Coordinated approaches for studying long-term ecosystem responses to global change

Marcelo Sternberg · Dan Yakir

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Introduction

The rapidly-growing world population, over-exploitation of natural resources, climate change and land-use changes stimulate ecological research at all scales. Within this complex reality, ecological research should aim to project future ecosystem states and processes over time scales of decades and centuries, and spatially from the plot size to the global scale. However, do we know what are the best strategies and requirements for achieving this goal? It is increasingly recognized that there are three key components to planning global change research: First, a long-term research approach is needed to identify ecological and physiological adjustments, feedbacks and community-level changes that are relatively slow in pace. Too often, global change experiments are conducted across a wide range of managed and natural ecosystems, effectively characterizing short-term, rapid and small-scale processes (Fraser et al. 2013).

Second, research within the global change framework should combine monitoring, observational research, experimental manipulations and modeling. In particular, ‘monitoring’, such as of background climatic conditions, should

be distinguished from long-term ‘experiments’ that permit the formulation of theory on ecophysiological and population-to-community-scale processes, and testing of that theory. In other words, we must conceive and conduct experiments at large enough spatial and temporal scales, and with sufficient complexity to effectively define ecosystem-level feedbacks (Osmond et al. 2004; Baldocchi et al. 2001).

In more recent years, we have had access to process-based models that provide a useful means of generating hypotheses that can be tested by observations and experimental work. This permitted us to conduct experiments *in silico*: searching for optimal fits between theory and observations using models and maximum likelihood statistics. The models used for long-term assessments are usually built upon knowledge of ecosystem processes, and are often parameterized by short-term observations and experimental manipulation data. While this is still necessary, we can now go beyond this and use observations in ways other than for parameterization. Observations can now be used to test the adequacy for theory to represent processes, and provide validation through the assimilation of observations into the models with robust statistical tests of how well the theory permits the model to match the data (e.g., Zobitz et al. 2011; Leuzinger et al. 2011).

The third component of global change ecological studies refers to the large-scale context of the study and its environmental representation. This may require large facilities, extensive instrumentation, and a large spatial scale of observation (e.g., remote sensing; Sellers 1993), networks of research sites (e.g., Baldocchi et al. 2001), or large-scale experimental systems (Gonzalez-Meler et al. 2014). While these requirements are often recognized individually, they are rarely discussed in an integrative manner within national or international research frameworks conducting global change research (Osmond et al. 2004).

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M. Sternberg and D. Yakir contributed equally to the writing and the submission of this paper.

M. Sternberg
Department of Molecular Biology and Ecology of Plants, Faculty of Life Sciences, Tel-Aviv University, 69978 Tel-Aviv, Israel

D. Yakir (✉)
Department of Earth and Planetary Sciences, Weizmann Institute of Science, 76100 Rehovot, Israel
e-mail: dan.yakir@weizmann.ac.il

For many of the environmental issues we are facing, it is no longer possible for a single investigator, or even a team of investigators, to address large-scale ecological questions at the local or regional level (Luo et al. 2011). Coordinated distributed ecological experiments based on international collaboration are needed to address problems at regional and global scales in order to understand ecological patterns and processes, and to develop solutions for environmental management based on sound scientific data (Fraser et al. 2013).

The lack of integrative national-scale frameworks in Israel, and many other countries, led to the convening of a special “Batsheva de Rothschild seminar on coordinated approaches for studying long-term ecosystem responses to global change”, in the fall of 2013, at the Ramat Hanadiv Nature Park in Israel (<http://www.ramat-hanadiv.org.il/en>). The seminar, supported by the Batsheva de Rothschild Fund of the Israel Academy of Sciences and Humanities, gathered international experts to discuss, and ultimately propose, a coordinated approach for a ‘National Platform for Long-Term Global Change Research’ in Israel. An Israeli program, in turn, can serve as a model for national-scale platforms, by virtue of Israel’s location in a complex ecological junction spanning a relatively small spatial scale (Safriel 2010; Sternberg et al. 2014). This seminar generated a cluster of papers by seminar participants, their colleagues and researchers who could not attend, but are conducting research of a similar nature, which comprise the Special Section of the current issue of *Oecologia*.

Features of the special section

While spanning a wide diversity of topics, this cluster of articles also demonstrates that a relatively narrow range of perspectives related to key requirements and experimental approaches are used to carry out ecological research within the global change framework discussed above.

At the outset, Schimel and Keller (2015) present an overview of their experience gained in managing and evaluating large ecological and Earth science research projects. The authors discuss the increasing need for large-scale experiments to conduct global change studies of the terrestrial biosphere. But also highlight the less apparent reality that this requires significant adjustments on the part of ecologists towards the planning and management of large projects. These aspects must be considered as ecological research scales up from the traditional, single research group studies, to “big science” based on large infrastructures, such as control facilities (Gonzalez-Meler et al. 2014), FACE experiments (Ainsworth and Long 2005), multi-disciplinary supersites (e.g., Hari and Kulmala

2005), or networks such as LTER (Franklin et al. 1990), FLUXNET (Baldocchi et al. 2001), or multidisciplinary network of observatories, such as TERENO (Zacharias et al. 2011) or NEON (Keller et al. 2008).

Natural rainfall gradients provide a particularly useful opportunity to study the long-term effects of contrasting climatic regimes on ecosystem functioning (Dunne et al. 2004; Rustad 2008; Emmett et al. 2004), especially in arid and semi-arid settings such as in Israel (Sternberg et al. 2011; Golodets et al. 2013). Several studies in this Special Section further demonstrate the utility of experiments along climatic gradients both for assessing long-term changes (the ‘space for time’ approach; e.g., Hänel and Tielbörger 2015), and for examining a substantial range of climatic parameters, such as temperature and precipitation (e.g., Mowll et al. 2015; Knapp et al. 2015).

Almost all the papers in this Special Section highlight the importance of the long-term perspective, either combined with large spatial coverage along climatic gradients (e.g., Mowll et al. 2015; Knapp et al. 2015; Smith et al. 2015), as a basis to identify responses to key ecosystem drivers at smaller scales (e.g., Wertin et al. 2015), to detect recovery from disturbance and assess system resilience (e.g., Trahan et al. 2015), or to identify community-level responses (e.g., Hänel and Tielbörger 2015). Several of the papers have combined the use of studies across gradients with manipulation of plots to conduct experiments on processes and mechanisms driving ecosystem change. This lies at the heart of constructing and testing theories of how processes are linked to variable ecosystem states. This is also at the heart of how we will be able to improve models to represent process–state interactions, even beyond the currently observed system.

While naturally occurring geographical and climatic variations are shown to be useful, direct manipulation of key climatic parameters, such as temperature, precipitation, soil water availability, CO₂ and nutrients, is ultimately needed to systematically quantify the effects of such parameters (e.g., Golodets et al. 2015; Knapp et al. 2015). Smith et al. (2015) highlight in particular the interactions of long-term perspective and resource manipulations: Chronic resource alterations result in a significant change in aboveground net primary production (ANPP) irrespective of ecosystem type, the length of the experiment, or the resource manipulated. However, the pattern of ecosystem response over time varies with ecosystem-type manipulation length, and plant community composition. As pointed out by Dorman et al. (2015), chronic resource limitation can also be the result of the interactions of competition intensity on limited rainfall.

Furthermore, the importance of considering multi-dimensional species effects on both chemical and physical ecosystem properties is highlighted by Sheffer et al. (2015), showing that man-made changes in the composition and

configuration of plant communities may result in complex unpredicted consequences to ecosystem biogeochemistry.

In summary, the papers in this Special Section reveal how the wide range of ecological studies, addressing diverse research questions, ecosystems and vegetation types, all point to the key requirements that should be integrated in order to advanced ecological research in an era of global change. Identifying such common requirements and strategies should facilitate planning and coordination of national-, regional-, and ultimately global-scale ecological research, which was the central aim of the “Batsheva de Rothschild Seminar on coordinated approaches for studying long-term ecosystem responses to global change”.

Author contribution statement D. Yakir and M. Sternberg jointly conceived this study and forum and jointly wrote the paper.

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