Ecosystem Carbon Fluxes and Storage

Christian Giardina*

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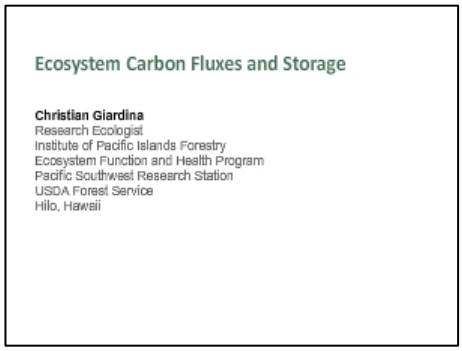
Slide 1. Ecosystem Carbon Storage and Fluxes

Hi, my name is Christian Giardina. I'm a research ecologist with the Pacific Southwest Research Station.

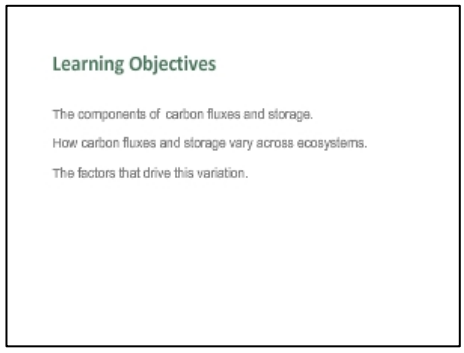


Slide 2. Acknowledgments

I'd like to start by acknowledging the funding agencies, the institutions and the individuals who are going to be contributing to the information I'm presenting today.

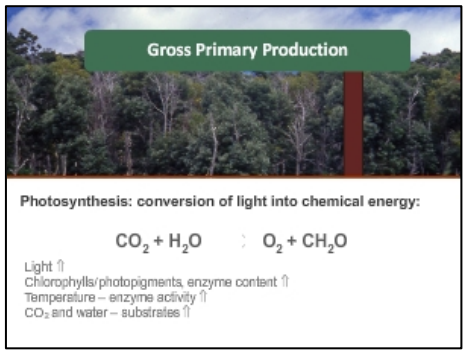
Slide 3. Learning Objectives

I have several learning objectives. I'm hoping that the folks who view this talk will finish the talk with an understanding of the components of carbon flux and storage in ecosystems, how carbon fluxes and storage vary across ecosystems, and then the factors that drive this variation.



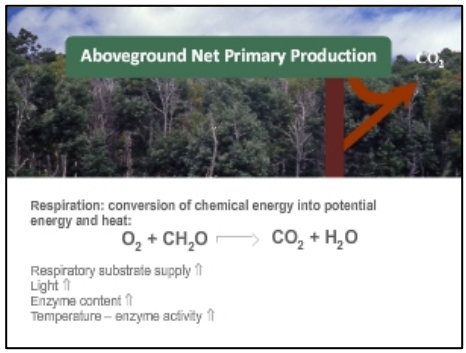
** This document transcribes the presentation given by Dr. Giardina. The presentation is part of General Technical Report NRS-93, "Forest and grassland carbon in North America: A short course for land managers." The full report, comprised of 15 presentations, is in DVD format and can be obtained at http://nrs.fs.fed.us/pubs/order/40110. The presentations and related materials can also be accessed at http://www.fs.fed.us/ccrc/carboncourse/*

Slide 4. Gross Primary Production



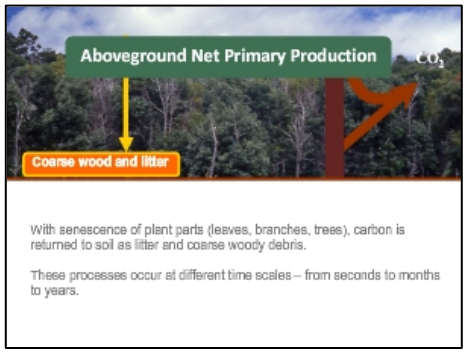
Starting with the most important flux in ecosystems, gross primary production, we want to give a little primer here about how ecosystems get the carbon responsible for storage and fluxes. Gross primary production is a total amount of photosynthesis that happens in the leaves of the canopy of plants. Basically it's the conversion of light energy into chemical energy, CO_2 plus water being turned into oxygen and sugars. Photosynthesis is sensitive to light, chlorophylls and photopigments or the amount of enzymes in the leaves, temperature, and CO_2 and water. Basically as these things increase, photosynthesis is able to increase.

Slide 5. Aboveground Net Primary Production



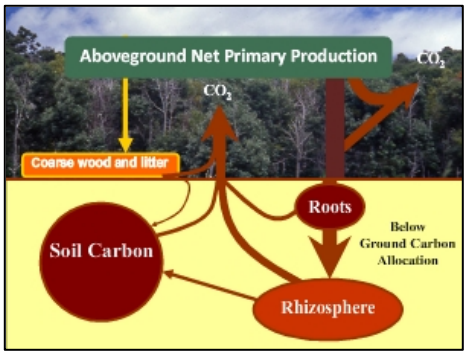
An often equally large flux in ecosystems is respiration. Respiration is the conversion of chemical energy into potential energy and heat. It's the opposite of photosynthesis. So you take sugar and oxygen and convert it into CO_2 and water, and it's sensitive to the respiratory substrate supply, light, enzyme content, and temperature, and the respiratory substrate supply or the compounds and the biomolecules that receive the chemical energy in the form of potential energy, and they do the work in living organisms. They help us continue day-to-day with all the things that we need to have that happen in our bodies, and plants have similar things going on with them. As you notice, the green bubble that was gross primary production is smaller, and it becomes aboveground net primary production as respiration results in a loss of sugars to the atmosphere. About half of all gross primary production is released on an annual basis as CO_2. Only half of what's photosynthesized sticks around as sugar.

Slide 6. Senescence



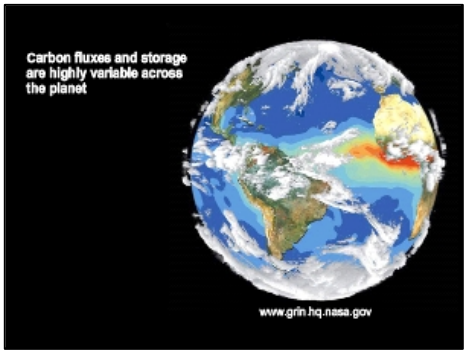
The third important flux I want to touch on in this primer is the conversion of living biomass into dead biomass, or senescence. And with senescence you have the release of plant parts, leaves, branches, trees and as you'll see roots in a second, into a form that's no longer living and released to soil where it becomes coarse woody debris and litter. These processes, gross primary production, ANPP[1], respiration, and senescence happen at different time scales from seconds to months to years, even centuries.

Slide 7. Belowground Carbon Allocation



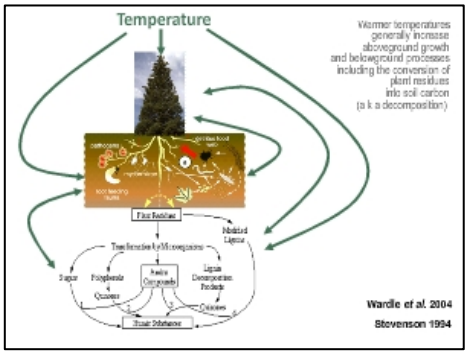
Now what's also important to realize is as complicated as the aboveground portion of the ecosystem can be, there's a whole other half of an ecosystem that we usually don't think about, and that's the belowground portion of ecosystems. Just like aboveground, we have primary production that's allocated belowground for different functions including the production of roots, the flux of carbon through roots into the rhizosphere which includes things like mycorrhizae, nitrogen-fixing bacteria that are often symbiotic with roots, and carbon will move through roots and the rhizosphere into the soil in a couple of different ways. One, through respiration, so just like aboveground plant parts respire, so do the belowground pieces, and they'll respire CO_2 in the atmosphere. Some of the senesced material belowground enters a soil carbon pool, and that'll also be respired into CO_2, and these different sources of CO_2 leave the ecosystem as soil respiration.

Slide 8. Carbon Fluxes and Storage are Variable



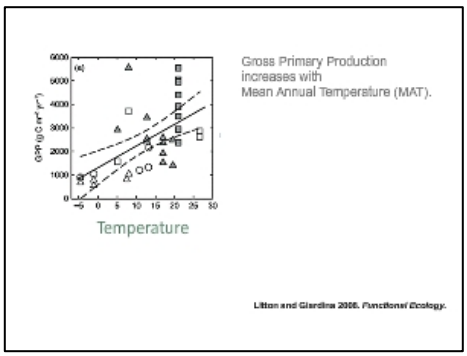
So carbon fluxes in storage are highly variable across the planet. While those processes typically occur in most ecosystems, the size, the distribution really varies quite a bit.

Slide 9. Temperature



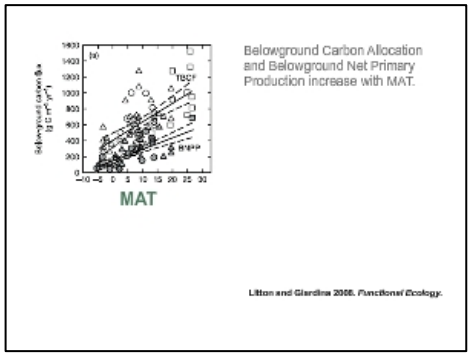
We'll start with temperature. Temperature is often viewed as an important driver of ecosystem processes. Warmer temperatures generally result in higher productivity above- and belowground, and also higher process rates for things like turning plant residues into humic substances or decomposition.

Slide 10. Gross Primary Production



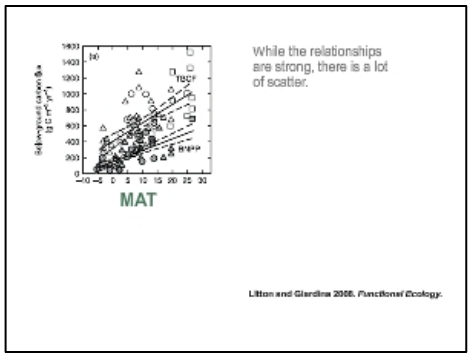
When you look at gross primary production, you see an increase of mean annual temperature. This is a plot that represents many sites where gross primary production was measured across the planet.

Slide 11. Belowground and MAT



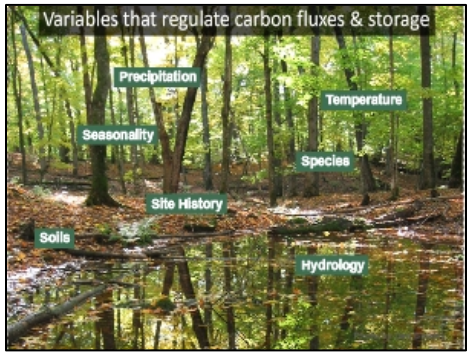
Similarly, belowground you see that both the amount of carbon allocated belowground and the amount of net primary production belowground increases with mean annual temperature.

Slide 12. Scatter



But what you'll also notice is that there's an awful lot of scatter in these diagrams.

Slide 13. Variables that Regulate Fluxes and Storage



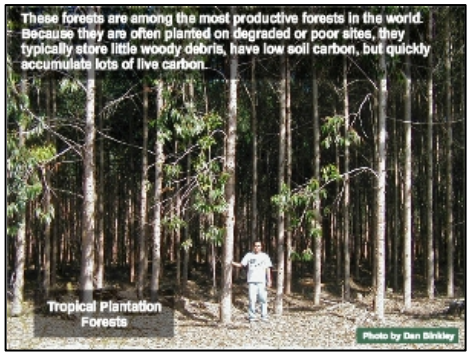
And the reason for that is that temperature doesn't by itself control carbon fluxes and processes and storage in ecosystems. Things like precipitation, or the total amount of water that enters an ecosystem, is also an important driver. The seasonality of precipitation or temperature can be more important than the total amount that comes in. How much comes in as snow versus rain? What is the temperature across the year? You have systems where temperature is pretty similar across the whole year, like where I live in Hilo, or you can have cold winters and warm summers like you find in the north woods. You also have species effects. You can have some species that have high growth rates, produce high quality litter, and that's litter that's easy to decompose, or you can have species that grow slowly and produce recalcitrant litter, or stuff that's really hard to decompose. Site history is an important driver. Is there a high return interval for fire that keeps carbon stocks low in a system? Or is there a land use history legacy of logging or other human activities? Soils are an important driver. You can have low fertility soils that don't provide very many nutrients to growing biomass, or you can have really fertile soils with very rapid growth because of an abundant nutrient supply. Finally, there's a hydrological aspect to the ecosystems that can really control both growth and carbon accumulation because of things like anaerobic conditions that result in slow decomposition or slow nutrient supply.

Slide 14. Northern Hardwood Forests

So moving through some different ecosystems just to give you a little tour of this variation, we can start with a northern hardwood forest. Because of seasonal climates here, that's cold winters and warm summers, a legacy of land use at the site at many different northern hardwood sites, poor soils, glacial outwash soils, they typically store low amounts of carbon in both woody debris and soil.

Slide 15. Tropical Plantation

Moving to the opposite end of the productivity spectrum, tropical plantation forests are some of the most productive ecosystems on earth because they are planted typically on agricultural lands, degraded lands, they don't have very much in the way of coarse woody debris, and they actually typically don't have a lot of soil carbon. They are planted on low quality sites, but because of management they accumulate lots of live carbon quickly.



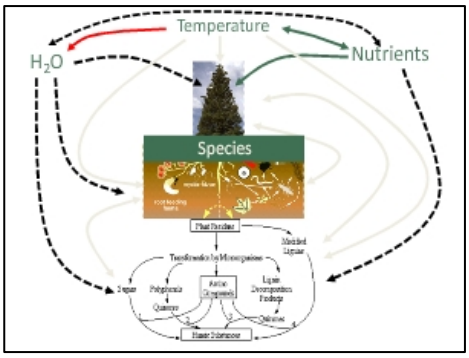
Slide 16. Subalpine Conifer Forest

Going to another extreme, subalpine conifer forests, these systems are some of the least productive ecosystems, forests on the planet. And they're not very productive because of cold winters, dry summers, but they do store a lot of coarse woody debris and a lot of soil carbon.

Slide 17. Subtropical Montane Rainforests

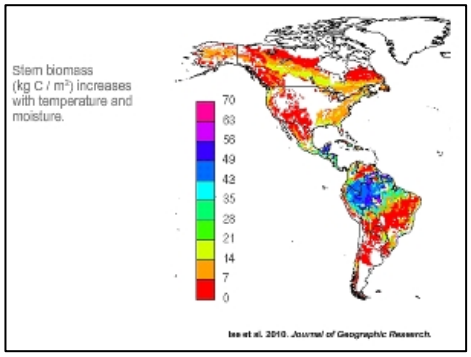
And then my favorite ecosystem, subtropical montane forests. These are highly productive because they're warm, they're wet, they often occur on volcanic soils which are very fertile, and this results in a lot of coarse woody debris and a lot of soil carbon.

Slide 18. Carbon Control: Temperature



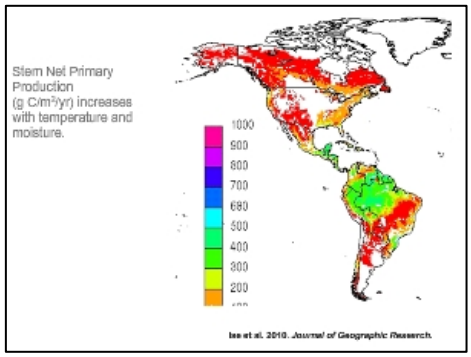
So when we look at water and nutrients and species and temperature, we get a really pretty complicated picture of how carbon fluxes and storage are controlled in ecosystems. There ’are a lot of interactions. For example temperature can negatively affect water by increasing evaporation and transpiration, and this in turn can affect productivity and processing of carbon.

Slide 19. Stem Biomass



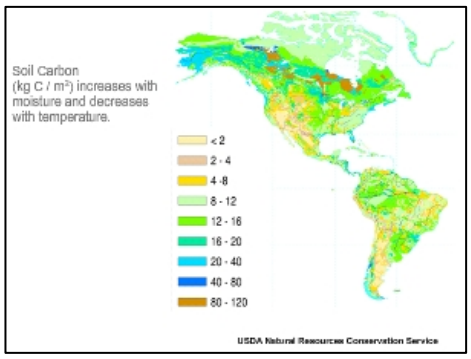
Just going through a couple of slides here thinking about the big picture, North and South America at the continental scale. When we look at stem biomass, we see that water and temperature come together to result in real high amounts of stem biomass, standing stem biomass, in regions like the Amazon in South America. Whereas in the desert Southwest, where you have warm temperatures but very low water availability, you have very low amounts of standing biomass in stems.

Slide 20. Stem Net Primary Production



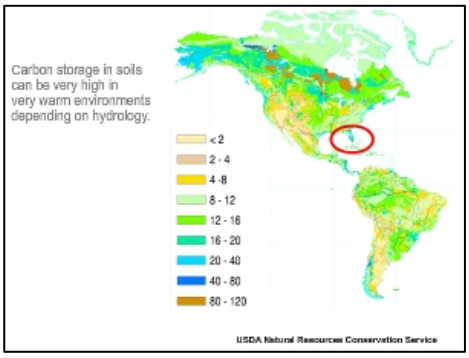
Looking at stem net primary production across the same area, you see a similar pattern wherein warm wet climates and in fertile places as well, like Central America on this figure, you see that you have high net primary production, so a lot of carbon is being produced every year. Again, in the desert Southwest you see real low amounts of net primary production, in part because water availability is so low there.

Slide 21. Soil Carbon



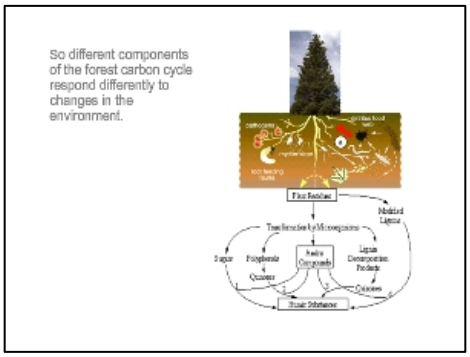
Soil carbon follows a slightly different pattern because of slightly different controls. So when you look at North and South America, you see high amounts of productivity in the Amazon Basin and low amounts of productivity in the desert Southwest, but the very highest amounts of soil carbon storage that you see occur in cold, wet climates in the northern half of this figure in northern Canada, where you have tremendous amounts of carbon stored in soils that are either saturated or frozen for a big part of the year.

Slide 22. Carbon Storage in Soils



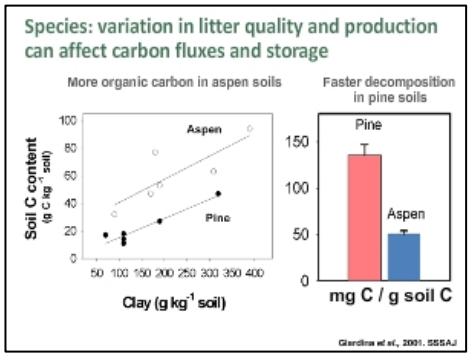
I want to emphasize that it's not a clean story and not an easy story, because if you go to Florida and you look at the lower part of the state, you actually have really high carbon storage in a warm system, and part of the reason for this high carbon storage is that it's inundated and wet, so moisture has a real important control on soil carbon accumulation and systems.

Slide 23. Different Components



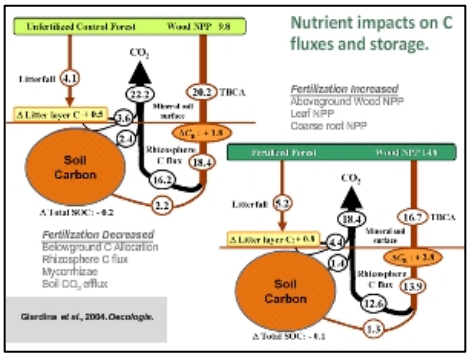
So the take home is that different parts of the ecosystem respond differently to variables, and changes in the environment are going to affect different carbon components of an ecosystem differently.

Slide 24. Species



I wanted to just touch on a little bit the species piece. There are some management opportunities with species that you can play with the species that are planted, or you can affect how regeneration happens on a site or reforest a site, and there are occasions when your selection of species will have an impact on both growth and carbon storage in soil. In this example is a study that we did in the Rockies. Aspen sites actually stored more carbon in soil, that's a figure on the left, but the carbon that was in soil also more quickly decomposed when it came from pine sites. So there are some potential for species to affect carbon process rates, fluxes, and storage.

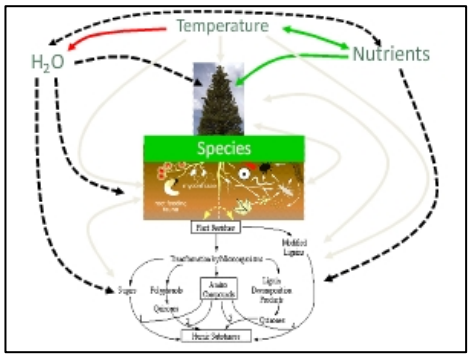
Slide 25. Nutrient Impacts on C Fluxes and Storage



There are also some potential impacts of management on ecosystems with regards to carbon fluxes and storage that have to do with nutrition or fertilization. In another study, this time in a eucalypt plantation in Hawaii, we found that when you add nutrients to the system, you increase aboveground wood net primary production, which is not surprising. Every forester who has gone through grad school or has worked in the field knows this, but you also had a pretty big increase in coarse root NPP[2] and you had a decrease in belowground carbon allocation, the amount of carbon that was sent belowground, the amount of carbon that moved through roots and the rhizosphere where mycorrhizae and bacteria do their thing, and this resulted in a decrease in soil respiration.

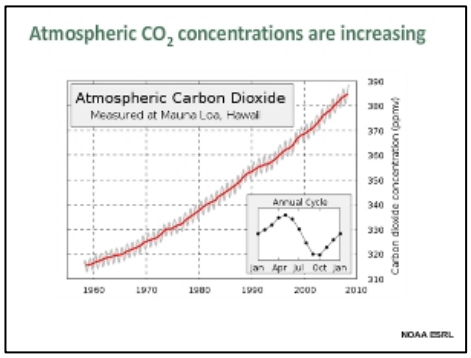
Slide 26. Intervention Points

So when we get back to this complicated figure and we think about all these interactions and how people can come in and tweak it, there are a number of intervention points for managers including species, including nutrition, and other things like spacing and stocking. But as we all know, these aren't the only variables that affect ecosystem fluxes of carbon and storage.



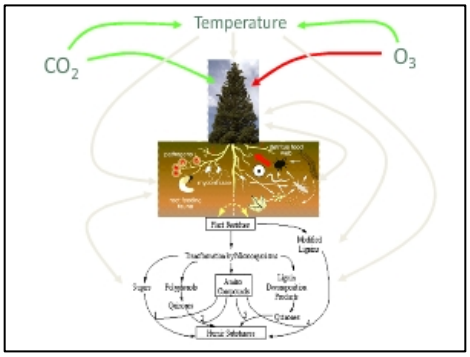
Slide 27. Atmospheric Carbon Dioxide Concentrations

We know that atmospheric carbon dioxide is increasing and these increases have effects on ecosystems.



Slide 28. More Variables

So we can throw more variables at this figure. CO_2 affects both temperature, but it has direct effects on plants. It can stimulate growth in some cases, but there are other gases in the atmosphere like ozone that are increasing, especially in industrialized areas, and ozone can have a negative effect on growth while having a positive effect on temperature, and it's not really clear how these two things can offset each other.

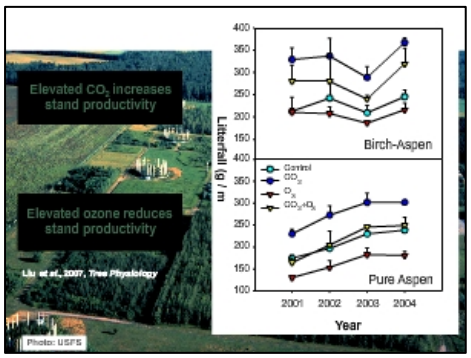


Slide 29. Aspen Free Air Carbon Dioxide Exposure

So I'm just going to take you to the last little bit here in the talk to northern Wisconsin where the Aspen FACE Experiment, the free air CO_2 enrichment exposes forest to both elevated CO_2 and ozone.

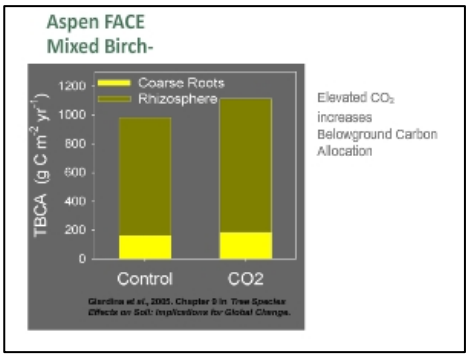
Slide 30. Graph: Aspen FACE Mixed Birch-Aspen

What we found in that experiment was that elevated CO_2 increases stand productivity, that's the blue dots in the top and bottom panel, and elevated ozone reduces stand productivity. In some cases the two cancelled each other as with Aspen, but in other cases where you had birch mixed in with the stands, elevated CO_2 seemed to buffer the effect of ozone.



Slide 31. Aspen FACE Mixed Birch

There was a similar effect belowground where elevated CO_2 increased belowground carbon allocation, and this showed up in both coarse roots and the amount of carbon that moved through the rhizosphere.

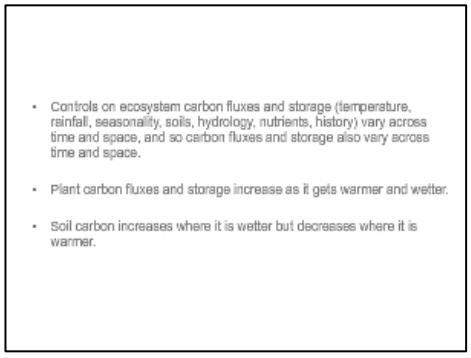


Slide 32. Take Home Messages

So I want to end here with some take home messages.

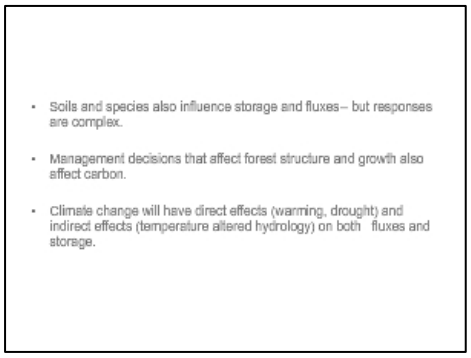
Slide 33. Take Home Messages

Controls on ecosystem carbon fluxes and storage, things like temperature and rainfall, vary across time and space and so do carbon fluxes and storage. Plant carbon fluxes and storage increase as it gets warmer and wetter. Soil carbon increases where it's wetter, but decreases where it's warmer, and there are exceptions.



Slide 34. Take Home Messages

Soils and species also influence storage and fluxes, but responses are complex. And then management decisions that affect forest structure and growth are also going to affect carbon. And finally, we need to keep in mind the climate change. You're going to have direct effects like warming and drought, and indirect effects like temperature-altered hydrology on both fluxes and storage.



Slide 35. Thanks

Thank you.

Footnotes

[1]ANPP=Annual Net Primary Production
[2]NPP=net primary production