Insight from integration

JOHN HARTE & LARA KUEPPERS

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Figure 1 | Early bloomers. Artificial warming experiments, such as that shown here in the White Mountains of California, in which plants growing in open-top warming chambers are compared with adjacent plants growing in normal conditions, can be used to study how plant flowering and leafing times alter in different temperature conditions, and thereby help to predict how plants will respond to climate change.

Anthropogenic climate change, a massive uncontrolled planetary disruption, is under way, and a predictive understanding of how it will affect ecosystems and how these ecosystem responses will feed back to the climate is badly needed. Meta-analyses, such as that presented by Wolkovich *et al.*[1], have the potential to augment current ecological understanding. But when such analyses fail to explicitly address methodological differences between data sources that are crucial for interpreting results, their conclusions can be misleading. Here, we urge caution in the use of meta-analyses to assess different approaches to predicting ecosystem responses to climate change, and we describe how integrating multiple investigative methods can better advance understanding.

To predict ecosystem responses, scientists can observe correlations between climate and ecosystem properties, and can conduct controlled experimental manipulations of climate. However, both methods have limitations as well as strengths — it is difficult, for example, to identify causal mechanisms from correlative observations, and controlled experiments on small spatial scales cannot reflect all aspects of larger environments. Predictions of ecosystem responses should strive to make use of information from differing approaches in a way that considers the strengths and drawbacks of each.

Simply comparing results from many different experimental and correlative studies, as Wolkovich and colleagues attempted, can obscure nuances of methodology and analysis that are essential for making accurate predictions. Alternatively, integrating observational and experimental methods within a single study[11] can simultaneously provide insight into issues that are obscured by meta-analyses and the mechanisms driving ecosystem responses. For example, we have studied the sensitivity of subalpine meadow plants to climate using two types of experimental climate change (year-round heating and snow removal) and two types of natural climate change (interannual variability and change along an elevation gradient). We found[12] that the timing of flowering, and many other ecological responses, are remarkably similarly sensitive to each of these four sources of climate change, provided that snow-melt date is used as an explanatory variable, rather than mean annual temperature, as used by Wolkovich and colleagues.

The type of experimental method used for such studies does matter, though. Had we used passive heating methods, such as open-top chambers (Fig. 1) deployed only during the growing season, we might have increased the mean annual temperature, but our experimental heating would not have advanced snow melt and we would not have observed a strong phenological response. Thus, meta-analyses should carefully consider both the appropriate explanatory variables and methodological differences across experimental studies. Explanatory variables are likely to differ from one type of habitat to another, and from one type of response variable to another. In lowland tropical regions, where snow is not a factor, there is a great need for integrative methods to determine which variables drive plant and animal, as well as biogeochemical, responses to climate change.

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Our observation that phenology responds to changing snow-melt date consistently across different observational and experimental methods might suggest that researchers could dispense with expensive warming experiments and rely solely on cheaper, easier correlative studies. But that would be a mistake. Diverse ecosystem responses play out over a range of timescales and require persistent multi-year manipulations to uncover causal mechanisms[13]. For example, the change in soil carbon levels that occurs over time in response to persistent shifts in plant-species composition is not easily captured by interannual climate variability, but we recorded it in our controlled 21-year warming experiment[14]. Furthermore, predicting climate impacts on species turnover, selection and adaptation may require integration of yet other types of observation and experiment, such as the use of data from the fossil record and reciprocal transplant experiments across climate gradients.

These examples demonstrate how controlled warming experiments, particularly those that proceed for longer than the typical research-funding cycle of 3–5 years, can provide a means of understanding both patterns in ecosystem responses and the multiple mechanisms that govern these changes. Such experiments will allow identification and manipulation of explanatory variables and, if they are performed in combination with observational studies that take advantage of climate variability in space and time, will guide our quest to predict the future of ecosystems under global change. ■

John Harte *is at the University of California, Berkeley, Berkeley, California 94720, USA.*
Lara Kueppers *is at the University of California, Merced, Merced, California 95343, USA.*
e-mails: jharte@berkeley.edu; lkueppers@ucmerced.edu

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