Assessing climate change causes, risks and opportunities in forestry

Paul J. Burgess, Andy J. Moffat and Robin B. Matthews

Abstract: *Forests play an important role in regulating the global climate by storing carbon that would otherwise be released as CO_2 to the atmosphere, and affecting the global energy balance through absorption of solar radiation. Forests are also affected directly by the impact of increased CO_2 levels and temperatures on ecosystem processes, and indirectly by human responses seeking to mitigate the net emissions of greenhouse gases (GHGs) or adapting to new climates. This paper assesses the significance of these different aspects in the context of poverty reduction. It provides a brief assessment of the global effect of deforestation on net global GHG emissions; assesses the positive and negative direct effects of climate change on forest productivity, forest disturbance, carbon sequestration, water and air quality, biodiversity and cultural services; and discusses the indirect effects on forestry of human responses to minimize net GHG emissions through new markets, other land use change and global, national and local initiatives.*

Keywords: *forests; climate change; land use change; ecosystem services; biomass; carbon*

Paul J. Burgess is with the School of Applied Sciences, Cranfield University, Bedford MK43 0AL, UK. E-mail: p.burgess@cranfield.ac.uk. Andy J. Moffat is with Forest Research, Centre for Forestry and Climate Change, Farnham, Surrey GU10 4LH, UK. Robin B. Matthews is with the Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH, UK.

Forests have multiple roles, which are determined by the people who live in them, work in them or use them. In the context of the United Nations Millennium Development Goal of halving extreme poverty by 2015, it is estimated that forest resources contribute directly to the livelihoods of 90% of the 1.2 billion people living in extreme poverty – that is, living on less than US$1 per day (World Bank, 2004). Forest products are vital to the poor. Wood fuel, for example, is the primary energy source for heating and cooking for some 2.6 billion people (Sampson *et al*, 2005). When adequate wood fuel is unavailable, the consumption of cooked food can decline, with adverse effects on health and nutrition (Sampson *et al*, 2005).

So how will climate change impact on forests and on the poor who depend upon them? We first examine the contribution of deforestation to global greenhouse gas (GHG) emissions and then how increased carbon dioxide concentration and climate change impact on forest processes, goods and services. Finally, we explore how society may respond to the predicted and actual effects of climate change, such as by creating new markets, new land use, new global agreements, plus national and local initiatives to promote adaptive forest management.

Deforestation and greenhouse gas emissions

Globally, forests occupy 3,900 million ha, or about 30% of the world's land area (Table 1). It is estimated that about 1,340 million ha (34%) of this is primary forest. Significant numbers of trees also exist outside of designated forests, within agroforests and agricultural landscapes, and even

Table 1. Estimated annual change in global land use in 2000, with areas (million ha).

To:	Forest	Woodland/grassland	Farmland	Urban areas	Losses	Gains	Net change
From:							
Forest	3,939.9	3.0	9.8	2.0	–13.0	5.7	–7.3
Woodland/grassland	1.4	3,435.5	1.0	2.0	–2.6	5.0	2.4
Farmland	4.3	2.0	1,513.8	1.6	–7.9	10.8	2.9
Urban areas	ns	ns	ns	380.0	0	20.0	2.0
Total					*–23.5*	*23.5*	

Ns = not significant. 'Farmland' includes cropland and intensive pasture.
Source: Holmgren, 2006.

Table 2. Estimated annual change in forest area since the 1980s.

Continent	Net annual change in forest area (million ha) 1980s	1990s	2000–05
South America	–5.2	–3.8	–4.3
Africa	–2.8	–4.4	–4.0
Oceania	–0.04	–0.4	–0.4
North and Central America	–1.2	0.3	–0.3
Asia	–0.9	–0.8	1.0
Europe	0.2	0.9	0.7
Global total	*–9.9*	*–8.9*	*–7.3*

Source: after Eliasch Review, 2008.

Table 3. Trends in sustainable forest management (1990–2005) on a global scale, and for five selected regions.

Change in area of:	1990–2005 annual change: World	Central America	South America	Africa	East Asia	South and SE Asia
Forest	↔	↓	↔	↓	↑	↓
Other wooded land	↔	↑	↔	↓	↓	↑
Primary forest	↓	↓	↓	↓	↔	↓
Designated conservation forests	↑	↑	↑	↔	↑	↑

↑ major positive change (greater than 0.5%); ↔ change between –0.5 and 0.5%; ↓ major negative change (less than –0.5%).
Source: FAO, 2006.

in urban areas. Trees and other plants take up atmospheric carbon dioxide through photosynthesis and store considerable amounts of carbon as woody tissue, leaves and roots. Because forest soils are typically uncultivated, substantial carbon reserves also accumulate from leaf litter and decayed roots. Reducing deforestation and increasing afforestation therefore constitute a key mechanism for constraining atmospheric GHG emissions. Although globally the annual net loss of the forest area has decreased in recent years (Table 2), the net loss was still about 7.3 million ha per year in 2000 (Table 1). This value was derived from a gross loss of 13 million ha of established forests and a gross gain of 5.7 million ha of new forests. For example, in Asia (Table 2), there are high rates of deforestation in Indonesia (South and South-east Asia), but high rates of afforestation in China (in East Asia; see Table 3). More recent figures, to be published by FAO in December 2010, suggest that the net annual loss in forest area between 2000 and 2010 was 5.2 million hectares (FAO, 2010).

One global annual estimate of the level of GHG emissions attributed to net deforestation (including losses from peat) is 8,530 Mt CO_2 equivalent (Barker *et al*, 2007). Assuming a global emission of 49,000 Mt CO_2 equivalent (IPCC, 2007b), this approximates to 17.4%. However, the uncertainty associated with this value is the 'largest in the global carbon budget' (IPCC, 2007a). For example, the IPCC (2007a) estimated an annual net GHG emission due to land use change (primarily conversion from forestry) of 5,800 Mt CO_2 equivalent in the 1990s. In some countries, however, the proportion of GHG emissions attributed to deforestation is disproportionately large – land use change in Indonesia and Brazil, for example, is estimated to be responsible for 84% and 59% respectively of the national emissions (Figure 1). However, the overall effect of deforestation on climate change is also complicated by changes in albedo (surface reflectivity) and heat fluxes. For example, a dark forested landscape generally reflects only 10–20% of solar radiation, compared with 40–50% for grassland and croplands (Eliasch Review, 2008). This could reduce the net effect of changes in forest cover on temperatures.

Direct impacts of climate change on forests

Increased temperature and carbon dioxide levels, as well as the human response to them, affect numerous forest processes that determine the capacity of forests to provide the goods and services that society values. Key processes include timber and wood-fuel production, carbon sequestration, water and air quality regulation and the maintenance of biodiversity and cultural services.

Forest productivity

Experiments suggest that the increasing concentrations of CO_2 from the current level of about 380 ppm to about 550 ppm will increase the above-ground growth rate of young trees by about 30% (Easterling *et al*, 2007), with

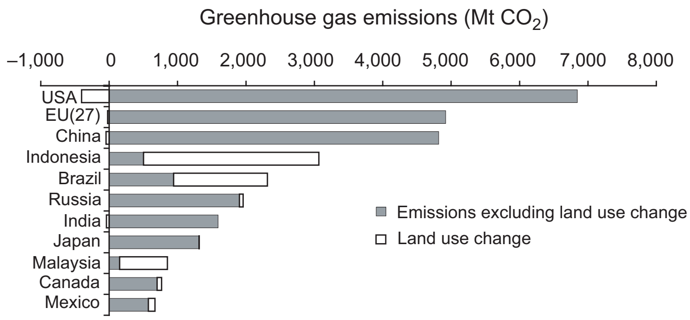

Figure 1. Total GHG emissions in 2000 for top 11 countries (or country groupings), highlighting the negative effects of land use change in Indonesia, Brazil and Malaysia, and the positive effects in the USA, EU27, China and India.
Source: WRI, 2009.

lower gains shown by mature trees. At present, the global annual wood harvest is about 3 billion m^3, about 0.7% of the living forest stock (FAO, 2006), and between 40 and 55% of this is used as fuel (Sampson *et al*, 2005). In the boreal regions, higher CO_2 levels, combined with higher temperatures, are likely to result in a net increase in global wood supply (Easterling *et al*, 2007). However, in other regions, such gains will not be achieved as temperature, water or nitrogen become limiting. For example, droughts are predicted to become more frequent and intense in the subtropical and Mediterranean-type forests in the western USA, northern China, southern Europe and Australia.

Forest disturbance

Forests are perennial systems that are vulnerable to pests, diseases, fire and other disturbances such as wind, snow, ice and floods (Dale *et al*, 2001). About 100 million ha of forests are damaged each year – by pests (37 million ha), diseases (31 million ha), fire (25 million ha) and other disturbance (8 million ha) (FAO, 2006). Under a warmer climate, the ranges of many forest pests are expected to expand and the frequency and intensity of outbreaks are expected to increase (Galik and Jackson, 2009). Higher temperatures in both boreal and tropical regions are predicted to increase fire frequency (Nabuurs *et al*, 2007). However, the effects can be complex. Seppälä *et al* (2009) report that forest fires in southern Africa decreased as rainfall decreased (because of less grass fuel) and human population increased. Higher sea surface temperatures have been linked with greater hurricane activity. Hurricane Katrina in 2005 converted 50–140% of the average annual US forest carbon storage rate into wind-blown or dead biomass (Chambers *et al*, 2007). By contrast, increased temperatures may reduce the frequency of ice storms, which are the primary source of tree mortality in some areas (Galik and Jackson, 2009). In other cases, severe disturbances can cause amplifying feedback loops, whereby deforestation leads to increased droughts, which result in further deforestation (Laurance and Williamson, 2001).

Carbon sequestration

Growing forests absorb more CO_2 than they emit and hence they can reduce annual net global GHG emissions. The IPCC (2007a) estimated that during the 1990s, excluding the negative effects of land use change, land (including agriculture and forestry) acted as a net sink of about 9,500 Mt CO_2 per year. Although the standard deviation on this value is large (± 6,200 Mt CO_2 per year), the mean value is equivalent to about 20% of the warming potential of gross global GHG emissions in 2004 (IPCC, 2007b). Whilst predicted increases in carbon dioxide concentration and temperature will lead to greater carbon sequestration where low temperatures are limiting, increased temperatures will also increase CO_2 losses from soil respiration (Rustad *et al*, 2001), and some forests may become net emitters rather than absorbers of CO_2 (Scholze *et al*, 2006).

Water and air quality

Forests regulate 57% of total water run-off globally (Millennium Ecosystem Assessment, 2005) and may become increasingly important as increased temperatures usually lead to more intense rainfall events. Coastal mangroves are also important nurseries for fish species and for protecting coastal areas from flood and storm surges. The projected increase in forest fires will have negative effects on air quality and human health. Seppälä *et al* (2009) cite World Health Organization data stating that 200 million people were affected by the 1997–98 forest fires in East Kalimantan in Indonesia.

Biodiversity

It is estimated that at least 80% of terrestrial biodiversity is found in the world's forests (World Bank, 2004). Thomas *et al* (2004) estimated that, from the current total, species extinctions from climate change in forested systems could range from about 1% in boreal forests and 4% in tropical forests, to 24% in temperate deciduous forests. The areas at greatest risk are those where current forest ranges are separated from potential future ranges. Rare montane habitats and Australian tropical forest are examples of this (Seppälä *et al*, 2009).

Cultural services

In developed countries such as the UK, the recreational and landscape value of forests can be greater than their value for wood production (Willis *et al*, 2003; CogentSi and PACEC, 2004). Tourism can also be dependent on forest habitats in less developed countries. However, few studies have investigated the likely effect of climate change on the provision of such services.

People's responses to climate change

Whilst adjustments within natural systems will only occur in response to actual physical changes, changes in managed systems can also result from responses to predicted effects. The greatest adverse effect of climate change on forests will tend to occur in tropical and subtropical areas where the greatest poverty already exists. Although developed countries will generally be less directly affected, they remain responsible for the largest amount of GHG emissions and therefore have a moral obligation to reduce emissions and to help those in poverty to adapt to the negative effects. The key human responses to climate change affecting the forest sector are likely to include the creation of new markets and the effect of climate change on other land uses, along with adaptation achieved through global, national and local initiatives. Whilst some of these responses aim to moderate harm, there are also beneficial opportunities.

New markets

A major current thrust of society's response to reduce CO_2 concentrations has been the promotion of renewable fuels based on biomass. There has also been a focus on reducing the carbon emissions associated with building construction to favour the use of timber rather than, say, concrete. Some of these market signals can unfortunately both create incentives for people to invest in establishing and managing forests and to clear existing forests for enterprises such as palm oil plantations. Whilst palm oil is a competitively priced renewable fuel, the loss of soil carbon in the process can create fuel with a larger carbon footprint than the fossil fuel it replaces. Sampson *et al* (2005) also report that unregulated and increased use of wood fuel may have significant health effects, as it is estimated that 1.6 million deaths per year are attributable to indoor smoke pollution. Such examples show that governments must ensure that market signals and regulation do not create perverse outcomes.

Changes in non-forest land use

In addition to growing bio-energy crops to reduce fossil fuel consumption, people are likely to adapt their land use in response to the different CO_2 levels, temperatures and water availability in future climates. In Africa, crop yields are likely to fall as a result of warmer temperatures and increased frequency of droughts (IPCC, 2007a). To meet future demand for food, this may well mean that agricultural production in affected countries can only be maintained through increasing the cultivated area. While some of this may come from marginal land, it is also likely to increase pressure to clear forests for agriculture.

Emerging global agreements

Redressing deforestation and using forests to deliver a wide range of goods and services (including carbon sequestration) is the subject of a wide range of global initiatives. For example, the 'Global Partnership on Forest Landscape Restoration' is a network that seeks to unite governments, organizations and communities with the common global goal of promoting an increase in sustainable forests.

In order to mitigate the effects of climate change, the Eliasch Review (2008) recommends that a cap-and-trade system is the most effective, efficient and equitable method of achieving long-term reductions in GHG emissions from the forest sector. Although the Kyoto Protocol (ending in 2012) allowed afforestation and reforestation to contribute to national targets, reducing emissions from deforestation and forest degradation (REDD) were not eligible, for a variety of reasons. It is anticipated that the global post-2012 climate regime will include mechanisms for allowing the GHG emissions from reductions in deforestation and degradation to contribute to national targets (Table 4). This would also support those seeking a global agreement to reduce tropical deforestation by at least 50% by 2020 and to halt global forest cover loss by 2030 at the latest (DECC, 2009).

Table 4. Possible scope of creditable activities related to forests in a post-2012 climate regime.

Changes in:	Reduced negative change	Enhanced positive change
Forest area (ha)	Avoided deforestation	Afforestation and reforestation (A/R)
Carbon density (carbon/ha)	Avoided degradation	Forest restoration and rehabilitation (carbon stock enhancement)

Source: after Angelsen, 2008.

However, there are several challenges that need to be addressed for the development of an agreeable global protocol. Climate change will cause the forest area in some regions to increase, whilst it will decline in others. A workable system will need to have politically acceptable targets related to baseline data (Myers, 2007). It will also be necessary to ensure that changes in forest area, and perhaps carbon storage per area, can be monitored, reported and verified (MRV). Moreover, there should be safeguards to ensure that the changes are additional and do not lead to deforestation elsewhere (leakage) or in the future (permanence). In Vietnam, research has shown that some of the increase in forested area was offset by an increase in timber imports, some of which were illegal (Meyfroidt and Lambin, 2010). In the medium to long term, carbon markets may well generate significant finance, but in the short term, international investment will be needed to develop the governance and mechanisms to administer the MRV systems. The annual finance needed to halve deforestation has been estimated at US$17–33 billion (Eliasch Review, 2008).

For the development sector, a key aspect of any climate change agreement is that the benefits of REDD are distributed equitably, ideally delivering co-benefits in terms of poverty reduction and human rights protection, or at the very least not disadvantaging already vulnerable people. Such an agreement is referred to as REDD+, in which reduced deforestation and degradation are integrated with sustainable forest management and conservation. There are also arguments that future agreements need to take a whole-landscape approach and comprehensively cover agriculture, forestry and other land uses (AFOLU) to avoid systematic double counting and leakage to other sectors.

National initiatives and land tenure

Although progress will be greatest where international and national initiatives are aligned, national and regional governments still have the right and responsibility to develop their own programmes to reduce the effect of forest management on GHG emissions and to adapt to the effects of climate change. It is estimated that about 80% of the world's forests are publicly owned (FAO, 2010), and only 6% of the forests in developing countries are covered by a formal, nationally approved management plan that exceeds five years (Nabuurs *et al*, 2007). Although national policies need to appreciate the innate conservatism of the forest sector in general, appropriate policies based on regulation, incentives and guidance can encourage adaptation. In many cases, this will require a more socially inclusive form of forest governance than has customarily been the case (Read *et al*, 2009). Moreover, in many countries, clarifying and securing land tenure rights for forest land alongside the development of national forest management plans is seen as essential for sustainable forest management (Eliasch Review, 2008; Nabuurs *et al*, 2007).

Adaptive forest management

Sustainable forest management recognizes that management evolves to ensure that forests provide an appropriate mix of ecosystem services. This may be within a single forest, or different forests areas may have specific roles. Globally, the area of forests designated for biodiversity conservation is increasing (Table 3). The area of plantation forests is also increasing, and although only comprising 3.8% of global forest cover in 2005, they supply about 35% of the global roundwood harvest (FAO, 2006). Sohngen *et al* (2001) suggest that by 2050, 75% of industrial wood will be harvested from plantations. Other forests may be managed principally to control soil erosion or water flows.

Climate change will undoubtedly challenge views on the balance of ecosystem services that it is most appropriate to derive from specific forests, and the forest sector needs to develop frameworks within which sound decision making can be adapted. Some current management options will become inappropriate. Seppälä *et al* (2009, p 136) use the term 'adaptive co-management' to indicate that forest management should be based on monitoring and learning – that is, mistakes will be made, but lessons need to be learnt from them. Different climates, species and management objectives mean that no management regime will be universally appropriate for all forests. Instead managers will need flexibility. There may be a need to plant new species or cultivars with improved insect and disease resistance. The optimal rotation length may increase if the value of carbon storage increases, even to the extent that harvesting becomes uneconomic (van Kooten *et al*, 1995). Wider tree spacings and use of stands of mixed species and ages may be introduced to reduce the susceptibility of the forest system to wind damage, drought stress or pest damage (Galik and Jackson, 2009). Finally, the term 'adaptive co-management' recognizes the wider impact of forest management on a range of stakeholders. For this reason, it is important that forest managers should engage key local stakeholders in the development of forest management plans.

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