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Plant Diversity and Carbon Storage Assessment in an African Protected Forest: A Case of the Eastern Part of the Dja Wildlife Reserve in Cameroon

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Abstract: Although the forests of the Congo basin are known for their richness in species, there are still several works in assessing their biomass. Mindful of this fact, the present study performed in the Dja biosphere reserve aims to assess plant diversity and carbon stocks. 10 transects of 5 ha each were assessed. 9,293 individuals divided into 47 families, 150 genera and 205 species were recorded. Euphorbiaceae was the most important family. The overall carbon stocks assessed was, 354.73 Mg C/ha. In the secondary forest the quantity of carbon stocks evaluated was 330.67±40.07 Mg C/ha. The Raphiales and Wetlands accumulated a quantity of carbon stocks of 15.06±0.08 and 9.00±2.06 Mg C/ha respectively. Euphorbiaceae stored an amount of 68.38 Mg C/ha, followed by the Mimosaceae which stores the amount of 51.07 Mg C/ha and the Irvingiaceae which stores an amount of 26.07 Mg C/ha. *Uapaca guineensis* stored 53.60 Mg C/ha. *Pentaclethra macrophylla*, *Petersianthus macrocarpus* and *Desbordesia glaucescens* all stored 117.56 Mg C/ha. For an index of diversity of 3.71, secondary forest stores approximately 93% of the total carbon stock. The test of comparison carried out showed a significant difference between the carbon stocks obtained on the land cover type (LCT) (ANOVA, F = 45.76; P < 0.001).

Keywords: Biomass, Carbon Stock, Dja Wildlife Reserve, Plant Diversity, Land Cover Type

1. Introduction

The humid tropics have been identified as a great reservoir of carbon into the atmosphere, priory because of the high deforestation rates and the frequency of burned biomass [1-2]. Forests play an important role in global carbon cycling, since they are large pools of carbon as well as potential carbon sinks and act as the atmosphere's cleanser. Tropical forests cover a surface area of more than 13 million km^2; corresponding to 33% of total forest area on earth [3]. Those of Central Africa account for about 20% of the total surface area of tropical forests [3]. From the biological point of view, these forests are probably the most threatened of the world. The Dja biosphere reserve is one of the most important forest located in the Congo basin [4]. After a long discussion on the contribution of forest ecosystems to the global carbon cycle, recognizing forest's importance through a process of Reduced Emissions from Deforestation and Degradation (REDD) mechanism, will not only be for its ability to absorb anthropogenic carbon but also, its function as carbon reservoir. Both these functions have been estimated globally in the absorption of approximately 3 Pg C year^{-1} (3 billion tons year^{-1}) through net growth (30% of CO_2) emissions from fossil fuel and deforestation) and the storage of an amount of carbon greater than that found in the atmosphere [5].

There is a great variation in the biomass estimates for different tropical forests (170.3-689.7 Mg ha^{-1}) [6-11]. The wide differences in the biomass estimates may result from variations in tree species and their strata within mature forest types on different soils or landform units, altitudes or regions [8, 12-13]. Accurately quantifying the role of tropical forests in the global carbon cycle is one of the key requirements to improving our understanding of current patterns of terrestrial carbon storage and exchange [12, 14-17]; humans emitted 8.7 Pg C yr^{-1} from fossil fuel use and 1.2 Pg C yr^{-1} from land-use change in 2008. In these emissions only approximately 3.9 Pg C yr^{-1} was added to the atmosphere, with the rest be absorbed by the oceans (2.3 Pg yr^{-1}) and terrestrial biosphere (4.7 Pg yr^{-1}) [18]. Tropical forests are implicated in both the emissions from land-use change, which are predominantly attributed to tropical deforestation [19], and absorbing a significant fraction of the carbon added to the atmosphere (1.3 Pg C yr^{-1}) over recent decades [16].

A most recent work carried in the Dja biosphere reserve reported more than 254 species and 44 families [20]. The present study carried out in the eastern part of the Dja biosphere Reserve aims to 1) harvest trees of diameter of breast height (dbh) ≥ 10 cm; 2) estimate the carbon sequestered in this part of the reserve and 3) assess the carbon stocks of the most taxonomic groups.

2. Material and Methods

2.1. Study Site

The eastern part of the Dja biosphere reserve is located in Lomié sub-division at about 350 Km from Yaoundé (Fig. 1). From the phytogeographic point of view, the forests have been classified as a moist evergreen tropical forest (Letouzey 1985). Relief maps show many shallow valleys. Average altitude is approximately 600 m. Precambrian crystalline metamorphic rocks, comprising schists, gneisses and quartzite [21] are overlain by soils that are red ferralitic, porous, sometimes more or less humus-bearing with areas that are hydromorphic because of the proximity of the groundwater [22]. Four seasons alternate during the year including two dry and two moist seasons, with approximately 1512 mm of rainfall per year, with 3 months having rainfall <100 mm. Mean annual temperature is 24.3°C, with mean monthly minimum temperatures of 23.4°C and mean monthly maximum temperatures of 26.5°C [23].

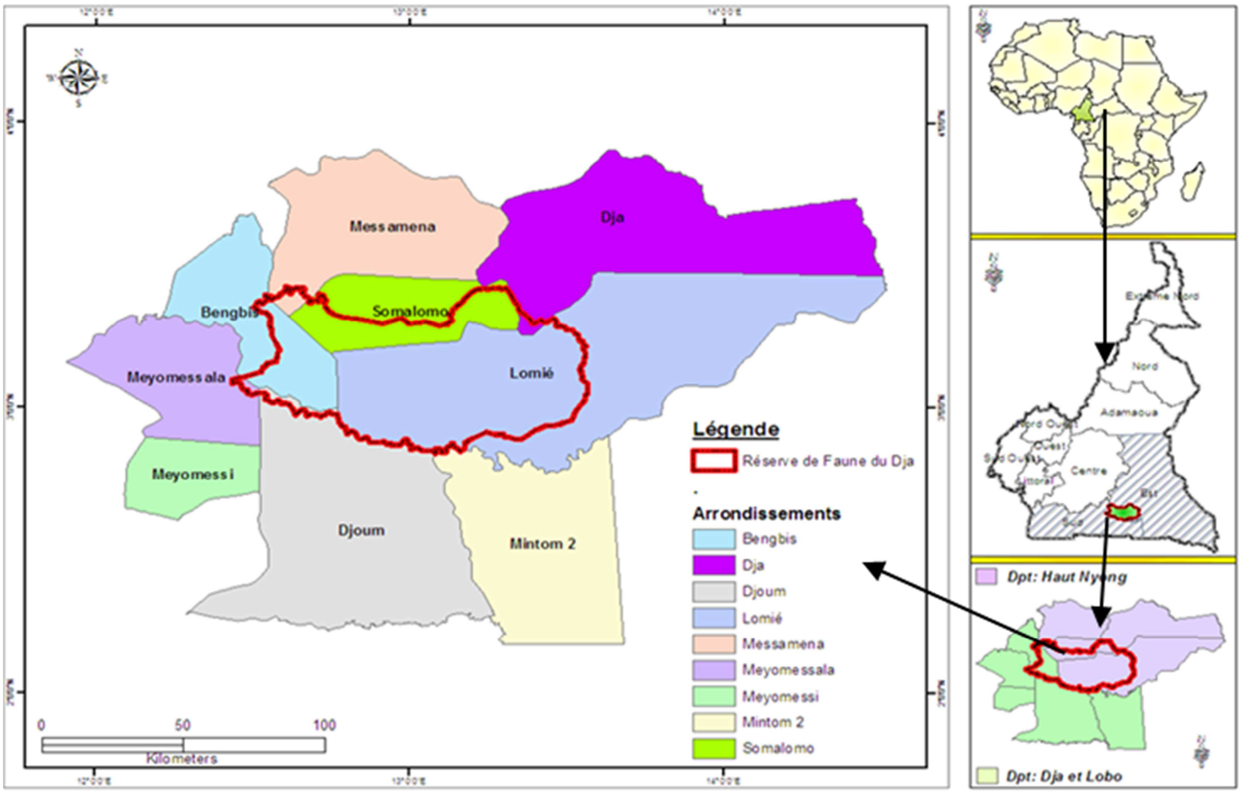

Fig. 1. *Localization of site.*

2.2. Data Collection

Data were collected in 10 transects of 2.5 km in length over 20 m in width each (Fig. 2). On each transect, all the trees of dbh ≥ 10 were measured in counting units which are the parcels of 250mx20m. The identification of species was made with the use of botanical keys and personal knowledge. For unidentified species on the field, specimens were selected for identification at the national herbarium of Yaoundé. On each transect, the dbh, the abundance of trees and their scientific names were recorded. For each transect, the area of each land cover type (LCT) was measured and the total area was obtained by summing up the partial areas of the 10 transects.

The assessment of the above ground biomass of trees was made by using the non-destructive method. Thus, the allometric formula used for the evaluation of tree biomass based on climatic index [24] and the dendrometric data collected on trees such as dbh and wood density were usually used. Knowing that it is very difficult to measure the tree height in forest, this variable was not considered.

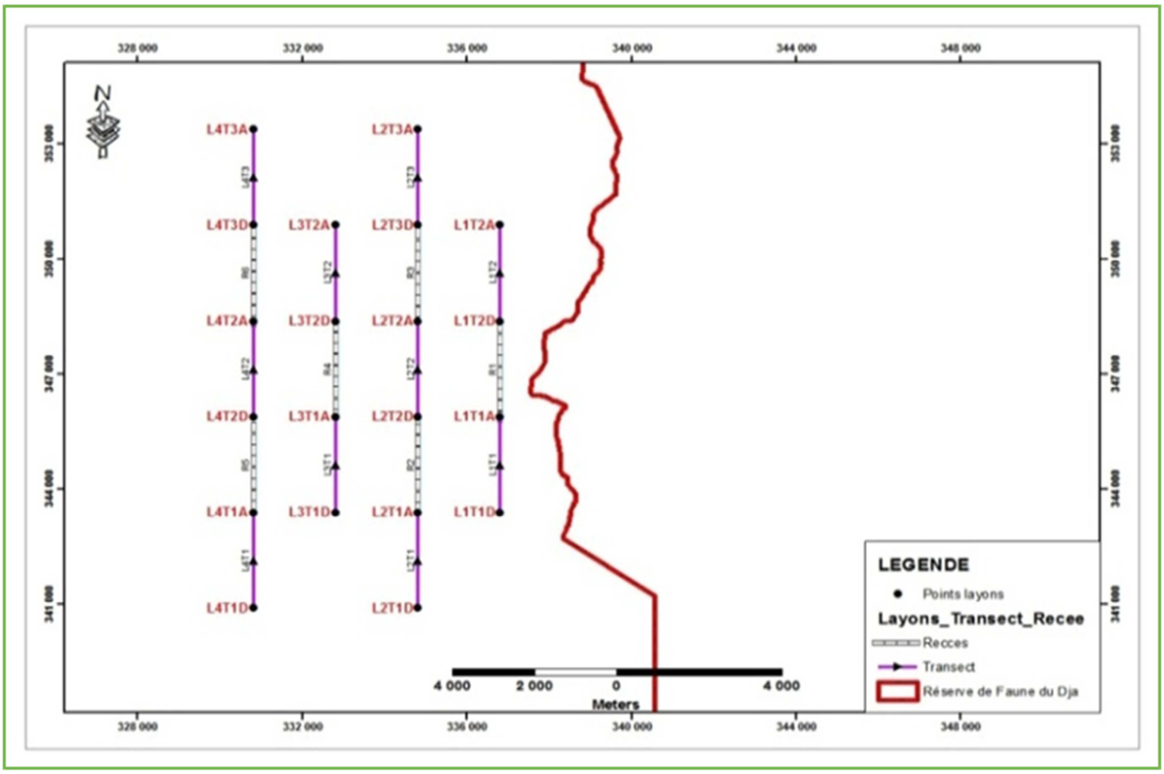

Fig. 2. *Sampling cartography.*

2.3. Data Analysis

The characterization of the diversity of trees found in the study area was done using multiple indices which are: Shannon's index: ISH= - Σ Ni/N $\log_2$ Ni/N where Ni= number of individuals of the i^{th} species and N= number of individuals of all species present in sample; Simpson's index: D'= Σ $(Ni/N)^2$ and Evenness EQ: EQ= ISH/$\log_2$ N. Basal area (BA) was used to determine stand characteristics or stand density: quantitative measure of the degree of stem crowding in a stand, were expressed in terms of basal area per unit area. The following formula was used to calculate basal area: BA =π × $DBH^2/4$.

The allometric formula used to evaluate the above ground biomass of the eastern part of the Dja wildlife reserve was that of Chave *et al*. [13]. This formula was developed with data collected on 4004 trees amongst which those of African tropical forests. Furthermore, this formula contrary to other pan tropical formulas developed till date in addition to the dbh of tree and the wood density. This formula goes thus: AGB (kg) =(α/0,6) Exp [-3,742 + 3,450*ln(D) - 0,148*$(\ln(D))^2$]; AGB = above ground biomass; ρ = wood density of tree species (g. cm^{-3}); D = dbh of tree (cm).

The wood densities of each species were obtained from the Global Wood Density Data Base [25]. For the tree species of which the densities remain unknown, we used the mean of densities of the trees belonging to the same genera and found in African tropical forest. The amount of biomass assessed on each transect was extrapolated at the hectare level. The amount of carbon stored per hectare was obtained by multiplying the biomass by 0.5 coefficient [26].

The one way Analysis of variance (ANOVA) was used to test the significant difference between the biomass in different LCT. This test was completed by the HSD test of Tukey to compare the LCT two by two. The conventional risk of error was adopted at P = 5% of Shapiro-Wilk test was used to test the normality of our data about LCT biomass. The parity test was done between stocks of carbon and abundance of trees.

3. Results

3.1. Vegetation

9,293 individuals divided into 47 families, 150 genera and 205 species were identified. The Loganiaceae was the only mono-generic and mono-specific family. Nineteen (19) families representing 92% of the flora with 8,500 individuals were the most abundant. These families were divided into 105 genera and 148 species. The Euphorbiaceae was the most abundant with 2.064 individuals representing 22.34% of the flora and the most diversified with 15 genera and 20 species; followed by the Apocynaceae, Myristicaceae, Sapindaceae, Lecythidaceae, Irvingiaceae, Meliaceae, Mimosaceae, Olacaceae, and Annonaceae (Table 1).

Table 1. *The top 19 most abundant families.*

	Absolute abundance			Relative abundance		
Families	**Number of individuals**	**Genera**	**Species**	**% individuals**	**% genera**	**% species**
Anacardiaceae	147	5	6	1.59	3.31	2.89
Annonaceae	960	9	13	10.39	5.96	6.28
Apocynaceae	325	5	6	3.51	3.31	2.89
Burseraceae	254	3	3	2.74	1.98	1.44
Caesalpiniaceae	294	11	14	3.18	7.28	6.76
Clusiaceae	134	5	6	1.45	3.31	2.89
Euphorbiaceae	2064	15	20	22.34	9.93	9.66
Irvingiaceae	477	3	7	5.16	1.98	3.38
Lecythidaceae	384	1	1	4.15	0.66	0.48
Meliaceae	530	7	14	5.73	4.63	6.76
Mimosaceae	533	7	9	5.76	4.63	4.34
Myristicaceae	336	3	3	3.63	1.98	1.44
Olacaceae	748	4	6	8.09	2.64	2.89
Rubiaceae	157	8	9	1.69	5.29	4.34
Sapindaceae	380	1	1	4.11	0.66	0.48
Sapotaceae	157	6	9	1.69	3.97	4.34
Sterculiaceae	265	7	14	2.86	4.63	6.76
Tiliaceae	203	4	4	2.19	2.64	1.93
Ulmaceae	152	1	3	1.64	0.66	1.44
Total	8500	105	148	92.01	69.53	71.49

Cola was the most diversified genus with 6 species representing 2.89% of the species; followed *Entandrophragma* (5 species) and *Diospyros* (5 species). *Uapaca* was the most abundant genus with 1,035 individuals representing 11.2% of the flora. *Uapaca*, *Plagiostyles*, *Polyalthia*, *Petersianthus*, *Eriocoelum* and *Pentaclethra* were the mono-specific genera. *Plagiotyles africana*, *Polyalthia suaveolens*, *Petersianthus macrocarpus*, *Eriocoelum macrocarpum* and *Pentaclethra macrophylla* were the most important species with 742, 451, 384, 380 and 334 individuals respectively.

Three Land cover types (LCT) were crossed: secondary forest, Raphiales and wet lands. The absence of the primary forest indicated the presence of intensive human activities on site for a long period. Total diversity for the index of Shannon (ISH) was 4 and 1 for Evenness (EQ) (Table 2). ISH ranges from 0.11 to 3.71 in different LCT. The higher value of ISH and EQ obtained in secondary forest explain the dominance of the flora by species such as *Uapaca guineensis*.

The mean basal area for trees with dbh ≥ 10 cm was 23.03 m²/ha for an average dbh of 32.34 cm. This value varies between 1.52 to 2.63 m²/ha in transects.

Table 2. *Diversity and carbon stocks in ecosystems according equation of Chave et al. [13]. ISH: Shannon index; EQ: Evenness; LCT: Land cover type; FII: secondary forests; W: wetlands; R: raphiales; A: abundance; BA: basal area.*

LCT	ISH	EQ	A	BA (m^2/ha)	Carbon stocks (Mg C/ha)
FII	3.71	0.93	174	99.40±0.17	330.67±40.07a
W	0.11	0.028	11	5.93±0.16	9.00±2.06b
R	0.15	0.037	69	44.56±0.16	15.06±0.08b

Data affected with same letter explain that there is no significant difference.

3.2. Carbon Stocks

Carbon stock and biomass have been deducted from 9,293 trees with a dbh of at least 10 cm. The amount of carbon stored in forest was 354.73 Mg C/ha. In different LCT, we are found 330.67±40.07 Mg C/ha in secondary forest; Raphiales and Wetlands stored 15.06±0.08 and 9.00±2.06 Mg C/ha respectively.

At the family level, Euphorbiaceae stored approximately 68.38% of the total stock. This family is followed by the Mimosaceae with 51.07Mg C/ha; and the Irvingiaceae with about 26.07 Mg C/ha (Table 3). Ten families have stored 262.57 Mg C/ha representing 73.64% of the total stock.

Table 3. *Amount of carbon stored in ten most abundant families.*

Families	Carbon in t/ha	% individuals	Mean DBH
Sterculiaceae	4.03	2.85	34.44
Olacaceae	4.84	8.04	25.86
Apocynaceae	5.04	3.49	32.73
Lecythidaceae	5.15	4.13	35.18
Annonaceae	6.61	10.33	26.08
Caesalpiniaceae	6.95	3.16	41.63
Meliaceae	7.54	5.7	32.68
Irvingiaceae	9.02	5.13	37.68
Mimosaceae	17.67	5.73	51.84
Euphorbiaceae	23.66	22.21	30.69

At the specific rank, *Uapaca guineensis* has stored more carbon with 53.60 Mg C/ha representing approximately 15% of the total stock; followed by *Pentaclethra macrophylla*, *Petersianthus macrocarpus* and *Desbordesia glaucescens*. The amount of carbon stored by these species was 117.56 Mg C/ha representing 33.10% of the total stock.

At the ecological point of view, the abundance and diversity of species are important factors in the sequestration of carbon (Table 3). For an index of diversity of 3.71 secondary forest which stores approximately 93% of the total carbon stock in Eastern part of the Dja biosphere reserve.

3.3. Comparison of Biomass in Different LCT

The Shapiro - Wilk normality test conducted showed that the data are not normally distributed (W = 0.8206; p-value = 0.003945). The test of comparison shows a significant difference between the carbon stocks by LCT (ANOVA, F = 45.76; P < 0.001). Tukey's test also showed a significant difference between the carbon stocks of secondary forests and wetland (t-value = 9,401; P < 0.001); carbon stocks of secondary forests and Raphiales in the other hand (t-value = 3,941; P < 0.01) (Fig. 3). Contrarily, there were no significant difference between carbon stocks in raphiales and wetland (t-value = 2.506; P = 0.05950). Considering the abundance of trees/ha, the ANOVA test gave similar results to those of carbon stocks. There were therefore a significant difference between tree density in secondary forests and wetlands (t-value = 7,064; P <0.001) and between secondary forests and raphiales (ANOVA, P < 0.01). Contrarily, there were no significant difference between raphiales and wetlands (ANOVA, P = 0.53445). The parity test between tree density and carbon stocks (ANOVA; df = 16; p- value = $9.928e^{-05}$) confirms these information. Thus, besides the basal area, the tree density affects carbon storage.

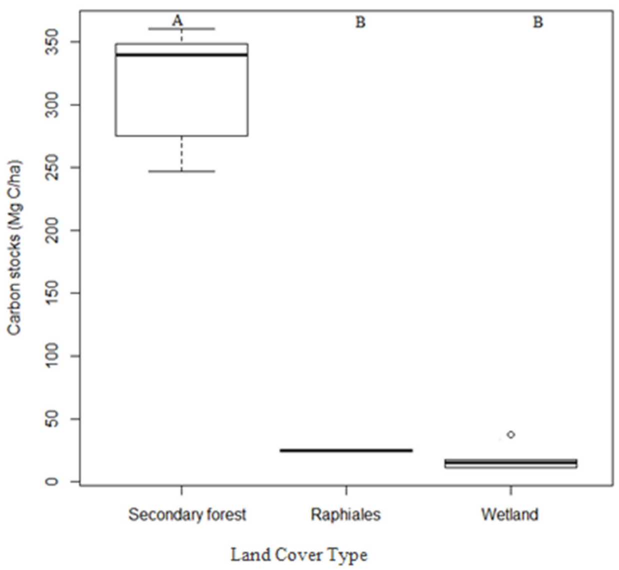

Fig. 3. *Carbon accumulation variations between types of land cover type.*

4. Discussion

The investigation yielded 9,293 individuals divided into 47 families, 150 genera and 205 species. The abundance of the Euphorbiaceae confirms the results already obtained in the several inventories made in many tropical forests [9-10, 27-30]. Annonaceae occupies more than 10% of the flora; these results are not surprising, since Sonké [28] reported a relative importance of *Polyalthia suaveolens* in the northern part of the reserve. The significant presence of species of the Malvaceae and the Ulmaceae confirms Letouzey's observation [31] who considers the flora as a transition zone between semi-deciduous forest and evergreen forest.

The overall carbon stock was 354.73 Mg C/ha which is comparable with a most recent works carried out in Cameroon [9] and higher than many others in the rainforests of the Congo Basin [10-11, 29, 33-34]. From the taxonomical point of view, Euphorbiaceae stored more carbon followed by Mimosaceae and Irvingiaceae. *Uapaca guineensis* was the most important species. The biomass from *Pentaclethra macrophylla, Petersianthus macrocarpus* and *Desbordesia glaucescens* (117.56 Mg C/ha) was comparable to the results in tree plantations in many countries such as the centre of the Himalayas in India and farm systems of the humid tropical forests of low altitude and young stands of *Annona reticulata* and *Annona squamosa* in Costa Rica [35-42]. Although this work has not taken into account belowground carbon as considered in the results in Costa Rica, the importance of the resulting stock is located at the level of the age of the agro systems; in Costa Rica, carbon stocks were evaluated in the plantations from 0-16 years and those of the India plantation from 0-8 years; the Dja biosphere Reserve is a protected area created since 1950 and therefore contains old stems.

Considering the LCT, given the fact that the secondary forests occupies a large surface area compared to the Raphiales and Wetlands; they also present a high population density which explains the differences observed between the results of the carbon stocks in secondary forests, raphiales and wetlands which are 330.67, 15.06 and 9.00 Mg C/ha respectively. However, the amount of the carbon stock obtained in the secondary forests in this study is 330Mg/ha and is slightly close to 298 Mg/ha obtained by Djuikouo *et al.* [9] in heterogeneous terra firme forests. By the way, these same authors obtained amount of carbon stocks in periodically flooded forests which are far above those obtained in wetlands in this study. This difference could result from the different methods used.

5. Conclusion and Recommendation

This study reveals that the eastern part of the Dja wildlife reserve is well diversified. In fact, we identified more than 200 tree species in coverage of 50 ha of sampled forests. We also noted the dominance of the Euphorbiaceae family amongst the families which constitute the flora core of this part of the reserve.

Uapaca guineensis is the most abundant at the specific level which explains the high diversity indices of ISH and EQ.

On the ecological plan, three land cover types which are dominated by the secondary forests have been assessed. This situation also explains the abundance of young stems and pioneer species such as *Musanga cecropioides* in this forest. The distribution of diameter classes shows that almost 80% of individuals assessed are found in diameter classes less than 60% which is evidence that this part of the reserve was illegally exploited. These individuals are mostly commercial species whose minimum exploitability diameter following the norms of forest logging and the forest law in Cameroon is 100 cm. This report makes this part of the reserve a potential carbon sink in the future decades and makes it eligible for REDD+ pilot projects.

The carbon present in the biomass was over 354 Mg C/ha but the carbon accumulation in the soil was not evaluated. Although many works have reported that the soil is the main carbon stocks at an ecosystem level, the stem represents the most important component from tree biomass.

It was noticed that the families constituting the flora core of this part of reserve stored almost 262 Mg C/ha and the Euphorbiaceae are the first with a total stock of 68.38%. The relative dominance of *Uapaca guineensis* makes it the species which stored more carbon that is 15% of the total stock. The secondary forests due to the high density of stems per hectare stored more than 330 Mg C/ha.

Considering the above we can recommend for the medium term the setting of a REDD+ pilot-project in this part of the reserve. The implementation of this project will create possibilities to get funding for the various activities of conservation. The deeper exploration of other parts of the reserve becomes imperative and urgent. This will permit a better understanding of the ecological phenomenon which occur in this protected area, to improve the biological knowledge of the diversity of tree and to assess the below carbon stock which are unknown. It is not evident to propose an allometric formula in central Africa because up to date there is none. While waiting that the COMIFAC (Central Africa Forest Committee) should develop the allometric formulae for central African forests, we are obliged to use the ones which are already established while taking to account data from the tropical African forests like that of Chave *et al.* [13, 24] which was used in this study.

Acknowledgments

Data available with permission from the authorities in charge of the conservation of the Dja biosphere reserve and we thank the Conservator of this protected area. We also express our gratitude to Rufford Small Grant Foundation who believed in this project and provide fund to carry out the project.

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