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COMMENTARY

Assessing community and ecosystem sensitivity to climate change – toward a more comparative approach

Melinda D. Smith, Kevin R. Wilcox, Sally A. Power, David T. Tissue & Alan K. Knapp

Smith, M.D. (corresponding author, melinda.smith@colostate.edu)[1],
Wilcox, K.R. (wilcoxkr@gmail.com)[2],
Power, S.A. (s.power@westernsydney.edu.au)[3],
Tissue, D.T. (d.tissue@westernsydney.edu.au)[3],
Knapp, A.K. (alan.knapp@colostate.edu)[1]

[1]Graduate Degree Program in Ecology, Department of Biology, Colorado State University, Fort Collins, CO 80523, USA;
[2]Department of Microbiology and Plant Biology, University of Oklahoma, Norman, OK 73019, USA;
[3]Hawkesbury Institute for the Environment, Western Sydney University, Penrith, NSW 2751, Australia

Abstract

Plant communities can vary widely in their sensitivity to changing precipitation regimes, as reported by Byrne et al., Mulhouse et al. and Sternberg et al. in this issue of *Journal of Vegetation Science.* But to understand why communities differ in their sensitivity, we argue that clearly defined metrics of sensitivity and coordinated research approaches are needed to elucidate mechanisms.

One of the most daunting tasks facing ecologists is the need to increase understanding of how ecological systems will respond to a changing climate. At present, we know a great deal about how climate has changed in the past, and forecasts for future change carry a high degree of confidence (IPCC 2013). However, forecasting ecological responses to these climate changes remains a challenge, in part because of differences in the sensitivity of ecological processes and systems to changing temperature and precipitation regimes (Smith et al. 2009; Dillon et al. 2010). Indeed, our understanding of how ecological systems, particularly communities and ecosystems, vary in their sensitivity to climate change *and the mechanisms underlying such differential sensitivity* lags far behind our ability to forecast climatic changes.

In this issue, three papers report results of research designed to increase our understanding of the sensitivity of arid and semi-arid plant communities to changing precipitation regimes. The papers use very different approaches – ranging from long-term observations to short-term experiments – to address this issue. Mulhouse et al. (2017) use long-term monitoring of plant communities to assess community dynamics in response to precipitation patterns. Sternberg et al. (2017) evaluate results from long-term grazing experiments within the context of variability in precipitation to determine how inter-annual precipitation legacy effects may influence plant diversity and biomass production. Finally, Byrne et al. (2017) directly manipulated precipitation amount in a short-term, multi-site experiment to examine plant community responses and sensitivity. Despite differences in approach, these three studies are linked by their conclusions that plant communities in some ecosystems are likely to be relatively insensitive to expected changes in precipitation, whereas others may be highly sensitive and respond dramatically to precipitation change.

While the results of these studies – that communities are expected to differ in their sensitivity to forecast changes in precipitation – are interesting, in aggregate they are limited by the binary (resistant vs responsive) and qualitative (more vs less sensitive) nature of their conclusions. This highlights the need to quantify ‘sensitivity’ as (1) a continuous variable and (2) in ways that more readily allow comparisons across studies if we are to advance our understanding of how and to what extent communities and ecosystems will respond to future climate change. A ‘systems’ definition of sensitivity (change in output per unit change in input) may be most appropriate for ecology. Such a definition is consistent with the general use of the term (to be ‘readily affected or changed by various external agents’; Merriam-Webster.com, Retrieved 9 Feb 2017 from https://www.merriam-webster.com/dictionary/sensitive). To determine how sensitive an ecological system is requires context, i.e. conditions where the external agent is not present or where different conditions all

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experience the external agent. Thus, from an ecological perspective, assessing sensitivity is inherently comparative – necessitating contrasts between treatments, across a range of environmental conditions, or among communities or ecosystems. Ultimately, if we are to advance a predictive understanding of ecological responses to climate change, we must be able to assess sensitivity – and the mechanisms underlying such sensitivity – in ways that can maximize our ability to compare across response variables, multiple research approaches and different communities and ecosystems.

Ecologists vary in their use of the concept of sensitivity when assessing climate and other global change effects on ecological systems (Appendix S1). Byrne et al. (2017) used 'sensitivity' 18 times and explicitly quantified sensitivity. On the other hand, Mulhouse et al. (2017) do not use the term at all, and Sternberg et al. (2017) discuss sensitivity, but not with regard to their results. Instead, because of the nature of the responses of their systems (i.e. the lack thereof), both Mulhouse et al. (2017) and Sternberg et al. (2017) focus on terms such as 'resistant' and 'buffering'. This suggests that there is a body of research that implicitly deals with sensitivity by focusing on how resistant (i.e. insensitive) a system is to change. Of those studies that do explicitly use the term, however, researchers often do not define sensitivity (i.e. such that units of sensitivity can be identified), or if they do, the term is used in very different ways (i.e. four major categories of definitions; Appendix S1). For the most part, sensitivity is used as a synonym for 'response', often reported as an absolute or relative change, or as a response ratio. In other words, the system (or variable) that responded the most to some aspect of global change in a study was deemed the most sensitive.

Depending on the sensitivity metric used, one may come to very different conclusions about differential sensitivity when comparing communities and ecosystems responses to climate change. Consider a hypothetical example comparing sensitivity in above-ground net primary productivity (ANPP) of arid vs mesic ecosystems to a drought (Appendix S2). Using either absolute or relative response metrics, entirely opposite conclusions about which ecosystem is more sensitive can be reached. Neither of these sensitivity metrics takes into account how much the driver is being changed, and for this example there is a greater proportional reduction in precipitation being imposed at the arid site than the mesic site. Thus, the conclusion about greater sensitivity for the arid site may be merely because a more extreme drought was imposed. Indeed, when the absolute response is expressed per unit change in precipitation (as the absolute ratio), then the conclusion is that both sites are *equally* sensitive. This is because even though there was a greater absolute loss in production for the mesic site, the loss relative to the amount of precipitation change was similar between the two systems. Sensitivity ratios that incorporate proportional changes in responses and treatments (metrics 4 and 5, Appendix S2) can yield additional conclusions regarding the differential sensitivity of these ecosystems to drought. Based on this example, we suggest that expressing sensitivity as the absolute ratio (metric 3, Appendix S2) is most useful for directly comparing responses among communities/ecosystems or between treatments because it reflects a functional relationship (e.g. loss in NPP or increase in species numbers per unit change in precipitation or temperature). Such relationships should also be useful for modellers.

In this issue, Byrne et al. (2017) defined sensitivity in a slightly different way – as the slope of the linear relationship between a community variable and the normalized precipitation amount (based on the long-term record), which is similar but not identical to the absolute ratio. They concluded that the mixed grass prairie community was more sensitive to changes in precipitation because the majority of community variables were significantly related to changes in normalized precipitation and/or had a larger slope than for the shortgrass steppe community. Byrne and colleagues' interest in normalizing precipitation amounts stemmed both from comparing sites with different amounts of annual precipitation, as well as from an experimental design that varied precipitation amount in very disparate ways among sites. This exemplifies a second important impediment to advancing our understanding of how and to what extent communities and ecosystems will respond to future climate change. In this case, comparability among studies assessing sensitivity would be increased if experiments were coordinated with agreed upon protocols that facilitated comparisons of results across disparate ecosystem types (Smith et al. 2009; Luo et al. 2011; Fraser et al. 2013). The Drought-Net Research Coordination Network, funded by the US National Science Foundation, is one such coordinated network recently established to (1) provide guidance for drought and precipitation change studies and (2) establish a new coordinated network of drought experiments – the International Drought Experiment (IDE). The goal of IDE is to impose drought treatments in directly comparable ways in order to facilitate comparisons of community and ecosystem sensitivity across a broad range of terrestrial ecosystems.

The three papers in this issue do an excellent job of identifying how plant communities may differ in their sensitivity to precipitation change. Unfortunately, understanding why these communities differ is hampered by the use of different definitions and metrics of sensitivity, as well as from disparate research approaches. While Byrne and colleagues take steps to increase comparability of sensitivity by using a common metric in their study, it is clear additional steps are needed. If we are to advance our

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understanding of how and why communities and ecosystems differ in their sensitivity to climate and other global changes, we suggest that adopting common metrics of sensitivity, a focus on mechanisms underpinning sensitivity and coordinated network approaches will be key to moving ecology towards that goal.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Use of the concept of sensitivity in ecology.

Appendix S2. A hypothetical example comparing sensitivity in above-ground net primary productivity (ANPP) of arid vs mesic ecosystems to a drought.