Long-term ecological research: re-inventing network science

Few of those involved in the birth of the National Science Foundation's (NSF) Long Term Ecological Research (LTER) network almost 30 years ago could have envisioned its leading role in defining continental-scale ecological science, as outlined in this issue of *Frontiers*. In these pages, 26 authors share their views on continental-scale ecological connectivity; 24 are LTER-affiliated. In his editorial (p 228), Steve Carpenter notes the importance of self-organizing networks of environmental scientists for identifying and addressing the non-linear and cross-scale phenomena that underlie and, in some cases, define global environmental change today. The LTER network is one of the best examples of such groupings: from early comparisons of populations and processes among two or three sites in the same biome have come groundbreaking, cross-network analyses of ecological change across multiple biomes exposed to varying degrees of human influence. And now, with the emergence of new, complementary networks, such as the National Ecological Observatory Network (NEON), the Global Lake Ecological Observatory Network (GLEON), the Water and Environmental Systems Network (WATERS), and the Oceans Observatory Initiative (OOI), comes the potential for research synergies hardly imaginable even 15 years ago.

Equal in importance to collaborations across physical networks are collaborations across disciplinary networks. If there is one overarching lesson to be learned from the evolution of LTER, it is the crucial importance of engaging with other disciplines – and especially with the social and behavioral sciences – to address today's big ecological questions. The greenlash discussed by Carpenter is often created, and usually abetted, by social interactions and institutions; we ignore this at our peril. LTER came of age alongside the Ecological Society of America's Sustainable Biosphere Initiative (SBI), and SBI's imprint is unmistakable in LTER science. LTER research increasingly embraces questions with human dimensions, as the ecological research community in general, and the LTER community in particular, have come to recognize the heavy, sometimes hidden hand of human influence in even the most remote locations. That recognition is abundantly clear in the articles in this issue of *Frontiers*: connectivity occurs within and across landscapes experiencing varying levels of human influence, sometimes direct and intentional, sometimes indirect and inadvertent – but rarely, if ever, absent.

The LTER network has embraced this challenge with a new, forward-looking initiative that is highly relevant to an emerging era of networked networks: Integrated Science for Society and the Environment (ISSE; www.lternet.edu/isse) recognizes and seeks to understand socioecological connections among organisms, processes, and ecosystems across varying geographic scales. Society receives services from ecosystems; in some cases, services are actively extracted, while in others they are underappreciated or even unrecognized. How these services are perceived, how perceptions affect behavior, and how behavioral change, in turn, affects ecosystem form and function are central to understanding the sustainability of the ecosystems on which we all depend. It is impossible to understand these linkages in the absence of interconnected, coordinated research sites, at which environmental scientists of all stripes – ecological, geophysical, social, and others – collaborate to address interdependent questions.

One major challenge facing connectivity science is nodal: how many sites are needed to test theories about the types, strengths, and interdependencies of connections among network nodes? For this reason, LTER is actively seeking partner networks with which to interact and, where possible, to share cyberinfrastructure and other resources common to environmental data collection and access. Continental-scale connectivity science requires continental-scale coverage by sites that are well-grounded in place-based science; how, otherwise, can socioecological hypo-theses related to connectivity be rigorously tested?

Early examples of socioecological research abound – many are described in this issue – and as new networks join the emerging constellation of environmental observatories, connectivity science will grow to more fully illustrate and define key linkages among globally dispersed ecosystems. Most LTER authors in this issue have also been heavily involved in the creation and development of more recent networks – NEON, GLEON, and WATERS among them – because the expertise and historical perspective afforded by LTER reinforce the value of new information from emerging networks, and provide a context for understanding and predicting future dynamics. All these networks recognize the importance of the coordinated sampling that allows information from multiple sites in disparate environments to address what is arguably the most pressing ecological question of our time: how to meet the needs of a sustainable future in an increasingly connected world.

This Special Issue of *Frontiers* is one of the strongest statements yet for the need to forge new networks, new collaborations, and new science to meet this increasingly global challenge. The LTER network stands ready to fully participate.

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