Full Carbon Analysis for Forestry—Rethinking some Fundamentals

By Kit Nicholson

Forests are often presented as the lungs of the planet, sequestering large amounts of CO_2. Sadly for lovers of forests, this is incomplete and misleading. Mature natural forests on drained soils exist in 'carbon equilibrium', breathing out as much carbon through decomposition as they breathe in through photosynthesis. Only in wetlands is there a significant net accumulation of carbon. But in wetlands, the accumulation of soil carbon is at least partly offset by some methane emissions and the net carbon impact is unclear.

IPCC guidelines require all the carbon content in felled forest to be included as emissions. But felling forests allows regrowth, during which time sequestration is higher than decomposition, and some of the carbon stock is safely sunk in timber. Thus, the extraction of timber from forests has a positive net impact on carbon balance, not a negative one. By extracting timber selectively from mature forests it is possible to obtain this carbon benefit, whilst also retaining most (but not all) the biodiversity benefits.

Forests are often presented as the lungs of the planet, but the analysis of their role in global carbon rarely considers that they breathe out as well as in. If forests are such impressive carbon sinks, where is all the carbon going? Mature natural forests have reached an equilibrium and there is very little net growth in biomass: the growth of younger trees is matched by the death and decomposition of older trees.

Evidence on carbon sequestration has focused on above-ground biomass. This evidence shows that there is a wide variety of circumstances within forests (Thompson and Matthews 1989, IPCC 2006, Aragao, Malhi et al. 2009, ITTO 2009). The Intergovernmental Panel on Climate Change (IPCC) guidelines suggest that mature tropical rainforests contain about 300 tDM/ha[1] biomass above ground and growth is about 3 tDM/ha[2]. According to the IPCC tables, below-ground biomass is 37% of above-ground biomass in tropical rainforests and is between 20% and 30% for other mature natural forests. Temperate forests have lower stocks, but similar growth rates. Plantation forests have lower stocks and higher growth rates.

Research evidence on decomposition and on the carbon stored in dead wood and litter is limited. The IPCC guidelines suggest that, in mature natural forests, it should be assumed that these stocks are stable and that the new supply of leaves and dead timber is matched by decomposition. Some of this decomposition involves direct emissions of carbon to the atmosphere. Some becomes part of soil organic matter, which may be assumed to contain roughly 58% carbon. For tropical rainforests, an average estimate of the stock of soil organic carbon is about 290 tC/ha (Jobbagy and Jackson 2000). Forests in more temperate climates may have between 40% and 70% of these levels of carbon.

Soil organic matter is subject to a process of decomposition within the soil. Where soils are well drained and have free access to oxygen, the decomposition is aerobic and results in the formation of CO_2. If oxygen is limited, typically because soils are wet, then at least part of decomposition is anaerobic and results in the production of methane (CH_4). Part of this CH_4 is oxidised into CO_2 before leaving the soil (Kane, Chivers et al. 2012). The IPCC guidelines suggest standard emissions from drained forest soils of 1.36 tC/ha for tropical forest, which roughly matches the suggested assumptions for forest growth of 3 tDM/ha. The IPCC assumptions therefore suggest that there is no net accumulation of carbon in the forest.

Long-Term Carbon Accumulation in Forests. It is not practical to measure directly the accumulation of carbon in forests because of the variety of observations that would be required and the length of time over which the processes take place. However, it is possible to deduce the net accumulation from the stocks of carbon in the soil and the long-term history of rainforests. If mature forests were making a net contribution to carbon balance, then the only place where this carbon could be accumulating would be in the soil, since the living biomass, above and below ground, is stable. However, forests are typically found on thin soils, except in some cases where wet conditions have led to deep peat soils.

If all the growth of tropical forests (ie 3 tDM/ha, according to IPCC guidelines) accumulated in the soil, then the depth of the soil should increase by about 0.2 mm/year[3]. This increase would also apply to temperate forests, since the typical dry matter growth is similar to that in tropical forests. There is some evidence that most tropical rainforests have been in existence at least since the Eocene period, about 30 to 50 million years ago, with some changes in species composition, depending on changes in climate (Burnham and Johnson 2004). If the forest dry matter had been accumulating in the soil for this period, the soil should be over 1km thick. It is possible to speculate about the possibility of periods of dramatic changes, such as extreme flooding and soil erosion, that could explain occasional destruction of soil, but the paleobotanical evidence appears to suggest strong continuity of vegetation, which is not consistent with dramatic change. Thus, it seems clear that, over the long term, there is little or no net accumulation of carbon in mature natural forests. This observation is not new and has been presented in diagrammatic summaries of carbon fluxes (Morison, Matthews et al. 2012).

Unlike dry forests, wetland forests do build up stores of carbon in peat soils, which can be many metres deep and can have high carbon content throughout the full depth of the soil. Wetland forests also exhale, and some of the carbon they exhale is in the form of CH_4, and so has a larger global warming impact (Kane, Chivers et al. 2012). They also sequester permanently some carbon within the peat. The relative role of the CH_4 emissions compared with permanent carbon sequestration in soils is unclear, although there is some suggestion that CH_4 emissions are low (Yavitt, Lang et al. 1990). From the perspective of carbon management, the importance of minimising decomposition applies in wetland forests as well as in dryland forests. However, of even greater importance is the need to avoid disturbing the soil in a way that could risk accelerating the emissions from the soil. In particular, the soils should not be drained to allow aerobic decomposition or, in the worst case, combustion.

Managed Forests. The contribution of forests to carbon balance is determined not by the rate at which forests are sequestering carbon, but by the rate at which forest management can decrease decomposition by extracting mature trees and using those trees for purposes that lock up the carbon in timber. The rate at which decomposition is reduced depends on the volume of timber extracted and the use to which the timber is put.

Merchantable timber typically accounts for about 50% of the above ground biomass in mature forest (IPCC 2006, Morison, Matthews et al. 2012). When this timber is harvested for construction, the carbon is stored so that emissions from decomposition are delayed for a period of perhaps 100 years, which extends beyond current climate change projections. Branches account for the majority of the remaining above-ground biomass, with leaves accounting for a small fraction. Where the branches are used for firewood, then they displace the need to use fossil fuels and thus contribute to greenhouse gas savings. If timber is used for furniture, it is also stored and delays emissions, but this is typically for shorter periods of perhaps 20 years. Timber used for furniture is often recycled for other purposes or burned as firewood, thus contributing to reduced greenhouse gas emissions from fossil fuels.

There are two main approaches to extracting timber from mature natural forests: the first is to clear-fell and replant with plantation forests; and the second is to extract timber selectively, taking out mature trees to maximise the growth of the forest. Both approaches ensure that no dead wood reaches the forest floor and thus minimise the emissions. This paper does not consider the implications of higher rates of soil erosion associated with clear-felling, which can be much more important than the sequestration and decomposition considered in the paper. The IPCC guidelines show that plantation forests have substantially higher growth rates than mature natural forests, but only when they use fast-growing species, like Eucalyptus and Pines. For mixed deciduous rainforest, there is no evidence that clear-felling and replanting generates higher growth rates than selective extraction of mature trees. Furthermore, the IPCC tables refer to the average growth rates in unmanaged natural forests, and selective harvesting should result in a substantial increase in average growth. The clear-felling option is likely to be cheaper, but involves much greater disruption to biodiversity.

Conclusions. It is vital to consider the whole carbon cycle when analysing the impact of land use on carbon balance. Most natural forests make little net contribution to global carbon, because sequestration is roughly matched by emissions from decomposition. In wetland forests, there may be some net sequestration, depending on whether the accumulation of carbon in peat is greater than the increased emissions arising from the fact that a part of the carbon is emitted as methane.

Unlike natural forests, managed forests do make a positive net contribution to carbon balance, because some decomposition is delayed by timber extraction. These carbon benefits can be achieved by the selective harvesting of mature timber in natural forests or by clear-felling and replanting with plantation trees. From a carbon perspective, plantations with fast-growing species make a higher contribution to carbon balance than selective harvesting.

Human intervention in managed land uses does create the possibility of improving the net carbon impact of the land use. In some cases, the harvesting of high-value products improves both the physical productivity of the land use and the carbon impact, since productivity is linked to carbon sequestration and the harvesting of products can reduce decomposition. There are some dangers that this intervention can lead to concentrated emissions from more powerful greenhouse gases, including methane. But these need to be measured carefully and may be less alarming than initially feared.

The full analysis of the whole carbon cycle tends to lead to lower estimates of the net carbon impact of different land uses, because, when viewed from the full carbon cycle, most land uses are close to a stable equilibrium. This means that it is more important to consider the impact of shifting from one land use to another, and the gains and losses in carbon stocks that can be achieved. These gains and losses are one-off changes, but they are often much larger than the net annual carbon impact of established land uses and take many years to happen[4] and so can make larger contributions to annual changes in carbon balance than differences in the annual net impact of established land uses.

Most valuations of forest benefits suggest that the biodiversity benefits are much more valuable to society than any benefits associated with carbon sequestration, even when these sequestration benefits are incorrectly based on sequestration without considering that decomposition will offset it. These biodiversity benefits are mostly lost by clear-felling, even when this is followed by natural regeneration or replanting of natural forest species. Thus, although clear-felling and plantation forestry are more productive from a carbon perspective (as well as from an economic perspective), the optimal policy is one of managed natural forest, in which some selective timber extraction provides economic benefits and carbon benefits, whilst also safeguarding most of the biodiversity benefits. But, even with careful selective timber extraction, there will still be some loss of biodiversity and there will always be an important role for large areas of protected natural forests that safeguard biodiversity, even though they make little or no contribution to carbon balance.

Decisions about agricultural land use are dominated by economic considerations and the net carbon impact is typically a minor factor that accounts for less than 5% of the economic value of production, even when valued at high carbon prices. However, it has become common to consider the carbon impact of agricultural land use, and this is likely to become more important as the world moves towards more sustainable energy use and the carbon balance of land use becomes more important. It is therefore essential that the analysis of carbon impact of land use considers the whole carbon cycle.

[1] tDM/ha = Tonnes of dry matter per hectare; tC/ha = tonnes of carbon per hectare; tWM = Tonnes of wet matter

[2] Conversion factors depend on the nature of forest and tree species. Convenient standards are: 1 tDM = 1.4 tWM = 2.3 m^3 wood = 1.3 m^3 timber = 0.45 tC = 1.62 tCO_2e

[3] Assuming a soil density of 1.5 tDM/m3

[4] For example, the IPCC recommends using a default period of 20 years for establishing changes in soil carbon levels following a change in land use

References

- Aragao, L. E. O. C., Y. Malhi, D. B. Metcalfe, J. E. Silva-Espejo, E. Jimenez, D. Navarrete, S. Almeida, A. C. L. Costa, N. Salinas, O. L. Phillips, L. O. Anderson, E. Alvarez, T. R. Baker, P. H. Goncalvez, J. Huaman-Ovalle, M. Mamani-Solorzano, P. Meir, A. Monteagudo, S. Patino, M. C. Penuela, A. Prieto, C. A. Quesada, A. Rozas-Davila, A. Rudas, J. A. S. Jr. and R. Vasquez (2009) "Above- and below-ground net primary productivity across ten Amazonian forests on contrasting soils." Biogeosciences, 6, 2759–2778.
- Burnham, R. J. and K. R. Johnson (2004) "South American palaeobotany and the origins of neotropical rainforests." Phil. Trans. R. Soc. Lond. B 359, 1595–1610.
- IPCC (2006) "Guidelines for National Greenhouse Gas Inventories: Volume 4 Agriculture, Forestry and Other Land Use."
- ITTO (2009) "Encouraging industrial forest plantations in the Tropics."
- Jobbagy, E. G. and R. B. Jackson (2000) "The Vertical Distribution of Soil Organic Carbon and its Relation to Climate and Vegetation." Ecological Applications, 10(2), 2000, pp. 423–436.
- Kane, E. S., M. R. Chivers, M. R. Turetsky, C. C. Treat, D. G. Petersen, M. Waldrop, J. W. Harden and A. D. McGuire (2012) "Response of anaerobic carbon cycling to water table manipulation in an Alaskan rich fen."
- Morison, J., R. Matthews, G. Miller, M. Perks, T. Randle, E. Vanguelova, M. White and S. Yamulki (2012) "Understanding the carbon and greenhouse gas balance of forests in Britain."
- Thompson, D. and R. Matthews (1989) "The Storage of Carbon in Trees and Timber." Forestry Commission Research Information Note 160.
- Yavitt, J. B., G. E. Lang and A. J. Sexstone (1990) "Methane fluxes in wetland and forest soils, beaver ponds, and low-order streams of a temperate forest ecosystem." Journal of Geophysical Research: Atmospheres 95(D13): 22463-22474.

Mokoro Ltd, The Old Music Hall, 106-108 Cowley Road, Oxford, OX4 1JE, United Kingdom Telephone: +44 (0)1865 403 179 mokoro@mokoro.co.uk