INTRODUCTION

Until recently, much of the debate and concern surrounding the loss of tropical forests has focused on the loss of biodiversity, and to a lesser extent, the loss of resources on which forest-based peoples depend. More recently, the potential impacts on climate and weather have been highlighted, in part reflecting growing evidence of the onset of the effects of global warming. These discussions have mainly been concerned with the role of forests as sinks and sources of carbon. However, this is not the whole picture. Forests also influence climate through their physical characteristics, influencing the transfer of water and energy to the atmosphere.

This report presents current evidence for the role of tropical forests, and in particular, those of the Congo Basin, in local, regional and global climate processes. Firstly, data on their significance as both a sink and source of greenhouse gases is presented. This is followed by a review of research into the role of this region's forests in weather patterns through their influence on atmospheric circulations. Finally, the significance of these findings for forest policy within the region and internationally is considered, focusing in particular on recent proposals to develop mechanisms to promote forest conservation within the international climate regime.

FORESTS & GREENHOUSE GASES

In the tropics, depletion of forest resources and land-cover change have been the primary source of carbon emissions. These phenomena are estimated to be releasing about 1.6 (0.8-2.4) Gt C/yr.[1], most of which is attributable to deforestation and degradation. By comparison, fossil fuel emissions are about four times this level, at 6.3 Gt C/yr. (Chomitz, 2006). These figures not only highlight the crucial role of forests in the carbon cycle, but also the shortcomings in our understanding of it, apparent from the wide range of possible values for emissions from land-use change.

BACKGROUND

Forests play an important role in the cycling of greenhouse gases, acting as both a sink and source of these gases. In discussions of global warming, most discussion is focussed on the role of carbon dioxide (CO^2), and indeed this is the most important of the greenhouse gases, having contributed some 58% of the greenhouse effect up to 2000 (Houghton, 2005a). However, there are in fact a number of greenhouse gases, and forests play a role in the cycling of a number of these. The most important after CO^2 are methane (CH^4) and nitrous oxide (N^2O), which contributed 21% and 6% of the greenhouse effect respectively until 2000 (Houghton, 2005a).[2] However, most assessments of the role of forests on climate change only consider CO2 emissions, and in fact, there are no reliable global estimates of emissions of either CH^4 or N^2O from land-use change (Baumert et al., 2005). Since there is little information available on the importance of other greenhouse gases, this report will only focus on the carbon cycle. However, it should be noted that emissions of these other gases are significant, one estimate suggesting that they could add up to 15% to the impact of forests on climate change (Fearnside & Laurance, 2004).

Forests influence the carbon cycle through their ability to store carbon and exchange it with the atmosphere. Plants absorb CO^2

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[1] 1 Gt = 1 billion tonnes / 1 x 109 tonnes

[2] The Kyoto Protocol is concerned with 6 greenhouse gases: Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF6)

through photosynthesis, and some is released through respiration or the decomposition of dead vegetation, while the remainder is stored in biomass, necromass and the soil (Locatelli & Karsenty, 2004). Therefore, forests act as a reservoir (storing carbon), a sink (absorbing carbon) and also as a source of carbon.

Calculating the carbon stored in forests and also the flux of carbon between the forests and atmosphere is extremely challenging. This is because of the lack of data on: the biomass values of forests, and thus the amount of carbon stored in forests; the extent and quality of the world's forests; and rates of deforestation and forest degradation (Achard et al., 2004; Palm et al., 2005; Zhang & Justice, 2001). Consequently, there remains considerable uncertainty among researchers as to the magnitude of these emissions.

Some figures have been placed on the level of uncertainty over the figures, illustrating the difficulties of budgeting within the carbon system. Houghton (2005b) suggested that there is 50% uncertainty in biomass values for the tropics, and that this translates into an uncertainty level of 80% for carbon flux estimates. Baumert et al. (2005) also highlighted the uncertainties of estimates of carbon emissions, suggesting that at the national level, the degree of uncertainty could be as high as 150%. Indeed, according to the IPCC's (Intergovernmental Panel on Climate Change) estimates, there is a gap in the global carbon budget, with a missing carbon sink of between 2-4 Gt C/yr. (Achard et al., 2004). While there is debate over this figure, this does illustrate our limited understanding of the land-atmosphere flux and the global carbon cycle.

FORESTS AS A RESERVOIR OF CARBON

Tropical forests are important reservoirs of carbon. Of the total carbon pool found in the terrestrial biosphere (which is an estimated 2480 Gt), about 17% is contained in tropical forests - 45% (212Gt) of which is found in vegetation and 11% (221Gt) in soils (Locatelli & Karsenty, 2004).

The importance of tropical forests as a carbon store lies in their high biomass. Dense lowland forests contain significantly higher biomass, and thus, carbon than other types of vegetation and even other types of forests – for example, they are estimated to contain 50% more carbon per unit area than temperate and boreal forests, and as much as 20-50 times more carbon than cleared lands (Houghton, 2005a).

The highest estimate for the biomass density of tropical rainforests is 500 t/ha. (cited in Gaston et al., 1998), although more typical values are between 100-400 t. The biomass of Central African forests is estimated to range between 200-344 t/ha. by Gaston et al. (1998) and between 125-281 t/ha. by FAO (1993). Brown & Gaston (1996) gave an average figure for the above-ground biomass in tropical African closed forests of 209 t/ha., while a figure of 250 t/ha. for the biomass (above and below-ground) of tropical forests was reported by Watson et al. (2000, citing Dixon et al., 1994)[3].

Translating these figures into the amount of carbon stored in forests depends on the estimates used for forest area as well as assumptions made about the distribution of different forest types. As the figures above illustrate, the biomass of forests varies considerably and its distribution within the tropics is particularly poorly known making it difficult to extrapolate over large areas and to produce average densities (Houghton, 2005a; 2005b; Locatelli & Karsenty, 2004). Estimates of the extent of forest are also uncertain. Many authors have used FAO's estimates for forest area, although these are known to be highly unreliable (Hoare, 2005), and the IPCC has noted that deforestation rates for the tropics could be in error by as much as 50% (cited in Achard et al., 2002).

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[3] By comparison, this latter figure was 150 t/ha. for temperate forests, while average values for the above-ground biomass of temperate and boreal forests were reported to range from 20-140 t/ha. These figures do not include below-ground carbon, which is considerable for boreal forests.

Reflecting this uncertainty in the data, there is a wide range in estimates for the size of the carbon pool within tropical forests. However, the available figures do give some indication of the significance of tropical forests and of those of Central Africa in particular.

For Central Africa[4], the above-ground carbon stock of forests was estimated to be 28.92 Gt in 1980 and 24.79 Gt in 1990 (+/- 25% for both figures) (Justice et al., 2001; Zhang & Justice, 2001). Gaston et al. (1998) estimated the above and below-ground carbon stock for Central Africa's forests in 1980 to be 30.7Gt, calculating that this represented over 70% of the total terrestrial carbon pool of Africa. Most recently, FAO (2006) estimated that the forests of central Africa contained 29.5 Gt of above-ground carbon and 39.2 Gt of carbon in total (including both above and below ground carbon, dead-wood and litter)[5].

Within Central Africa, the Democratic Republic of Congo (DRC) contains by far the greatest biomass because of the country's extensive forest resources. Gaston et al. (1998) estimated the carbon pool of DRC to be 16.9 Gt in 1980, equivalent to 55% of the regional total, or one third of the total carbon pool of tropical Africa. Zhang & Justice (2001) produced a similar figure, estimating that DRC accounted for 59% of the total for Central Africa in 1980, while FAO's figure was slightly higher, at 63% (FAO, 2006).

To put these figures in some perspective, the carbon stored in Central Africa's forests is equivalent to about 4 years of total global emissions of CO^2 based on current estimates. This brings us to the issue of carbon flux, and the role of forests as a source of carbon.

FORESTS & CARBON FLUX

Globally, the biosphere is currently a sink of carbon. Of the 7-8 Gt of carbon emitted each year from anthropogenic sources, about one third is taken up by forests (Locatelli & Karsenty, 2004). However, in the tropics, due to the high rates of deforestation and degradation, forests are a net source of carbon. Indeed, if current trends continue, it is estimated that these land-cover changes will contribute about 50% as much carbon as has been emitted from fossil fuel combustion since the start of the industrial revolution (Houghton, 2005a).

However, as mentioned above, there remains considerable uncertainty about the flux of carbon between the biosphere and atmosphere because of shortcomings in the basic data: namely biomass values, forest area and rates of deforestation and degradation.

It is not only the rates of deforestation, but also its distribution that is poorly understood in many regions. The types of forests that are being cleared will affect the levels of carbon emissions. For example, deforestation tends to occur primarily in forests of lower density. Indeed, in the 1990s in Amazonia, more than half the forest clearing was of forests of lower biomass (Achard et al., 2004). Furthermore, the rate of change between different types of vegetation or land-use is difficult to determine. For example, land-use change is often characterised by relatively small changes, for example, through the fragmentation of forests, although this may eventually result in complete conversion to agricultural land (Houghton & Hackler, 2006).

The level of forest degradation is an issue of much debate. For example, estimates of forest area based on satellite imagery often underestimate forest degradation, because small-scale clearings, such as those resulting from selective logging, are not detected (Achard et al., 2004). In Central Africa, forest degradation is highly significant, because of the prevalence of selective logging here – it has been estimated that 30% of the region's forests have already been selectively logged (Laporte et al., 2004).

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[4] Defined by these authors as the 6 countries of the Congo Basin: Cameroon, Central African Republic, Congo-Brazzaville, Democratic Republic of Congo, Equatorial Guinea, Gabon.

Uncertainty over estimates also reflects the difficulties of modelling an evolving and responsive system. For example, in estimating carbon fluxes, there is a need to track the carbon beyond the initial deforestation, accounting for the use of the wood products extracted and the subsequent changes in vegetation – for example, whether it is converted to agriculture or reforested. There is also uncertainty as to how forests will respond to climate change as a result of the greenhouse effect – for example, this could result in forest deterioration if there is a decline in rainfall, so releasing additional carbon, or an increase in temperatures could stimulate photosynthesis and forest productivity, enhancing the role of forests as a carbon sink (Cramer et al., 2004; Locatelli & Karsenty, 2004). However, more complex models are constantly being developed to allow for different outcomes and feedback phenomena.

CHANGES IN BIOMASS

The amount of carbon that is released as a result of deforestation will depend on the rate at which this occurs, and also on the subsequent land-use. For example, if deforested land is reforested, then a significant proportion of the carbon initially released could be reabsorbed. However, if the land is converted to pasture or permanent agriculture, the net loss of carbon will be greater. In Sub-Saharan Africa it was estimated that during the 1990s only 16% of the change in forest area was accounted for by conversion to permanent agriculture, while the remaining area was converted to long and short-term fallows as well as being subject to forest degradation and fragmentation, for example, as a result of logging, grazing and fuel-wood harvesting (Houghton & Hackler, 2006).

One factor influencing the rate of land-use change is the intensity of logging activities, for example, whether there is clear-felling or selective logging. As mentioned above, selective logging prevails in Central Africa, and for this reason, forest degradation is thought by some researchers to be a more important source of carbon emissions than deforestation for this region. For example, Gaston et al. (1998) estimates that degradation and deforestation accounted for 63% and 37% of emissions respectively from Central Africa in the 1980s (see table 1).

Some studies have been undertaken in Congo-Brazzaville to assess the amount of carbon emitted as a result of selective logging, these calculating that 9-10 t C are released per hectare (Brown et al., 2005; Parveen et al., 2005). This is relatively low, given that the dense forests of the region typically contain over 250 t C / ha., but it needs to be borne in mind when modelling future scenarios that selective logging is often the first stage in a process of forest degradation and deforestation. In addition, there is evidence from research in Amazonia that forest fragmentation can in itself have a dramatic impact on biomass levels, because of the ecological changes that are brought about in the forest, in particular, with an increase in tree mortality. Laurence et al. (1997) found that, as a conservative estimate, 36% of the biomass was lost within 100m of forest edges.

As highlighted above, forest fragmentation is an important phenomenon in Central Africa, and could become even more widespread, depending on the policy options that are pursued in the near future, especially in DRC. In addition to the area of forest already being selectively logged, the network of logging roads is becoming ever more extensive. Satellite imagery from 1999-2001 showed that just one third of the region's forests were low access (that is those forest areas of at least 100,000 hectares and at least 2 km from public roads), and of this area, nearly 60% was within 10km of a logging road (Minnemeyer, 2002).

The carbon flux resulting from deforestation

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[5] Although comparison of these estimates would suggest that there has been an increase in the size of the carbon pool in Central Africa over the last two decades, this does not represent reality since the region has experienced extensive forest degradation and deforestation. Rather, this represents the uncertainty of these estimates, as noted earlier, based as they are on very different estimates of forest biomass and forest area.

TABLE 1: Estimated decline in the above-ground carbon pool in Central Africa in the 1980s (million tonnes/decade). (Source: Gaston et al., 1998.)

COUNTRY	TOTAL REDUCTION IN C POOL	DEFORESTATION	DEGRADATION
CAR	348	80 (23%)	268 (77%)
Congo-B	320	14 (4%)	306 (96%)
Cameroon	416	123 (30%)	294 (70%)
DRC	2501	827 (33%)	1674 (67%)
Eq. Guinea	45	11 (24%)	34 (76%)
Gabon	803	606 (76%)	196 (24%)
TOTAL	4433	1661 (37%)	2772 (63%)

TABLE 2: Carbon lost by conversion of tropical forest to various land-uses. (Source: Houghton, 2005a)

LAND USE	CARBON LOST TO THE ATMOSPHERE AS % OF INITIAL CARBON STOCKS	
	VEGETATION	SOIL
Cultivated land	90-100	25
Pasture	90-100	12
Degraded cropland pasture	60-90	12-25
Shifting cultivation	60	10
Degraded forests	25-50	<10
Logging	10-50	<10
Plantations	30-50	<10

will depend on the subsequent vegetation, and some estimates have been made of the carbon lost as a result of conversion of tropical forest to other land-uses. Houghton (2005a) estimated the percentage of carbon stocks lost from tropical forests, from both soils and vegetation (table 2).

Palm et al. (2005), from research undertaken in Cameroon, sought to take into account the change in carbon levels over time, calculating the above-ground carbon storage of different land-use systems during a full agricultural rotation. On this basis, the loss of carbon resulting from conversion of logged over forest was estimated (see table 3) (Palm et al., 2005).

These data highlight the significant loss of carbon that can result from the conversion of forests to other land-uses, with 90-100% being lost from above-ground carbon for certain agricultural systems. Also apparent is that some land-use systems have a less drastic effect – including long rotation shifting cultivation and agroforestry systems.

TABLE 3: Above-ground time-average carbon storage of land-use systems in Cameroon. (Source: Palm et al., 2005)

LAND-USE	CARBON STORAGE (T C/HA.)	CARBON LOST ON CONVERSION FROM LOGGED FOREST TO ALTERNATIVE LAND-USE (T C/HA.)
Logged forest	228	-
Shifting cultivation (long fallow)	77	151
Jungle cacao (permanent)	89	139
Jungle cacao (rotational)	61	167
Oil palm	36	192
Crop-bush fallow	38	190
Crop-Chromalaena fallow	6	222

CARBON-FLUX ESTIMATES

Although there are wide variations in the estimates, it is apparent that deforestation and degradation is a significant source of carbon emissions. Indeed, land-use changes are the largest source of emissions in developing countries, accounting for about one third of their total emissions.

A widely quoted figure is that about one fifth of global anthropogenic CO^{2} emissions, estimated at 7-8 Gt C / yr., come from tropical deforestation (Chomitz, 2006; Stern, 2006). These figures are based on IPCC's estimate of CO2 emissions for the 1990s, put at 1.6Gt C (+/- 0.8). However, if the full range of possible values is considered, these emissions could account for as little as one tenth or as much as one third of all anthropogenic emissions (Baumert et al., 2005; Fearnside & Laurance, 2004).

The reported values for emissions from land-use change in the tropics largely fall within those given by the IPCC, ranging from 0.5 to 2.5Gt C / yr. in the 1990s (Achard et al., 2004; DeFries et al., 2002; Fearnside & Laurance, 2004; Palm et al., 2005). For tropical Africa, the range of estimates for the 1990's is 0.12 to 0.42 Gt/yr. (UNFCCC, 2006a). Some of these estimates are shown in table 4 below.

An important factor accounting for the wide-divergence in these estimates was the figures used for forest area. For example, both Achard et al. (2004) and Defries et al. (2002) assumed a much lower rate of deforestation than the other three studies listed, based on their assessment of satellite data. Both these studies are also considered to have underestimated the level of forest degradation (UNFCCC, 2006a). Fearnside & Laurance (2004) suggest that Achard et al. (2004) may in fact have underestimated carbon emissions from forests by a factor of two, certainly for the Amazon and possibly in other tropical regions. They question these figures partly on the basis of the estimates used for forest degradation and biomass and their assumptions regarding forest re-growth.

Estimates for Sub-Saharan Africa also show a wide range in values. Achard et al. (2004) gave a figure of 0.157 Gt C / yr. for emissions from this region, while Brown et al. (1989, cited in Houghton & Hackler, 2006) gave a very high estimate of 0.47 Gt C / yr. The estimate of Houghton & Hackler (2006) is in between

TABLE 4: Estimates of carbon loss from African tropical forests to the atmosphere attributed to deforestation. (Gt C / yr) (Source: UNFCC, 2006a)

	Fearnside (2000)	Malhi & Grace (2000)	Houghton (2003b)	DeFries et al. (2002)	Achard et al. (2004)
Period	1981-1990	1980-1995	1990s	1990s	1990s
Africa	0.42	0.36	0.35	0.12	0.157
Total of regional estimates for the African, Asian and American tropics	2	2.4	2.2	0.91	0.98

these two, at 0.29 Gt, but they also state that the margin of error for this figure is +/-70%.

For Central Africa, estimates for emissions from land-use change are only available for the 1980s, and these range from 0.02 - 0.44 Gt / yr. (BSP, 1992; Gaston et al., 1998; Zhang & Justice, 2001). The highest figure, of 0.44 Gt is from the calculations of Gaston et al. (1998; & see table 1 above). These figures represent about 90% of all anthropogenic carbon emissions from within Central Africa (i.e. considering fossil fuel combustion and other sources) and 20% of the total emissions from tropical Africa (BSP, 1992).

All these studies show that DRC is by far the most significant source of carbon emissions from land-use change – a consequence of the vast areas of dense forest to be found within this country. Thus, Gaston et al. (1998) calculated that DRC accounted for 56% of the total for Central Africa (0.25 Gt), while Zhang & Justice (2001) estimated this to be 47% (0.2 Gt).

IN SUMMARY

Regardless of the uncertainties in the data, it is undoubted that continued deforestation will play a large role in the build-up of greenhouse gases in the atmosphere (Cramer et al., 2004). If current trends continue, tropical deforestation will contribute 3 billion tonnes of carbon each year (Chomitz, 2006), with emissions from deforestation from throughout the world expected to total 40 billion tonnes of carbon between 2008-2012. This alone will raise atmospheric CO2 levels by about 2 ppm – greater than the cumulative total of aviation emissions since the invention of aeroplanes (Stern, 2006).

Until recently, the Congo Basin forests have contributed a relatively small amount to the total emissions from land-use change, accounting for about 4% of all such emissions from the tropics in the 1980s. However, this figure is likely to grow if the wrong policy options are pursued in the coming months and years.