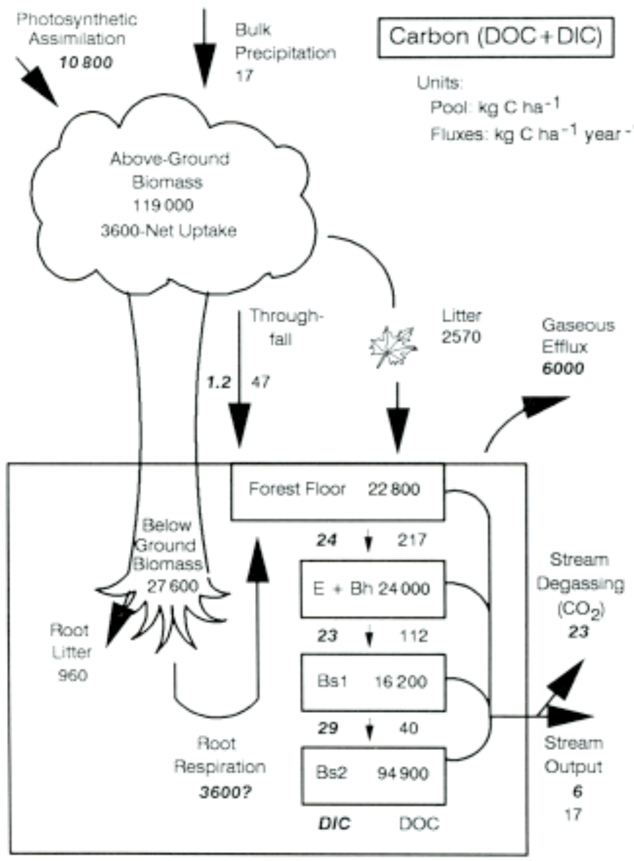
Ecosystem Carbon Budgets, Part 1

Background



Ecosystem ecology is concerned with the pools and fluxes of materials and energy, integrating both the living and nonliving components of natural systems. As such, ecosystem scientists have developed a variety of methods for measuring and estimating the components of these material and energy budgets, ranging from the primitive (e.g., harvesting and weighing biomass) to the positively high-tech (e.g., infrared gas analysis and satellite imagery). More often than not, no single method can be used to quantify the entire budget, so a variety of methods have to be collaboratively combined to coax the relevant quantities from the overwhelming complexity of natural ecosystems.

The development of carbon budgets for natural systems is especially important. Carbon is not only (by mass) the most common element in living things, when combined with hydrogen and oxygen to form sugars and lipids, it is also the main energetic currency of life. Thus, much of the action in ecosystems can be tracked by following the carbon. As you have learned, in terrestrial ecosystems, carbon is fixed from the atmosphere by autotrophic primary producers (e.g., plants) via photosynthesis, and it returns to the atmosphere through the process of respiration, which is used by all aerobic organisms to generate ATP – the energy transport molecule for most cellular processes.

Because ecosystems exchange carbon with the atmosphere, quantifying and understanding ecosystem carbon budgets is also a critical part of the science of climate change. Forest ecosystems, both wild and managed, are especially important in this regard, because trees, with their resilient but metabolically inert structural tissues, represent a potentially large pool of “sequestered” carbon, which is removed from the atmosphere as the plants grow, and is released back to the atmosphere only slowly (even over millennia) as the trees’ tissues decompose. Carbon sequestration by forests is an important component of many climate mitigation strategies and it will likely play an increasingly prominent role in the policy discussion as humans get around to addressing this most critically important environmental issue of our time.

However, even though trees represent a large carbon pool, measuring ecosystem carbon budgets is not as easy as just going out and weighing a few trees. Forest ecosystems are dauntingly complex, with a convoluted network of trophic interactions that all involve carbon transfer. In particular, decomposition processes in forest soils are a key part of the forest carbon budget, and some forest soils can contain as much carbon per square meter as the trees themselves. So quantifying soil carbon pools and fluxes, and the transfers of carbon from the plants to the soil, is very important.

Over the next three weeks, we will be investigating the carbon budgets of two nearby ecosystems on the BFEC: the hilltop eastern white pine (*Pinus strobus)* plantation and a riparian oldfield successional forest dominated by sycamore (*Platanus occidentalis).* We will estimate four carbon pools: aboveground carbon in live biomass, aboveground carbon in dead woody biomass, carbon in the forest floor, and mineral soil carbon. We will also measure two carbon fluxes on two very different time scales. First, based on patterns of growth recorded in the rings of the trees, we will estimate the live mass carbon increment of the trees. Finally, on a much faster timescale, we will directly measure the rate at which carbon is released from soil in the form of carbon dioxide (CO_2) via respiration.

QUESTIONS FOR YOUR CONSIDERATION:

- **Photosynthesis moves carbon from atmosphere to plants. Soil respiration moves carbon from biota back to the atmosphere. What processes move carbon from plants to the soil, i.e., what different paths can carbon take from leaf to soil?**
- **How else can carbon leave the soil?**
- **What fraction of a tree is carbon? Does this vary a lot between species? Between young and old trees?**

Study Design – Back Story

For this exercise, we will be taking advantage of a sort of ongoing natural experiment at the BFEC. In honor of Earth Day 1990, Dr. Thomas Jegla arranged for the Newark Audubon Society to donate 1,000 white pine seedlings to Kenyon College. Drs. Ray Heithaus and Kathy Van Alstyne supervised Kenyon students and community members in the planting of these trees on a hillside above the BFEC farmhouse. The trees were planted in two grids, distinguished by 10 and 15 foot spacing between seedlings. Then in the spring of 1992 students in the Experimental Ecology class measured the surviving trees and began a large-scale experiment by fertilizing half of the individuals in each spacing. From the Fall of 1992 to 2001 students in An Introduction to Experimental Biology continued data collection.

At around the same time (1994), two plots of BFEC land along the Kokosing River that had long been utilized for crop agriculture were removed from cultivation and allowed to undergo secondary succession. Early on, these fields were colonized by typical, early successional species, including goldenrods. Over time, more woody species began to colonize the sites, including ash-leaved maple, sycamore, cottonwood, multiflora rose, black cherry, and several oaks. The site we will be sampling lies between the Kokosing Gap Trail and the river, near the southeast corner of the BFEC property.

This project will require three weeks to complete, based on the following schedule:

1. Week 1 – Field sampling at the Pine Plantation site
2. Week 2 – Field sampling at the Sycamore site and Respiration set up
3. Week 3 – Laboratory tissue analyses and Budget calculations

Because the procedure (like the problem itself) is a complicated one, it is extremely important that you come to class prepared and ready to work in a focused manner. The complicated procedure also means that we are going to have to divide up our tasks and work collaboratively.

Sampling Procedure

Our forest inventory measurements will be based on those used by the USDA Forest Service as part of the Forest Inventory and Analysis Project, as adapted by Bradford et al. (2010) for carbon budget estimation. We will establish a circular plot 20 m in diameter using two tapes and an ultrasonic transponder. The plot will be divided in quarters along the east-west and north-south axes, and each quarter will be the responsibility of four student researchers. Within each quarter, we will collect data for the following:

1. **Aboveground tree biomass:** Measure the diameter at breast height (dbh) of each tree (> 2.5 cm dbh) and identifying it to species. Record if a tree looks dead.
2. **Understory woody biomass:** Measure diameter at 15 cm above ground and identify all woody seedlings, shrubs, and saplings (< 2.5 cm dbh) within a 3 m radius micro plot, centered 4.5 m N-S and 4.5 m E-W of the main plot center.
3. **Understory herbaceous biomass:** Collect all living plant matter (clipped to ground level) in a single 0.25 m^2 quadrat located 7 N-S and 7 m E-W of the plot center. Place it in a paper bag and label it.
4. **Forest floor biomass**: Collect all non-living organic material in the same 0.25 m^2 quadrats mentioned above, including the organic soil horizon and fine plant roots. **Separately bag and label the organic litter and soil fractions.**
5. **Mineral soil:** carbon will be measured in a mineral soil core sample taken from each quadrat after the forest floor material is removed. Place the soil core in a paper bag and label it.
6. **Downed woody biomass:** Search the quarter plot for any downed branches or trunks with a basal diameter > 5 cm. Record the species of the downed wood if possible.
7. **Tree coring for estimates of woody mass increment:** Take two increment cores from your quarter plot on your smallest tree > 5 cm dbh and the largest tree in your quarter plot. I will demonstrate the method.

Place the cores in the provided straws and label them.

Once we have collected all of the samples we will return to the lab to dry our materials for later analysis. Place all of the labeled paper bags in the drying oven in Higley 320, which is set to approximately 60° C.

IMPORTANT FOR NEXT WEEK: Select one member of your group to meet with me next Monday between 2 and 4 to weigh your dried samples and to prepare materials for the soil respiration component of our laboratory. You must confirm the appointed person with me before you leave.

Aboveground Biomass Calculations: Plant Allometry

Based on our measurements of trunk/stem diameter, we want to make estimates of plant mass, which we can then sum to find our total aboveground biomass, and from there, our estimates of aboveground carbon in woody material. We can make these estimates based on so-called *allometric* relationships between trunk cross-sectional area and tree mass. In general, the relationship takes the form

$$M = aD^b,$$

where *M* is tree mass (kg), *D* is diameter (either dbh or at 15 cm for shrubs, in cm) and *a* and *b* are parameters from a regression line relating log *M* to log *D*. Such power-law relationships provide a very useful tool for biomass estimation, but more generally they are used in many areas of biology to estimate (and try to understand) how the properties of organisms are related to their size (or some other important, component measure).

Jenkins et al. (2003) provide a wealth of information and parameter sets for different types of tree species. Note that their parameters are based on rearranging the above equation algebraically to yield.

$$M = \exp(\beta_0 + \beta_1 \ln D)$$

and the parameters are β_0=ln(a) and β_1=b from the first equation. For shrubs, Grigal and Ohmann (1977) provide parameter estimates for a and b for a variety of forest shrub species.

Before you leave today, you need to calculate the aboveground woody biomass for the plot, based on these equations. The papers are available online.

Supplemental references (Online)

Bradford, JB. et al. 2010. Carbon pools and fluxes in small temperate forest landscapes: Variability and implications for sampling design. Forest Ecology and Management 259: 1245-1254.

Jenkins, JC et al. 2003. National-scale biomass estimators for United States tree species. Forest Science 49:12-35.

Grigal, DF and LF Ohmann. 1977. Biomass estimation for some shrubs from northeastern Minnesota. USDA Forest Service Research Note. North Central Forest Experiment Station. St. Paul, MN.