# Appendix 1

Methodology proposal to monitor African Forest Carbon Stock – 18 May 2008

TABLE OF CONTENTS

# 1 DEMOCRATIC REPUBLIC OF CONGO FOREST PRESENTATION

The **Democratic Republic of Congo** is located in the heart of Africa, and straddles the equator, between Latitudes 20° North and 13,5° South and between Longitudes 12°' East and 31,5° East.

The country is divided in four main floristic areas:

- The ***région soudanienne* (Sudanese area)**: narrow strip of herbaceous and ligneous savannas, sited in the Northern part of the *Cuvette Centrale* (Central Basin);
- The ***région zambézienne* (Zambezian area)**: broad strip of herbaceous and ligneous savannas with patches of clear forests in the South;
- The **région guinéo-congolaise (Guineo-congolese area)**: shadow forest of the Cuvette Centrale (Central basin);
- The **région morcelée montagnarde (parcelled montaneous area)**: Afro-montaneous forests, situated on the Eastern part of the country in the African graben, interrupted by large lakes.

The DRC dense forest covers in total 128 millions hectares (source: state of the forest 2006). It is divided into two parts: a small and severely degraded massif in the Bas-Congo Province and a very large massif in the *Congo cuvette* area. Swampy forests cover important areas, evaluated to more than 8 millions hectares. The dry dense forests (locally called "Miombo) represent also an important part of the forest area, estimated around 45 million (FRM, 2003)[1].

### *Forest Management*

The forest management plan is the cornerstone of sustainable forest management. This old forest management concept was not or little implemented in Central Africa until the years 1990. The build up of the sustainable management concept, its integration in the forest laws, brought on the launch of forest management projects by forest operators. These new Management Plans now take into account all functions of the forest, and not exclusively the function of production, and are effectively implemented by the private operators and the States.

The Democratic Republic of Congo falls into step with the international sustainable forest ecosystems process, and the new 2002 forest law incorporates new demanding requirements as regards forest Management. The effective development of the management process is delayed by the finalisation of the old forest titles conversion and by the difficult activity revival after the end of war and the

[1] *FRM, CHEZEAUX, E., 2003. Assistance à la revue économique du secteur forestier en RDC. Analyse du potentiel forestier et des pratiques de gestion forestière. p. 4.*

reluctance of the private sector to invest in a country under reconstruction. Nowadays, 5 private operators launched their forest management process, over a 4.7 million ha area, covering around 20% of the concede area. In 2008, the two first management plans were forwarded to the SPIAF for technical evaluation. Situation will probably change in 2008 with the end of the conversion process, which will regulate the sector and encourage process successful operators for managing their concessions.

***Table 1: Areas for some land use and land cover in the Democratic Republic of Congo***

| | Official (SPIAF and DGF) | ***FRM*** |
|---|---|---|
| Country area (million of ha) | **234** | ***234*** |
| Forest area[2] (million of ha) | **128** | ***148*** |
| Protected area (million of ha) | ***22,6***[3] | ***8,8***[4] |
| Area under concession (million of ha) | ***22,1*** | ***22,1*** |
| Apart from management (million of ha) | ***X*** | ***17,5*** |
| Management under process (million of ha) | ***X*** | ***4,7*** |
| Management Plan agreed (million of ha) | ***x*** | ***0*** |
| Available Inventoried area (million of ha) | ***21***[5] | ***2,3***[6] |

2 *Including "Clear dry Forests", secondary forests and mangroves*

3 *Including protected areas located outside the dense forest massif*

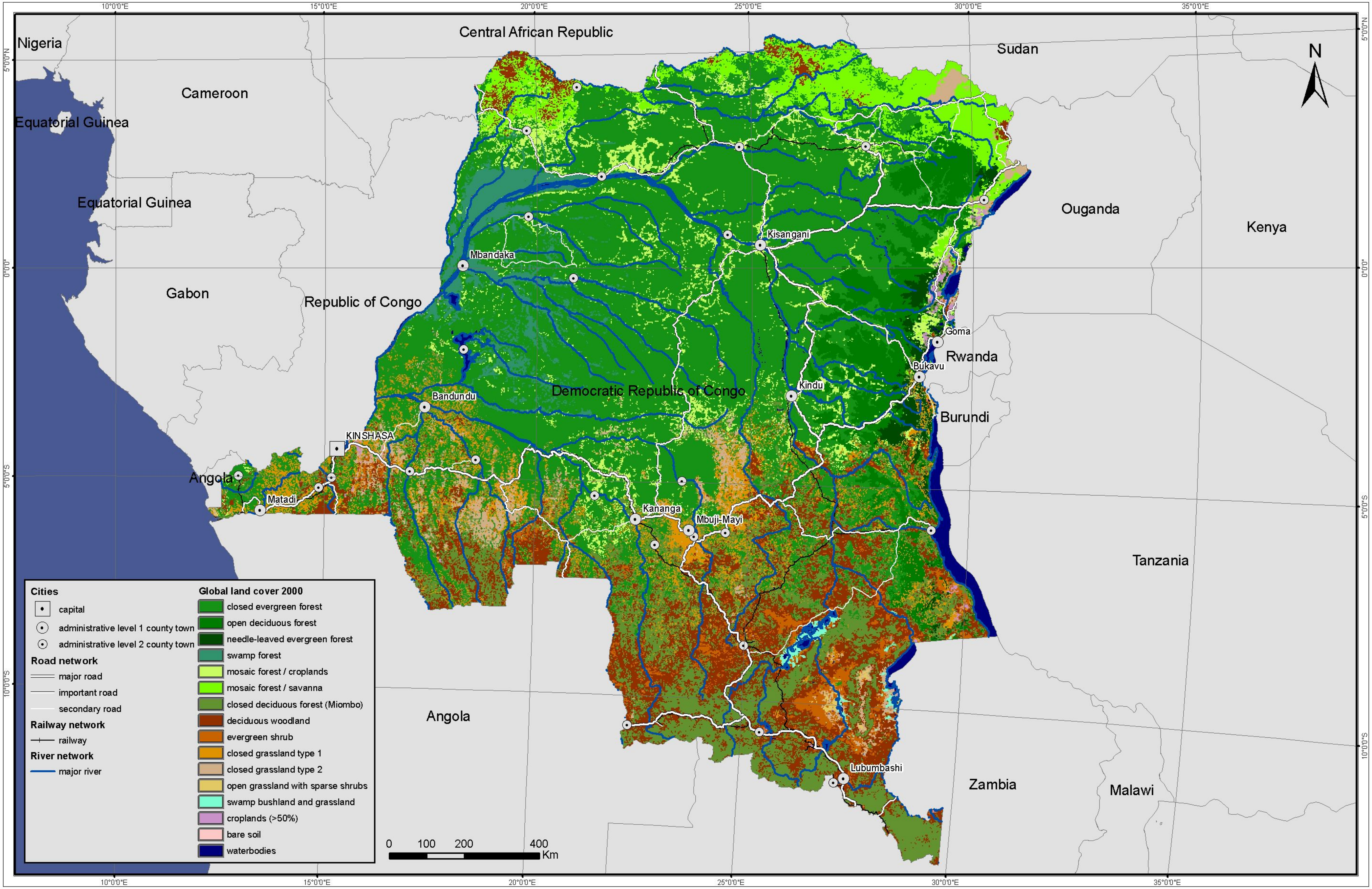
4 *This figure concerns only the protected areas in dense forest massif*

5 *National inventories and allocation inventories conducted by the SPIAF*

6 *Only management inventories*

# DEMOCRATIC REPUBLIC OF CONGO
# INFRASTRUCTURES AND LAND COVER

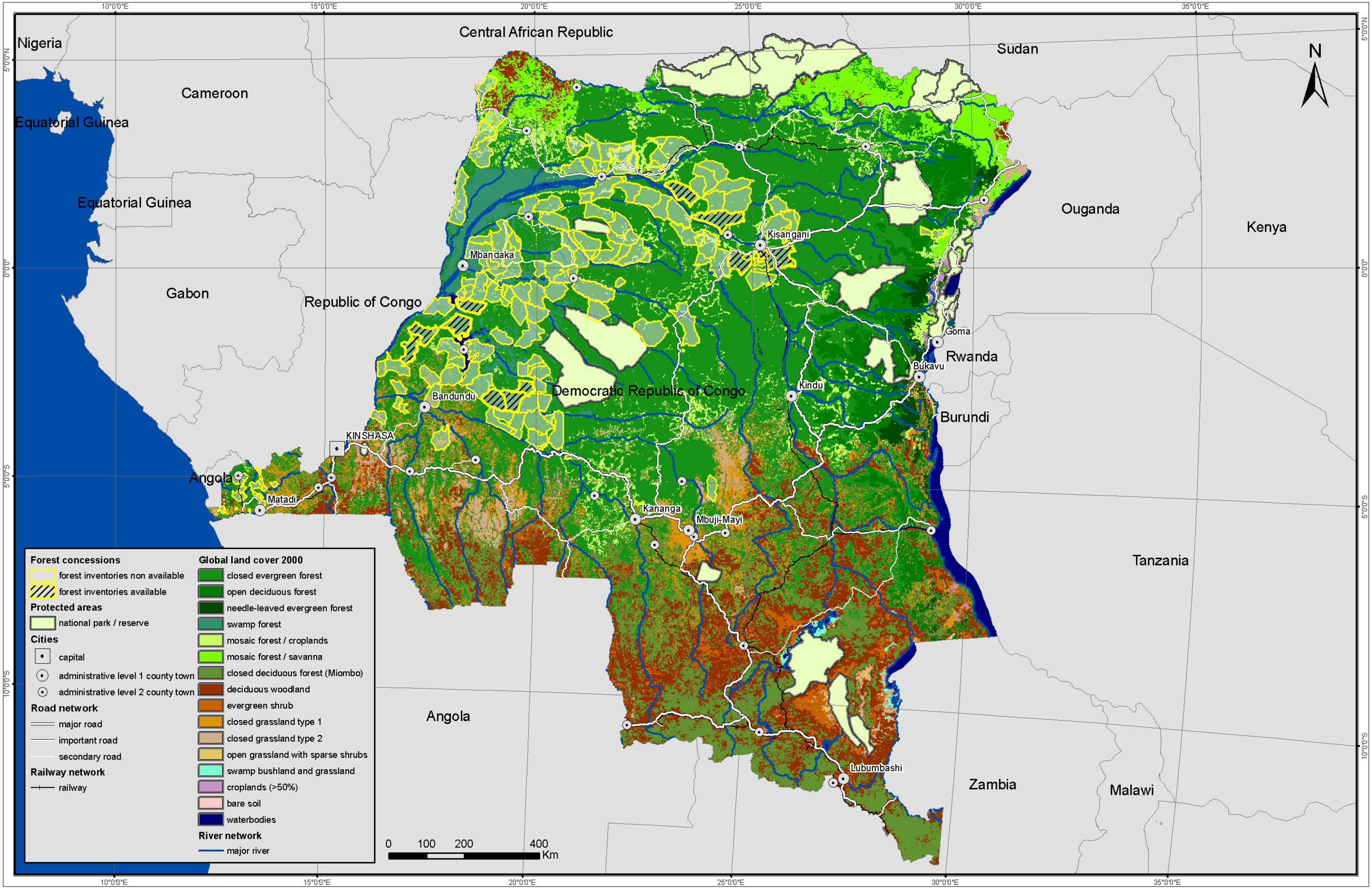
FORET RESSOURCES MANAGEMENT




*FRM, Montpellier, May 08*

# DEMOCRATIC REPUBLIC OF CONGO
# FOREST CONCESSIONS AND LAND COVER

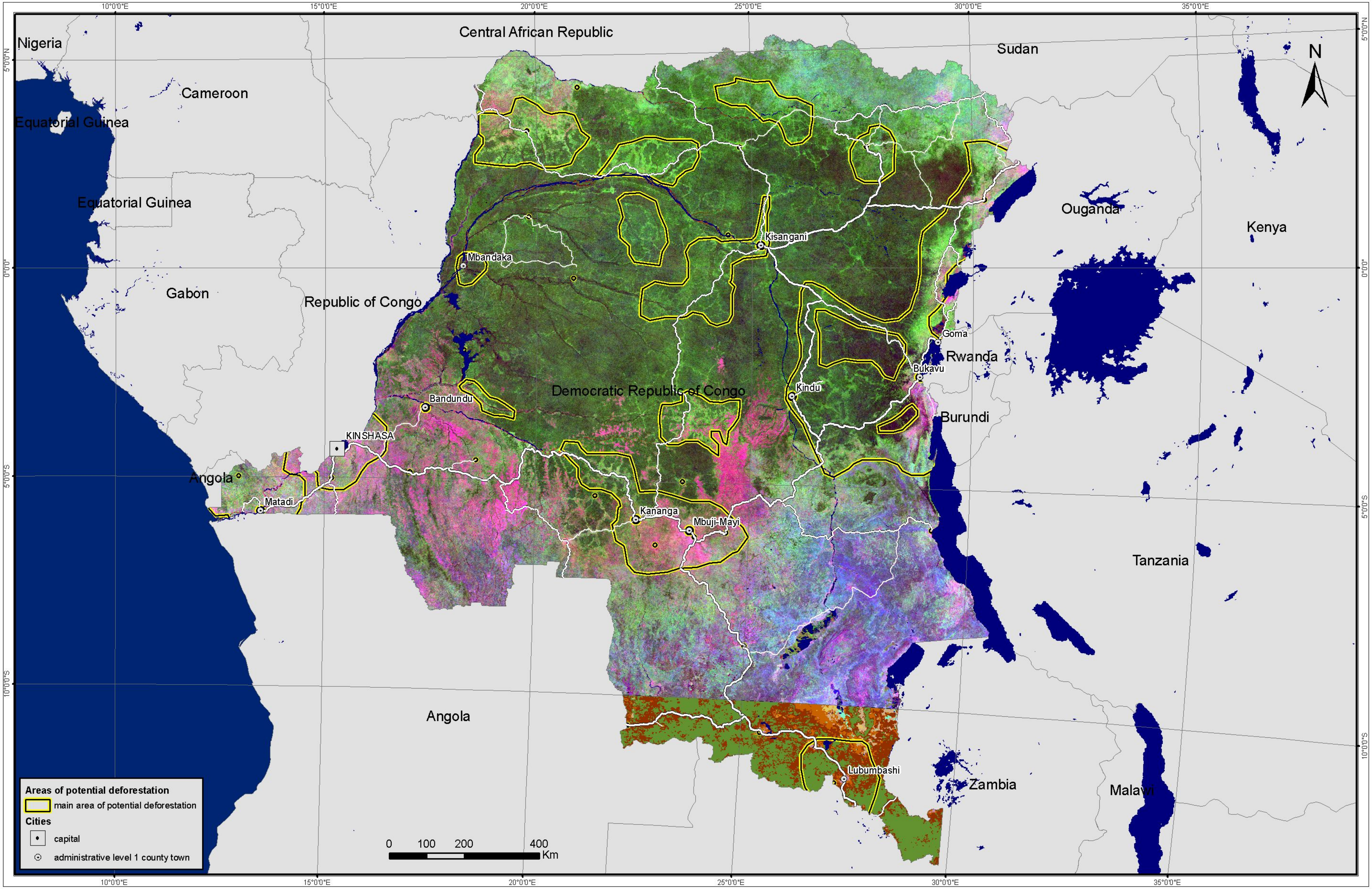
FORET RESSOURCES MANAGEMENT




*FRM, Montpellier, May 08*

DEMOCRATIC REPUBLIC OF CONGO
POTENTIAL AREAS OF DEFORESTATION
based on expert knowledge

FORET RESSOURCES MANAGEMENT




Cloud free composite image MODIS (1999-2002). Resolution: 500m. CARPE, University of Maryland. GLC2000 complement below 10°S

*FRM, Montpellier, May 08*

# 2 DEFINITIONS

**Deforestation**: change in land cover status from forest to non-forest, under human induced activity

**Forest degradation**: reduction of tree cover and forest biomass per hectare, via selective harvest, fuel wood cutting or other practices, but where the land still meets your country's definition of "forest" land

*Definition of forest land types and inclusion of vegetation formations are inspired by LETOUZEY (1969[7]).*

**Forest Land**: Land spanning more than 1 hectare (applicable range: 0.05ha up to 1 ha) with trees higher than 5 metres (applicable range: 2 to 5m) and a canopy cover of more than 10 percent (applicable range from 10 to 30%), or trees able to reach these thresholds in situ. Minimal surface considered is a 100m by 100m square. No Forest Definition was adopted by the country regarding the UNFCCC proposal.

*The Forest Land category is 100% included in the REDD issues.*

> **Dense Tropical Forest**: Forest of native species under tropical conditions where there are or not visible indications of human activities, included in the forest land. This class includes moist tropical forest.
>
> **Forest savannas**: Forest of native species mixed with herbaceous vegetation, included in the forest land definition. These class includes several land types, namely dry dense forest, open forest and tree savannas.

**Non forest savannas**: Herbaceous vegetation with some ligneous vegetation, excluded of the forest land definition. Including several land types, namely shrub savannas, bush savannas, herbaceous savannas and pasture land.

**Stratification**: statistic term for a grouping of homogenous types, applied in forest cartography to map the forest into different homogenous strata.

**Stratum**: homogenous class in statistics, used in forest cartography to identify an homogenous forest area.

*7 LETOUZEY, R., 1969. Manuel de Botanique Forestière – Afrique Tropicale – Tome 1. Centre Technique Forestier Tropical. 189p.*

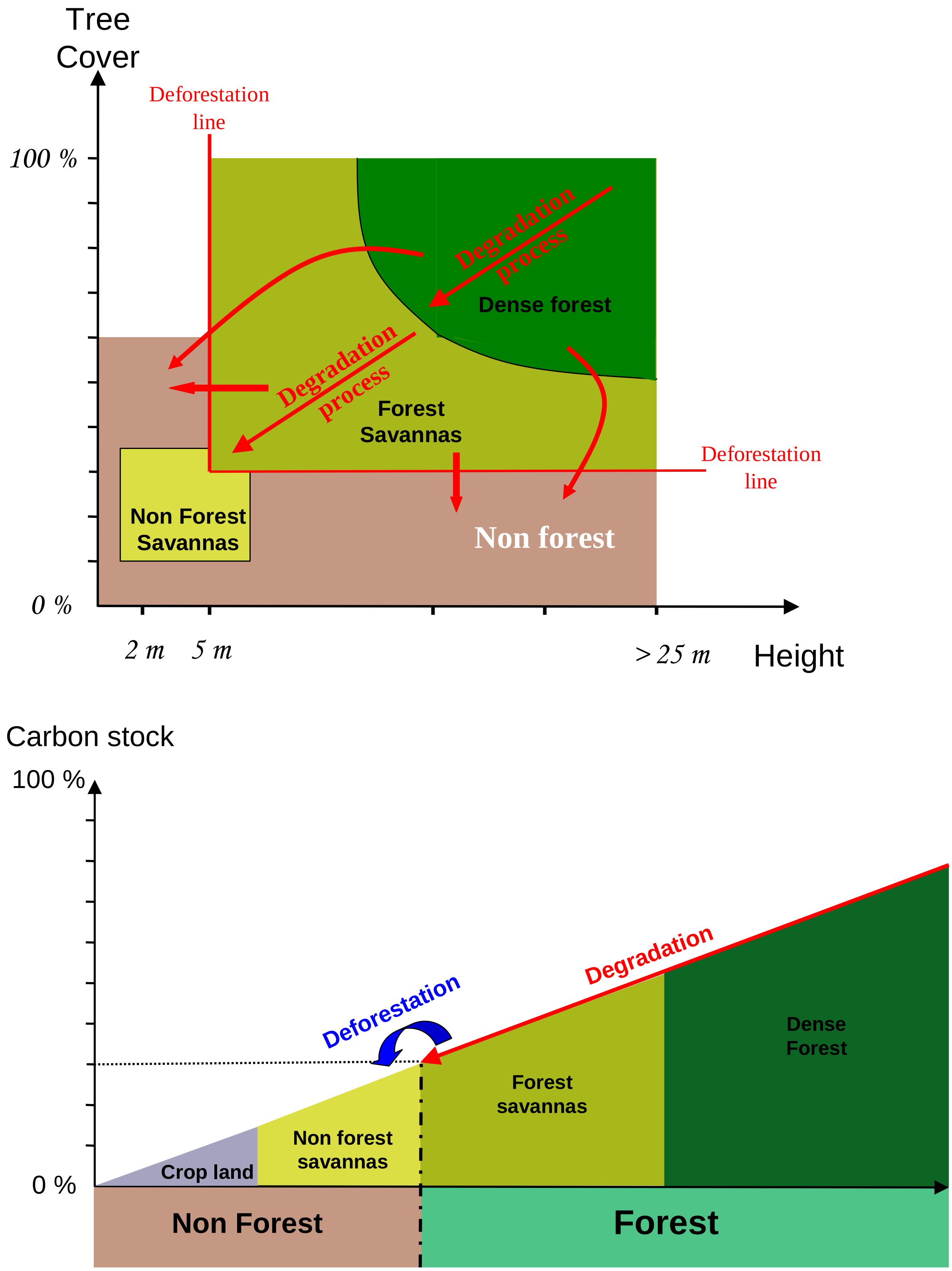



*Figure 1: Representation of Deforestation and Degradation, regarding tree cover and height*

# 3 METHODOLOGY

## 3.1 INTRODUCTION

Quantification of carbon stock from forest lands is based on a method combining a national scale work with local analysis to validate the results. Firstly, a wall-to-wall mapping of the national land use is done using Geographic Information Systems and remote sensing tools. This mapping uses IPCC strata as defined in their recommendations. These strata will be linked to carbon sink pools also defined by IPCC.

Estimations of biomass stock is calculated for each identified stratum: forestry science uses forest management inventories results to obtain Volume Over Bark, linked to each kind of forest. The treatment of these data combined with Wood Density and expansion factors (BEF, Biomass Expansion Factor, VEF, Volume Expansion Factor, Roots-to-shoot ratio…) are employed to estimate the stock of all biomass “pools” in forest areas.

Another method is suggested to quantify local biomass stock in areas where forest inventories results are not available. This method combines basal area of trees with volume by an allometric equation. This relation needs to be studied in depth for each identified stratum.
.
Once the volume of these areas has been obtained, Wood Density and expansion ratios are used to determine precisely the biomass stock. This method must be improved, but once it has been developed, it could prove quicker and cheaper than to conduct forest inventories.

Finally, surfaces of different strata combined with biomass stock of each stratum determine biomass at national scale.

## 3.2 METHODOLOGY STEPS

1. Selection and definition of the forest strata in accordance with IPCC standards and in functions of carbon storage variability,
2. Identification of the corresponding forest strata on maps,
3. Analysis of the available forest management inventory data for each forest stratum,
4. Quantification of the Volume over bark for each forest strata:
    - **a.** Based on the analysis of field inventory data when available,
    - **b.** Based on use of a quick appraisal field method (see part 4.3) when inventory data are not available (like in protected area, in concessions not involved in management process…),
5. Quantification of the entire Volume over bark,
6. Use of the different coefficients to estimate carbon storage of all the biomass pools.

## 3.3 GIS AND REMOTE SENSING MONITORING OF THE FOREST

To establish historical trends and monitor deforestation and forest degradation in the country, remote sensing and Geographical Information System (GIS) tools and methods are combined.

### 3.3.1 *Satellite data used*

Considering the significant surfaces areas that require monitoring and the high temporal resolution needed, our main source of information is remote data. In our process, data at three different resolutions is needed. To establish historical trends, medium resolution data is sufficient to do a global wall-to-wall analysis of deforestation. To monitor deforestation, medium and high resolution data can be used. To monitor degradation of the forest, high to very high resolution data is needed. It is not available as archives to establish an historical forest degradation trend.

The choice of remote sensing imagery source depends on usefulness, cost and availability to cover the country. The following data producers have been highlighted to establish historical trends and monitor deforestation (Table 2).

Future research to find very high resolution images covering the country will be led at a later stage to complete the table below, with data to be used to monitor degradation of the forest.

***Table 2: Remote sensing data useful to monitor deforestation and degradation of the forest***

| Satellite | Sensor | Resolution | Coverage | Cost |
|---|---|---|---|---|
| Landsat | TM and ETM+ | 30m | 180*180km | 600 US$ / scene |
| Terra | ASTER | 15m | 60*60km | 60 US$ / scene |
| Spot 5 | HRVIR / HRG | 5 to 20m | 60*60km | 2000 € / scene |

### 3.3.2 *Establishing historical trends*

Following JRC and UCL study[8] and GOFC-GOLD recommendations, historical trends will be established based on medium resolution imagery for the years 1990, 2000 and 2005. Existing results of a JRC and UCL study, already used by the FORAF Project, will be used if possible and, as necessary, improved using Landsat imagery. These results will be completed by coarse resolution imagery (Terra MODIS and Spot VGT) offering a daily temporal resolution, thereby easily providing complete cloud-free composite images.

[8] *MAYAUX, Ph., DEFOURNY, P., DUVEILLER, G., 2008. Deforestation and degradation estimates in the Congo Basin.* Presentation at REDD-COMIFAC meeting, Paris, march 2008.
*DUVEILLER and Al., 2008. Deforestation in Central Africa: Estimates at regional, national and landscape levels by advanced processing of systematically-distributed Landsat extracts.* Remote Sensing of Environment, article in press.

#### *3.3.3 Mapping land use and land use change and forestry (LULUCF)*

We will follow IPCC recommendations[9] and classify the land uses into six global strata: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. If possible, strata will be detailed into sub-strata (FRM can map up to a dozen sub-strata of dense forest).

#### *3.3.4 Monitoring deforestation*

Figure 2 illustrates the general process set up to monitor deforestation, based on GOFC-GOLD recommendations (2007)[10] and a French study of land use and land use changes in French Guiana[11].

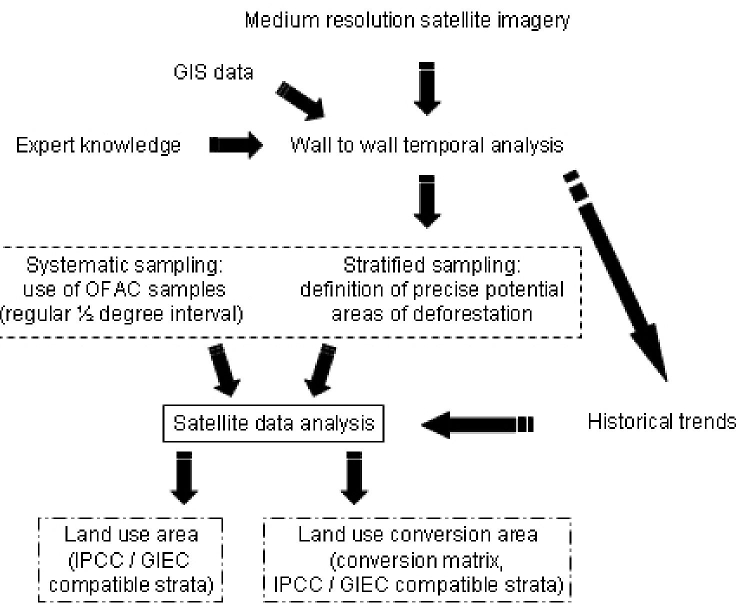



***Figure 2: Overview of the general process***

The satellite data analysis operation can be detailed into detailed steps, as described in the Figure 3 below.

[9] *International Panel On Climate Change, 2003. Good Practice Guidance for Land Use, Land Use Change and Forestery. Institute for Global Environmental Strategies, Japan.*

[10] *GOFC-GOLD, 2007. First draft of: Reducing Greenhouse Gas Emissions from Deforestation and Degradation in Developing Countries: A Sourcebook of Methods and Procedures for Monitoring, Measuring and Reporting. GOFC-GOLD Project Office, hosted by Natural Resources Canada, Alberta, Canada.*

[11] *STACH, N., 2008. Monitoring land use and land use changes in French Guiana by optical remote sensing.* Presentation of IFN, IRD, ONF, Cemagref and IGN.

*STACH, N., SALVADO, A., 2008. Suivi de l'occupation du sol et des changements d'occupation du sol en Guyane par télédétection satellitaire – rapport final.* Inventaire Forestier National, Bron.

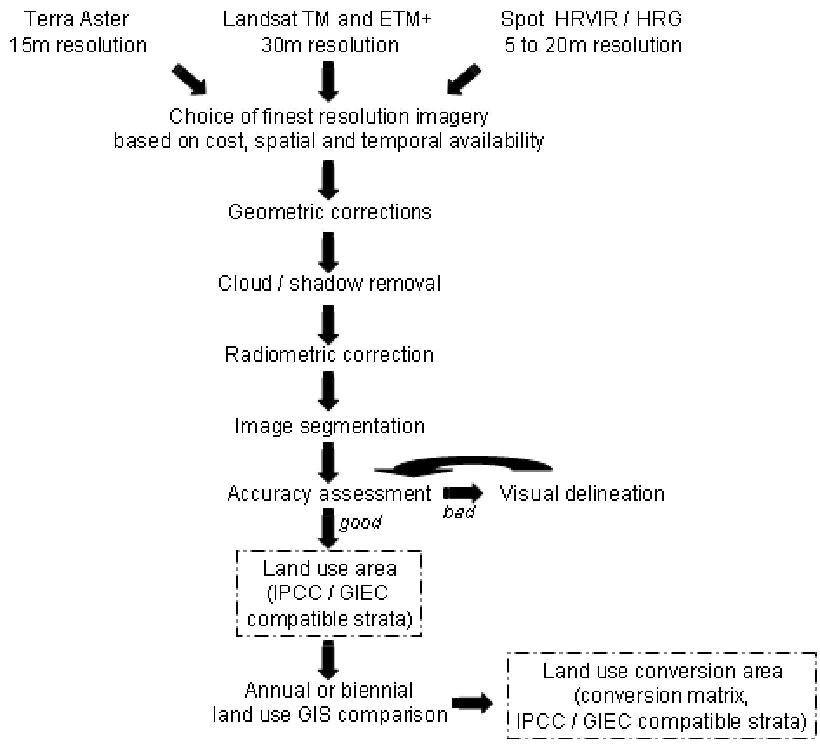



***Figure 3: Satellite data analysis process***

**Details on step 1: Selection of the satellite imagery format which will be used**

This selection, as described above, determines the feasibility of the study (cost, temporal resolution, spatial cover) and its level of precision (imagery resolution and minimum mapping unit).

Landsat imagery enables the continuous cover of the country for more than thirty years. Available, low cost, and pixel size are the main arguments for using it in the project. **Erreur ! Source du renvoi introuvable.** shows deforestation in Northern DRC at two dates: 1990 and 2001.

Terra Aster imagery, also enables the use fine resolution imagery at low cost,.
Spot imagery, more expensive, has been chosen for the data high resolution. Spot spatial cover of the country is not satisfactory yet, but a future reception ground station, based in Central Africa, may improve greatly the availability of some scenes.

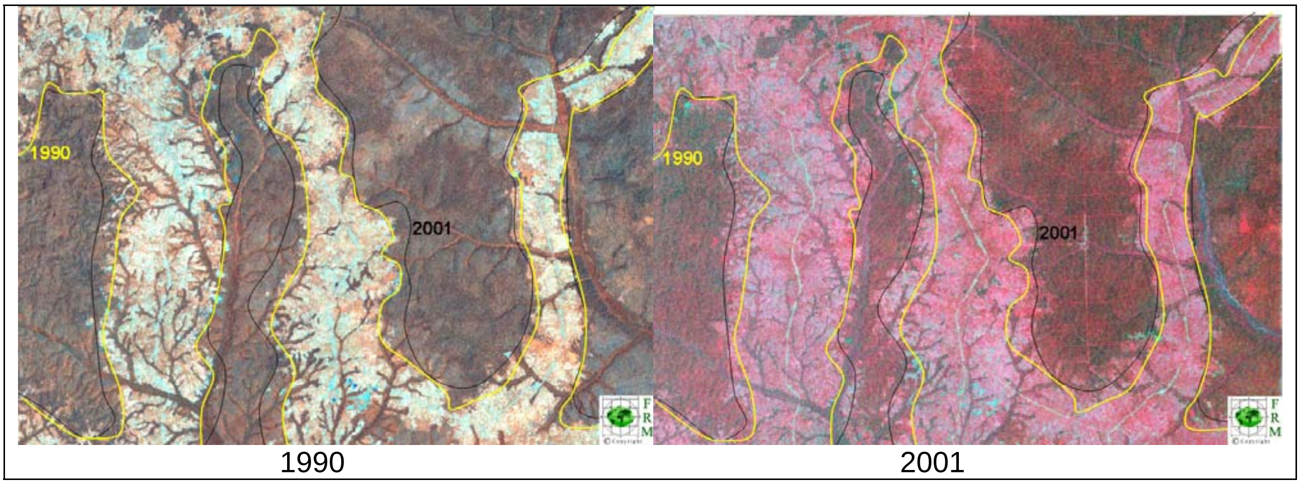



*Figure 4: Deforestation in Northern DRC*

**Details on step 3: Choice of areas to be monitored**

The sampling strategy chosen is a mixed approach of systematic and stratified sampling. Used with success in French Guiana, this methods offers the best of both sampling solutions, and is preferred to wall-to-wall analysis, more costly and more time consuming. The location of the stratified samples will be set after the wall-to-wall temporal analysis that will give the spatial and temporal trends for the past recent years. Sample size must be set; the sample size of OFAC's systematic sampling is already set at 20*20 km.

**Details on step 4: Selection of analysis methods**

Two methods give the best results to monitor deforestation.
**Visual delineation**: this first method has been used with success by FRM to identify a dozen of dense tropical forest strata over millions of hectares of tropical forest. Figure 5 : Extract of a FRM's land use map done using visual delineation
shows an extract of a land use map done at FRM, distinguishing 8 detailed forest strata. This method is time consuming and requires a good interpreter's expertise.

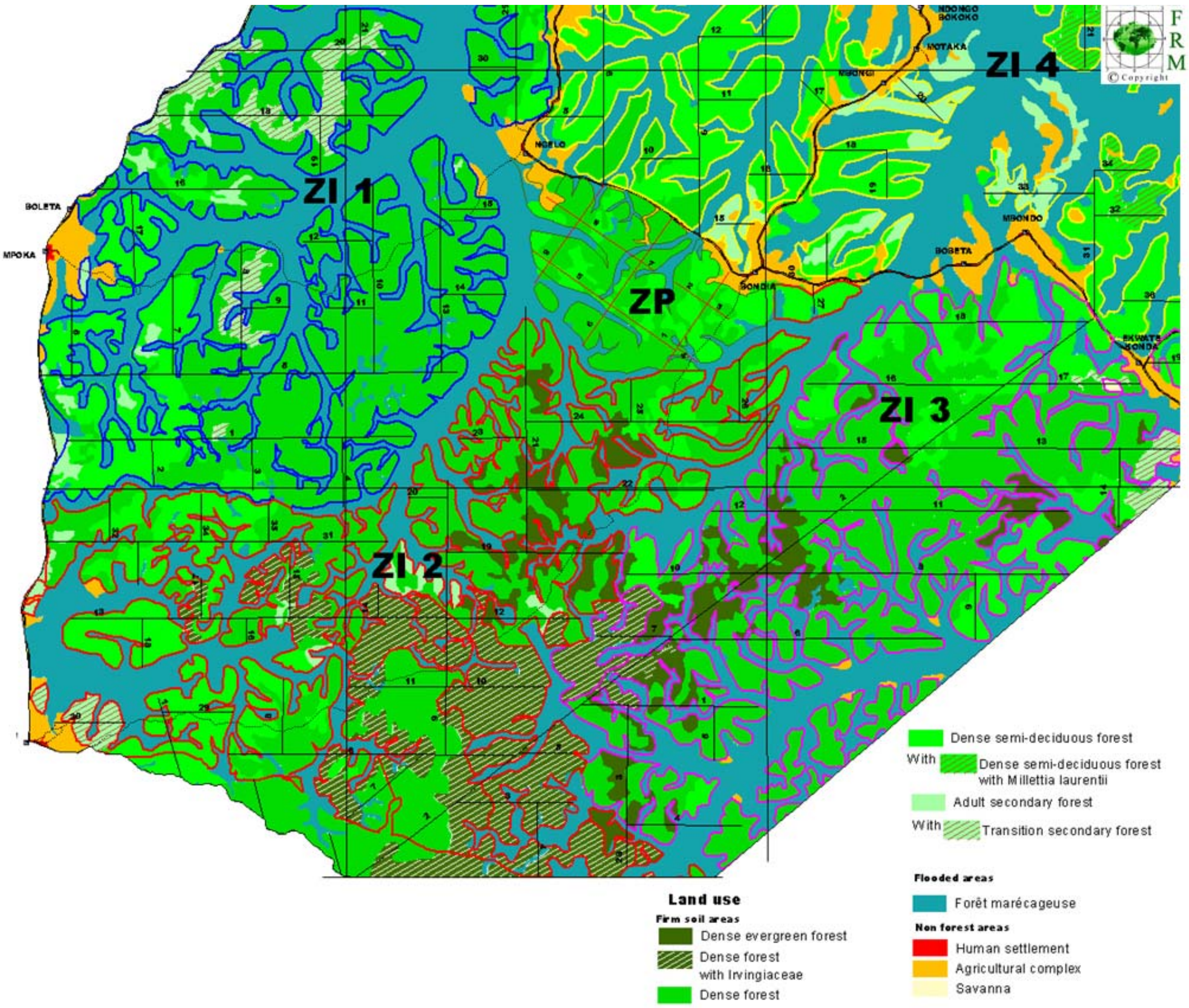



***Figure 5 : Extract of a FRM's land use map done using visual delineation***

- **Multi-date object based segmentation** groups similar and spatially adjacent pixels. It has been proven that this method is efficient to monitor deforestation. The method is less time consuming than visual delineation and is more objective.

If accuracy assessment of imagery segmentation shows good results during the training phase, this method would be applied to all sample images, and would be backed up by visual delineation when showing bad accuracy.

### *3.3.5 Monitoring degradation of the forest*

Monitoring degradation by the use of remote sensing is more challenging than monitoring deforestation. Working and collaborating with research units is required to achieve that monitoring (FRM works with a French research unit: Botany and computational plant). The work is based on advanced image processing algorithms, applied to very high resolution imagery. A database of forest inventories results is then used to calibrate, strengthen and validate the advanced image processing algorithms and ensure the quality of the degradation monitoring. The degradation can only be detected using these techniques beyond a certain threshold, linked to impact on the canopy. In the Congo Basin forests, the degradation with the most important impact on biomass and carbon stocks is due to extensive or illegal logging activities.

## 3.4 BIOMASS ASSESSMENT IN THE AFRICAN MOIST TROPICAL FOREST CONTEXT

This note presents the methodology to estimate biomass carbon stock in African tropical moist forests based on the results of forest field inventories. Biomass is understood as:

" all organic material both above-ground and below-ground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc…" (IPCC, 2003).

All the forestry biomass has been classified in 5 pools: Above-ground biomass (**AB**), Below-ground biomass (**BB**), Dead Wood (**DW**), Litter (**L**) and Soil Organic Content (**SOC**) The definition all the pools come from Good Practice Guidance for LULUCF (2003)[12] (see Table 3).

***Table 3: Definitions of the biomass' pools from Good Practice Guidance for LULUCF***

| Pool | | Description |
|---|---|---|
| **Living Biomass** | **AB**: Above-ground biomass | All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. |
| | **BB:** Below-ground biomass | All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter. |
| **Dead Organic Matter** | **DW:** Dead wood | Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country. |
| | **L:** Litter | Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. This includes the litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included in litter where they cannot be distinguished from it empirically. |
| **Soils** | **SOC:** Soil organic Content | Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically. |

[12] *Intergovernmental Panel on Climate Change, 2003. Good Practice Guidance for Land Use, Land Use Change and Forestry. Institute for Global Environmental Strategies.*

The different studies quantifying the carbon stock in tropical forest ecosystems have shown the importance of live vegetal biomass (both aboveground and underground biomass) and the soil as carbon pools. The values obtained from carbon stock from research by OHLER[13] (1980) and POELS[14] (1987) in Surinam are presented in Table 4 and Figure 6.

***Table 4: Comparative table between values from Ohler and Poels research in Surinam (tons/ha)***

| | **AB**: Aboveground Biomass | **L**: Litter | **DW**: Dead Wood | SOC: Soil Organic Content | **BB**: Belowground Biomass |
|---|---|---|---|---|---|
| Ohler (1980) | 449,9 | 12,2 | 22,67 | 129,2 | 65,3 |
| Poels (1987) | 472,1 | 13,2 | 24,9 | 172,7 | 108,5 |
| Mean value | 461 | 12,7 | 23,785 | 150,95 | 86,9 |
| % | 62% | 2% | 3% | 21% | 12% |

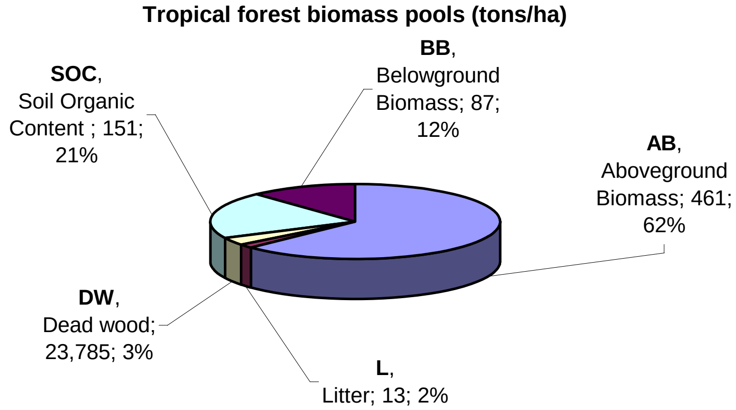



***Figure 6: Tropical forest stock of carbon pools (tons/ha) in Surinam, adapted from Ohler (1980) and Poels (1987)***

The results show that important pools of carbon stock are live vegetal biomass and soil that represent together 95 % of the carbon stocked in the tropical forest. The methodology proposed estimates carbon stock from Aboveground and Belowground Biomass (AB and BB) and Soil Organic Content (SOC) that suppose 95 % from the total of stock of Biomass. The pools from Dead Wood (DW) and Litter (L) are not included, supposing only 5 % of all the biomass stock and which studies to obtain data are hard and quite expensive.

[13] *OHLER, F.M.J.* Phytomass and mineral content in untouched forest. *CELOS report no. 132, Paramaribo, Suriname.*

[14] *POELS, R.L.H., 1987. Soils, water and Nutrients in a Forest Ecosystem in Surinam. Agricultural University Wageningen The Netherland: 249 p.*

Bibliographic work allows to put forward generic values of carbon stock from the Congo Basin area:

Cameroon: Primary forest, in a moist climate: 310 t/ ha

National values for: Democratic Republic of the Congo 279 t/ha (FAO, 2003),

#### *3.4.1 Biomass stock Assessment in moist tropical forests from Forest Management inventory results*

The carbon assessment method is outlined by the FAO Forestry Paper 134 (BROWN, 1997)[15] and relates field measurements of tree diameters (or volume) to forest carbon stocks using allometric relations. This estimation uses the volumetric data (VOB, volume over bark) from forest inventories that count all the trees, defined as:

*"stem volume of **all** living trees with more than 10 cm diameter at breast height (or above buttresses if these are higher), over bark measured from stump to top of bole, excluding branches" (FAO, 1998).*

Today, this quality data is only found in national inventories, research work and sustainable forest management field inventories counting all the trees species in a specific area. Only forest management inventories enable to know with extreme precision volume data over large area.s. Forest timber extraction inventories only focus on a few commercial species, they are not suitable to calculate VOB.

Based on forest inventory data, the method applies coefficients to estimate the carbon stock of all the pools composing the forest ecosystem. These coefficients and ratios are obtained from research studies and enable to quantify the different carbon stock pools. Starting with inventory results, ratios are applied to obtain each carbon pool stock, as showed in Figure 7.

[15] *BROWN S., 1997. Estimating Biomass and Biomass Change of Tropical Forest: a Primer. FAO Forestry Paper – 134 - http://www.fao.org/docrep/W4095E/W4095E00.htm*

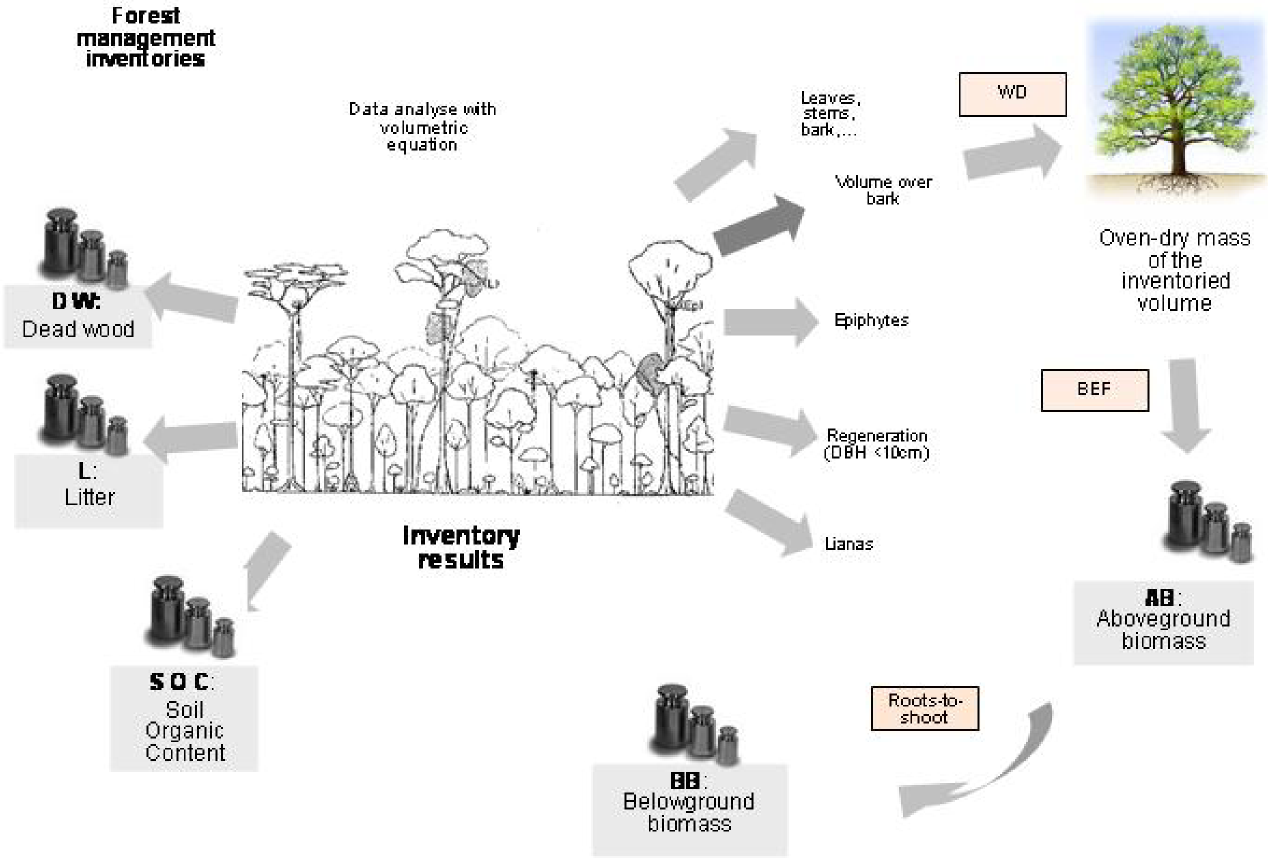



***Figure 7: Biomass stock assessment from forest management inventories IPCC's pools***

The benefits of this methodology is that it is accurate, databases are already accessible (see Table 1), generic methodologies and relations are avalaible and the most costly task –the field inventories- is already accomplished: in the Congo basin countries. Sustainable forest management plan field inventories have covered very large forest surface areas in recent years. Analysis of the inventory results shows the high heterogeneity of the Congo forests and provides up to date and abundant data to caracterise African tropical moist forests.

The limitation is that a generic relation is not appropriate for all regions: knowledge on African tropical forest ecosystems is steadily increasing with the recent of African tropical forest studies, but information is still sparse. Consequently, research's data do not allow to determine with precision the carbon stocks of African tropical forest (HOUGHTON ET AL.[16] 2001; EVA ET AL.[17], 2003; FEARNSIDE ET LAURANCE[18], 2003).

*16 HOUGHTON, R. A. 2000. Aboveground Forest Biomass and the Global Carbon Balance. In: Global Change Biology (2005). 11, pp. 945-958. http://www.whrc.org/resources/published_literature/pdf/HoughtonGCB.05.pdf*
*17 EVA, H.D., ACHARD, F., STIBIG, H.J., and al., 2003. Reponse to comment on "determination of deforestation rates of the world's humid tropical forests". Science, 299, 1015 b*
*18 FEARNSIDE PM, LAURANCE, WF., (2003) Comment on 'Determination of deforestation rates of the world's humid tropical forests'. Science, 299.*

After a first research period to define the parameters according to local conditions and determine the stock of forest and savanna biomass, the method of forest biomass stock assessment will be combined with satellite interpretation. This combination of tools can be used to quantify biomass stock at a national scale. This methodology analyses satellite images covering the entire territory and decomposes the national forest areas in strata, using image analysis tools (see part 3.3).

#### *3.4.1.1 Original Data: Forest inventory*

Different kinds of inventories results are available within the DRC territory. They differ according to:

- localisation,
- area covered,
- elaboration date,
- accuracy
- data measured (number of tree species, DBH minimum…).

A first type is constituted by national inventories, conducted since the 1970s.
These different national inventories are heterogeneous, regarding inventoried species lists, data processing… Consequently, the use of this first kind of field data is not suitable for a precise volume assessment.

A second type of field inventory are the inventories carried out in the framework of sustainable forest management projects, on 12 concessions in DRC and covering 1 850 000 hectares, (see Map 2). These different inventories will permit to estimate the volume over bark (inventoried volume), for each forest stratum. These field inventories for sustainable forest management complies with DRC's National Management Inventory Norms. It is a systematic and synthetic inventory based on experimental, rectangular and adjacent plots, laid along parallels transects.

These inventory transects are present in the different forest strata. All living trees above 10cm DBH, of any species are inventoried.

Volume Over Bark is defined by the FAO (1998) as the "*stem volume of all living trees with more than 10 cm diameter at breast height (or above buttresses if these are higher), over bark measured from stump to top of bole, excluding branches*".

These inventories are based on a survey rate ranging from 0.8% up to 1.2%. All plots are georeferenced thanks to GPS field points. The georeferencing enables the spatial analysis of all data issued from the field inventory for the sustainable forest management.

The processing of inventory data for each forest stratum will help the specific characterisation of the different forest strata according to, for example:

- Density by species and diameter class,

- Basal area by species and diameter class,
- Volume over bark by species and diameter class,
- Density and volume relative errors,
- Structural histograms, representing the density distribution according to diameter class,
- Distribution maps of different parameters (density, volume, basal area…) for each species.

To illustrate this R-PIN, the table below provides examples of results obtained by FRM in such inventories in 7 concessions in DRC, showing the significant differences existing between forest territories in terms of Volume over bark and consequently in terms of carbon stock.

***Table 5: Dendrometric characteristics (trees with DBH > 10 cm) obtained by FRM on 7 concessions***

| Concession number | Density (trees/ha) | Basal Area ($m^2$/ha) | Volume (m3/ha) | Surface Area (ha) | Total Volume (m3) |
|---|---|---|---|---|---|
| 1 | 282 | 18.8 | 183 | 168 000 | 30 744 000 |
| 2 | 240 | 15.3 | 140 | 115 000 | 16 100 000 |
| 3 | 348 | 19.5 | 179 | 122 000 | 21 838 000 |
| 4 | 314 | 21 | 204 | 170 000 | 34 680 000 |
| 5 | 360 | 19.4 | 177 | 111 000 | 19 647 000 |
| 6 | 248 | 15.4 | 141 | 65 000 | 9 165 000 |
| 7 | 297 | 21 | 204 | 94 000 | 19 176 000 |
| **Total** | | | | **845 000** | **151 350 000** |

In each case, statistics studies permitted the evaluation of volume accuracy:

***Table 6: Accuracy of volume computations for a forest concession***

| Forest type | Area (ha) | Volume (m3/ha) | Coefficient of variation (%) | Standard error (%) |
|---|---|---|---|---|
| Eastern Province concession | 168 000 | 282 | 24 | 0.8 |
| Bandundu Province concession | 115 000 | 240 | 33 | 1.3 |

Transition between density and volume is permitted by volume tables. Volume tables with one entry can be defined as a relation between diameter and volume

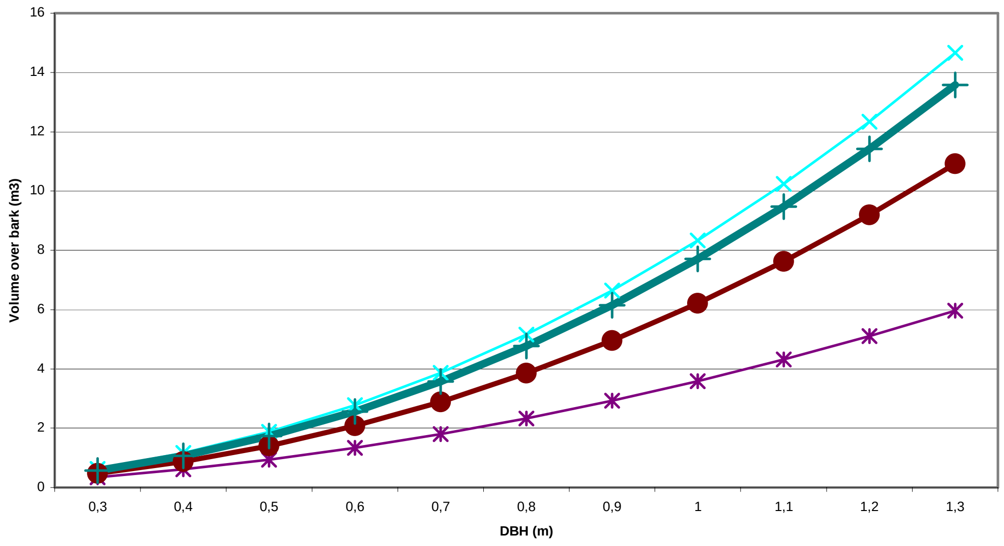



***Figure 8 : Wenge volume tables constructed from dendrometric studies in different concessions***

Some national volume tables by species issued from diverse studies and research projects are available. These general equations are completed with specific and precise volume tables elaborated during field studies, which are carried out when preparing each sustainable forest management plan.

As we can see in the above table, volume tables are variable within the DRC's forest. This type of specific volume table is suitable for a precise estimation of the Volume over bark.

Some complementary studies would be necessary in order to improve volume tables:

- Construction of volume tables with two entries: diameter and height,
- Construction of specific volume tables for each forest stratum.

For the estimation of the carbon stocks present in each forest stratum, it is crucial to characterize each parameter, and particularly the Volume over bark, in accordance with the forest stratum considered.

This characterization should be calibrated during methodological consolidation.
To illustrate the potential variability of volume, density and basal area within DRC territory (and therefore in different forest strata), a short study was carried out within two forest concessions in DRC.

The two histograms presented below illustrate the potential variability between different forests within DRC territory.

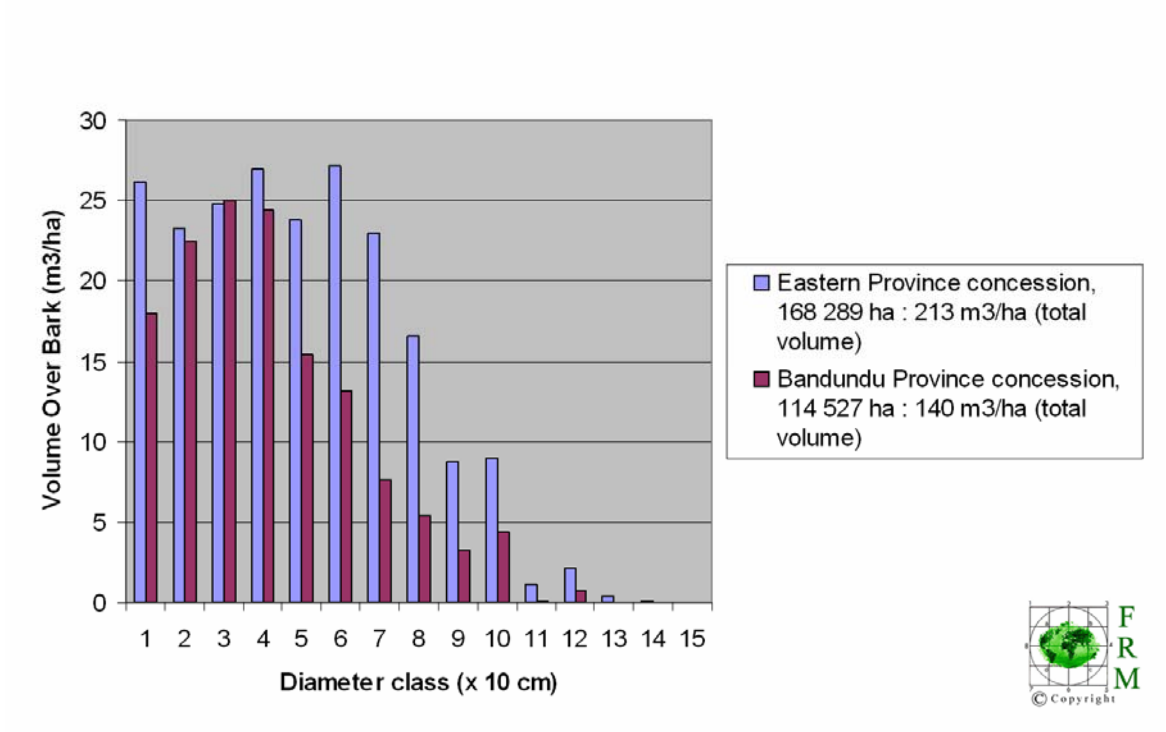



*Figure 9: Volume Over Bark per ha according to diameter classes*

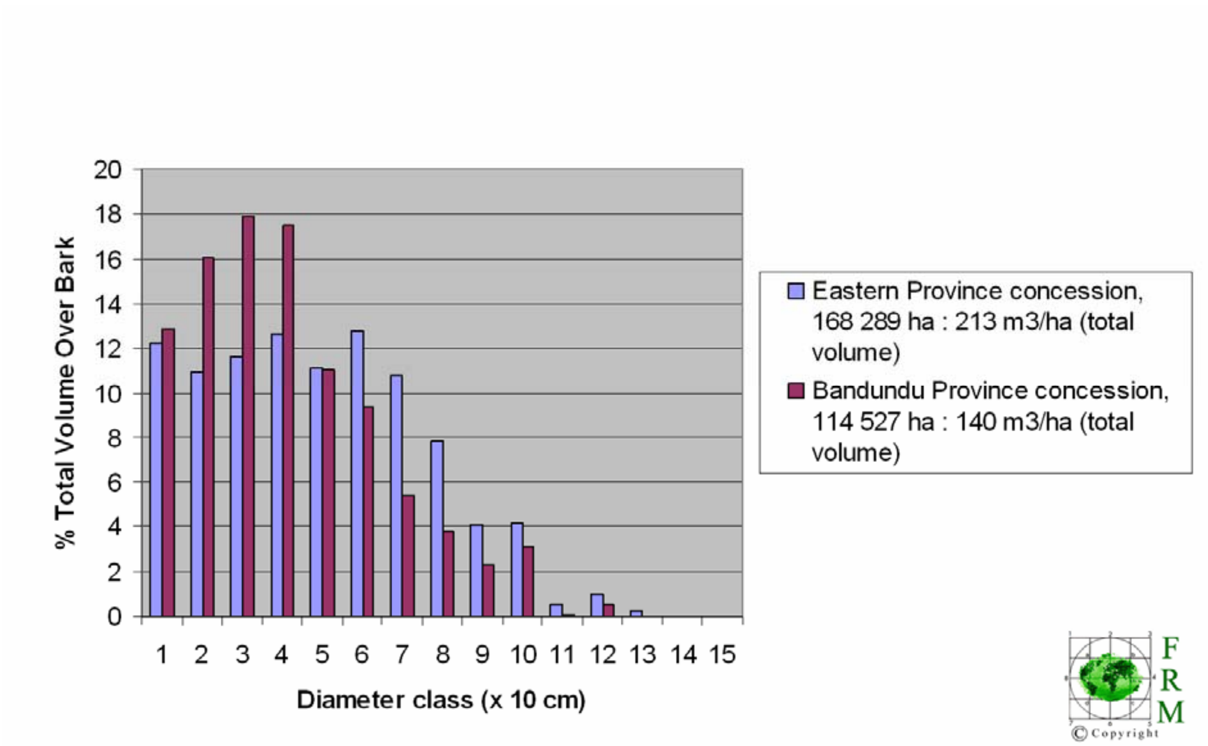



*Figure 10: Percentage of Volume Over Bark according to diameter classes*

To illustrate this variability with a spatial point of view, the mapped distribution of the total basal area is presented in the next illustration.

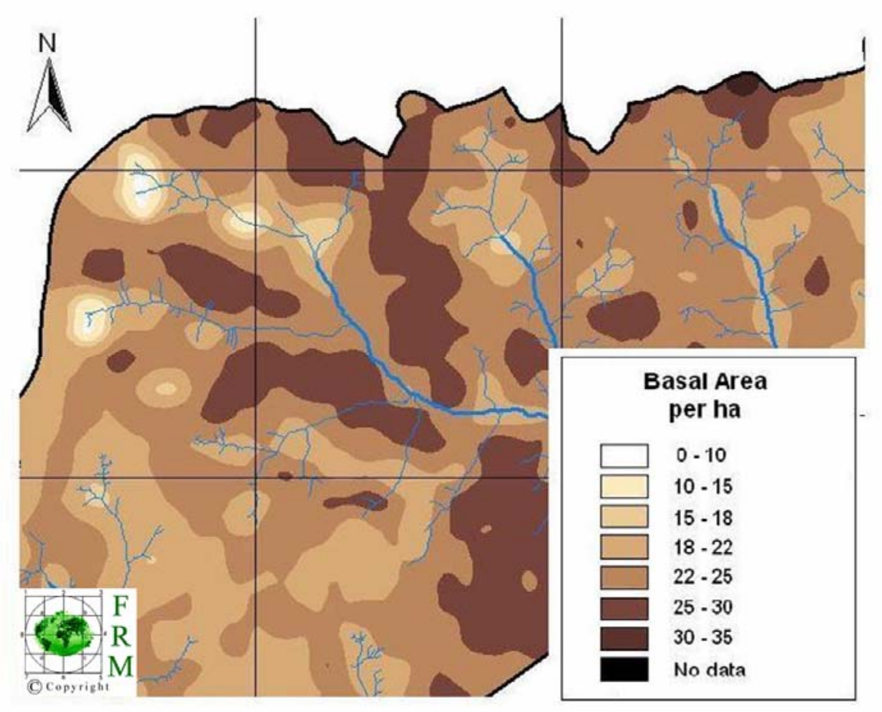



***Figure 11: Example of basal area distribution on a forestry concession in Congo Bassin***

These figures are some examples of all the different uses which can be made of the field data and an evidence of the necessity when working on forest to focus on a stratum-based approach.

#### *3.4.1.2 General Equation*

Taking VOB as “initial” data, biomass density can be calculated knowing the biomass of the inventoried volume and expanding this value using ratios to estimate other pools (BROWN AND LUGO, 1992)[19]

Biomass density (t/ha) = VOB * WD * BEF (1+r) * (VEF[20])

with

WD: Volume-weighted average wood density (oven-dry biomass per $m^3$ of green volume)

BEF: Biomass expansion factor (ratio of above-ground oven-dry biomass of trees to oven-dry biomass of inventoried volume)

r: Root-to-shoot ratio to estimate underground biomass density from above-ground biomass density

VEF: Volume expansion factor (ratio to harmonise the inventory results)

*19 BROWN S. and LUGO A.E.,1992. Aboveground biomass estimates for tropical moist forests of the brazilian amazon. Interciencia vol 17 n°1: 8 -18p.*

*20 The presence of this factor in the equation is based on the inventory methodology, see above*

#### *3.4.1.3 original data and corrective ratio*

***VOB (VolumeOver Bark ($m^3$/ha)***

The forest management inventories establish a methodology counting all trees above 10 or 20 cm DBH (Diameter Breast Height (1,30 m)) and estimate VOB from one entry equations (DBH) based on forest measurements and dendrometric studies results (see Map 2). This produces concrete and precise results from local forest state and specific volume tables established for regional conditions.

To calculate national carbon stock, the literature ((GARZUGLIA M. and SAKET M.[21], 2003) established a general value of VOB of 231 $m^3$/ha for the Democratic Congo Republic.

#### *3.4.1.4 WD (Wood density ; t/ $m^3$)*

Wood density is defined as the "*oven-dry mass per unit of green volume*" (tons/m3).

REYES ET AL.[22](1992) estimated an « average » of WD for tropical tree species by region. For the tropical Africa, they obtained a mean of 0,58 t/$m^3$ (between 0,50 and 0,79) from a sample of 282 species. African Wood Density data employed by FAO (1997) is 0,56 t/$m^3$ (between 0,50 and 0,79). The deviation from Reyes' value is minimal (< 4%).

In some cases (in Africa it is quite common), Wood Density is expressed in units of mass at 12% moisture content per unit of volume. A regression equation enables to convert wood density based on 12 % moisture content to wood density based on oven-dry mass and green volume (REYES ET AL.;1992):

$WD = 0.0134 + 0.800\ WD_{12\%}$

with 379 samples ($r^2$= 0,99)

WD: Oven-dry mass per unit of green volume (tons/$m^3$)
$WD_{12\%}$: 12% moisture content mass per unit of green volume (tons/$m^3$)

CHAVE AND AL[23]. (2005) have developed a pan-tropical model, invalidating the old model:
$WD = 0.872\ WD_{12\%}$

with 1893 samples ($r^2$ =0.983)

[21] *GARZUGLIA M. and SAKET M., 2003.* Wood volume and Woody Biomass: Review of FRA 2000 Estimates. *Working paper n° 68, Rome, 2003.* http://www.fao.org/docrep/007/ae153e/AE153e00.HTM

[22] *REYES, G., S. BROWN, J. CHAPMAN, AND A. E. LUGO, 1992. Wood densities of tropical tree species. USDA Forest Service, General Technical Report SO-88, Southern Forest Experiment Station, New Orleans, Louisiana, USA.*

[23] *CHAVE J, ANDALO C, BROWN S, CAIRNS MA, CHAMBERS JQ, ET AL. (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests.* Oecologia *145: 87–99*

As the proposed methodology identifies different forest strata, each kind of forest has a typical tree composition, with a particular WD. That will enable to estimate a more performing WD from each scenario using the equation (BROWN, 1997).

$WD_t = [(V_1/V_t) * WD_1 + (V_2/V_t) * WD_2 + \ldots + (V_n/V_t) * WD_n]$

with:
$WD_1$: Wood Density of species 1
$WD_t$: Total Wood Density
$V_1$: Volume of species 1
$V_t$: Total volume

The detailed inventory work and wood properties databases will enable to create a specific WD for each kind of forest according to structure and composition.

For example, three types of forest have been analysed using data from FRM management inventories for the preparation of this R-PIN: an Okoume (*Aucoumea klaineana P.*) forest, a North Congo moist tropical forest and a Limbali (*Gilbertiodendron dewevrei J.L.*) forest. The knowledge of the physical properties of wood allows to define a Wood Density which is specific to each type of forest. To estimate this WD, the existent data from wood density (12 % moisture) (ATIBT, 1986)[24] from all the known species has been used and has been converted to oven-dry wood density using the equation of CHAVE AND AL. (2005). The estimation has been done with species representing 90 % of total VOB present in each of the studied forests. The remaining 10 % has been obtained by an extrapolation of the results obtained. For the unknown densities, a standard African wood oven-dry density (0,56 $t/m^3$) used by FAO (1997) has been employed. This example shows the variability of values that WD can represent in the estimation of a biomass stock.

***Table 7:Biomass density regarding forest types***

| Type of forest | Density ($ton/m^3$) | Variation from FAO mean (0,56 $t/m^3$) |
|---|---|---|
| Closed moist forest | 0,62 | + 9 % |
| Limbali forest | 0,66 | - 14% |

***BEF (Biomass Expansion Factor): total Biomass / Commercial Biomass***

The BEF is defined as

« *the ratio of total aboveground oven-dry biomass density of trees with a minimum DBH of 10 cm or more to the oven-dry biomass density of the inventoried volume*”.

The used ratios have been calculated from sources from a large selection of forest types (from moist to seasonally dry climates) in the inter-tropical area. The volume of data used allows to calculate

[24] *ATIBT, 1986.* Atlas des bois tropicaux. Tome 1 – Afrique. *ATIBT. Paris, p. 208*

independently the above-ground biomass density and biomass of the inventoried volume (BROWN ET AL. 1989)[25].

The value of BEF is strongly related to the biomass of the inventoried volume according to the following equations (BROWN AND LUGO, 1992)[26]

BEF = Exp [3,213 – 0,506 * Ln (BV)]     if BD = VOB * WD < 190 t /ha

BEF = 1,74     if BD = VOB * WD >= 190 t /ha

with

WD: Volume-weighted average wood density (oven-dry biomass per $m^3$ of green volume);

VOB: Volume Over Bark, ($m^3$/ha);

BEF: Biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of inventoried volume)

with sample size = 56 , adjusted $r^2$ = 0,76

These values, proposed as reference in FAO Paper, are not far away from the value used by the IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (1,5, mean between limits from 1,3 to 1,7. These values have been accepted in the different studies presented in the Workshop on Reducing Emissions from Developing Countries on August-September 2006 in Rome by Sandra Brown.

In the Amazone forest, BEF values range from 1,65 to 1,53, with 1,58 as a mean value. No specific study or data applied to African forests has been done, so studies fixing country values are absolutely recommended to determine this value with more precision based on local conditions. The value range found in the literature for tropical forest is between 1,1 and 2,5 (BROWN AND LUGO 1992; BROWN 1997; in FORDA and JICA[27],2005).

A useful study to be carried out would allow developing specific BEF in the relation with each forest strata, correlating the above-ground biomass expansion factor according to the structure of the forest. As we can observe in the literature on general forest (DAWKINS[28], 1963; HEINSDIJK[29], 1957-58;

[25] *BROWN S., GILLESPSIE A. and LUGO A. E., 1989. Biomass estimation Methods for Tropical Forest with Applications to Forest Inventory Data.* For. Sci. *35 (4): 881-902 p.*

[26] *BROWN S. and LUGO A.E.,1992. Aboveground biomass estimates for tropical moist forests of the brazilian amazon.* Interciencia *vol 17 n°1: 8 -18p.*

*27 FORDA & JICA, 2005.* Manual of Biomass Survey and Analysis http://project.jica.go.jp/indonesia/0065045I0/archives/pdf/manual_miomass.pdf

*28 DAWKINS H.C., 1963. Crown diameters: their relation to bole diameters in tropical foret trees – Commonwealth Forestry Revue, 42 (114), pp. 318 - 333*

*29 HEINSDIJK D., 1957/1958. The upper story of tropical forest. Tropical Wood, 1957, 107, pp. 66 – 84; 1958, 108, pp.31 - 45*

Paijmans30, 1951; …) the structure and importance of the biomass is strongly correlated with Diameter Classes distribution and the presence of “emerging” and dominant trees. As already seen in Forestry Inventories analyses treated above, relationship between Diametric Class distribution and biomass stock will enable to obtain more accurate results. This goal could be obtained by new research works

***VEF (Volume Expansion Factor)***

This factor is defined as

*“ratio of inventoried volume for all trees with a minimum diameter (DBH) of 10 cm and above to inventoried volume for all trees with a minimum diameter of 25-30 cm and above”* (FAO, 1997).

Forest inventories methodologies are not an international standardised work, therefore they provide volume data from a minimal Diameter Class that can change from one area to another. A method to standardise inventory results has been developed by Brown in 1990, based on inventories carried in tropical Asia and America. This method is used to adapt inventory results when diameters are above 10 cm DBH to **VOB,** which is volume for trees including the 10 cm diameter class )

For VOB with minimum DBH over 30 cm, the equation is:

VEF = Exp [1,300- 0,209 * Ln (VOB $_{30}$)] for $VOB_{30} < 250\ m^3/ha$

VEF = 1,13 for VOB $_{30} > 250 m^3/ha$

Estimations from minimum DBH over 30 cm is not recommended, the correction coefficient cannot be applied with accuracy and obtained results carry a high relative rate of error (BROWN[31], 1990).

#### *3.4.1.5 Estimation of biomass stock of others pools in tropical forests*

The forest ecosystem biomass is composed of more elements than the aerial part of the trees: twigs, stumps and roots for all trees alive and dead as well as all shrubs and bushes on the forest. The biomass pools are:

- epigean biomass, including:
  - biomass from trees and palms with less than 10 cm DBH;

*30 PAIJMANS K., 1951. Een voordbeeld van intertepratie van Luchtfoto’s van oerwoud: Het Malili – complex op Celebes. Indonesia Tectona, 41, pp. 111-135*

*31 BROWN, S., 1990. Volume expansion factors for tropical forests. Unpublished Paper, Prepared for the Forest resource Assessment-1990 Project (available from author).*

- biomass from lianes;
- biomass from epiphyts.

- epigean dead biomass (necromass): litter and dead wood;
- hypogean biomass, composed by organic material degradated in the soil and the roots.

Studies from African tropical moist forest ecosystem are inexistent, so the literature about this subject has to refer to another tropical forestal areas from where biogeographic parameters and forest growing are not equal but allow to establish a first approach waiting for research results that will provide data and specific ratio and coefficient to adapt the biomass' estimations to local context. The bibliography is quite abundant in Amazonian moist forest. Even if a lot of characteristics are similar between the African and Amazonian tropical rain forests, the south America forest has a more open underwood and a low density of big trees and trees with "contreforts". The higher abundance of palm trees in wet areas in Amazonia is also to remark.

#### *3.4.1.6 Biomass from trees and palms with less than 10 cm DBH;*

Almost all the studies already done in the area don't focus on the biomass' estimation, being more specific in only one area of the underwood. The reference case used as exemple is the study of PUIG AND AL[32]. (1990), focused on Guyane tropical forest.

The quantity of biomass from this pool is 2,7% of all epygean biomass; 2,3% correspondes with trees with less than 10 cm of DBH and 0,4% from regeneration of less than 1 cm of DBH and palm trees. Another study done in Brasil (NASCIMENTO AND AL.[33], 2000) estimated the underbrush volume and found higher values: 5,6% of the biomass is represented by all epygean biomass; of which 5,3% are trees with under 10 cm of DBH and 0,3% are from regeneration under 1 cm of DBH and palm trees.

#### *3.4.1.7 Biomass from lianas (creepers)*

African forests don't have any special study that determines the biomass stock of this pool. Approaching by paralelism, we can take reference from the Amazon forest. The studies of the creepers in Venezuelan tropical moist forest by PUTZ[34] (1983) and LAURENCE[35] (1997 and 1999)

---

[32] *PUIG H., RIERA B. & LESCURE J.P., 1990. Phytomasse et productivité.* Bois et Forêts des Tropiques *n° 220. Spécial Guyane: 25-32 p.*

[33] *NASCIMENTO H.E.M. and LAURENCE W.F., 2001. Total aboveground biomass in central Amazonian rainforests: a landscape-scale study.* Forest Ecology and Management. *5793, pp. 1-11*

[34] *PUTZ, F.E., 1983. Liana biomass and leaf area of a « Terra firme » forest in the Rio Negro bassin, Venezuela.* Biotropica. *15: pp. 185-189*

[35] *LAURANCE W., FEARNSIDE P.M., LAURENCE S.G., DELAMONICA P.? LOVEJOY T.E. RANKIN-DE-MERONA J.M., CHAMBERS J.Q., GASCON C., 1999. Relationship between soils and Amazon forest biomass: a landscape-scape study.* Forest Ecology and Management. *118, pp. 127 - 138*

estimates this pool represents less than 2% of the total epygean biomass and around 4,5% of the total biomass production.

#### *3.4.1.8 Biomass from epiphytes*

Epiphytes grow attached to the trunks and branches of trees and other plants, some even on the surface of living leaves. In closed rain forests the majority of the epiphytes grow high above the ground where relatively strong illumination compensates for lack of soil and the precarious water supply. The mode of life of epiphytes is highly specialized.

Studies of epiphyts biomass are already done in South America: two studies in French Guyana (PUIG ET AL., 1990)[36] and BORDEVAL[37] (1996), one in Costa Rica (NADKAMI, 1984)[38] and one in Panama. The percentage from total forest biomass is around 0,3% (0,98 ton/ha) for the study of PUIG ET AL.(1990). Other studies (FITKAU and KLINGE[39],1973) give 100 ton/ha. We can affirm that epiphyts' biomass is not really important in the estimation of biomass stock.

### *3.4.2 Hypogean biomass or Belowground Biomass (BB)*

#### *3.4.2.1 Roots: Roots-to-shoot ratio*

This factor allows to estimate biomass of root system from Above-ground Biomass. The root systems of tropical trees are very varied and they have not received a lot of studies (RICHARDS, 1952)[40]. It is not an exaggeration to say that "of the majority of tropical trees the root system is entirely unknown" (JENIK, 1978)[41]. It is a quite "variable" value and recent studies in tropical forest show that ratio between roots biomass and aboveground biomass varies between 4% and 230% (BROWN, 1997)

Nowadays, two methods are proposed to calculate the biomass stock from the roots, regression equations allow to estimate the above and below ground biomass from measurements of stem

---

[36] *PUIG H., RIERA B. & LESCURE J.P., 1990. Phytomasse et productivité.* Bois et Forêts des Tropiques *n° 220. Spécial Guyane: 25-32 p.*

[37] *BORDEVAL, B., 1996. Mesures de la diversité spécifique des plantes vasculaires en forêt sempervirente de Guyane, thèse. Museum d'Histoire Naturelle: 53p.*

[38] *NADKAMI, N.M., 1984. Ephiphyte Biomass and nutrient capital of a neotropical elfin forest,* Biotropica*. n° 16: 249 – 256 p.*

[39] *FITTKAU, E.J., KLINGE, H., 1973. On biomass and trophic structure of the Central Amazonian Rain forest ecosystem.* Biotropica *5, pp. 2 - 14*

[40] *RICHARDS,P.W., 1952.* The tropical rain forest: an ecological study. *Cambridge university Press, Cambridge. p.575*

[41] *JENIK,J., 1978. Roots and root system in tropical trees: morphologic and ecologic aspects. Ch. 14 in* Tropical Trees As Living Systems*, Tomlinson, P.B. & Zimmermann, M.H. (eds), Cambridge University Press*

diameter and height ($D^2$*H). DEANS ET AL[42]. (1996) propose an equation to calculate this ration using the equation:

Root/shoot = 0,223 + 0,0199 x $D^2$ x h

where:

D: Stem diameter at breast height (m)
h: Tree Height

with adjusted $r^2$ = 0,60

A conversion factor can be used to establish a relationship between volume of a tree and root-to-shoot ratio, allowing to estimate a specific Root/Shoot ration for different kinds of forest.

Another study uses a mean root/shoot ratio based on this study and recalculation of other published studies from moist tropical forests. It indicated a root to shoot of about 0,25.

Studies from this kind of values show that the values are not really different. Comparative studies between SANGIER AND AL. (2001) and ATJAY do not demonstrate big deviations (<5%):

***Table 8: Dry matter biomass of shoot and root per $m^2$***

| Tropical forest | Shoot | Root | Root/total | Total | Total Ajtay |
|---|---|---|---|---|---|
| Kg (DM) /m² | 30,4 | 8,4 | 0,22 | 38,8 | 36,7 |

The biomass stock of BB (Belowground Biomass) is not really well known in the Africa context. Recommendations for estimate values are proposed by new research lines in section 4.6. CARBOCAF is a project developing research works focused in characterise forest types and building biomass equations for the main tree species and species groups in Central Africa. This project will enable to provide regional data to adapt allometric equations to the different national contexts.

## 3.5 EPIGEAN DEAD BIOMASS (NECROMASS): LITTER AND DEAD WOOD

### *3.5.1 Litter*

Litter is composed of dead vegetal material (pollen, dead leaves, branches, …) falling from trees and not yet transformed into inorganic material. In tropical forest ecosystems, degradation of this pool is very quick, caused by the right factors: high humidity degree, constant hot temperature and work performed by a myriad of insects, bacteria… Litter only constitutes 2 % of total forest biomass stock. This low importance in the total carbon stocked in biomass, combined with the complexity of the

[42] *DEANS J.D., MORAN J., GRACE J., 1996. Biomass relationships for tree species in regenerating semi-deciduous tropical moist forest in Cameroon. Forest Ecology and Management 88: pp. 215-225.*

process and the lack of studies on African tropical forest litter biomass stock, affected the decision not to include this pool yet in the biomass stock estimation. Once research studies start providing significant data, the pool will be included in the computation of biomass stock estimations.

Moreover, the development of a model for Soil Organic Carbon assessment could include the litter and provide an estimation of the turn over.

#### *3.5.2 Dead wood*

Dead Wood is defined as woody material no longer supporting growth, not self supporting,
and lying on the ground. The importance of dead wood in nutrient cycling, soil development and wildlife habitat, and as substrate for plant growth is crucial. Its influence in the regeneration process and phytosociologic composition are also key factors in the forest ecosystem. In a carbon biomass stock, dead wood is not considered as an important pool, estimated only at 3% of all the biomass stock.

Knowledge of the dead wood is significant in temperate areas, but the lack of studies on tropical ecosystems is obvious, even if scientists are beginning to study and report on the contribution of dead wood to the total biomass stock. This factor, linked to the low amount of carbon stocked in this pool, has influenced the decision not to include this pool in the estimations for the moment, waiting for research results.

## 3.6 SOIL ORGANIC CONTENT, SOC

SOC depends of several conditions such as climate (pluviometry, temperature), soil composition, relief, soil cover and consequences of these factors (albedo, potential evap-transpiration, hydric regime…)[43]. The carbon content is mainly concentrated within the first meters of soil. This organic carbon results from the decomposition process of the dead wood (DW) and litter (L). The SOC is not stable in time and measuring it requires a laboratory analysis of samples. No alternative has been developed, SOC cannot be measured by remote sensing.

In the REDD process, we would like to have a precise idea of the SOC, because soil cover change may have a very important impact on this carbon pool. GUO and GIFFORD (2002)[44] indicate that converting a forest into cropland results in a 42% loss of the soil carbon.

We are facing a difficulty here as we would like to have an annual evaluation of our carbon stock for the REDD accounting; but systematic field sampling would be too expensive. Collecting most of the data influencing the evolution of the SOC (mean annual temperature, precipitations) could easily be

[43] *GRACE, J., SAN JOSE, J., MEIR, P., MIRANDA, H., MONTES, R., 2006. Productivity and carbon fluxes of tropical savannas.* Journal of Biogeography*, n°33. pp. 387-400.*

[44] *GUO, L., GIFFORD, R, 2002. Soil carbon stocks and land use change: a meta analysis.* Global Change Biology *n°8. pp. 345-360.*

done annually (some data is already collected annually and made publicly available), soil vegetation cover will be identified for the purpose of AB accounting.

However, facing this difficulty, a team of scientists developed a model called YASSO[45] which was build for temperate forest ecosystems. YASSO was partially adapted to tropical conditions and was integrated into CO2Fix, a tool used in CDM (Clean Development Mechanism) carbon accounting. The precision of the tropical adaptation appears to be low due to a shortage in available data. The model only requires simple inputs (mean annual temperature and pluviometry).

In the REDD, this model can be adapted as a starting point to determine precisely the levels of SOC on a national scale, but the tropical adaptation of the model should be reinforced by a dedicated collection and the analyses of samples. The importance of the savanna zones can not be ignored regarding carbon soil, GRACE and al. (2006)[2] stressed the importance of the savannas soil in the Climate Change regulations, underlining the slow degradation of these soils.

We estimate the sampling requirement at around 1.000 plots for a correct adaptation in Tropical Africa. These plots should be divided between each strata found after analysis of the local conditions (slopes, soil composition, regional climate, soil cover…). Several documents and techniques can help us designing an exhaustive sampling plan: a Digital Elevation Model (DEM) can be used for the slopes, climate data and geological and pedological maps of countries and/or the entire region are also available (ie: Geological Map of Africa, 1963, Association of African Geological Survey, UNESCO). For each plot, sampling should be carried out up to 1 meter depth. Samples should be taken for each 10 cm or for each pedological horizon, resulting in around 8.000 samples to analyze, mainly to know the carbon content.

[45] *LISKI, J., PALOSUO, T., PELTONIEMI, M., SIEVANEN, R., 2005. Carbon and decomposition model Yasso for forest soils.* Ecological Modelling *189. pp.168-182.*

# 4 RECOMMANDATION ABOUT METHODOLOGY

## 4.1 GENERALITIES

The biomass stock of savanna forest areas needs to be quantified with the same methodology as the methodoloy used for forest land, adapted to the specific context of the savanna forest area ecosystem. As is the case of African forest are, knowledge on biomass stock of this ecosystem is sparse.

Development of the methodology is based on the link between volume over bark (VOB) and global biomass stock. The first research project must define the relationship between VOB, Aboveground Biomass (AB), Belowground Biomass (BB), Root-to-shoot ratio and Soil Organic Content (SOC).

To obtain these ratios, field work must establish the sampling design to measure and estimate the forest savanna biomass. To number of plots should be determined by the consideration of estimated ecological variance, targeted precision and estimation error. The size of the plot must be large enough to contain an adequate number of trees per plot to be measured.

The different measurements must enable to quantify the carbon stock of the three pools chosen for biomass stock estimation. They also must enable to obtain data and allometric equations adapted to the local context.

Once the different ratio have been obtained and adjusted, the method develops an allometric equation enabling to link the basal area of a plot with the volume over bark.

After obtaining this equation with a low error ratio, the next step is to carry out a “quick inventory” measuring the basal area only in a defined grid of plots. The ratios will be sufficient to extrapolate results of basal area to volume over bark, and after that to biomass stock estimation for the different pools.

## 4.2 DEGRADATION MONITORING

Monitoring degradation using remote sensing is more challenging than monitoring deforestation. FRM works with researchers to achieve that monitoring. This work is based on advanced image processing algorithms, applied to very high resolution imagery. FRM's database of forest inventories results is used to calibrate, strengthen and validate the advanced image processing algorithms and ensure the quality of the degradation monitoring. The degradation that can be detected using these techniques are over a certain detection threshold as regards the influences on the canopy. Such degradation, in the country, is due to extensive or illegal logging activities and is the degradation having the most important impact on biomass and carbon stocks.

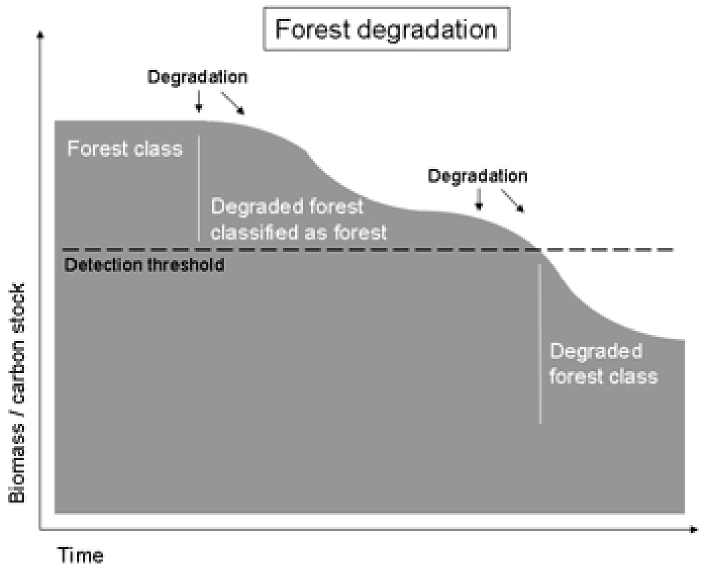



***Figure 12: Threshold of the forest degradation***

### *4.2.1 The use of very high resolution satellite imagery or aerial photos*

Ikonos or Quick-Bird data are the finest imagery available for non-military use. Their resolution is metric and can be compared to classical aerial photos used to monitor forest canopy. These data are quite expensive (10 to 40 USD the square kilometer for non-orthorectified products) but their quality is at quite constant level (while aerial photo missions are difficult to set up with standardized parameters, compromising the reproducibility of the process). Depending on the image analysis done, SPOT5 imagery (2.5m) is also adapted but more expensive. Cloud cover is the main constraint to a correct image recording, while sun exposition variability is the main constraint in the reproducibility of image analysis.

#### 4.2.2 The advanced image processing algorithms

Monitoring tropical rainforest, as regards its complexity and density, is the most challenging of all. For example, some algorithms allow the identification of each individual crown. But to predict the tropical rainforest stand structure parameters (tree density, diameter of the tree of mean basal area, mean canopy height), a powerful holistic approach using an index of canopy texture has been developed by a French research unit - Botany and computational plant - (Couteron and al., 2005). It allows us to estimate and monitor the above-ground biomass. FRM's unique database of forest inventory results is the key element to the calibration and validation of these algorithms.

##### 4.2.2.1 Details on the proposed solution

As an alternative to direct measurement of physical attributes of the vegetation and individual tree crown delineation, Couteron and Al. (2005) present a powerful holistic approach using an index of canopy texture that can be extracted from either digitized air photographs or satellite images by means of two-dimensional spectral analysis by Fourier transform. The authors defined an index of canopy texture from the ordination of the Fourier spectra computed for 3545 1-ha square images of an undisturbed tropical rain forest in French Guiana. This index expressed a gradient of coarseness vs. fineness resulting from the relative importance of small, medium and large spatial frequencies in the Fourier spectra. Based on 12 1-ha control plots, the canopy texture index showed highly significant correlations with tree density (R2 = 0·80), diameter of the tree of mean basal area (R2 = 0·71), distribution of trees into d.b.h. classes (R2 = 0·64) and mean canopy height (R2 = 0·57), which allowed the authors to use digital aerial photographs to produce predictive maps of reasonable accuracy for stand structure parameters. Two-dimensional Fourier analysis is a powerful method for obtaining quantitative characterizations of canopy texture, with good predictive ability on stand structure parameters.

In another study, Proisy, Ch., Couteron, P., Fromard, F. (2007) assessed the potential of Fourier-based textural ordination (FOTO) to estimate mangrove forest biomass from very high resolution (VHR) IKONOS images. For two distinct study sites in French Guiana, FOTO indices derived from a 1m panchromatic channel were able to consistently capture the whole gradient of canopy grain observed from the youngest to decaying stages of mangrove development, without requiring any intersite image correction. In addition, a multiple linear regression based on the three main textural indices yielded accurate predictions of mangrove total aboveground biomass. Since FOTO indices did not saturate for high biomass values, predictions were furthermore unbiased, even for levels above 450 t of dry matter per hectare. Maps of canopy texture (with RGB coding) and biomass were then produced over 8000 ha of unexplored, low accessibility mangrove.

### 4.2.3 Application of these methods on large areas

Two main activities at the development stage of the project must be taken in account: calibration of the image processing algorithms in association with the Botany and computational plant architecture research unit, and coding of software that will ease all operations needed for each steps of the image analysis process (calibration, test, run of the algorithms, validation).

#### 4.2.3.1 Collaboration with researchers

The Botany and computational plant architecture joint laboratory (involving researchers from several French Research Agencies (CIRAD, CNRS, INRA, IRD) and from the University of Montpellier 2) collaborate with FRM to adapt the image processing algorithms to the needs of the project, and to calibrate the final version, during a development stage requiring twenty to fifty man / days. During this stage, Ikonos or Spot5 images covering plots already inventoried by FRM teams will be used to test and validate the algorithms.

#### 4.2.3.2 The coding of an ergonomic (user friendly) software

The tools used to develop the image processing algorithms are powerful but complex to handle, and user interfaces are to be developed. To calibrate the algorithms using FRM database or during the operational stage when calibrating and using the algorithms on numerous sample plots, an ergonomic tool would be appropriate. Nev@ntropic, company formed from a partnership between Spot Image and IRD, will code specific software to ensure the correct use of the algorithms, improve their computing efficiency and ease image analysis. This coding requires twelve man / months of developments to be fully operational. The coding will be started at the same time than the calibration of algorithms done by the researchers. (Preliminary assessment can be undertaken based on quickly designed beta-versions before the software development stage is fully completed).

#### 4.2.3.3 Application to a varying density of sample plots

After one year of development, an operational solution is expected to work and to be ready for wide-scale implementation. FRM will use it as follows:

FRM’s knowledge of the Congo Basin forests enables the definition of forest classes based on their sensibility to degradation.

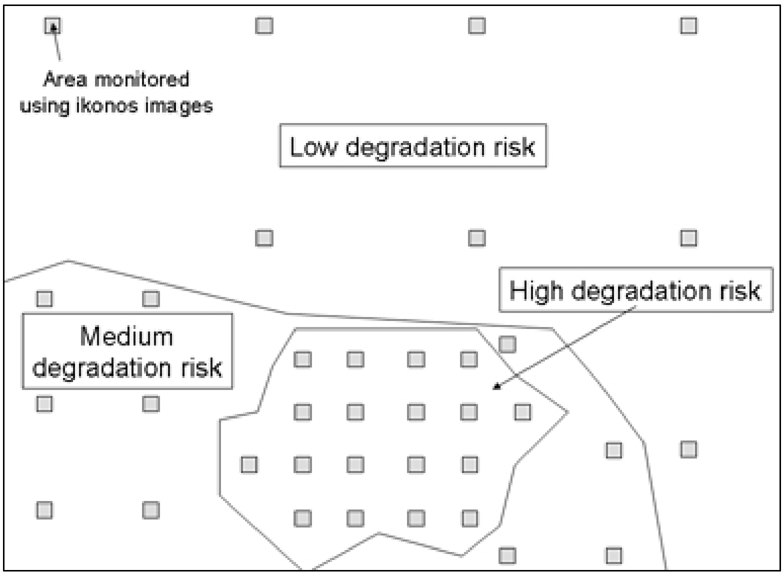



***Figure 13: Degradation risk***

A varying density of sample plots that cover a given percentage of the total forest will be monitored, depending on the precision level requested and the varying sensibility to degradation of the zone. It limits the price of very high resolution data and the time of processing and ground truthing. A given percentage of these sample plots will be surveyed from the ground in order to calibrate and control the quality of the automated processes.

***Table 9: Costs to monitor a forest covering a total area of one million hectare if sample plots cover 1% of it***

| Price of very high resolution data | Amount for all sample plots (covering 1% of the forest) |
|---|---|
| 10 USD / sq. km | 1 000 USD (10 000 ha) |
| 20 USD / sq. km | 2 000 USD (10 000 ha) |
| 30 USD / sq. km | 3 000 USD (10 000 ha) |

Costs for data acquisition must be added to the cost of data analysis (which is complex and requires advanced expertise) and ground truth.

#### *4.2.4 References*

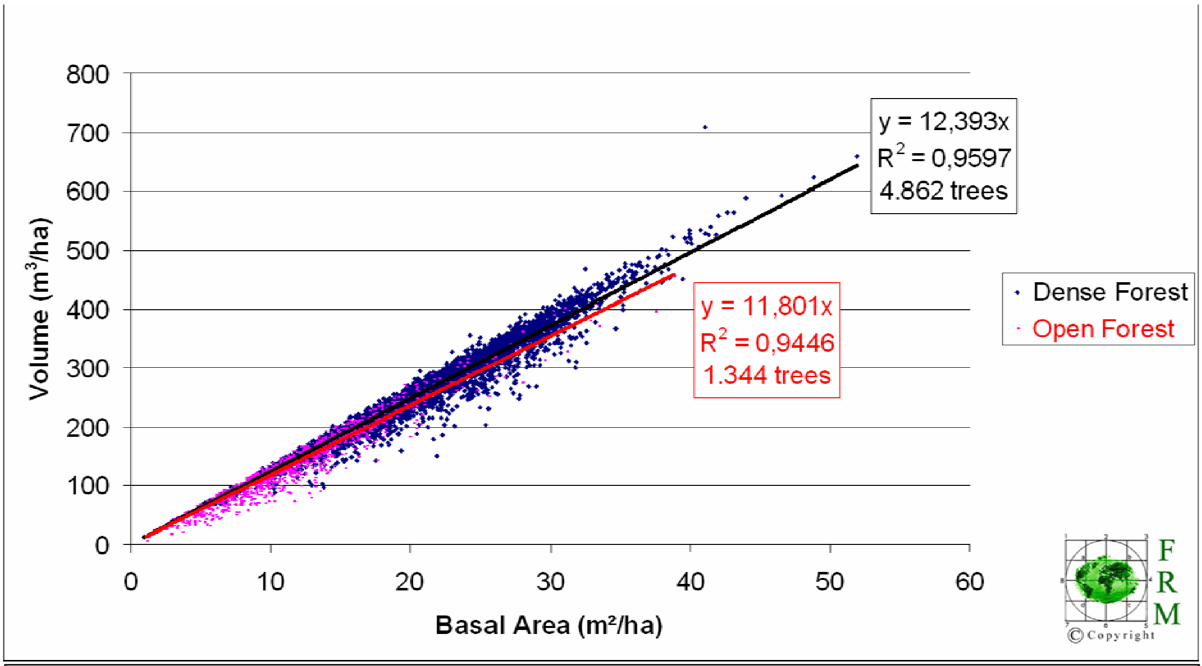
Couteron, P. and Al. (2005). *Predicting tropical forest stand structure parameters from Fourier transform of very high-resolution remotely sensed canopy images.* Journal of Applied Ecology, Volume 42, Number 6, December 2005 , pp. 1121-1128(8).

Proisy, Ch., Couteron, P., Fromard, F. (2007). *Predicting and mapping mangrove biomass from canopy grain analysis using Fourier-based textural ordination of IKONOS images*. Remote Sensing of Environment, 2007, 109 (3), pp. 379-392.

## 4.3 QUICK FIELD APPRAISAL OF BIOMASS

In order to assess the carbon storage monitoring, FRM proposes a quick appraisal field method when inventory data are not available (applicable in protected area, in concessions not involved in the management process…). Furthermore, this method will permit to avoid regular and costly field inventories.

This quick appraisal method gives a direct relation between Volume Over Bark (VOB) and basal area. This relation result from a treatment of field inventories for sustainable forest management. As a consequence it will be possible to estimate the volume with basal area measures with these simple relations. These measures can be done very quickly during field studies.




BAYOL, N. , CASSAGNE, B. , CHEVALIER, J.F. , DHORNE, P. , MARTINEZ PLAZA, S. 2008.

***Figure 14: Distribution of field inventory data regarding VOB and Basal Area***

This methodology wildly long used in temperate forests by all the foresters[46] can be adapted in tropical forests.

Figure 14 illustrates the adaptation of these relations between volume and area basal for different forest strata. This methodology will be developed for each forest stratum eligible to the REDD process.

[46] *PARDÉ, J., 1961. Dendrométrie. 350 p.*

A budget should be allocated to the consolidation of this simple and efficient method, and first field studies should confirm the applicability of the concept.

## 4.4 RECOMMENDATION: FOREST TIMBER LOGGING

The commercial logging activity is one of the most important activities in the forest areas of the country. It concerns a significant part of the national territory. To monitor logging impact on carbon stocks, factors are required to link reported data or readily monitored components with the total carbon impact. From this impact, we must separate the permanent impacts (such as roads and infrastructures) from the non permanent impacts, such as logging activities and harvested tree gaps.

For the permanent impacts, the affected surface must be identified (see Table 10) and reported to volume over bark. Once VOB determined, allometric equations will enable to estimate the permanent loss of biomass carbon stock.

***Table 10: Mean surface impacts of logging activity, from FRM database***

| Causes | Logging gap | LogYard | Roads | Extraction roads | TOTAL |
|---|---|---|---|---|---|
| % affected (area) | 8,0 | 0,3 | 0,9 | 6,8 | 15,9 |

For the non permanents impacts, numerous studies have examined logging and the associated damages, both in conventional and reduced impact scenarios. However, they were not linked to carbon impact. In that case, the carbon impact of logging is calculated as the difference in carbon stocks between a forest which has been harvested and one which has not, focusing on the logging gaps (BROWN et AL)[47].

To estimate the evolution of the carbon stock in logged areas, the regenerating dynamics of the forest must be known and quantified. Today, specific studies are being conducted by FRM in collaboration with several research institutes: CIRAD (France), IRAD (Cameroun), CNIARF /CRFO / CRFL (Congo), CENAREST-IRET (Gabon), ICRA (CAR), JRC (Joint Research Center) and universities (Kinsagani (DRC), Gembloux (Belgium)… Some of these researches are conducted to determine the evolution of regenerating process. That process is still little known, hence the necessity of research studies to understand it and estimate the evolution of the different biomass stock pools during forest recomposition.

[47] *BROWN S., PEARSON T., MOORE N., PARVEEN A., AMBAGIS S., SHOCH D.. Winrock Internatinal,. http://carpe.umd.edu/resources/Documents/rpt_carbon_congo_3_2005_winrock.pdf/view?set_language=fr*

## 4.5 ALLOMETRY

Recommendations for future consolidation of the methodology previously exposed turn around the unknown tropical moist forest ecosystem carbon stock capacities. General values obtained from other region of the world can be a source of error. It has been repeatedly shown that extrapolating their use from other sites can generate important bias in biomass estimation (CARBOCAF)[48]. This paper proposes simple research works that enable calibration of the general model to local context and in a short time obtaining regional accurate values.

Moist Forest Biomass stock parameter research:

### *4.5.1 BEF: Biomass Expansion Factor*

Parameters to obtain biomass stock of the different pools have to be specific to the localisation of the assessment, especially considering the strata. BEF (Biomass Expansion Factor) is an important expansion factor employed to calculate Aboveground Biomass from VOB (Volume Over Bark). BEF is a general value that has to be built for each forest kind (stratum).

These studies will develop general allometric equations to estimate biomass of stems, branchs and leaves (canopee) for each stratum. They would combine tree measurements as well as destructive sampling to establish relation between biomass stock and measurable Diameter Class structure. Trees are selected according to the distribution of DBH and stem shape. The aim is to characterise each stratum, and built a specific BEF for each one. It will estimate with more precision the carbon stock from the biomass, on a stratum-based approach

### *4.5.2 VEF: Volume Expansion Factor*

The VEF (Volume Expansion Factor) is another ratio used to obtain carbon stock from forest inventory results. It harmonises the results from different inventories with a consolidated methodology. This factor is not really well known and would enable to establish a link with old inventory results. It could be combined with the studies to determine new local BEF and linking these values to basal area and Diametric Class Distributions;

---

[48] *Characteristing forest types and building biomass equations for the main tree species and species groups in Central Africa: providing tools to quantify, understand and predict above-ground carbon stocks (CARBOCAF), not published*

## 4.6 ROOTS TO SHOOTS RATIO

Belowground Biomass (BB) represents roughly 20% of the carbon stock in the tropical forest. This BB is derived with a simple ratio from the Aboveground Biomass (AB). The accuracy of the used Roots to shoots ratio is crucial in carbon stock calculation. As none of those ratios was specifically built for African tropical forests, existing roots to shoots ratios are not suitable to obtain accurate enough results in the case of Africa carbon accounting.

We suggest that a large field survey may be launched in order to establish roots to shoots ratio applicable to Central Africa forests.

These Roots to shoots ratios should be linkable with stand basal area or Volume Over Bark (VOB) data, which can easily be collected. To complete this task taking into account the time constraints for building a reliable methodology, we suggest a three steps approach to precise the roots to shoots ratio.

**Large scale destructive sampling** with a weighing of the roots above 10 cm in diameter. This work could easily be done on a large scale when trees are uprooted to create sunlight strips along forest roads. Trees are pushed aside by a bulldozer making the moist part of the root system accessible. A small team of cutters could divide the roots and prepare the pieces to be attached to a numeric weighing-hook installed on a heavy machine. The grader or bulldozer can then lift the roots fragment. This can be done quickly to provide a first approximation of the roots to shoots ratio.

This first part of work could be done in the coming months, as soon as the budget is defined and the funds are raised. The task is simple and some concession holders are ready to welcome such operations. Even if fine roots are not taken into account, this work could give rapidly a first approximation of roots importance in the carbon stock accounting, at a relatively low price considering the REDD issue.

The two last points suggested are more extensive and have to be seriously planned before being engaged.

**Excavation of finer roots.** Excavation of finer roots should be done on the most prevalent species, in the most represented forest strata. This excavation should include all roots above 2 cm in diameter. Approximately 10 to 15 excavations could give a precise range of roots to shoots ratio.

This second part of the work will take more time because of the need for an appropriate organization on site, with land filters and so on. A reasonable schedule would be between one and two years.

**Roots from 2 cm down to 2 mm** For the fragments of roots from 2cm down to 2mm, a study of bibliographic references should give a precise enough idea. (Roots not larger than 2mm are taken into account in the soil organic content pools, as recommended by IPCC GPG for LULUCF).

This last part of the work should be scheduled when the first two work components are completed, but an exhaustive bibliography exercice on the subject can be conducted at the same time as work Steps 1 and 2. The time delay would then be reduced to a few weeks to adapt this part of the data and obtain applicable and accurate roots to shoots ratios for African tropical forests.

## TABLE LIST



## FIGURE LIST



## MAP LIST

# Appendix 2

## Indicators monitored by OFAC(Extracts)

Indicators monitored by OFAC(Extracts)

| Work Scale | Number of indicators |
|---|---|
| Regional level indicators | 89 |
| National level indicators | 158 |
| Indicators at Management Sites Level | 172 |
| ***Total*** | ***419*** |

| Indicators at regional level | Number of indicators |
|---|---|
| Forest cover | 4 |
| Legal and institutional framework | 2 |
| Forest logging in Central Africa | 41 |
| Biodiversity conservation and valorisation in Central Africa | 42 |
| ***Total*** | ***89*** |

| N.1 Forest Cover |
|---|
| **N.1.1 Forest surface area** |
| N.1.1.1 National Forest surface area |
| N.1.1.2 Surface area by forest type at national level (reference typology proposed by FORAF) |
| N.1.1.3 Planned surface area of the Permanent State Forest |
| N.1.1.4 Total planned Total surface area of the production forests |
| **N.1.2 Evolution of the national Forest Cover** |
| N.1.2.1 Evolution of the national Forest Cover 1990 – 2000 |
| N.1.2.2 Evolution of the national Forest Cover 2000 – 2005 |
| N.2.1.6 Zoning plan / land allocation zoning plan |
| N.2.2.5.1 Major technical equipment held by the administration (expl. GIS, computer data base...) |
| N.3.3 Industrial forest concessions under sustainable management |
| N.3.3.1 Total surface area of planned production forests at national level |
| N.3.3.1.1 Total surface area already allocated as concessions and number of concessions |
| N.3.3.1.2 Total surface area of the annual harvestable coupes |
| N.3.3.2 Total surface area and number of concessions at provisional convention stage (preparatory phase of the Management Plan) |
| N.3.3.3 Total surface area of the concessions and number of concessions with approved management plans |
| N.3.3.4 Total surface area (and number) of certified concessions (by type of certificate) |
| N.3.3.5 Total surface area (and number) of concessions engaged in the certification process (having at least organised one pre-audit) |
| N.3.3.6 Total surface area (and number) of concessions having obtained a legality certificate |

| |
|---|
| N.3.3.7 Total production achieved in forests with approved management plans |
| N.3.3.8 Location map of the concessions |
| N.3.4 Management of municipal forests |
| N.3.4.1 Total surface area of forest allocated to municipalities |
| N.3.4.2 Total surface area and number of municipal forests with approved management plan |
| N.3.4.3 Total surface area and number of certified municipal forests by type of certificate |
| N.3.4.4 Total surface area and number of municipal forests engaged in the certification process |
| N.3.4.5 Total surface area of municipal forests with legality certificate |
| N.3.4.6 Total production achieved in municipal forests with approved management plan |
| **N.3.5 Management of Community forests** |
| N.3.5.1 Total surface areas already reserved by the communities |
| N.3.5.2 Total surface area of community forests with approved simple management plans |
| N.3.5.3 Total surface area of community forests in exploitation |
| N.3.5.4 Total surface area of certified community forests by certification type |
| N.3.5.5 Total surface area of community forests with legality certificate |
| N.3.5.6 Total Production achieved in community forests |
| N.4 Biodiversity conservation and valorisation |
| **N.4.1 State and evolution of the biodiversity constitutive elements** |
| N.4.1.1 Evolution of species frequency and distribution |
| ***Regulation Services*** |
| N.4.2.9 Air, global climate, local climate, water cycle, erosion, sanitation, diseases, parasites, pollination, natural risks [to be reviewed in 2009] |

# Appendix 3

Priority Actions for the REDD Readiness – 5 June 2008

## a. Inventories and local biomass knowledge, definitions and implementation of the monitoring methodology.

- Study of the carbon stock in savannas and agricultural lands, study of the carbon stock post harvesting dynamics in logged areas
- Construction and development of a satellite imagery station in Central Africa, requested to monitor DD
- Enforcement of the degradation monitoring methodology
- Design of a new methodology for quick field appraisal (linking the basal area to biomass density)
- Study to establish allometric equations adapted to Africa, to compute the carbon stock included in the biomass. Precision of ratios used: Biomass Expansion Factor, Roots to shoots Ratio… (partly included in the CARBOCAF project submitted to the GEF)

## b. Baseline

- Elaboration and drafting of a methodology to design a baseline with perspective science, considering future DD levels in the absence of REDD strategies, not based on historical DD levels only.

## c. REDD strategy

- Better definition of measures to implement to reduce DD and locate *hot spots* (areas under high DD pressure)
- Elaboration and implementation of a mechanism to manage the collected REDD funds
- Consolidation of national skills and capacities involved in the REDD process: (i) Directorate of the Sustainable Development, (ii) SPIAF (Permanent Service for Inventory and Forest Management Planning, (iii) DGF (Directorate of Forest Management), (iv) SNR (National Service of Afforestation, (v) other agriculture services implied in the vulgarization of agricultural techniques, fish farming and breeding.

Appendix 4

List of attendees of REDD consultation meeting of the 18th of April 2008

**SEANCE DE TRAVAIL SUR LA REDD DU 18 AVRIL 2008**
**Liste des participants**

| N° | NOM & POST-NOM | INSTITUTION | COORDONNEE (Tél. & E-mail) |
|---|---|---|---|
| 01 | John KATENDE KAMBA | Finances | 081 599 84 10 |
| 02 | KASOKO LUMINA Robert | Finances | 081 895 40 38 |
| 03 | Françoise VAN de VEN | F I B | |
| 04 | Marcel NYUMBAIZA MALUNGU | Institut National des statistiques | 081 657 68 33 |
| 05 | BULUBULU Jean Damas | Agriculture | 099 810 49 04 bulubuludamas@yahoo.fr |
| 06 | MBIKAYI NKONKO | INERA | 081 317 87 90 nkonkombikayi@yahoo.fr |
| 07 | Théo WAY NANA | ONG | 0812435469 |
| | Guy LIAKI | ONG | 0815263279 |
| | Jacques IPOMA | ONG | 0813633396 |
| 08 | Flory BOTAMBA | ONG | 0999915109 |
| 09 | Charles WASIKAMA | PNUD | 081 388 49 35 |
| 10 | MWANAMBUYU KABALA | Cellule de Coord. du PNFoCo | 099 991 83 57 mwakabala@yahoo.fr |
| 11 | KANU MBIZI Léon | PNFoCo/MECN | 099 823 15 55 kanumbizi@yahoo.fr |
| 12 | MALELE MBALA Sébastien | SPIAF | 081 508 07 20 semalele@yahoo.fr |
| 13 | ZASY NGISAKO | SPIAF/MECN | 081 412 40 42 zasygermain@yahoo.fr |
| 14 | | WCS | |
| | Richard EBA'A ATYI | FORAF/OFAC | 0990681139 |
| | LUMBUENAMO | WWF | |
| 15 | MBUYI KALOMBO | DDD | 081 982 44 10 mbuyi_kalombo@yahoo.fr |
| 16 | KILOLA LUTSWAMBA | MECN-T | 099 822 91 81 gilkil_58@yahoo.fr |
| 17 | MUBILAYI François | DDD | |
| 18 | KAVIRA Sylvie | DDD | 018 242 45 19 kavsylvie@yahoo.fr |
| 19 | Béatrice MAKAYA | Primature | 099 886 71 84 / 089 862 66 89 beatricemakaya@yahoo.fr |
| 20 | MBUMBA KANDA | MECN-T | 099 999 60 75 mbumbaka2007@yahoo.fr |
| 21 | MWAMBA KYUNGU | DGF/MECN | 099 936 99 84 philank@yahoo.fr |
| 22 | DJENGO BOSULU | SNR/MECN | 099 836 80 91 djengofrederic@yahoo.fr |
| 23 | BAMANGANA | SNR/MECN | 081 510 35 10 |
| 24 | SEMEKI NGABINZEKE Jean | DCI/MECN | 089 961 12 37 jsemeki@yahoo.fr |
| 25 | Léon MUBA MOPILI | DCI/MECN | 081 920 35 54 leon_muba@yahoo.fr; mubaleon@gmail.com |
| 26 | BAPINGA MUSELU | METTELSAT | 089 892 11 62 |
| 27 | PALUKU VINYATSI A. | METTELSAT | 081 811 21 65 palukuvinyatsi@yahoo.fr |
| 28 | Dr. Benvit PEMBE NSIESE | Ministère du Plan | 099 999 10 97 bnpembe@yahoo.fr |
| 29 | Désiré BUJIRI/CDU | Ministère du Plan | 099 816 96 81 |
| 30 | | MINES | |