THE MAGNITUDE AND PERMANENCE OF FOREST CARBON SINKS

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The magnitude and permanence of forest carbon sinks

Forests contain about 45% of the global stock of carbon. A sustainably managed forest, comprising stands representing all stages in the life cycle, operates as a functional system that maintains an overall carbon balance, taking up carbon dioxide (CO_2) from the atmosphere, retaining a part of the carbon in the growing trees, transferring another part into the soils, and exporting carbon in forest products. On a time scale of tens of years, most forests accumulate carbon through growth of the trees and increase in the soil carbon reservoir, until major disturbance occurs. Recently disturbed and newly regenerating areas lose carbon, young stands gain carbon rapidly, mature stands gain carbon at a lesser rate, and over-mature stands may lose carbon. In a forest managed sustainably with all components of the life cycle equally represented, the standing stock of carbon in the trees would be constant with time, whilst carbon continued to accumulate in the soil.

However, few forests around the world are managed sustainably in this way. In reality the age structure of the population of trees, of stands or of compartments comprising a forest is skewed as a result of over-exploitation and bursts of planting. Furthermore, it seems that not even the long-lived, mature forests are in a state of equilibrium, but rather are going through a period of transition as particular processes in the carbon and nutrient cycles experience transient responses, on different time scales, to the already entrained climate change

There is little doubt that forests plantations created since 1990 in afforestation and reforestation programmes, in accordance with Article 3.3 of the Kyoto Protocol, will be taking up increasing amounts of carbon dioxide, growing strongly, and adding to the terrestrial store of carbon, in the immediate future and probably over the next 50 years.

More controversial, however, are the size and permanence of the existing carbon sinks in older plantations, established in the 19^{th} and 20^{th} centuries, and in the long-lived semi-natural and natural forests around the world, particularly in the tropics. These questions are of great relevance to attempts to resolve uncertainties in the open-ended Article 3.4 of the Protocol. Recent continuous measurements of net exchange of CO_2 by over 70 such forests, some now extending over more than five years, have demonstrated that these forests are sequestering up to six tonnes of carbon per hectare each year. At the present time only three or four of these 70 plus forest stands, have been shown to be consistent carbon sources over several years. These observations give rise to two key questions. Firstly, why are almost all these forests carbon sinks at the present time; and secondly, are they likely to continue as sinks into the future as climate changes. The answers to the first question are key to projections with respect to the second.

The results from CO_2 fertilisation experiments lasting several years on young trees of very many different species with unrestricted rooting, suggest that the ongoing rise in atmospheric CO_2 concentration is at least in part responsible for the almost ubiquitous observations of current forest carbon sinks. Such experiments with nutrient fertilisation as an additional variable indicate, in general, that addition of nitrogen greatly enhances the results of fertilisation with CO_2 and suggests that increasing atmospheric deposition of nutrients is also partly responsible for current carbon sinks in mature forests. Thus, recent observations that the additional carbon sink resulting from CO_2 fertilisation of pole stage stands of pine is transitory or small on low or moderate fertility sites, but is considerably enhanced by nutrient fertilisation, are not unexpected. None the less, interpretation of transitory responses to CO_2 fertilisation treatment of stands of pole-stage trees after just four years should, however, be treated with caution. It will take many years for the feedbacks between the carbon and nitrogen cycles to be expressed and for the forest ecosystem within FACE rings to acclimate fully to the treatments imposed.

If that is the case, why should we not expect the present carbon sinks to continue and indeed to increase as atmospheric CO_2 concentration and nutrient deposition increase over the next 50 years? The third element of climate change, following-on the rise in atmospheric CO_2 concentration, is the projected increase in global temperature. It is widely supposed, on the basis of very many short-term experiments, that oxidative processes associated with respiration by the trees themselves both above and below-ground (autotrophic respiration) and by micro-organisms in the soil (heterotrophic respiration) will increase in rate very rapidly as temperature increases. It is hypothesised that the rise in temperature will, therefore, lead to return of CO_2 to the atmosphere at an ever-increasing rate, offsetting and ultimately completely negating the carbon sequestration resulting from CO_2 and nitrogen fertilisation. Whilst temperature is certainly a driver of respiration, this attractive, simple hypothesis, is not in accord with results from recent experiments. The rate of autotrophic respiration also depends strongly on the availability of substrate (starch, sugars, polyols) and thus adjusts in relation to the carbon input through photosynthesis. Cutting off the input by darkening the leaves or girdling the stem, for example, leads to dramatic reductions in CO_2 emission from leaves and roots, respectively, i.e. CO_2 emission is closely coupled to CO_2 input on comparatively short time scales of days to weeks. A recent forest experiment demonstrated that soil respiration was halved as a result of girdling plots of pine trees, the first reductions being evident after just a few days. Similarly, the rate of 'soil' respiration' has been found to acclimate to experimentally induced increase of 5 °C in soil temperature through the growing season, so that after four years of treatment the rates of CO_2 emission on the heated and unheated plots are now similar. Furthermore, the stem volume growth of the trees on the unfertilised heated, plots is increasing at up to 80% per year. It is clear that major uncertainties exist in our understanding of these interactions; these are certainly transient responses between processes linked by feedbacks, the outcomes of which are hard to predict with present knowledge. None the less, models that associate a carbon and nitrogen cycle and take into account likely feedbacks amongst nutrient availability, CO_2 concentration and temperature project a steady forest carbon sink for 100 or more years to come.

Changes in the global distribution of rainfall is a fourth component of climate change that is likely to have dramatic effects on the existing carbon sinks over the next 50 years. Current annual carbon sequestration by forest stands in regions of Mediterranean climate is at the bottom end of the range cited above. A number of experiments have demonstrated that the additional carbon sink induced by CO_2 fertilisation in such conditions is very constrained by the availability of water and can be considerably enhanced by irrigation (analogous to the enhancement of the additional CO_2-induced carbon sink by nutrient fertilisation). However, much more dramatic effects are projected to occur over extensive areas, notably the Amazon basin, as a result of projected substantial reduction of the present abundant rainfall. If trees, stands and eventually the forest die, as the result of reduction of rainfall, then such existing carbon sinks will certainly become sources.

Forests are removing significant amounts of CO_2 from the atmosphere at the present time and will continue to sequester carbon. Our interest in carbon sequestration by forests as a means of mitigating global climate change is essentially focussed on the next 50 years. The emission of CO_2 to the atmosphere through the consumption of fossil fuels, and the consequent rise in atmospheric CO_2 concentration, is proceeding at such a rate that the mitigating action of forests is constantly decreasing in relation to the size of the problem. Unless checked at source within this period, the outlook is bleak.