Ecology in a connected world: a vision for a "network of networks"

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We live in a connected world. Global economists and health professionals who track infectious diseases have long known this. But what does it mean in terms of how we operate as ecologists? How do we adjust our thinking about ecological systems and modify our sampling strategies to account for the fluxes and flows of materials among locations? What are the consequences of connectivity, not only at the global scale, but also at relevant continental, regional, and local scales? How do we identify connections among non-adjacent and seemingly disconnected locations, to both minimize the element of surprise and mitigate or avert potential impacts? These are the kinds of questions addressed in the papers in this Special Issue of *Frontiers*.

As ecologists, we need to recognize the extent to which system dynamics are driven by connectivity and to assess the consequences of changes (decreases or increases) in connectivity. Fortunately, we have resources available to attack these problems. The connectivity framework described in Peters *et al*. (p 229) provides the perspective, sampling strategy, and predictive capability needed to better understand these dynamics. Although the framework was developed for continental-scale research, the principles are applicable at a broad range of spatial scales.

In an ecological context, connectivity is defined as the transfer of materials by wind, water, humans, and animals between locations. Studying this phenomenon at local to continental scales will require new approaches that build on and augment existing scientific resources in novel ways. Most research groups and sites are part of networks that recognize the value and importance of measuring similar responses and drivers in different ecosystem types. However, simply collecting similar types of data is insufficient in a connected world. For example, the hundreds of research sites within the US will need to be integrated to capture the biotic, climatic, and environmental heterogeneity that characterizes this country. Existing sites have the expertise, instrumentation, and infrastructure to serve as the foundation for an interconnected network of sites. But it is only through collaborative, multi-agency research efforts that we can hope to create the "network of networks" required to address connectivity issues.

In some cases, such as at US Department of Agriculture (USDA) sites, data collection has been ongoing for nearly a century; sites within the National Science Foundation's (NSF) Long Term Ecological Research (LTER) program have been sampling intensively for nearly 30 years. This wealth of long-term data is the most reliable way to document historical patterns and to disentangle future directional trends from short-term variability and cyclic behavior. Existing efforts are an important step in gaining access to thousands of long-term datasets from many sites (eg www.ecotrends.info), but inclusion of more datasets and involvement of more sites are needed to build the required knowledge and research infrastructure.

Advances in remote sensing, combined with spatial and temporal analytical tools, including simulation models, will be invaluable in obtaining information across scales. The seamless integration of these multi-scale measurements and models will be needed before we can predict the impacts of propagating events, such as Hurricane Katrina. Admittedly, we need to go beyond the continental scale, by interacting effectively with other countries and continents.

Efforts are underway to begin to develop a "networks of networks". Existing networks recognize the importance of including more sites in their study designs (eg LTER Decadal Plan, www.lternet.edu/decadalplan); these networks are poised to address connectivity questions. Other efforts use the internet to link many sites (>600 to date). Designs of emerging networks, such as the National Ecological Observatory Network (www.neoninc.org), include common measurements at the continental scale. But to be successful, proposed networks must take advantage of the comprehensive coverage in time and space provided by the hundreds of existing sites. At present, it remains to be seen if these proposed initiatives will collect the multi-scale measurements required for connectivity studies.

The papers in this Special Issue provide examples of research questions and approaches that we believe are necessary for conducting effective research at the continental scale. New insights are discussed for five topics (spread of invasive species and infectious diseases, p 238; climate change and aquatic systems, p 247; climate change and coastal systems, p 255; climatic and societal gradients across landscapes, p 264; climate change and terrestrial systems, p 273) that are critical elements of our connected world, now and in the future. The authors and I are grateful to NSF, USDA–ARS, the LTER network, and the Consortium for Regional Ecological Observatories (COREO) for funding this Special Issue.