

OUR FORESTS AND THE GLOBAL CARBON CYCLE

by William Schuster

Humans have substantially perturbed the Earth's carbon cycle, mainly through a massive increase in the rate of carbon input from geologic reservoirs into the atmosphere via the combustion of fossil fuels. The resultant rise in atmospheric carbon dioxide from about 280 to 350 parts per million (ppm) has begun to initiate changes in plant growth, climate patterns, and the cycling of elements other than carbon. Even as our societies plan ways to slow this increase, CO₂ levels are expected to rise to at least 500 ppm in the foreseeable future. The Earth's biota collectively control and regulate the carbon cycle; for example, plants consume one seventh of the atmosphere's CO₂ each year. Thus, they not only react to the changes we cause but also at the same time exert substantial controlling influences.

It is perhaps under appreciated that our forests have been helping to slow the rate of atmospheric CO₂ increase in this century. This is due to the fact that the bulk of our northern temperate zone forests have been recovering and regrowing from very heavy logging that occurred during the nineteenth century. They therefore have been a substantial sink for anthropogenically produced CO₂, and likely repositories for some of the "missing" carbon in global balance equations. Although modelers have estimated the magnitude of carbon sequestration due to forest regrowth, our failure to balance the global carbon cycle has brought into question the accuracy of these estimated parameters. Such uncertainties hamper our ability to confidently predict future changes and responses to the world's biota and climate.

The magnitude of annual carbon sequestration in forests and its rate of change over time are critical parameters. More empirical studies are needed, particularly studies that can help identify factors that control temporal variations in carbon storage rates.

A Relationship Between Forest Age and Carbon Storage

Changing rates of temperate forest carbon storage are critical because we expect less annual carbon storage as forests mature, potentially leading to more rapidly increasing atmospheric CO₂. Biomass is expected to accumulate in aggrading forests for centuries, or until ecosystem respiration finally reaches a level equivalent to carbon fixation from photosynthesis. But there are inadequate empirical data to accurately project the decline in carbon storage rates as forests mature, particularly in the later stages of forest succession. Similarly, we have an imperfect knowledge of what factors regulate forest biomass accumulation and which, if any, of these factors may be successfully manipulated. Some well-studied forests, such as the Hubbard Brook forest in the White Mountains of New Hampshire, have apparently reached a state of zero net carbon accumulation in less than a century of regrowth. Others, such as portions of the Harvard Forest in Massachusetts, are continuing to aggrade at measured rates of up to 4 metric tons of carbon per hectare each year. This disparity highlights our need for more studies over a larger area and a longer timespan to fully understand the carbon dynamics of regrowing forests and decipher implications for the future.

Experimental Studies at Black Rock

The Black Rock Forest in the Hudson Highlands of New York represents one good location for such studies. The forest communities are typical of those from the large eastern oak-hickory region that stretches from the southern Appalachians into southern New England. Heavily logged and cleared during the past century, they were incorporated into a forest preserve early in the 20th century and have been regrowing since. In 1930, the Black Rock Forest's management established a series of long-term experimental growth sites dispersed throughout Black Rock's 1,500 hectares. A pair of plots were established at each site. One was lightly thinned to favor certain desirable tree species while the other was left as an unmanipulated control. Dominant trees at the time averaged 40 years of age. Forest regrowth, including all regeneration and mortality, has been measured every five years since, providing a robust dataset of forest regrowth over nearly seven decades.

In 1993, we set out to re-examine all of these plots and quantify the resultant rates of carbon sequestration. Several plots had been manipulated in the intervening years, primarily areas of above-average tree growth where some of the largest trees had been harvested. But eight plots remained completely unaffected. Measuring the size of each remaining tree on these plots and using a series of regression equations developed by ecologists and foresters, we quantified the carbon content of these stands. We remeasured the trees each year for five successive years to accurately gauge the modern trends in carbon storage rates.

Patterns Uncovered

Results that initially appeared disparate revealed, after analysis, some consistent patterns (*Figure 1*). The data clearly document steady carbon storage over seven decades interrupted by three periods of stasis or even loss of carbon. The first period of reduced carbon storage was between 1945 and 1955. The excellent long-term climate record at nearby West Point, New York fails to indicate climatic reasons for this period of slow growth. However, an insect infestation that attacked chestnut oak trees in particular may explain the downturn.

More rapid growth then resumed until the mid-1960's when the most significant drought in the nearly 200-year record of precipitation was recorded at West Point. Almost no net carbon was gained on these plots between about 1964 and 1968 due to the combination of slow tree growth and outright mortality. Then growth (and carbon storage) rebounded on nearly all plots until 1981, when gypsy moth caterpillars caused forest-wide tree defoliations. The 200+ year tree-ring record from eastern hemlocks showed this as the single slowest period of diameter growth. Chestnut oak trees showed a significant growth reduction as well.

Five of the eight plots lost biomass between 1981 and 1985. However, since that time forest regrowth has rebounded and the stands continue to store carbon to this day. Thus it appears that despite differences in site, species composition and age, factors such as climate and insect outbreaks exert regional controls on carbon storage rates.

What Has Been Learned...

The long-term effects of the 1930 forest thinning experiment include carbon storage rates that are 10% greater on thinned plots over 70 years. The results are only marginally statistically significant due to the number of plots. But it must be recognized that actively thinning these plots did not really increase net carbon storage. Instead, the bulk of the wood removed was sold and burned as firewood, directly adding carbon to the atmosphere.

The data also suggest that manipulating species composition can have effects on carbon storage rates. Over a long period of time under the same conditions, red oaks store more carbon than white oaks. Sugar maples store more carbon than red maples. Black birch trees often decline in carbon storage after age 50, while yellow birches often accelerate in growth rate.

These results suggest that active forest management in temperate forests can be used as a technique to manipulate carbon sequestration. However, one must keep in mind the many simultaneous effects that can occur. For example, it would be foolhardy to decimate old growth forests simply to try to increase carbon storage rates. In addition to the energy expended in the process, other factors to be considered are the loss of carbon in the processing of the logs and decomposition of the tops, the risk of unsuccessful forest regeneration, the loss of old growth habitat and reduction of biodiversity, changes of hydrologic balance and microclimate, aesthetic considerations, and other environmental effects of logging practices.

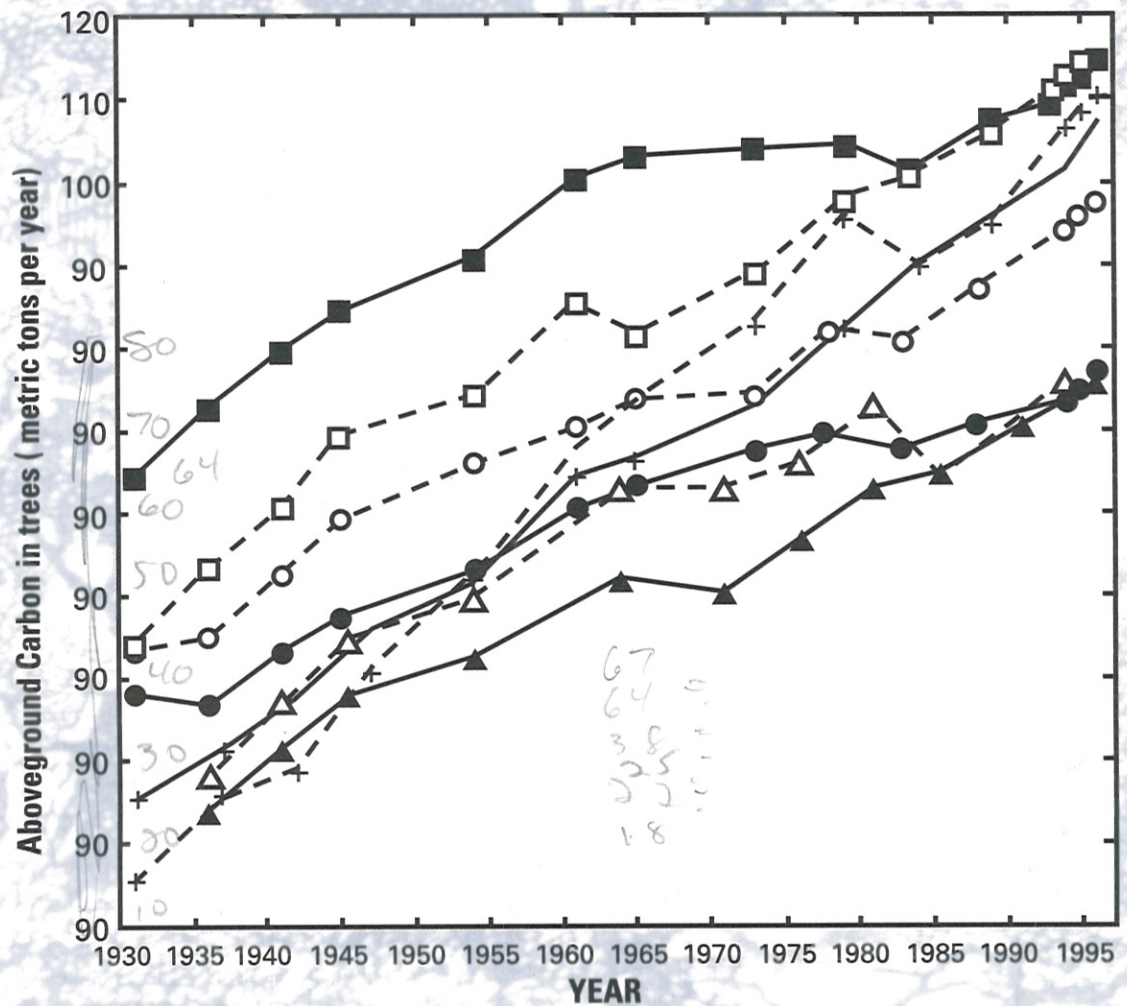
Can Be Applied to the Future

The prognosis for the future is that carbon storage will probably decline over time in most forests that have already reached a century of regrowth. Average storage rates on the Black Rock Forest plots are now just under 1 metric ton per hectare per year, about 25% less than they were during the 1930's. However one pair of plots shows unreduced carbon storage continuing to this day. Preliminary data suggest that these may be located on above-average sites for tree growth with slightly less acidic soils that have a greater water holding capacity. Apparently continued high productivity and storage may be obtainable in some areas. There is an intriguing possibility that under these site conditions the trees are growing faster due to the input of nitrogen from acid rain or a from a positive feedback associated with rising atmospheric CO₂. The possibilities demand further investigation. As usual, our studies have produced some potentially useful information but we have much more to learn.



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Carbon sequestered over 65 years on eight forest plots
Black Rock Forest, New York



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