BIOGEOCHEMISTRY

Taking stock of forest carbon

Forests take up and store large quantities of carbon. An analysis of inventory data from across the globe suggests that temperate and boreal forests accounted for the majority of the terrestrial carbon sink over the past two decades.

Peter B. Reich

Imagine a tree trunk, tens of metres tall, lying across the forest floor. Now image you and two dozen, better three dozen, friends, lifting it by hand. Therein lies the significance of trees and forests when it comes to carbon sequestration; trees are heavy, and carbon accounts for almost half their dry weight. Forests are an important net carbon sink globally: each year they remove more carbon from the atmosphere by photosynthesis than they return via all processes, including respiration and deforestation. The exact magnitude of this global forest carbon sink is difficult to gauge, but is thought to lie between 2.0 and 3.4 Pg of carbon per year for intact forests. Now, writing in *Science*, Pan and colleagues[1] use forest inventory data to estimate the magnitude of the forest carbon sink over the past two decades, in what is probably the most up-to-date and thorough study of its kind.

The forest carbon sink has been estimated using several approaches, each with its own strengths and weaknesses. Global vegetation models have been used to determine the size of the land carbon sink, as have mass balance methods, which rely on estimates of oceanic and atmospheric sinks, and inverse modelling techniques, which rely on measurements of the concentration and geospatial distribution of carbon dioxide[2,3].

Pan and colleagues[1] use yet another approach to assess forest carbon stocks and fluxes across the globe between 1990 and 2007; one that is reliant on forest-inventory and land-cover data, ancillary data and estimates. The simplicity of the approach undoubtedly belies the Herculean effort involved: they assessed the carbon content of live biomass, dead wood, litter, soil organic matter and harvested wood products in tropical, temperate and boreal forests, and examined how these stocks changed over time. According to their analysis, intact forests and those re-growing following disturbance sequestered around 4 Pg C yr^{-1} over the measurement period — equivalent to around 60% of emissions from fossil fuel burning and cement production combined. This gross sequestration number sounds more favourable than it is though, as tropical deforestation resulted in the release of almost 3 Pg C yr^{-1}. Thus, globally, the net forest carbon sink (counting all gains and losses, including from deforestation) amounted to just 1.1 Pg C yr^{-1}, or one seventh of emissions from fossil fuel and cement production (Fig. 1), in line with previous estimates. Furthermore, the net forest carbon sink from forests remaining intact — a number given emphasis in previous scientific assessments — was 2.4 Pg C yr^{-1}, in the middle of the range of previous estimates[1,2].

The contribution of tropical, temperate and boreal biomes to the forest carbon sink was also explored. In the tropics, re-growth of cleared and logged forests, and continued growth of intact tropical forests, generated a colossal carbon sink of 2.83 Pg C yr^{-1}, which largely, but not entirely, counterbalanced emissions associated with deforestation. As a result, the tropics served as a relatively small net source of carbon to the atmosphere

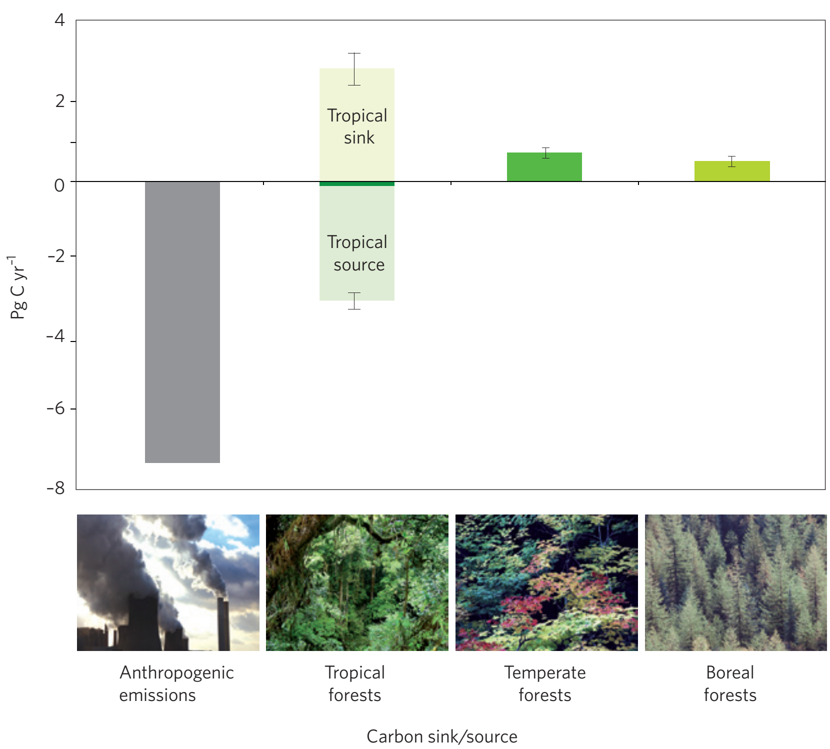

Figure 1 | The global forest carbon sink. Pan and colleagues[1] used forest inventory data to show that temperate and boreal forests comprised 100% of the net forest carbon sink between 1990 and 2007. Despite the gross sequestration of large quantities of carbon, tropical forests served as a small net source of carbon to the atmosphere (dark green bar), due to the even larger losses of carbon dioxide associated with deforestation. The error bars represent estimated uncertainties based on a combination of quantitative methods and expert opinion. The uncertainty associated with the net tropical carbon balance is not known. Anthropogenic emissions and forest carbon data, and uncertainty, taken from ref. 1. Image credits (from left): 1,2, © iStockphoto.com/bronswerk/raciro; 3,4, © Getty Images.

over the measurement period (Fig. 1). In contrast, temperate and boreal forests — which together accounted for much less than half of the global gross forest carbon uptake — were responsible for the entire net forest carbon sink (Fig. 1).

The magnitude of the carbon sinks and sources in the tropics suggests that tropical forests are key to future carbon cycling. Pan and co-workers suggest that, if managed appropriately, tropical forests could serve as a large net sink of carbon in the future and make the United Nation's Reducing Emissions from Deforestation and Forest Degradation (REDD) programme a meaningful contributor to offsetting emissions. Conversely, if deforestation were to continue unabated, and disturbance from land-use, drought, fire and climate were to grow this century, as seems likely, then tropical forests could become a large net source of carbon to the atmosphere, with serious consequences for the global climate system.

Of course, the uncertainties associated with their estimates of carbon-sink size are significant. In attempting to estimate global pools of carbon in forests in all forms, numerous assumptions were used. Even in countries with the most sophisticated forest inventories — largely developed nations in Europe and North America — insufficient coverage of all forest sectors, together with errors in accounting, mean that large uncertainties are evident at the national scale. As a result, the magnitude of the uncertainty associated with the global carbon sink is large and nearly matches that of the sink itself.

More important than these uncertainties, perhaps, is the question of whether the current sink strength of the world's forests will persist over the next 25 to 50 years. There are many reasons why it might not, including warming-induced emissions from boreal forests, heightened deforestation in the tropics, and a reduction in the fertilization effect of increased levels of carbon dioxide, as other resources, such as nutrients and water, become proportionally more limiting[4–7].

Furthermore, forests influence climate in numerous other ways, aside from carbon cycling. Forests emit greenhouse gases other than carbon dioxide, such as nitrous oxide and methane[8], and often reduce the reflectivity of the Earth's surface by absorbing solar radiation[9]. Although both of these processes act to increase radiative forcing, their impact on future climate will depend on variables such as land use, forest management and human disturbance. For example, shifts in land management that alter the extent and timing of soil waterlogging may influence trace-gas emissions, and shifts in forest management towards species that differ in spectral qualities could influence albedo[9,10]. Although difficult to quantify on a global stage, these additional emissions and biogeophysical effects need to be considered when assessing the role of forests in the climate system.

The findings of Pan and colleagues[1] demonstrate the ongoing importance of forests as a key carbon sink. Unfortunately, however, they do not provide a road map to the future. Whether the carbon-sink strength of the world's forests will shift this century, and whether emissions of greenhouse gases (other than carbon dioxide) and shifts in surface reflectivity will act to dampen or amplify anthropogenic warming, remains to be seen. ❐

Peter B. Reich is at the Department of Forest Resources, University of Minnesota, St Paul, Minnesota 55108, USA, and the Hawkesbury Institute for the Environment, University of Sydney, News South Wales, Australia.
e-mail: preich@umn.edu

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POLICY

China's regional emissions

The reduction of carbon dioxide emissions is a pressing challenge for China. Now research demonstrates that China's local energy-related emission patterns are important for setting effective greenhouse-gas abatement policies.

Yongfu Huang and Jingjing He

It is no longer news that China, with its unprecedented economic development, has become one of the world's biggest energy consumers and, therefore, one of the world's largest carbon dioxide emitters. The international debate around the magnitude and trend of China's carbon footprint has spurred research on the issue and encouraged the Chinese government to take on measures to address climate change. Fair and effective national abatement efforts should reflect the differences in regional contributions to China's carbon dioxide emission levels. However, little is known about the different regional emission paths behind China's carbon footprint. Chinese regions show very diverse economic conditions, with highly developed areas relying on state-of-the-art technologies and others still under-developed depending on old infrastructure and technologies. The level and trend of their carbon emissions vary substantially, but the differences are not captured in an aggregate indicator such as the national carbon footprint. Writing in *Energy Policy*, Meng and colleagues[1] highlight the great disparities in regional emission patterns in China and show how these differences are important for climate policy.

Thanks to remarkable economic growth over the past three decades, China's domestic living standards have been greatly enhanced, and between 1981 and 2005 about 600 million people[2] were lifted out of poverty. Nevertheless, China's economic wonder has come at a high price. Owing to the huge consumption of fossil fuels, especially coal, to meet its increasing demand for energy, China's natural environment has deteriorated rapidly. Increased levels of air and water pollution endanger people's health, and extreme weather events have increased in scale and frequency presenting a growing threat to the population. The Chinese government has realized the need to tackle these environmental problems and, in