Natural versus Anthropogenic Control of Ecosystem Carbon Stocks

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Abstract

Large-scale carbon budgets are dynamic on a wide range of time scales, as a consequence of a diverse set of mechanisms. The mechanisms driving changes in carbon inventories reflect both direct and indirect effects of human actions and ecosystem processes. The tools for quantifying impacts of the direct effects of humans and of some kinds of ecosystem processes are quite mature. But the tools for quantifying and attributing a wide range of indirect responses are still primitive. Progress in attributing and projecting changes in large-scale carbon balance will require fundamental advances in understanding and modeling the interactions between human and ecosystem processes.

Inventory techniques for quantifying ecosystem carbon stocks are improving, developing from a foundation for assessing harvestable forest resources toward a set of general tools for supporting carbon accounting. The challenges, however, in moving from the timber industry to carbon accounting are daunting and far from completely resolved. Required advances include not only quantifying the carbon in soils and non-marketable components of the vegetation but also extending the analysis to ecosystem types not covered in traditional inventories. Assessing leakage and additionality becomes even more challenging when the domain of interest includes multiple types of ecosystems, with different dominant life forms. Remote sensing with LIDAR and RADAR are among the most promising techniques for efficiently extending inventories to poorly characterized ecosystems, including tropical forests, savannas, shrublands, and tundra.

Attributing changes in ecosystem carbon stocks to particular mechanisms is complicated by the diversity of possible mechanisms and by the range of possible interactions among mechanisms. In the past, it was often sufficient to work with three basic groups of mechanisms: (1) direct effects of human actions (e.g. harvesting, planting, or genetic improvement), (2) direct effects of natural processes (e.g. fire, storms, or insect outbreaks), and (3) indirect effects of changes in climate or the composition of the atmosphere (e.g. warming, altered precipitation, or elevated CO_2). Increasingly, this list of possible mechanisms must be expanded to include additional indirect of human actions. Some of these are unexpected consequences of climate change (e.g.

altered wildfire frequency). Others result from human actions not necessarily related to climate change. Potentially important processes in this category include changes in the deposition of biologically available nitrogen, effects of atmospheric pollutants, and changes in the abundance of invasive species. Finally, we are beginning to see evidence of processes driven through interactions among some of these indirect anthropogenic drivers and ecosystem processes. For example, warming temperatures are, in some locations, altering the life cycle of forest insect pests in a way that is leading to increased forest damage.

In general, neither inventory techniques nor simulation models are well positioned to provide powerful tools for unraveling this multi-process attribution problem. For a few specific mechanisms (e.g. effects of climate change on wildfires), simulation models are increasingly sophisticated and powerful. For most of the mechanisms that involve invasives or other kinds of biotic interactions, specific examples have been analyzed with a largely informal process based on observation and intuition. Progress in the analysis and forecasting of these biotically mediated, indirect effects will require both a new class of observations and a new generation of models.

In the United States, an ambitious new program, the National Ecological Observatory Network NEON), will address many of these needs. NEON will combine long term observations at core sites, studies along gradients, and manipulative experiments to address questions of ecosystem responses to global change, at the continental scale. Although carbon budgets are not the sole focus of NEON, its multi-process approach hold the promise of providing key insights necessary to interpret changes as they occur and to help with the development of models designed to forecast changes before they occur.

Outside the economically developed countries, the challenges of quantifying carbon stocks are severe, and the challenges of attributing changes to particular mechanisms are profound. Recent improvements in techniques for remote sensing of selective logging have the potential to help address one group of important challenges. But, just as increased needs for inventories will likely stimulate increased investments in obtaining them, increased motivation for attributing changes in carbon balance may also stimulate further investments.

The broadening suite of processes and interactions leading to changes in ecosystem carbon stocks creates diverse challenges for carbon accounting. Some of these are biogeochemical, but others are political or ethical. While the carbon accounting community is not in a position to resolve the non-biogeochemical aspects of these questions, the clearest, most comprehensive analyses can make a real contribution to supporting good solutions.