CLIMATE CHANGE AND FORESTS

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INTRODUCTION

Mitigating global climate change through forestry was first proposed in the 1970s (Dyson 1977). It was not until the late 1990s, however, that international negotiations considered this potential at a global level, called for a definition and quantification of forests' role, and proposed a mechanism for international collaboration.

In 1992, the UN Framework Convention on Climate Change (UNFCCC) was adopted as a consequence of worldwide concern over global warming. It aims at stabilizing the concentration of greenhouse gases (GHGs) in the atmosphere in an effort to prevent human-induced disturbances to the global climate system. The industrialized countries and countries in transition that are parties to the UNFCCC (listed in Annex 1 of the Convention) committed themselves to carrying out national inventories of greenhouse gas emissions and carbon sinks, and to working toward meeting voluntary goals in the reduction of emissions. At the UNFCCC's third meeting of the Conference of the Parties, held in Kyoto, Japan in December 1997, an additional legally binding instrument was adopted, the so-called Kyoto Protocol. Thirty-nine developed countries (consisting of a slightly modified list of UNFCCC's Annex 1 countries) committed themselves to reducing their GHG emissions between 2008 and 2012 by at least 5 percent compared to 1990 levels. Parties can meet this commitment by reducing sources or protecting or enhancing sinks of greenhouse gases. The Protocol foresees the inclusion of changes resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and avoidance of deforestation.

The Kyoto Protocol also sets up a framework for the transfer of emission credits between parties. Three flexible mechanisms were introduced that permit signatory countries to partially or fully meet their commitments: projects jointly undertaken by Annex I countries (Joint Implementation), projects between Annex I and non-Annex I countries (Clean Development Mechanism) and emissions trading. Although the Kyoto Protocol has not been ratified and it is as yet[1] undecided whether forests will be included as sinks within the ambit of the flexible mechanisms, the potential impact of the negotiations' outcome merits a close look at the role of forests in the context of climate change.

GLOBAL CARBON CYCLE

The International Panel for Climate Change (IPCC)[2] estimates that the global, mean temperature of the Earth's surface has increased by 0.3-0.6ºC over the past 100 years (IPCC 2000). Predictions are that global warming will cause significant variations in climatic patterns over the next century that may have negative impacts on regional and global biomes. It is now generally accepted that this change in global temperature is caused primarily by rising atmospheric concentrations of 'greenhouse gases', principally carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). $CO_{2,}$ the most important of these greenhouse gases, accounts for some 65 percent of the "greenhouse effect". The rise of atmospheric CO_2 concentrations since the beginning of the industrial revolution has been caused by anthropogenic activity, in particular the combustion of fossil fuels, cement manufacture and deforestation.

Terrestrial ecosystems play a significant role in the global carbon cycle. An estimated 125 billion tonnes[3] of carbon (tC) are exchanged annually between vegetation, soils and the atmosphere, accounting for two-fifths of the total exchange of carbon between the earth and the atmosphere (see Figure 1). Forests account for some 80 percent of this exchange. While the world's forests are absorbing carbon, they are also releasing it.

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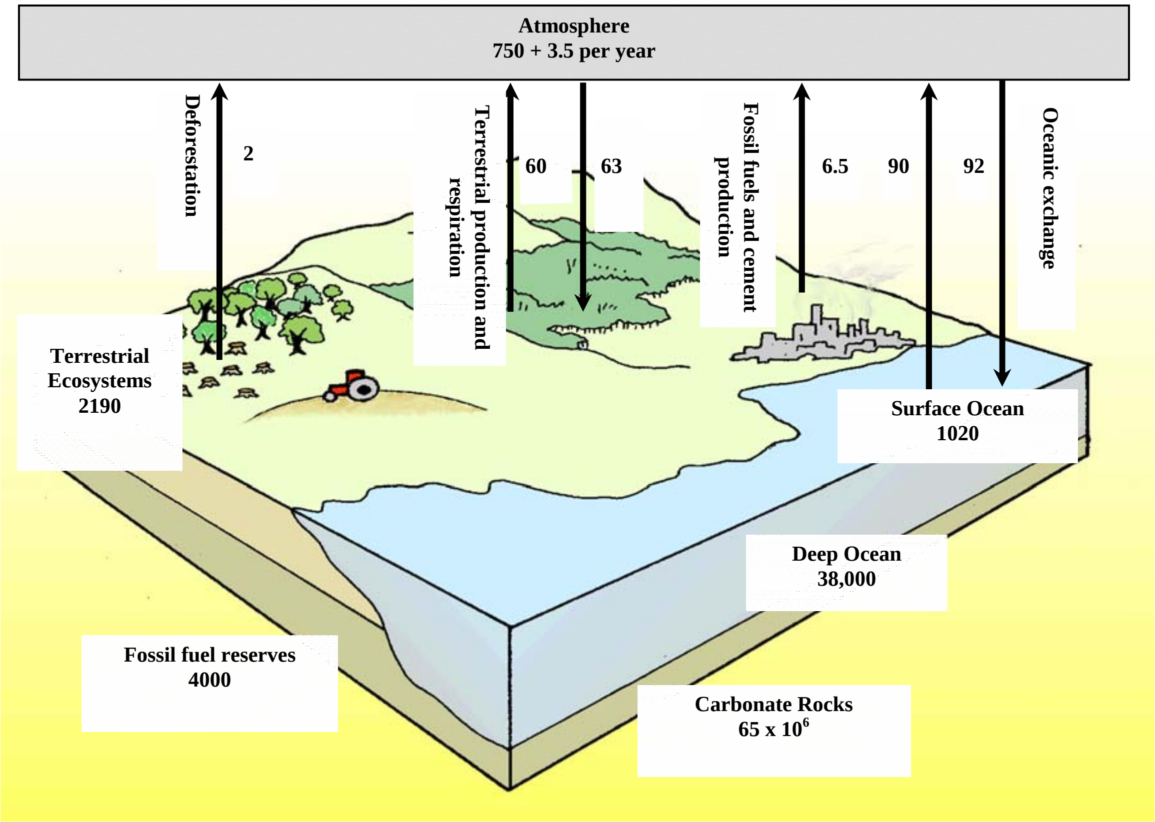
[1] as of October 2000

[2] The IPCC was set up in 1988 by the World Meteorological Organization and the United Nations Environment Programme. It provides scientific, technical and socio-economic information and advice related to human-included climate change to the world community, but in particular to the Parties of the UNFCCC.

[3] 1 billion tonnes is equivalent to a gigatonne, or Gt, which is referred to elsewhere in the text

Deforestation is a significant source of carbon emissions; evidence suggests that deforestation in the 1980s may have accounted for one-fourth of all anthropogenic CO_2 emissions (Houghton 1999).[4] However, it has been suggested that the terrestrial biosphere could be managed over the next fifty years to conserve or sequester 60-87 billion tC in forests and another 23-44 billion tC in agricultural soils (Brown *et al*. 1996).

Figure 1: An Estimate of the Current Global Carbon Cycle (all units in billion tC)



Note: The magnitude of the fluxes between the atmosphere and the oceans and terrestrial biosphere are still uncertain and are the subject of ongoing research.

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[4] Data for carbon emissions due to land use change in the 1990s are not yet available.

ROLE OF FORESTS IN THE GLOBAL CARBON BUDGET

Carbon stocks in forest ecosystems

Carbon accumulates in forest ecosystems through the absorption of atmospheric CO_2 and its assimilation into biomass. Carbon is stored in living biomass, including standing timber, branches, foliage and roots; and in necromass, including litter, woody debris, soil organic matter and forest products. Any activity that affects the amount of biomass in vegetation and soil has potential to sequester – or release - carbon from/to the atmosphere.

Overall, forests contain just over half of the carbon residing in terrestrial vegetation and soil, amounting to some 1,200 billion tC (see Figure 2). Boreal forests account for more carbon than any other terrestrial ecosystem (26 percent of total terrestrial carbon stocks), while tropical and temperate forests account for 20 percent and 7 percent respectively (Dixon *et al* 1994). In comparison to other vegetation in other terrestrial ecosystems, forest vegetation has a very high carbon density (see Figure 3).

Figure 2: Terrestrial carbon stocks by ecosystem (Dixon *et al* 1994, Schlesinger *et al* 1997)

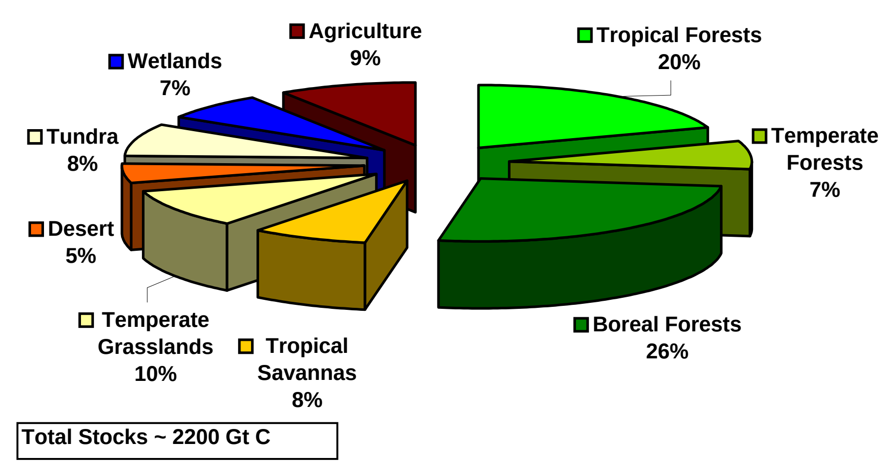
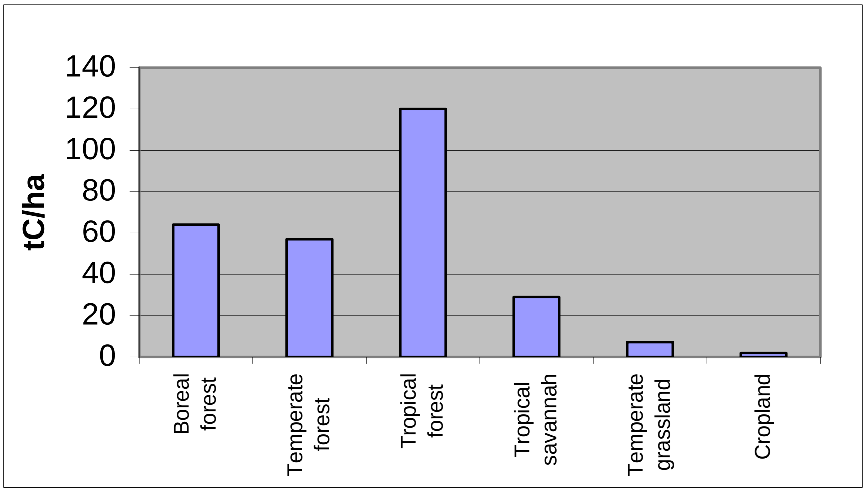


Figure 3: Above ground carbon density for selected vegetation types (IPCC 2000)



The carbon stored in the soil and litter of forest ecosystems also makes up a significant proportion of the total carbon pool. Globally, soil carbon represents over half the stock of carbon in forests. There are, however, considerable variations between ecosystem and forest types. Between 80 and 90 percent of the carbon in boreal ecosystems is stored in the form of soil organic matter, whereas in tropical forests the carbon is fairly equally distributed between vegetation and soil (see Table 1). The primary reason for this difference is the influence of temperature on the relative rates of production and decay of organic matter. At high latitudes (i.e. cooler climates), soil organic matter accumulates because it is produced faster than it can be decomposed. At low latitudes, however, warmer temperatures encourage rapid decomposition of soil organic matter and subsequent recycling of nutrients.

Table 1: Carbon density and stock of vegetation and soils for different ecosystems (Dixon *et al* 1994)

Ecosystem	Country	Vegetation carbon density (t ha^{-1})	Soil carbon density (t ha^{-1})	Vegetation carbon stock (Gt[5])	Soil carbon stock (Gt)	Total Carbon stock (Gt)
Boreal	Russia	83	281	74	249	323
	Canada	28	484	12	211	223
	Alaska	39	212	2	11	13
Temperate	USA	62	108	15	26	41
	Europe	32	90	9	25	34
	China	114	136	17	16	33
	Australia	45	83	18	33	51
Tropical	Asia	132-174	139	41-54	43	84-97
	Africa	99	120	52	63	115
	America	130	120	119	110	229

Carbon fluxes from forest ecosystems

All forest biomes have undergone major changes in distribution since the last glacial maximum (18,000 years ago), when the climate was both cooler and more arid than it is today. Boreal and northern temperate forests were squeezed between advancing ice sheets and steppe tundra from the north and expanding semi-desert and steppe tundra from the south, while tropical rainforests retreated into small pockets as savanna expanded. The amount of carbon stored in terrestrial biomes was 25 to 50 percent lower than at present. Terrestrial carbon storage peaked in the warm, moist early Holocene period about ten thousand years ago and subsequently declined by about 200 billion tC to the level today (2200 billion tC), probably because of a gradual cooling and aridification of the climate.

Prior to the nineteenth century, humans exerted only a modest influence on terrestrial carbon storage through fire, fuel use and deforestation, but since the outset of the industrial revolution, human activities have had a major effect on the global carbon cycle. Between 1850 and 1980, over 100 billion tC were released to the atmosphere through land use changes, representing around one-third of the total anthropogenic carbon emissions over this period (Houghton 1996).

Until the late nineteenth century, most forest clearing and degradation took place in temperate regions. In the twentieth century, the area of temperate forest largely stabilized and tropical forests became the primary source of CO_2 emissions from terrestrial ecosystems (Houghton 1996). Today, forest cover in developed countries is increasing slightly: between 1980 and 1995 there was an average increase of 1.3 million ha per year (FAO 1999). In recent decades, many temperate forest regions (such as Europe and eastern North America) have become moderate carbon sinks through the establishment of plantations, the regrowth of forests on abandoned agricultural lands, and increased growing stock on forest. In contrast, tropical forests have become a major source of carbon emissions; the rate of tropical deforestation is estimated to have been 15.5 million ha per year over the period 1980-1995 (FAO 1999).

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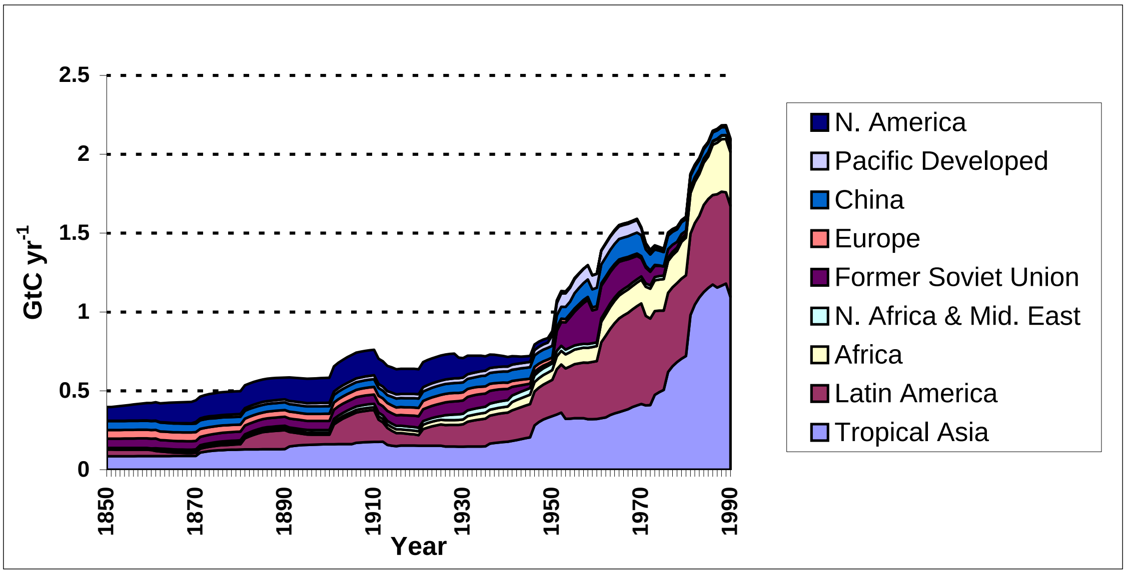
[5] 1Gt is equal to 1 billion tonnes

Net carbon emissions due to land use change in the 1980s are estimated to be between 2.0 and 2.4 billion tC per year, equivalent to 23-27 percent of all anthropogenic emissions (Houghton 1999, Fearnside 2000). Tropical deforestation accounts for most of the carbon emissions from land-use change. The burning of biomass also releases other greenhouse gases, including methane and nitrous oxide. Burning of forest biomass accounts for 10 percent of global methane emissions. Forest degradation also results in carbon loss. An estimated net emission of 0.6 billion tC annually was due to degradation of forests in the tropics during the 1980s (Houghton 1996). In tropical Asia, the loss of carbon due to forest degradation almost equals that due to deforestation.

Figure 4: Carbon emissions from land use change (source: Houghton 1999)



There is accumulating evidence that human-induced changes in concentrations of atmospheric gases are affecting the carbon cycle in forests. Global atmospheric CO_2 concentrations have risen from 280 ppm before the industrial revolution to 370 ppm in 2000, and nitrogen deposition rates in forests near industrial regions have increased substantially. Both these effects are likely to lead to an increase in plant growth and productivity. Permanent forest sample plots in climax forests of North and South America have shown significant increases in forest biomass in recent years. Other evidence for enhanced carbon uptake in forest regions comes from micrometeorological measurements of CO_2 fluxes above forests and assessments of atmospheric CO_2 distributions at continental scales. These studies suggest that, through the combined effects of reforestation, regrowth of degraded forests and enhanced growth of existing forests, between 1 and 3 billion tC are absorbed per year, approximately off-setting the global emissions from deforestation.

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If the temperature at the earth's surface increases over the twenty-first century as predicted, all ecosystems will experience the most rapid period of climate change since the end of the last ice age. The distribution and composition of forests will be affected by this change, and management strategies will need to accommodate the prospect of rapidly shifting climate zones and ecosystem margins.

Box 1 presents the predicted impacts on major forest types under climate change scenarios as indicated by IPCC models of global climate change in the twenty-first century. The models show a fair degree of consistency in their predictions of global warming, with less agreement on changes in precipitation. All these model scenarios assume that no big "surprises" will occur (e.g. the sudden release of methane from ocean

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[6] The contents of this section are based on WCMC (in press) *Forests in flux: forest ecosystem response to climate change* and are reproduced with kind permission of the World Conservation Monitoring Centre

deposits or the oxidation of northern forest soil carbon reserves either of which would lead to accelerated warming, or the slowing down of the North Atlantic thermohaline circulation which would possibly lead to climate cooling). Using the IPCC climate prediction scenarios, the key changes expected towards the end of the twenty-first century are:

- the atmospheric concentration of CO_2 will approximately double;
- the mean global temperature will increase by 1.5-4.5 °C;
- precipitation will increase globally by 3-5 percent;
- sea level will rise by about 45 cm.

Regional climate predictions are needed to determine the impacts on forests. There is a fair degree of confidence in most regional temperature predictions. The largest increases in temperature will be in the northern high latitudes, with lower increases nearer the tropics and in regions with a strong oceanic influence. Although precipitation will increase globally, regional predictions are less reliable. Overall, the key climatic changes controlling forest growth responses will be temperature increases at high latitudes and changes in rainfall at low latitudes. Any regions with increased temperature and unchanged or reduced rainfall will experience significant reductions in soil moisture, which will constrain plant growth and increase the likelihood of fire. Large outbreaks of fire may lead to significant losses of forest cover.

Existing forest stands may persist for some time under a changed climate, but long-term responses to climate change will depend on the capability of species to adapt to the new conditions or to change their geographical distributions. This capability will be determined by the variation within and between species in their physiological responses to changes in temperature, CO_2 concentration, soil moisture and, in some areas, increased nitrogen deposition. It will also depend on soil types and the ecological relationships between species that affect pollination, dispersal and damage through herbivory or pest and pathogen attacks. The nature of the landscape and the intensity of human activities will also be factors. For example, habitat fragmentation will affect how effectively species can change their geographic range in response to ecosystem shifts. Mountains may be particularly important refugia in a warming climate because many species will find it easier to shift their range upward in altitude to a cooler climate than upward in latitude over large distances. Changes in species distribution may lead to new species assemblages and may involve species losses.

Changes in forest cover could induce feedback effects on the climate by modifying surface temperatures and by influencing atmospheric CO_2 concentrations. Forests have a lower albedo (*i.e* reflect less light) than other ecosystems and, through extensive root systems, have more access to soil water than other types of vegetation. In consequence they absorb more solar energy, which can lead to heating, and lose more water through evaporation, which can lead to cooling. In tropical zones evaporation processes tend to dominate and the net effect of forests is to cool and moisten the atmosphere, whilst at higher latitudes albedo effects are more important, leading to local warming.

Box 1: Impacts of climate change on different forest types

Boreal forests will experience the largest temperature increases of all forests. The warming effect is expected to be greater in winter (4.0 °C above 1970s levels by the mid twenty-first century) and slightly lower in summer (2.5-3.0 °C above 1970s levels). Reduced moisture in the soil during summer will increase drought-stress and the frequency and extent of wild fires. Climate zones are expected to shift northwards as much as 5 km per year. Boreal forests will make gains in areas to the north, but will experience dieback and replacement at their southerly extremes. Changes in the frequency, intensity and extent of wild fires in response to increased heat stress will play a critical role in determining the dynamics of the changes at the southern fringe of the boreal forests. Models used to predict the long term potential changes in the distribution of vegetation suggest that the overall response may be either a reduction (by up to 36 percent) or an expansion (by up to 16 percent) of boreal forest area, though a reduction is more likely. Few tree species are likely to go extinct, but local species loss may be significant.

Temperate forests will be affected most at higher latitudes by climate warming (2.6 °C above 1970s levels by the midtwenty-first century) and at lower latitudes by changes in rainfall. Drought-stress at certain low-latitude margins (such as the Mediterranean and south-western USA) may lead to significant dieback, whilst increased temperature may enhance growth at higher latitudes. Climate zones will shift toward the poles at rates of up to 5 km per year. The potential area available for temperate forest growth is likely to expand by between 7 percent and 58 percent. The high level of fragmentation of many temperate forests is likely to limit effective dispersal of some tree species (and have an impact on forest-based wildlife). This may lead to significant species losses locally.

Tropical forests are expected to warm by 2.0 °C above 1970s levels by the mid twenty-first century, with larger increases in continental interiors. Changes in rainfall regime, however, are likely to be more important than changes in temperature, although model predictions of regional rainfall patterns vary substantially. Where there are reductions in rainfall and higher temperatures, reduced soil moisture is expected to be the most significant threat to tropical forests. These effects may increase vulnerability to fire or lead to significant dieback or changes in vegetation types in marginal areas. Interannual variability through large-scale climatic events (such as caused by El Niño), may exacerbate rainfall extremes. Depending on future climate scenarios, the potential tropical forest area could shrink up to 30 percent or expandup to 38 percent. In most tropical regions, the impact of human activities, such as deforestation or fire, will be more important, however, than climate change in determining forest cover. A shrinking of the area of tropical forests, particularly of moist tropical forests, would likely result in significant species losses.

Tropical montane cloud forests are expected to warm by 1.0-2.0 °C by the mid twenty-first century, but are most threatened by changes in the height of the cloud base, on which they depend for dry season water supply. Cloud base heights are likely to rise as much as 2 meters per year, This would affect the species in this area. Where mountains are isolated and insufficiently high to accommodate upward changes in cloud height, climate change may lead to local, if not total, extinction of some montane vegetation species (many of which are endemics). There is evidence from cloud forest in Monteverde, Costa Rica, that such changes are already occuring. Cloud forests may be harbingers of climate change effects on global forest ecosystems.

Mangrove forests are expected to be able to adapt to rising temperatures, but may be threatened by rising sea levels. This threat will be particularly acute on sediment-poor coasts, such as those found on small islands, and in areas where inland disperal of forest species is constrained by human land use.

Source: WCMC, in press

CARBON MANAGEMENT STRATEGIES

There are three possible strategies for the management of forest carbon (see Table 2). The first is to increase the amount or rate of carbon accumulation by creating or enhancing carbon sinks (carbon sequestration). The second is to prevent or reduce the rate of release of carbon already fixed in existing carbon sinks (carbon conservation). The third strategy is to reduce the demand for fossil fuels by increasing the use of wood either in durable wood products (i.e. substitution of energy intensive materials such as steel and concrete) or as biofuels (carbon substitution). These strategies are not mutually exclusive. A number of carbon sequestration and carbon conservation initiatives have already been developed, including Activities Implemented Jointly[7] (AIJ) under the UNFCCC and Land Use Change and Forestry (LUCF) carbon projects.

Table 2: Overview of terrestrial carbon management strategies and potential land use and forestry activities (Bass *et al* 2000)

Carbon management strategy	**Type of land use and forestry activity**
Carbon sequestration	• Afforestation, reforestation and restoration of degraded lands • Improved silvicultural techniques to increase growth rates • Implementation of agroforestry practices on agricultural lands
Carbon conservation	• Conservation of biomass and soil carbon in existing forests • Improved harvesting practices (e.g. reduced impact logging) • Improved efficiency of wood processing • Fire protection and more effective use of burning in both forest and agricultural systems
Carbon substitution	• Increased conversion of forest biomass into durable wood products for use in place of energy-intensive materials • Increased use of biofuels (e.g. introduction of bioenergy plantations) • Enhanced utilisation of harvesting waste as biofuel feedstock (e.g. sawdust)

Carbon sequestration

The carbon sequestration potential of afforestation/reforestation (AR) is specific to the species, site and management involved, and is therefore very variable. Typical sequestration rates, in tC per hectare per year, for AR are: 0.8-2.4 tC in boreal forests, 0.7-7.5 tC in temperate regions and 3.2-10.0 tC in the tropics (Brown *et al* 1996). The sequestration potential for agroforestry practices is even more variable, depending on the planting density and production objectives of the system.

Assuming a global land availability of 345 million ha for AR and agroforestry activities, Brown *et al* (1996) estimate that approximately 38 billion tC could be sequestered over the next fifty years (30.6 billion tC by AR and 7 billion tC from increased adoption of agroforestry practices) - see Figure 5. Studies of tropical regions indicate that an additional 11.5-28.7 billion tC may be sequestered through assisted regeneration of some 217 million ha of degraded land.

However, the actual availability of land for forestry activities may be considerably less when social and economic factors are taken fully into account. Only one-third of ecologically suitable land may actually be available for AR activities (Houghton *et al* 1991). Under this scenario, AR and agroforestry activities would absorb about 0.25 billion tC per year and restoration of degraded lands a further 0.13 billion tC per year.

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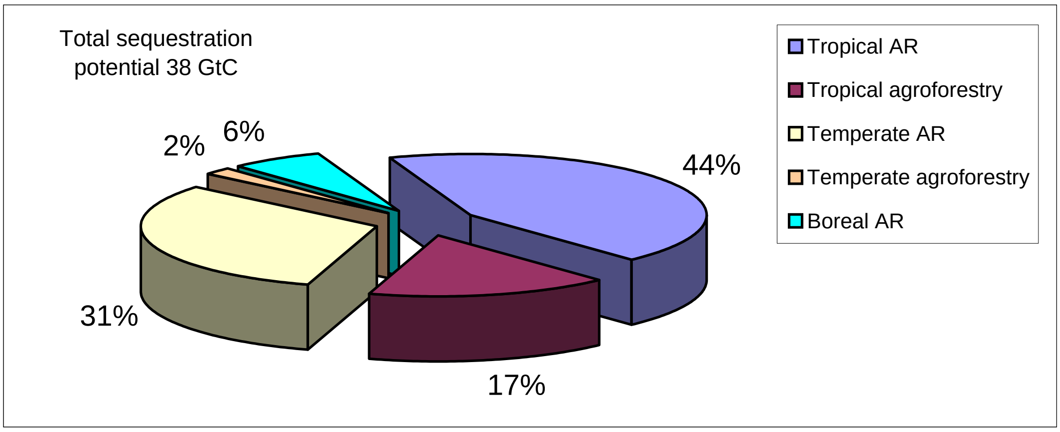
[7] AIJ projects are pilot projects under the UNFCCC to test and evaluate the feasibility of achieving the Convention’s objectives through cooperative efforts between Parties to avoid, sequester or reduce GHG emissions.

Figure 5: Potential contribution to global sequestration by AR and agroforestry activities 1995-2050 (data from Brown *et al* 1996)



Silvicultural activities that increase the productivity of forest ecosystems such as timely thinning, can increase forest carbon stocks to some extent. However, the effect of varying silvicultural systems on total carbon stocks in comparison to AR activities is relatively low (Dixon *et al* 1993).

Carbon conservation

The conservation of existing forest carbon stocks has the greatest potential for rapid mitigation of climate change. As the majority of carbon emissions from deforestation occurs within a few years of forest clearance, reducing the rate of deforestation will produce a more immediate effect on global atmospheric CO_2 levels than will AR measures, in which similar volumes of carbon may be removed from the atmosphere but over a much longer period.

The potential for carbon conservation through the maintenance of forest cover is dependent on the assumed baseline for non-project deforestation (i.e. “business as usual”). In principle, 1.2-2.2 billion tC could be conserved annually if deforestation were completely stopped (Dixon *et al* 1993). However, while carbon revenues could improve the economics of forest land, projects will also have to address the underlying causes of deforestation and unsustainable use to achieve effective carbon conservation. Brown *et al* (1996) estimate that a reduction in deforestation in tropical regions could feasibly conserve 10-20 billion tC by 2050 (0.2-0.4 billion tC per year).

The conservation of carbon stocks in existing forest may be achieved through improved management practices. Potentially the most important is the use of reduced impact logging in the tropics. Conventional logging practices may result in a high level of damage to the residual stand, with up to 50 percent of remaining trees damaged or killed (Kurpick *et al* 1997). Application of reduced impact logging techniques can reduce the level of damage to the residual stand by 50 percent (Sist *et al* 1998) and hence reduce the level of carbon emission associated with logging. Nabuurs and Mohren (1993) calculated that long term carbon conservation due to reduced impact logging in tropical rainforest may be between 73 and 97 tC per hectare. Given that an estimated 15 million hectares of tropical forest is logged each year (Singh 1993), the majority of which is considered to be unsustainable (Poore 1989), the potential for increased carbon storage is large. The additionality of carbon conserved through RIL techniques is dependent on the assumption that conventional logging would continue in the absence of intervention and there are concerns over quantifying the changes in carbon stocks associated with changes in harvesting practices (IPCC 2000 Chap 4).

Wildfires result in large losses of carbon from forests every year. Weather conditions brought on by climate change, such as the enhanced El Niño, increase the potential risk of wildfires. Fire management practices have the potential to conserve carbon stocks in forests. However fire prevention and fire fighting efforts must be combined with land use policy changes and measures to address the needs of rural populations if fire management is to be effective. There could also be problems of assessing the baseline for fire prevention projects, which will be dependent on interactions between human factors and stochastic factors such as weather.

Carbon substitution

Biofuels currently provide 14 percent of global primary energy supply. In developing countries biofuels account for one third of total energy supply. If current biofuel use were to be replaced by fossil fuel derived energy, an additional 1.1 billion tC per year would be released into the atmosphere (IPCC 2000 Chapter 5). In contrast to the combustion of fossil fuel, the use of sustainably produced biofuels does not result in a net release of CO_2 into the atmosphere since the CO_2 released through the combustion of biofuels is taken up by re-growing biomass. The substitution of fossil fuels by sustainable biofuels will therefore result in a reduction of CO_2 emission directly proportional to the volume of fossil fuel replaced. Predictions of the future role of biofuels in meeting energy requirements range from 59-145 x 10^{18} J for 2025 and 94-280 x 10^{18} J for 2050 (Bass *et al* 2000). The future usage will depend to a large extent on the development of technologies that permit efficient use of biofuels, such as the gasification of wood products.

New biofuel plantations will also have a long-term positive sequestration effect if they replace a land use with lower sequestration rate. Although the long-term average carbon density of a forest managed for biofuels (particularly for short-rotation coppice) will be lower than an unharvested forest or long rotation plantation, they store more carbon than most non-forest land uses. Conversely if natural forests are replaced with short rotation coppice for biofuel production, the beneficial effect of fossil fuel substitution will be lost by the emissions resulting from forest conversion.

The use of wood products in place of materials which are associated with the release of large volumes of carbon dioxide (either during processing, such as cement, or through energy consumption, such as steel) could also lead to significant net CO_2 emission reductions.

Experiences in LUCF project based activities

There are currently 16 approved international AIJ projects involving land use change and forestry (UNFCCC 2000). Table 3 provides a summary of a representative set of LUCF projects currently under implementation covering some 3.5 million hectares (IPCC 2000 Chap 5). Eighty-three percent of this area is managed for the conservation of carbon in existing forests, either through forest protection (i.e. zero harvesting) or forest management (sustained production). Long-term carbon conservation by these projects varies from 40-108 tC per hectare from forest management and 4-252 tC per hectare from forest protection. The estimated total lifetime sequestration effect of these project is 5.7 million tC from forest management and 40-108 million tC from forest protection. A further 180,000 ha is managed for AR activities and will offset[8] an estimated 21.7 million tC over project time scales. Two projects, covering 200,000 ha, involve agroforestry and are expected to offset an additional 10.8 million tC. Box 2 gives some example of activities undertaken in LUCF projects.

The cost per tonne of carbon for the projects described in Table 3 ranges from US$ 0.1 to US$ 15 per tC. However, it should be noted that the approaches for calculation of the costs of carbon sequestration vary considerably between projects and long term estimates may need to be revised upwards. The eventual uptake of carbon sequestration potential will be dependent on the comparative costs of emissions reduction from the energy sector; some studies indicate that the market for carbon from the forestry sector may be below 1 billion tonnes.

Table 3: Comparison of selected LUCF projects (IPCC 2000 Chap 5)

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[8] In this context, a carbon offset is the amount of carbon withdrawn from the atmosphere by storage in vegetation and soil over an agreed period (100 years is the convention used by the IPCC to calculate warming potential) to compensate for the radiative forcing of an emission of a specified quantity of CO_2 or other greenhouse gas.

Project type		No. of projects	Area (million ha)	Carbon stored (million tC)	Carbon stored (tC ha^{-1})	Costs ($/tC)
Sequestration	AR	8	0.18	21.7	26-328	1-28
	Agroforestry	2	0.2	10.8	56-165	0.2-10
Conservation	Protection	7	2.9	40-108	4-252	0.1-15
	Management	4	0.33	5.7	0.2-85	0.3-8

Box 2: Examples of Joint Implementation projects currently in operation

Rio Bravo Conservation and Management Area, Belize

The Rio Brava project involves the protection of 14,000 ha of “endangered” forest land and the development of a sustainable management programme for an additional 46,000 ha of forest. The project is managed by a Belizean NGO, the Programme for Belize, and is financed in part by carbon offsets sold to a group of US electricity utilities. In total, an estimated 2.5 million tC would be conserved over the 40 year life of the project, with an average potential of 36 tC per ha at a cost of US$ 3 per tC. The baseline case against which carbon benefits are calculated assumes that, without the project, whole area of endangered forest would be deforested within five years. The land was previously privately owned and probably would have been sold to neighbouring farmers who expressed interest in expanding their farms.

Reduced Impact Logging in Sabah, Malaysia

Under this project, which involves the forest concession Innoprise Corporation Sdn. Bhd. and New England Power of USA, reduced impact logging techniques were adopted for use in 1,400 ha of dipterocarp forest in Malaysia for a period of two years The resulting 50 percent reduction in damage to the forest vegetation (compared with conventional logging methods) conserved an estimated 40 tC per ha at a cost of about US$ 8 per tC. The calculation of carbon benefits assumes that use of conventional logging methods would have continued if the project had not intervened. Thus, carbon conserved is additional for only as long as conventional logging practises would have continued.

Scolel Te community forestry project in Chiapas, Mexico

The project was set up by the University of Edinburgh and the Edinburgh Centre for Carbon Management in the UK and El Colegio de la Frontera Sur in Mexico, with funds from the Department for International Development of the UK. Its aim is to develop model planning and administrative systems by which small farmers can gain access to carbon markets. Under the project, small farmers and local communities identify reforestation, agroforestry and forest restoration activities which are both financially beneficial and are intended to sequester or conserve carbon The proposed activities are entered into a planning and evaluation system and the offsets are sold through a trust fund managed by a local NGO, Ambio. The systems are now well developed and carbon has been sold to various purchasers, including the International Automobile Federation. Around 300 farmers, with an average of about 1 ha of forest each, are currently involved. The average sequestration potential is 26 tC per ha at a cost of US$ 12 per tC.The system applies a simple additionality criterion: carbon sequestration is deemed to be additional if one of the objectives of the planned afforestation is carbon sequestration. The baseline used is the mean carbon storage of the previous land use, the assumption being that the land use would have continued in the absence of project intervention.

Carbon sink project in Mato-Grosso, Brazil

The project aims to sequester carbon in a plantation of native species established on degraded land. The plantation is about 5000 hectares in size and is located on a private landholding of 15,000 hectares. Only the plantation constitutes the carbon sink, but efforts are also being made to conserve the natural forest even though it doesn’t count toward the carbon balance. The project is funded by the French car manufacturer, Peugeot, as a contribution to its environmental preservation policy. It is managed by ONF Brazil, a subsidiary of the Office National des Forêts of France, and the Instituto Pro Natura, a Brazilian NGO. The duration of the project is 40 years. Peugeot’s contribution is US$ 10 million. The objective is to maximize carbon sequestration, while using local species and maintaining or enhancing the biological diversity in the area. The project represents a first step toward reestablishing natural forest through the rehabilitation of pastures and the elimination of introduced grass species. The baseline is based upon the continuation of the previous land use.

Management of the “Reserva forestal Malleco” in Chile

The project purchases the right to implement the management plan on 16 625 hectares of natural, State-owned forest. Chilean regulations prohibit the transformation of this kind of forest to exotic species plantations. The purpose of the project is to promote sustainable management of the forest to prove its feasibility in both economic and carbon sequestration terms. The project is managed by the Corporacion Nacional Forestal of Chile (CONAF) and the Office National des Forêts of France and is sponsored by the French Fund for World Environment. The project involves an adjustment of the methods of measuring carbon flux for this kind of ecosystem. The calculation of carbon benefits will be done from a “without project scenario” baseline.

Sources: Stuart and Moura Costa 1998; IPCC 2000 Chap 5; Tipper *et al* in press; and Conseil Général du Genie Rural des Eaux et des Forêts, pers. com.

ACCOUNTING FOR CARBON SEQUESTRATION BY FORESTRY

The accounting of greenhouse gas emissions attributable to nations, companies and industrial processes has become an important component of international agreements and national policies to address climate change. The accounting of carbon benefits attributable to forestry activities has become an area of significant interest because of the potential of forestry to contribute to national emission reduction targets negotiated under the UNFCCC, and the potential value of forestry projects to offset emissions from specific businesses or business activities.

National carbon accounting

National emissions or uptake of carbon by forests are accounted on an annual basis and are expressed in tonnes of CO_2 released or sequestered. Advances toward the targets set under the Kyoto Protocol are measured in terms of emissions or uptake relative to 1990. Under Article 3.3 of the Protocol, only the uptake of carbon by afforestation, reforestation and avoided deforestation may be counted towards national emission reduction targets. The precise definitions of afforestation, reforestation and avoided deforestation are still being discussed.

Project carbon accounting

Additionality and baselines

While national emissions and uptake of carbon are measured in absolute terms within national boundaries, the effect of forestry projects are measured relative to a hypothetical “without project scenario” or “baseline”. The definition of a project baseline could be derived in a number of ways, including the extrapolation of previous trends in land use change, the expected impacts of current standard forestry practices, or by modelling of the social and economic pressures on forest resources. Standard methods have yet to be agreed upon. When a project and baseline case are compared, so-called “additionality” tests may be applied to ascertain whether carbon sequestration is attributable to the project or simply to incidental factors, including shifts in policy or socio-economic conditions outside the scope of the project.

Project boundaries and leakage

The setting of project boundaries will have an important effect on the emission reductions attributed to project activities. If a project envisages the protection of a particular area of forest but involves the shifting of forest clearing to another area, there is potential for a “leakage” of project benefits. Similarly, if an afforestation project leads to a reduction in timber prices and subsequent reduced investment in commercial plantations or increased clearance of forest land to fulfil subsistence food requirements, the net sequestration will be reduced. Project boundaries also need to be set to include all flows or stocks of carbon that might be significantly affected by project activities; this may include carbon stored in harvested timber products.

Project timescales and crediting

The long timescales associated with forest growth, particularly in temperate and boreal regions, and the potential reversibility of carbon gains through forestry activities are key features of land use change and forestry projects. A number of alternative conventions for crediting the carbon sequestration or avoided emissions from forestry have been proposed:

- *Ex-ante*, or up-front, crediting of future carbon sequestration which would enable project developers to take credit for carbon uptake and storage that will occur in the future. This would make project development relatively easy but would require other mechanisms to guarantee fulfilment and long-term maintenance of carbon gains.
- Staged crediting, in which credit for carbon sequestration would be accrued in stages, so that project developers would have to demonstrate carbon gains before gaining recognition.
- *Ex-post*, or delayed, crediting in which credit for sequestration would only be given after carbon had been stored for a certain time, e.g. 40 or 50 years. This type of crediting would provide a strong measure of guarantee of carbon offset project effectiveness, but would provide little incentive for their development.

CONCLUSIONS

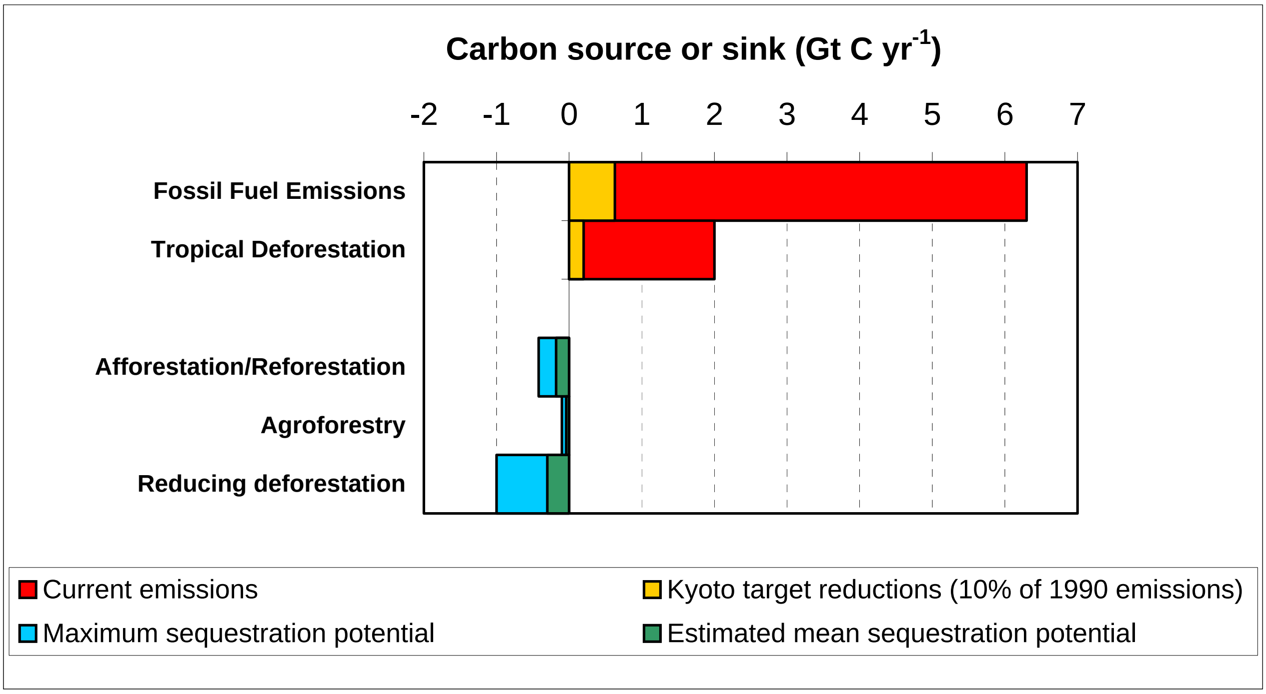
Forests are an important component of the global carbon cycle. They both influence and are influenced by climate change. And their management or destruction will have a significant impact on the course of global warming in the twenty-first century.

Forest ecosystems contain over half of all terrestrial carbon. They account for about 80 percent of the exchange of carbon between the Earth and the atmosphere. Although forest ecosystems absorb between 1 and 3 billion tC annually through regrowth in degraded forests, reforestation, and CO_2 and nitrogen fertilisation effects, they release about the same amount (2 billion tC) each year through deforestation. Deforestation in the 1980s may have accounted for one-quarter of all anthropogenic CO_2 emissions.

If predicted climate changes materialize, the impacts on forests are likely to be dramatic and long-lasting. Forest ecosystems may persist for some time under changed climatic conditions, but long-term responses will depend on the capability of species to continue adapt to the new conditions or to change their geographical distribution.

Forest management can contribute towards emissions reductions and to supporting attempts to control CO_2 emissions (see Figure 6). Conservation of existing carbon stocks in forests is potentially a more powerful tool than carbon sequestration. However, forestry measures alone will not be enough to halt the increase in atmospheric CO_2 concentrations. They may only complement efforts to reduce CO_2 emissions from the burning of fossil fuels.

Figure 6: Estimates of carbon sources and the sink potential of various land use options



Note: For AR, the potential rate assumes that 30 percent of suitable land is used; the maximum rate assumes that all available land is used. For reducing deforestation, the potential rate is based on the estimates of Brown *et al*. 1996; the maximum rate assumes a steady decline in tropical deforestation, with a complete halt after 50 years.

The Kyoto Protocol may have a profound influence on the forest sector. But its precise impacts will depend on which forestry activities are included as eligible measures for climate change mitigation and what rules and standards are applied to potential projects. Opinions about the role of forestry within the Protocol's "Clean Development Mechanism" (CDM) are divided.

Opponents of forestry's inclusion within the CDM argue that incentives for carbon sequestration are likely to lead to uncontrolled investment in industrial-scale forestry activities, with negative social and biodiversity consequences. Some observers fear that the availability of forestry as a low-cost means of achieving emission reduction targets will divert investment from efforts to reduce emissions at source. There are also concerns about the sustainability and measurability of forestry project impacts.

Proponents, however, see potential social, economic and biodiversity benefits arising from investment in high quality conservation, agroforestry and sustainable forest management initiatives and argue that the additional economic (or carbon) value given to forests may provide useful impetus to sustainable forest management efforts.

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