Forests and woodlands in an ever-changing world: climate-driven dynamics at centennial to multimillennial timescales

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Humans are both perpetrators and victims of climate change. With regard to carbon dioxide concentration, we are going into completely new territory. We can act to minimize the risk that our activities will change the climate in ways that will be unpleasant for us. We can also minimize the risks inherent in the fact that we are susceptible to all climate changes whether natural or human induced.

Observations about past climate change

Climate is non-stationary, multivariate and complex. Climate variability is continuous on all time scales. As Figure 1 illustrates, new climatic realizations appear all the time and the "cloud" that represents the climate space we live in may be changing all the time.

[insert Figure of climate space based on actual data illustrating variability]

Modal or regime changes are often rapid. An example of this is the rapid shifting between modes of the Pacific North American (PNA) teleconnection, which is related to the strength of the Aleutian Low. The PNA involves a change in atmospheric circulation mode that is correlated with precipitation. In its positive phase, the PNA causes Alaska to be wet, and the Northern Rocky Mountains and Great Plains to be dry, with the opposite impacts during the negative phase.

As illustrated in Figure 2, climate has changed state in the past. Evidence for these state changes are derived from paleoclimate inferences such as sand dunes moving or stabilizing, lake levels rising or falling, changes in the salinity of lakes, spruce and fir expansion versus pine and sage brush expansion, and glacier advance or retreat based on radio C dating.

{insert slide - climate changing state - which one was this?]

Biotic responses

Niche theory is useful in understanding how species respond to climate change (see Figure 3). Each species can tolerate a range of conditions with regard to a set of variables. The realized niche is a subset of the potential niche that is the larger array of tolerances of the species. In reality, we can only see the realized niche; we can't see the potential niche. Because species can only survive within their niche, climate change can threaten a species' survival if the rate of climate change is faster than the adaptive response capability of the species.

[Insert niche illustration - which one Steve?]

In many cases, there is not enough genetic variation within a species to respond to rapid climate change. If we lay diagrams of species' niches over each other, we can observe the overlap zone that determines what species may form communities.

Species assemble and disassemble as climate changes, breaking up old communities and forming new ones. Even if we could predict climate change accurately, we could not accurately predict the responses of species and communities to this change. [Steve - add something on: tragedy of the fundamental niche?]

Case Studies

During the Last Glacial Maximum (LGM, 22,500 years ago), there is evidence of southward shifting of the geographic ranges of white spruce, jack pine, red pine, and Utah juniper by as much as 1000 km. Many species that are now widespread and abundant (e.g., paper birch, eastern hemlock, eastern white pine, Ponderosa pine, Colorado piñon) existed as small, widely dispersed populations on the LGM landscape. Other species (papershell piñon, blue spruce) occurred as much as several hundred kilometers north of their modern distribution limits. A now-extinct species of spruce dominated forests in much of the lower Mississippi Valley. These are examples of species responses to climate change.

Climatic changes during the last deglaciation (9,000 to 18,000 years ago) led to dramatic and often-rapid changes in plant distributions and vegetation composition. Northward spread of many plant species onto formerly glaciated territory was rapid, often exceeding 100 meters per year. These migrations were paced primarily by climatic change and ice retreat; seed dispersal does not appear to have been limiting.

There are also examples of species responses for which there are no analogs, and surprises are always possible. In addition, climate variability can shape the pattern of the expansion of species. For example, the converting of sagebrush/juniper communities to ponderosa pine is generally shaped by climate changes.

Conclusions

Forest and woodland sensitivity to climatic change presents unique challenges to managers. "Restoration" to some historical ideal is likely to be elusive as continual evolution provides an ever-moving target; in other words "you can't go home again." Natural forest and woodland systems are transient in both time and space. The structure of any ecosystem is a vestige of past occurrences, with many species adjusting their ranges and populations to past or ongoing climatic changes. In some cases (e.g., woodland invasion of steppe or conifer invasion of hardwood forests) these adjustments may induce profound changes in ecosystem properties (soil chemistry, litter accumulation, nutrient availability, disturbance regimes).

All of these processes, of course, will be influenced by future climatic change and directly or indirectly by rising concentrations of atmospheric CO_2. Forests are susceptible to natural climate variability in addition to human-caused climate change. The critical challenge we face is development of flexible management approaches that can respond to the complex and non-stationary nature of environmental variability and the dynamic responses of ecological systems. Because prediction is likely to elusive (even if we could predict climate change we could not predict species and ecosystem responses to it), our focus should be on risk assessment, identifying key vulnerabilities and developing adaptive strategies to cope with these.