Forest woman, Cameroon.

forests in a changing climate

will forests' role in regulating the global climate be hindered by climate change?

december 2008 | issue 115

Friends of the Earth International

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introduction

There has been considerable research into the critical role that forests play in regulating climate. There is also a growing body of evidence pointing to the significant negative impacts that climate change itself is likely to have on forests, especially in relation to the way that forests interact with the planet's carbon and hydrological cycles.

However, the more recent research papers seems to be widely dispersed and may be difficult for interested parties to access. This information briefing aims to bring together available current and/or relevant research to inform discussion about reducing carbon emissions from deforestation, especially within the UN Framework Convention on Climate Change.

This briefing is one of two papers from Friends of the Earth International relevant to the forests/climate nexus. The other considers the potential impacts of mechanisms intended to reduce emissions from deforestation in developing countries (REDD).

Burning down primary forests to open up a palm oil plantation in West Kalimantan.

executive summary

In 2005, forests were estimated to cover almost 4 billion hectares - about 30% of the world's land area (FAO, 2005). Forests are also home to an estimated 50-90% of all species on earth (WRI, 2008); and 1.6 billion people rely heavily on them for their livelihoods (FAO, 2008). For these reasons alone, deforestation should be halted.

However, these vast terrestrial ecosystems are also inextricably linked to the planet's carbon, hydrological and nitrogen cycles, which are themselves components of the planet's climate-regulating system.

The ways in which the Earth's forests and its climate interlink are complex and sometimes unexpected. They are nevertheless predicted to change significantly as temperatures rise, and forests' climate-regulating function may be significantly diminished or even eliminated as a result.

According to the Food and Agriculture Organization (FAO), net rates of deforestation are currently decreasing. This would be good news if it were not for the fact that these calculations include the expansion of tree plantations, masking real information about the fate of the world's old growth forests. There are also concerns that FAO's data is inaccurate (Grainger, 2008).

Even so, FAO's figures still show a net loss of 7.3 million ha per year between 2000 and 2005 (FAO, 2005:3). Furthermore, it has also been estimated that the rate of deforestation in tropical primary forest in seventeen key countries was 25.6% higher between 2000 and 2005 than it was between 1990 and 2000 (Mongabay, 2008b).

This relentless deforestation releases so much carbon into the atmosphere that it accounts for almost 18% of all anthropogenic greenhouse gas emissions (IPCC, 2007, also see table below) – more than that of the entire transport sector. As such, it has been observed, *"Curbing deforestation is a highly cost-effective way of reducing greenhouse gas emissions and has the potential to offer significant reductions fairly quickly."* (Stern, 2006)

However, it must be remembered that much of the carbon absorbed by trees (especially those that are subsequently turned into timber and paper) is eventually returned to the atmosphere. In terms of mitigating climate change, stopping deforestation should not be seen as anything other than a temporary and partial solution: it is important, and for many different reasons, but it is not a substitute for keeping carbon locked underground. It is necessary to address both concerns simultaneously.

Furthermore, it's not just a matter of *whether* trees exist or not: how they grow and die is also highly significant in terms of their impact on climate. In a vicious circle, changes in climate, including increasing temperature, affect the rate at which trees and other plants photosynthesise, transpire and decompose, thus influencing the global land–atmosphere carbon flux.

These impacts can be so significant that they may cause forests to dieback. This could be irreversible, because forests help to regulate the local and regional climate, giving rise to the precipitation and milder temperatures to which they themselves are adapted.

Recent research (detailed below) indicates a net carbon transfer, from the atmosphere to plants and the soil, in the order of 1 billion tonnes[1] per year during the 1980s and 1990s (not taking into account the additional carbon released due to land-use change). In other words, intact forests act as a net carbon sink.

Further research indicates that in the short term and at lower rates of temperature increase (below 2°C), forests' ability to act as a carbon sink increases. However, in the longer term and at higher temperatures (especially above 3°C), forests could lose this critical climate-regulating ability, becoming a net carbon source.

The increased ability to sequester carbon expected at lower rates of temperature increase, is referred to as 'carbon fertilisation': increasing levels of atmospheric CO_2 are thought to lead to increased plant growth. Obviously, whether or not this is the case is extremely important when considering ways of mitigating climate change. However, the available research on this is inconclusive.

1 For ease of comparison this briefing endeavours to give all figures in billions of tonnes. It should be noted, however, that the same quantity may be referred to as a billion metric tons, a Gigatonne (Gt) or a Petagram (Pg). 1 tonne is also used rather than 1 megagram.

Left: Forest woman, Cameroon.
Right: Woman harvesting fruit in West Kalimantan.

executive summary

continued

The only conclusion that can be drawn at the moment is that uncertainty about carbon fertilisation is still so great that climate change mitigation strategies should not depend upon it. Further research is needed in this area, to determine whether or not carbon fertilisation is a real phenomenon, and if so, how it might impact climate change.

Critically, data from the Consultative Group on International Agricultural Research (CGIAR) shows that intact old growth forest stores significantly greater quantities of carbon than either plantations or logged forests (Palm *et al.,* 1999:1). Even the most conservative of its estimates indicates that plantations store only 20% of the carbon that intact old growth forests do. Replacing old growth forests with plantations (to produce feedstock for biofuels or pulp, for example) is not an option (however profitable it may be).

It is essential to revise the FAO's definition of forests to exclude plantations. The current inclusive definition allows the expansion of plantations to be prioritised over and above the protection of old growth forest, to the detriment of the climate, biodiversity and peoples' livelihoods. Furthermore, any mitigation proposals intended to increase forest cover should focus on community-led reforestation using native species.

It is also important to take into account the various ways in which different types of forest – boreal, temperate and tropical – interact with the climate. In 2001, the Intergovernmental Panel on Climate Change (IPCC) estimated that temperate forests were sequestering something in the region of 1.4-2 tonnes of carbon/ha/yr and therefore acting as carbon sinks. However, whilst boreal forests can be carbon sinks or sources, depending on the forest type in question, tropical forests are a significant net carbon source, because of deforestation and forest degradation (IPCC, 2001a:5.6.1.1).

Cleared land, ready for oil palm trees, West Kalimantan.

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However, the data on which these types of assessment have been made has recently been brought into question, following research into the 'missing carbon sink'. (This is the difference between computer model estimates and ground-based testing of carbon sequestration in northern forests.) This new research finds that some 40% of the CO_2 previously assumed to be absorbed by northern forests is actually being taken up in the tropics. Tropical forests remain a carbon source, but by a much narrower margin than previously thought. This new knowledge reemphasizes the importance of protecting the world's remaining tropical forests.

Furthermore, forest soils need to be protected too. Over two-thirds of the carbon in forest ecosystems is contained in soils and associated peat deposits. In particular, major carbon stores are held in forest soils at higher latitudes, where organic matter decomposes more slowly, and peatland forests in the tropics (in Southeast Asia, for example), where decomposition is inhibited by anaerobic conditions. But this carbon is released when forests are cut and forest soils disturbed.

The world's peatlands cover just 3% of the world's surface, but contain 550 billion tonnes of carbon in the form of compressed organic material (this is twice the amount contained in forests) (Ramsar, 2008).

However, these peatlands are being rapidly destroyed, especially in Southeast Asia, where forests are being cleared to plant oil palm plantations. This alone is estimated to account for a massive 8% of global CO_2 emissions.

New research from China also indicates that old growth forests may store much higher levels of carbon in their soil than had previously been thought. All in all, it is clear that carbon losses from forest soils must be taken into account when calculating the potential climate impacts of deforestation. Stopping deforestation on peatlands is an absolute priority. Peat should retain its IPCC classification as a fossil fuel.

Forest fires are also increasing, both in frequency and intensity, with disastrous consequences for both biodiversity and the world's climate: burning organic matter releases large amounts of stored carbon into the atmosphere. The fact that climate change is also contributing to this increase in wildfires is supported by recent research from the US, which shows a sudden increase in the frequency and duration of wildfires in the mid-1980s. This was particularly marked in the Northern Rockies, where land-use change is clearly not the cause, and is strongly associated with increasing spring and summer temperatures and earlier spring snowmelt.

As forests disappear, carbon-packed forest soils are exposed to more sunlight, causing them to warm up or, in the case of permafrost, melt. This also leads to increased soil decomposition rates and the release of large quantities of carbon into the atmosphere.

The fires that raged throughout rural Indonesia in 1997 are a telling example of the damage that could be inflicted in the future. Although Indonesia suffers frequent forest fires, these were some of the worst so far, affecting no less than 6% of the country's total landmass and releasing 2.57 billion tonnes of carbon into the atmosphere – the equivalent of 40% of the total amount of carbon dioxide released into the atmosphere due to fossil fuel burning that year. Large losses from forest fires have also been incurred in many other countries in the last two decades, including in the Brazilian Amazon, China, Mexico and Paraguay.

Deforestation and other forest management policies that lead to the drying of forests need to be stopped. These include forest management policies that suppress forest fires that are a natural part of ecosystem regeneration in some forests. This aids the build-up of woody debris on the forest floor that can then fuel hot and very destructive forest fires (Environment Canada, 2008). Governments need to finance and otherwise resource a global forest-fire fighting effort, to assist those countries unable to prevent or stop the resulting out-of-control forest wildfires.

Forests are also involved in driving atmospheric circulation and rainfall patterns. Critically, forests aid the movement of water from the soil, via trees, to the atmosphere, through a process know as transpiration: this contributes to the formation of clouds and rainfall. Forest vegetation also emits isoprenes, which serve as condensation nuclei, again aiding in the formation of clouds and raindrops.

The extent to which climate change is likely to affect transpiration rates is uncertain (although it is at least predicted that climate change will lead to an 'intensification' of the global hydrological cycle). Higher temperatures and stronger winds could increase transpiration rates, but increased CO_2 levels and drier soils could have the opposite effect.

We can at least conclude that the destruction of forests is likely to cause significant changes to weather and the climate, both regionally and globally; and thus to ecosystems and food production. There are thus multiple reasons to protect forests; and a strong argument for significantly improving effective collaboration between the various intergovernmental fora, civil society organisations and forest-dependent communities that are working on or impacted by climate, forests and biodiversity, poverty and hunger.

Forests also play a part in the world's nitrogen cycle, helping to fix atmospheric nitrogen and convert it into nitrates that are turned into amino acids and proteins, the building blocks of life. However, excess nitrogen, from fertiliser applications or from pollution from industry, transport and agriculture, can boost soil respiration in tropical forests, leading to significant increases in carbon emissions. The impacts of nitrogen pollution need to be included in analyses underpinning the development of climate change mitigation measures. The use of fertilisers in forest management should be stopped.

Forest ecosystems and tree species distribution are also likely to be impacted by changing temperatures and CO_2 concentrations, as well as changes to rainfall, growing seasons and freeze-thaw patterns. Estimates suggest that one-seventh to two-thirds of the world's temperate and boreal forests, for example, could undergo some type of change in the middle part of the century. Research also indicates that the largest and earliest impacts are likely to be in the boreal forests, because of changes to seasonal thaw patterns, longer growing seasons, and reduced growth in trees stressed by summer drought. (However, if temperatures rise by more than 3°C over the century, then boreal forests will be at greater risk of dieback and disturbance, mainly due to forest fire).

Overall, there is a high risk of forest loss predicted in Eurasia, eastern China, Canada, Central America, and Amazonia; and forests are expected to shift into the Arctic and semiarid savannas. Substantially larger areas are predicted to be affected if temperatures climb by more than 3°C.

As a result of climate change, there is also likely to be significant and increasing damage to ecosystems from changing patterns of insect and pathogen pest damage; and these outbreaks may also shift towards the Poles. However, the ecological interactions are complex and hard to assess.

Extreme weather events, including hurricanes, tornadoes, unexpected drought, heavy rainfall, flooding, and ice storms are also considered to be increasing in frequency and severity as a result of climate change and are likely to have significant impacts on forests.

how forests regulate climate

forests and the carbon cycle

The greenhouse effect is a natural occurrence. The warming or 'blanketing' effect of greenhouse gases (GHGs), such as carbon dioxide and water vapour, permits life on earth. However, additional emissions of GHGs caused by human activity (known as anthropogenic emissions) have increased atmospheric concentrations of GHGs by around 35% since the pre-industrial era (IPCC, 2007b). This causes more of the Sun's reflected heat to be trapped within the atmosphere, increasing the warming effect and resulting in climate change.

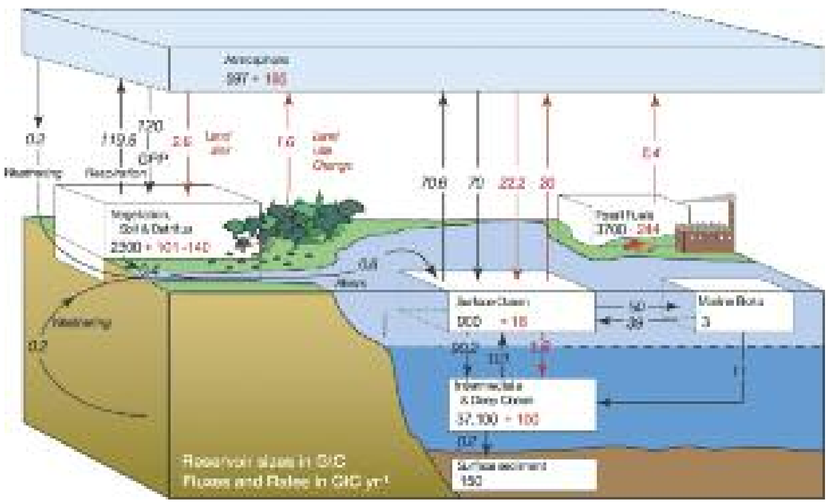
The planet's global carbon cycle, a key component of the greenhouse effect, involves the natural emission, absorption and storage of huge quantities of carbon. It has been estimated that over 200 billion tonnes of carbon are exchanged between the Earth itself, its oceans and its atmosphere, every year[2] (IPCC, 2007b: Figure 7.3). Carbon can be stored in a number of ways including in coal and oil, in the oceans and in organic matter in plants.

Trees and other plants convert carbon dioxide into carbon as they photosynthesise and grow. The carbon is stored as biomass in the tree, and oxygen is released back into the atmosphere. Some of this carbon is transferred to the soil either through the roots, or when leaves fall, or when trees die and decompose. Thus carbon is stored in both the trees and the underlying forest soils. However, as Woods Hole Research Center explains, *"If the global totals for photosynthesis and respiration are not equal, carbon either accumulates on land or is released to the atmosphere."* (WHRC, 2008). The world's vegetation and soil currently sequesters 2,300 billion tonnes of carbon. (IPCC, 20007b: Figure 7.3)

Recent research indicates a net carbon transfer, from the atmosphere to plants and soil, in the order of 1 billion tonnes per year during the 1980s and 1990s (not taking into account the additional carbon released due to land-use change). In other words, the planet's vegetation, including forests, is acting as a net carbon sink (Scholze *et al.,* 2006). More recent figures from the IPCC give a slightly reduced figure of 0.6 billion tonnes for the 1990s (IPCC, 20007b: Figure 7.3)

However, the overall carbon cycle is leading to the release of carbon into the atmosphere. This is caused primarily by the removal of underground carbon (in the form of coal, oil and gas) and changing land-use (which includes deforestation). The carbon released into the atmosphere is more than that absorbed by the forests and the world's oceans, as the diagram below demonstrates.

FIGURE 1 **GLOBAL CARBON CYCLE (BILLION METRIC TONS CARBON)**



Source: *IPCC, 2007b: Figure 7.3.*

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Vegetation and soils have been estimated as storing some 2,300 billion tonnes of carbon (IPCC, 2007b: Figure 7.3), and forest vegetation and forest soils have in the past been estimated to account for some 1,146 billion tonnes of this (Dixon *et al.*, 1994).

Because of extensive deforestation, in order to free up land for agricultural purposes and to provide timber for wood fuel, timber, and pulp and paper, the 'land use change and forestry' sector (LUCF) is estimated to contribute 24% to global CO_2 emissions, and 18% of all greenhouse gas emissions (although it must be added that calculations in this sector are somewhat uncertain) (WRI, 2005).

Indeed, the IPCC reports that forestry was the third largest source of anthropogenic greenhouse gas emissions in 2004, behind energy use and industry:

TABLE 1 CONTRIBUTION TO ANTHROPOGENIC GHG EMISSIONS

SECTOR	CONTRIBUTION TO ANTHROPOGENIC GHG EMISSIONS IN 2004 IN TERMS OF CO_2-EQ
Energy supply	25.9%
Industry	19.4%
Forestry	17.4%
Agriculture	13.5%
Transport	13.1%
Residential and commercial buildings	7.9%
Waste and waste water	2.8%

Source: *(IPCC, 2007:5).*

Key countries responsible for LUCF emissions include Indonesia (34%), Brazil (18%), Malaysia, Myanmar and the Democratic Republic of Congo. If developing countries are considered as a group, LUCF CO_2 emissions make up one third of their total emissions (WRI, 2005).

Industrialised countries, including the EU and the US, have negative LUCF emissions, but this is primarily because their forests have already been cleared and because of current re-growth (WRI, 2005). Temperate forests are considered to be net carbon sinks at present (IPCC, 2001a: 5.6.1.1).

The situation is less clear in boreal forests. Some are net carbon sources and some net carbon sinks: it depends on different forest types. In the tropics, however, the IPCC states that forests are still a net carbon source, because of land use change (IPCC, 2001a: 5.6.1.1).

forests store carbon in vegetation

Forest vegetation may contain as much as 300 tonnes of carbon per hectare (Palm et al., 1999). The vegetation in tropical forests contains 60% of the total carbon held in forest vegetation (IPCC, 2001a: 5.6.1.1).

"Of the approximately 8 billion tons of carbon emitted each year, about 40 percent accumulates in the atmosphere and about 30 percent is absorbed by the oceans. Scientists believe that terrestrial ecosystems, especially trees, are taking up the remainder." (NSF, 2007)

Carbon flux rates change, depending on land use patterns, the type of vegetation cleared, the fate of that vegetation, and what is put in its place. There are also variations in the rate at which different forests, or different types of forest, absorb CO_2. These variations are critical to understanding the forest-climate nexus and developing effective policies to mitigate climate change and protect forests and biodiversity (ANU E Press, 2008).

Nevertheless, much of the carbon that is absorbed by trees is eventually returned to the atmosphere. This happens when trees die and decompose, and when timber products are incinerated or left to rot. If they rot in landfill, they release carbon in the form of methane, a greenhouse gas that is considerably more potent than carbon dioxide. Re-using and recycling prolongs the life of both timber and paper and can therefore delay the release of stored carbon back into the atmosphere.

young trees v old trees Which absorb carbon more quickly, young trees or old? The answer to this question is critical: it may influence whether governments choose to protect forests or continue to log them, replacing them with plantations.

The Finnish Forest Industries Federation has argued that: "Forests put an effective break on the warming climate, as trees have an appetite for carbon dioxide, the main greenhouse gas. The hungriest of all is a young, growing forest... The type of forest needed to control the greenhouse effect is different from that needed to nurture biodiversity; in fact, the faster the seedling grows the better... In terms of controlling the greenhouse effect, forests should be regenerated, and more use made of timber as a raw material." (FFIF, 1995)

However, although it is true that young trees grow and absorb carbon dioxide more rapidly than old trees, this does not compensate for the smaller carbon pools in younger trees in plantations (ANU E Press, 2008). They may absorb carbon dioxide more slowly, but older trees already have much greater stores of carbon in their biomass.

one how forests regulate climate

continued

Furthermore, such trees can live for hundreds and even thousands of years (GD, 2008). They do eventually die and rot, releasing stored carbon back into the atmosphere, but in an intact forest they will be replaced by new growth, with the release and uptake of carbon remaining in balance.

Data from the Consultative Group on International Agricultural Research (CGIAR) also supports the argument that old growth forests store significantly greater quantities of carbon than either plantations or logged forests.

Replacing old growth forests with plantations is thus not an option in terms of climate change mitigation.

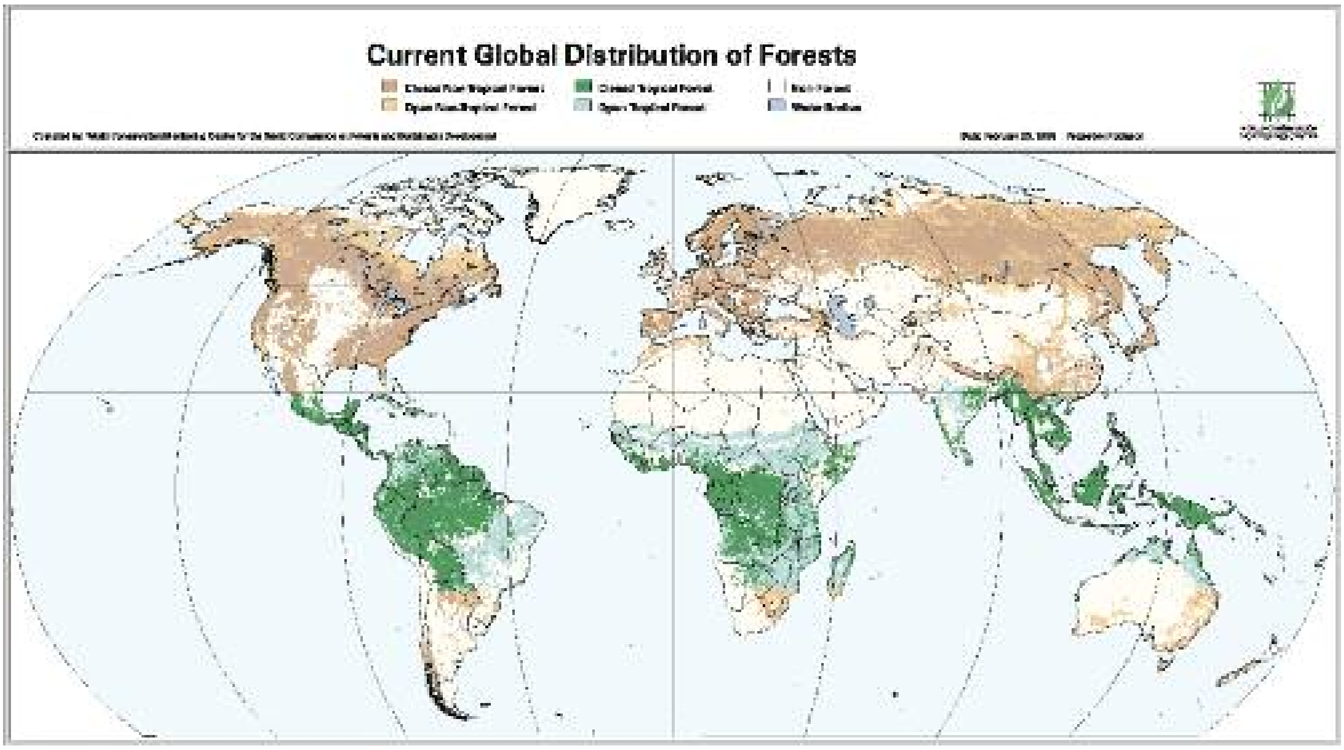
tropical v temperate forests and the 'missing carbon sink' The world's natural forests can be split into two main categories: the tropical forests, either side of the equator; and the temperate and boreal forests, mainly found in the northern hemisphere (with a small proportion in Australia, New Zealand, South Africa, Argentina and Chile).

TABLE 2 TIME-AVERAGED ABOVE GROUND CARBON STOCKS IN SLASH-AND-BURN AND ALTERNATIVE LAND USE SYSTEMS

SYSTEM	CARBON (TONS C HA^{-1})
Primary forest	300
Logged forests	100-200
Shifting cultivation (25 year rotation)	88
Permanent complex agroforests	90
Complex agroforests (25-30 year rotations)	40-60
Tree plantations	11-61
Crop short fallow (<5 yrs)	5
Pastures and grasslands	3

Source: *(Palm et al., 1999:1, for CGIAR).*

FIGURE 2 DISTRIBUTION OF TROPICAL, TEMPERATE AND BOREAL FORESTS



Source: *WCFSD, 1999.*

These two different regions need to be considered separately in relation to carbon pools[3], loss of carbon because of deforestation, and carbon absorption.

The largest vegetation and soil carbon pools are in tropical forests (60 and 45%, respectively, of the totals for forests) because of their large extent and relatively high carbon densities. Carbon stocks in forests vary, depending on the type of forest because of climate, soil, management, frequency of disturbances, and level of human-caused degradation (IPCC, 2001a: 5.6.1.1)

Before 1900, the greatest CO_2 emissions were caused by deforestation in temperate countries to make way for agricultural expansion. Since then, however, the balance of emissions has changed: temperate deforestation has decreased and tropical deforestation increased.

Since the 1940s, tropical deforestation has accounted for the greatest net carbon emissions from the natural environment. Overall, Northern forests still act as net carbon sink, but tropical forests, because of drastic land use changes including deforestation, are a net carbon source (that is, they emit more carbon because of deforestation than can be absorbed by the remaining trees) (NSF, 2007).

In 1994, scientists reported that deforestation in tropical forests was leading to carbon emissions in the region of 1.6 billion tonnes per year; and that this was being somewhat countered by forest expansion and carbon sequestration in temperate and boreal forests of about 0.7 billion tonnes per year, leading to a net flux to the atmosphere of about 0.9 billion tonnes per year (Dixon *et al.,* 1994).

In 2001, the IPCC estimated that temperate forests were sequestering something in the region of 1.4-2 tonnes of carbon/ha/yr. Boreal forests were quite variable, depending on forest type. Tropical forests, on the other hand, remained a net carbon source (IPCC, 2001a: 5.6.1.1).

However, the data on which assessments like these are based has been brought into question recently, by a study into the 'missing carbon sink'. This missing sink is the difference between computer model estimates and ground-based testing of carbon sequestration in Northern forests (WHRC, 2008). Computer models indicated that these forests were absorbing some 2.4 billion tonnes per year, but tests indicated that the real absorption rate was only about half of that (Terradaily, 2007).

The research found that whilst Northern forests remain a carbon sink, and tropical forests remain a source, the actual figures are quite different from those produced by computer modelling. Using aircraft samples taken over many years, researchers found that Northern forests are actually taking up just 1.5 billion tonnes of carbon per year; and tropical forests are actually absorbing a great deal more CO_2 than previously estimated (and are a net source by just 100 million tonnes). In other words, some 40% of the CO_2 assumed to be absorbed by Northern forests is actually being taken up in the tropics (NSF, 2007).

Clearly, such results will be highly significant in determining which forest policies should be deployed in the effort to mitigate climate change.

forests store carbon in forest soils

Forest soils store a huge quantity of carbon because of the large amounts of organic material, such as leaves and decaying wood, that fall to and decompose on the forest floor. Over two-thirds of the carbon in forest ecosystems is contained in soils and associated peat deposits (Dixon *et al.,* 1994).

This is especially true for forest soils at higher latitudes, where organic matter decomposes more slowly, and in peatland forests in the tropics (in Southeast Asia, for example) where decomposition is inhibited by anaerobic conditions (Dixon *et al,* 1994).

During harvesting, the ecology of forest soils is disturbed by heavy machinery and changing levels of light and water, resulting in significant losses of carbon to the atmosphere. Forests soils also release carbon when fertilisers are applied (GFC, 2007).

New research from China indicates that old growth forests may store much higher levels of carbon in soil than had previously been thought (although it also speculates that this may also be a response to a changing environment). Scientists found that the top 20cm soil layer in old growth forests in southern China accumulated atmospheric carbon at an unexpectedly high average rate of 0.61 tonnes of carbon/ha/year between 1979 and 2003 (Zhou *et al.,* 2008).

forest peatlands According to the Ramsar Convention on Wetlands, the world's peatlands cover some 400 million ha and are *"major contributors to the biological diversity of many regions of the world"* (Ramsar, 2008b). They also contain about 550 billion tonnes of carbon in the form of compressed organic material. To put this into perspective, the carbon in these soils, which cover just 3% of the world's surface, is the same as that contained in all terrestrial biomass, and twice that sequestered in forests (Ramsar, 2008).

Peat is still used as a fuel in many parts of the world, despite the fact that it takes many thousands of years to form. It is also being rapidly destroyed in places such as Southeast Asia, where forests are being cleared to plant oil palm plantations. This alone is estimated to account for a massive 8% of global carbon dioxide emissions (Hooijer *et al.,* 2006). Drained peat releases carbon dioxide as it oxidizes. Forest fires on dried out peat soils release even more (Biofuelwatch, 2008).

3 A carbon pool is any kind of reservoir of carbon, such as forests or soil.

one how forests regulate climate

continued

Globally, peat loss is leading to a net loss of 3 billion tonnes of CO_2 every year - equivalent to 10% of global emissions from fossil fuels (UNEP, 2007).

It is worth noting that the peat industry has been struggling to have peat reclassified as a biofuel, both within the EU and the IPCC, stating that peat has a "fluctuating climate impact" (SPPA) and is a "slowly renewable biomass fuel." (SPPAb) Finland argued the peat industry's case in the IPCC.

Nevertheless, the IPCC resisted. In its glossary attached to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, it clearly and explicitly treats peat as a fossil carbon rather than a biofuel *"due to the length of time required for peat to re-accumulate after harvest"* (IPCC, 2006).

The Swedish Peat Producers' Association, however, seems to think that the IPCC has shifted on this issue somewhat, saying that, *"the IPCC decided, on a proposal by Finland, to abandon the concept of peat as a fossil fuel. Instead peat is simply to be classed as peat, a classification that reflects the fact of peat's fluctuating climate impact."* (SPPA)

forest fires and carbon emissions

The increasing prevalence of forest fires also contributes to climate change. Burning organic matter releases large amounts of stored carbon into the atmosphere: tropical deforestation produces 20% of all carbon emissions that can be attributed to human activity, destroying carbon sinks at the same time (Picard-Aitken, 2007). Furthermore, as the forest disappears, the soil beneath it warms up or, in the case of permafrost, melts. This leads to increased soil decomposition rates and further carbon emissions (ScienceDaily, 2007).

The impact of forest fires is even worse if the forest is based on peatland. Indonesia is again the main example, suffering peatland forest fires on an almost annual basis. The worst of these, in 1997, is estimated to have released as much as 2.57 billion tonnes of carbon into the air (Page *et al,* 2002) – the equivalent of 40% of the total quantity of CO_2 released into the atmosphere due to fossil fuel burning that year.

forests and the hydrological cycle

Forests are also a key component of the planet's hydrological cycle, influencing it in a number of different ways. Most importantly, forests aid the movement of water from the soil, through trees, to the atmosphere, through a process known as transpiration. This contributes to the formation of clouds and rainfall.

Transpiration rates are influenced by radiant energy, soil moisture, humidity, wind and stomata resistance (Pike, 2003). Forest vegetation also emits isoprenes, which serve as condensation nuclei, aiding in the formation of clouds and raindrops (Claeys *et al.,* 2004). Forests are thus involved in driving atmospheric circulation and rainfall patterns.

Increased forest harvesting, including road building, can affect evapotranspiration rates, *"eliminating transpiration and evaporation from the elevated canopy."*(Hetherington, 1987) Forest harvesting also affects the amount of solar radiation reaching the ground and other hydrologic processes, including snowmelt and soil freezing, with consequences for run-off (Pike, 2003).

The presence of forests also affects run-off rates because forest soils are particularly absorbent. There therefore tends to be less run-off and higher water tables in forested areas. Deforestation can lead to a lowering of local water tables (Pike, 2003). Increased run-off can also lead to soil erosion, siltation in watercourses and flash floods.

Forests and other types of vegetation also tend to capture and temporarily store rain and snow, thereby increasing eventual evaporation rates (Pike, 2003).

Clearly, the removal of forests is likely to cause significant changes to weather and the climate both locally and regionally; and thus to ecosystems and agriculture. The role of forests in weather and climate regulation, ecology and agriculture will be constrained both by deforestation and potential dieback (in itself caused by climate change).

forests and the nitrogen cycle

Forest ecosystems need nitrogen. Micro-organisms in forest soils and some tree species, such as alder (which has nitrogen-fixing root nodules) help to convert atmospheric nitrogen into organic nitrogen, making it available for conversion into plant and animal proteins. High-energy events, including lightning and forest fires, also help to fix small but significant amounts of nitrogen.

However, excess levels of nitrates can be detrimental to human, plant and animal health. With respect to forests, nitrogen pollution from power generation, transport and agriculture can lead to stream and soil acidification, forest decline and acid rain - even from stationary sources many hundreds of miles away (ScienceDaily, 2007b).

Excess nitrogen can boost soil respiration in tropical forests, leading to significant increases in carbon emissions (Cleveland and Townsend, 2006). This may occur because of nitrogen pollution, or in forests where fertilisers have been applied (GFC, 2007). However, the links between excess nutrients, such as nitrogen and phosphorous, tropical forests and climate change need further exploration (ScienceDaily, 2007b).

two how climate change affects forests

how climate change affects forests

The precise effect that climate change is likely to have on forests is difficult to quantify, especially given the complex and dynamic relationship that exists between forests and the planet's climate. For example, young trees growing in today's already changing climate may react differently from older trees, and this factor adds further uncertainty to any research undertaken using mature stands of trees (Alig *et al.*, 2004). Effects may also vary in different parts of the world.

However, researchers have identified and are attempting to quantify general trends. Climate change affects forests as atmospheric concentrations of CO_2 increase, and temperatures and rainfall patterns change. These changes affect forests' ability to sequester carbon; cause a range of disturbances to forest ecosystems; lead to changing distributions of tree species; and can generate extreme weather events that impact forests. The severity of these impacts is likely to be closely related to degree to which temperature increases (Scholze *et al.,* 2006).

Land use change (ie deforestation) is obviously a significant factor affecting forests' ability to sequester carbon. However, it's not just a matter of whether trees exist or not: how they grow and die is also highly significant. Changes in climate, including temperature increases, affect the rate at which trees and other plants photosynthesise, transpire and decompose, thus influencing the global land–atmosphere carbon flux.

forests – switching from carbon sinks to carbon sources?

Temperature increases can cause forests to die back, and this process can become irreversible, because forests help to regulate climate, contributing to the precipitation and milder temperatures to which they themselves are adapted.

Die back is already being reported in some regions, such as the Sierra Nevada mountains in California, where the dieback of pine and fir trees has nearly doubled since 1983 (Holmes, 2007). It is also feared that the Amazon rainforest, which helps to regulate the global climate, could suffer significant dieback in coming years (Malhi et al., 2008; WWF, 2007). One recent study estimates that 55% of the Amazon rainforest could be damaged or destroyed within 20 years, releasing 15-26 billion tonnes of carbon into the atmosphere, if the lethal combination of deforestation, forest fires and climate change continues (Nepstad *et al.,* 2008).

It seems that the fate of forests and their ability to sequester carbon are closely tied to temperature. Recent research states that if temperature increases remain below 2°C, the world's forests may continue to act as a carbon sink throughout the 21st century. However, if temperatures increase between 2°C and 3°C, forests' ability to absorb carbon could increase until the middle of the century but then decline; and if temperatures increase by more than 3°C, the sink effect would again increase initially but then cease by 2100 (although this latter result is rather uncertain statistically speaking) (Scholze *et al.,* 2006).

In other words, at least in the short term and at lower rates of temperature increase, these researchers argue that forests' ability to act as a carbon sink will increase. However, this argument is based on acceptance of a phenomenon known as 'carbon fertilisation'. This refers to an expected increase in tree growth as levels of CO_2 in the atmosphere also increase. However, research into this phenomenon has been inconclusive so far (see below).

Even so, Scholze *et al's* research indicates that, in the longer term and at higher temperatures, forests could lose their critical climate-regulating ability.

carbon fertilisation

'Carbon fertilisation' refers to the idea that increasing quantities of carbon in the atmosphere mean that more carbon dioxide is available for photosynthesis, and that plant growth will increase as a result. Obviously, whether or not this is the case is extremely important when considering ways of mitigating climate change.

However, there are differing opinions about whether the carbon fertilisation effect really exists (as reported by Sohnberg *et al.,* 2007). Satellite data show a greening of land, indicating that there is more growth (Guardian, 2008). But does this translate into increased carbon uptake? Research has so far yielded contradictory results.

Some argue that carbon fertilisation effects do exist but may be constrained by changes in weather and nutrient availability (Melillo *et al.,* 1993).

Others agree that carbon fertilisation exists, but argue that carbon dioxide absorption levels reach a 'saturation point' (and that these saturation points differ between species). In short, there is only so much carbon dioxide that plants can absorb (Gitay *et al.* 2001).

two how climate change affects forests

continued

Scholze et al's research (as detailed above) also works on the basis that increased levels of CO_2 will have physiological effects, but that a saturation point will be reached; and that the effects of carbon fertilisation will then become outweighed by the impacts of higher rates of global warming. This is because temperature affects the relative balance between increasing uptake of CO_2 during photosynthesis (due to increasing atmospheric concentrations) and increasing respiration as temperatures increase (Scholze *et al.,* 2006).

Others, however, comment on the uncertainty of some of the research undertaken so far, worrying about the accuracy of carbon-climate models and the assumptions they are based on: *"However, the contribution of CO_2 fertilization to the future global C cycle has been uncertain, especially in forest ecosystems that dominate global [net primary productivity], and models that include a feedback between terrestrial biosphere metabolism and atmospheric [CO_2] are poorly constrained by experimental evidence."* (Norby *et al.,* 2005)

This last group of researchers decided to analyse actual tree growth, subjecting trees to elevated levels of CO_2 (550 ppm) in four CO_2 enrichment experiments in forest stands. The results were positive, supporting those who theorised about the existence of the carbon fertilisation phenomenon: *"We show that the response of forest [net primary productivity] to elevated [CO_2] is highly conserved across a broad range of productivity, with a stimulation at the median of 23 ± 2%... The surprising consistency of response across diverse sites provides a benchmark to evaluate predictions of ecosystem and global models"* (Norby et al., 2005).

The IPCC also quotes similar research in a 13-year-old loblolly pine plantation in Northern Carolina, USA, in which CO_2 levels were maintained at 200 ppm above the ambient level. After two years, the growth rate of the CO_2-enriched trees had increased by about 26%. This study also concluded, however, that saturation was expected to occur, as plants became acclimatised to increased CO_2 levels and because lack of availability of other nutrients would also limit growth increases (IPCC, 2001a: 5.6.3.1.3; Gitay *et al.,* 2001).

Another study in 2006 also supported the carbon fertilisation theory, finding that most studies over the last 50 years have reported increases in net primary productivity in forests (Boisvenue and Running, 2006).

Recent research even indicates that growth rates for trees in the Amazon has increased to such an extent that their ability to absorb carbon more or less counteracts carbon emissions from deforestation in the Amazon. The researchers suggested that elevated levels of atmospheric CO_2 are the most likely reason for this increased growth (Phillips *et al.,* 2008).

However, not all studies agree. A new research report suggests that trees are actually absorbing less carbon dioxide as the world warms, at least in Northern regions. 14 research institutes, from Europe, Canada, China and the US, have collected data over two decades, including satellite data and measurements of local levels of atmospheric CO_2, from 30 different Northern sites, including in Siberia, Alaska, Canada and Europe.

Because of seasonal variation in tree growth, forests have a 'cut off' date in the autumn, when they switch from being net carbon sinks to net carbon sources. Satellite data showed increased greening (as mentioned above) and scientists from these institutions expected a longer growing season and a delayed 'cut off' date (leading to more CO_2 absorption).

They found the opposite. As temperatures increased, the 'cut off' date moved forward, in some cases by as much as a few weeks. They found that *"both photosynthesis and respiration increase during autumn warming, but the increase in respiration is greater. In contrast, warming increases photosynthesis more than respiration in spring."* They found that the CO_2 being released in the autumn was 10% higher than that being absorbed in the spring (Piao *et al.,* 2008).

Dr Piao from the Le Laboratoire des Sciences du Climat et l'Environnement in France commented that *"If warming in autumn occurs at a faster rate than in spring, the ability of northern ecosystems to sequester carbon will diminish in the future"* (Mongabay, 2008c.)

Still, there is disagreement about this too, as Colin Prentice of the University of Bristol points out, *"Over a longer period of decades, models predict changes in vegetation structure, including tundra regions becoming forested, and the forests tend to take up far more carbon than the tundra. So I would be sceptical about reading any particular future implication into these findings."* (Guardian, 2008)

Similarly, Kirschbaum comments that, *"Responses [to CO_2 and temperature changes] can be negative in some circumstances and positive in others, but on balance, there appears to be no reason to expect dramatic overall changes in plant growth"* (Kirschbaum, 1998).

The only conclusion that can be drawn for now, it seems, is that uncertainty about carbon fertilisation is still so great that climate change mitigation strategies should not rely on it, but should focus elsewhere. Any benefits from carbon fertilisation would be an additional benefit. There also needs to be further research into the differential impacts of climate change on tropical, temperate and boreal forests.

changing distribution of tree species

Forest ecosystems are likely to be seriously impacted by changing temperatures and CO_2 concentrations, as well as changes in rainfall, growing seasons and freeze-thaw patterns:

"However, ecological consequences are potentially more serious [than impacts on growth]. The distribution of many species tends to be limited to a narrow range of environmental conditions. With climate change, conditions may change to become completely unsuitable over much of a species' current natural range. This may cause the loss of a large number of many unique species that currently inhabit the world's tropical forests...Ecological and ecophysiological factors... add additional impacts to tropical forests that are already being impacted by a range of other direct and indirect anthropogenic factors." (Kirschbaum, 1998)

Estimates suggest that one-seventh to two-thirds of the world's temperate and boreal forests, for example, could undergo some type of change in the middle part of the century (Sohngen et al., 2007). Research also indicates that the largest and earliest impacts due to climate change are likely to be in boreal forests, because of changes to seasonal thaw patterns, which increase growing season length, and summer drought, which can cause stress and therefore reduce growth (IPCC, 2001a: 5.6.3.1.2). However, if temperatures rise by more than 3°C over the century, then boreal forests will be at greater risk of dieback and disturbance (mainly due to forest fire) (Sohngen *et al.,* 2007).

In the UK, the Forestry Commission (focusing primarily on productive timber species) is already expecting changes in tree species' distribution. It predicts, for example, that Norway Spruce may no longer be grown successfully in most of the UK; that Sitka spruce, Corsican pine, Douglas fir and beech may increasingly be grown in Scotland; and that beech will cease to be a suitable species to grow and harvest in southern England (Forestry Commission, 2002). Clearly, this trend is likely to apply to both plantation and natural forest species.

However, it also cautions against planting with species of different provenances in anticipation of climate change, arguing that the risk of damage from spring frosts will remain, and may worsen in the case of autumn frosts (Forestry Commission, 2002).

Left: Iwokrama Forest, Guyana.
Right: Pine forests in Haiti.

Similarly in the USA, significant shifts in species distribution and forest cover are expected. One analysis of four different studies found that *"Collectively, the results suggest substantial change in the potential habitats of several species and communities"* (Hansen and Dale, 2001). The study goes on to predict that forest area in the US will decrease by 11%, with forest being replaced by savanna and arid woodlands. Some communities, such as oak/hickory and oak/pine in the East and ponderosa pine and hardwoods in the West, may increase. But others, including alpine habitats, sagebrush, sub-alpine spruce/fir forests, aspen/birch and maple/beech/birch are expected to decrease greatly or disappear (Hansen and Dale, 2001).

However, it has also been argued that responses to climate change are likely to be highly variable, with some ecosystems being damaged but others enhanced. So, for example, boreal and alpine forests might experience increased growth rates, because their growing seasons and the ambient temperature, both of which might change, are currently limiting factors to growth (IPCC, 2001a: 5.6.2.1).

Scholze et al. predict a high risk of forest loss in Eurasia, eastern China, Canada, Central America, and Amazonia (Scholze *et al.,* 2006). They also anticipate the extension of forests into the Arctic, and semiarid savannas (Scholze *et al.,* 2006), although there is also the possibility of bog and muskeg formation.

increasing damage by insects, pathogens and other pests

Forest ecosystems are also affected by pest infestations, forest fires, wind-throw, ice damage, drought and extreme weather events, all of which are in turn affected – in terms of their frequency and intensity - by climate change. These changes may be exhibited as a reduction in forest quality even where the forest continues to exist.

The IPCC recognises that, as a result of climate change, there is likely to be significant damage to ecosystems from changing patterns of insect and pathogen pest damage. However, they also point out that the ecological interactions are complex and hard to assess. Past evidence, however, suggests that longer and/or more severe outbreaks may be expected, and that these outbreaks may shift towards the Poles. The IPCC comments that, *"All of these responses will tend to reduce forest productivity and carbon stocks, although the quantitative extent of these changes is hard to predict"* (IPCC, 2001a: 5.6.3.1.3).

In temperate and boreal forests, for example, there may be an increased incidence of canker diseases in poplars and other tree species, because of decreased bark moisture content. Armillaria root disease, found in different places throughout the world, may also spread if conditions are warmer and drier.

two how climate change affects forests

continued

The IPCC gives the following example of the significance of insect damage and ways in which it can be related to climate change:

complex Interactions: north america's southern boreal forests, pests, birds, and climate change

The eastern spruce budworm *(Choristoneura fumiferana)* is estimated to defoliate approximately 2.3 million ha in the United States and affects 51 million m3 of timber in Canada annually. Although the budworm usually is present at low densities, budworm densities can reach 22 million larvae ha^{-1} during periodic outbreaks. Outbreaks can extend over 72 million ha and last for 5-15 years, killing most trees in mature stands of balsam fir.

Weather is thought to play a role in determining the budworm's range. Outbreaks frequently follow droughts or start after hot, dry summers. Drought stresses host trees and changes plant microhabitats. Moreover, the number of spruce budworm eggs laid at 25°C is 50% greater than the number laid at 15°C. In some areas, drought and higher temperatures also shift the timing of reproduction in budworms so that they may no longer be affected by some of their natural parasitoid predators. Weather, at least in central Canada, also may play a role in stopping some outbreaks if late spring frosts kill the tree's new growth on which the larvae feed.

Control of some populations of eastern spruce budworm may be strongly aided by bird predators, especially some of the wood warblers. Birds can consume as much as 84% of budworm larvae and pupae when budworm populations are low (approximately 100,000 ha^{-1}), but once larvae populations exceed 1,000,000 ha^{-1}, bird predation is unable to substantially affect budworm populations. This predatory action of birds works in concert with those of other predators, mostly insects.

The spruce budworm's northern range may shift northward with increasing temperatures—which, if accompanied by increased drought frequency, could lead to outbreaks of increasing frequency and severity that lead to dramatic ecological changes. Increasing temperatures also might reduce the frequency of late spring frosts in southern boreal forests, perhaps increasing outbreak duration in some of those areas.

A changing climate also might decouple some budworm populations from those of their parasitoid and avian predators. Distributions of many of the warblers that feed on spruce budworms could shift poleward, perhaps becoming extirpated from latitudes below 50°N. Replacing biological control mechanisms with chemical control mechanisms (e.g., pesticides) ultimately may yield a different set of problems; there are economic and social issues relating to large-scale pesticide application.

Source: *(IPCC, 2001a: 5.6.2.2.2).*

It has also been shown that in the western United States, for example, warmer temperatures have *"already enhanced the opportunities for insect spread across the landscape"* (Crozier, 2002).

Similarly, the UK's Forestry Commission comments that changing climate will *"alter the fine balance between host tree, pathogens, insect pests and their predators".* Climate change will affect all of the following but in uncertain ways: winter dormancy, flushing date, growth, host-pathogen balance, insect population, evapotranspiration and soil turnover/mineralisation (Forestry Commission, 2002).

The Forestry Commission also gives the following examples of predicted changes in populations of pathogens, insects and mammal pests that all have a bearing on tree growth in commercial plantations:

- *Warmer weather is likely to encourage pathogens such as rust fungi (poplar) and phytophthora cinnamomi (oaks, chestnuts and other species).*
- *Increased temperatures are also likely to benefit the insect and other vectors of pathogens, such as the fungi that cause Dutch elm disease.*
- *Trees stressed by drought may be more susceptible to pathogens such as sooty bark disease (sycamore).*
- *Warmer weather could change the synchrony between host and insect pest development, including through increased winter survival of insects such as the green spruce aphid.*
- *Temperature changes could also encourage the appearance of exotic species such as the Southern pine beetle and Asian longhorn beetle.*

Local farmers' rubber plantation, burned down illegally by an oil palm company in West Kalimantan, 2008.

more forest fires

Whilst forest fires are part of the natural cycle of some forest ecosystems, suppression of forest fires can cause more harm than good, as it allows a build-up of inflammable forest materials.

Nevertheless, the fact that the frequency of forest fires is increasing (FAO, 2008b) is likely to have significant consequences for ecosystems. Fires consume plants, woody debris and soil organic matter, and kill forest-dwelling animals that cannot escape or survive the heat and smoke. They can also change soil productivity, forest structure and sedimentation rates in streams, with consequences for aquatic flora and fauna (ASC & MNHC, 2005).

Climate change is also a key driver. A trend toward hotter and drier conditions is, in general, likely to exacerbate the effects of fire by increasing the frequency, intensity, and size of burns. *"All it takes is a low snowpack year and a dry summer. With a few lightning strikes, it's a tinderbox,"* says Professor S. Tom Gower of the University of Wisconsin-Madison, who also observes that that *"Based on our current understanding, fire was a more important driver (of the carbon balance) than climate was in the last 50 years. But if carbon dioxide concentration really doubles in the next 50 years and the temperature increases 4 to 8 degrees Celsius, all bets may be off."* (ScienceDaily, 2007)

There are numerous reasons for the increasing frequency of forest fires, including land clearing, the presence of plantations (which are drier than forests) and certain agricultural and forestry practices. These include reducing the acidity of peat-based soils in the case of oil palm plantations, and facilitating and increasing sugar cane harvests.

Fragmented forests also mean more forest edge. These fragments/forest edges tend to be drier and more frequently logged, and are often adjacent to cattle pastures that are frequently burned (Laurance and Williamson, 2002).

It has been noted, for example, that the frequency of wildfires is increasing in Amazonia. In 2005, 2006 and 2007 there have been severe droughts in some areas; and in 2005 a large fire, covering some 2,800 square miles, burned for the first time in Acre State, in the south western Amazon.

Large losses from forest fire have also been incurred in many other countries in the last two decades or so, including in the Brazilian Amazon, China, Indonesia (Kalimantan and Sumatra), Mexico and Paraguay.

The fires that raged throughout rural Indonesia in 1997 (and do so every year) affected no less than 6% of the country's total landmass in 1997 and released 2.57 billion tons of carbon into the atmosphere (GFC, 2007). The damage inflicted by such fires and the associated haze is catastrophic. In Indonesia, wildlife, natural habitats and ecosystems in the worst affected areas were devastated. The IPCC points to land use change as the most significant factor, but does point out that *"The Indonesian fires of 1997-1998 were associated with a significant, but not unique, drought over much of the region"* (IPCC, 2001a: 5.6.2.2.1).

Furthermore, the area of boreal forest burned annually in western North America has doubled in the past 20 years (0.28% in the 1970s to 0.57% in the 1990s), in parallel with the observed warming trend in the region (IPCC, 2001a: 5.6.2.2.1).

Recent research also shows a sudden increase in the frequency and duration of wildfires in the mid-1980s, especially in the Northern Rockies forests, where land use change is not the cause. Rather, this change is strongly associated with increasing spring and summer temperatures and earlier spring snowmelt (Westerling *et al.,* 2006).

Decades of misguided forest management that suppressed natural fire patterns also led to a massive build-up of woody (DSF, 2008).

The IPCC reports similar studies, and adds that:

- *more rain can be a contributory factor (since it leads to the growth of more fine woody fuel);*
- *increasing numbers of lightning strikes can increase the risks of forest fire;*
- *there has been an increase in the risk, severity and frequency of forest fires in Europe; and*
- *the fire season is prolonged in some places, with an earlier start to the fire season along with increased severity of forest fires in, for example, parts of Canada and Russia (IPCC, 2001a: 5.6.2.2.1).*

On the other hand, the IPCC also argues that increased precipitation or stable temperatures can also be associated with decreasing risks of forest fire in other regions, such as eastern Canada. It also remarks that forest fires are less prevalent in developed countries generally, with the exception of countries in the former Soviet Union, Canada and the US. The IPCC argues that this is probably because of an improvement in fire prevention and control (IPCC, 2001a: 5.6.2.2.1).

Analysis in the US has indicated the possibility of a 10% increase in the seasonal severity of fire hazard over much of the United States (Alig *et al.,* 2004); and Scholze et al. also predict more frequent wildfires in Amazonia, the far north and many semiarid regions. (Scholze *et al.,* 2006)

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continued

extreme weather events

Extreme weather events, which are becoming more frequent and intense because of climate change, also damage forests (for more detail see IPCC, 2001a: 8.2.3). As the IPCC points out, *"Such events generally are highly localized and take place in a relatively short period of time but have long-term economic impacts. There is some evidence of recent increases in damage from such extreme events."* (IPCC, 2001a: 5.6.2.2.3) These extreme weather events include hurricanes, tornadoes, unexpected drought or heavy rainfall, flooding, and ice storms.

The IPCC reports, for example, that wind-throw damage in Europe appears to have increased steadily since about 1950, with wind-throws exceeding 20 million m3 occurring 10 times since then (IPCC, 2001a: 5.6.3.2.1).

Drought also has a particularly debilitating impact on forests. As the FAO, comments, "plants have a considerable ability to adapt to changing conditions and can tolerate even extremely high temperatures, provided sufficient water is available" (Kirschbaum, 1998). Similarly, research in the USA indicates that forest biomass is likely to contract in scenarios with less moisture (Bachelet et al., 2004).

The impact of climate change on forests' role in the hydrological cycle in general remains uncertain. The global hydrological cycle itself is expected to 'intensify' although precise impacts are uncertain at the moment (Defra/ARIC, 2008). Increased temperatures will tend to increase transpiration rates in forests, but drought, or even decreased soil moisture, will limit the quantity of water available to transfer. Increased levels of carbon dioxide will also suppress transpiration by causing stomata to close (Pallas, 1965). Increased rainfall may also lead to increased river flooding.

Rainforest in Borneo, Indonesia.

conclusions

There has been considerable research into the critical role that forests play in regulating climate. There is also a growing body of evidence pointing to the significant negative impacts that climate change itself is likely to have on forests, especially in relation to the way that forests interact with the planet's carbon and hydrological cycles.

However, more recent research seems to be widely dispersed and may be difficult for climate change and biodiversity negotiators and other interested parties to access. Yet this information is critical to decisions currently being made at the intergovernmental level, especially within the UN Framework Convention on Climate Change, which is now considering ways of reducing carbon emissions from deforestation.

This briefing brings together available current and/or relevant research, from which we can make some preliminary recommendations. Friends of the Earth international believes that governments must bear in mind that:

- ***Climate change is likely to have a significant negative impact on forests, which could lose their climate-regulating abilities.*** *Forests as a whole are predicted to lose their climate-regulating abilities if temperatures rise above 2°C. Forest ecosystems and tree species' distribution are likely to be severely disrupted by climate change; and the scale of this disruption is predicted to increase as temperatures rise.*
- ***Tropical forests are absorbing more carbon than previously thought; but they are also severely threatened by climate change.*** *Urgent action to stop deforestation in tropical forests, especially in the Amazon, must be an immediate priority, before dieback sets in and becomes irreversible, with unknown consequences for our climate.*
- ***Forest soils store huge quantities of carbon, especially in peatlands, and much of this carbon is lost to the atmosphere when these soils are denuded or otherwise disturbed.*** *Forest soils must be included in all calculations relating to the contribution that forests make to mitigating climate change. Peat should retain its IPCC classification as a fossil fuel.*
- ***Deforestation and inappropriate forest management policies lead to the drying out of forests, escalating the threat of forest fires and consequent emissions of vast quantities of carbon.*** *Governments should finance and otherwise resource a global forest fire-fighting fund and expertise, to assist countries unable to prevent or stop out-of-control forest wildfires on their own. At the same time, forest management policies should be changed to allow natural forest fires, thus reducing the risk of catastrophic, out-of-control fires.*
- ***The destruction of forests is likely to cause significant changes to weather and the climate and thus to ecosystems and food production.*** *There are thus multiple reasons to prioritise the protection of forests and governments need to ensure coordinated and effective collaboration between the various different national, regional and intergovernmental fora working on climate change, forests, biodiversity, development and hunger.*
- ***Excess nitrogen can boost soil respiration in tropical forests, leading to significant increases in carbon emissions.*** *The impacts of nitrogen pollution on forests need to be included in analyses underpinning the development of climate change mitigation measures. The use of fertilisers in forest management should be stopped.*
- ***Storing carbon in forests cannot be considered a long-term or permanent solution to climate change.*** *Avoiding deforestation is important, both in terms of mitigating climate change in the short-term and to protect the planet's biodiversity. However, it cannot be a substitute for keeping fossil carbon in the ground. Governments must implement a moratorium on all public financing and subsidies for oil, coal and gas exploration, and rapidly phase in subsidies for clean energy alternatives; and the UNFCCC must prioritise policies and mechanisms to phase out fossil fuel use and promote alternatives.*
- ***Replacing old growth forests with plantations is not an option.*** *At best, tree plantations store just 20% of the carbon that old-growth forests lock away. The FAO's definition of forests needs to be revised immediately, so that it explicitly excludes plantations. The inclusion of plantations in REDD policies and projects, for example, could lead the continued replacement of old growth forests with plantations.*
- ***The timber industry is wrong to promote the use of timber products in place of more fossil-fuel intensive goods (WBCSD, 2007).*** *This encourages the spread of plantations that store minimal levels of carbon and are anyway harvested within just a few decades. It also increases demand for timber products whatever their source, making it ever more difficult for governments to halt deforestation.*
- ***There is an urgent need to address the direct and underlying 'drivers' of deforestation.*** *Governments should focus on stopping industrial deforestation by reducing consumption of and national and international demand for forest products. They should also address insecure land tenure; recognize Indigenous Peoples' land rights; remove trade and investment liberalisation rules that fuel deforestation; stop corruption; and promote the re-use and recycling of timber and paper products (to delay the release of stored carbon back into the atmosphere).*
- ***Forest management should support community-led reforestation and forest restoration programmes.*** *Any climate change mitigation proposals intended to increase forest cover should focus on community-led reforestation or restoration programmes, using mixed native species (for more details see FOEI, 2008).*

glossary

You can find the UNFCCC glossary here:
http://unfccc.int/essential_background/glossary/items/3666.php

CGIAR	Consultative Group on International Agricultural Research
FAO	UN Food and Agriculture Organization
FOEI	Friends of the Earth International
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
LUCF	Land Use Change and Forestry
LULUCF	Land Use, Land Use Change and Forestry
REDD	Reduced Emissions from Deforestation in Developing countries
UNFCCC	United Nations Framework Convention on Climate Change

Members of the Allicock family from the Iwokrama Forest in Guyana.

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