**Prediction in Ecology: Sharp eyes, clever thinking and new tools**

Draft from Peter Groffman; November 11, 2020

“Prediction is very difficult, especially if it's about the future!” This quote from Niels Bohr a Nobel laureate in Physics resonates across all fields of science. The scientific process, with its focus on uncertainty and consensus, is inherently hostile to prediction. Yet prediction is what society wants from science. We do all this research and people would like us to be able to say something about what our efforts tell us about the possibilities for the future.

The challenge of prediction is acute in Environmental Sciences, and particularly so in Ecology and Ecosystem Science. Ecosystems are complex systems where change is the product of interactions between diverse biotic and abiotic components, multiple external drivers of change, and internal emergent system properties that underlie stability and resilience. But there is a great need for understanding the future states and functions of ecosystems and the diverse and important “services” that they provide to humans that range from producing food and other natural products, cleaning the air and water, providing recreational opportunities, and supporting mental health. This need has only grown as the nature and extent of global environmental changes in climate, atmospheric chemistry, species distributions, and land cover have intensified over the past 75 years.

While Ecologists have not been as aggressive with prediction as scientists in other disciplines such as climate science or economics, they have not ignored the need altogether. Early efforts focused on the development of complex mechanistic simulation models that could predict future states of ecosystems, similar to the Earth System models that are used by the climate community. Ecologists have also developed empirical predictive approaches based on strong drivers such as climate, much like the data-based models that Economists use to predict business cycles. But ecosystems are constantly producing surprises that cause us to question our fundamental conceptual assumptions as well as our predictive algorithms. Prediction in Ecology has been a repeated series of one step forward, two steps back.

Interestingly, the shyness about prediction in Ecology and more broadly in Environmental Science is in contrast to the great successes these disciplines have had over the past 70 years in diagnosing problems, proposing solutions, and then convincing society to implement those solutions. Examples in species recovery and conservation (e.g., bald eagles), reversal of ecosystem degradation (e.g., Lake Erie), and management of regional scale interactions between the atmosphere and ecosystems (e.g., acid rain) highlight that Ecology is a discipline with deep mechanistic insights into the factors underlying the future state of the systems we study.

One of the most powerful tools that Ecologists have used to develop mechanistic insights and predictions is long-term studies. Ecologists recognized in the 1960s that they were studying complex systems that were slow to change and that long-term studies, along with experiments, models and comparative studies would be necessary for the discipline to develop a predictive capacity. The U.S. Long Term Ecological Research (LTER) network was founded by the National Science Foundation (NSF) in 1981 to conduct long term research at a range of competitively chosen sites, and similar networks have emerged across the globe since that time. More recently, the NSF founded the National Ecological Observatory Network (NEON), a more structured observatory network to provide systematic, publicly available data on key ecological variables. These efforts have led to successful predictions, especially of ecosystem processes; fluxes of energy, water, carbon and nitrogen. More challenging has been prediction of ecosystem structure. Our ability to predict just what plants and animals we can expect to find in a given place at a particular time has remained elusive.

Research in the U.S. NSF LTER network is loosely organized around five core areas; primary production, fluxes of inorganic matter, fluxes of organic matter, disturbance regimes, and populations and community. As part of an annual synthesis meeting process, LTER scientists were asked to make predictions about populations and communities at their sites. The result was a series of case studies, published as a series of five papers in the journal ECOSPHERE, that illustrate the state of prediction in this most difficult area of Ecology.

What do these case studies tell us? First, there is no substitute for sharp eyes and clever thinking. Observations of species occurring outside their range, speculation about how events in the distant past (e.g, farming in the 1700s) influence the species growing in forests today, and hypotheses about connections between air, water and organisms over continental scale distances have produced unexpected insights into how ecosystems are changing. Second, new tools have helped. High-resolution sensors on the ground, in the water and in the air are transforming the way we can monitor ecological systems and observe important events that previously would go undetected. And finally, the process of science has changed to be more interactive and collaborative, within and between disciplines. The capacity of the LTER network to provide a platform for groups to come together and synthesize results, and to interact with other disciplines has transformed our ability to take on the hardest questions. This is especially obvious in analysis of human-dominated systems, where we have new approaches to engage with stakeholders that observe, manage and use the ecosystems we study.

We hope you will read our case studies and enjoy the richness of prediction about what ecosystems in the LTER network will look like in 50 years or so. And we look forward to further development of our predictive capacity as the network ages and navigates the transition from long- to very-long term ecological research with new tools, models and interactions. And we ferverently hope that we will be able to continue to attract bright young scientists with sharp eyes, and the capacity for clever thinking.

How do we do it:

* Big mechanistic models – like in climate
* Empirical models – like in economics
* But these don’t work in Ecology:
	+ Observations by individuals
	+ Long-term monitoring at sites
	+ Combination of data streams
	+ Synthetic thinking
	+ From long to very long
* And what about humans
	+ Scenarios
	+ Very long term thinking