# ECONOMIC ESTIMATION OF CARBON STORAGE AND SEQUESTRATION AS ECOSYSTEM SERVICES OF PROTECTED AREAS: A CASE STUDY OF LOBEKE NATIONAL PARK

**L Zapfack[1], NV Noiha [2*] & MRB Tabue [1,3]**

[1]*University of Yaounde I, Faculty of Science, Department of Plant Biology, P.O. Box. 812 Yaounde, Cameroon.*
[2]*University of Ngaoundere, Faculty of Science, Department of Biological Sciences, Laboratory of Biodiversity and Sustainable Development, P.O. Box. 454 Ngaoundere, Cameroon.*
[3]*Ministry of Forestry and Wildlife/Dja Biosphere Reserve, PO Box: 34430 Yaoundé, Cameroon.*

**noiha64@yahoo.fr*

*Received May 2015*

**ZAPFACK L, NOIHA NV & TABUE MRB. 2016. Economic estimation of carbon storage and sequestration as ecosystem services of protected areas: a case study of Lobeke National Park.** Although national parks are known for their high capacity of carbon storage and sequestration, few studies have been dedicated to determine the monetary value of this ecosystem service. Accordingly, this study aims to assign monetary values to this service in a protected area, the Lobeke National Park, located in southeast Cameroon. Flora diversity, carbon storage and sequestration in biomass of the park were assessed in 37 transects. A total of 71,725 trees, diameter at breast height ≥ 5 cm, from 76 families, 156 genera and 217 species were harvested. Ebenaceae, Euphorbiaceae, *Dichostemma glaucescens, Mareyopsis longifolia, Diospyros suaveolens* and *Diospyros crassiflora* were the most abundant taxa. Above ground biomass (AGB) was estimated at 318.04 tons $ha^{-1}$ and below ground biomass (BGB) at 56.16 tons $ha^{-1}$. AGB varied significantly between types of land used ($p < 0.001$). Carbon stock varied significantly with DBH and basal area ($p < 0.001$). The total carbon throughout the park was evaluated at 81,520,966.8 tons corresponding to over 298 million tons of $CO_2$ sequestrated by the park. The value of the service of carbon sequestration was evaluated at 1,434,769,015.68 USD. The Lobeke National Park is designated as a carbon sink in Africa.

Keywords: Biomass, congo basin, diversity, mitigation, sink

## INTRODUCTION

Covering about 7–10% of the earth's surface area, tropical forests store an important volume of carbon in the world (Anonymous 2008). These forests generate more and more interest because of their major role in the process of mitigating climate change (Noiha et al. 2015a) by sequestering an important quantity of green house gases (GHG) from deforestation and forest degradation (Anonymous 2003). The increased emissions of GHG in the recent decades has enhanced the society's perception of the social and economic damage that may be caused by climate change, leading to an increasing interest in minimising the potential impacts of these changes (Parry et al. 2007).

The intention of 'Reducing Emission from Deforestation and Forest Degradation' (REDD) is that developing countries may be financially rewarded for keeping carbon stored in their natural forests. This can prevent the economic growth of these countries at the expense of environmental services promoted by such forests. Although unofficial, the contribution of REDD to the volume (tonnes) of $CO_2$ traded in voluntary carbon markets has increased over time (Dziedjou-Kwouossu et al. 2011, Scholz et al. 2008). These voluntary transactions are being carried out in an attempt to secure a market reserve, following the regulation of REDD in the ambit of climate convention. In 2007, the volume of $CO_2$ negotiated from REDD projects was 1.2 million tonnes, while in 2010, this value increased to 19.5 million tonnes (Dziedjou-Kwouossu et al. 2011). This increase was not observed in afforestation and reforestation projects, which went from 3.5 million tonnes of $CO_2$ in 2007 to 5.8 million tonnes of $CO_2$ in 2010. The program aims to reduce deforestation but not to stop it. From the climate change perspective, the objective is to stabilise $CO_2$ concentrations at the lowest possible. To serve as a carbon offset, reductions of gas emissions obtained under REDD must meet certain criteria including permanence (reduction in the long term), additionality (change of usual practice) and leakage (WRI 2009). In addition to these three criteria, reduction of gas emissions must be measurable, notifiable and verifiable as outlined in the Bali action plan (Dziedjou 2011). These criteria are intended to ensure the credibility of reducing gas emissions by demonstrating that reduction of gas emissions is real.

The countries of the Congo basin gathered within Commission des Forêts d'Afrique Centra' (COMIFAC) are aware of the importance and quality of their massive forest. They have an important responsibility both towards their own people and the entire planet, its implications as an essential approach, structuring and transversal developmental strategies (Anonymous 2006).

Economic and ecological challenges faced due to climate change include increase in the price of essential commodities such as oil, increase in the rate of poverty, disappearance of certain species, widespread drought, melting polar glaciers, landslides and increase in the frequency of storms, tsunamis and hurricanes. According to the REDD concept, it would be important to have sufficiently accurate information on carbon stocks in all potential carbon sinks formally recognised. Among these is the Lobeke National Park located in Tri-National de la Sangha (TNS). TNS is a shared surface area between three countries, i.e. Cameroon, Congo and Central Republic Africa. With a total surface area of more than 44,000 km$^2$, the TNS is very rich in biodiversity (Emana et al. 2009).

Data on plant diversity and biomass have not been fully exploited in the Congo basin. Some data on plant diversity and carbon stocks were obtained from Dja Reserve (Sonké 2004, Djuikouo et al. 2010, Tabué 2014). However, based on investigations conducted on exploited species in Lobeke National Park (Noiha et al. 2015b), there were no records of any sampling on plant diversity and biomass. Some data, however, were available from the agroecosystems surrounding the park (Zapfack et al. 2013) and were compared with the data assessed in many countries (Baes et al. 1977, Matthews et al. 2000, Prakash & Lodhiyal 2009, William et al. 2011). It is in this context that the project on biodiversity and carbon sequestration in the TNS, case of Lobeke National Park in southeast Cameroun, was initiated.

This study aimed to assign monetary values to the service provided by natural ecosystems regarding carbon storage and sequestration in a protected area, considering approaches related to REDD.

## MATERIALS AND METHODS

### Study site

Lobeke National Park is located between latitudes 2° 05' to 2° 30' N and longitudes 15° 33' to 16° 11' E (Figure 1). Its surface area is approximately 217,854 ha. The climate is typically equatorial with four seasons. The Lobeke region is located in the northwest of the Congolese basin slope, and is one part of the Congo basin with typical metamorphic formations composed essentially of quartzites, shales, limes stones and dolerites. The streams draining the area of Lobéké feed the rivers Sangha and Ngoko, two tributaries of the Congo River. Rainfall spread throughout the year with two peaks in April and October. The maximum height of precipitation is approximately 1,500 mm year$^{-1}$ (Ekobo 1995).

On the phytogeographic plan, Lobeke National Park is a transitional forest between the evergreen forest of Dja and semi deciduous forest of Sterculiaceae and Ulmaceae (Letouzey 1985).

### Data collection

Data was collected in thirty seven transects of 5 ha each. The total area of investigation was 185 ha for a survey rate of about 0.085%. Compass and GPS were used to establish transects of 2.5 km long × 20 m wide (Figure 2). All trees with a diameter at breast height (dbh) ≥ 5 cm were assessed and measured throughout each transect using standard forestry methods (Lewis et al. 2009). Herbarium specimens were collected from each plant to confirm field identification, based on specimens at the National Herbarium

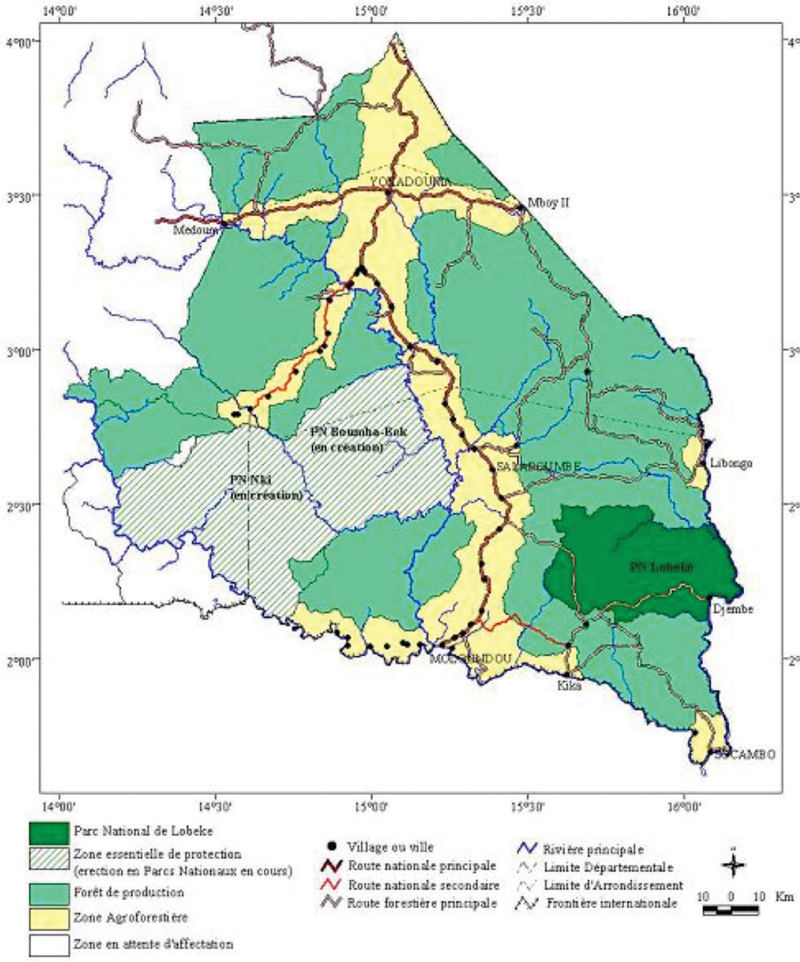


**Figure 1** Localisation of site in Tri-National de la Sangha (TNS) (MINFOF 2005)

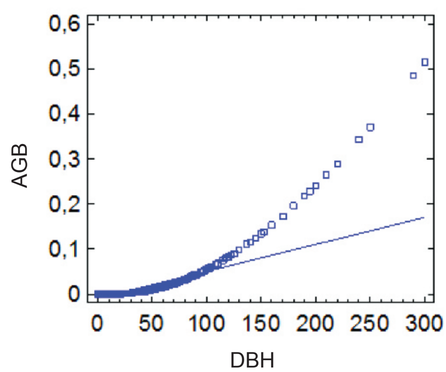


**Figure 2** Regression curve showing relationship between above ground biomass (AGB) and diameter at breast height (dbh)

of Cameroon. At the origin of the transect and at every 500 m along the transect, herbs and individuals less than 5 cm of dbh were inventoried in a distance of 10 m, to assess biodiversity. Similarly, at the origin and at every 500 m along each transect, samples of herbs, litter and underground root were collected. Sampling of weeds, litter and roots were collected along the transect using boards of sizes 1 × 1 m², 0.5 × 0.5 m² and 0.2 × 0.2 m² respectively. Herbs, litter and underground roots biomass were obtained by direct destruction. The roots were extracted from soil by washing the soil dug to a depth of 50 cm. In total, 222 soil samples, i.e. 4.44 m³ of soil, were washed in the nearest stream. Small-mesh sieve was used to obtain roots from the soils.

## Data analysis

*Abundance and diversity*

Abundance was estimated for each harvested taxa using the following equation:

$$A = (ni/N) * 100$$

where ni = number of individuals of species i and N = total number of the flora.

Types of land used (TLU) were identified throughout each transect. The diversity of each TLU was determined using Shannon index (ISH), to compare data:

$$ISH = -\Sigma \ pi \log_2 (pi)$$

where pi = frequency of species i (ni⁄N), ni = number of individuals of species i and N = number of individuals of all the species.

*Species density and basal area*

The following formula was used to obtain density:

$$D = ni/S$$

where D = density, ni = number of individual of species i and S = basal area. Only species of a DBH ≥ 10 cm were taken into account.

The following formula was used to calculate basal area of each species:

$$S = \pi(Di^2/4)$$

where S = basal area, Di = diameter of the individual of species i and $\pi$ = 3.14

*Above ground biomass (AGB)*

Biomass was estimated using allometric regression model and DBH was used for the assessment of the mass of the carbon. The following allometric model (Chave et al. 2005) was used to evaluate carbon sequestered by each individual and infer carbon of all timbers:

$$AGB = \alpha Exp\ [-1{,}499 + 2{,}148*\ln(DBH) + 0.207 * (\ln(DBH)^2 - 0.0281 * (\ln(DBH))^3]$$

where $\alpha$ = density of wood and DBH = diameter of breast height at 1.3 m. This model was used since the work was carried out in a tropical humid forest and individuals of a DBH ≥ 5 cm were harvested.

*Below ground biomass (BGB)*

Grass, litter and root samples collected in the field were dried to a constant weight for three days in an oven.The following equation was used to estimate carbon in big roots:

$$Wr = 0.0264 * (D^2L)^{0.775}$$

where Wr = mass (kg), L = height of root (m) and D = diameter of root (cm).

Total carbon was obtained by summing carbon in herbs, wood, litter and roots. The stock $ha^{-1}$ by the surface area of the park was multiplied to estimate total carbon in the forest. The ratio $CO_2\ C^{-1}$ molecular weight was used to convert carbon stocks (tonnes of Carbon $ha^{-1}$) into tonnes of $CO_2\ ha^{-1}$ (44/12) and thus, the total $CO_2$ sequestered in the forest.

According to Ecosystems Marketplace (2008), the transaction price for conservation was estimated at 4.8 USD $tonne^{-1}$ of $CO_2$. This ratio was used to estimate the ecological service value.

*Statistical test*

One-way ANOVA was used to compare data in the TLU via XLSTAT 2007. STATGRAPHICS plus 5.0 was used for multiple regression analysis.

# RESULTS

## Abundance and diversity

Samplings showed 72,838 individuals of plants including 71,725 timbers and 1,113 herbs, divided into 76 families, 228 genera and 310 species. This investigation revealed 156 genera and 217 species of timbers.

**Table 1** Important families of the Lobeke National Park flora

| Families | Ni | A | ISH | BA ($m^2$) | D (ind $ha^{-1}$) | AGB (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| *Annonaceae* | 6630 | 9.24 | 0.44 | 388.66 | 943.41 | 19.10 |
| *Apocynaceae* | 2742 | 3.82 | 0.18 | 240.82 | 90.25 | 12.79 |
| *Bignoniaceae* | 1712 | 2.38 | 0.11 | 116.23 | 12.68 | 5.45 |
| *Caesalpiniaceae* | 4171 | 5.81 | 0.28 | 766.70 | 60.72 | 48.53 |
| *Ebenaceae* | 14,583 | 20.33 | 0.98 | 266.31 | 596.85 | 9.33 |
| *Euphorbiaceae* | 15,539 | 21.66 | 1.05 | 468.79 | 608.93 | 20.05 |
| *Fabaceae* | 1652 | 2.30 | 0.11 | 152.02 | 105.03 | 8.93 |
| *Flacourtiaceae* | 1950 | 2.71 | 0.13 | 38.26 | 102.63 | 1.24 |
| *Meliaceae* | 1849 | 2.70 | 0.12 | 432.97 | 32.84 | 29.61 |
| *Olacaceae* | 3077 | 4.28 | 0.21 | 200.48 | 24.77 | 9.57 |
| *Rubiaceae* | 3314 | 4.62 | 0.22 | 207.48 | 211.39 | 10.12 |
| *Sterculiaceae* | 1554 | 2.16 | 0.10 | 707.32 | 5.09 | 48.36 |
| *Violaceae* | 3056 | 4.26 | 0.20 | 34.36 | 397.02 | 1.00 |
| Relative values | 86.20 | 86.14 | | 72.28 | 86.28 | 70.45 |
| Total | 61,829 | 86.14 | 4.13 | 4020.4 | 3191.61 | 224.08 |
| Total of flora | 71,725 | 100 | | 5562.03 | 3699.03 | 318.04 |

Ni = number of individual species I, A = abundance, ISH = shannon index, BA = basal area, D = density, AGB = above ground biomass

The flora was dominated by 13 families with 86.2% of individuals. Ebenaceae and Euphorbiaceae were the most abundant and common families (Table 1). Flora was dominated by 15 important genera with more than 1000 individuals. *Diospyros* was the most common genus, > 14,000 individuals, and the most abundant (Table 2).

Table 3 shows the most important species of the flora. These species, 19 in total, represented 65.86% of the vegetation. *Dichostemma glaucescens, Mareyopsis longifolia, Diospyros suaveolens* and *Diospyros crassiflora* were the most common and abundant species of the flora with more than 5000 individuals each (Table 3).

In terms of DBH, 85, 140 and 209 species of DBH < 5 cm, 5 ≤ DBH <10 cm and ≥ 10 cm were harvested respectively. Trees of DBH ≥ 10 cm were the most abundant (Table 4).

Among the 3 TLU harvested (Table 5), secondary forest was the most important with 64.24% of individuals, while wetland was less important with 4.26% individuals.

Ebenaceae and Euphorbiaceae were the most diversified families of the flora, ISH = 1.05 and 0.98 respectively (Table 1). *Diospyros, Dichostemma* and *Mareyopsis* were the most diversified genera (Table 2). *D. glaucescens, M. longifolia, D. suaveolens* and *D. crassiflora* were the most diversified species (Table 3). Secondary forest was the most important in terms of diversity (Table 5).

## Basal area and density

The most important basal areas were those of Caesalpiniaceae and Sterculiaceae with 766.7 and 707.32 $m^2$ respectively. With a high basal area, these families were not too dense. The most dense family was Annonaceae with 943.41 individuals $ha^{-1}$ followed by Euphorbiaceae with 608.93 individuals $ha^{-1}$ and Ebenaceae with 596.85 individuals $ha^{-1}$ (Table 1). *Gilbertiodendron, Terminalia* and *Diospyros* were genera with important basal area. *Diospyros, Meiocarpidium, Thomandersia* and *Mareyopsis* were the most dense genera with 596.85, 306.62, 278.42 and 211.83 individuals $ha^{-1}$ respectively (Table 2). *Gilbertiodendron dewevrei* and *Terminalia superba* were the biggest species of the flora with 371.06 and 370.22 $m^2$ of basal area respectively. However, the densest species was *Rinorea* sp. followed by

**Table 2** Abundance and diversity of common genera of the Lobeke National Park flora

| Genres | Ni | A | ISH | BA ($m^2$) | D (ind $ha^{-1}$) | AGB (t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| *Diospyros* | 14,583 | 20.33 | 0.987 | 266.31 | 596.85 | 9.33 |
| *Dischotemma* | 6571 | 9.16 | 0.444 | 97.85 | 174.53 | 2.83 |
| *Mareyopsis* | 6149 | 8.57 | 0.416 | 126.09 | 211.83 | 4.20 |
| *Strombosia* | 2916 | 4.06 | 0.197 | 166 | 24.04 | 7.46 |
| *Meiocarpidium* | 2237 | 3.11 | 0.151 | 30.67 | 306.62 | 0.92 |
| *Oncoba* | 1868 | 2.60 | 0.126 | 36.1 | 100.74 | 1.16 |
| *Markhamia* | 1517 | 2.11 | 0.102 | 101.98 | 10.98 | 4.71 |
| *Pausinystalia* | 1491 | 2.07 | 0.10 | 105.33 | 76.95 | 5.04 |
| *Funtumia* | 1397 | 1.94 | 0.094 | 84.73 | 38.15 | 3.82 |
| *Terminalia* | 1373 | 1.91 | 0.092 | 370.22 | 2.20 | 22.86 |
| *Gilbertiodendron* | 1311 | 1.82 | 0.088 | 371.06 | 32.71 | 24.36 |
| *Thomandersia* | 1279 | 1.78 | 0.086 | 5.70 | 278.42 | 0.15 |
| *Anthonotha* | 1250 | 1.74 | 0.084 | 30.56 | 21.98 | 1.16 |
| *Monodora* | 1173 | 1.63 | 0.079 | 27.7 | 41.48 | 1.02 |
| *Polyalthia* | 1026 | 1.43 | 0.069 | 97.84 | 108.25 | 4.73 |
| Total | 46,141 | 64.26 | 3.115 | 1918.14 | 2025.73 | 93.75 |

Ni = number of individual species I, A = abundance, ISH = shannon index, BA = basal area, D = density, AGB = above ground biomass

*Meiocarpidium lepidotum, Thomandersia hensii, D. crassiflora, D. suaveolens* and *M. longifolia* (Table 3). Trees of DBH ≥ 10 cm represented 98.51% of the basal area. However, those of DBH < 5 cm were very dense (Table 4). Density was significantly high in secondary forest ($F = 33$, $p < 0.001$) in TLU (Table 5).

## Above ground biomass (AGB)

The most abundant families of the flora represented 70.45% of the biomass. Caesalpiniaceae and Sterculiaceae were the most important families. Their biomass was estimated at 48.53 and 48.36 t C $ha^{-1}$ respectively followed by Meliaceae, Euphorbiaceae and Annonaceae. With about 5 individuals $ha^{-1}$, Sterculiaceae was one of the most important family in terms of biomass (Table 1). The stock of carbon depends significantly on DBH ($p < 0.001$).

Figure 2 shows the results of fitting a multiple linear regression model to describe the relationship between AGB and DBH. The equation of the fitted model is:

$$AGB = -0.00914359 + 0.000601464 * DBH$$

where AGB = above ground biomass and DBH = diameter at breast height. There is a statistically significant relationship between the variables at 99% confidence level ($p < 0.0001$). This explains the reason why Caesalpiniaceae and Sterculiaceae were the most important families with regards to carbon stock.

## Below ground biomass (BGB)

The BGB concerned herbs, litters and underground roots. The carbon stock in herbs and small shrubs were 0.605 tonne of C $ha^{-1}$. Litter and small roots from soil were 3.10 and 7.35 tonnes of C $ha^{-1}$ respectively (Table 6).

## Ecological service value

Total carbon stock in the park was obtained by summing the values at the level of timbers, herbs, litters and roots. The total carbon throughout the park (off set the carbon dissolved in the soil) was estimated at 81, 520, 966.8 t (374.2 × 217,854) (Table 6), which corresponded to 298,910, 211.6 tonnes of $CO_2$ sequestrated by the park. The ecological service which paid

**Table 3** Most abundant species of the Lobeke National Park flora

| Species | Ni | A | ISH | BA ($m^2$) | D (ind $ha^{-1}$) | AGB(t $ha^{-1}$) |
|---|---|---|---|---|---|---|
| *Dichostemma glaucescens* | 6571 | 9.16 | 0.44 | 97.85 | 174.53 | 2.83 |
| *Mareyopsis longifolia* | 6149 | 8.57 | 0.41 | 126.09 | 211.83 | 4.20 |
| *Diospyros suaveolens* | 5745 | 8.00 | 0.38 | 107.29 | 232.85 | 3.65 |
| *Diospyros crassiflora* | 5339 | 7.44 | 0.36 | 92.32 | 255.29 | 3.41 |
| *Rinorea sp.* | 3013 | 4.20 | 0.20 | 33.64 | 396.11 | 0.98 |
| *Strombosia pustulata* | 2916 | 4.06 | 0.19 | 166.00 | 24.04 | 7.46 |
| *Meiocarpidium lepidotum* | 2237 | 3.11 | 0.15 | 30.67 | 306.62 | 0.92 |
| *Diospyros bipindensis* | 1504 | 2.09 | 0.10 | 26.45 | 52.03 | 0.87 |
| *Pausinystalia macroceras* | 1491 | 2.07 | 0.10 | 105.33 | 76.95 | 5.04 |
| *Funtumia elastica* | 1393 | 1.94 | 0.09 | 81.68 | 38.15 | 3.61 |
| *Terminalia superba* | 1373 | 1.91 | 0.09 | 370.22 | 2.20 | 22.86 |
| *Gilbertiodendron dewevrei* | 1311 | 1.82 | 0.08 | 371.06 | 32.71 | 24.36 |
| *Thomandersia hensii* | 1279 | 1.78 | 0.08 | 5.70 | 278.42 | 0.15 |
| *Markhamia tomentosa* | 1264 | 1.76 | 0.08 | 88.38 | 8.58 | 4.12 |
| *Anthonotha fragrans* | 1246 | 1.73 | 0.08 | 30.53 | 21.93 | 1.16 |
| *Diospyros sp.* | 1233 | 1.71 | 0.08 | 17.58 | 46.39 | 0.53 |
| *Monodora myristica* | 1173 | 1.63 | 0.07 | 27.70 | 41.48 | 1.02 |
| *Oncoba gilgiana* | 1044 | 1.45 | 0.07 | 21.77 | 32.58 | 0.71 |
| *Polyalthia suaveolens* | 1026 | 1.43 | 0.06 | 97.84 | 108.25 | 4.73 |
| *Total* | 47,307 | 65.86 | 3.11 | 1898.1 | 2340.94 | 92.61 |

Ni = number of individual of species I, A = abundance, ISH = shannon index, BA = basal area, D = density, AGB = above ground biomass

**Table 4** Abundance of individuals following the class of dbh

| dbh | Ni | Number of species | Number of genera | Number of family | A |
|---|---|---|---|---|---|
| <5 cm | 2517 | 85 | 49 | 29 | 3.51 |
| 5≤dbh<10 | 14822 | 140 | 102 | 40 | 20.66 |
| ≥10 cm | 54386 | 209 | 151 | 47 | 75.82 |
| Total | 71725 | | | | 99.99 |

Ni = number of individual i, A = abundance

**Table 5** Diversity and abundance of the types of land used (TLU)

| TLU | Ni | A | ISH | BA | D (ind ha$^{-1}$) | AGB (t ha$^{-1}$) |
|---|---|---|---|---|---|---|
| Primary forest | 22590 | 31.49 | 1.52 | 1832.12 | 1181.34 ± 0.54 | 106.30 ± 21.8 |
| Secondary forest | 46075 | 64.24 | 3.11 | 3609.31 | 2390.59 ± 0.54 | 205.85 ± 21.8 |
| Wetland | 3060 | 4.26 | 0.20 | 120.63 | 127.11 ± 0.54 | 5.88 ± 21.8 |
| Total | 71725 | 100 | 4.85 | 5562.03 | 3699.03 ± 0.54 | 318.04 ± 21.8 |

Ni = number of individual of species I, A = abundance, ISH = shannon index, BA = basal area, D = density, AGB = above ground biomass

**Table 6** Economic evaluation of the ecological service

| | Litter | Herbs and shrubs | Small roots | Big roots | Timbers | Total |
|---|---|---|---|---|---|---|
| Tons of C ha$^{-1}$ | 3.1 | 0.605 | 7.35 | 45.1 | 318.04 | 374.2 |
| Total in Park | 675,347.4 | 131,801.67 | 1,601,226.9 | 9,825,215.4 | 69,286,286.16 | 81,520,966.8 |
| Value in USD | | | | | | 1, 434, 769, 015.68 |

Carbon in tonnes ha$^{-1}$, economic estimation in USD

4.8 USD per tonne of carbon, gave a value of 1,434,769,015.68 USD.

## DISCUSSION

### Abundance and diversity

The remarkable presence of Euphorbiaceae, Ebenaceae and Annonaceae corroborate pre-existing investigations in the Dja Biosphere Reserve and Djoum Forest (Sonké 2004, Zapfack 2005, Zapfack et al. 2013, Kengne 2007, Tabué 2014). Not only was Euphorbiaceae the most abundant family, it was also the most diversified, ISH = 1.05 (Table 1). This Euphorbiaceae dominance is confirmed by a high diversity and abundance of *Dichostemma* and *Mareyopsis* which were amongst the important genera of the flora. The importance of Ebenaceae was confirmed by the high presence of *Diospyros* which was the most abundant genus in the park. The remarkable presence of *Meiocarpidium*, the 5th genus of the flora, justified the abundance of Annonaceae in the park. In the Dja Reserve, *Polyalthia* was amongst the most diversified genus (Sonké 2004, Tabué 2014). The high abundance of *D. glaucescens* and *M. longifolia* on one hand and *D. suaveolens* and *D. crassiflora* on the other hand justified the abundance of Euphorbiaceae and Ebenaceae respectively.

### Biomass

For the entire Park, the stock of carbon was estimated at 374.2 tonnes of C ha$^{-1}$. This stock was comparable with the study of Rana et al. (1989) in the Himalayan region who concluded that the carbon allocation in seven dominant forest types of the region ranges from 166.8 tonnes of C ha$^{-1}$ to 440.1 tonnes of C ha$^{-1}$. This value was very high compared to that of Djuikouo et al. (2010) in heterogeneous *terra* firme forests, *G. dewevrei* forests and periodically flooded forests in the Dja Reserve, and with many anterior results in the tropics (Saugier 1999, Clark & Clark 2000, Dewalt & Chave 2004, Robert & Saugier 2004, Chave et al. 2005, Picard et al. 2006, Lewis et al. 2009). Carbon stocks were significantly higher than those obtained in agro-ecosystems in the centre of the Himalayas in India, in tropical moist lowland forests in Costa Rica and in young stands of *Annona reticulata* and *Annona squamosa* in the Campus of Aurangabad University (Prakash & Lodhiyal 2009, William et al. 2011, Chavan & Rasal 2012). The total $CO_2$ concentration was very high explaining an important ecological service provided by the park.

The stock of carbon was directly correlated with the DBH of trees as shown in the regression curve. There was a correlation between basal area and DBH. This could be easily explained as it has been shown that the basal area depends on DBH. *Thomandersia hensii* with a mean basal area of 5.7 $m^2$ stored 0.15 tonne of C $ha^{-1}$ thus, *G. dewevrei, T. superba* and *Strombosia pustulata* with an average basal area of 371.06, 370.22 and 166 have sequestered 24.36, 22.86 and 7.46 tonnes of C $ha^{-1}$ respectively. Basal area and DBH are important factors for carbon stocks. The economic value (USD 1,434 million) of carbon storage in 217,854 ha of the Lobeke forests would be higher if biomass from liana and soil were included.

## CONCLUSION

The study showed the importance of tropical forests in sequestration of $CO_2$. Comparing the value obtained in this study with that from many tropical rain forests, the Lobeke National Park could be designated as a carbon sink within the Congo basin in Africa. In regards with the quantity of $CO_2$ estimated at the end of the investigation, Lobeke National Park could provide an important ecological service to the world. In the context of REDD, and since natural forests are under degradation due to exploitations necessary for development, such conserved forests are welcomed in mitigating climate change for the welfare of humanity.

## ACKNOWLEDGEMENT

This work was conducted in the framework of the Fondation du Tri-National de la Sangha (FTNS). The authors sincerely thank the general manager and the staff of the foundation.

## REFERENCES

Anonymous 2003. *Programme Sectoriel Forêt Environnement (PSFE).* MINEF, Yaoundé.

Anonymous 2006. *Les Forêts du Bassin du Congo.* Rapport Partenaire pour les Forêts du Bassin du Congo (PFBC). COMIFAC, Yaoundé.

Anonymous 2008. *Etats des Forêts du Basin du Congo.* COMIFAC, Yaoundé.

Baes CF, Goeller HE, Olson JS & Rotty RM. 1977. Carbon dioxide and climate: the uncontrolled experiment. *American Scientist* 65: 310–320.

Baker TR, Phillips O, Malhi Y et al. 2004. Increasing biomass in Amazonian forest plots. *Philosophical Transactions of the Royal Society B: Biological Sciences* 359: 353–365.

Chavan BL & Rasal GB. 2012. Carbon sequestration potential of young A reticulate and *Annona squamosa* from University campus of Aurangabad. *International Journal of Physical and Social Sciences* 2: 193–198.

Chave J, Andalo C, Brown S et al. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87–99.

Chave J, Jean O, Frans B et al. 2007. Above ground biomass cycling in a rain forest of Eastern South America. *Journal of Tropical Ecology* 24: 355–366.

Christopher P, Brooks GV, Klooster S, Bobo M & Torregrosa A. 2001. Biomass burning losses of carbon estimated from ecosystem modeling and satellite data analysis for the Brazilian Amazon region. *Atmospheric Environment* 35: 1773–1781.

Clark DB & Clark DA. 2000. Landscape-scale variation in forest structure and biomass in tropical rain forest. *Forest Ecology and Management* 137: 185–198.

Dallmeier F, Kabel M & Rice R. 1992. Methods for long-term biodiversity inventory plots in protected tropical forest in long term monitoring of biological diversity in tropical area: methods for establishment and inventory of permanent plots. Pp 11–46 in Dallmeier F (ed) *MAB Digest 11.* UNESCO, Paris.

Dewalt JS & Chave J. 2004. Structure and biomass of four lowland neotropical forests. *Biotropica* 36: 7–19.

Djuikouo MN, Doucet JL, Nguembou CK, Lewis SL & Sonke B. 2010. Diversity and aboveground biomass in three tropical forest types in the Dja Biosphere Reserve, Cameroon. *African Journal of Ecology* 48: 1053–1063.

Dziedjou-Kwouossu PJ. 2011. Evaluation des stocks de carbone a la périphérie nord du parc national de Lobéké (village Libongo): perspectives de valorisation. MSc. thesis. University of Dschang, Dschang.

Ecosystems Marketplace. 2008. *State of the Voluntary Carbon Market.* Forest Trends, Columbia. www.ecosystemmarketplace.com.

Ekobo A. 1995. Conservation of the African forest elephant (*Loxodonta africana cyclotis*) in Lobéké, Southeast Cameroon. PhD thesis. University of Kent, Canterbury.

Emana S, Henk H, Léonard U & Mathias H. 2009. *Affectation des Terres dans le Complexe D'aires Protégées de la Sangha (TNS) : Etat D'occupation Actuelle des Terres et Orientations Générales de Gestion.* FTNS, Yaoundé.

Kengne OC. 2007. *Biodiversité et Savoir-Faires Locaux dans le Village Nkoleyeng.* Msc thesis. University of Yaoundé I, Yaoundé.

Letouzey R. 1985. *Notice de la Carte Phytogéographique du Cameroun au 1:500000è.* Institut de la Cartographie Internationale de la Végétation, Toulouse.

Lewis LS, Lopez-Gonzalez G, Sonke B et al. 2009. Increasing carbon storage in intact African tropical forests. *Nature* 457: 1003–1006.

Matthews E, Payne R, Rohweder M & Murray S. 2000.

Forest ecosystem: carbon storage sequestration. Carbon sequestration in soil. *Global Climate Change Digest* 12: 19–99.

Noiha NV, Zapfack L & Mbade LF. 2015a. Biodiversity management and plant dynamic in a cocoa agroforest (Cameroon). *International Journal of Plant & Soil Science* 6: 101–108.

Noiha NV, Zapfack L, Ngueguim JR, Tabue MRB, Ibrahima A & Mapongmetsem PM. 2015b. Sequestered standing carbon stock in selective exploited timbers grown in tropical forest: a case study from the national park of Lobeke (Cameroon). *Journal of Botanical Sciences* 4: 19–24.

Parry ML, Canziani OF, Palutikof JP, van der Linden PJ & Hanson CE. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge.

Picard N, Moussa B, Fadiala D et al. 2006. Évaluation de la productivité et de la biomasse des savanes sèches africaines: l'apport du collectif Savafor. *Bois et Forêt des Tropiques* 288: 75–80.

Prakash S & Lodhiyal LS. 2009. Biomass and carbon allocation in 8-year-old Poplar (*Populus deltoids* Marsh) Plantation in Tarai Agroforestry Systems of Central Himalaya, India. *New York Science Journal* 2: 49–53.

Rana BS, Singh RP & Singh SP. 1989. Carbon and energy dynamics of seven central Himalayan forests. *Tropical Ecology* 30: 253–264.

Robert M & Saugier B. 2004. Contribution des écosystèmes continentaux à la séquestration du carbone. *Edafologia* 11: 45–65.

Saugier B. 1999. Bilan carboné des écosystèmes forestiers. *Forest French Review*: 239–253.

Scholz I. & Schmidt L. 2008. *Reducing Emissions from Deforestation and Forest Degradation in Developing Countries: Meeting the Main Challenges Ahead.* Deutsches Institut für Entwicklungspolitik. German Development Institute, Germany.

Sonké B. 2004. *Forêts de la R*éserve du Dja (Cameroun). *Etude floristique et structurale. Meise.* National Botanical Garden of Belgium, Belgium.

Tabue MRB. 2013. Diversité floristique et stock de carbone dans la partie Est de la Réserve de Faune du Dja. MSc. Thesis. University of Yaounde I, Yaounde.

White L & Edwards A. 2001. *Conservation en Forêt Pluviale Africaine: Méthodes de Recherches.* Wildlife Conservation Society, New York.

William F, Federico EA & Rey-Benayas JM. 2011. Carbon accumulation in aboveground and belowground biomass and soil of different age native forest plantations in the humid tropical lowlands of Costa Rica. *New Forests* 262: 1400–1408.

WRI (World Resources Institute). 2009. *Des Forêts du Bassin du Congo pour le Climat Global : Questions et R*éponses pour *Appréhender les D*éfis et les *Opportunités de la REDD.* World Resources Institute, Washington.

Zapfack L, Noiha NV, Dziedjou KPJ, Zemagho L. & Fomete NT. 2013. Deforestation and Carbon Stocks in the Surroundings of Lobéké National Park (Cameroon) in the Congo Basin. *Environment and Natural Resources Research* 3: 78–86.

Zapfack L. 2005. *Impact de l'agriculture itinérante sur brûlis sur la biodiversité végétale et la séquestration du carbone.* PhD thesis. University of Yaounde I. Yaounde.

 