resource systems. *Commun. Earth Environ.* **2**, 42 (2021).
8. Hughes, T. P., Linares, C., Dakos, V., van de Leemput, I. A. & van Nes, E. H. Living dangerously on borrowed time during slow, unrecognized regime shifts. *Trends Ecol. Evol.* **28**, 149–155 (2013).
9. Dakos, V., Carpenter, S. R., van Nes, E. H. & Scheffer, M. Resilience indicators: prospects and limitations for early warnings of regime shifts. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **370**, 20130263 (2015).
10. Santos, F. C. & Pacheco, J. M. Risk of collective failure provides an escape from the tragedy of the commons. *Proc. Natl Acad. Sci. USA* **108**, 10421–10425 (2011).
11. Rocha, J. C., Schill, C., Saavedra-Díaz, L. M., Del Pilar Moreno, R. & Maldonado, J. H. Cooperation in the face of thresholds, risk, and uncertainty: experimental evidence in fisher communities from Colombia. *PLoS ONE* **15**, e0242363 (2020).
12. Barrett, S. & Dannenberg, A. Climate negotiations under scientific uncertainty. *Proc. Natl Acad. Sci. USA* **109**, 17372–17376 (2012).
13. Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P. & Spierenburg, M. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio* **43**, 579–591 (2014).
14. Peterson, G. D., Carpenter, S. R. & Brock, W. A. Uncertainty and the management of multistate ecosystems: an apparently rational route to collapse. *Ecology* **84**, 1403–1411 (2003).
15. Vea, E. B., Ryberg, M., Richardson, K. & Hauschild, M. Z. Framework to define environmental sustainability boundaries and a review of current approaches. *Environ. Res. Lett.* **15**, 103003 (2020).
16. McCool, S. F. Planning for sustainable nature dependent tourism development. *Tour. Recreat. Res.* **19**, 51–55 (1994).
17. Bruckner, T., Petschel-Held, G., Leimbach, M. & Toth, F. L. Methodological aspects of the tolerable windows approach. *Clim. Change* **56**, 73–89 (2003).
18. UN Environment Programme. *Convention on Biological Diversity. Aichi Biodiversity Targets* https://www.cbd.int/sp/targets/ (2010).
19. Dearing, J. A. et al. Safe and just operating spaces for regional social-ecological systems. *Glob. Environ. Change* **28**, 227–238 (2014).
20. Strassburg, B. B. N. et al. Global priority areas for ecosystem restoration. *Nature* **586**, 724–729 (2020).

Acknowledgements

We thank J. Rockström, W. Steffen, G. Peterson, V. Galaz, B. Reyers, S. Cornell, J. Kuiper and H. Hillebrand for their comments on this manuscript. L.W.-E. is funded by the ERC Advanced grant no. ERC-2016-ADG 743080 (Earth Resilience in the Anthropocene Project).

Author contributions

S.J.L., L.W.-E., A.S. and J.C.R. conceived and wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to S.J.L.

Peer review information *Nature Ecology & Evolution* thanks the anonymous reviewers for their contribution to the peer review of this work.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.