CHAPTER 1

CENTRAL AFRICAN FOREST COVER AND COVER CHANGE MAPPING

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Introduction

Central Africa contains the second largest area of contiguous moist tropical forest in the world, covering about 2 million km^2 (Mayaux *et al.*, 1998). The Congo Basin is occupied by vast and still uninterrupted tracts of rainforests from the Gulf of Guinea to the Albertine Rift. Salient features include the presence of the world's largest tropical swamp forest in the central part of the Congo Basin, and two mountainous regions in Cameroon and in eastern Democratic Republic of Congo (DRC).

The central region is characterized by low deforestation rates resulting from small localized clearings usually associated with shifting agricultural activities (Mayaux *et al.*, 2003; Hansen *et al.*, 2008). The situation can be explained by the absence of a significant local market for wood products and a poor transportation infrastructure. However, coastal Central Africa has experienced more intensive forest exploitation. Here, population growth and agricultural expansion, as well as emerging marketing opportunities have exerted a strong pressure on forest resources.

This has been the general understanding of forest change in the Congo Basin but until the mid 1990s this was based on patchy and anecdotal information, without spatially explicit delineation of forests and statistically robust estimates of forest cover change. The lack of up-to-date and accurate information on the current state and evolution of forested areas in Central Africa has often been cited as a limiting factor in the design of efficient forest management policies. Efforts to improve regional and national capabilities to address the problem of forest and land use monitoring have thus received particular attention in recent years (Mayaux *et al.*, 1998; Duveiller *et al.*, 2008).

Photo 1.1: At the fringes of their geographical coverage in Cameroon, forests mix with savannas

The accurate delineation of Congo Basin forests is also needed to provide information for global scientific applications and regional environmental policies. It establishes the boundary conditions for General Circulation Models simulating climate and for land surface process models used for Earth system energy, water and material transport studies as well as biogeochemical cycle modelling. The improved accuracy with which such maps depict actual land cover at some specified time could increase the reliability of the regional scenarios generated by the models.

Policy users also need information on the state of the world's land cover to develop sustainable development policies and strategies at scales ranging from local projects to the global perspective of multilateral environmental agreements such as the UN Framework Convention on Climate Change (UNFCCC), the UN Convention to Combat Desertification (UNCCD), the Convention on Biological Diversity (CBD) and the Ramsar Wetlands Convention. The reporting mechanisms under the terms of multilateral environ-

Photo 1.2: Logging roads provide the primary means of access to forest areas

mental agreements ask for assessments of natural resources, including land cover. In particular, the prominent role of forests in the carbon cycle was underlined during the recent negotiations on climate in Copenhagen and Cancún. Concrete mechanisms are now under development by the Convention of Parties (such as REDD+ and CDM) and require detailed information on the land cover and the land cover changes.

Land cover information is also needed to measure the impact and effectiveness of management actions associated with sustainable development policies. Addressing issues such as sustainable management and use of forests and other land resources in developing countries, forest conservation and restoration, extension of surfaces dedicated to agriculture, desertification and watershed degradation will all substantially benefit from the availability of accurate baseline land cover information (FAO, 2005).

This chapter presents the most recent available results on the spatial distribution and the evolution of Congo Basin forests, based on the processing and analysis of a vast amount of satellite images acquired over the last two decades. First, it will detail a new map of the forest types built upon previous studies and taking advantage of a combination of the best satellite data available. Then, the best available estimation of land cover change is described thanks to two complementary land cover change studies respectively based on: (i) a sample of Landsat sub-scenes covering the entire territory of the 6 forested countries, and (ii) a wall-to-wall coverage of Landsat mosaics for the DRC.

A new Congo Basin vegetation map

Satellite-based mapping of forest cover in the Congo Basin is challenging due to the persistent cloud cover, the fragmentation and variability of the landscape, while field based inventories are limited by the vast extent and inaccessibility of the territory. Previous State of the Forest (SOF) reports relied on the fusion of the different available maps. For the 2006 SOF report, a synthesis of two maps was performed, GLC2000 (Mayaux *et al.*, 2004) was merged with a forest/non-forest map obtained from MODIS time-series analysis (Hansen *et al.*, 2003). For the 2008 SOF report, five sources of information were merged to establish the best available map at the time, mainly focusing on the humid forest.

Capitalizing on the previous results and taking advantage of much more recent satellite time series, a new forest map covering consistently the 8 countries of Congo Basin has been produced (figure 1.1). The production of this new map relied on a semi-automatic method combining statistical classification, expert consultation and manual editing (Verhegghen & Defourny, 2010). The methodology developed takes advantage of the spatial resolution of MERIS (300 m resolution) and the time-series of 8-years of SPOT-Vegetation (SPOT-VGT), providing a better delineation of the small features and improved discrimination of the vegetation type respectively. This vegetation class discrimination relied on a systematic analysis of the different seasonal spectral profiles in order to split classes showing differences in terms of seasonal dynamic of green biomass.

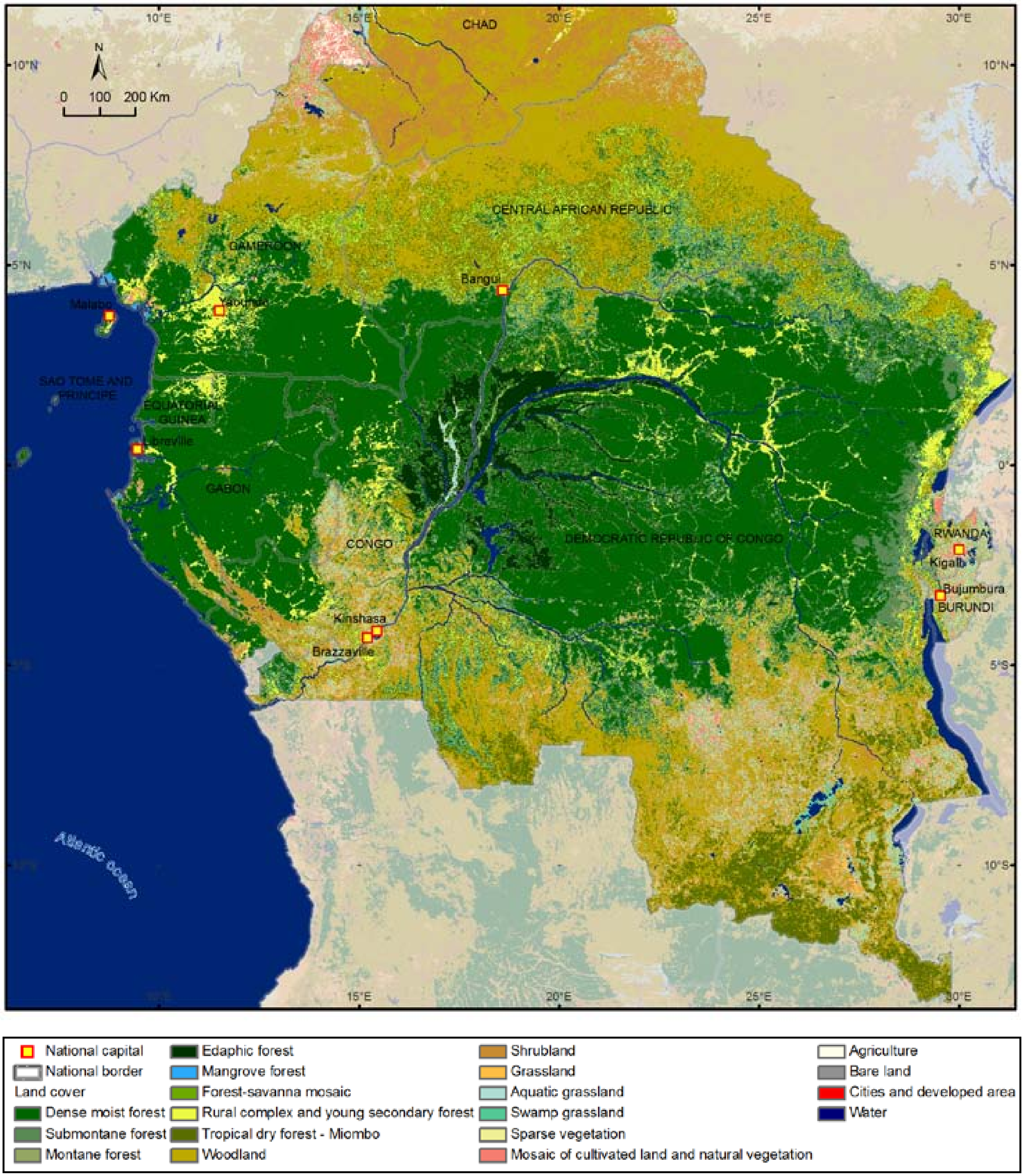


Figure 1.1: Congo Basin land cover map derived from 300 m resolution data
Source: Verhegghen & Defourny, 2010

The following land cover classes were mapped for the Congo Basin at 300 m resolution for the first time:

- Dense moist forest
- Submontane forest
- Montane forest
- Edaphic forest
- Mangrove forest
- Forest-savanna mosaic
- Rural complex and young secondary forest
- Tropical dry forest - Miombo
- Woodland
- Shrubland
- Grassland
- Aquatic grassland
- Swamp grassland
- Sparse vegetation
- Mosaic of cultivated land and natural vegetation
- Agriculture
- Irrigated agriculture
- Bare land
- Cities and developed area
- Water

Map description (based on Mayaux *et al.*, 1997)

The dense moist forest is found in the western part of Cameroon and covers the major portion of the Congo Basin from Gabon and Equatorial Guinea to Kivu (DRC). Submontane (1,100 - 1,750 m) and montane forests (> 1,750 m) exist in the Albertine Rift. Small forest blocks are also found in the west of Cameroon (i.e. foothills of Mount Cameroon, Bamenda and Bamiléké highlands). Given the high density of the river network, edaphic forest (semi deciduous tall trees on permanently or seasonally flooded land) occupies very large areas in the central Congo Basin (also known as the "*cuvette*").

In the DRC, Cameroon and Equatorial Guinea, the dense moist forest is fragmented along road networks and around villages. "Rural complex and young secondary forest" is a mixture of forestry fallows, personal gardens, subsistence crops and plantings. Mapping the state of tropical forest degradation of the Atlantic countries is improved because of the increased availability of satellite images (including almost 3,000 images daily SPOT-VGT observations). From these data it is possible to detect (at that scale) patterns of settlements and road impacts in the forests in Equatorial Guinea, Cameroon and Gabon (figure 1.2).

[1]Data available on http://www.esa.int/esaEO/SEMGSY2IU7E_index_1.html

[2]Data available on http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php

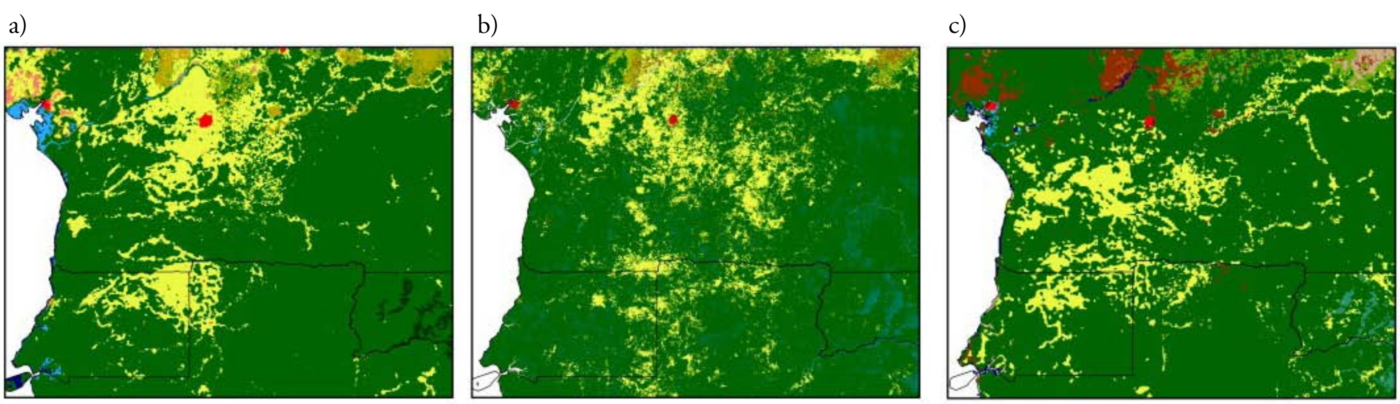


Figure 1.2: Example of the improved discrimination of vegetation classes using the 8-years SPOT-VGT time-series analysis depicting networks of deforested areas usually not detected due to the persistent cloud coverage. a) 300 m resolution Congo Basin land cover map; b) Globcover[1] (300 m resolution); c) GLC 2000[2] (1 km resolution).

Sources: Verhegghen & Defourny, 2010; Defourny et al., 2009; Mayaux et al., 2004

The dense dry forests in Central African Republic (CAR) (relics of dense moist forests) and Miombo woodlands in southern DRC have been combined into the "Tropical dry forest - Miombo" class. This formation can be defined as a mixed vegetation formation of a sparse herbaceous stratum under a 15 to 20 m tall forest stand. Miombo woodland is often subject to fires and covers southern province of Bandundu and large parts of the province of Katanga (both in DRC).

The "forest-savanna mosaic" contains forest and savanna elements. Gallery forests are tree formations occurring along the river banks in the middle of shrub or grass vegetation. The mapping of the forest-savanna transition zones in CAR as well as the southern savannas in DRC is well depicted by the higher spatial resolution of the MERIS (Medium Resolution Imaging Spectrometer) instrument. The precise delineation of the forest gallery network in CAR clearly illustrates this improvement (figure 1.3). The improved spatial resolution also enables a more accurate depiction of the "rural complex" class in the humid forests.

Photo 1.3: Land use mosaïc of natural forest, plantations and farms

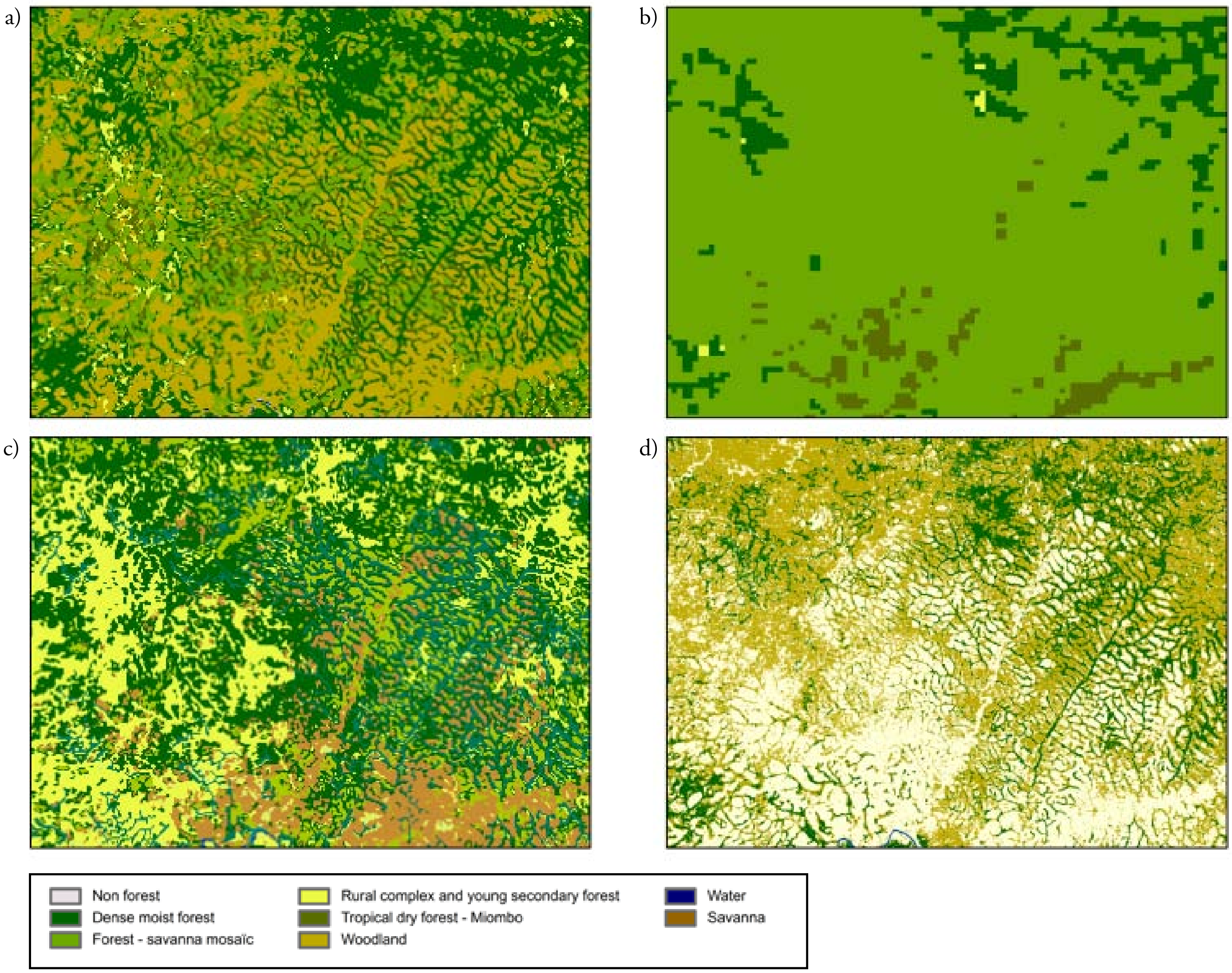


Figure 1.3: Visual comparison of the new Congo Basin land cover map with earlier maps in a forest-savanna zone where the improvement is related to the higher spatial resolution. a) 300 m resolution Congo Basin land cover map (see figure 1.1); b) GLC 2000 (1 km resolution); c) Globcover (300 m resolution); d) 60 m resolution DRC FACET Atlas (OSFAC, 2010)

Sources: Verhegghen & Defourny, 2010; Mayaux et al., 2004; Defourny et al., 2009; OSFAC, 2010

Photo 1.4: A mangrove in Gabon, linking the terrestrial and marine environment

Mangroves are remarkable, highly productive forest ecosystems comprised of small groups of trees, shrubs, palms and ferns adapted to survive in the harsh interface between land and sea. These species are characterized by physiological traits which overcome the problems of anoxia, high salinity and frequent tidal inundation. These fragile ecosystems are present mainly in Cameroon, Equatorial Guinea and Gabon.

The "woodland" covers large areas in CAR, Cameroon and in the DRC provinces, Katanga, southern Bandundu, Kasai Occidental and Oriental. In this formation, the herbaceous layer is continuous, while the tree layer is sparse but very rich in species.

Derived forest areas

Area estimates of the 20 land cover classes have been reported in table 1.1. For some countries, area estimates of some classes are significantly different than previous estimates. This apparent discrepancy is due to the effect of improved spatial resolution. Indeed, while a 1 km pixel identified a mosaic of forest-savanna in a transition zone or in a forest gallery landscape, the 300 m pixel can often delineate each class and map them separately. Furthermore, the dense moist forest area of CAR, as reported here, is drastically higher than in the 2008 SOF report, since it includes many gallery forests outside the Congo-Guinean domain at the fringes of the large forest block and up to the "Bongo" forests.

Photo 1.5: Village on the shore of the Lukénie River, DRC

Forest cover change

Local and regional forest cover dynamics impact climate, biodiversity and ecosystems services. National and international decision makers need reliable, objective, verifiable (according to international standards) and up-to-date information to define and monitor forest policies and to report to international conventions. Satellite remote sensing is currently the most adapted system to measure deforestation in vast and inaccessible forests such as in Central Africa.

To address the challenge of monitoring forest dynamics over the last few decades, two complementary strategies have been pursued, both of which rely on satellite data. On one hand, a sampling approach has been designed over Cameroon, Congo, Gabon, Equatorial Guinea, CAR and DRC in collaboration with national experts. The sampling approach captures four forest cover change processes (i.e. deforestation, degradation, reforestation and regeneration). On the other hand, vast amounts of satellite data have been processed to deliver a spatially explicit wall-to-wall map of forest cover and deforestation for the entire DRC.

Table 1.1: Area estimates (in hectares) of the land cover types for the 8 countries as derived from the Congo Basin land cover map

Land cover class	Cameroon	Congo	CAR	DRC	Gabon	Equatorial Guinea	Burundi	Rwanda
Lowland dense moist forest	18,640,192	17,116,583	6,915,231 (*)	101,822,027	22,324,871	2,063,850	8,412	172
Submontane forest	194,638	0	8,364	3,273,671	0	24,262	36,311	39,061
Montane forest	28,396	10	0	930,863	19	6,703	57,212	180,259
Edaphic forest	0	4,150,397	95	8,499,308	16,881	0	0	0
Mangrove forest	227,818	11,190	0	181	163,626	25,245	0	0
Total dense forest	**19,091,044**	**21,278,180**	**6,923,690**	**114,526,051**	**22,505,397**	**2,120,060**	**101,936**	**219,492**
Forest-savanna mosaic	2,537,713	517,068	11,180,042	6,960,040	51,092	0	70,465	54,405
Rural complex and young secondary forest	3,934,142	3,664,609	713,892	21,425,449	1,405,318	507,281	297,748	304,699
Tropical dry forest - Miombo	1,292,106	297,824	3,430,842	23,749,066	31,337	172	35,127	4,344
Woodland	11,901,697	2,659,375	34,381,438	36,994,935	787,231	4,669	297,137	373,999
Shrubland	2,561,163	2,101,556	4,002,258	6,705,478	619,347	1,308	222,700	146,936
Grassland	177,385	1,191,956	62,015	4,372,677	341,688	86	201,875	153,696
Aquatic grassland	20,156	328,254	96,531	75,888	18,857	1,060	0	258
Swamp grassland	128,622	0	0	701,308	0	0	0	2,206
Sparse vegetation	0	95	0	2,129	0	0	0	0
Mosaic of cultivated land and natural vegetation	3,475,766	1,794,050	977,811	12,907,360	304,097	1,098	1,251,030	1,297,014
Agriculture	667,918	60,239	8,994	0	19,535	172	0	50,538
Irrigated agriculture	60,669	0	26,362	181	0	0	0	831
Bare land	0	0	0	41,935	0	0	0	95
Cities and developed area	38,507	2,941	7,199	41,716	18,332	401	0	286
Water	276,637	296,726	35,452	3,944,206	325,017	27,861	20,433	142,591
Total	**46,163,526**	**34,192,873**	**61,846,529**	**232,448,418**	**26,427,250**	**2,664,168**	**2,498,451**	**2,751,390**

(*) For CAR, 3,994,399 ha of the 6,915,231 ha of lowland dense moist forest belong to the Congo-Guinean domain as defined by Boulvert (1986), the rest belonging mainly to the edaphic domain.

Source: Verhegghen & Defourny, 2010

Forest cover change sampling

Based on the lessons learned from the study presented in the 2006 SOF report (Duveiller *et al.*, 2008), study objectives were twofold. The first one was to deliver a valid estimate of complex forest dynamics at the national level. The second purpose was to enhance national capacity for monitoring, assessing and reporting on forests and land use changes.

National forest remote sensing involvement was considered by all parties as an essential dimension of the overall process. While several steps, such as image selection, pre-processing and automated classification were completed by the Joint Research Centre of the European Commission (EC-JRC) and a team of the *Université catholique de Louvain* (UCL), 15 national experts (photo 1.6) were invited for a 2-weeks workshop to validate the automatic pre-interpretation for land cover mapping and forest change detection. In joint collaboration with the Forest Resources Assessment (FRA) 2010 remote sensing survey, this regional validation workshop was organized at the Regional Post-graduate Training School on Integrated Management of Tropical Forests and Lands (ERAIFT) in October 2009 in Kinshasa (DRC). The workshop was designed based on a preliminary test with the *Direction des Inventaires et Aménagements forestiers* (DIAF, ex-SPIAF) team in February 2009. For consistency, a final visual check was completed by the UCL team and results were returned to the experts during a 1-day post-processing meeting in Brazzaville in February 2010.

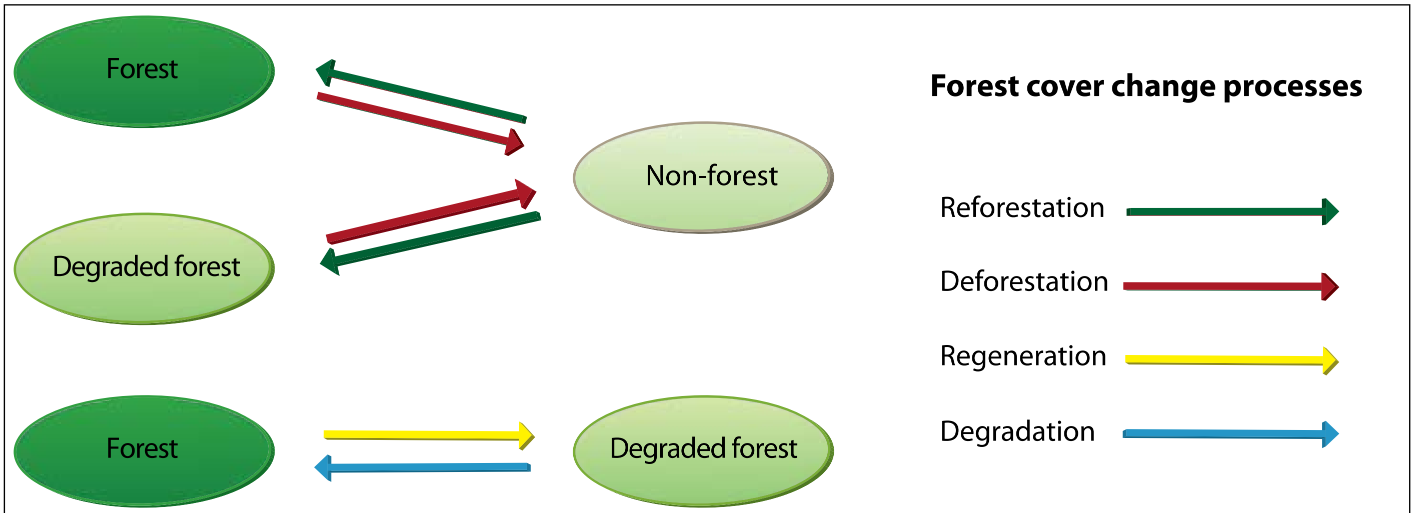
Photo 1.6: Participants of workshop organized at ERAIFT (Kinshasa - DRC) in October 2009. From left to right: André Kondjo Shoko (DRC), Roger Mambeta, Fidel Esono Mba (Equatorial Guinea), Jean-Daniel Mendomo Biang (Cameroon), Eddy Bongwele (OSFAC), Florence Bwebwe, Andre Mateus (Angola), Grégoire Begoto (CAR) Fransisca Mande (Angola), Christophe Musampa (DRC), Astrid Verhegghen (UCL), Philippe Mayaux (JRC), Roberto Ncogo Motogo (Equatorial Guinea), Cherubin Brice Ouissika (Congo), Bruno Nkoumakali (Gabon), Martin Mbemba (OFAC), Marcel Ibara (Congo), Gidéon Neba Shu (Cameroon), Carlos de Wasseige (OFAC), Céline Ernst (UCL), Pierre Defourny (UCL), Jean-Sylvestre Makak (Gabon), Confiance Mfuka (OFAC), Erik Lindquist (FAO). Missing: Héritier Koy Kondjo (DRC), Astère Bararwandika (Burundi) and Patrick Lola Amani (OSFAC)

The statistical approach proceeded with a systematic grid sampling of 0.5° over the dense and edaphic forests of the 6 countries of the Central African Forests Commission (COMIFAC). As the number of cloud free images was not sufficient to deliver relevant statistics at the national level, Equatorial Guinea and Gabon were oversampled every 0.25°. Each sample unit of observation corresponds to a 20 by 20 km sub-scene extracted from Landsat imagery (30 m resolution) acquired around 1990, 2000 and 2005. This resulted in 547 sample sites over the Congo Basin.

The overall method (Ernst *et al.*, 2010) consisted of four stages:

- image selection and pre-processing;
- automatic image processing including object segmentation and pre-labeling of seven land cover classes jointly defined with FRA2010;
- editing and validation by national experts using a specific visual interpretation tool;
- harmonization of the land cover maps for each sample, date normalization of forest cover change according to the image acquisition date and statistics extraction.

The forest cover dynamic was quantitatively assessed for each country by computing the annual rates of the forest cover change, i.e. deforestation, degradation, reforestation and regeneration as illustrated in figure 1.4. Deforestation is the sum of two sub-processes: the conversion of forest cover to non-forest cover and the conversion of degraded forest cover to non-forest cover. In order to reflect actual loss of forest area, a weight was given to each of these sub-processes. Reforestation is the inverse process of deforestation. Degradation is the transition from dense forest to degraded forest through canopy openings.



Forest: at least 70 % of the segment area corresponds to a continuous layer of trees, either in "green" stage or in "leafless" stage. The tree height is 5 m or more.

Degraded forest: a part of the segment or several spatially separated portions of the segment are covered by a continuous tree layer. The total area of tree cover in a segment ranges between 40 % and 70 % for the high tree mosaic class and between 10 % and 40 % for the low tree mosaic class. The tree height is 5 m or more.

Non-forest/other land cover: contains land cover other than tree cover (e.g. herbaceous vegetation cover, bare land, artificial surfaces, agricultural crops…).

Minimum mapping unit: the minimum mapping unit, corresponding to the smallest segment area, is 5 hectares.

Figure 1.4: Forest cover change processes: reforestation, deforestation, regeneration and degradation.
Source: Ernst et al., 2010

Changes in forest cover between 1990 – 2000 and 2000 – 2005

The results of the forest change sampling method estimate that for the Congo Basin, the gross deforestation annual rate is 0.13 % for the period 1990-2000, and this rate doubled for the period 2000-2005. A similar trend is observed for the net deforestation as well as for the gross and net degradation. These new estimates at the basin scale indicate a doubling of the forest cover change rate between both periods. Fortunately, this increase is observed for the deforestation/degradation and for the reforestation, indicating a more dynamic forest landscape. Table 1.2 details the forest change rates for each country, except for Equatorial Guinea for 2000-2005 due to the lack of cloud free data. The evolution of gross deforestation between 1990-2000 and 2000-2005 is quite significant for DRC, Cameroon and Congo while it becomes stabilized in Gabon and CAR. Net deforestation decreases in Cameroon and Gabon, it remains stable at 0.6 % per year in CAR and increases in Congo and DRC.

National annual degradation and regeneration rates are estimated as well (table 1.3). On the Congo Basin scale, the annual net degradation rate is 0.05 % between 1990 and 2000 and 0.09 % between 2000 and 2005. In Cameroon, Congo and CAR, there is almost no evolution in net degradation rate between both periods of time, unlike in DRC. It is important to remind that this quantified measure of degradation is based solely on detected change in forest cover as defined in figure 1.4 and not in qualitative terms (e.g., change in species composition).

Table 1.2: National annual deforestation and reforestation rates in the dense forest zones of the Congo Basin between 1990 and 2000, and between 2000 and 2005. The number of processed samples (n) and their confidence interval are mentioned for each country

Country	1990 - 2000				2000 - 2005			
	n	Gross deforestation (%)	Gross reforestation (%)	Net deforestation (%)	n	Gross deforestation (%)	Gross reforestation (%)	Net deforestation (%)
Cameroon	51	0.10 ± 0.05	0.02 ± 0.01	0.08	20	0.17 ± 0.14	0.14 ± 0.19	0.03
Congo	70	0.08 ± 0.03	0.04 ± 0.02	0.03	40	0.16 ± 0.06	0.08 ± 0.05	0.07
Gabon	58	0.08 ± 0.03	0.03 ± 0.01	0.05	12	0.07 ± 0.05	0.07 ± 0.07	0.00
Equatorial Guinea	8	0.13 ± 0.09	0.11 ± 0.18	0.02	0	-	-	-
CAR	26	0.09 ± 0.05	0.02 ± 0.02	0.06	23	0.10 ± 0.06	0.04 ± 0.05	0.06
DRC	334	0.15 ± 0.02	0.04 ± 0.01	0.11	242	0.32 ± 0.05	0.10 ± 0.03	0.22
Congo Basin	547	0.13 ± 0.02	0.04 ± 0.01	0.09	337	0.26 ± 0.04	0.09 ± 0.02	0.17

Source: Ernst et al., 2010

Table 1.3: National annual degradation and regeneration rates in the dense forest zones of the Congo Basin between 1990 and 2000, and between 2000 and 2005. The number of processed samples (n) and their confidence interval are mentioned for each country

Country	1990 - 2000				2000 - 2005			
	n	Gross degradation (%)	Gross regeneration (%)	Net degradation (%)	n	Gross degradation (%)	Gross regeneration (%)	Net degradation (%)
Cameroon	51	0.08 ± 0.06	0.02 ± 0.01	0.06	20	0.14 ± 0.12	0.07 ± 0.08	0.07
Congo	70	0.04 ± 0.02	0.01 ± 0.01	0.03	40	0.08 ± 0.03	0.05 ± 0.03	0.03
Gabon	58	0.05 ± 0.02	0.01 ± 0.01	0.04	12	0.04 ± 0.05	0.05 ± 0.08	-0.01
Equatorial Guinea	8	0.05 ± 0.03	0.02 ± 0.02	0.03	0	-	-	-
CAR	26	0.04 ± 0.02	0.01 ± 0.01	0.03	23	0.05 ± 0.03	0.02 ± 0.02	0.03
DRC	334	0.07 ± 0.01	0.02 ± 0.00	0.06	242	0.16 ± 0.03	0.04 ± 0.02	0.12
Congo Basin	547	0.07 ± 0.01	0.01 ± 0.00	0.05	337	0.14 ± 0.02	0.04 ± 0.01	0.09

Source: Ernst et al., 2010

For each time-interval, the spatial distribution of deforestation, reforestation, degradation and regeneration processes over Congo Basin is illustrated (figures 1.5 and 1.6). Between 1990 and 2000, it is apparent that deforestation, reforestation and degradation phenomena are more important in accessible areas such as the forest fringe or along the Congo River. This seems to be less pronounced with the annual regeneration rate. Between 2000 and 2005, deforestation and degradation processes tend to reach less accessible areas.

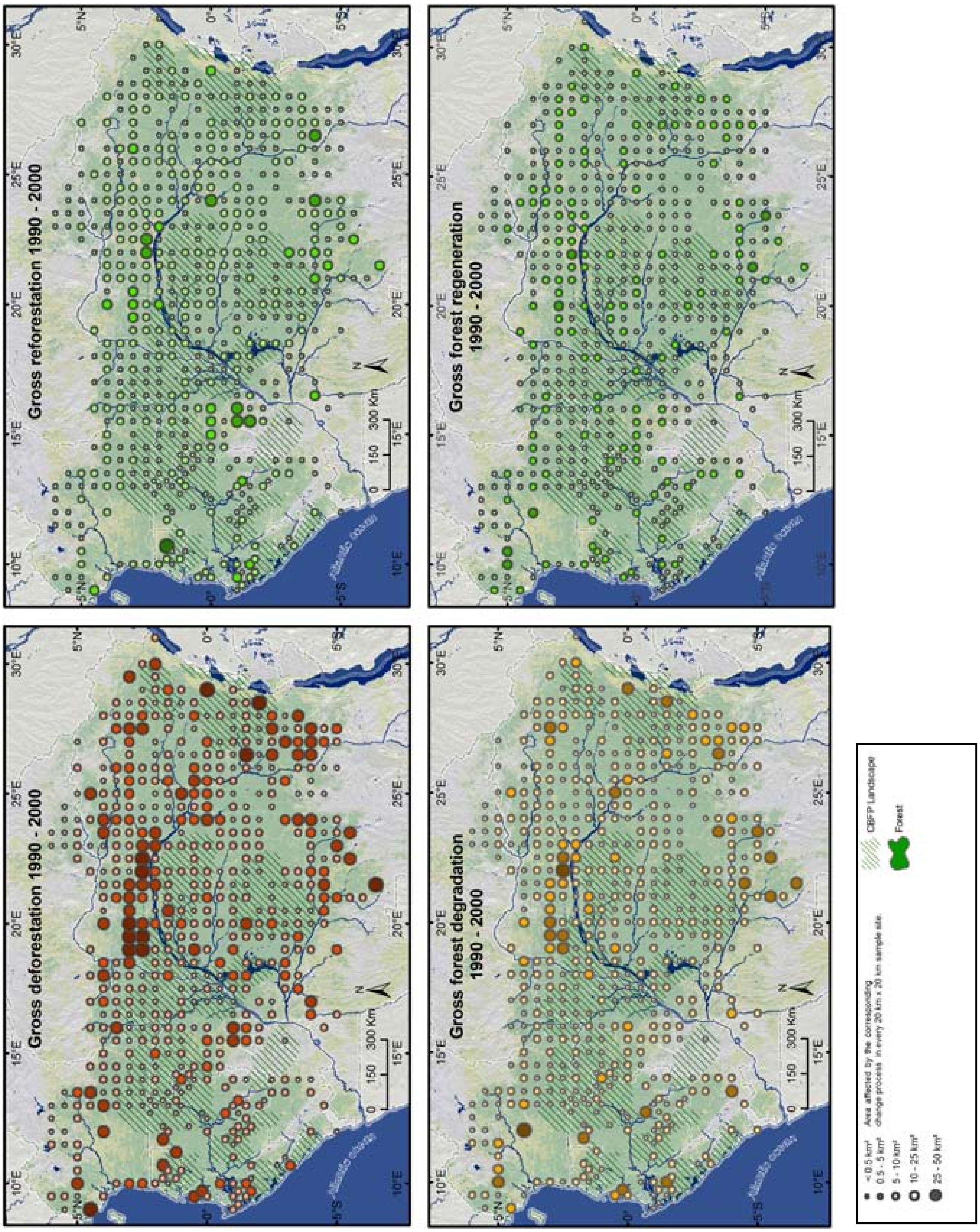


Figure 1.5: Spatial distribution of forest change dynamics that occurred between 1990 and 2000 over the Congo Basin. The circle size is proportional to the surface affected by the corresponding forest cover change process.

Source: Ernst et al., 2010

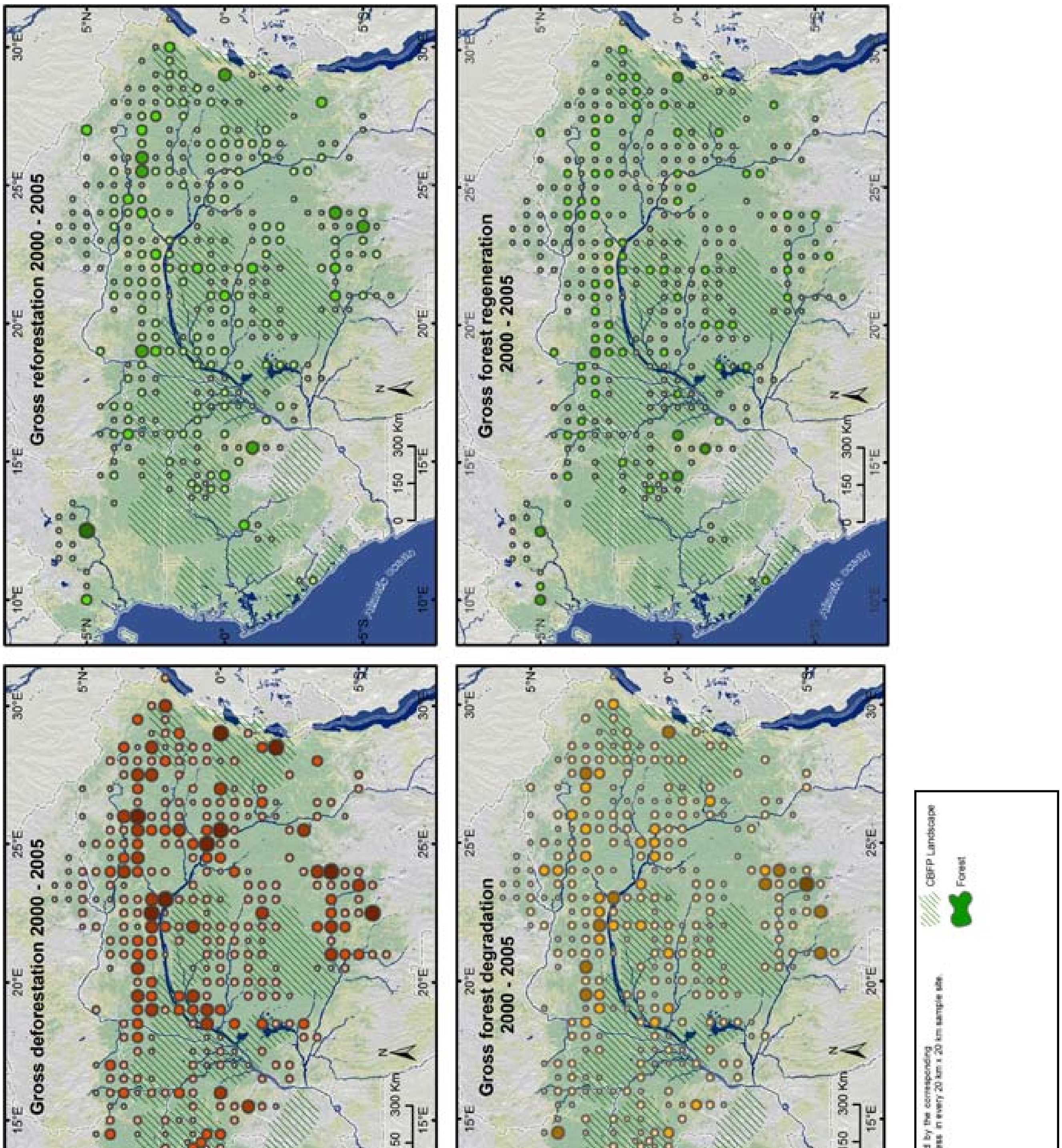


Figure 1.6: Spatial distribution of forest change dynamics that occurred between 2000 and 2005 over the Congo Basin. The circle size is proportional to the surface affected by the corresponding forest cover change process.

Source: Ernst et al., 2010

Photo 1.7: Water and forests are intricately linked in the Congo Basin

The regional and national figures presented here are slightly different from the SOF 2008 estimates. While the previous study processed the same Landsat data set for 1990-2000, the number of samples and their increased size (4 times larger) have contributed to much better sampling rate (increasing the sampling rate from 3.3 % to 13.6 %) and more robust results. The confidence intervals associated with the estimates are lower than those obtained by Duveiller *et al.* in 2008, indicating a more reliable study. The legend has also been simplified to reduce subjectivity in the visual interpretation. Furthermore, in this study, national experts with local knowledge have been involved in the validation process to help ensure better results, thus the outcome benefitted greatly from individual country contributions.

The Global Forest Resources Assessment (FRA) 2010 (FAO, 2010) also reports net loss of forests in COMIFAC countries. The reported rates of loss are different from those calculated in this study. Care needs to be taken when comparing the results of the two studies, as the FRA estimates are derived from statistics delivered by each country and the approach can vary from one country to another. There is no global approach as the one offered by remote sensing. Furthermore, the FAO statistics take into account the whole national territory including all woody vegetation, whereas we only consider the dense forest as defined in figure 1.4. A global remote sensing survey is currently being carried out for FRA 2010 to obtain more detailed and more comparable information on forest change dynamics. These results are expected at the end of 2011 (FAO, 2010) and will be based on the same Landsat data used in this study.

Forest cover and change mapping for DRC

The *Observatoire satellital des Forêts d'Afrique centrale* (OSFAC), South Dakota State University (SDSU) and the University of Maryland have implemented wall-to-wall mapping at moderate spatial resolution (60 m) to better quantify spatio-temporal trends in forest cover change for Central Africa. A new product, the initial result of OSFAC's *Forêts d'Afrique centrale évaluées par Télédétection* (FACET) product suite, quantifies forest cover and forest cover loss from 2000 to 2010 for the DRC using Landsat imagery.

The method is the first to exhaustively mine the Landsat archive in an attempt to overcome the persistent cloud cover found within the Congo Basin. A total of 8,881 Landsat images were processed to create a decadal time-series data set around 2000, 2005 and 2010. The mass-processing of Landsat imagery enabled cloud-free quantification of forest cover extent and loss for 99.6 % of the land area of the DRC. Three forest types were mapped: (i) primary forest (mature forest with a canopy cover > 60 %), (ii) secondary forest (regrowing forest with a canopy cover > 60 %) and (iii) woodlands (woodland formations with a canopy cover between 30 % and 60 %). Year 2000 total forest cover was estimated to be 159,529 thousand hectares with gross forest loss from 2000 to 2010 totaling 2.3 % of forest area. Total forest cover loss (table 1.4) increased by 13.8 % between the 2000-2005 and 2005-2010 intervals, with the greatest increase occurring within primary tropical forests. Forest cover loss intensity (figure 1.7) was distributed unevenly and was most correlated with areas of high population density and mining activity. While gross deforestation for all protected areas increased by 64 % between the 2000-2005 and 2005-2010 intervals, protected areas and Congo Basin Forest Partnership (CBFP) landscapes had lower rates of gross deforestation than areas outside of protected areas or CBFP landscapes. Additional FACET products for other Congo Basin countries are forthcoming.

Photo 1.8: Raphia stands are rich in biodiversity, but difficult to access

Figure 1.7: Landsat-scale forest cover loss for 2000-2005 (orange) and 2005-2010 (red) for the DRC
Source: OSFAC, 2010

Table 1.4: Forest cover and loss in DRC (thousands hectares)

Forest type	2000 Forest cover (x 1,000 ha)	2000 - 2005 Forest loss (x 1,000 ha)	2005 - 2010 Forest loss (x 1,000 ha)
Primary forest	104,455	367	701
Secondary forest	18,293	1,168	947
Woodland	36,781	201	328
Total	**159,529**	**1,736**	**1,976**

Source: OSFAC, 2010

Gross deforestation rate derived from the forest change maps (table 1.4) is apparently different from the one obtained using the samples validated by the national experts (table 1.2). The difference between the forest legends and the methods respectively used fully explains this apparent discrepancy. Furthermore, for the 2000-2005 period shared by both studies, a detailed comparison showed that the harmonization of legends and approaches provided a gross deforestation rate as high as 0.323 % per year from the mapping products (OSFAC, 2010) which is very similar to the 0.32 % estimated by the sampling approach.

Box 1.1: Causes of deforestation: a spatial model applied to the DRC

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Within the framework of the UN-REDD programme (The United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation), led by the DRC REDD National Coordination, a quantitative study covering the periods 1990-2000 and 2000-2005 was carried out on the causes of deforestation and forest degradation. This statistical and spatial model gauges the different variables that explain changes in forest cover over the entire DRC. It establishes the link between deforested areas, mapped by remote sensing, socio-economic factors and associated infrastructures on the ground.

An overview of literature on the subject, a bibliographic study of material specifically related to the DRC and expert opinion, all provide the theoretical reasons for deforestation and forest degradation. These potential variables are grouped together in nine subsets: agriculture, infrastructures, forest logging, economic factors, transport communications, demographic factors, socio-cultural factors, institutional factors and biophysical factors. Nevertheless, the causes for deforestation that are covered in the study are limited to those that can be derived directly or indirectly from available cartographic data. It was not possible to model causes such as governance or insecurity. As a result of geographic data collected by different partners, the variables were calculated and assembled into a Geographic Information System (GIS).

Two different levels of modeling were used, national and sub-national. The sub-national scale corresponds to a set of zones defined in terms of large biomes in DRC (according to WWF eco-regions) and to a map of land cover at 1/3,000,000 (Vancutsem *et al.*, 2006). For these two levels, an objective and quantitative approach, based on multivariate statistical analysis calculated from the most detailed information on deforestation available, provided a national model that explains nearly 50 % of deforestation and degradation for the period 1990-2000 and nearly 40 % for the period 2000-2005. On the sub-national scale, each model's explanatory power varies by 40 to 80 % for the two periods and uses five different variables. The models are however limited by the availability of data. This rigorous scientific approach provides an objective evaluation of the different factors affecting deforestation, quantifying their respective importance and excluding a certain number of them. At the national level, the study shows that the diminishing but significant influence of surrounding villages, the increase in population, the presence of degraded forests and roads, and forest fragmentation play a key role in the process of deforestation. On the sub-national scale, differences appear according to the specificities of the different zones, depending on their respective contexts.

The REDD National Coordination has provided for a land survey protocol to be drawn up with national partners to validate the results of the model. This validation is intended to contribute towards collectively building a national consensus on the dynamics of deforestation and forest degradation.

The coming years will be critical for forest resources of the Congo Basin. Population growth, immigration, economic development in the region plus increasing demand at the global level will inevitably increase the pressures on natural resources. The evaluation of threats remains a delicate exercise with many uncertainties. Primary direct threats to forest cover (not to biodiversity) are detailed below. For more information, a statistical analysis of drivers of deforestation in DRC has been conducted by UCL in the framework of UN-REDD (see box 1.1).

Fuelwood

Fuelwood is the main energy source for people in developing countries (see chapter 5). Wood energy in Africa represents over 80 % of total domestic energy consumption across all countries and Africa is the only continent where wood energy should continue to grow in the coming decades (Marien, 2009). Forests, most notably peri-urban forests, play a key role in providing fuelwood or charcoal. Fuelwood collection has a major impact on deforestation and degradation particularly in heavily populated areas. Developing forest plantations for wood energy, developing sustainable management of forests, and improving energy processing will have major positive impacts on the state of the forests, especially peri-urban forests.

Agriculture

Limited access to improved agricultural technologies has long led farmers to practice shifting cultivation in most tropical African communities. This practice has been part of the ecosystem for many centuries but it becomes a problem when fallow periods are shortened as more land is required for production, leading to a decline in the regeneration of trees, soil fertility and agricultural yield (Boahene, 1998). This generally occurs along main roads, near villages and on the outskirts of urban centers (Devers & Vande weghe, 2007). Without support for modernizing food production in these communities, the threat of deforestation and degradation will increase in the future.

Mining and oil extraction

Africa has extensive mineral resources, constituting approximately one third of global mineral resources. This proportion rises to 89 % for platinum, 81 % for chromium, 61 % for manganese and 60 % for cobalt. The subsurface strata of the Congo Basin contain very important oil and mineral resources, including iron, copper, manganese, uranium as well as diamonds and gold (Reed & Miranda, 2007). These resources currently provide significant revenues for the region's countries. According to many experts, this leading position should strengthened by 2015. Much of these resources are exploited in artisanal and small scale operations but even so mining is a significant threat to forest ecosystems.

Resource extraction not only has direct impacts such as deforestation, pollution and natural resources degradation but also precipitates indirect impacts linked to infrastructure development. Failure to apply better practices for appropriate mitigation of environmental impacts and a lack of compensatory measures are clearly a threat for forests within the Congo Basin. Promotion of coherent and integrated land use planning and resource governance must be a priority in order to reduce the adverse effects of mining and oil extraction.

The Congo Basin lies above and close to major oil deposits. The oil industry is important in the Gulf of Guinea and in the forests of the coastal sedimentary basin. The economies of Equatorial Guinea, Gabon and Republic of Congo are heavily dependent on this industry. In DRC, the recent discovery of large reserve of oil in the Albertine Rift (Kivu) and Mbandaka could be a new source of pollution particularly alarming close to some protected areas (in March 2011, the DRC government has put the brakes on oil exploration in Virunga National Park (bloc V)). As the global demand for oil increases, the pressure to extract oil will intensify.

Photo 1.9: Palm oil plantations compete for land with natural forests

Agrofuels

Agrofuels consist of a wide range of fuels which are in some way derived from biomass. Oil palm is a traditional native crop for Central Africa but in recent years, African communities are facing the expansion of large scale oil palm plantations (mostly in DRC and Cameroon). Forest areas in the Congo Basin have been converted to monoculture oil palm aimed at the production of agrofuels and at present, there is a very strong push for the establishment of even larger plantations. Poor transportation networks remain an obstacle for broad development of plantations within the central region. Land grabbing for monoculture agrofuel plantation is increasing but no reliable statistics are available.

Box 1.2: Land degradation in Central Africa: environmental, economic and social impacts

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Land degradation in Central Africa has led to the destruction of soil properties and has resulted in serious economic, social and environmental problems. It is a major concern for decision-makers and populations alike in the sub-region. In the context of water and land management, combatting land degradation is a matter of prime importance.

In order to deal with this problem, all Central African countries joined the United Nations Convention to Combat Desertification (UNCCD) and developed National Action Plans to combat desertification. In September 2008, the sub-region also drew up and adopted its Sub-Regional Action Programme to Combat Land Degradation and Desertification (PASR-LCD).

In most countries in the sub-region, sustainable land and natural resource management is an issue which cuts across several rural development areas of activity. Many ministerial departments involved in rural activities deal with the problem with budgets allocated to them by the State. However, each one acts independently of the other.

A study was commissioned by the Economic Community of Central African States (ECCAS) and COMIFAC, with financial support from the World Mechanism, in order to prepare an advocacy document on the economic, social and environmental impacts of land degradation in Central Africa.

The results of this study clearly show that land degradation in Central Africa has significant environmental, economic and social repercussions. While some areas are more affected than others, all ten COMIFAC member countries have to pay a high price. Overall, the following can be noted: (i) from an environmental perspective, land degradation leads to a decrease in natural vegetation, a fall in crop yields due to the loss of soil fertility, a reduction or even loss of biodiversity, a change in water quality due to various types of chemical pollution; (ii) from an economic perspective, consequences are noticeable in the agricultural sector where loss of production for seven subsistence crops (maize, rice, sorghum/millet, cassava, taro/yam, sweet potato, beans) are estimated at $ 2.4 billion yearly and $ 5 billion when this estimate covers both subsistence and cash crops; (iii) from a social perspective, populations in the sub-region suffer from energy and food crises, poverty, health problems and the lack of resources leads to conflicts.

In order to mitigate this problem in Central Africa, each country should (i) include matters relating to sustainable land management into policies and poverty reduction programs and give them national priority status; (ii) launch a detailed study on the costs of land degradation; (iii) develop a national land use plan and a national multi-sectorial policy document; (iv) establish monitoring mechanisms to monitor informal sectors of resource exploitation; (v) set up policy, institutional and incentive measures to promote technical and financial partners, farmers and breeders and many other stakeholders, to invest in sustainable land management.

Logging

Industrial logging temporally generates inevitable impacts (disturbance to the remaining trees) as well as avoidable impacts on the forests, including soil erosion, water pollution and reduction of the regeneration capacity. Logging increases human presence in the forest, from logging camps and providing access through road construction. Logging also removes nutrients and escalates forest fragmentation (Devers & Vande weghe, 2007). However, the direct impacts can be mitigated by (i) improving the legal and institutional frameworks, (ii) promoting a better forest governance[3], (iii) implementing forest management plans, (iv) forestry certification, and (v) by better local involvement (e.g. decentralization and benefit sharing).

The impact of informal or artisanal logging could be more serious than industrial logging as they are not subject to any kind of regulation. Despite its importance, there is a general lack of statistics, studies and information about this sector.

[3] In the framework of Forest Law Enforcement, Governance and Trade (FLEGT) three Voluntary Partnership Agreements (VPA) have been signed.

The forest cover change estimates delivered here in the context of the Observatory for the Forests of Central Africa (OFAC) are of critical importance for national forest policy as well as for the Reducing Emissions from Deforestation and Forest Degradation (REDD) programme. They may serve as reference for the period 1990-2000 and possibly for 2000-2005 for the countries covered by a sufficient number of samples. In the near future, the sampling approach will be repeated for 2010. Similarly, forest cover change mapping will be extended.

Photo 1.10: The vastness of the forest does not render it inaccessible

Conclusions

Forest cover monitoring in the Congo Basin is most practically achieved through remote sensing. However, the use of data from optical sensors is constrained by persistent cloud cover particularly over western parts of the basin, limited data acquisition strategies for the region, data costs, the absence of ground receiving stations in Central Africa, and the shortage of human and technical capacity for remote sensing in the region (COMIFAC, 2010). At the same time, the potential for systematic monitoring has increased over the past few years as a result of improved satellite data access (specifically the open and free access to the USGS Landsat archive as of December 2008), gains in computational power, development of automated and semi-automated methods and increasing capacity in the region.

As described above, increased global demand for mineral, energy and wood resources from Africa, the investment in infrastructure to access these resources, and increasing human population pressure (with commensurate increased demand for fuelwood and food production) are likely to accelerate deforestation and forest degradation. Both forest cover monitoring studies described here report deforestation increases in the Congo Basin: a doubling of the annual rates of gross deforestation between 1990-2000 and 2000-2005 from the sampling approach, and a near doubling in the loss of primary forest between 2000-2005 and 2005-2010 from the wall-to-wall approach.

Progress continues to be made in mapping forest and vegetation types at higher spatial resolutions, a necessary advance in forest cover monitoring. This can be achieved through making use of complementary satellite derived data sets (such as in the MERIS/SPOT-VGT mapping described here) and other initiatives such as the wetlands (including flooded forest and inundated grasslands) of the "*cuvette centrale*" recently mapped using a combination of Landsat data, JERS radar data and elevation data from the Shuttle Radar Topography Mission (Bwangoy *et al.*, 2010). Classifications of this type are critical for habitat delineation, understanding ecosystem functions and services, as well as for carbon monitoring.