CHAPTER 1

Evolution of forest cover at a national and regional scale and drivers of change

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1. Introduction

Tropical forests lie at the heart of international challenges of climate change and biodiversity conservation. As the second largest tropical forest ecosystem in the world after the Amazon rain forest, the Congo Basin forest plays a key role in the continental climate system. These African forests provide livelihoods (food, medicinal products, fuel, fiber, non-timber forest products) to 60 million people living within or near them, as well as fulfilling social and cultural functions. These forests contribute indirectly to feeding an additional 40 million people who inhabit regional urban centers (Nasi *et al.*, 2011).

Mapping forests and monitoring forest change is critically important. The state of forests affects the well-being of millions of people, the regional and global environment, and biodiversity status. Precise knowledge about a forest's surface area, botanical composition and dynamics provides information essential for implementing and monitoring environmental and economic policies. The essential roles played by forests are central to multilateral environmental agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), specifically Reducing Emissions from Deforestation and Forest Degradation (REDD+) policies which recognize the role of forests in the carbon cycle, and the Convention on Biological Diversity (CBD), which considers the loss of forest habitats a leading cause of decreased biodiversity. The European FLEGT policy (Forest Law Enforcement, Governance and Trade) requires information on the traceability of timber products and the legality of logging.

Photo 1.1: Gombé (Didelotia sp) in a mature forest, south-west Gabon

This chapter provides a partial overview of initiatives underway to monitor Central African forests using satellite imagery. The scale of analysis ranges from local to national and to the whole of Central Africa. Most of the studies identify areas affected by deforestation but more recent efforts attempt to monitor more finite changes in forest cover such as forest degradation and biomass reduction.

Photo 1.2: Mixed forest canopy in northern Gabon

2. National forest cover monitoring initiatives

Several countries including Gabon, Cameroon, the Congo, the Central African Republic (CAR) and the Democratic Republic of Congo (DRC), have officially committed to the REDD+ process (see Chapter 5). These countries are required to set up an integrated Measurement, Reporting and Verification (MRV) system to monitor changes in deforestation and/or forest degradation as well as improved forest cover. Mapping areas of forest cover change is indispensable to develop strategies adapted to local conditions to better monitor these dynamics. Highly detailed national maps are required only every three to five years, but changes in forest cover must be monitored more frequently. This MRV approach requires that national standards be established (such as the definition of the forest in terms of forest cover) and the involvement of national experts in mapping and validation processes.

Table 1.1: *Partial list of projects supporting national and local forest cover change mapping initiatives..*

Name (*)	Country	Leader	Institutional Partners / Countries	Technical Partners	Donors	Duration	Period of analysis	Coverage	Application IPCC recommendations
GSE-FM	Cameroon	GAF	MINFOF, MINEP	FAN	ESA, KFW	2008-2010	1990-2000-2005	Country	No
	Congo	GAF	MDDEFE	SIRS, JR	ESA, FFEM	2010-2014	1990-2000-2010	Country	Yes
	Gabon	SIRS	AGEOS	GAF, JR	ESA, FFEM	2010-2014	1990-2000-2010	Country	Yes
OSFT	CAR	Astrium	MEEDD	IGNFI	AFD	2010-2014	1990-2000-2010	33 Sub prefectures (55% Country)	Yes
REDDAF	CAR	SIRS	MEEDD	GAF, CESBIO, JR, LACCEG	EU	2010-2013	1990-2000-2010	South-West Region	Yes
	Cameroon	GAF	MINEPDED	SIRS, CESBIO, JR, GTG	EU	2010-2013	1990-2000-2010	Center Province	Yes
FACET	Congo and DRC	OSFAC	-	SDSU, UMD, WRI	CARPE/ USAID, NASA, CBFF/ADB	2009-2013	2000-2005-2010	Country	No
ReCover	DRC	Norut	OSFAC	ALUFR, GMV	EU	2010-2013	1990-2000-2005-2010	West Region	No
REDDiness	Congo, Gabon	Eurosense	MEF (Gabon), CNIAF (Congo)	ITC, IRD	EU	2011-2013	2007-2012	South Congo, South-East Gabon	No

(*) Refer to the list of acronyms at the beginning of the report for the meaning of the abbreviations used in the table

Mapping methodologies may differ from one country to another because of different conditions and national standards. National and local forest cover change mapping initiatives are presented in Table 1.1. This section will then provide details on the national mapping initiatives for only Gabon, Cameroon, the Congo, and the CAR as the mapping of the DRC (FACET) was published previously in the State of the Forest 2010.

2.1 Gabon

Gabon has complete forest cover maps for the years 1990, 2000 and 2010. This mapping was performed under the framework of the GSE-FM Gabon project by processing Landsat satellite images for 1990 and 2000, and a combination of Landsat and Aster images for 2010. To cover the entire territory of Gabon, 300 satellite images were used because of permanent cloud cover, where without cloud cover, only fifteen Landsat images would be required.

Detailed mapping was conducted first for the reference year 2000. Each image from 2000 was processed and classified separately to extract forest cover. Detailed quality control was applied to each image and the results were "mosaicked" to create the Forest/Non Forest (F/NF) national layer for the year 2000. This F/NF map then was superimposed on images from 1990 and 2010 to extract the changes observed and classify them using a nomenclature compatible with that used

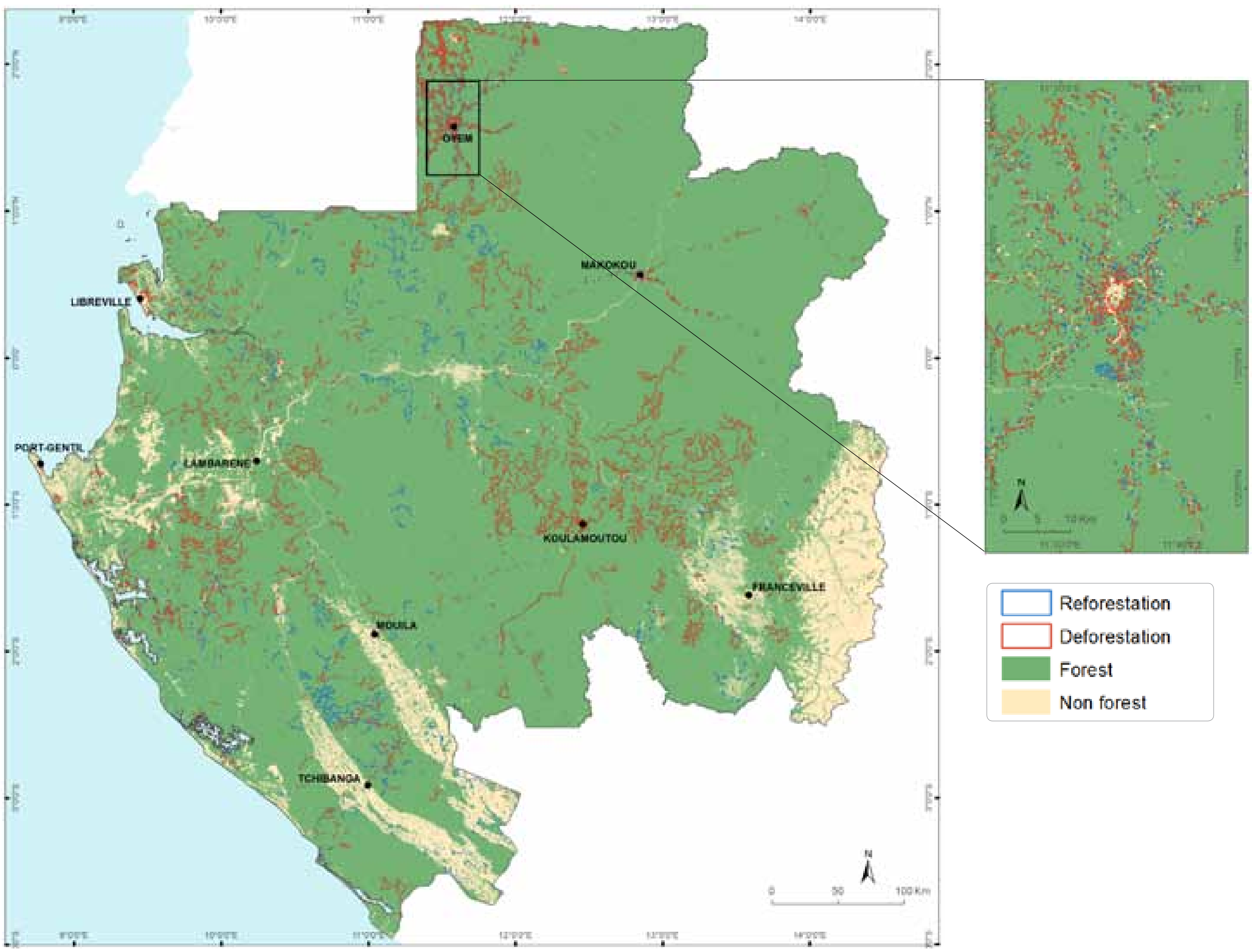

Figure 1.1 : Map of forest cover and change in Gabon between 1990 and 2000
Source : GSE-FM Gabon

by the IPCC. Accuracy of the derived F/NF maps was assessed at approximately 98 % for the three periods. The methodology used is described in detail by Fichet *et al.* (2012 and 2013). To improve the forest change estimate, the F/NF maps were combined with a photo-interpreted systematic sampling covering 1 % of Gabon (Sannier *et al.*, 2014). The results for all of Gabon are presented in Table 1.2. Forest covers more than 88 % of the territory, or about 236 000 km².

Table 1.2: *Forest cover change estimation in Gabon between 1990, 2000 and 2010*

	Unit	1990	2000	2010	1990-2000	2000-2010
Gabon	km²	267 667			Net deforestation	
Forest cover	km²	237 380	236 570	236 335	810	235
	%	88.68	88.38	88.29	0.34	0.10
Uncertainty (95 % CI)	km²	±664	±711	±698	±293	±259
	%	±0.25	±0.27	±0.26	±0.13	±0.11

Source: GSE-FM Gabon

The net deforestation rate between 1990 and 2000 is 0.34 %, representing a nearly 800 km² reduction in forest cover. Gross deforestation is estimated at slightly over 1 200 km². Almost half of the deforestation is due to logging and the opening of roads while nearly a third is from the conversion of forest into crop land, prairies and savannas. Slash-and-burn agriculture merges with the savanna on the satellite images. Nearly 400 km² have been reforested, 60 % by conversion of savannas/prairies into forest and 25 % from the reforestation of logging roads.

A clear slowing of deforestation occurred between 2000 and 2010 with an observed deforestation rate of 0.10 %, a value which is not significantly different from zero. This reduced deforestation rate may be related to the low rural population density, weaker agricultural dynamics and institutional measures taken by Gabon regarding national parks and the forest code. Thirteen national parks are located over the entire territory and the forest code has required operators to develop forest management plans. Another possible explanation may be found in ecological conditions broadly favorable to rapid forest regeneration, notably very good rainfall and a good dissemination of seeds by a wide range of animal species (Doucet, 2003). The ruggedness of the terrain also hinders the permanent logging of forests. Reasons for the reduced deforestation rates must be confirmed by studies underway in Gabon on the causes of deforestation and reforestation.

Photo 1.3: Peri-urban areas are less and less forested

2.2 Cameroon

Full national satellite image coverage based on Landsat data for 1990 and 2000, and DMC data for 2005/06 were acquired and analyzed to complete the forest cover assessment for Cameroon. The forest and non-forest areas were mapped for these years with a Minimum Mapping Unit (MMU) of 5 ha. Two separate projects (GSE-FM Cameroon and REDDAF) have undertaken mapping activities in the country, but budgetary constraints limited most work to the Eastern Province and Central Provinces.

Based on the production of forest/non-forest (F/NF) maps of the Eastern Province, change maps were generated for the periods of 1990-2000 and 2000-2005 (figure 1.2). The changed areas were then classified into the five IPCC-compliant categories: cropland, grassland, wetland, settlement land and other land. Training data necessary for the F/NF classification was derived from Very High Resolution (VHR) imageries and from data acquired during field campaigns.

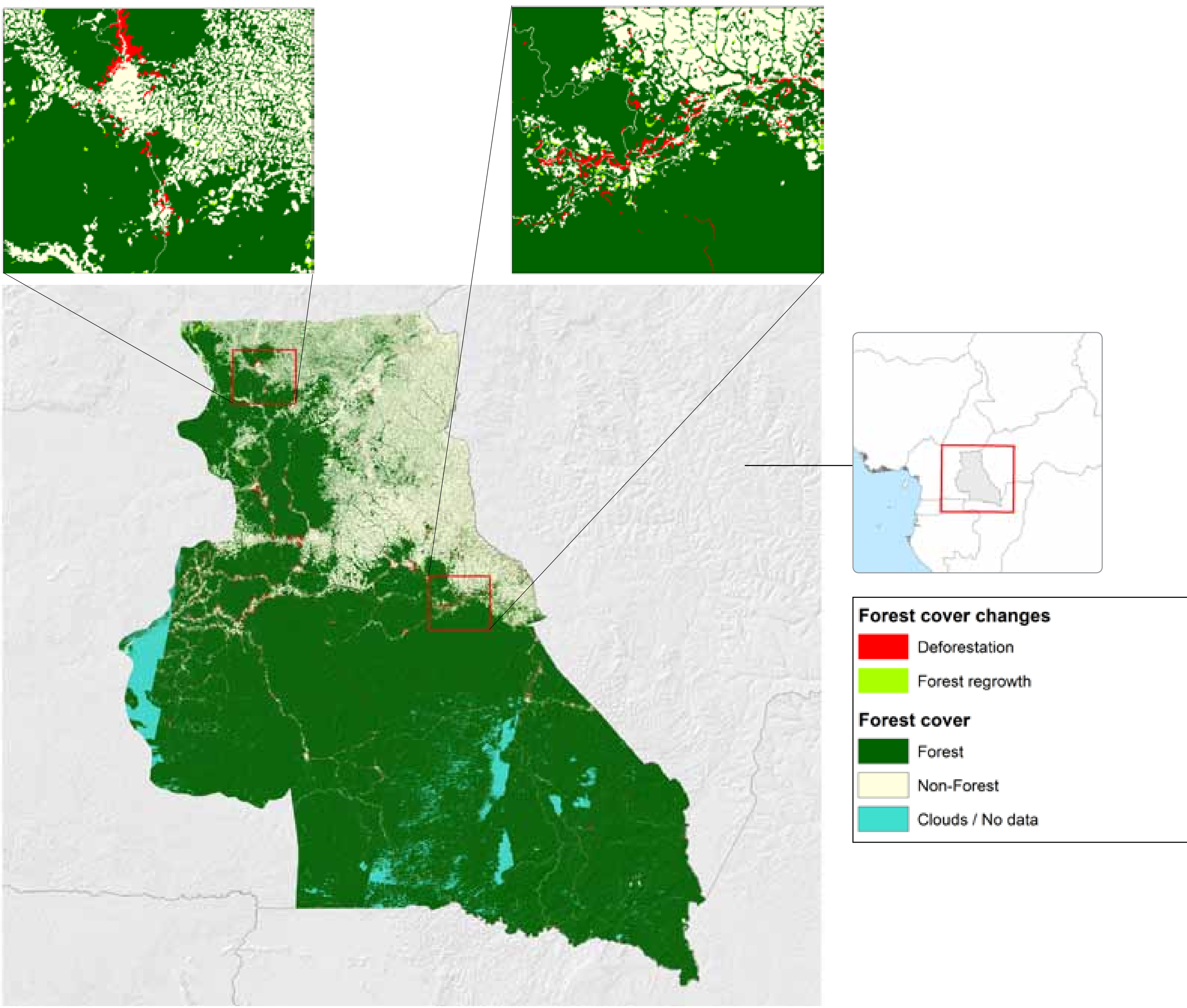

Figure 1.2: Forest cover change (in red) in the Eastern Province of Cameroon for the periods 1990-2000 and 2000-2005
Source: GSE-FM Cameroon

Table 1.3 presents forest cover change for the three reference years, (1990, 2000 and 2005). Because of cloud cover, the mapped area represents about 96-98 % of the 112 950 km² of the Eastern Province. Therefore, this mapped area (and corresponding forest cover areas) differs slightly between the two periods (*). The gross deforestation rate for the 1990-2000 period was estimated at 0.86 %. There was significant regrowth (0.21 %) during this period, leading to a net deforestation rate of 0.65 %. For the period 2000-2005, the gross deforestation rate was 0.07 %. Given the high rate of regrowth (0.10 %), the net deforestation rate over the 2000-2005 period is estimated at -0.03 %.

***Table 1.3**: Forest cover change estimations in the Eastern Province of Cameroon over the period 1990-2000-2005*

Eastern Province		1990	2000 (a)*	2000 (b)*	2005	1990-2000	2000-2005
Mapped area	km²	108 854		110 781		Net Deforestation	
Forest cover	km²	87 991	87 424	89 187	89 209	567.7	-22.9
	%	80.83 %	80.31 %	80.51 %	80.53 %	0.65 %	-0.03 %

(*) see in the text for explanation
Source: GSE-FM Cameroon

2.3 Republic of Congo

A forest cover and change mapping exercise for the years 1990-2000-2010 was performed within the framework of the GSE-FM Congo project. While the project goal is to cover the whole country to build a National REDD Strategy with the involvement of the Cameroonian government (MINFOF and MINEP), first analyses were only performed for the Northern Congo (Likouala and Sangha Provinces). To overcome the problem of heavy cloud cover in some parts of the country, different satellite sensors were used (Landsat-4, -5, -7, Aster, DMC, RapidEye and SPOT). Areas where forest cover change occurred were classified into the IPCC-compliant land cover classes. Preliminary results over Northern Congo indicate net deforestation rates of approximately 0.21 % for the period 1990-2000 and 0.03 % for the period 2000-2010 (table 1.4). Between 1990 and 2000, the gross deforestation rate was 0.35 % whereas the regrowth accounted for 0.14 %. For the second period (2000-2010), the gross deforestation rate was 0.27 % and the regrowth rate increased up to 0.23 %.

Photo 1.4: Relic forest protected by villagers in Bas-Congo, DRC

***Table 1.4**: Forest cover change areas Northern Congo (Likouala and Sangha Provinces) over the period 1990-2000-2010*

Likouala & Sangha		1990	2000	2010	1990-2000	2000-2010
Average Mapped area	km²	124 774			Net Deforestation	
Forest cover	km²	120 422	120 171	120 131	251.1	40.4
	%	96.5	96.3	96.3	0.21 %	0.03 %

Source: GSE-FM Congo

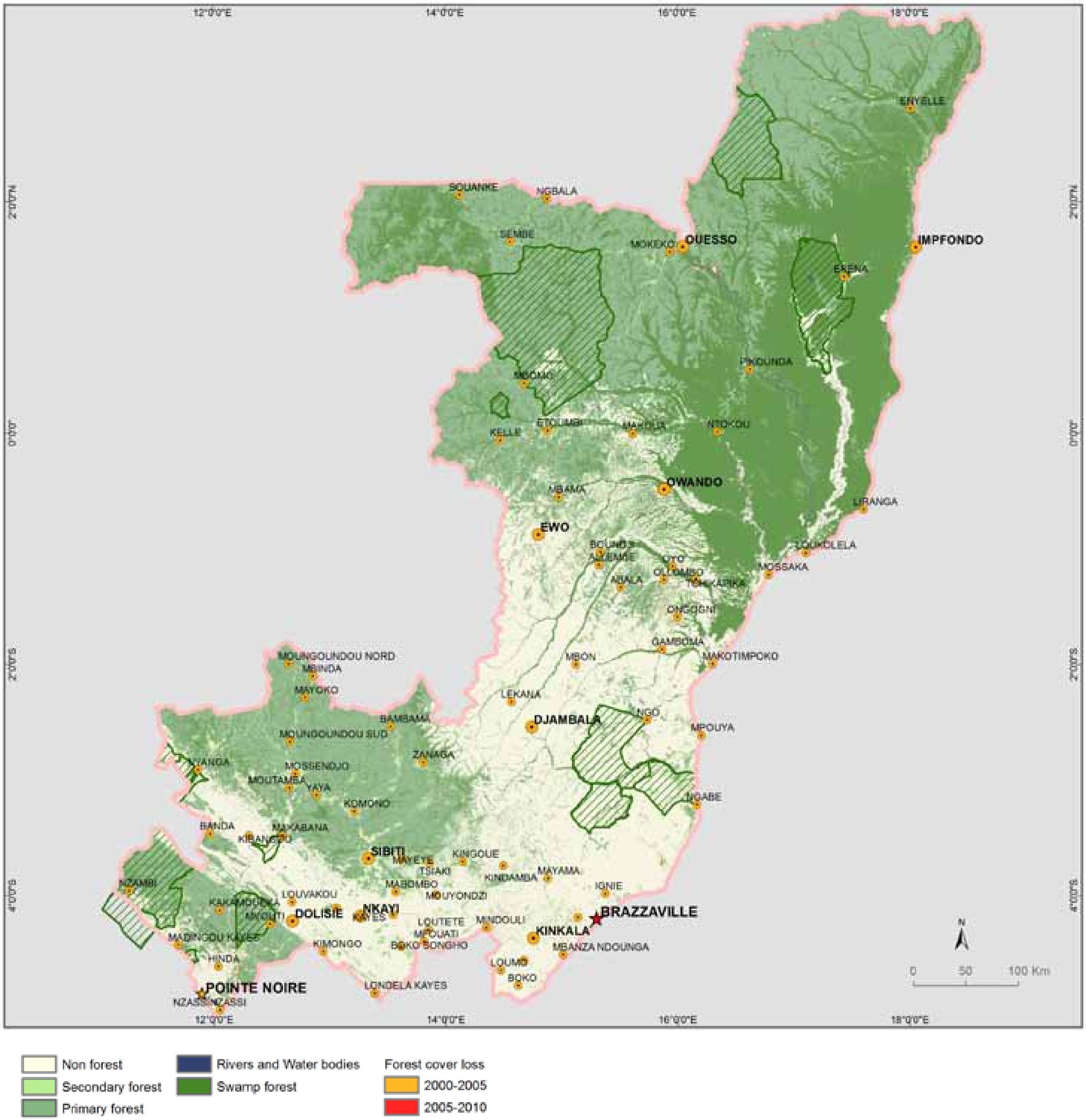

Figure 1.3 : Forest cover loss map of the Republic of Congo for the period 2000-2005-2010
Source : FACET Congo

Another mapping initiative over the Republic of Congo is the FACET atlas, a wall-to-wall mapping exercise performed over the entire national territory. FACET (*Forêts d'Afrique Centrale Évaluées par Télédétection*), quantitatively evaluates the spatiotemporal dynamics of forest change in Central Africa through the use of multi-temporal satellite data. FACET is a joint project of the *Observatoire Satellital des Forêts d'Afrique Centrale* (OSFAC) and the University of Maryland. The approach used for the Congo FACET atlas is similar to that used to produce the FACET atlas for the DRC (Potapov *et al.*, 2012), which was presented in the 2010 SOF Report (de Wasseige *et al.*, 2012). An exhaustive exploration of the Landsat ETM+ satellite archive was carried out in order to map the extent and loss of forest cover in the Congo from 2000 to 2010. A total of 1 788 ETM+ images were processed to achieve the final map. This method is an evolution of the approach used by Hansen *et al.* (2008), where MODIS data are used to pre-process time series Landsat images, which are in turn used to characterize the extent and loss of forest cover. Forest cover has been mapped for 2000, and forest cover loss has been analyzed from 2000 to 2005 and from 2005 to 2010 (figure 1.3).

Forest cover change was analyzed across the entire national territory, with 99.9 % of the land area covered by cloud-free Landsat observations. The total forest cover in 2000 was estimated at 229 385 km² (table 1.5). *Terra firme* primary forests comprise 52 % of the total forest area, whereas secondary forest and swamp forest cover 4 % and 44 % of the total forest area, respectively. The area of gross forest cover loss between 2000 and 2010 was estimated at 1 700 km² or 0.7 % of the total 2000 forest area. For the total loss of forest cover, 51 % occurred in *terra firme* primary forest, 34 % in secondary forest, and 16 % in swamp forest. The forest cover loss rates varied by forest type: the highest rate occurred in secondary forest (6.7 %) and the lowest rate occurred in swamp forest (0.3 %). The forest cover loss rate for primary forest was 0.7 %. Most of the forest cover loss in primary forests is attributed to the expansion of agriculture and logging in pristine forests, which could potentially change plant and animal species composition as well as ecosystem dynamics. The total forest cover loss nearly doubled from the 2000-2005 to the 2005-2010 intervals. The greatest rate of increase occurred in swamp forest, where the loss increased nearly three-fold (284 %), while *terra firme* primary forest loss increased by 182 %.

Table 1.5: *Forest cover loss for the Republic of Congo over the period 2000-2005-2010 (area reported in square kilometers)*

		2000	2005	2010	Forest Loss	
					2000-2005	2005-2010
Congo	km²	339118				
Primary Forest	km²	117 708	117 403	116 846	305.4	557.2
Secondary Forest	km²	8 534	8 310	7 962	224.6	347.4
Swamp Forest	km²	101 443	101 374	101 178	68.9	195.9
Total Forest	km²	229 385	228 786	227 685	598.8	1 100.5
	%	67.6 %	67.5 %	67.1 %	0.26 %	0.48 %

Source: FACET Congo

Box 1.1: Monitoring deforestation in the DRC – the TerraCongo project

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The *TerraCongo* project, initiated in 2011, stems from a collaboration between the Brazilian Space Agency INPE, and FUNCATE (a Brazilian foundation charged with the technical development of methods and tools for the Amazon forest monitoring system), the FAO, and a number of countries participating in the UN-REDD program (www.un-redd.org), notably the DRC, Paraguay and Papua New Guinea. The collaboration aims to build national capacity for tropical forest Monitoring and Measurement, Reporting and Verification (M and MRV) based on (mostly) freely available technology and data. Other goals of the project include reinforcing the technical and professional capacities of national experts during the implemen tation phase, as well as incorporating existing national data and methods into the TerraCongo system. FAO serves as a catalyst for the south-south transfer of technology and technical capacity building (notably, the Brazilian *TerraAmazon* software) and to promote and generate freely available, open-source remote sensing tools.

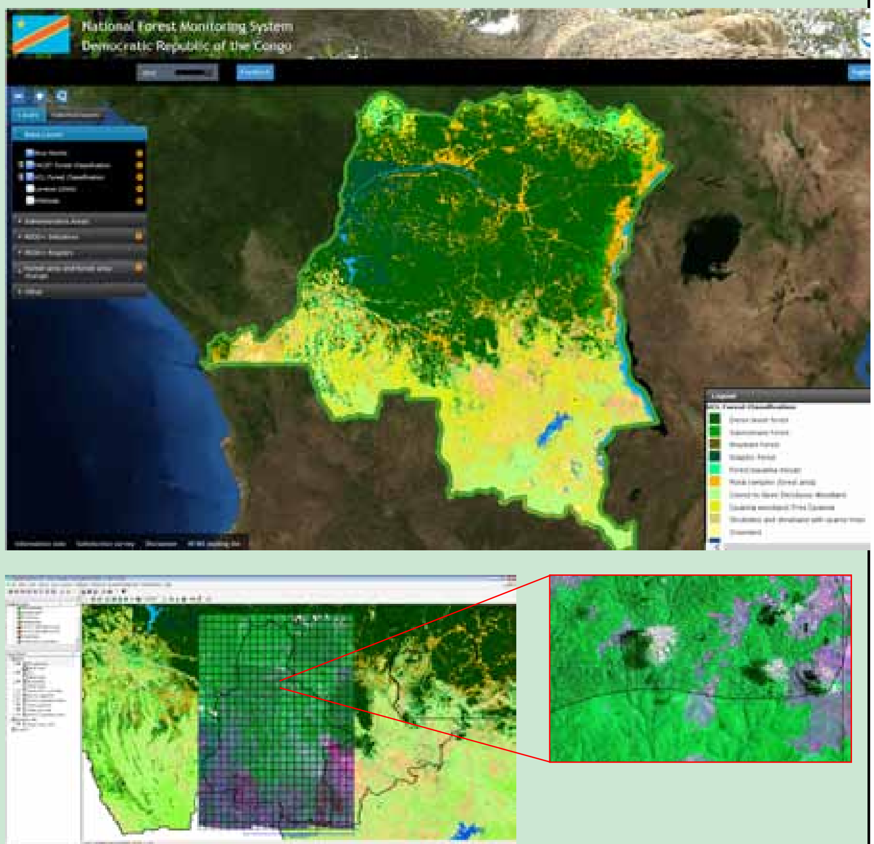


Figure 1.4: Presentation of the DRC forest monitoring initiative

DRC's *TerraCongo* is the first country implementing this initiative. The first phase of the project focuses on forest monitoring and data dissemination through the internet, which together form the DRC's official National Forest Monitoring System (NFMS). Currently the project only encompasses the Kasai-Occidental province, which has about 96 000 km^2 of forest. Kasai-Occidental province was chosen to start because it received the highest feasibility rank in an assessment that considered several criteria (surface area, deforestation rates, REDD+ activity, cloudiness, data availability, topography, forest plots, and forest types). This initial phase will be followed by the successive inclusion of all of the DRC's provinces, each which will each be stored in separate databases.

The measurement of the forest area for the TerraCongo project is based on freely available Landsat satellite data, free tools for image processing (e.g. http://km.fao.org/OFwiki/index.php/Open_Foris_Geospatial_Toolkit), and the free-of-charge *TerraAmazon* software (www.terraamazon.org) that facilitates multi-user editions of land cover maps. All satellite imagery used in the project is corrected and segmented. The data processing occurs in two main stages: the delineation of forest area for the year of reference and the detection of changes to the delineated forest area in subsequent years. Data pre-processing for the first stage makes use of the officially-adopted forest map, the DRC FACET map, which provides training data for image segment classification. The resulting initial forest map is estimated to be about 85% accurate (based on comparisons with high-resolution imagery in Google Earth, and not accounting for time differences). Data pre-processing for the second stage involves the automatic detection of change in forest cover between images from different dates.

In both data processing phases, a group of five national experts from DIAF (Department of Forest Inventory and Management), who received training in Brazil, Italy, and the DRC, post-process and validate the information derived though automated data processing to ensure that the forest areas conform to the DRC's official definition of a forest as submitted to the UNFCCC secretariat. This is done using a dedicated workspace in the *TerraAmazon* software, with two separate projects (implemented in the same database); one for the finalization of forest mask, and one for the periodic assessment of forest area change. Recent efforts focus on gathering high-resolution imagery to aid Landsat data interpretation and project validation, and on the handling of all data pre- and post-processing into the open and free software.

Results from the above-described work are published through the official NFMS web-portal of DRC (www.rdc-snsf.org), which was officially launched in December 2011 (COP), and is available to import, process, and disseminate any data related to forest Monitoring and MRV.

2.4 The Central African Republic (CAR)

The forest mapping exercise in the CAR, undertaken under the framework of the REDDAF and OSFT projects, covers about 345 000 km² in the southern part of the country, or 55 % of the national territory spread over 12 prefectures of the main rainforests area. Dense rainforest areas are in the south, while gallery forests and areas of more open and drier woodland formations are found in the north. The forest maps were produced from the classification of Landsat satellite images for the earliest periods, and SPOT 4/5 and RapidEye for the more recent ones.

For the three prefectures in the southwest (Sangha Mbaéré, Lobaye and Ombella-Mpoko), the methodology is identical to that used in Gabon (F/NF maps of the pivotal years 1990, 2000 and 2010 : see paragraph 2.1). For the nine other pre-

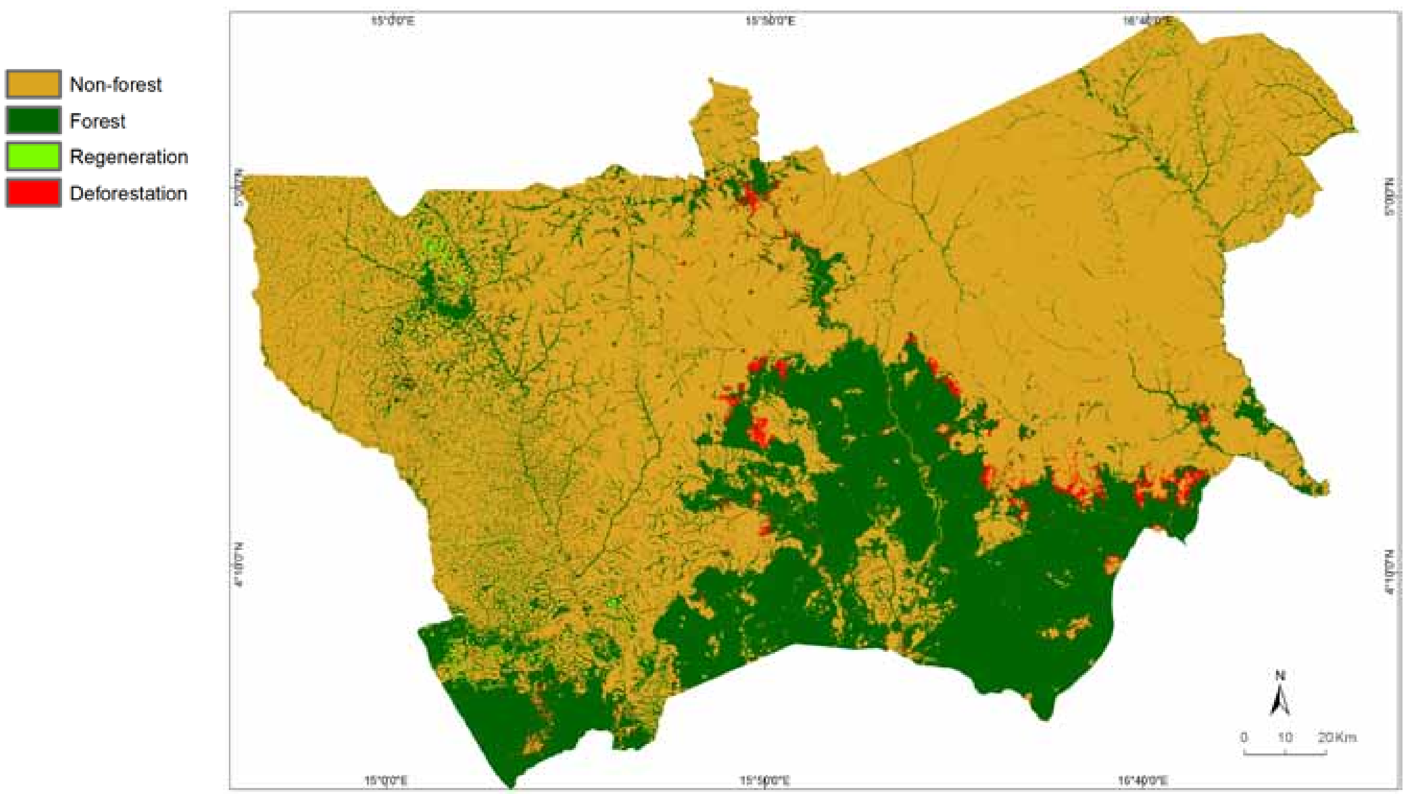


Figure 1.5 : Map of forest change between 2000 and 2010 in Mambéré Kadei province (Lot 1), CAR
Source : OSFT

Table 1.6: *Historical evolution (1990-2000-2010) of dense rainforest area in CAR, per prefecture*

Prefecture	Total area (km²)	1990		Changes 1990-2000 in dense rainforest		Changes 2000-2010 in dense rainforest	
		Dense rainforest area		*Deforestation*	*Regrowth*	*Deforestation*	*Regrowth*
		(km²)	*(%)*	*(km²)*	*(km²)*	*(km²)*	*(km²)*
Mambere-Kadei	30 100	9 845	32.7 %	694	59	436	151
Nana-Mambere	27 400	3 342	12.2 %	251	17	244	19
Ouham-Pende	23 300	1 093	4.7 %	105	25	99	7
Ouham	27 300	3 733	13.7 %	200	27	187	28
Kemo-Gribingui	16 800	4 582	27.3 %	318	32	347	15
Ouaka	49 200	5 246	10.7 %	263	112	188	120
Haute Kotto	16 200	4 174	25.8 %	182	23	254	27
Basse Kotto	17 200	2 750	16.0 %	54	102	53	160
Mbomou	60 400	23 668	39.2 %	362	141	364	116
Haut Mbomou	24 000	5 731	23.9 %	117	139	74	144
Sangha Mbaéré	18 700	17 713	94.7 %	124	34	118	55
Lobaye	18 400	10 223	55.6 %	119	7	128	64
Ombella-Mpoko	32 100	6 536	20.4 %	308	1	115	14
Total	**361 100**	**98 636**	**27.3 %**	**3 097**	**718**	**2 607**	**919**
Net deforestation			(km²)	2379		1688	
			(%)	2.41 %		1.75 %	

Source: OSFT and REDDAF-CAR

fectures, a detailed map of the year 2010 was produced using 10 m resolution SPOT images. Forest cover changes over the periods 2000-2010 and 1990-2000 were analyzed through comparisons with lower resolution Landsat images. The detailed map for 2010 was made with 6 land cover classes: dense forest, wooded savanna, savanna, settled area, wetland, and crop land. Figure 1.5 illustrates the changes in Mambéré Kadei province.

Forest change was assessed by comparing the 1990, 2000, and 2010 maps. These changes are presented by prefecture in Table 1.6.

The deforestation rate is relatively low in the rainforests of the CAR, at about 2 % over 10 years, with the exception of certain prefectures such as Nana-Mambere and Kemo-Gribingui, which have higher deforestation rates (reaching up to 7 % over 10 years). The dense rainforest in the CAR lost 4 % of its total area (4 067km²) in 20 years, or an average of 0.20 % per year.

3. Regional assessment of forest cover change

Photo 1.5: Conversion of primary forest into manioc fields

Efforts to harmonize forest cover monitoring at the regional scale complements various national initiatives (table 1.7). As certain criteria, including the definition of forest mapping can differ from one country to another; it is difficult to make comparisons between countries. Regional approaches permit a coherent overall assessment of the Central Africa forests. Two types of regional analyses are being conducted, each with its own advantages and disadvantages. The first, designed for a regional or even national but not local scale is a sampling approach that enables a better understanding of forest change because it covers the period 1990 to 2010. The second is wall-to-wall mapping, which is indispensable for the implementation of national and local policies but requires the processing of extensive satellite imagery using sophisticated tools.

Table 1.7: *The different approaches used to monitor forest cover in Central Africa between 1990 and 2000, and between 2000 and 2010*

	1990-2000		2000-2010		
Country	**National mapping**	**Mapping by sampling**	**National mapping**	**Mapping by sampling**	**Atlas FACET**
Cameroon	X(East)	X	X(East)	X	X*
Congo	X(North)	X	X(North)	X	X
Gabon	X	X	X	X	X*
Eq. Guinea		X		X	X*
CAR	X(South)	X	X(South)	X	X*
DRC		X		X	X
Chad		X		X	
Regional		X		X	X*

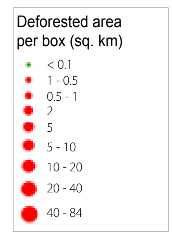
(work in progress)*

Under the framework of the TREES project, launched in 1992 by the European Commission, a new assessment of deforestation was carried out using the 1990-2000-2010 time series covering the Congo Basin. Maps were developed based on satellite images using updated image processing techniques. The maps were compared to determine the deforestation rate for each country of the Congo Basin. This study contributed to the FAO's 2010 Global Forest Resources Assessment (FRA) (FAO, 2012).

The TREES/FRA approach uses extracts from satellite images of 10 x 10 km plots dating from 1990, 2000, and 2010. The images were selected through a systematic sampling on each half degree of latitude/longitude (and even a quarter of a degree for Gabon and Equatorial Guinea, frequently covered by clouds), resulting in a potential total sample of 510 points systematically distributed over the rainforests of Central Africa. However, only 311 sites had good quality images for these three periods. Although the target years were 1990, 2000, and 2010, some images used were for years near these dates because of persistent cloud cover and the low number of images available. Most of the missing samples for these dates were in coastal areas of Gabon, Equatorial Guinea and Cameroon. The Landsat satellites that provided the data for 1990 and 2000 samples encountered technical difficulties in 2010. Therefore, the 2010 data set was built by combining data from several different satellites with similar spectral resolution : DMC (short revisit period and 22 to 32 m resolution), SPOT-4 and -5 (20 and 10 m resolutions). In all, 43 % of the images used for the 2010 analysis were DMC, 22 % SPOT, and 34 % Landsat TM.

Forest cover changes over the 1990-2000-2010 period were estimated based on an original image processing chain : visual selection of the best images available, recalibration, calibration, masking clouds and shadows, segmentation, detection and classification of change (Raši *et al.*, 2013). The processing chain was adapted for the DMC and SPOT samples (Desclée *et al.*, 2013). The automatically produced land use maps were verified and detected errors were recoded. The comparison of pairs of maps validated between 1990 and 2000, and between 2000 and 2010, enabled forest cover changes to be measured at the level of each sampling point (Mayaux *et al.*, 2013). Changing deforestation over the entire Congo Basin is presented in Figure 1.6.

Photo 1.6 : Munaya River, Cameroon



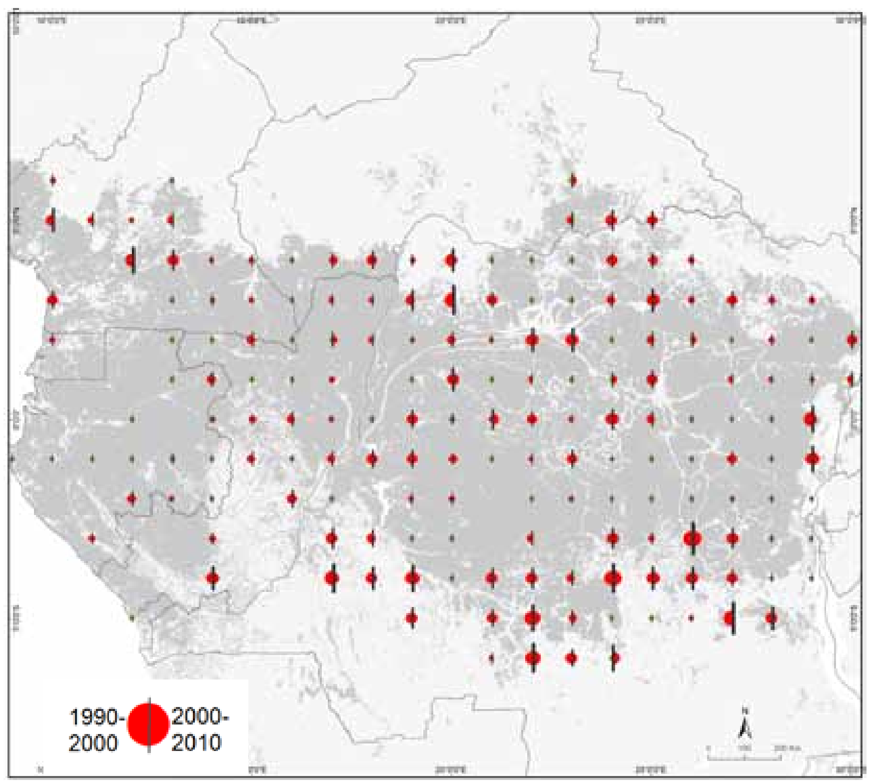


Figure 1.6 : Gross deforestation in the Congo Basin standardized at the level of each point sampled between 1990 and 2000, and between 2000 and 2010
Source : JRC

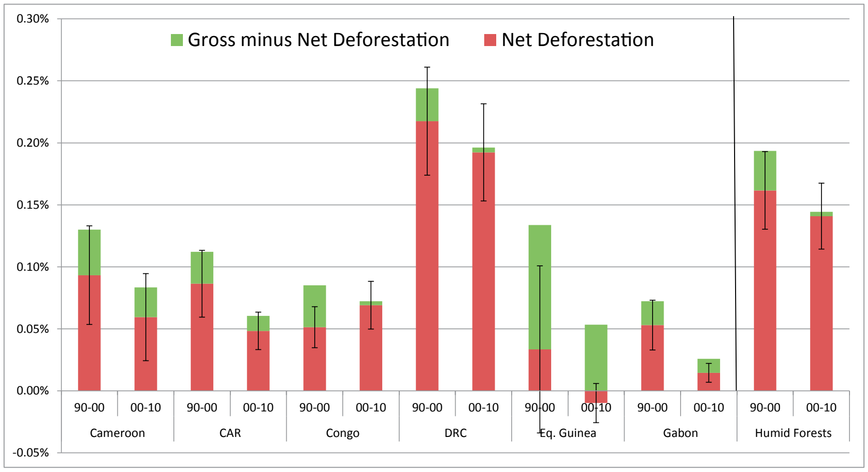


Figure 1.7: Annual deforestation rates (gross and net) of Central African rainforests between 1990 and 2000, and between 2000 and 2010 (with standard error bar). The numbers are presented in Annex 1A.*

*Sources: UCL (1990-2000) and JRC (2000-2010) *Preliminary results*

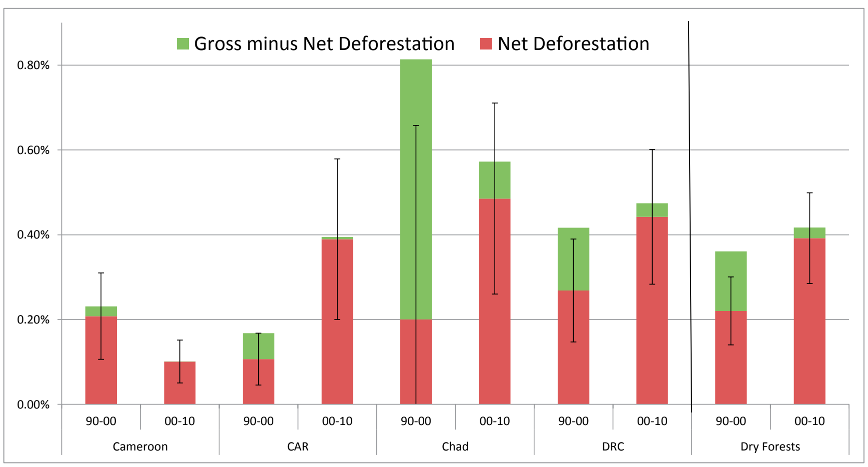


Figure 1.8: Annual deforestation rates (gross and net) of Central African dry forests between 1990 and 2000 and between 2000 and 2010 (with standard error bar). The numbers are presented in Annex 1B.*

*Source: JRC *Preliminary results*

Figure 1.7 indicates the estimated deforestation rates per country and for all of the rainforests of Central Africa between 1990 and 2000, and between 2000 and 2010. The overall trend is a reduction in the deforestation rate, which drops from 0.19 % to 0.14 % for all of the Congo Basin rainforests. Reforestation also is decreasing and remains negligible.

A similar analysis was carried out for Central African dry forests. These dry forests are located outside the Guinea-Congo rainforest ecoregion. The approach described for the 1990-2000 period by Bodart *et al.* (2013) was extended over the 2000-2010 period for the COMIFAC countries. The main countries concerned are Cameroon, the CAR, the DRC, and above all Chad. The data for 1990 and 2000 were provided by Landsat and for 2010 by DMC (62 %) and Landsat TM (38 %). The results of this study are presented in Figure 1.8. While the gross deforestation rate is similar between 1990 and 2000 and between 2000 and 2010 (0.36 % vs. 0.42 %), reforestation decreases, dropping from 0.14 % to 0.03 % between these two periods.

3.2 Regional Landsat-scale forest extent and disturbance FACET map

A set of map products has been generated as part of the FACET program. These products, delivered as hard and soft-copy atlases of forest type, extent and loss at national scales, represent the first medium spatial resolution maps of their kind. We report here an addition to the FACET product suite, which to date consists of national scale products for the DRC (presented in SOF 2010) and the Republic of Congo (presented in Section 2.3). These mapping methods have now been extended to the regional scale, characterizing the following countries of Central Africa: Cameroon, the CAR, Congo, the DRC, Equatorial Guinea and Gabon.

Medium spatial resolution Landsat imagery is the data of choice in quantifying forest extent and change over large areas. The Landsat program meets several requirements for operational monitoring including a formal data acquisition strategy, an open data policy (data are provided free of charge and are readily accessible through the Glovis facilities; http://glovis.usgs.gov), and radiometric and geometric correction of the data, which obviates the need for onerous pre-processing by users. The successful launch of Landsat 8 in February 2013 assures the continuation of the program.

Methods for mass-processing the Landsat archive in support of land monitoring programs are now being implemented. Data-intensive computational methods allow for the querying of every Landsat pixel, enabling researchers to overcome the primary limitation of optical earth observation data sets for tropical Africa: cloud cover. FACET processing of Landsat data includes per pixel quality assessment in order to retain only viable land surface observations for forest characterization. Technical methods for processing and characterizing Landsat data in this manner are presented by Potapov *et al.* (2012). For this first regional product, data from 1999 through 2012 were included. To date, FACET products include two maps: a forest extent reference at time 1 and a forest cover loss estimate between time 1 and time 2 (Hansen *et al.*, 2013).

Regional-scale Landsat-derived forest extent and loss map products were derived and are displayed together in Figure 1.9: a percent tree cover map for 2000 and a forest cover loss estimate map for the period of 2000 to 2012. Forest cover loss (in red) includes areas with tree cover greater than 30 % of surface area that experienced stand-replacement disturbance between 2000 and 2012.

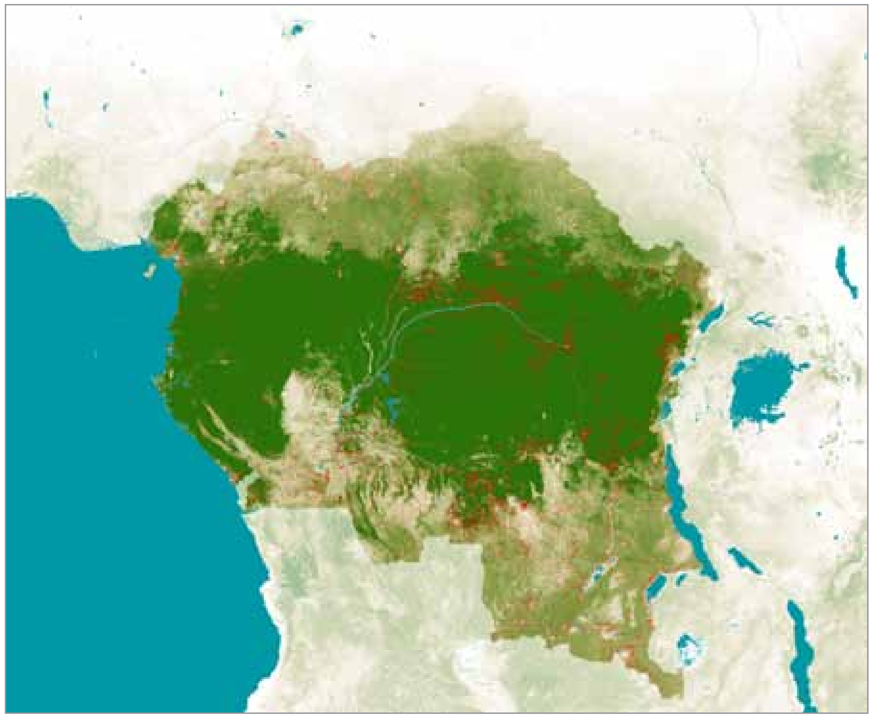


Figure 1.9: Landsat-derived regional percent tree cover and forest cover loss for tree cover ≥ 30 % canopy cover

Source: FACET

Photo 1.7: Village and Landscape of South Kivu

A regional subset is shown in Figure 1.10, illustrating the variation in forest disturbance between countries along the northern fringe of the Congo Basin rainforest. The background image captures the high data quality of the input Landsat data and the lack of cloud or haze contamination, which was possible because of the mass-processing of the Landsat archive.

Such regional maps demonstrate capabilities that could be adopted by national agencies responsible for forest monitoring. As an example, FACET data have been incorporated into UN-REDD activities, including the use of FACET as the primary thematic layer for forest cover extent and loss for the DRC's National Forest Monitoring System (NFMS). National monitoring tasks in support of the REDD+ initiative will require such data in establishing baseline carbon emissions estimates. Forest definitions used in REDD+ may vary based on tree height and cover density. For this regional map, the percent canopy cover of 5 meter or taller trees was estimated per pixel. Percent tree cover maps allow users to vary the definition of a forest based on canopy cover and enable the disaggregation of forest loss by canopy density strata. The mapped forest cover loss is for stand-replacement disturbances only, and it does not include an assessment of forest degradation due to selective logging. Additionally, to properly model carbon emissions for REDD+ monitoring objectives, it is necessary to label forest loss events by antecedent forest type and identify the change dynamic (mechanical clearing, fire, storm damage). The regional product will be made freely available at the CARPE and OSFAC websites (carpe.umd.edu and osfac.net).

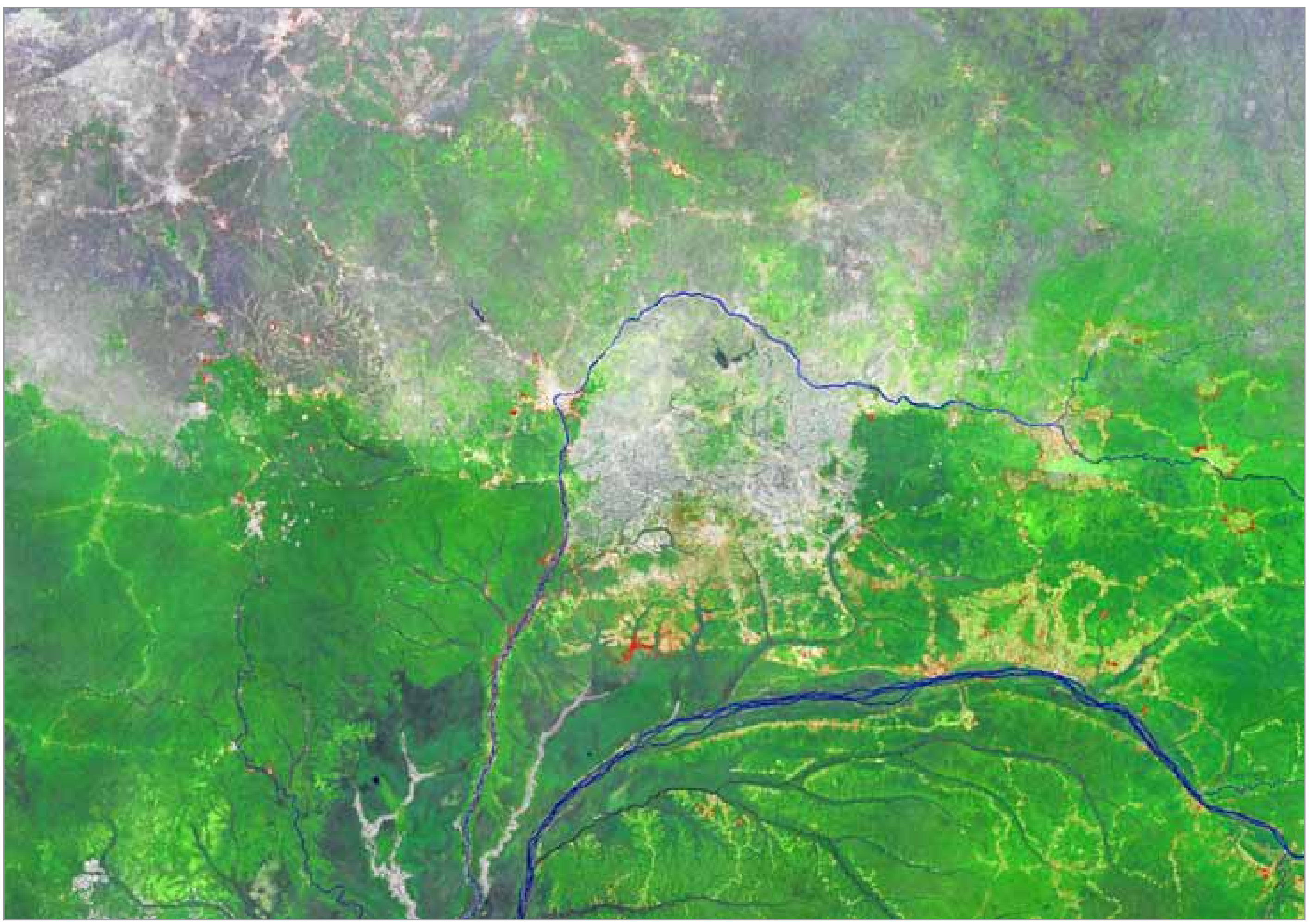


Figure 1.10 : Regional subset of Figure 1.9, with forest cover loss from 2000 to 2012 in red and a background composite image of Landsat in 5-4-3 false color

Source : FACET

4. Advances in forest degradation and biomass mapping: Case studies

Within the framework of sustainable forest management and the UN-REDD program, new tools are required to provide reliable and continuous information on changes in forest carbon stocks. Forest monitoring focuses not only on deforestation processes (conversion of forests into other land uses), but also on forest degradation, meaning the reduction of carbon stocks within degraded forest areas. By using remote sensing, numerous activities contributing to carbon stock reduction can be monitored, from selective logging to fire wood harvesting. Although deforestation estimation methods are robust, reliably assessing forest degradation remains a challenging task which requires advanced satellite image analysis technologies.

Photo 1.8: Forest remnants in the Bateke Plateau are most often found in the valleys or on the hills – Bateke Plateau, DRC

4.1 Evaluation of forest degradation

To exploit forest resources, access roads to reach trees and extract logs are required. The roads are organized into networks with heavily used main roads, secondary roads leading to timber harvest areas, and lastly skid trails that provide access to each tree selected for harvest.

A preliminary study developed a prototype tool to annually estimate the extension of logging roads based on Landsat image time series data. This tool was then used in a study conducted in southeast Cameroon, southern CAR, and the north of the Republic of Congo where forests are semi deciduous and where population densities are low. The majority of logging operations in these areas are managed by private companies.

Box 1.2: Improvement of forest-type mapping using MODIS

Valéry Gond, Adeline Fayolle, Alexandre Pennec, Sylvie Gourlet-Fleury
CIRAD

Generally speaking, it is impossible to distinguish between different types of forests on satellite image maps of Central African tropical rainforests because forests are shown as a big tinted green area. Yet studies carried out on the ground prove that a wide diversity of forest types exist. Within the CoForChange (www.coforchange.edu) project, the study of a chronological dynamic of satellite images and their underlying data have produced a map detailing forest types in the Sangha corridor (0°-5° north latitude and 13°-19° east longitude). The data from the MODIS satellite, which provide indices of EVI vegetation over 16 days at a resolution of 500 m, were used for the period 2000-2009. The spatial dynamic of rains was analyzed using monthly meteorological averages at a resolution of 8 km (http://earlywarning.usgs.gov/fews/africa/index.php). Inventory data from 37 898 forest plots were used to validate the map. Finally, the Cameroon vegetation map by Letouzey (1985) was used for validation (Gond *et al.*, 2013).

Figure 1.11 shows an excerpt of the map made. In the legend, the colored histograms represent average monthly precipitation, the thick line shows variation of photosynthetic activity throughout the year compared with the dotted lines which represent average photosynthetic activity of the study zone. In the north of the map, the brown and yellow colors highlight the transition between the savannas and the forest edge. The shades of green differentiate the types of tropical rainforests identified via analysis of satellite data: the darker the shade of green, the greater the proportion of evergreen trees; conversely, the lighter shade of green indicates an increase in semi-deciduous trees. The pink-shaded areas indicate agro-forestry zones close to transportation routes and urbanized areas. Finally, orange-shaded areas show southern savannas, which are clearly distinguishable from northern savannahs through their different vegetative cycle revealed by their photosynthetic activity.

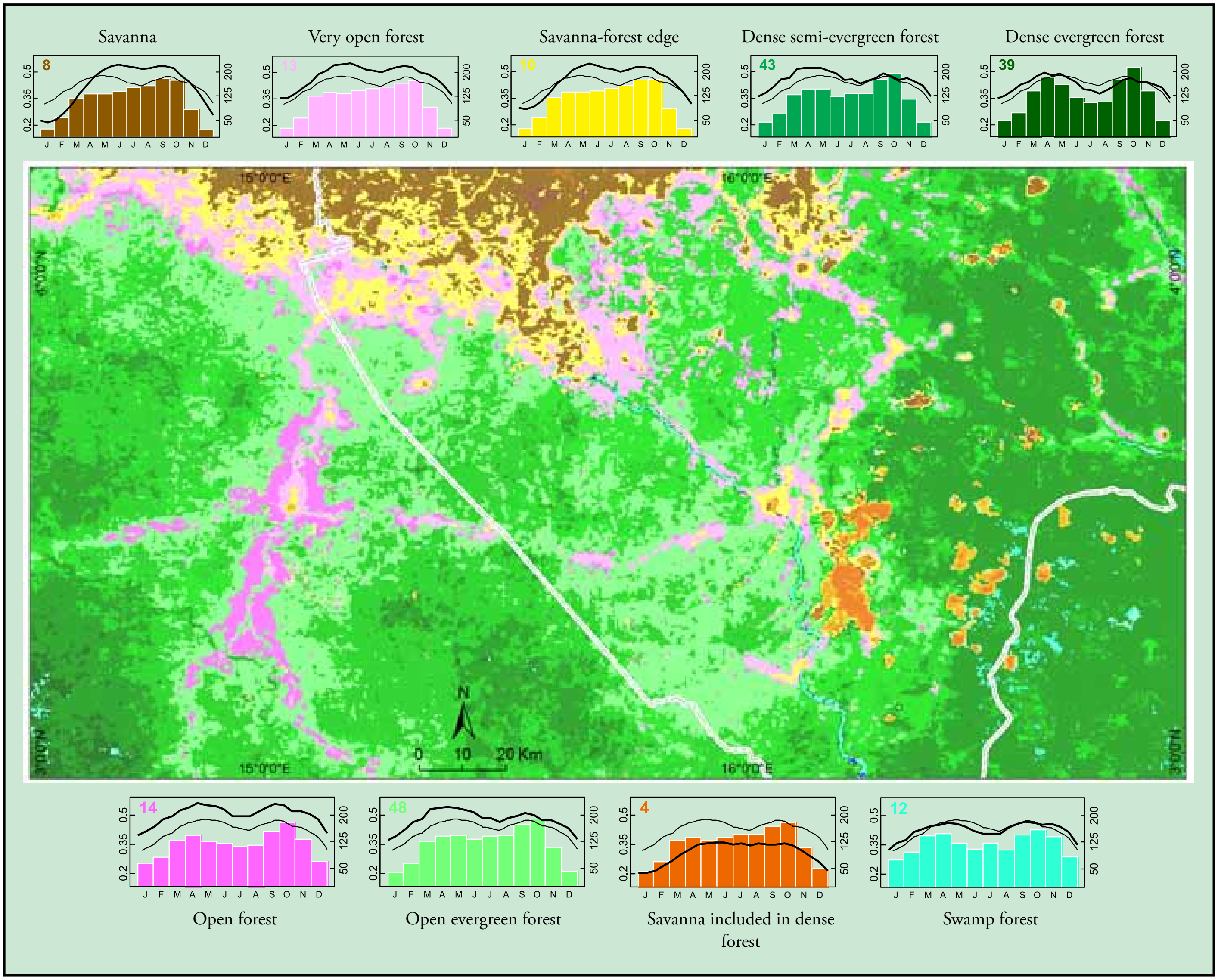


Figure 1.11 : Excerpt of map of the Sangha interval showing the northern borders of the Yokadouma (Cameroon) to the west, Nola to the east (Central African Republic) up to the sandstones of Carnot on the Republic of border

Based on Landsat images, several indices were calculated after increasing the contrast between forest areas and roads which are generally associated with bare soil, by applying a spatial filter (Gond *et al.*, 2004). Threshold values were adjusted to identify bare soil (Bourbier *et al.*, 2013). The results were produced on the scale of a 500 m grid in order to be compatible with MODIS sensor data. To estimate the development of logging roads (figure 1.12), the percentage of pixels of bare soil was calculated based on an annual composite of MODIS images on each 500 m-sided cell. These percentages were considered to be Canopy Opening Indicators (COI). By analysing COI time series, the evolution of road networks can be monitored and the impact of forestry operations can be assessed.

COI were calculated for the period 1999 to 2003 using Landsat images. The changes in COI provide information regarding changes in the opening and closure of forest cover. This technique permits an assessment of logging road networks and potentially of degraded forests in Central Africa.

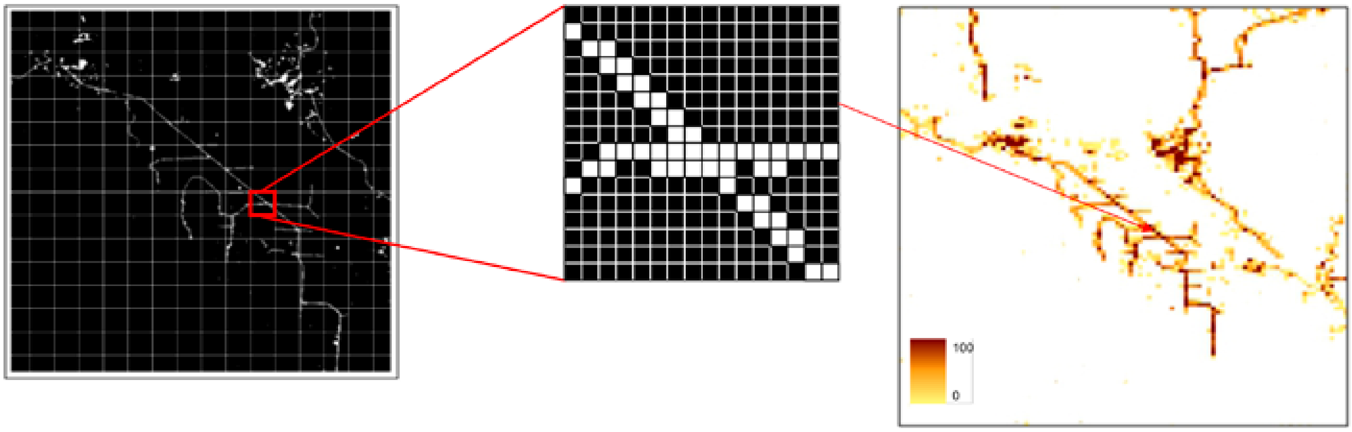


Figure 1.12 : The canopy opening indicator from Landsat (left) is aggregated on a 500 m sided grid (center) to estimate the ratio of bare ground area (right)

Source : Bourbier et al., 2013

Box 1.3 : Regional map of tree cover percentage obtained from radar data

Alexandre Bouvet
JRC

A new wall-to-wall map of the percent tree cover has been created for Sub-Saharan Africa. The map is the result of a supervised classification applied on a mosaic of double-polarization data (HH and HV) from PALSAR, the Japanese L-band synthetic aperture radar (Bouvet *et al.*, 2011). The mosaic covers the African continent at a spatial resolution of about 100 m. The Vegetation Continuous Fields (VCF) product from MODIS, which gives the percentage of the surface covered by trees in each 0.25 km^2 pixel, is used as training data for the classification. The following tree cover classes are retained: 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, and >60% (the PALSAR signal saturates for tree cover higher than 60%). Compared to VCF and other vegetation maps available at large scales, the improved spatial resolution allows the detection of fine structures (e.g. gallery forests) and the reduction of the number of mixed pixels, as shown on Figure 1.13. High-resolution samples of classified optical data from the Global Forest Resources Assessment 2010 (FRA 2010) Remote Sensing Survey, available at each square degree, have been used for the validation of these results. The accuracy of the forest/non-forest classification is estimated to be around 89% over the whole of Sub-Saharan Africa.

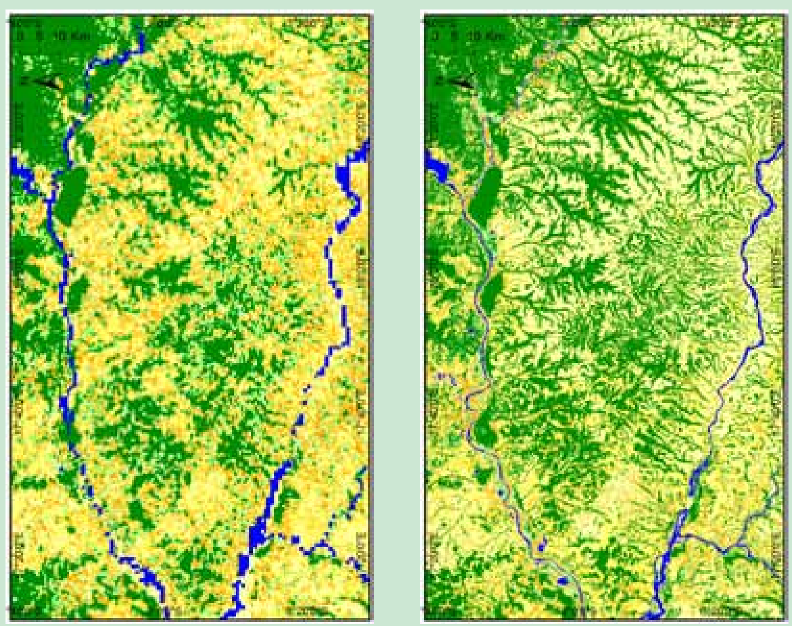


Figure 1.13 : Comparison of VCF percent tree cover (left) and classified PALSAR maps (right) (subset centered on -2.5°S, 15.5°E)

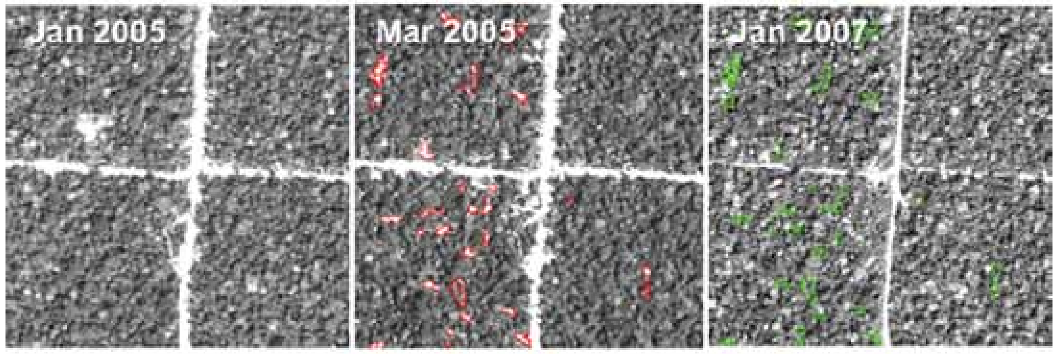


Figure 1.14 : Monitoring selective logging clearings based on SPOT temporal series imagery between January 2005 and January 2007 (Desclée et al., 2011)

A second study based on SPOT images permitted an assessment of forest cover change on a certified forest concession in the Republic of Congo (Desclée *et al.*, 2011). Forest disturbances were detected through changes in satellite images between 2005 and 2007. For example, on a 20 000 ha felling area, a 7 % loss of forest cover in the area logged was observed between January and March 2005 (figure 1.14). Sixty percent of this loss was caused by logging gaps and 40 % by logging roads. The 2007 analysis shows that the logging gaps had closed and only the main roads remain (figure 1.14). These forest cover monitoring maps can then be compared with information provided by the logging company. The precise monitoring of logging gaps requires annual fine spatial resolution satellite images.

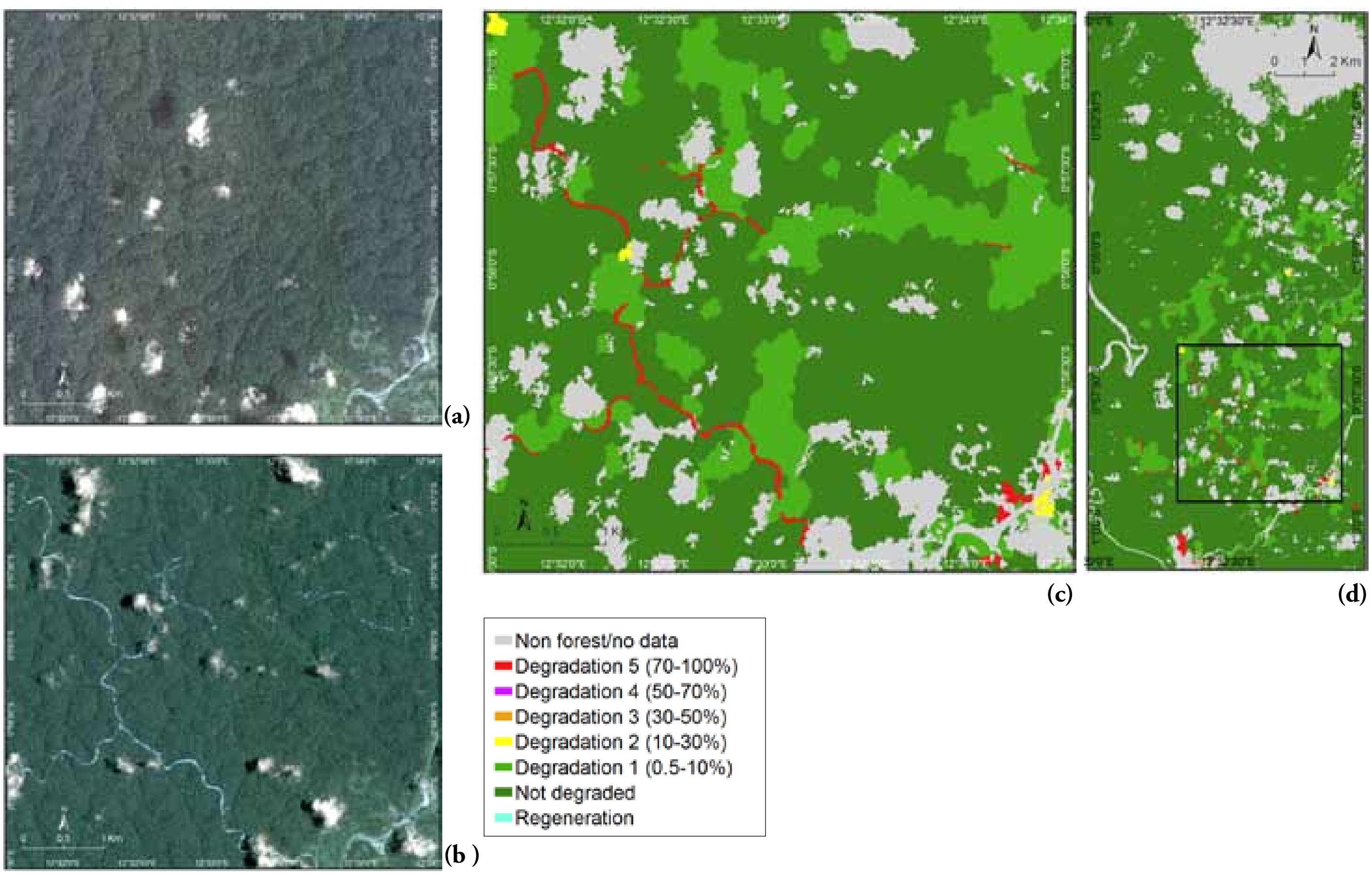


Figure 1.15 : Degradation mapping in central Gabon derived from Quickbird images acquired in (a) December 2010 and (b) March 2012. The degradation map (in c) shows the percentage area difference of small patches of bare soil for the period 2010-2012, d) the whole 20x10 km study area with black box indicating the location of the figures a, b and c.

Source : REDDiness

The potential of optical and radar satellite imagery to detect and monitor forest degradation was evaluated within the framework of the REDDiness project. Degradation mapping was performed over a test site of 20 x 10 km in central Gabon with multispectral, high-resolution Quickbird imagery (2.4 m) acquired between 2010 and 2012. The mapping was based on semi-automatic, object-based classification. First, large objects that have similar image characteristics were identified for both dates. Within these large objects, smaller patches that contain bare soil in one of the images (e.g. canopy gaps, logging roads) were detected. Five levels of forest degradation were then defined based on the percentage area difference of bare soil within each large object between both years. Forest degradation level 5 is considered deforestation when the threshold of tree cover falls below the definition of forest (figure 1.15).

The persistent cloud cover in large areas of the Congo Basin hampers effective multi-temporal analysis of forest degradation. To overcome this problem, radar imagery was used to detect forest degradation signs, although the processing and interpretation of these data for small-scale degradation features is complex and requires expertise in radar signal analysis.

Photo 1.9: Caesalpinaceae Forest, south-west Gabon

Box 1.4: Different approaches to mapping forests in response to persistent cloud cover

Baudouin Desclée and Philippe Mayaux
JRC

It is possible to map large tropical forest areas such as Central Africa with remote sensing. The techniques in use are, however, highly variable. The quality of results depends on several parameters, such as the images used, the pre-processing undertaken, the classification method, and the training data. Wall-to-wall mapping is referred to when a map covers a complete region, while sampling analysis is conducted on a representative sample of the area under study. The advantage of the first technique is that it provides exhaustive information on the entire region of interest, but it requires considerable image processing to combine many different images. The sampling approach focuses the analysis on a more limited area but allows a rapid picture of forest change over larger areas. The classification techniques used are either pixel (all of a satellite image's pixels are classified) or object (the image is divided into homogeneous polygons and assigned a land use category) methods. The advantage of the pixel approach is that information is obtained at a more precise spatial level (the scale of a pixel), while the object approach allows more coherent cartographic information (group of pixels with similar behavior). The challenge of the latter approach involves determining the relevant level of aggregation, often defined by the minimum mapping unit.

A major constraint on mapping tropical forests, particularly in Central Africa, is persistent dense cloud cover. This poses problems when analyzing optical images and suitable methods are needed to circumvent this difficulty. There are several options: (1) multi-sensor analysis, (2) image composition, and (3) use of radar images.

The first approach uses satellite images from different sensors to cover a large region with an adequate number of cloudless images. However, it is limited by the availability of images and access to these data. For example, access to Landsat images, which are widely used to monitor forests, was problematic in Central Africa between 2003 and 2013 because of a problem with the Landsat-7 ETM+ sensor in 2003 and the loss of Landsat-5 image reception over the area since 2001. Images acquired by other sensors (for example, SPOT, Aster, DMC and RapidEye) are therefore added to the multi-sensor analysis to cover the area of interest. Image compositing is a more recent approach which combines parts of many images to obtain a composite image without clouds. The advantage of this technique is that a cloudless image is obtained, but given that information from different dates are combined, it is more difficult to identify when a change in forest cover has occurred. The third option to address the issue of cloud cover is to use radar images with a signal undisturbed by clouds. However, this signal is influenced by other parameters (such as topography, soil humidity etc.) which renders it more complex to interpret. It is therefore useful to combine radar data with other information sources, for example, optical images.

These different forest mapping approaches each involve advantages and disadvantages in responding to an important challenge: mapping forests in a very cloudy region. The hunt for new solutions to produce more precise maps is constantly changing with the availability of new satellites.

4.2 Mapping forest biomass

As tropical regions have persistent cloud cover, satellite-based monitoring with cloud-penetrating sensors combined with optical images will play a crucial role in future MRV systems. As part of the ReCover project (Häme *et al.*, 2012 ; Haarpaintner *et al.*, 2012), a biomass map was produced over a 68 000 km^2 region in western DRC based on space-borne LiDAR data from ICESat/GLAS sensor over the period 2003-2009 (figure 1.16). Biomass was estimated by an interpolation and conversion of ICESat/GLAS based on tree heights at 1 km² resolution. For this first map, the allometric equation provided by Saatchi *et al.* (2011) was used. Additional input was a Forest/Non-Forest (F/NF) map derived from Landsat data and combined with both optical at higher resolution (Pedrazzani *et al.*, 2012) and cloud-penetrating radar data (Einzmann *et al.*, 2012). The resulting F/NF maps were produced for the years 1990, 2000, 2005 and 2010 at 30 m resolution.

Two methods for the direct assessment of forest degradation have been tested in Cameroon in the framework of the REDDAF project : (1) a NDVI-based approach, which compares the values of this vegetation index derived from RapidEye satellite data between 2009 and 2011 ; and, (2) the application of Cosmo-Skymed stereo satellite data to compute 3D models illustrating logging gaps and logging roads. Finally, a transferable model to estimate above ground biomass for low carbon forests using SAR data has been developed (Mernoz *et al.*, 2014). Figure 1.17 presents the results of this model, a biomass map for the Adamawa region in Cameroon covering about 15 000 km². Extensive (21 plots) biomass field measurements were carried out in 2012 and used for the calibration and validation of the inversion model using SAR data. This model could offer a cost-effective approach for estimating above-ground biomass in a low-carbon forest, requiring stronger validation and replication over other regions.

The Emission Factor assessment, measuring changes in carbon stocks of different forest carbon pools, focused on planned selective logging, one of the main agents of forest degradation in Cameroon.

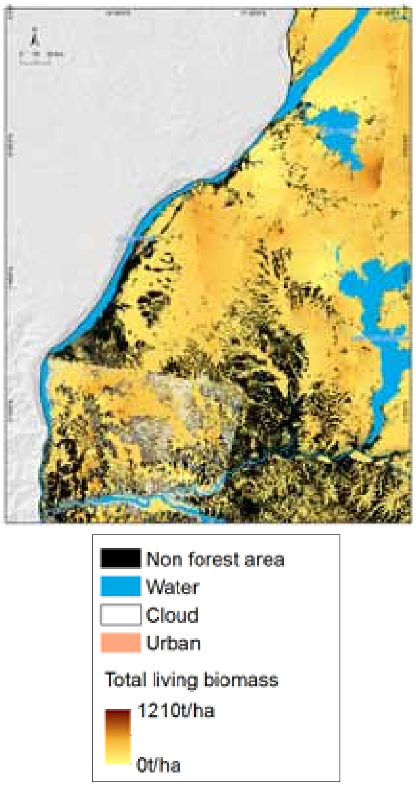


Figure 1.16 : Biomass map in forested areas over Eastern DRC derived from a combination of forest/non-forest and tree height maps
Source : ReCover.

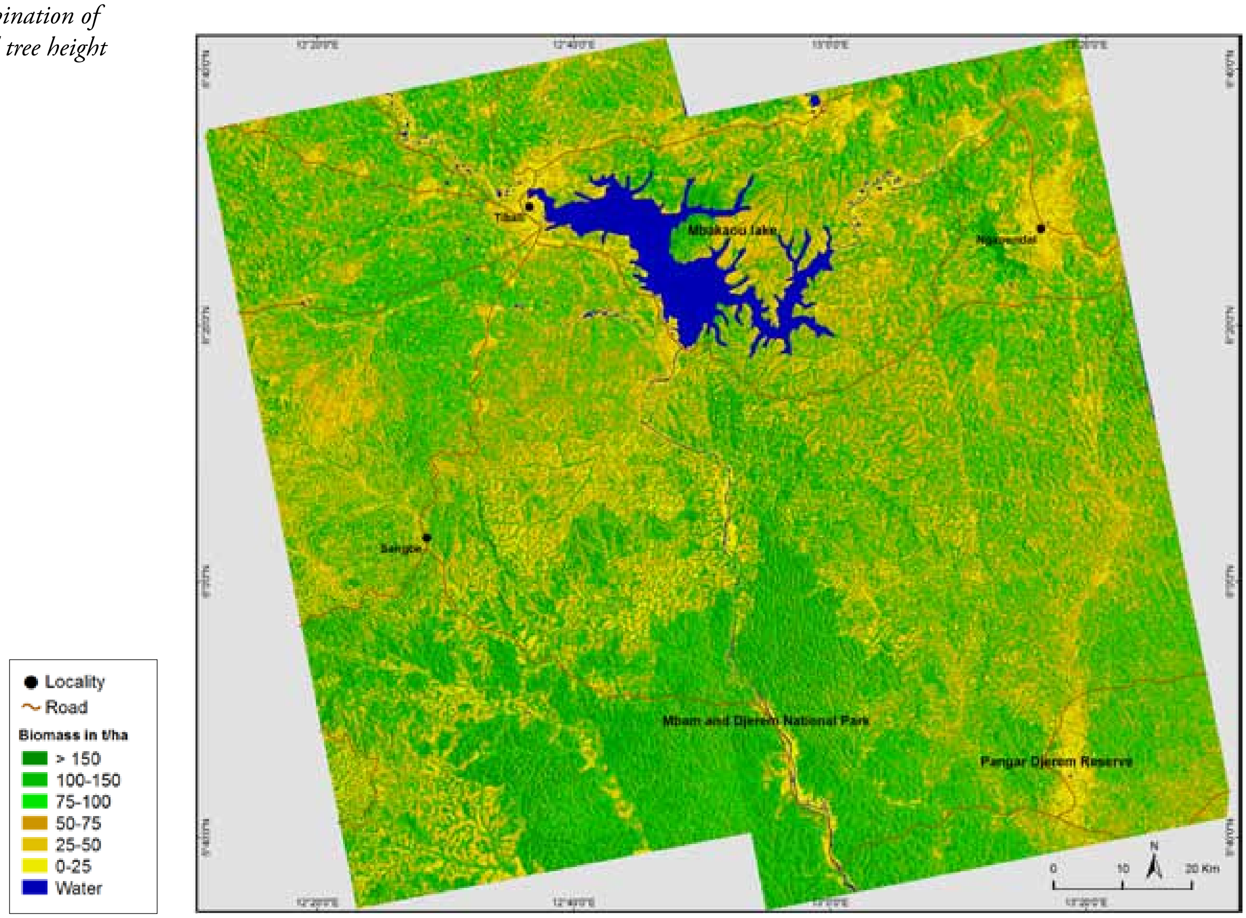


Figure 1.17 : Biomass mapping results for the Adamawa region, Cameroon
Source : REDDAF-Cameroon

Two field inventories assessed biomass and carbon impacts from selective logging in a FSC-certified forest concession as well as in a non-certified concession. The sampling design was based on Carbon Impact Zone (CIZ) plots in the logging gaps with an additional plot 50 m from the CIZ plot. The additional plot measures carbon stocks in intact forest. The size of the CIZ plots depends on the size of the damaged area caused by the fallen timber tree which is determined by the damaged and survivor trees around the logging gap. The results of the inventory of 67 plots indicated a total biomass including soil of 326 t/ha, with the above ground biomass accounting for 285 t/ha. A comparison of the CIZs with the intact plots indicated that in non-certified logging concessions, 1.97 tons (± 0.41) of carbon were removed per ton of extracted timber while on certified concessions the same factor was 1.34 tons (± 0.22).

These results demonstrated that improved forest management and logging practices can lead to a substantial reduction of emissions. This study also illustrated that it is possible to track degradation signals from selective logging using remote sensing imagery; however, it is important to note that having a high temporal frequency of satellite data is necessary for degradation assessment.

Based on these case studies, satellite imagery has a high potential to detect forest degradation, but it requires good-quality remote sensing imagery at frequent intervals (at least once per year) and at high spatial resolutions (<10 m). This has implications for the costs of a national monitoring system, and a sampling approach may be required to reduce costs. Persistent cloud cover is the main problem for optical image acquisition in the Congo Basin, but radar has its own intrinsic difficulties. The limited availability of optical and radar archive imagery makes it currently difficult to set proper baselines for forest degradation. Systematic observation strategies where a satellite sensor frequently covers the territory using the same observation characteristics are needed to help overcome these problems.

Photo 1.10: Secondary track for transporting timber – Bandundu Province, DRC

Box 1.5: Using the latest airborne technology for assessing forest biomass in DRC

Aurélie C. Shapiro[1], Mina Lee[2], Johannes Kirchgatter[1], Sassan Saatchi[3]
[1]WWF – Germany ; [2]WWF – DRC; [3]University of California, Los Angeles

Following the announcement of national forest biomass mapping in DRC (see box 8.3 in SOF 2010), the *Carbon Map and Model* project (CO2M&M[1]) launched in 2012 is now collecting airborne laser scanner data (LiDAR, for Light Detection and Ranging) to complement field and satellite data for estimating carbon stored in DRC forests. This strategic data collection for biomass assessment is being conducted through a sampling approach that mimics field forest inventory techniques. As national LiDAR coverage is not affordable, a stratified random sampling strategy will create the most unbiased dataset possible (i.e. widely and evenly distributed) while consistently representing the various forest types over the entire country. To that end, 212 plots covering about 400 000 ha in total area are being flown between 2013 and 2014 to acquire simultaneous LiDAR data and high resolution color aerial photos, providing one of the most comprehensive airborne forest inventories ever achieved in DRC.

LiDAR scanners are active sensors which use an altimetry approach to very accurately estimate the land surface elevation (<10 cm) as well as the forest height (figure 1.18). LiDAR pulse also provides information about the forest structure in dense forests (canopy, density). Existing and new "classical" field plots are being used to regionally calibrate LiDAR data, which will create an extensive data set to validate the methodology. LiDAR data, calibrated by field inventories, will then be scaled-up to satellite imagery and with other data to estimate biomass throughout the whole country.

1 http://www.wwf.de/themen-projekte/waelder/wald-und-klima/carbon-map-and-model-project.

In addition to estimating carbon stocks, this LiDAR data can be used in a variety of applications including forest health, biodiversity and conservation research. The LiDAR campaign will also provide information about forest disturbances such as logging in forest concessions, the extent of forest degradation and the regenerating capacity of tropical forests. According to Zhuravleva, *et al.* (2013), forest degradation can represent a significant component of carbon emissions in the Congo Basin. Therefore, by the end of 2015, this project will provide essential information on DRC's forest carbon stocks and emissions related to forest management, conservation and deforestation.

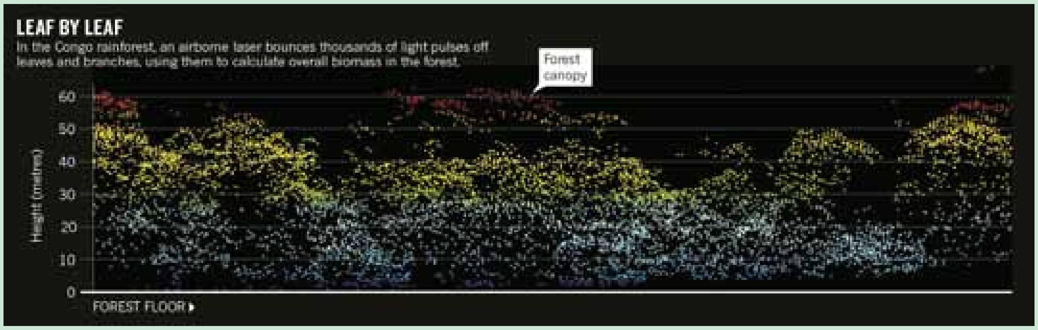


Figure 1.18 : Schematic showing the combination of airborne LiDAR estimating forest height and ground elevation which combined with auxiliary data result in a biomass map at 1 hectare resolution.

5. Analysis of deforestation drivers

5.1 Deforestation drivers and underlying factors

Photo 1.11 : Canopy in the mist – Monts de Cristal, Gabon

Numerous recent studies (Defourny *et al.*, 2011 ; Ernst *et al.*, 2013 ; Mayaux *et al.*, 2013 ; Megevand, 2013) have identified the direct factors and underlying causes of deforestation in the Congo Basin. In this region, small scale deforestation phenomena are observed, corresponding to increasing slash-and-burn agricultural activities, artisanal timber logging, artisanal charcoal production, and firewood harvesting.

Artisanal charcoal production is mainly to supply urban centers which create a circle of degradation around major cities in the region (Kinshasa, Douala, Yaoundé…). In the future, increased use of fossil fuels which are the focus of increasing exploration in the Congo Basin, could diminish wood's part of the energy mix in the region, but wood will likely continue to predominate.

The expansion of crop areas is linked to village agriculture, which mainly supplies local markets and nearby urban centers. To date, industrial agriculture has had limited impact on forest cover with the exception of oil palm and rubber plantations set up near large transportation axes. Some public policies whose impacts should be studied (notably regarding biofuel) and large agro-industrial projects certainly will influence deforestation.

Industrial logging has not yet been determined to be an important direct factor in deforestation because of low logging densities concentrated on a few high-value species. However, the concurrence of high human population densities with the opening of logging roads promotes substantial local forest cover degradation.

Mining and oil sectors do not cause important deforestation, at least in terms of surface area, but the local air and river pollution generated from these activities impacts the condition of forests. Numerous new projects are being considered in these sectors (for example, oil exploration in Virunga National Park) that will have a more pronounced impact on forests.

The consensus for the main underlying causes of forest degradation are rural and urban demographic pressure, rural poverty, the development of new infrastructure, and inadequate control over the governance of the forest sector. Deforestation remains low when the rural population density remains below a threshold of 8 inhabitants per square kilometer, and increases rapidly once this threshold is passed. The proximity of towns in terms of transport time strongly influences forest ecosystem degradation. The absence of quality road infrastructure hinders the development of agricultural and fuel wood activities. When transportation times exceed 16 hours, the influence of urban centers becomes statistically negligible (Mayaux *et al.*, 2013) except along waterways. Studies have shown that poor governance at the local and national level is also an underlying factor favoring deforestation, in particular in areas where poor or nonexistent spatial planning allows illegal activities to continue unchecked (Rudel, 2013).

5.2 Simulation of forest cover loss in the DRC through 2035

A simulation of the risks of forest cover loss in the DRC through 2035 was undertaken by UCL in collaboration with the FAO under the REDD+ initiative. The national DRC REDD+ strategy continues through 2035.

This study was based on forest cover change in the DRC between 2000 and 2010 described in the FACET atlas (Potapov *et al.*, 2012). The deforestation and forest degradation drivers identified by Defourny *et al.* (2011) in the DRC were used in a simulation of forest cover loss at a spatial resolution of one square kilometer. The distribution of the human population and the time required to reach markets in urban areas are the two variables that spatially explain forest cover change dynamics in the DRC (Kibambe and Defourny, 2010; Kibambe *et al.*, 2013).

The calibration of the simulation model used FACET atlas land use maps made in 2000 and 2005. The 2010 forest cover map in this atlas served to validate the model. Two scenarios allowed a comparison of the simulations made: a business-as-usual (BAU) scenario predicting a doubling of the population in 2035, and a conservative scenario envisioning an annual forest cover loss similar to that observed between 2000 and 2005.

While the forest cover loss observed between 2005 and 2010 was estimated to be 19759 km² (Potapov *et al.*, 2012), or 14 % more than in the 2000-2005 period, the conservative simulation (2nd scenario) underestimated it by about 13 %. According to the conservative simulation, the annual forest cover loss rate is 0.19 %, an unrealistic figure given observed trends. Ernst *et al.* (2013) observed a doubling of gross deforestation rates, passing from 0.11 % per year between 1990 and 2000 to 0.22 % per year between 2000 and 2005. Potapov *et al.* (2012) indicate that the gross forest cover loss (all types of forests considered together) rose from 0.22 % to 0.25 % per year between the periods 2000-2005 and 2005-2010.

Based on scenario 1 (BAU), the annual forest cover loss rate was estimated to be 0.31 % with the hypotheses of demographic growth of 2 % to 3 % in rural areas, a maximum population density of 6 inhabitants/km² in forest areas (Kibambe and Defourny, 2010), and a demand for forest land per rural household of 0.25 hectares (Tollens, 2010). This rate of 0.31 % is four times less than the estimate by Zhang *et al.* (2002).

The simulations nonetheless showed that the conservative hypothesis could be a good indicator of short term forest cover change (about 5 years) because the forest areas converted into non-forest areas are small in DRC forests. In contrast, the simulation based on demographic growth shows that forest cover losses could be higher if the Congolese population doubles between now and 2035 over the life of the DRC REDD+ national strategy.

6. Perspectives for monitoring tropical forests

The different mapping and forest monitoring initiatives in Central Africa demonstrate the great international interest in tropical forests. The trend is towards more wall-to-wall mapping of forests because increasing amounts of satellite imagery are available (notably with the arrival of new Landsat-8 and Sentinel-2 satellites) and the resolution of images is increasingly fine. To be able to compare these different maps, it is critical to harmonize the methods and definition of land use classes, as well as to provide more information on the quality and accuracy of information, which is currently rarely the case. The mapping of certain countries such as Rwanda, Burundi and Sao Tome and Príncipe also is crucial to obtain an overall picture of the ensemble of COMIFAC countries.

Aerial studies of forest degradation and biomass are still under development. They will require better integration of field data, particularly for biomass, through the development of a field data collection and archiving network. It also is important to reinforce regional capacities to collect, process and analyze forest monitoring data in order for this to be conducted by experts from the region. The Libreville SPOT receiving station project may act as a springboard.

Photo 1.12: Typical vegetation in the dense humid rainforests, Cameroon