Trends in
Ecology & Evolution

CellPress

Forum

Rethinking experiments that explore multiple global change factors

Xiaoqi Zhou [1,*] Xinyun Gu, [1] and Simeon J. Smaill [2,*]

Our current capacity to predict the responses of ecosystem functions under global change factors is limited. We propose new and more efficient approaches to experimental design and modeling that utilize interactions between ecosystem functions to improve our understanding of their sensitivity to global change factors.

Multiple global change factors are influencing terrestrial ecosystems

Increased atmospheric carbon dioxide concentrations, climate warming, and shifts in rainfall patterns are examples of post-Industrial Revolution global changes that have profoundly affected the functioning and diversity of terrestrial ecosystems [1]. Although these issues have generated significant concern among scientists, politicians, and the general public, various other global changes beyond warming and drought are also occurring, including widespread alterations in land use, increases in nitrogen deposition rates, biological invasions, soil salinization, and surface ozone concentrations [1,2]. Any of these global changes has the potential to individually affect ecosystem processes in a given location, but as global changes rarely occur in isolation, it is necessary to consider the influence of multiple changes in concert [3]. Unfortunately, our current capacity to explore the interactions (additive, synergistic, or otherwise) among global change factors is limited, reducing our ability to predict the net effects on ecosystem functions [2].

Limitations to global change factor experiments

Illustrating this issue, a recent review of the sensitivity of terrestrial carbon cycles to multiple global change factors determined that the vast majority of experiments (>98% of studies) incorporated only one or two factors, with a very small minority of relevant studies considering three or more factors simultaneously [4]. It should be noted that many of these experiments determined that variations in the studied global change factors produced consistent linear responses in carbon cycle processes, and that nonlinear responses (including synergistic and antagonistic interactions) between pairs of global change factors were rare [4]. However, given the limitations in the extent of the combinations studied, it is unknown whether this outcome can be extrapolated to three or more global change factors operating simultaneously.

Carrying out experiments incorporating multiple global change factors can address this uncertainty, but the material and financial resources required to establish and maintain these trials on a meaningful scale is substantial, and this is likely to be the predominant reason for the current lack of such studies. Considering that the short- and long-term results of these experiments can fluctuate, the length of time required to provide definitive results is also unknown [5]. To address this uncertainty, we propose new approaches to experimental design and modeling that utilize interactions between or among ecosystem functions to improve our understanding of their sensitivity to global change factors.

Plant productivity as an indicator of critical thresholds in global change factors

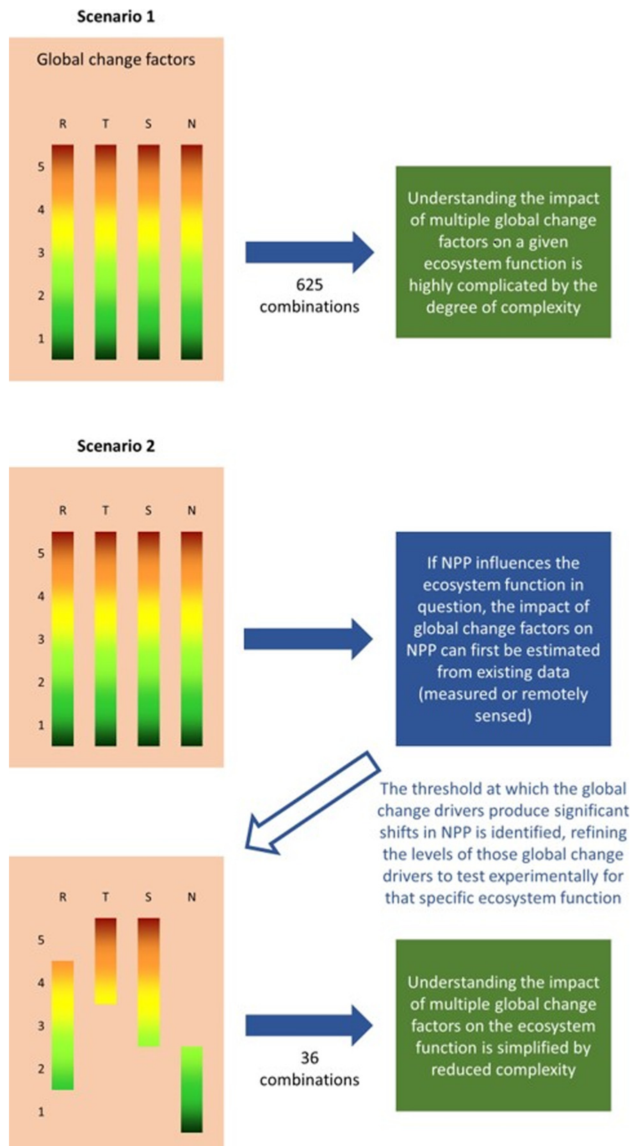
As an example, we considered the cascade of effects from interacting global change drivers to net primary productivity (NPP), then to soil methane efflux which is a critical ecosystem function [1]. NPP and soil methane efflux are both affected by various global change factors, such as temperature and rainfall [6], but changes in NPP can also affect soil methane efflux [7]. Increased NPP enhances litterfall and root exudation, providing more organic material for methanogenesis [7]. Conditions that decrease soil moisture tend to support enhanced methane oxidation [6], but if soil drying is sufficient to stress plants (manifest as reduced NPP), soil atmospheric ethylene concentrations increase, thus reducing methane oxidation capacity [8]. These interactions suggest that it could be possible to use changes in NPP as an indicator: when a combination of global change drivers alters NPP beyond a certain threshold, changes in other ecosystem functions are more likely to occur. This position is supported by Migliavacca *et al.* [9] who showed that forest NPP can be used to explain considerable variation in multiple ecosystem functions.

High-resolution spatial estimates of NPP are available from space-based spectral observations, creating datasets that are both vast and sensitive to global change factors, which can also be spatially tracked [1,2,7]. Site-specific data can be sourced from historic and contemporary data from a network of long-term biodiversity monitoring, and research networks provide another avenue to link NPP and ecosystem functions with multifactorial impacts of global change on ecosystem functions. This network incorporates 73 fixed long-term biodiversity monitoring and research plots, ranging in size from 2 to 120 ha, which have been established around the world (www.forestgeo.si.edu/sites-all). These plots – located in Europe (four plots), Asia (32 plots), America (28 plots), Africa (five plots), and Oceania (four plots) – provide comprehensive, dynamic vegetation field data, such as the individual size, species, and spatial positioning of each plant, and also local climate data such as temperature, rainfall, and nitrogen deposition can be recorded [10]. We propose that data from the sites in this network could be used to identify critical thresholds in global change drivers based on observed alterations in NPP at a given site; these thresholds could then be used to inform the design of manipulative global change driver experiments at locations similar to that site.

Whatever the approach, it is indisputable that ecosystem models that account for the multifactorial impacts of global change are needed. Recently, Rillig *et al.* [2] constructed a multifactor model of global change based on this principle, simulating up to ten global change factors that affect ecosystem functions in concert. In addition, biodiversity–ecosystem function modeling allows for interactions among species, as species diversity increases through complementary effects and selection effects [11]; similarly, we can draw an analogy with the multifactorial nature of global change, with observations of complementary effects, selection effects, and other interactions [12]. This method can be applied through the use of spectral data that are also increasingly available from space-based observations [7].

Simplifying global change factor experiments by incorporating plant data

On the basis of the large amount of field vegetation dynamic data provided by the long-term biodiversity monitoring and research network, and the newly developed remote sensing technology, we are confident that sufficient observational data will be available to model and identify critical thresholds in multiple global change factors simultaneously. This information can then be used to design more efficient trials and experiments that test precise combinations of the levels of global change factors, greatly reducing the effort and cost required to undertake this research (Figure 1).



Trends in Ecology & Evolution

Figure 1. Conceptual illustration of the pathway to simplifying experiments assessing the impact of multiple global change factors on a given ecosystem function. In scenario 1, the global change factors of rainfall (R), temperature (T), soil salinization (S), and nitrogen deposition (N) are divided into five hypothetical levels (e.g., extent and frequency) to address their interactive effects on a given ecosystem function. This creates 625 combinations that need to be assessed and replicated to produce suitable data. If the ecosystem function in question is influenced by net primary productivity (NPP), then scenario 2 could be followed. In this case, the impact of global change factors on NPP can be characterized by existing field or remotely sensed data, allowing only the combinations of global change factors that elicit significant change in NPP to be identified and tested experimentally for that ecosystem function. The net outcome of this scenario is greatly simplified experiments that will be more affordable but still target the critical thresholds of the global change factors.

Concluding remarks

We acknowledge the need and urgency to study the impact of multiple global change factors simultaneously on ecosystem functioning [2–4]. Through the pathways outlined here (exploration of the interactions among ecosystem functions, the long-term biodiversity monitoring and research network, and model development), we can further improve our understanding of the multifactorial effects of global change on ecosystem functions. We believe that, as we work towards this goal, we will become increasingly accurate in predicting changes in ecosystem functioning under multifactorial scenarios of future global change.

Acknowledgments

The research was jointly supported by the National Natural Science Foundation of China (No. 32171635 and No. 31870497) and the Fundamental Research Funds for the Central Universities and the Resilient Forests program, which is funded by the New Zealand Ministry of Business, Innovation and Employment (MBIE) Strategic Science Investment Fund, and in part by the New Zealand

Forest Growers Levy Trust (C04X1703). We thank editor Professor Andrea Stephens and the anonymous reviewers for their many constructive comments on earlier versions of this manuscript.

[1]Zhejiang Tiantong Forest Ecosystem National Observation and Research Station, Shanghai Key Lab for Urban Ecological Processes and Eco-restoration, Institute of Eco-Chongming, School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200241, China
[2]Scion, PO Box 29237, Riccarton, Christchurch 8440, New Zealand

*Correspondence:
xqzhou@des.ecnu.edu.cn (X. Zhou) and
Simeon.Smaill@scionresearch.com (S.J. Smaill).

https://doi.org/10.1016/j.tree.2023.01.009

References

1. IPCC (2021) *Climate Change 2021: The Physical Science Basis*. Cambridge, UK
2. Rillig, M.C. *et al.* (2019) The role of multiple global change factors in driving soil functions and microbial biodiversity. *Science* 366, 886–890
3. Gamfeldt, L. and Roger, F. (2017) Revisiting the biodiversity–ecosystem multifunctionality relationship. *Nat. Ecol. Evol.* 1, 0168
4. Song, J. *et al.* (2019) A meta-analysis of 1,119 manipulative experiments on terrestrial carbon-cycling responses to global change. *Nat. Ecol. Evol.* 3, 1309–1320
5. Melillo, J.M. *et al.* (2017) Long-term pattern and magnitude of soil carbon feedback to the climate system in a warming world. *Science* 358, 101–105
6. Tate, K.R. (2015) Soil methane oxidation and land-use change – from process to mitigation. *Soil Biol. Biochem.* 80, 260–272
7. Zhou, X. *et al.* (2021) Incorporation of NPP into forest CH_4 efflux models. *Trends Plant Sci.* 26, 1210–1212
8. Zhou, X. *et al.* (2021) Manipulation of soil methane oxidation under drought stress. *Sci. Total Environ.* 757, 144089
9. Migliavacca, M. *et al.* (2021) The three major axes of terrestrial ecosystem function. *Nature* 598, 468–472
10. Chen, L. *et al.* (2019) Differential soil fungus accumulation and density dependence of trees in a subtropical forest. *Science* 366, 124–128
11. Tilman, D. *et al.* (1996) Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature* 379, 718–720
12. Feng, Y. *et al.* (2022) Multispecies forest plantations outyield monocultures across a broad range of conditions. *Science* 376, 865–868