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Nature Conservation, and Tourism of
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REDD

Reducing Emissions from Deforestation and Forest Degradation

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Reducing CO_2 Emissions from Deforestation and Degradation in the Democratic Republic of Congo: A First Look

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Reducing CO_2 Emissions from Deforestation and Degradation in the Democratic Republic of Congo: A First Look

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Table of Contents

Tables and Figures

Executive Summary

- Reducing Emissions from Deforestation and Forest Degradation (REDD) is a potential tool to alleviate poverty in developing countries. Current international aid is about $800 million per year in the DRC; REDD could help add between $120 million to $400 million per year directly to rural households.

- The DRC has 1.1 million km^2 of dense humid tropical forest, the largest forest estate in all of Africa. Seventeen billion metric tons of carbon are stored in the DRC's forests, of which 11% is in protected areas and 17% in current logging concessions.

- Deforestation today is mainly driven by rural households (population density). The effect of swidden (slash-and-burn) family agricultural systems on emissions depends on the degree of fragmentation in the landscape, and the spatial distribution of forest biomass. For the period 1990 – 2000 CO_2 emissions from land cover change amounted to 0.22 Pg per year (0.06 Pg of carbon). Areas with higher emission levels do not always correlate directly with areas of highest deforestation rates or population since deforestation occurring in higher biomass areas emits proportionally larger amounts of CO_2 per unit of land cleared.

- Mean annual household emissions are 15.5 tons per year on 0.62 ha of clearing. For a 50 percent reduction in carbon emissions, total rural household compensation will range between $120 million to $400 million per year for 10 years, depending on the level of compensation required. The mean carbon price to accomplish this compensation would range from $19 to $65 per ton.

- Future deforestation may be driven largely by the expansion of palm oil plantations into forest regions. Chinese companies are currently paying more than $300 per hectare for forest lands with the goal of transforming these areas into palm plantations. The opportunity costs of slowing the expansion of palm oil into dense forests may be higher than the costs of slowing swidden agriculture. Virtually all of the dense humid (high carbon) forests of the DRC are on soils and in climatic conditions that are suitable for palm oil production. The costs of the DRC REDD program will depend on the development of a plausible reference scenario of increasing CO_2 emissions from forest conversion to palm oil plantations.

- Timber production, if properly managed, can maintain most forest carbon stocks and offset opportunity costs of slowing the expansion of palm oil and swidden agriculture. In 2003 the government reduced the forest area under logging concessions to ~26 million hectares. With careful management and oversight, the timber industry could generate economic returns with low carbon emissions. The timber industry could generate $47 million per year in tax revenue – from estimated gross earnings of $810 million. Carbon emissions associated with that activity would then be 15 million tons per year.

- Protected areas that are fully implemented can also reduce future emissions from palm oil cultivation and swidden agricultural expansion. Most do not contribute to CO_2 emissions, with the exception of the Bili-Uere hunting reserve in the North, and the Kahuzi Biega and Virunga national parks in the East. Both parks in the East have suffered from years of war and mass migration of refugees from Burundi and Rwanda. Parks and protected areas will play an important role in the long term management of forests and can be a source of carbon-derived income for countries with large forest estates and low deforestation.

- The dense humid "carbon rich" forest region of the DRC contributes 64% of DRC's total CO_2 emissions while the "carbon poor" savanna region contributes 36%. National policies are needed to insure minimal leakage and most effectively reduce emissions across the whole country.

- Clarification of land tenure and traditional rights, improved governance and a thorough understanding of the economics of household decisions are key factors in successful implementation of REDD policies. More importantly, REDD must be viewed as a substantial economic incentive for the development of institutional capacity within the DRC to govern its forest estate.

1. Historical Context

DRC Quick Facts	
Population:	66 million
Forest Area:	1,231,808 km^2
Timber - exports:	300,000 m^3
Timber - domestic:	1.5 million m^3
Logging concessions:	261,565 km^2
Protected Areas:	236,118 km^2
Total mining concessions:	1,020,805 km^2
Total Degraded Forest	13,653 km^2
Per Capita GDP:	$100-300

The past leaves its mark on the future of any nation, and the impact of a turbulent history is perhaps nowhere more evident than in the Democratic Republic of Congo (DRC). Created as The Congo Free State - in reality a personal fiefdom of Leopold II of Belgium - in the 1870's and then subsequently sold to Belgium in 1908, the DRC has long been exploited for both human and natural resources. Abrupt transition to independence in 1960 left the country in chaos from which Mobuto Sese Soko wrested control in 1965, beginning a devastating reign that lasted until 1997 when he was deposed by Laurent Kabila in the First Congo War. The re-named Democratic Republic of Congo[1] then struggled through another period of strife, from 1998 to 2003, involving 8 nations and some 25 warring factions. This "Forgotten War" resulted in continued hardship for the country, and delivered the highest number of war-related deaths since World War II. OXFAM recently estimated the cost of war to be $18 billion, equivalent to 29% of GDP for the years 1996-2005.[2]

Assisted by the leadership change to Joseph Kabila after his father's assassination in 2001, and the first free elections in 2006, the prospect of peace and stability is finally a tangible one, despite lingering regional conflicts. The recent elections have moved the country closer to economic stability and investment has increased, as the DRC struggles to manage the huge economic potential associated with its natural resources[3]. With strategic planning for development, economic growth in the DRC can avoid continuing to focus on exploitation of natural resources, and in the process increase opportunities for longer term stability and sustainable development while maintaining and profiting from its rich and diverse tropical forest ecosystem.[4] The DRC is keenly aware of the value of its forests beyond timber production, and recently (12 November, 2007) announced the protection of more than 3 million hectares in the newly established Sankuru Natural Reserve[5]. They also committed to increase protected areas to 15% of the country. The expansion of protected areas is critically needed not only to preserve biodiversity and ecosystem integrity, but also to ensure buffering of the system from climate changes that are projected to force the region into a state with no present analog.[6] Protected areas will, however, incur opportunity costs equivalent to the value of alternative land uses, such as oil palm concessions. This is an important consideration in a multi-dimensional effort to reduce deforestation.

In 1997 the Food and Agricultural Organization (FAO) estimated a deforestation rate of 0.6% per year (1,142,000 ha yr^{-1}) for the Congo basin[7]. For the same approximate time period, estimated forest losses in Indonesia and Brazil were 1.0% per year (1,084,000 ha) and 0.5% per year (2,554,000 ha), respectively. More current deforestation rates in the DRC are estimated to be less than 0.3% (500,000 ha yr^{-1}) and mainly associated with slash and burn agriculture (FAO 2006),[8] but industrial logging operations are expanding in the region[9] and oil palm is expected to increase rapidly following recent (October 2007) Chinese investment of $1 billion. The combination of rapid population growth and low land and labor productivity in the DRC is increasing pressure on the forest margins, which are often already degraded.

Central African nations are working to identify the most promising approaches to avoid an increase in rates of forest degradation and deforestation. These assessments require the most up-to-date information on carbon stocks, emissions and trends, and the identification of policy "levers" that hold the greatest potential to foster both forest conservation and equitable economic development.

This report provides a synthesis of current knowledge and data sets necessary for the DRC to monitor carbon emissions and identify pertinent approaches to address emerging *Reduced Emissions from Deforestation and Degradation* (REDD) policies. Critical data sets reviewed here include: the distribution of above-ground carbon stocks, drivers of land-cover change and associated deforestation rates, and recent carbon flux estimates. In addition, the results identify key sectors that may contribute to avoiding or reducing carbon emissions and quantify their potential income generation. Finally, an institutional and governance framework is presented that would enable the DRC to successfully implement a carbon emissions reduction strategy.

2. Reducing Emissions from Deforestation

While green house gas (GHG) emissions from the burning of fossil fuels are the principal cause of global warming and must be reduced significantly in Annex 1 countries, tropical deforestation contributes about 15-35% of annual global carbon dioxide (CO_2) emissions. Approximately 350 billion tons of carbon (350 PgC) are currently sequestered in tropical forests and could be released to the atmosphere via increased deforestation and degradation. Reducing tropical deforestation is therefore an important step toward the stabilization of GHG concentrations, but it is also critical to the conservation of biodiversity and water resources. Tropical countries are seeking viable options for reducing their emissions from deforestation, and countries such as the Democratic Republic of Congo (and other Congo basin countries) are also focused on developing systems to maintain the large quantities of carbon sequestered in their forests. To reach this goal, there is a pressing need to identify and initiate policies and practices that will conserve forests and carbon, but that also fit within policies designed to advance economic development and alleviate poverty.

The majority of GHG emissions from land use change come from deforestation and forest degradation in tropical countries, with the highest emissions associated with industrial agriculture and cattle ranching in the Amazon, palm oil plantations in SE Asia, and household slash-and-burn agriculture in Africa[10-11]. Currently carbon credits for reducing rates of deforestation have been excluded from the Clean Development Mechanism (CDM) of the Kyoto protocol.

The first proposal to compensate the reduction of greenhouse gas emissions via REDD was launched during COP9 in Milan by Environmental Defense and the Instituto de Pesquisa Ambiental da Amazônia (IPAM or Amazon Institute for Environmental Research).[11] In the compensated reduction proposal, developing countries that succeed in reducing their national deforestation rates against a reference scenario, or baseline, could receive compensation through trading in international carbon markets. Reductions below the agreed upon reference scenario could be issued and sold to Annex I countries, companies, or traders. Reductions would be calculated against national (or potentially regional, e.g., the Pan-Amazon, Central Africa) deforestation reference scenarios, since this would not be a project-based mechanism like the CDM. Reductions would be credited *ex post facto*, after verification using validated remote sensing technology.[12,13]

In 2005, during the UNFCCC annual meeting (COP11/MOP1) in Montreal, Papua New Guinea (PNG), on behalf of the Coalition for Rainforest Nations and with the support of all Parties from the floor, put forward a submission to further consider whether incentives to reduce emissions from deforestation in developing countries could be included under the UNFCCC. The COP tasked the Subsidiary Body for Scientific and Technical Advice (SBSTA) of the UNFCCC with assessing this topic, and reporting back to the COP with recommendations at the annual meeting in 2007 (CoP13/MoP3). As part of this process, the DRC contributed to a submission coordinated by the Central African Countries through the "Commission des Forêts d'Afrique Centrale" (COMIFAC) in support of REDD.[14]

Compensated Reduction, as defined above, is not a universal solution for addressing deforestation. Countries with intact forest estates and low deforestation would have little to trade in a reduction portfolio under a Compensated Reduction scheme. These countries need a mechanism that supports maintenance of carbon stocks as well as identifying the potential for poverty alleviation in rural households through REDD. Furthermore, it is inevitable that as access to these carbon-rich forests increases, they will be increasingly at risk of deforestation and therefore it is vital to establish and maintain protection or sustainable use programs. Here we discuss the elements of a combined portfolio of reducing emissions from current levels while avoiding deforestation from future land use options. It is therefore vital to establish national and international forest policies and financial mechanisms to promote the long term management of these forests for the benefit of the local communities and the climate.

3. Building Knowledge for REDD

One of the limitations on implementation of REDD policies is the availability and accuracy of data sets to establish past and current rates of carbon loss or sequestration, and to predict the areas that are most at risk of clearing and associated increased emissions. In this section we describe the best currently available spatial data sets for the DRC, and briefly describe an approach to accurately estimate carbon stocks, deforestation and degradation at the national level.

3.1 *Carbon stocks*

Among the tropical continents, information on carbon distribution is least available in Africa. Most above-ground live carbon or biomass in Africa is sequestered in woody vegetation (trees), with the largest expanse of non-degraded forest found in the DRC. With more than 1.1 million km^2 of dense humid forest[15], the DRC contains about one quarter of all African forest land and nearly half of its tropical moist forest[16]

Biomass information is generally derived from a combination of forest inventories (field plots measuring the structure of forests), allometric relationships (converting sampled tree measurements into wood biomass estimates), and climatic data.[17] This approach provides estimates of small forest plots, but fails to capture the extensive spatial heterogeneity that characterizes forest biomass at the landscape level. Moreover, forest inventories are scarce and often obsolete and, as a result, there has been little reliable recent information on the amount and spatial distribution of carbon in the region. Such information, however, is crucial for reducing the uncertainty in carbon emissions, better managing exploited forests, and quantifying the impact of REDD policies on those carbon stocks.

Methods based on remotely sensed data show varying degrees of success in estimating forest biomass.[18] Using a combination of satellite imagery and recent fine scale forest inventories, it is possible to generate the necessary information for monitoring and updating carbon stocks (Figure 1).[19] Indeed, a comprehensive map of biomass distribution across Africa was recently derived from a network of field inventory plots and hundreds of MODIS satellite images acquired over a four-year period (2000-2003).[20] This map allowed us to identify the areas of high biomass (carbon) density, which, when combined with information on land cover change enabled us to determine areas with the highest potential for reducing or avoiding CO_2 emissions. The maps can also be used in various policy scenarios of land-cover change, allowing us to predict the associated level of carbon that could be conserved or lost through emissions associated with deforestation and forest degradation.

In order to participate at a national scale, the DRC and other African nations will require a national carbon monitoring system. The monitoring system should be simple, robust and provide an update of carbon loss or gain on a regular basis. The best system will have to combine vegetation structure inventories (with measures such as diameter breast height and canopy height) acquired from field surveys with high resolution satellite imagery (~30 meter resolution) to provide the basis for verification of changes in emission rates[21]. Support from international development agencies, including the readiness fund of the Forest Carbon Partnership Facility, can assist with the development of such carbon monitoring systems, enhancing the capacity for national forest inventory on a regular basis.[22]

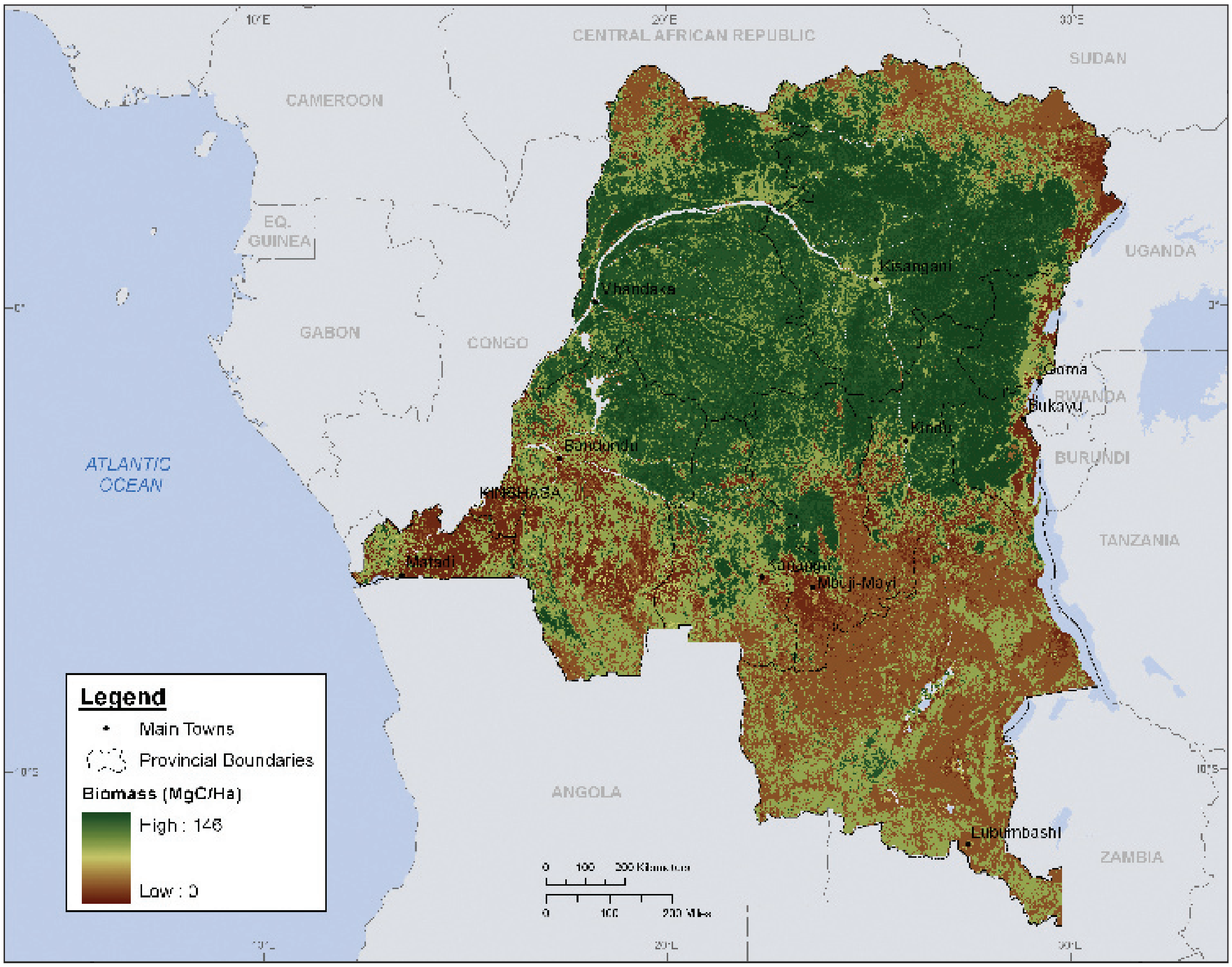

Figure 1. Distribution of above-ground carbon stocks (MgC/ha) in the DRC. High biomass forests are located primarily in the three Northern provinces (Equateur, Orientale and North Kivu) but also extend south into the Bandundu, Western and Eastern Kasai, Maniema, and South Kivu provinces.

3.2 *Current drivers of carbon emissions*

Deforestation and forest degradation result from a combination of factors that generally operate at two different levels. While most countries are facing pressure from a subset of a range of direct causes (such as farming, cattle ranching, logging, mining, and fuelwood extraction), these proximate causes are driven by different underlying causes, including macroeconomic forces and societal factors. A primary industry in the DRC is mining[23], but we do not attempt to account for mining here other than to note its importance to the economy. As with mining, the drivers of deforestation are complex and often case- or country-specific.[24]

To better understand land cover change processes in the DRC, we analyzed a set of potential drivers of land cover change, such as population and infrastructure, and generated a map of potential forest area loss for the entire DRC. We divided the region into cells of 10x10 km and predicted for each cell how much forest area has been converted to non forest, and what the probability for each cell was to lose 0.25, 2.75, 7.5, and 17.5 km^2 of forested land.[25] Results show that deforestation is mainly driven by population density[26], the degree of fragmentation in the landscape, and the spatial distribution of forest biomass.

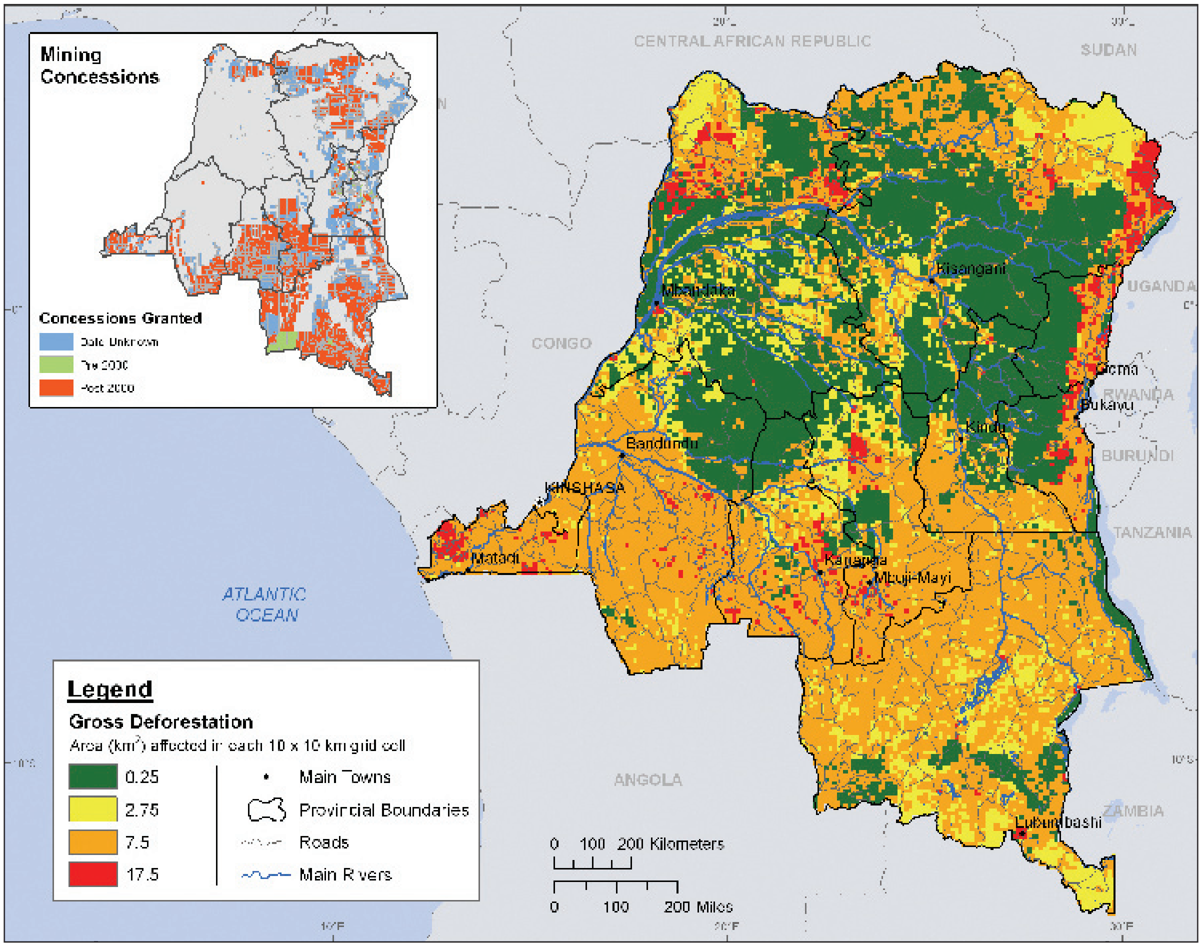

Figure 2. Distribution of deforestation and mining concessions (insert-top-left) in the DRC. Economic necessity and a potentially vast income from mining epitomize the trade-offs between development and resource protection faced by the DRC. Deforestation in the DRC is in large part a result of household clearing for slash-and-burn agriculture. See text for more details.

In the DRC, deforestation is concentrated mainly where anthropogenic activities such as agriculture and mining are more intense and thus the forest is already fragmented. Deforestation is highest in three areas of the DRC: the north-central region; in the northeast close to the border with Uganda, Rwanda and Burundi; and in the southwest.

Degradation is less well documented than deforestation in the DRC, and in the tropics in general, and is also more difficult to map. Degraded forests are generally those impacted by poor forest management and can lead to a loss of carbon.[27] However, the potential economic benefits of combined logging and carbon income from forest concessions may outweigh the costs. In the DRC it is relatively rare to have deforestation along developed logging roads, probably because logging primarily takes place in remote forests where population density is low. However, logging roads in remote forest ecosystems do provide access to hunters and poachers, and logging is thus a major force in the loss of biodiversity and wildlife in these regions, and must be carefully monitored.[28]

While mining concessions are not entirely incongruous with carbon storage, depending on the amount of associated deforestation and degradation, mineral exploitation in Central Africa has typically not been advantageous to local populations. It has the potential to dramatically degrade the DRC's forest and water resources, as well as exploit the people for inexpensive labor and leave them poorer than when they practiced more traditional livelihoods. Although unlikely to compete with income from mineral exploitation, an effective carbon market that is coupled with effective governance could strengthen the negotiating position for the DRC by relieving immediate cash constraints driving widespread awarding of mining concessions.

3.3 *Estimating current carbon emissions*

Although relatively low, the total carbon flux emitted for the 4 tropical regions of Africa is increasing, as shown in Figure 3. A prosperous economic future in the region coupled with the current governance scenario – Business As Usual – is likely to result in higher rates of deforestation.

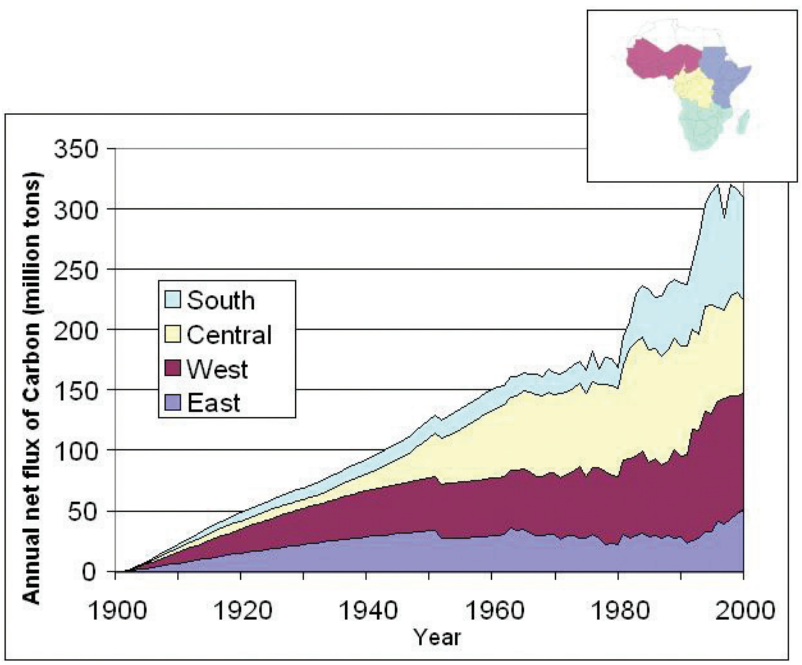

Figure 3 Annual flux of carbon in million of tons from land use – land cover change (Houghton et al., 2006).

To identify where emissions are occurring within the DRC we estimated the magnitude and spatial distribution of emissions for the period 1990-2000 (Figure 4). To do this, we combined our deforestation map (Figure 2) with our map of biomass for the year 2000 (Figure 1)[29]. The results show an average annual CO_2 emissions level from the DRC of 0.22 Pg per year during the period 1990 – 2000[30], assuming that all the areas mapped as deforested between 1990 and 2000 released all their standing carbon stock to the atmosphere over that period. In reality, some of the forest carbon was not immediately released to the atmosphere but remained as dead wood or as wood products removed from the forest, both of which have slower decay and emission rates. If we better account for decay rates and regrowth, a more realistic estimate of average annual emissions that takes the fate of carbon pools into account is between 0.10 – 0.15 Pg CO_2.[31]

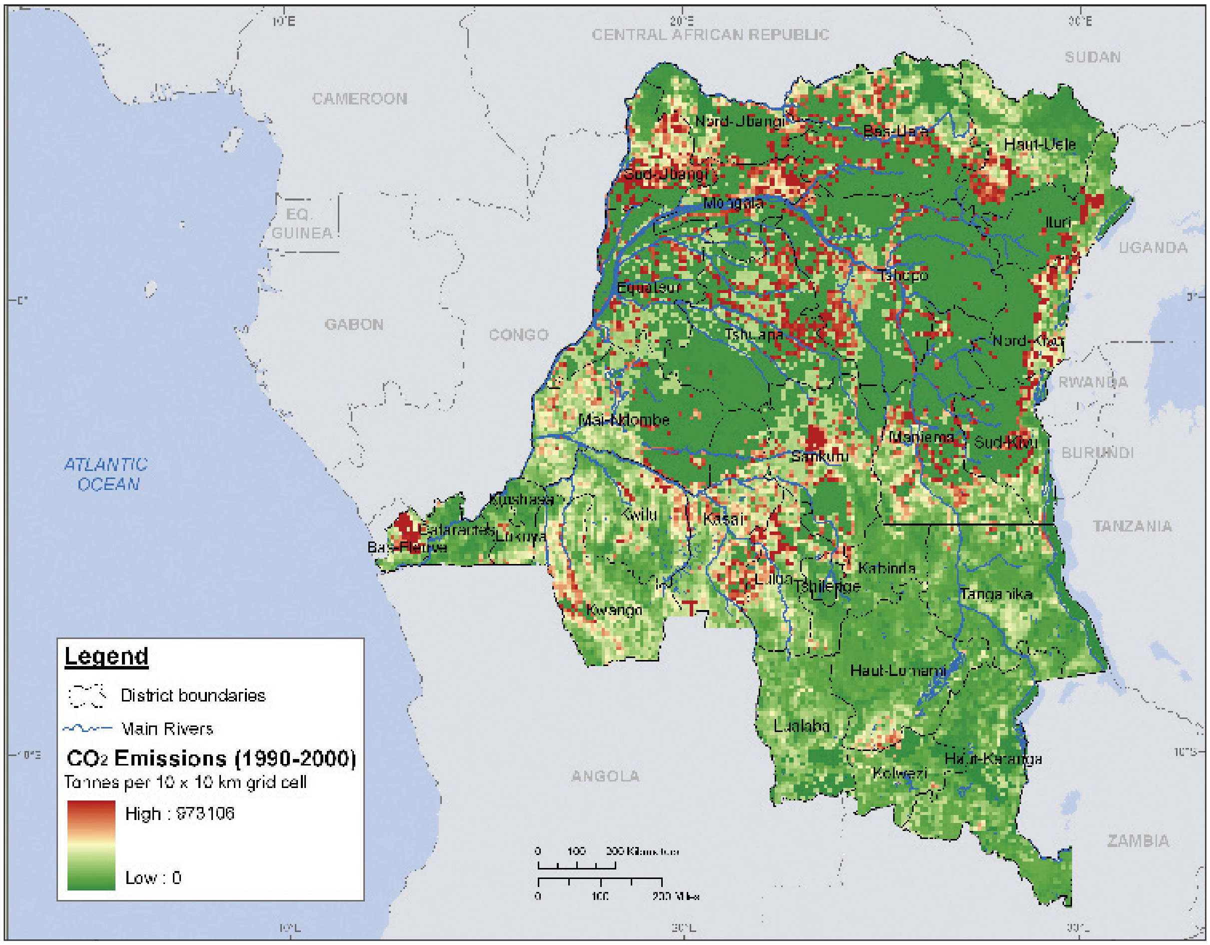

Figure 4. The first spatial estimates of CO_2 emissions distribution across the DRC. These estimates are derived from land cover change 1990-2000. When compared to the deforestation map it is possible to observe that emissions are not exclusively deforestation-driven. Emissions are related to spatial distribution of biomass. Areas with low deforestation but high biomass may emit equally to areas with high deforestation but low biomass.

The overall distribution of the highest CO_2 emissions corresponds well to the "high deforestation" and "medium to high biomass" areas of Eastern DRC and the Equator Province, in addition to those areas depicted as "medium deforestation" and "high carbon," such as the Opala, Ikela, Yahuma and Lodja regions. It is interesting to note that deforestation by itself is not sufficient to capture the magnitude and spatial distribution of CO_2 emissions. For example, areas characterized by low biomass and high deforestation can have lower emissions than areas with low deforestation and high biomass. Coupled biomass and deforestation information is required to properly assess CO_2 emissions.

3.4 *Future drivers of deforestation*

Escalating oil prices and a world-wide surge in the demand for biofuels could push palm oil plantations into the forests of the DRC in a new phase of Congolese deforestation. While future emissions are uncertain, the DRC has the largest carbon stocks in Africa (17 million tons of C)[32] -- greater than those of any other tropical country except Brazil and Indonesia. If rates of deforestation in the DRC were to increase to the rates observed in these two countries, emissions from the DRC could grow substantially. Given the amount of carbon held in the forests of DRC, total long-term emissions to the atmosphere must be constrained to avoid harmful climate impacts.

In a recent agricultural suitability mapping exercise, the Woods Hole Research Center estimated that 61% of the dense humid forest formation of the DRC is suitable for the production of palm oil (approximately 47 million ha). There are early signs that this expansion has begun. In October 2007, a Chinese company signed a contract to develop more than 3 millions hectares of the DRC as palm oil plantations. We estimate that just one third of these areas will be established in previously abandoned oil palm plantations.[33] Since many of these original oil palm plantations are now established in secondary forest, a gross estimate for carbon emissions from this acquisition is approximately 150 million tons (3 million ha at 50 tC/ha).

An understanding of the likely trajectory of palm oil plantation expansion and other agro-industries in the DRC is critical to the development of a REDD program. In this report, we present an hypothetical curve of future carbon emissions from DRC deforestation and forest degradation to demonstrate, conceptually, how the expansion of agro-industry will affect the future scenario of deforestation and emissions. Countries with historically low levels of emissions should qualify for compensation of reductions in emissions below an adjusted "reference scenario" that includes projections of emission increases. Figure 5 shows a scenario where rural population growth is 3 percent per year, oil palm plantation increase to a total of 9 million ha[34], and logging concessions increase from 26 million ha to 45 million ha, resulting in carbon emissions would increase from an estimated 81 million tons in 2008 to 172 million tons of carbon within 30 years. It is therefore important that reduction strategies be devised in conjunction with the maintenance of carbon stocks. In the graph, we also depict where emissions levels would be if the area converted to oil palm were equal to half to a quarter of the total area deemed physically feasible (i.e. 23 million ha). Government income (Net Present Value) from this scenario is $1.7 billion, using the more conservative oil palm production estimate and $4 billion using the scenario where almost 25 percent of forest land suitable for palm oil production changes is converted. A more realistic scenario would be developed with the government of DRC to maintain low rates of deforestation, and identify how future emissions from agro-industry and logging can both be reduced.

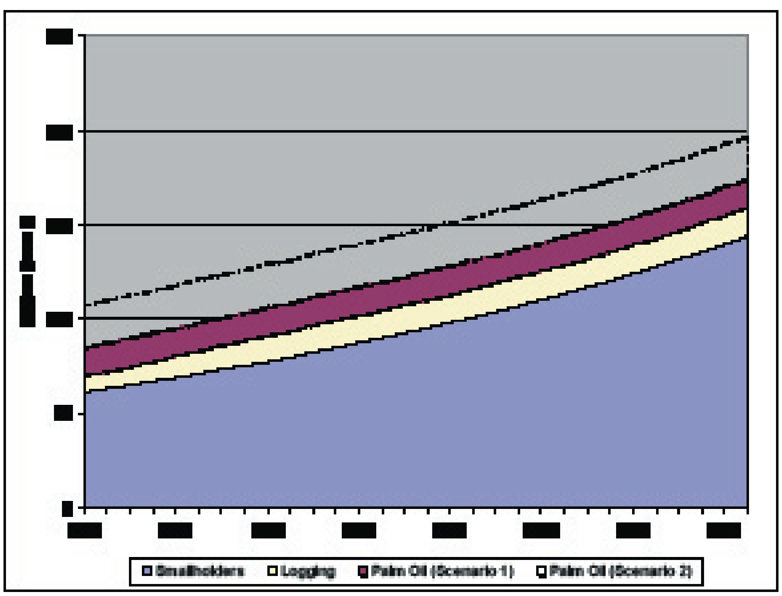

Figure 5. Projected emission for the DRC over 30 years. Oil palm area increases up to 9 million ha, households increase from 4 to 8 million, and timber concessions increase from 25 million ha to 45 million in the first ten years then stabilize. Highest curve (dashed line) represents a scenario whereby 23 million ha of oil palm comes under production, which is approximately a quarter of the area deemed suitable for production in the DRC.

4. Emission Reduction Strategies and Carbon Supply Curves

Even though countries with low deforestation appear to have low current emission rates, programs to maintain low or reduced emissions require that the government, and local carbon emitters, forego alternatives and incur opportunity costs. For example, much of the 98 million ha suitable for oil palm in the DRC lies in the dense humid forest and is also suited for logging (or is already allocated as Protected Areas). When the government sets lands aside for protection it sacrifices the potential income from the concessions; in the case of a timber concessions the government foregoes the difference between what it earns from the timber concession and the oil palm concessions.

Furthermore, since much of the emissions are associated with households, the government must develop a strategy to offset current loss of welfare. If households currently earn the equivalent of $500 per year, a strategy must be avaliable to compensate the loss of whatever portion of welfare is lost due to change in land use. Population increases present an additional dilemna as the percentage reduction must also increase per household if the targets are to be met.

Low deforestation countries such as the DRC can offer programs that begin with the improvement of government capacity to regulate forest use, and then transition into market-based mechanisms within the country. Below we discuss how the different components of the country carbon bundle could operate. In the case of the DRC, carbon emissions from three sources are considered: households, the timber industry and industrial agriculture such as oil palm.

These preliminary scenarios can be used as a means to assess the potential implications of different actions the Congolese government might take. Various scenarios can be developed to identify the most effective and politically feasible ways to reduce deforestation rates and associated carbon emissions. The scenarios can also help us to identify key sectors for the implementation of REDD pilot projects. Finally, the scenarios can frame the broad-based discussions and communication with relevant stakeholders at the local level. We illustrate this idea with three potential sources of carbon: households with traditional rights to the land, the timber industry, and protected areas.

4.1 *Reducing emissions from households*

CO_2 emissions can be linked to household level slash-and-burn agriculture. Yet the overall financial benefits of this activity are low[35] and may be easily offset. Poor rural households throughout the African continent depend on manual labor; capital and credit is scarce and production is limited by total family labor availability. While the range of income may vary across households depending on market access and other factors, the labor constraint and the lack of capital substitution options are stringent.

To estimate how much current and future emissions can be reduced, and at what price by households in the DRC, we combine GIS datasets on rural population with estimates of biomass and production values. These three components allow us to put forth a preliminary supply curve for carbon and prioritize the expenditure of carbon income to increase emissions reductions and carbon stock protection. As seen from Figure 3, emissions do not directly follow deforestation or population since individuals in high biomass areas emit proportionally larger amounts for the same area cleared.

Table 1 provides an estimate of household carbon emissions, the area cleared, and the price of carbon required to replace a range of current incomes. This allows us to bracket a range of preliminary estimates for a carbon price in rural households. For example, if we assume a required compensation of $300 per year,[36] with a goal of 50 % reduction in emissions, the most cost-effective location to invest would require a carbon price of $10.24 (Province Orientale, in the District of Bas-Uele) to avoid these emissions.[37] Should that region be more productive and required compensation of $1,000 per year, then the carbon price would have to be $34.12. Rationally, a scheme to purchase carbon should be ordered by Districts presented in Table 1, where the results are sorted in ascending order based on carbon prices for income of $300 per year (i.e., Prov. Orientale, Bas-Uele District is the most cost effective and Kasai Oriental, Tschilenge District the least cost effective).

If we estimate payment to each household (there are approximately 4 million rural households) at $300 per year, this would cost (or generate to the economy if based on carbon markets) $1.2 billion. A program for emission reductions could be phased in over 10 years, leading to income generation from carbon payments of $120 million per year up to the sustained total of 1.2 billion. By comparison, a household payment of $500 per year would require generation of $200 million per year, and $1,000 payment would require $400 million per year (again assuming a 10-year timeframe). Assuming the same household compensation listed above, the weighted mean carbon price would need to be $19, $32, or $65, respectively, for the three levels of compensation.

Table 1. Household Carbon Emissions and Land Clearing by District and Province (sorted by carbon price)

Province[a]	District	Forest Cover[b]	Annual Regional TCO2 Emissions[c]	Carbon Stock per ha[d]	Total Rural Households[e]	Household Carbon (TC) Emissions[f]	Area (ha) Cleared per Household[g]	Carbon Price if Reimbursement = $300/year[h]	$500	$1000
Province Orientale	Bas-Uele	78%	14,366,100	47.98	66,176	58.61	1.22	10.24	17.06	34.12
Equateur	Tshuapa	100%	12,239,900	62.50	90,119	36.67	0.59	16.36	27.27	54.54
Kasai Oriental	Sankuru	78%	13,168,400	49.20	106,655	33.34	0.68	18.00	30.00	59.99
Katanga	Lualaba	1%	5,229,450	15.44	42,438	33.27	2.15	18.03	30.06	60.11
Equateur	Equateur	93%	10,613,900	60.99	88,507	32.38	0.53	18.53	30.88	61.77
Maniema	Maniema	70%	12,476,100	48.04	115,268	29.22	0.61	20.53	34.22	68.44
Bandundu	Mai-Ndombe	72%	12,494,200	46.65	115,805	29.13	0.62	20.60	34.33	68.66
Province Orientale	Tshopo	98%	15,746,200	64.22	146,460	29.03	0.45	20.67	34.45	68.90
Equateur	Mongala	95%	9,703,850	58.54	102,722	25.51	0.44	23.52	39.21	78.41
Bandundu	Kwango	16%	10,663,000	22.42	114,496	25.15	1.12	23.86	39.77	79.54
Equateur	Sud-Ubangi	66%	12,498,500	40.74	146,143	23.09	0.57	25.98	43.31	86.61
Province Orientale	Haut-Uele	51%	9,097,280	29.40	115,016	21.36	0.73	28.10	46.83	93.65
Kasai Occidental	Kasai	60%	12,652,100	39.80	160,395	21.30	0.54	28.17	46.95	93.91
Equateur	Nord-Ubangi	60%	4,945,28[0]	42.81	74,672	17.88	0.42	33.55	55.92	111.85
Katanga	Tanganika	5%	7,711,670	12.23	129,290	16.10	1.32	37.26	62.09	124.19
Kasai Occidental	Lulua	34%	8,824,190	28.73	170,484	13.98	0.49	42.93	71.56	143.11
Katanga	Haut-Lomami	1%	6,518,030	12.44	136,707	12.87	1.04	46.61	77.68	155.36
Katanga	Kolwezi	0%	2,623,550	17.93	63,547	11.15	0.62	53.83	89.71	179.42
Bas-Congo	Bas-Fleuve	32%	3,340,920	22.08	99,545	9.06	0.41	66.21	110.35	220.71
Katanga	Haut-Katanga	0%	6,264,380	12.66	194,709	8.69	0.69	69.07	115.12	230.24
Bandundu	Kwilu	19%	9,000,710	17.28	289,860	8.38	0.49	71.56	119.27	238.55
Bas-Congo	Lukuya	3%	1,383,870	12.99	51,633	7.24	0.56	82.91	138.19	276.38
Kasai Oriental	Kabinda	3%	2,954,860	9.63	126,263	6.32	0.66	94.96	158.26	316.52
Sud Kivu	Sud-Kivu	66%	7,139,520	49.29	306,078	6.30	0.13	95.27	158.78	317.56
Nord Kivu	Nord-Kivu	74%	7,594,950	53.21	352,684	5.81	0.11	103.19	171.99	343.97
Province Orientale	Ituri	65%	4,903,900	47.61	261,895	5.06	0.11	118.68	197.80	395.60
Bas-Congo	Cataractes	1%	1,119,410	6.63	110,131	2.74	0.41	218.63	364.38	728.76
Kasai Oriental	Tshilenge	3%	604,191	8.01	158,527	1.03	0.13	583.07	971.78	

[a] Kinshasa Province and District are not represented in the calculations.

[b] Percentage of dense humid forest per District, derived from MODIS satellite imagery.

[c] Regional CO_2 emissions are calculated by a combination of deforestation and biomass estimates. The unit is the annual tons of CO_2 emitted annually for the period 1990-2000 per district. These estimates and the subsequent carbon emissions are assuming that all of the carbon is emitted immediately after deforestation and does not account for slower emission rates. We therefore believe that these estimates are a little high and will be adjusted when field information becomes available.

[d] Biomass estimates derived from the combination of forest inventories and satellite imagery. Baccini et al, (*forthcoming*) have produced the first map of Africa's above-ground biomass derived from satellite imagery.

[e] The number of households (HH) in each district is calculated from the GRUMP data set assuming 70 % of population to be rural in each District and assuming that average household size is 8 people. The Center for International Earth Science Information Network (CIESIN), 2004 *Global Rural-Urban Mapping Project (GRUMP): Urban/Rural Population grids*. Palisades, NY: CIESIN, Columbia University, available at http://sedac.ciesin.columbia.edu/gpw/. Data are year 2000 population counts, adjusted to match UN totals.

[f] Annual household emissions are calculated by dividing total CO_2 emissions by 10 for the emissions period and then by the number of households in each District. We then multiply the household CO_2 emissions by a factor of 0.27 to arrive at carbon emissions per household per year.

[g] The area cleared is calculated by dividing the available carbon per ha by household carbon emissions; resulting in the area required to be cleared to emit that much carbon.

[h] The carbon price is calculated by assuming a household would be able to reduce a maximum of ½ of its emissions. We assume annual payments of $300, $500 or $1,000 and divide ½ of the current household emissions by that payment to calculate $/ton of reduced carbon emissions per household.

4.2 *Managing carbon supply by the timber industry*

While managing carbon by the timber industry may appear paradoxical, logging remains one of the most underestimated components of sustainable development. Historically abused in many tropical countries, logging has never fulfilled its potential role as a renewable driver of economic development with a low carbon footprint. Many of the concerns leveled at logging are well-justified: unequal distribution of income, encouraging migration into forest areas, forest degradation, and minimally controlled access to forest products, among others. Of these problems, forest degradation can be linked directly to poor quality logging, which can be improved through reduced impact logging techniques. The other issues are a combination of many factors and are closely tied to inadequate forest governance. However, the technology for robust forest management is available and a suite of public and private policy options are available to governments to support a well-managed estate[38].

We suggest that there is an economic opportunity to match a well-managed forest estate with the carbon markets. Few other land use options can reduce emissions and maintain carbon stocks while creating as much economic wealth, provided that wealth benefits the country and local populations. Timber exports from all of Central Africa are approximately 9 million m^3 (roundwood equivalent, 2001), of which the DRC supplies less than 300,000 m^3, despite its occupying sixty percent of Central Africa's forests.[39]

Currently, more than 26 million hectares of the estimated 60 million hectares of the DRC's "productive" forests have been contracted to logging companies, and 1.4 million hectares of forest are already mapped as affected by logging in the DRC.[40] The potential for logging in the DRC has been estimated at some 14 million m^3 per year. If we include both international and domestic markets, we account for 2 million m^3, or approximately 14 percent of the potential.

Assuming that the timber concessions are eventually restored to their former area of 45 million ha, a sustainable 30-year harvest would allow the selective harvest of 1.5 million ha per year. With only 9 m^3 per ha one could produce 13.5 million m^3 per year. A price of $60 per m^3 log generates gross earnings of $810 million. If a combined area and volume tax on these earnings totals 10 percent, then government revenue from logging could be as much as $81 million per year.

Carbon emissions from logging are low as much of the carbon stock is maintained during the logging process. We estimate that about 13.9 million tons of carbon was lost between 1970-2003 – or about 420,000 tons per year, mainly in the Equator province. If the timber sector returned to 45 million ha and harvested on a 30 year rotation – 1.5 million ha per year – it would emit approximately 15 million tons of carbon per year.[41]

While the new DRC forest law (Law 11/2002, 29 August 2002) offers a framework to improve forest practices for the logging industry, there is still a need for improvements in relations with local populations, particularly the forest peoples who have been marginalized in much of the country. Furthermore, careful management of the industry as it rebuilds and expands is needed and could be supported through a government-run carbon stock management program.

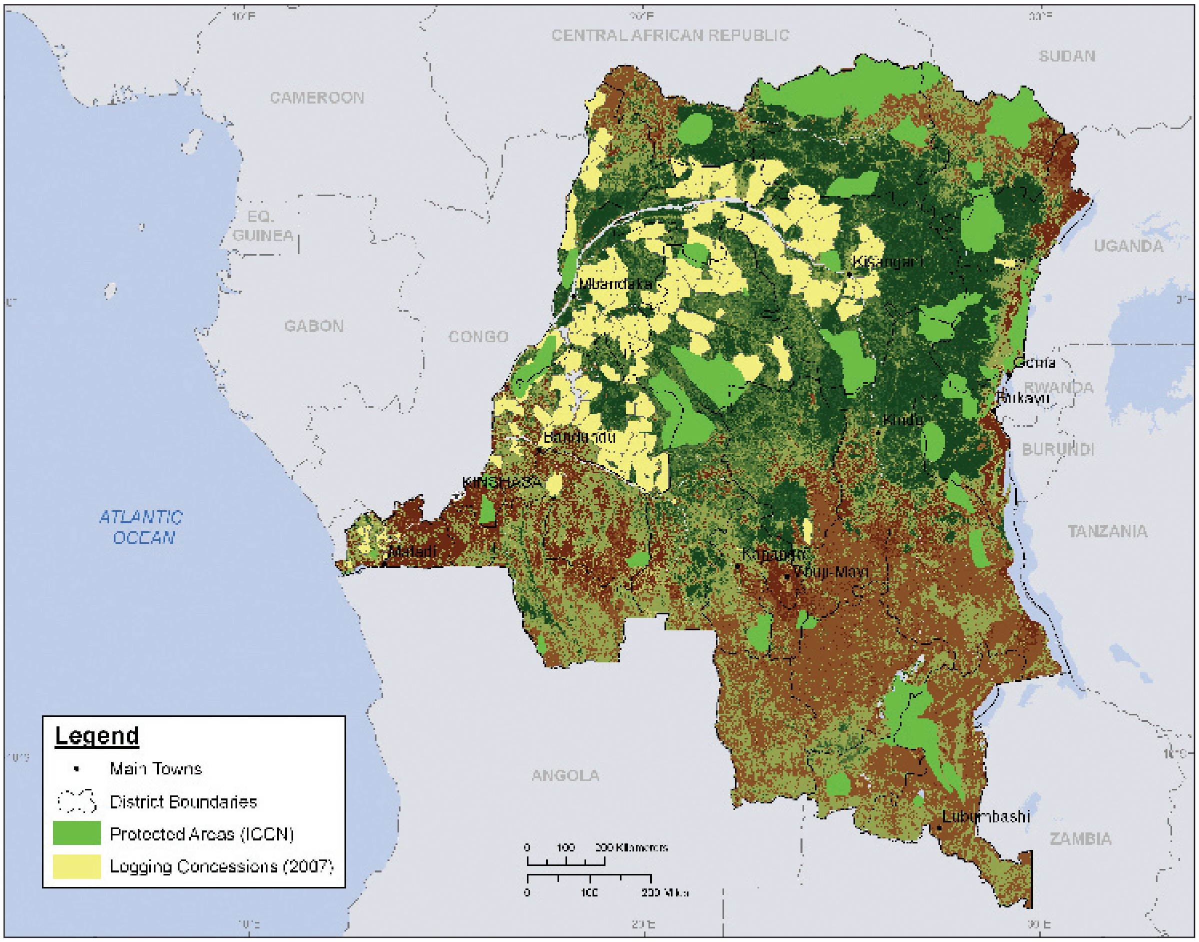

Figure 6. Logging concessions and protected areas of the DRC covered more than 43.5 million ha (until 2002). Currently, more than 20 million hectares of the 60 million hectares of "productive" forests in the DRC's forests have been contracted to logging. The informal logging industry, however, dwarfs formal production an estimated fivefold. The protected areas of DRC cover circa 24 million ha (10%) of the territory and there are plans to expand this area by 15% (an increase of 35 million ha).

The temporary reduction of timber concessions is appropriate from an international perspective, but it is unlikely to change local demand for timber or incentives for illegal logging. It is therefore imperative that the rehabilitation of the forest sector is a high priority. In a recent report on forests in the DRC,[42] a priority action agenda included the following four items:

- *Complete corrective and preventive measures to dispose of the legacy of mismanagement;*
- *Regulate the timber sector as it restarts;*
- *Develop and implement a broader vision of multipurpose forest uses; and*
- *Rebuild institutions and strengthen national leadership.*

These priority items are essential for the timber sector as well as a larger market that includes carbon from the forest concessions.

4.3 *Carbon management in protected areas: facing the opportunity costs*

Most parks and protected areas did not contribute significantly to CO_2 emissions, with the exception of the Bili-Uere hunting reserve in the North, and the Kahuzi Biega and Virunga national parks in the East. Both parks in the East have suffered from years of war and mass migration of refugees from Burundi and Rwanda. While it is difficult to estimate the exact numbers of refugees, reports suggest that more than 3.5 million people were living in the park between 1993 and 1994.[43] Ideally, socio-economic and cultural research needs to be targeted in each of these regions to identify, jointly with local populations, on the best way to reduce deforestation.

The protected areas of the DRC cover circa 24 million ha (10%) of the territory and there are plans to expand their area by 15% (including the new Sankuru forest reserve).[44] The Protected Areas can be separated into 4 categories: National Parks (9) - 8,521,066 ha; Biosphere Reserves (3) - 320,833 ha; Forest Reserves (6) - 2,010,635 ha; Faunal, Nature, or Hunting Reserves (23) - 12,759,288 ha. Assuming a cost of managing the DRC protected areas of $10 per ha[45] , the total costs of management for the protected areas would be $24 million per year.

As noted earlier, the forests of the DRC are under increasing pressure from the oil palm industry. In October 2007, a Chinese company signed a contract to develop more than 3 millions hectares of the DRC as palm oil plantations. We estimate that just one third of these areas will be established in previously abandoned oil palm plantations. Since many of these original oil palm plantations are now established in secondary forest, a gross estimate for carbon emissions from this acquisition is approximately 150 million tons (3 million ha with 50 tons C/ha). Moreover, the Chinese government has recently signed a $5 billion agreement with the DRC that provides access to mineral reserves.[46] As shown in Figure 2, much of the DRC has recently been partitioned into mining concessions.

In a similar manner to timber concessions, but without the extractive income earning potential, protected areas are an important component of the bundle of carbon goods that a country can supply to the market. In the case of protected areas, the carbon goods are held in stock but face the opportunity costs generated by alternative uses of that land. This provides an example of possible costs associated with stocks in protected areas, and illustrates the point that a bundle of carbon goods is available in low deforestation countries, and a low-cost compensation mechanism can be based on avoiding deforestation (even in the face of low threats of immediate deforestation) and storing carbon indefinitely (assuming permanence).

4.4 *An emission reduction scenario*

Here we explore a the possible reduction strategy for the DRC. In this case palm oil production is constrained to 3 million ha, phased in over 10 years, logging increases to 45 million ha, and smallholder emissions are reduced by one half after accounting for population growth. Although emissions increase slightly, they are far below the projected future possibilities shown above. In this scenario, the government will forego a net present value of $1.2 billion in income from palm oil, maintain the same returns to logging concessions and, as in the table above, realize a 50 percent reduction in emissions requiring compensation of between $**1.2 and $4** billion. This is clearly a preliminary example of the opportunity costs of emission reductions, but shows the trade-offs and potential for a carbon market even in countries with large forest estates and low deforestation .

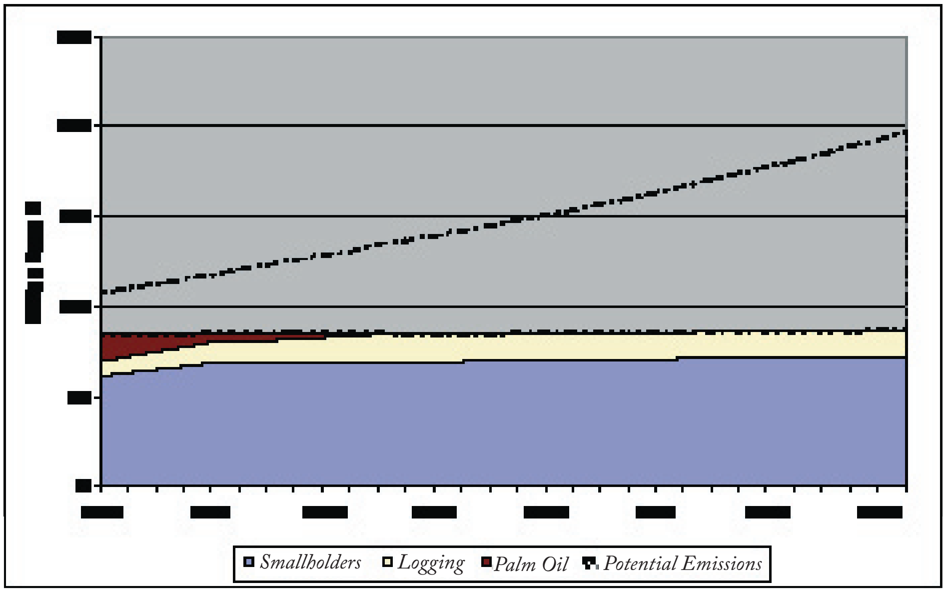

Figure 7. A hypothetical emission reduction scenario, based on 50 percent reduction from households, 3 million ha of oil palm, and 45 million ha of timber concessions. Dashed line represents potential emissions from Figure 5.

5. Delivering carbon-derived Income

The first steps in a carbon market overseen by the UNFCC will necessarily include government participation. Although government oversight may incur additional transaction costs, the nature of the carbon good is inextricably linked to societal welfare and thus government intervention. Furthermore the preparation for a more flexible, voluntary or direct carbon market where individual emitters seek effective emission-reducing alternatives will require strategic capacity building and then monitoring.

Here we recommend that the government of the DRC be supported, partially through the carbon markets – based on establishing the carbon supplies described above – to complete the rehabilitation of its related government structure: a daunting task, and one we hesitate to underestimate. In the absence of such a goal, however, it is unlikely that any measures to secure environmental services through REDD will succeed. Rather than shying from the task at hand, it is perhaps more helpful to estimate what it would take and where the carbon market can play a significant role.

Historically, resource use has been based on the exploitative flow of natural resources – how much can be taken out of the ground or from the land and how quickly – and is a driving force of conflict. We begin here by describing a framework for funding distribution of carbon-derived income, which will help identify how sale of a natural resource stock, rather than flow, could bolster the country wealth. We recommend that the carbon market be supplied with a bundle of carbon goods from the DRC based on the three sources identified above: households, protected areas and timber concessions. The DRC would receive income which would then be distributed into: a Governance Fund; a Private Forest Stewardship Fund; and a Public Forest Stewardship Fund. The combination of these funds should both help alleviate poverty and protect natural resources.

Each year, the market can readjust the basket of carbon goods purchased from the DRC. In the early stages of the market, we see a significant role for government as many of the goods are either public or emerging private markets. A future where government and private interests "compete" in a carbon market is, however, a distinct possibility once the market is better established. Finally, the funds described below may also have overlap among carbon suppliers.

5.1 *Governance Funds*

Perhaps the most daunting task at hand for the DRC is continued progress towards adequate governance. The brief overview of past mismanagement presented in the introduction gives but a taste of the obstacles facing the DRC in a search for sustainable development. These hurdles cannot be discounted.[47] The World Bank estimates that international donors have given $800 million in both 2004 and 2005 – approximately $15 per capita,[48] but also notes that this amount is completely inadequate for the task at hand. The World Bank itself has a portfolio in the DRC worth some $2.2 billion over the next few years and the current government budget is estimated at $2.45 billion per year (Table 2).

Table 2. Government *Expenditures in the DRC 2006/2007*

Item	FC Billions	USD	Percent
Public debt	229	410,278,571	16.7%
Financial expenses	146	261,830,357	10.7%
Personnel	347	620,304,248	25.3%
Supplies and material	39	70,723,092	2.8%
Contracts	61	109,140,235	4.4%
Transfers and interventions	194	347,099,655	14.1%
Equipment	174	311,275,640	12.7%
Construction	177	316,329,640	12.9%
Total	1,370	2,446,981,439	100.0%

Source: DRC Ministry of Finance

The rapid design and implementation of an effective system of government-run distribution is the biggest hurdle in the efficient distribution of income derived from a carbon market in the DRC. The basis of functional governance is present in the DRC, but filling in the structure with effective implementation and oversight is a work in progress. The details of an income distribution system within the DRC are beyond the scope of this report, but it is perhaps sufficient to state that the aim of this fund is to consolidate and strengthen existing government programs in the overarching goals of economic development and poverty alleviation.

5.2 *Private Forest Stewardship Funds*

Although households do not hold formal property rights, they hold a level of *de facto* ownership over land. This makes them private forest stewards and the direct managers of forests. Funds must therefore be designated to the reduction of emissions, coupled with increases in living standards for forest-dependent communities.

To reduce deforestation in the "medium deforestation, high biomass" regions, a doubling of agricultural productivity at the household level could bring a reduction of emission by 50 percent. It is an ambitious goal that will require providing farmers with access to disease-resistant crop varieties that will be able to better exploit the relatively high levels of nutrients that characterize the first year of cropping, the use of soil amendments such as organic and chemical fertilizers, leguminous green manures, kitchen wood ash, improved seeds, and so forth.[49] Implementing an intensification of agriculture to increase agricultural productivity will also depend on the strengthening of agrarian services, organizing farmers, rural credit and savings organizations, and rural infrastructure.

Household decisions are complex and any technology or policy innovation that increases the productivity of farming in the humid forest region runs the risk that additional land and labor resources will be allocated to that particular activity, increasing deforestation[50]. Therefore, careful design, monitoring and follow-up of this program is essential. However, we have shown that average carbon prices of $19 to $65 could potentially deliver a 50% reduction in emissions from households.

5.3 *Public Forest Stewardship Funds*

When the government grants concession rights to private companies, these companies become the stewards of public forests. This is true for both logging and industrial agricultural production. A fund designated to public forest stewardship must either provide the resources to ensure well-managed public forests or offset the opportunity costs of awarding concessions. In other words, if awarded, logging and oil palm concessions must be well managed and the governance capacity must be sufficient to ensure this happens. These concessions generate income for the government and should a carbon market seek to reduce these concessions it must provide equal value.

In what economists might term revealed preference, the aforementioned ZTE International investment of $1 billion in a 3 million hectare oil palm plantation gives some approximation of the value with which carbon must compete if it is to avoid future deforestation for industrial agriculture – this estimate represents an input of approximately $333 per ha. If we assume an average of 100 tons of carbon per ha, we have an equivalent cost of competing with this investment of only $3.33 per ton.[51] While it is probably not in a country's best interest to attempt to dissuade all agricultural production, a market-based mechanism for carbon may be better able to encourage the optimal mix of production and protection for sustainable development.

This industrial agriculture sector is currently the least developed in the DRC, with oil palm as probably the most pressing potential competitor. Recall, however, there are 98 million ha suitable for oil palm production. It is also worth mentioning here because as economic stability returns, commensurate with additional investment, rents for alternative uses of lands will rise. Projection of potential industrial agricultural production and the land use changes brought on by mining and other uses will be an important early step to prepare for market integration.

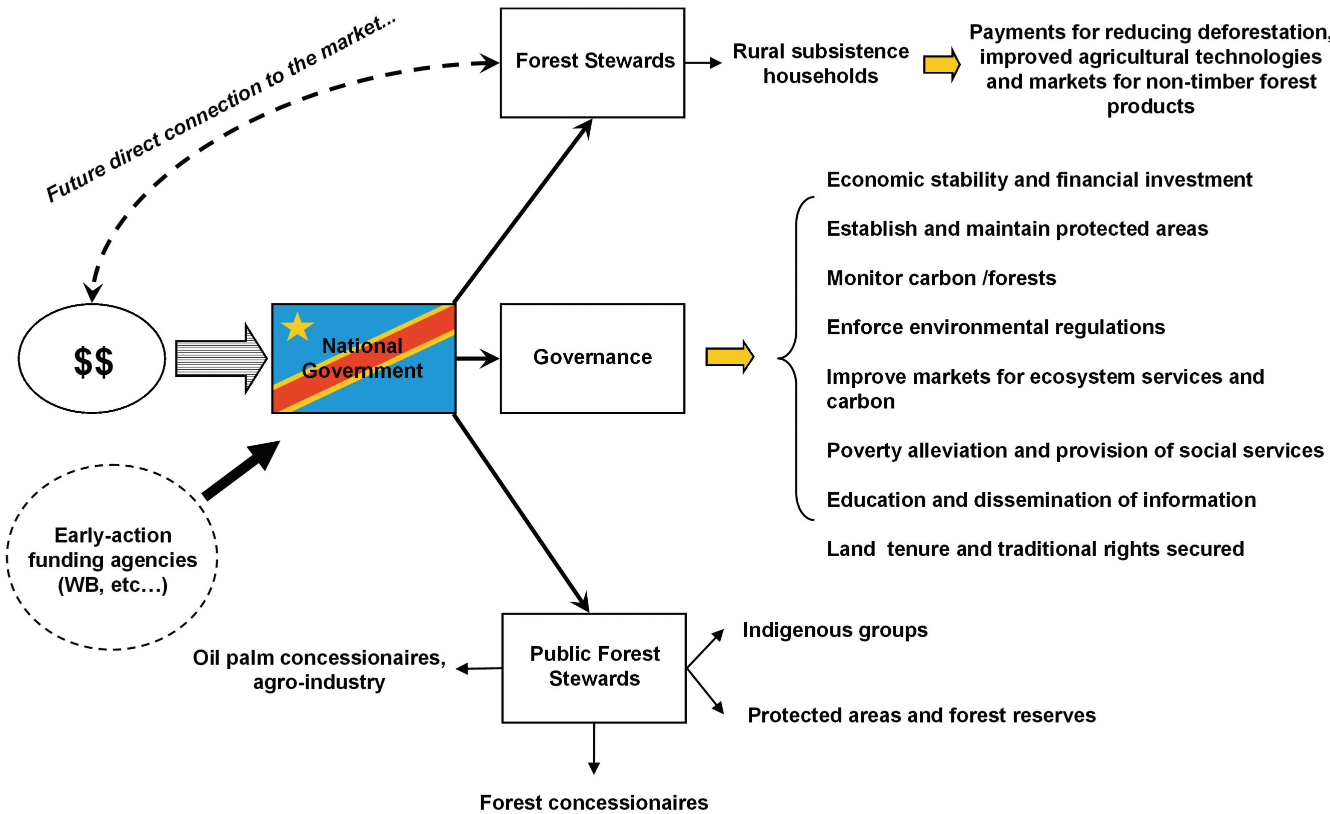

Figure 8. Design and distribution of carbon-derived income. Three funds are proposed: a Governance Fund to stabilize and improve the current government structure; a Public Forest Steward Fund to distribute income to individuals dependent on public forests and support management of protected areas and timber concessions; and Forest Steward Fund that would offset lost income and encourage good forest management by households.

6. Conclusion

The DRC stands poised to enter an era of stability and economic development. As with other countries with large forest estates and low deforestation, this economic development will put at risk large carbon stocks. It is important that these countries access carbon financing that differentiates the carbon between stocks and flows and accurately estimates the opportunity costs of reducing deforestation. The DRC can eventually sell a bundle of differentiated carbon goods on the market that include carbon in protected areas, carbon in logging concessions and carbon in household and community lands. The first two represent the maintenance of carbon stocks in some form of "avoided deforestation" and the third "reduced deforestation." As essentially different goods, they can be priced differently.

This report provides a synthesis of current knowledge and data sets necessary for the DRC to monitor carbon emissions and identify pertinent approaches to address emerging *Reduced Emissions from Deforestation and Degradation* (REDD) policies. Critical data sets reviewed here include: the distribution of above-ground carbon stocks, drivers of land-cover change and associated deforestation rates, and recent carbon flux estimates. These results provide a first look and are already being refined. Nonetheless, they identify key sectors that may contribute to avoiding or reducing carbon emissions and quantify their potential income generation. Finally, an institutional and governance framework is presented that would enable the DRC to successfully implement a carbon emissions reduction strategy.

Endnotes

[1] Previous names have been Congo Free State, Belgian Congo, The Congo, Congo-Leopoldville, Congo-Kinshasa, and Zaire.

[2] OXFAM (2007) Africa's Missing Billions. Briefing Paper 107. http://www.oxfam.org.uk/resources/policy/conflict_disasters/downloads/bp107_africa_missing_billions.pdf

[3] *The Economist*, "Mending Africa's broken heart", 27 July 2006

[4] Buys, P., U. Deichmann, and D. Wheeler, (December 2006), Road network upgrading and overland trade expansion in Sub-Saharan Africa, World Bank, Washington, D.C.

[5] www.grouplavenire.net

[6] Williams and Jackson (2007) Novel climates, no-analog communities, and ecological surprises. *Frontiers in Ecology and the Environment* 9(5):475-482 (see Figure 4d).

[7] FAO. *State of the World's Forests*. Oxford: Words and Publications, 1997.

[8] Food and Agricultural Organization (2006), Global Forest Resource Assessment.

[9] Laporte et al. (2007) *Expansion of Industrial Logging in Central Africa*. Science.

[10] Houghton, R.A., and J.L. Hackler. 1999. Emissions of carbon from forestry and land-use change in tropical Asia. *Global Change Biology 5*:481-49

[11] Moutinho and Schwartzman, editors (2005) *Tropical Deforestation and Climate Change.* Amazon Institute for Environmental Research, Belém, Pará, Brazil. Chomitz, K.M. (2006) *At Loggerheads? Agricultural Expansion, Poverty Reduction, and Environment in the Tropical Forests*. A World Bank Policy Research Report.

[12] Various technologies adequate to this end are already in use and are improving rapidly, e.g., Mollicone et al. (2007) *Avoiding deforestation: An incentive accounting mechanism for avoided conversion of intact and non-intact forests*, Climatic Change (83): 47-493. Also see Defries, et al. (2006) *Reducing Greenhouse Gas Emissions from Deforestation in Developing Countries: Considerations for Monitoring and Measuring*. GOFC-GOLD Report No. 26

[13] ALOS Kyoto & Carbon Initiative Science Plan, www.eorc.jaxa.jp/ALOS/kyoto/KC-Science-Plan_v2.pdf. Kintisch (2007). *Carbon emissions: Improved Monitoring of Rainforests Helps Pierce Haze of Deforestation*, Science vol.27.

[14] Commission des Forêts d'Afrique Centrale (www.comifac.org), including Burundi, Cameroon, Congo, Gabon, Equatorial Guinea, Central African Republic, DRC, Rwanda, Sao Tomé and Principe, and Chad.

[15] Laporte et al, (1998) A new land cover map of central Africa derived from multi-resolution, multi-temporal AVHRR Data, *International Journal of Remote Sensing,* 19(18): 3537-3550.

[16] More information on the tropical forest of Central Africa and their carbon stocks can be found in Holmes 2002, Lumbwe, 2001. Baker, et. al, 2003, Laporte et al. 2007.

[17] Brown, S, and Gaston. 1996. *Tropical Africa: Land Use, Biomass, and Carbon Estimates for 1980*. NDP-055, Carbon.

[18] Saatchi et al. (2007) Distribution of aboveground live biomass in the Amazon basin. Global Change Biology (2007) 13, 816-837.. Baccini et al. (2004) Forest Biomass Estimation over Regional Scales Using Multisource Data, Geophysical Research Letters 31(1). Foody, et al (2001) Mapping the Biomass of Bornean Tropical Rain Forest from Remotely Sensed Data. Global Ecology and Biogeography 10(4): 379-387.

[19] Baccini et al, (*forthcoming*), A first map of Tropical Africa's above-ground biomass derived from satellite imagery, Ecosystems.

[20] Due to the large area and a dearth of high quality and cloud-free remotely sensed data, several years of data between 2000 and 2003 were necessary to derive the biomass / carbon stocks map.

[21] Laporte et al. (2004), Toward an Integrated Forest Monitoring System for Central Africa. In: *Land Change Science: Observation, Monitoring, and Understanding Trajectories of Change on the Earth Surface*, Remote Sensing and Digital Image Processing, Vol (6), Ed. G. Gutman. ISBN: 1-4020-2562-9, p 97-110.

[22] The National Forest Authority of Uganda already has in place a system for providing biomass assessment every 5 years.

[23] Reed and Miranda (2007). *Assessment of the Mining Sector and Infrastructure Development in the Congo Basin Region*, World Wildlife Fund report. The rapid increase in mining concessions is likely the result of a "gold-rush" as investors seek to establish extraction rights.

[24] In general, however, the dominant causes of deforestation (infrastructure extension, agricultural expansion and wood extraction) interact with five main underlying factors (demographic, economic, technological, and policy – cultural. Geist and Lambin (2001) *BioScience* 52(2) analyzed deforestation across 152 countries and identified these proximate and ultimate causes of deforestation. Although the efficacy of broad analysis of deforestation has been questioned, these causes are broadly accurate in defining major components and drivers. See also Sunderlin et al. (2000), Economic crisis, small-scale agriculture, and forest change in southern Cameroon, *Environmental Conservation*, 27(3):284-290

[25] Duveiller et al. (forthcoming) Deforestation in Central Africa: estimates at regional, national and landscape levels by advanced processing of systematically-distributed Landsat extracts. *Remote Sensing of Environment*.

[26] Shapiro, 1995 *Population growth, changing agricultural practices, and environmental degradation in Zaire,* Population & Environment, Springer.

[27] Brown et al. (2006) estimate that logging in the northern Republic of Congo leads to the loss of approximately 10 TC per ha. Combine this estimate with the total area degraded by industrial logging mapped from Landsat imagery over the period 1970-2000 and it has been estimated that some 14 million tons of C were lost over this 30 year period (Laporte et al., 2007 *Science*).

[28] Malcom and Ray (1998) Influence of timber extraction routes on Central African small-mammal communities, forest structure, and tree diversity. *Conservation Biology* 14 (6):1623-1638. Robinson et al. (1999) Conservation of wildlife harvest in logged tropical forests. *Science* 284(5414): 595-596.

[29] To properly estimate emissions, information about biomass for the year 1990 was required. The biomass in 1990 was derived as biomass (in 2000) / (1 - ΔFa) where biomass 2000 is the biomass derived from MODIS (figure 1), and ΔFa is the percentage of forest area lost.

[30] Equivalent to 0.07 Pg of C per year (where carbon is 27% of the molecular weight of CO_2).

[31] A recent estimate for all of Central Africa was approximately 0.33 Pg CO2 per year (Houghton and Hackler 2006).

[32] 20% of the Total Above Ground Biomass is used to estimate soil carbon

[33] Many oil palm plantations have been abandoned for more than a decade allowing for substantial regrowth and carbon storage that would be emitted in preparation for new fields.

[34] Of the forest area in the DRC 77 million ha are estimated to be suitable for oil palm plantations

[35] The calculation presented here is a simple representation of transfer based on cash income and probably underestimates the true value of the forest to the households. There may be some goods that are essentially irreplaceable with cash, and the transfer of cash into an economy based largely on subsistence may be complex. Therefore, further research into the cultural role of forests, the multiple benefits of the forests – in particular fuel wood and bush meat - and economics of household decisions is required to provide a more accurate carbon supply curve from households.

[36] The average household in this estimation contains 8 people and $1 per day per household ($365 per year per household) is a conservative estimate. However, per capita GDP has been reported as low as 0.29 cents per day in 2002 (Debroux, L. et al. (eds.) 2007. *Forests in Post-conflict Democratic Republic of Congo: Analysis of a Priority Agenda*. 82 p ISBN 979-24-4665-6.)

[37] Annual household C emission ranges from 1.03 to 58.61 tons per year.

[38] Debroux et al., ibid

[39] Laporte et al. (1998), ibid. estimate the DRC dense humid forest cover at some 1.45 million km^2, or more than 60 % of the country. Also, the informal domestic market is estimated to be in the range of 1.5 million m^3.

[40] Only industrial logging – also, does not include illegal logging

[41] Assuming emissions of 10.2 tons of carbon per ha of forest harvest, although with good forest management, this could be reduced.

[42] Hoare A., 2007 Clouds on the Horizon: The Congo Basin's Forests and climatic change, The Rainforest Foundation, ISBN: 978-1-906131-04-3

[43]Debroux et al. (2007). Ibid.

[44] Internal Organization for and the United Nations. 2000. *World Migration Report 2000*. Internal Organization for Migration, Geneva, Switzerland.

[45] In "Protected areas of the Democratic Republic of Congo". *Conservation Biology* 19 (1): 15-22, Inogwabini, B., et al. (2005) suggest that with current funding (and a decrease in funding for maintenance of protected areas during the 80s and 90s), parks are in partial protection and many reserves remain mostly unprotected. They show a range of spending on parks per km^2 from $400 (Zimbabwe, Kenya) to more than $ 2,000 in South Africa

[46] Wilkie et al, 2001 (*Beyond Boundaries: Regional Overview of Transboundary Natural Resource, Management in Central Africa*, BSP 125) estimates current DRC government spending on protected areas to be approximately $8 per km^2 so our estimates are considerably higher than that ($1,000 per km^2). The range of international per ha expenditures in protected area are from $5,610 in the Netherlands to $0 in neighboring Angola. www.worldwildlife.org/bsp/publications/africa/125/125/titlepage.html

[47] See http://biopact.com/2007/07/dr-congo-chinese-company-to-invest-1.html for a discussion of the ZTE International investment and http://biopact.com/2007/09/china-opening-up-congo-for-minerals.html for a brief commentary on the Chinese government loan to the DRC.

[48] A report by Gobal Witness in 2004 "Same Old Story: A background on the natural resources in the Democratic Republic of Congo" emphasizes the fragility of the government structure.

[49] For more discussion on the country profile and World Bank Programs in the DRC go to http://web.worldbank.org. The donor figure excludes peacekeeping, humanitarian assistance, and election support. The CIA World Factbook estimates the donor assistance for FY03/04 to be some $2.2 billion but does not clarify the destination and this may include the factors excluded from the estimate above. The DRC Ministry of Finance recorded $850 million in donor receipts in 2006 (35% of total receipts) on its website. The DRC budget from the Ministry of Finance for 2006 was $ 2.45 billion. The CIA World Factbook gives an overview of data and general statistics for all countires, see - www.cia.gov/library/publications/the-world-factbook/

[50] Serageldin, I. (1991). Saving Africa's Rainforests. (contribution to Conference on the Conservation of West and Central Africa Rainforests, Abijan, Cote d'Ivoire, Nov 5-9, 1990), World Bank, Washington, D.C.

[51] Angelsen, A. & D. Kaimovitz (2000): "Rethinking the Causes of Deforestation: Lessons from Economic Models ", *World Bank Research Observer* 14(1):73-98.

[52] This is a simple calculation and ignores potential employment and the multiplier effect of money in the economy, i.e., the current estimate covers only the initial investment and does not include the downstream impacts, possibly underestimating the price required for carbon. Furthermore, should there, for example, be only 50 tons of carbon stored the price would double to $6.33.