COMMENTARY:

# A role for tropical forests in stabilizing atmospheric $CO_2$

R. A. Houghton, Brett Byers and Alexander A. Nassikas

**Tropical forests could offset much of the carbon released from the declining use of fossil fuels, helping to stabilize and then reduce atmospheric $CO_2$ concentrations, thereby providing a bridge to a low-fossil-fuel future.**

A 35-year transition from fossil to renewable fuels may be possible[1], but fossil fuel emissions continue to rise. The world's largest emitter, China, is not committing to peak carbon emissions until 2030, and among developed countries, very few are aiming to end fossil fuel use by 2050. Thus, it is unlikely that fossil fuel emissions will fall in the next decade, or that they will fall by more than 80% by 2050. More likely, emissions from fossil fuels from 2015 to 2050 will exceed 250 Pg C, resulting in cumulative carbon emissions of over 400 Pg C between 2000 and 2050, and a greater-than-50% chance of exceeding a global warming of 2 °C (ref. 2). So are we already committed to a warming of 2 °C or greater? Not necessarily — absorption of carbon by tropical forests could offset much of the release of fossil fuel carbon between now and 2050, thus stabilizing and then reducing the $CO_2$ concentration in the atmosphere within just a few decades, and providing a bridge to a fossil-fuel-free world.

Absorption of carbon by tropical forest management is not the solution to climate change. It may be part of the solution[3], but the potential for accumulating carbon in the world's forests and soils is small relative to the amount of carbon in coal, oil and gas reserves[4]. For example, the total loss of carbon from land as a result of human activity over the past centuries has been 200–300 Pg C (ref. 5), and even if all of this loss were to be recovered through reforestation, the uptake of carbon would be far from sufficient to offset unabated long-term use of fossil fuels. Further, the current net emissions of carbon from tropical deforestation and degradation account for as little as 8–15% of total annual carbon emissions, and that percentage has declined as fossil fuel use has continued to increase[6,7,8].

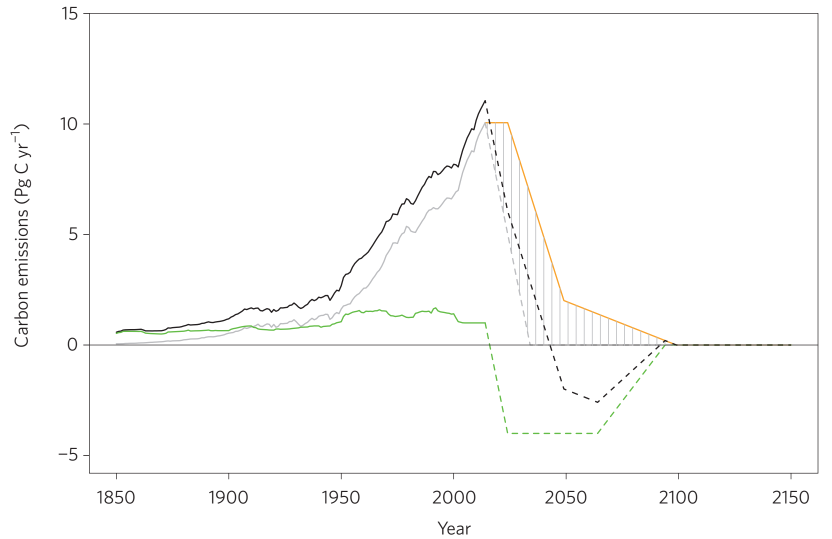


**Figure 1 |** The potential role for tropical forest management in stabilizing atmospheric $CO_2$. Annual emissions of carbon from fossil fuels (solid grey line) and tropical forest management (solid green line), and total carbon emissions (solid black line), are plotted for 1850–2015. From 2015, the total emissions that are required for a 75% likelihood of avoiding warming in excess of 2 °C (dashed black line) are shown. The dashed grey line represents the fossil fuel emissions if this likelihood is achieved by fossil fuel changes alone. The orange line represents the emissions from fossil fuels if simultaneous changes in forest management are implemented (dashed green line). The hatched area represents the effect of tropical forest management on carbon emissions mitigation. Negative emissions represent the removal of carbon from the atmosphere.

The conclusion that forest conservation and restoration is largely irrelevant for mitigation is incorrect, however, for two reasons. First, the relatively small net emissions of carbon from forest management hide a greater potential for carbon storage. Gross emissions from forest management are two to three times greater than net emissions[9], suggesting that enhancing carbon uptake and reducing emissions could account for as much as 50% of total carbon emissions. Second, changes in land management can be implemented more quickly than the transition from fossil to renewable fuels.

To achieve a 75% likelihood of avoiding warming in excess of 2 °C through changes in fossil fuel emissions alone, such emissions would have to be eliminated over the next 20 years or less (Fig. 1). In contrast, the same likelihood could be achieved if, first, tropical forest management removed

5 Pg C $yr^{-1}$ from the atmosphere, phased in linearly over the next 10 years, and, second, fossil fuel emissions were held constant for the next 10 years and then reduced linearly to a level equal to 20% of 2014 emissions by 2050 before further linear reduction to zero by 2100. In this latter case, the cumulative reduction in net emissions over the next 50 years from fossil fuel use versus from forest management would be roughly equal.

This estimate for the potential of forest management to remove carbon from the atmosphere is based on the gross sources and sinks of carbon associated with three types of forest management in the tropics[7,10]. First, deforestation and degradation of forests in tropical regions currently release about 1 Pg C $yr^{-1}$ (and by some estimates, twice that amount). If deforestation and degradation were stopped, those emissions would cease. Second, carbon is accumulating in secondary forests recovering from harvests and from swidden agriculture at rates as high as 3 Pg C $yr^{-1}$. This gross rate of uptake is taking place now. If the associated gross emissions from harvests and re-clearing of fallows were stopped, the accumulation of up to 3 Pg C $yr^{-1}$ in growing forests would continue for decades before declining as the forests mature. A third activity, more challenging than the first two because of higher costs per hectare, would be the re-establishment of forests on lands previously forested but not currently used productively. Estimates of the areas available for reforestation vary[11,12], but re-forestation of 500 million hectares could sequester at least 1 Pg C $yr^{-1}$ for decades. Together, the three activities would reduce total emissions by as much as 5 Pg C $yr^{-1}$ (a reduced source of 1 Pg C $yr^{-1}$ and increased sinks of 4 Pg C $yr^{-1}$). The rate of carbon accumulation in forests diminishes as forests mature, however, and thus the 4 Pg C $yr^{-1}$ sink would last, conservatively in our analysis, for approximately 50 years (to 2065) before declining linearly to zero by 2095 (Fig. 1). As the large trees containing most of the above-ground forest carbon tend to be absent in degraded forest (as they are sought after in selective logging), and large trees can take well over a century to mature fully, the absorption is likely to continue at a high level well beyond a 50-year period[13]. Even if the re-forestation of 500 million hectares was not undertaken, less-conservative assumptions on how long the remaining 3 Pg C $yr^{-1}$ sink would continue yield similar results.

We recognize that implementation of these strategies has political and economic challenges, not least as current management of tropical forests is responsible for net emissions of carbon, not a net uptake. We focus on tropical forest management because they are currently the dominant net source of terrestrial carbon to the atmosphere and hold large stores of carbon in their biomass. Indeed, estimates of the sum of above- and below-ground carbon (that is, peat) within tropical forests are greater than 500 Pg C (ref. 10), about half the estimates of the carbon within fossil fuel reserves[2,14]. Managing tropical forests to help stabilize and then reduce $CO_2$ concentrations could be implemented more quickly than the phasing out of fossil fuels, not needing as much development (technical, economic, marketing, infrastructure, and manufacturing and installation capacity) as the expansion of renewables to scale. Furthermore, many tropical forests are already growing (accumulating carbon) and will continue for some decades as long as they are not selectively logged, harvested, burned, or cleared for agriculture or other uses. The biophysical effects of tropical forests (for example, albedo and evapotranspiration) do not offset the biogeochemical effects (carbon sequestration), as they may in boreal forests[15]. And, finally, the recent United Nations Framework Convention on Climate Change (UNFCCC) efforts to proceed with REDD+ ('reduce emissions from deforestation and forest degradation in developing countries'; http://redd.unfccc.int/) demonstrates political willingness to manage forests for climate change mitigation[16].

Our focus on tropical forests does not preclude management of forests and other ecosystems outside the tropics for additional removal of carbon from the atmosphere. Efforts in temperate zone forests and in agricultural lands, grasslands and wetlands could increase the amount of carbon withdrawn from the atmosphere each year, and the huge stores of carbon in arctic and boreal systems highlight the need to keep permafrost from thawing[17]. In this context, it is worth noting that, in addition to the sources and sinks of carbon attributable to the land management suggested above, other natural processes on land remove approximately 25% of the carbon emitted each year[6]. The calculations here are based on the assumption that these natural sinks on land will continue.

Above-ground carbon in forests represents a vulnerable pool of carbon, subject to droughts, fires, insects and other disturbances. Thus, the management of forests to accumulate carbon must not delay or dilute the phasing-out fossil fuel use. On the contrary, the deliberate accumulation of carbon on land may be of little long-term benefit if climate change proceeds because of unrestrained use of fossil fuels, and if forests, as a consequence, return to being sources of carbon on a warming and drying Earth[18].

Despite reference here to forest management, we note that the potential for increasing carbon sinks in tropical forests is also related to changing traditional agricultural practices, including eliminating swidden. There is potential in modifying agricultural methods to enhance above- and below-ground storage of carbon within agricultural lands.

Used strategically, the removal of carbon from the atmosphere by tropical forest conservation and restoration could help stabilize and then reduce the $CO_2$ concentration in the atmosphere during the decades needed for an orderly transition away from fossil fuels, and could play a role equal to that of timely fossil fuel elimination in avoiding dangerous climate change. The Bonn Challenge to re-forest 150 million hectares of degraded lands and the goal of the New York Declaration on Forests to eliminate deforestation by 2030 are good first steps. But the timing and extent of action is critical. Not only should the restoration of the biosphere happen in concert with the phasing out of fossil fuels, but the longer we wait, and the higher the rate of fossil fuel emissions, the smaller the potential role of tropical forests in offsetting those emissions. ❐

*R. A. Houghton* and Alexander A. Nassikas are at the Woods Hole Research Center, 149 Woods Hole Road, Falmouth, Massachusetts 02540-1644, USA. Brett Byers is at Million Acre Pledge, 310 Hillside Avenue, Piedmont, California 94611, USA, and Rainforest Trust, 7078 Airlie Road, Warrenton, Virginia 20187, USA.*
**e-mail: rhoughton@whrc.org*

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