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Diversity, structure and carbon storage potential of the Dja Wildlife Reserve vegetation cover

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Abstract

The current study was carried out in the Dja Wildlife Reserve. The objectives of the study were to map the vegetation cover types, characterize the forest structurally and to estimate carbon stocks of the Dja Wildlife Reserve. The Landsat 8 satellite images processed using Erdas Imagine 2014 and Arc GiS 10.0 software were used to map the validated vegetation with the field information. Flora data were collected on 50 transects distributed in the different Types of vegetation cover. Thus, the vegetation map showed 11 types of vegetation cover in the Dja Wildlife Reserve. Seven (7) major types of vegetation cover were characterized and they had an overall diversity estimated at 270 species in 50 families and 187 genera. Tree densities ranged from 193 to 351 stems/ha while basal area ranged from 20.23 to 30.85 m^2/ha in different types of vegetation cover with an average of 26.12 m^2/ha for the studied forest. The diametric structure of the forest showed a decrease in the number of individuals with increasing diameter. Carbon stocks did not vary significantly between vegetation cover types with an estimated average of 2009.97t/ha (ANOVA, $p < 0.05$). The fact that 82.8% of individuals belonged to class [10-40] makes the Dja Wildlife Reserve an impressive carbon sink in the Congo Basin for decades to come.

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Introduction

Forests are of primordial importance considering the goods and services they provide to millions of people around the world (Adingra and Kassi, 2016).

In addition to wood supply, forests are critical habitats for the ecosystem services they provide (Miller and Tangley, 1991; Mendelsohn and Balick 1995; Pearce, 1999). Forests regulate local and global climate, improve soil stabilization, water retention and water quality, facilitate pollination, improve the aesthetics of the landscape, provide habitats for many animal and plant species and constitute a huge genetic information (Chiabai *et al.*, 2011; Tayo, 2014).

Tropical forests over the years are losing important vegetation cover, estimated at 7 million hectares a year (FAO, 2016). This loss of forest cover is due to natural causes (fire, diseases, earthquake and volcanism) or anthropogenic causes (logging, mining and expansion of agriculture).

The Food and Agricultural Organization (FAO) in 2008 estimated that the annual rate of deforestation in Cameroon was about 200 000ha and degradation rate of approximately 1%. In Cameroon, slash-and-burn shifting cultivation contributes 80% to deforestation and degradation and is therefore the main source of CO2 emissions into the atmosphere (Nnah and Klauss, 2014). Several authors have indicated that greenhouse gases are responsible for global warming (Dorvil, 2010; Muoghalu, 2014).

This issue is nowadays one of the main concerns of the international community. The definition of a global climate policy requires a reliable estimate of the carbon stocks of forest ecosystems (Torquebiau, 2002; Durot, 2013) and in this context, the assessment of wood resources in less disturbed forest ecosystems areseen as a better option of landuse system likely to help solve several environmental problems in tropical countries where deforestation remains a major concern (Torquebiau, 2002).Carbon storage is an ecosystem service that can be appreciated by knowledge of the composition and structure of the biotic community (Smith *et al.*, 2017).

Several studies have estimated carbon fluxes in forest ecosystems by measuring the net primary productivity (Waring *et al.*, 1998; Fahey *et al.* 2005; Siccama *et al.*, 2007; Richardson *et al.*, 2009).

During the definition and implementation of conservation policies created protected areas that constitute a mode of land use which favours the maintenance of the vegetation cover. Public authorities in the definition and implementation of conservation policies have created protected areas that are a land use mode that advocates the maintenance of vegetation cover.

The multiple pressures facing tropical forests make protected areas a true reservoir of biodiversity. Despite the protection statutes they enjoy, protected areas also face various pressures including multi-faceted poaching. To ensure a better management of the resources of these ecosystems, it is essential to know them by assessing their potential, the pressures or threats that weigh on them in order to plan relevant actions necessary for their preservation.

The objectives of the current study were to map the vegetation cover types, characterize the forest structurally and to estimate carbon stocks of the Dja Wildlife Reserve.

Material and methods

Location of study area

The Dja Wildlife Reserve stretches from the southern part of the South Region of Cameroon to the East Region, with 80% of its total surface area in the East Region and 20% in the South Region, 245 km southwest of Yaoundé and 2 km from the city of Lomié (Fig. 1).

The administrative area of the Dja Wildlife Reserve has a surface area of 526 000 ha and its geographical coordinates extend between 2°40'and 3° 23' N and 12° 25'and 13° 35' E(Salle and Monfort, 1999).

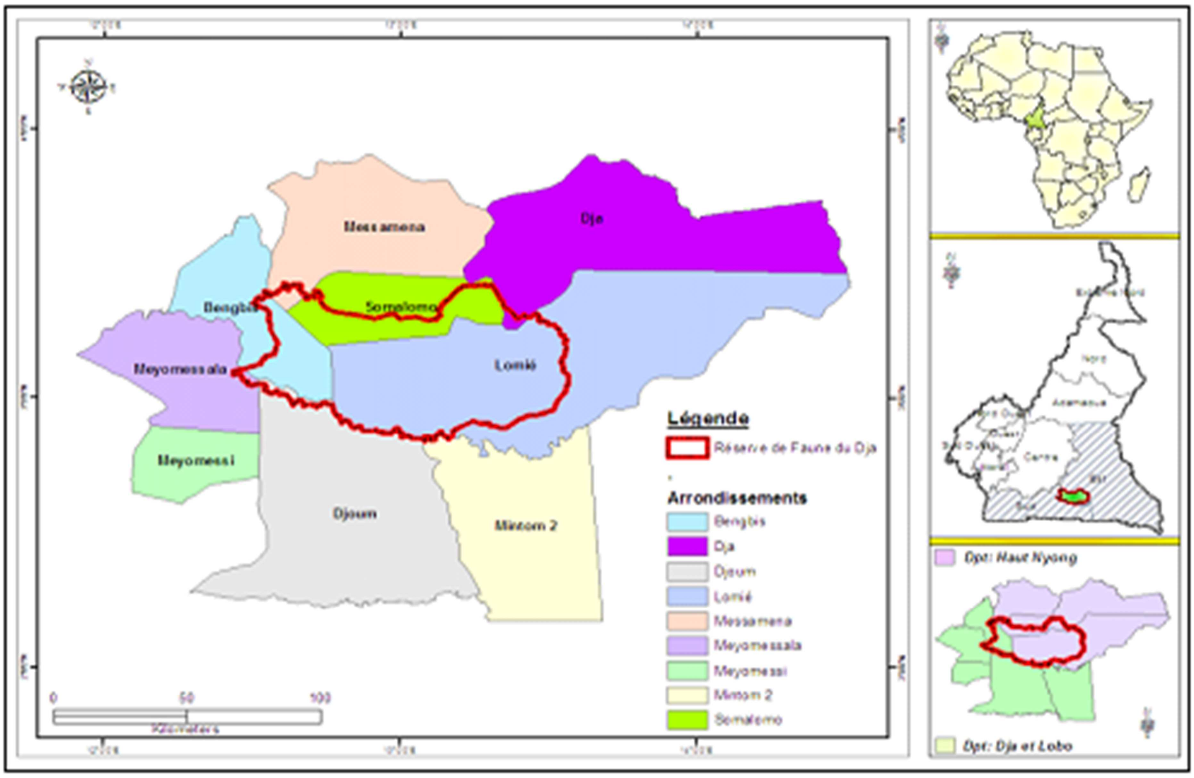


Fig. 1. *Administrative location Dja Wildlife Reserve.*

It is delimited on 3/4 of its perimeter by the Dja River which forms its natural limit. The vegetation of the Dja Wildlife Reserve is the Congolese, Dja type with evergreen forest belonging to the Guineo-Congolese domain. It consists of large trees sometimes attaining 50 to 60 m in height dominated by *Baillonella toxisperma* (Letouzey, 1968). The climate is the equatorial typewith four seasons slightly distinct (Letouzey, 1968). Monthly average temperatures from 1961 to 1994recorded at Sangmélima, Akonolinga, Lomié, Djoum and Messamena meteorological stations show that temperatures range from 23.5 °C to 24.5 °C with maximum in February and a minimum in July (Salle and Monfort, 1999).

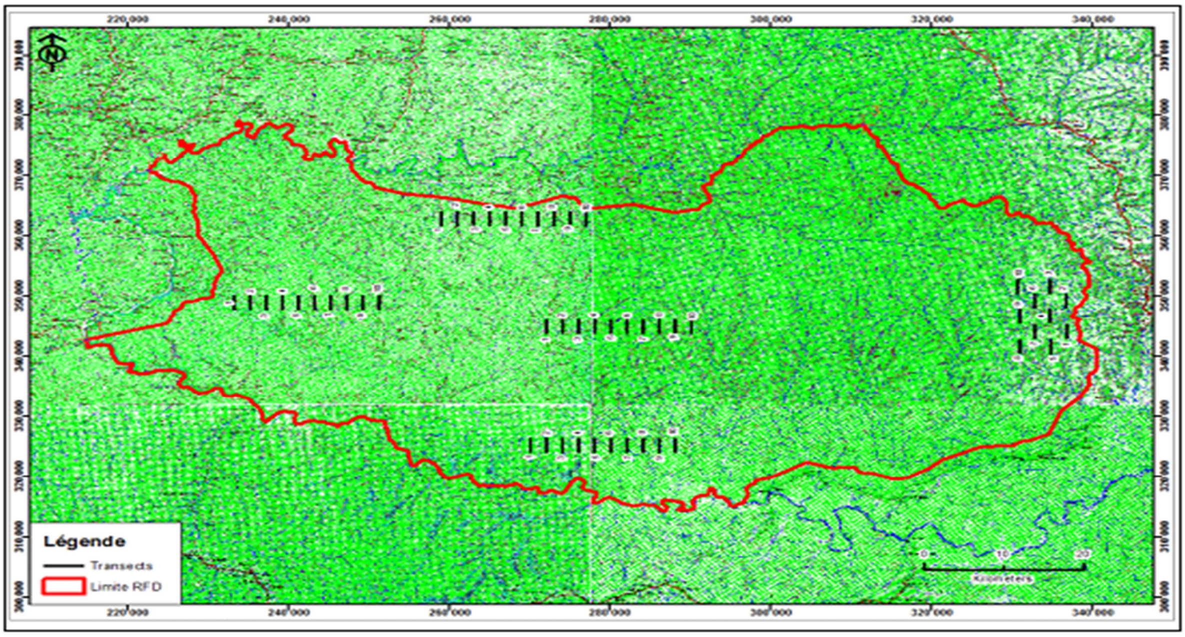
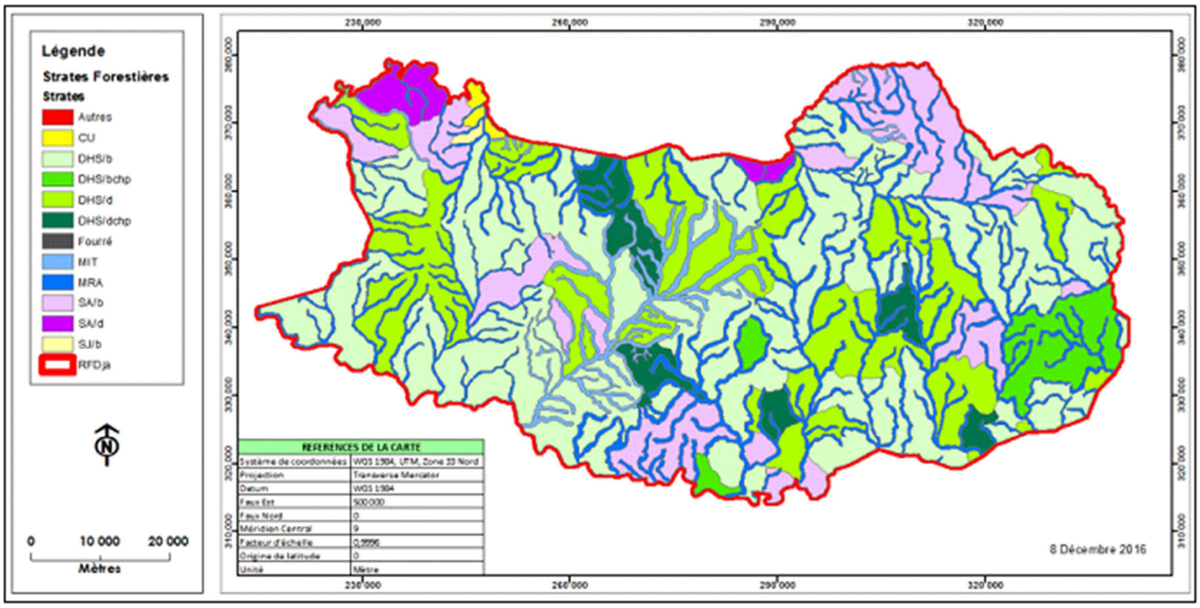


Fig. 2. Map of sampling design.

The Dja Wildlife Reserve belongs to the southern plateau of Cameroon with an average altitude of 600m. In general, the topography of the area presents alternating shallow valleys on either side of the ridge line that crosses the reserve from east to west. According to Letouzey (1985), the forests of the Dja Wildlife Reserve are based on schists, micaschists and possibly melanocratic rocks towards the East and of all materials that produce clay soils.



REFERENCES DE LA CARTE	
Système de coordonnées	WGS 1984, UTM, Zone 33 Nord
Projection	Transverse Mercator
Datum	WGS 1984
Faux Est	500 000
Faux Nord	0
Méridien Central	9
Facteur d'échelle	0,9996
Origine de latitude	0
Unité	Mètre

Fig. 3. Vegetation map of the Dja Wildlife Reserve. Legend. DHS b: High density dense humid evergreen forests; DHS d: low density dense humid evergreen forests; DHS CHP b: dense humid evergreen forest with high density of forest gaps; DHS CHP d: dense humid forest with low density of forest gaps; SA b: high density aged secondary forest; SA d: low density aged secondary forests; SJ b: high density young secondary forests; MIT: temporarily flooded swamps; MRA: raphiales swamps; F: Thickets; CU: Crops; Others: saline and rocks.

Methods

Mapping of the Dja Wildlife Reserve

The vegetation cover of the Dja Wildlife Reserve was studied by establishing a 1:50 000 scale maps. The map was developed from the analysis of Land Sat 8 satellite images by photo interpretation which made it possible to identify the different types of vegetation cover (TVC) that constitute the massif (Lebœuf *et al.*, 2015). This primary work was then superimposed on recent satellite images (land sat 8 mosaic) with a resolution of 30m for bands ranging from aerosol to mid-infrared 7bands covering the area. Firstly, the form of the image was obtained using Erdas Imagine 2014 software and radiometric and geometric corrections were done to improve the discrimination of the information layers and bring out the image in ageometry compatible with Geographic Information Systems (GIS) and image processing systems (Lu *et al.*, 2012). In a second step, a digital enhancement of the image was made to facilitate visual interpretation. From a supervised classification using the maximum likelihood algorithm by selection of pure pixels of the image, different spectral signatures were identified and confirmed by: the calculation of the confusion matrix, the evaluation of class reparability and spatial evaluation of the distribution of thematic classes. It was scanned using Arc Gis 10.0 software. The purpose of this superposition was to confirm the large sets of the vegetation cover types.

This software made it possible to determine the areas of each identified vegetation cover type and the field trips during the plant survey work helped to validate the information provided by the images (Lu *et al.*, 2011).

Data collection

Floristic inventory

Sampling in the 7 vegetation cover types selected for characterization studies was carried out in 50 transects of dimensions 2500 mx 20 m distributed in the North, South, Center, East and West portions of the Dja Wildlife Reserve, giving a total surface area of 250ha surveyed, corresponding to a sampling rate of 0.0475% (Fig.2). Each transect was segmented into 10 sub-plots of 250 mx 20 m (0.5 ha). In addition to the geographical coordinates collected, information on ligneous individuals encountered was also collected.

A total of 500 plots were sampled. The inventory in these subplots concerned all trees with diameter at breast height (dbh) ≥ 10 cm.For each of the sampled trees, in addition to their scientific and/or vernacular name, their diameters were measured at 1.30 m above the ground and 30 cm above the buttresses for trees with buttresses. Specimens were collected for trees surveyed and used to confirm their identifications at the Cameroon National Herbarium, Yaoundé. However, the field survey data were also used to validate the vegetation map obtained by supervised classification.

Biomass estimation

The dbh obtained during the inventories were used for the assessment of the aboveground biomass for the different tree individuals (Brown *et al.*, 1989).

The biomass of large trees roots inventoried was obtained by multiplying the above-ground biomass by a conversion factor of 0.24 (Mokany *et al.*, 2006).Litter was collected in square plots of 1 m^2 beginning at point zero (0 m), in the middle (1250 m) and at the end of each transect (2500 m). Samples of litter were enclosed in plastic bags, latter parcelled in envelops and dried in an oven and their dry weights were measured using a precision balance. On transects 2500 m long, the grasses were collected at the beginning (0 m), in the middle (1250 m) and at the end (2500 m) in of 0.5 x 0.5 m^2. These samples were cleared of fauna and soil and then packaged in airtight bags to prevent mixing. In the laboratory, they were transferred into envelopes, dried at constant temperature until a constant weight representing dry biomass was obtained.

The biomass of the soil roots or rootlets was estimated by collecting soil blocks in 20 x 20 cm and 20 cm depth square plots installed at the beginning (0 m), in the middle (1250 m) and at the end of each transect (2500 m). The soil samples were then separated from the roots by washing with water. A sufficiently fine meshed sieve was used to screen the low-density roots that floated on the water surface. These samples were packaged and then dried in an oven at constant temperature oven until constant weights representing dry biomass were obtained.

Data analysis

The R software was used for data analysis (R Core Team, 2016). Data normalization test was done using Shapiro-Wills test, the analysis of variance (ANOVA) and the Turkeys test were used to test the significance of the vegetation cover types for the parameters: basal area and carbon stocks. Principal Component Analysis (PCA) assessed the correlations between floristic diversity, structural parameters, and carbon stocks.

Description of the vegetation

For each TVC in the study area, the sampling effort was evaluated from the accumulation curves obtained by the scarcity method using the software package "Biodiversity R" (Kindt and Coe, 2005) of the free R statistics software (R Core Team, 2016).

Floristic diversity

Diversity indices were used to study the diversity of the Dja Wildlife Reserve. The Shannon's diversity index (H) was used to characterize plant species diversity in the study area (Frontier & Pichod-viale, 1993). The Shannon's diversity index was calculated using the formula:$H = -\Sigma \frac{Ni}{N} \log_2 \frac{Ni}{N}$, where Ni = number of i species; N = total number of species.

This index accounts for both abundance and the evenness of tree species present. This index gives more value to rare plant species (Guedje *et al.*, 2002).

Piélou equitability was calculated using the formula: $EQ = \frac{H}{\log_2 N}$, (Sonké, 2004). This index corresponds to the ratio of diversity observed to a maximum.

This index corresponds to the ratio of the observed diversity to the maximum possible diversity of the number of species (N). Piélou's equitability or Evenness (EQ) varies from 0 to 1. It is equal to 0 when almost all the numbers are concentrated on a single species. It tends to 1 when all species have substantially the same abundance. Low equitability is of high importance for some dominant species (Dajoz, 1982).Simpson's diversity index represents the probability at which two individuals taken at random in a studied population belong to different species (Tchoumi, 2001).It measures the manner in which individuals are distributed in a community. Simpson's index is calculated using the formula:$D = \boldsymbol{\Sigma}(\frac{Ni}{N})^2$.

Species richness indicates the total number of species in a studied population

Structure of plant populations

Structural elements that assisted in the characterization of this forest include basal area, distribution of diametric classes, average diameter, number of stems per hectare, and ecological importance value index (IVI). The basal area is estimated by the formula:$S = \boldsymbol{\Sigma}\left(\pi \frac{dbhi}{4}\right)^2$.

The diametrical structure of the vegetation was obtained using a histogram where the trees were divided into eleven diameters classes with an amplitude equal to 10 cm. The number of stems per hectare or density (d) of trees $(d = \frac{N}{S})$is the ratio of the total number of stems and the total sample surface. The ecological importance value index is given by IVI= RF+RD+RBA and is the sum of relative frequency (RF), relative density (RD) and relative basal area (RBA).

Evaluation of carbon stock

The aboveground biomass of tree species was estimated with allometric equation through the non-destructive method (Chave *et al.*, 2004).

This equation was chosen due to the fact that there is no allometric equation specific to the study area. Several authors have also used this equation to estimate carbon stocks in many tropical forests (Bocko *et al.*, 2017; Imani *et al.*, 2017; Sullivan *et al.*, 2017 and Madountsap *et al.*, 2017).In addition, Chave's equation is a pan-tropical equation developed using data from 58 countries including Cameroon which takes into account climatic a climatic factor (E) which is a function of environmental equations. Chave's equation is as follows:

$$Y = \mathbf{e}^{(-1{,}803-0{,}976E+0{,}976\ln(\rho)+2{,}673\ln(D)-0{,}0299(\ln(D))^2)}$$

Where ρ : density of wood (g/cm³ ou kg/cm³ ; D : diameter (cm) and Y:biomass in kg. E: environmental factor which according to Chave *et al.* (2014), was extracted from the world map using the geographical coordinates of each transect.

Density values of the tree species were obtained from already existing values for the tree species surveyed (Brown, 1997; www.worldagroforestry.org bases and Global wood density database (Zanne *et al.*, 2009)).

Belowground biomass (BGB) was obtained from the aboveground biomass using the formula: BGB = 0.24 × AGB (Mokany *et al.*, 2006). Total biomass (TB) was given by: TB = AGB + BGB (FAO, 1997) where TB is the total biomass in tons, AG Bis the aboveground biomass and BGB represents belowground biomass. These biomasses were extrapolated to a hectare scale using an expansion factor.

The carbon stocks were obtained by multiplying the biomasses obtained by the coefficient 0.47 (Zapfack *et al.*, 2013). The amount of dioxide carbon sequestered was deduced using the formula:$\mathrm{m\,CO2} = \frac{44}{12}\mathrm{m\,C}$ (GIEC, 2009).

Results

Vegetation map of the Dja Wildlife Reserve

The Dja Wildlife Reserve covers a surface area of 526004 ha and is sited on hydromorphic, firm soils and rocky outcrops.

This forest presents eleven (11) types of vegetation cover (Fig.3).

Characterization of vegetation cover types in the Dja Wildlife Reserve

Of the 11 TVC identified in the Dja Wildlife Reserve, only seven (7) most abundant sampled were described in this study.

The surface areas of the various vegetation cover types identified are presented in table 1.

Table 1. Surface areas of types of vegetation cover in the Dja Wildlife Reserve.

TVC	DHS b	DHS d	DHS CHP b	DHS CHP d	SA b	SA d	SJ b	MIT	MRA	F	CU et Others
Surface area (ha)	205000	101730	20115	20394	61115	8157	654	22688	84425	1	1631

Floristic diversity of vegetation types

This work resulted in the collection of 60.750 individuals from 52 families, 187 genera and 270 species in the study populations. The descriptive parameters of floristic diversity are presented in table 2.

Table 2. Species diversity of different TVC.

TCV	Nb plots	Family	Genus	Species	Nb of individuals	% of species	H	EQ	D
DHS b	148	47	175	239	17657	88.19	4.43	0.81	0.98
DHS CHP b	32	43	136	174	2813	64.21	4.16	0.81	0.97
DHS CHP d	37	45	152	204	6081	75.28	4.16	0.79	0.97
DHS d	104	47	166	225	14147	83.03	4.20	0.78	0.97
MIT	39	47	147	187	3925	69.00	4.26	0.81	0.98
MRA	83	50	170	230	9859	84.87	4.41	0.81	0.98
SA b	57	49	159	214	6268	78.97	4.40	0.82	0.98

In general, the accumulation curves shows a variation in the number of species between 47 and 270 species. Specifically, there are significant variations between the different TVC (Fig.4).

Population structures in the different TVC

Ecological importance value index of families in different TVC

Sixteen (16) families representing 32% of families had IVIs greater than 75% (Table 3). In this group, six (6) families showed very impressive ecological importance in all TVC.

These families (Fabaceae, Phyllanthaceae, Annonaceae, Irvingiaceae, Euphorbiaceae and Olacaceae) had an IVI above 100% and constituted the floristic background of the Dja Wildlife Reserve. In all TCVs, there was variation in IVI of families from 1 to 134.65%.

Ecological importance value indices of species in different TVC

Twenty one (21) species making7.78% of the listed species had IVIs greater than 60% in all TVC (Table 4). Among them, *Plagiostyles africana*, *Petersianthus macrocarpus*, *Uapaca guineensis* and *Polyalthia suaveolens* had great influence on the ecology of all TVC. These species had values of IVI > 100%.

Densities and basal areas in different TVC

Basal area varied from 20.23 to 30.85 m²/ha in the TVC with an average of 26.12 m²/ha (Table 5). With regards to the basal areas, the diameter of the average tree and the number of stems/ha, DHS b was the oldest TVC while DHS CHP d was the most disturbed TVC.

An average density of 259 stems/ha was obtained for the entire reserve. The average tree of the reserve measured 31cm in diameter. In DHS b, the forest under storey was very clear with a dominance of large tree individuals. In the DHS CHP d, a much closed forest under storey was observed with a high abundance of individuals of small diameters.

Table 3. Ecological importance value indices of top families in different TVC.

IVI (%)								
Family	DHS b	DHS CHP b	DHS CHP d	DHS d	MIT	MRA	SA b	Mean
Fabaceae	136.70	132.79	132.87	135.53	138.00	133.25	133.41	134.65
Phyllanthaceae	117.92	119.35	120.63	118.88	111.69	119.17	109.53	116.74
Annonaceae	109.73	113.92	117.34	113.97	113.25	116.47	117.80	114.64
Irvingiaceae	105.74	112.94	114.38	115.08	108.42	113.70	119.20	112.78
Euphorbiaceae	106.26	115.54	114.28	112.95	109.21	109.03	109.76	111.00
Olacaceae	105.43	108.46	113.19	113.94	108.04	113.10	114.60	110.97
Malvaceae	100.33	106.69	98.21	102.74	98.08	103.95	110.16	102.88
Lecythidaceae	98.09	95.67	110.95	108.55	101.57	97.37	104.12	102.33
Meliaceae	100.01	110.15	93.77	102.76	100.90	96.78	103.21	101.08
Apocynaceae	99.07	82.43	106.59	105.07	94.75	97.63	103.08	98.37
Myristicaceae	89.72	101.38	102.85	90.99	87.73	84.52	99.32	93.79
Burseraceae	84.30	82.69	99.12	101.07	83.53	91.41	91.88	90.57
Anacardiaceae	89.42	93.50	97.11	90.47	89.31	84.73	81.38	89.42
Rubiaceae	83.67	58.37	78.28	87.13	78.94	88.53	93.37	81.18
Cannabaceae	82.58	62.08	101.54	89.69	67.92	75.31	80.70	79.97
Sapindaceae	76.99	93.02	75.15	75.77	71.39	89.19	78.06	79.94

Analysis of variance (ANOVA) showed that there was a significant difference between basal area (m^2/ha) and TVC (ANOVA, p = 0.0006). Moreover, 2 by 2 comparisons revealed that there was a significant difference between the basal areas of the DHS CHP b and DHS CHP d on one hand and the other between the basal areas of the DHS CHP b and DHS d. However, the basal area of DHS b, DHS CHP b, MIT, MRA, and SA b were not significantly different.

Distribution des individuals per class of diameter

In all TVC, the diameter class 20-30 cm dominated and there was a sharp decrease in the number of individuals with increasing diameter (Fig.5).

Carbon stocks in the different Types of Vegetation Cover

The study populations of trees stored an average of 209.97 tC/ha. This stock includes carbon stored at the level of large roots. Table 6 presents the carbon distribution according to the TCVs. The Analysis of variance do not show a significant difference between the carbon stocks in the different TVC ($p < 0.05$).

The Correlations between carbon stocks, structural parameters (basal area and number of stems per hectare) and floristic parameters (species richness, diversity indices) are presented by the first two components of the PCA. These components express 85.65% of the total inertia (Fig. 6). Following these 2 dimensions, all the variables used in the dataset contribute significantly to the formation of the two main components. However, some variables such as basal area, number of stems, Shannon index, species richness, and EQ show a highly significant contribution in contrast to others.

The number of stems per hectare, carbon stock and basal area (m^2/ha) contributes very significantly and positively to the 1st dimension of the PCA, thus respectively R = 0.93; p = 0.0024, R = 0.93; p = 0.0026 and R = 0.93; p = 0.0028.Whereas The Shannon and species richness have a highly significant contribution to the 2nd dimension of the PCA (R = 0.92; p = 0.0038 and R = 0.87; p = 0.0116 respectively for these two parameters). On the other hand, the Pielou's Equitability contribute also significantly to the 1st dimension; but negatively (R = -0.88 and p = 0.0092 for the basal area, R = -0.863 and p = 0.0122 for the number of stems/ha).

Table 4. Ecological importance value indices of species in different TVC.

IVI (%)								
Species	DHS b	DHS CHP b	DHS CHP d	DHS d	MIT	MRA	SA b	Mean
Plagiostyles africana	98.78	110.53	110.09	104.75	95.25	97.46	100.30	102.45
Petersianthus macrocarpus	98.02	95.67	110.98	108.52	101.54	97.31	103.91	102.28
Uapaca guineensis	99.26	114.95	107.54	117.09	104.66	85.51	85.01	102.00
Polyalthia suaveolens	92.40	97.79	107.87	102.09	102.96	103.73	100.18	101.00
Pentaclethra macrophylla	94.89	106.83	105.71	98.38	89.09	92.18	85.67	96.11
Desbordesia glaucescens	88.36	76.48	103.01	105.52	94.68	92.58	103.37	94.86
Strombosiopsis tetrandra	88.18	68.71	81.78	97.12	90.53	97.72	87.61	87.38
Aptandra zenkeri	76.50	79.21	95.42	86.06	77.94	75.22	80.98	81.62
Santiria trimera	74.99	62.46	95.86	96.12	70.04	83.08	85.94	81.21
Eriocoelum macrocarpum	76.99	93.02	75.15	75.77	71.35	89.19	78.06	79.93
Strombosia pustulata	71.66	70.87	89.60	75.15	72.33	80.21	85.69	77.93
Hylodendron gabunense	65.21	78.79	90.01	79.60	77.62	77.31	72.03	77.23
Tabernaemontana crassa	70.38	58.04	86.89	87.42	55.91	65.97	71.72	70.91
Duboscia macrocarpa	62.88	72.35	58.53	70.48	61.25	75.45	91.82	70.39
Alstonia boonei	74.45	44.27	72.64	69.56	65.66	74.14	77.27	68.28
Anonidium mannii	53.66	86.11	90.25	71.78	43.33	65.50	63.08	67.67
Irvingia gabonensis	67.27	38.61	80.38	65.20	78.35	64.07	65.52	65.63
Trichilia welwitschii	54.35	95.31	66.43	54.06	65.59	67.26	47.33	64.33
Pterocarpus soyauxii	59.68	36.55	73.50	72.67	81.95	59.68	55.04	62.72
Coelocarion preussii	53.33	78.39	78.19	60.99	40.90	66.89	46.10	60.68
Trichoscypha acuminata	64.17	44.65	85.18	65.83	57.72	56.77	48.50	60.40

Carbon stocks in different storage pools

Carbon stocks varied substantially from one pool to another and trees are the most efficient storage pool in this forest storing an average of 205.2 tC/ha while herbs were the least suitable pool for this activity (Fig.7). There were high significant difference between carbon stocks per pool (ANOVA, p = 0.0000).

Table 5. Basal area, density of trees and average tree in each vegetation cover type.

TVC	Sampled surface (ha)	Number Stem/ha	Basal area (m^2/ha)	Average tree (cm)
DHS b	74	263	28.36 ± 28.86^{ac}	32.2
DHS CHP b	16	193	20.23 ± 7.45^{a}	31.1
DHS CHP d	18.5	351	30.85 ± 20.15^{c}	32.3
DHS d	52	293	28.70 ± 16.42^{bc}	28.4
MIT	19.5	220	22.51 ± 9.94^{ab}	31.4
MRA	41.5	254	23.19 ± 9.43^{ab}	29.9
SA b	28.5	240	24.50 ± 8.25^{ac}	31.7

Carbon stocks at the level taxa

The 15 most abundant families stored on average 170.23 tC/ha corresponding to more than 81% of the carbon stocks of the studied population. In addition, Fabaceae, Irvingiaceae, Mimosaceae and Phyllanthaceae contribute substantially to the stocks of all TVC and the total carbon stock. Their contribution amounted to 98.72 tC/ha corresponding to 46.79% of the total carbon stock. Sixteen genera (16) contributed significantly to carbon storage. The average of their stock was estimated at 103.15 tC/ha, about 48% of the total carbon stock of the studied forest. In addition, four genera showed great potential for carbon storage with high contributions in all TVC. They are *Uapaca* (16.38 tC/ha), *Pentaclethra* (15.08 tC/ha), *Desbordesia* (13.81 tC/ha) and *Petersianthus* (11.31 tC/ha).

Table 6. Carbon stocks in different TVC.

TVC	Sampled surface (ha)	Carbon stocks C (t/ha)
DHS b	74	218.2±238.9
DHS CHP b	16	162.1± 58.6
DHS CHP d	18.5	237.0±137.3
DHS d	52	225.6±134.5
MIT	19.5	183.5± 87.6
MRA	41.5	178.9± 71.7
SA b	28.5	195.6± 58.6
RFD	250	209.97

The ten (10) species most suitable for carbon storage in all TVCstored an average of 91.26 tC /ha, equivalent to 43.45% of the total carbon stock. Four species had high carbon storage capacity with impressive stocks in TVC. These are: *Uapaca guineensis* (15.39 tC/ha), *Pentaclethra macrophylla* (15.08 tC/ha), *Desbordesia glaucescens* (13.81 tC/ha) and *Petersianthus macrocarpus* (11.31 tC/ha).

Discussion

Types of Vegetation Cover

The Dja Wildlife Reserve vegetation shows forests on dry land (79%), forests on hydromorphic soils (20%) and other non-forested land: crops, rocks, thickets and saline areas (1%). These results are slightly different from those of the mapping works (Lejoly, 1995; Sonké, 1994 and Sonké, 1998), which mention that the Dja Wildlife Reserve vegetation consists of forests on rock (5%), forests on hydromorphic soils (20 %) and forest on firm soils (75%).

This slight difference can be explained by the precision of the image processing tools used at this present time. In addition, the DHS b is the largest type of vegetation cover and occupies an area of more than 205 000 ha, nearly 39% of the total area of the Dja Wildlife Reserve (526,004 ha). The fact that TVC on firm land (DHS b, DHS d, DHS CHP b, DHS CHP, SA b, SA d, SJ b) cover an area of 417242 ha and types of vegetation cover on hydromorphic soils (MIT and MRA) extend over an area of 107.113 ha confirm the physiognomy of the Dja Wildlife Reserve and its belonging to the Guinean-Congolese evergreen forest on wet soil and dry soil according to Letouzey (1985).

Vegetation

Within the framework of this study, 60750 individuals of dbh ≥ 10 cm were recorded in 250 ha sample area. They are grouped into 270 species, 187 genera and 50 plant families. The high floristic diversity is far from reflecting all the flora of the forest considering, its large surface area on one hand and the use of a single inventory method on the other hand. Indeed, Kokou *et al.* (2005), using a combination of several inventory methods obtained larger list of species in Togo for smaller sacred forests. These authors also showed that the species richness of sacred forests increases significantly with their area. As a result, the species richness of the Dja Wildlife Reserve is likely to increase if several botanical inventory methods are combined (Kokou *et al.*, 2005, Vroh *et al.*, 2010). It would therefore be wise for a more comprehensive assessment of the Dja Wildlife Reserve's flora to combine transect methods and plots as the transects make it possible to cross several types of ecological environments at the same time while the plots favour an almost exhaustive enumeration especially when their dimensions are of average sizes.

The accumulation curve of the diversity of the different types of vegetation cover according to the rarefaction method recommended by Vandermeer *et al.* (2000); Gotelli *et al.* (2001) to assess the species richness shows that this effort, although sufficient in some types of vegetation cover remain insufficient in others; this is especially true since of the 500 plots studied, 148 (29.6%) were placed in the DHS b, for example, which indicates that further sampling in the latter would inevitably lead to the discovery of other species.

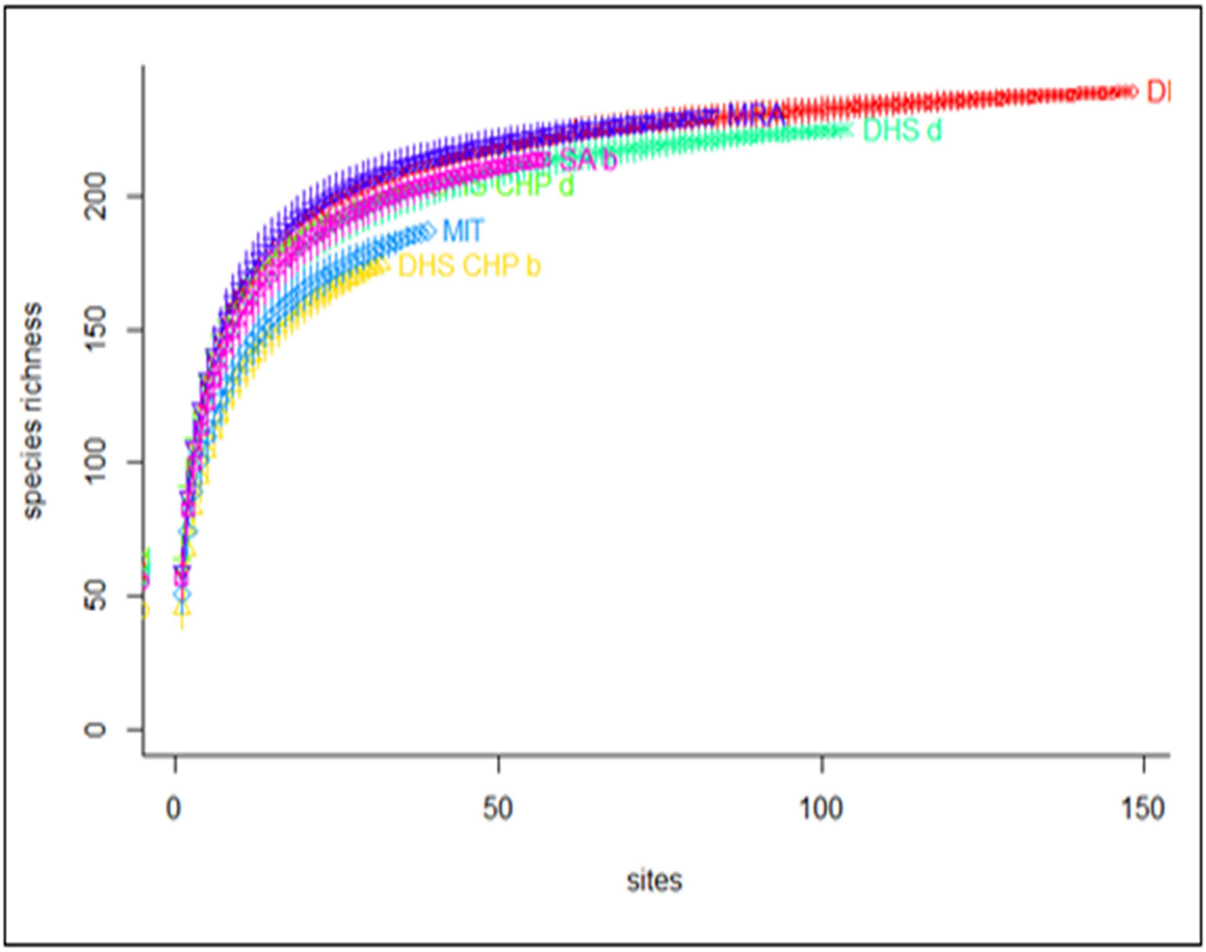


Fig. 4. Diversity accumulation curves for the different TVC.

However, the number of identified species, genera and families coupled with values of calculated diversity indices indicate a significant floristic richness of this forest compared to some tropical forests in Africa (Ngueguim *et al.*, 2010;Gone Bi*et al.*, 2013; Boni *et al.*, 2016; Zapfack *et al.*, 2016 and Momo *et al.*, 2017). On the other hand, this rich floristic diversity is similar to those obtained in the Dja Wildlife Reserve (Sonke, 2004, Djuikouo *et al.*, 2010), in the Takamanda Forest Reserve in south-western Cameroon (Sunderland *et al.*, 2003) and in the Marahoué National Park in Ivory Coast (Dibi *et al.*, 2008). In terms of species diversity, Fabaceae (36 species) and Malvaceae (22 species) were the most diverse. Indeed, in disturbed environments Wilson (1992) showed that certain so-called pioneer species can be formed rapidly and increase the biodiversity of the environment exponentially. Such species do not fit vigorously and sustainably in the communities where they have emerged. These are strictly heliophilous and semi-heliophilic species that colonize holes that occurred like forest gaps. This could also be the reasonfor the differences observed between the studies of (Sonké, 2004 and Djuikouo *et al*, 2010) and the results of the present study in the Dja Wildlife Reserve.

From the point of view of the most abundant plant families, those of Fabaceae, Rubiaceae, Euphorbiaceae, Olacaceae, Annonaceae and Apocynaceae have been found by several authors to be the most representative of the African rainforests (Sunderland *et al.*, 2003, Sonke, 2004, Dibi *et al.*, 2008, Djuikouo *et al.*, 2010, Amani *et al.*, 2013, Zapfack *et al.*, 2016), which is consistent with the results of this study. Among the species, *Uapaca guineensis* is the most abundant with 7.81% of the individuals of the studied population.

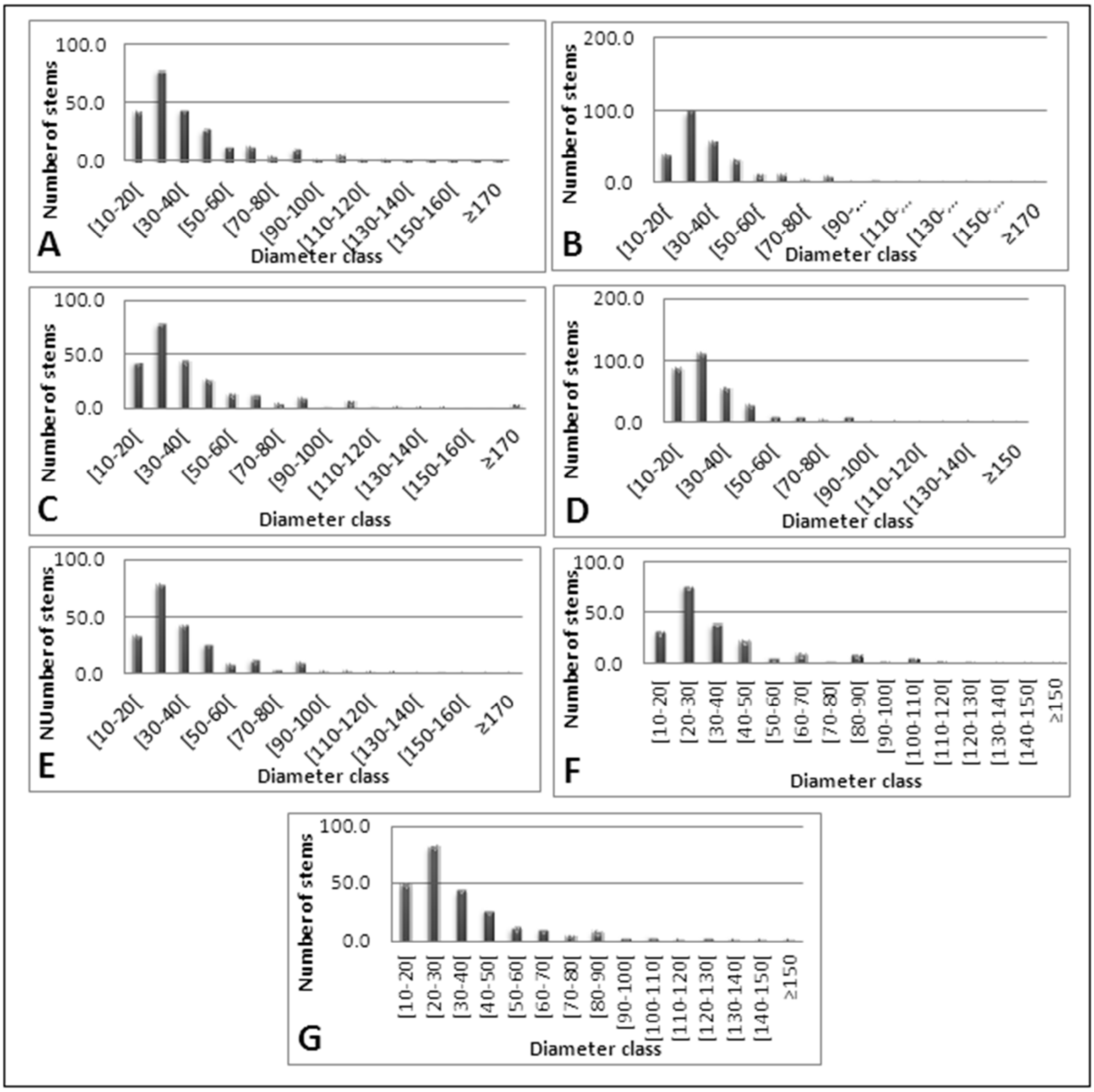


Fig. 5. Abundance of individual per diameter class in all TVC. A:DHS b; B:DHS d; C:DHS CHP b; D: DHS CHP d; E: SA b; F: MIT et G: MRA.

This is due to its strong ability to compete, its affinity with environmental conditions and the ease of dissemination of its diaspores (Devineau, 1984). This species has the ability to grow in swamps as well as firm soil. On the other hand, the so-called rare species in this study are thought to be lacking these three above-mentioned abilities. The family Fabaceae was the most abundant in this forest with about 12.82% of individuals. It was followed by Phyllanthaceae (9.9%) and Annonaceae with 9.47%. According to Sonke (2004), Djuikouo *et al.* (2010) and Tabue *et al.* (2016), Euphorbiaceae are the most abundant family in the Dja Wildlife Reserve. This is true because the genus *Uapaca* and all its species belonged to this family. With the phylogenetic APG III classification, this genus belongs to the Phyllanthaceae family. This same classification made it possible to transfer all the species of the Mimosaceae and Ceasalpiniaceae families to the Fabaceae family. This observation questions the name of the Dja Wildlife Reserve once known as "Euphorbiaceae forest" (Sonké, 2004). The Dja Wildlife Reserve could therefore take the new name “Fabaceae forest”.

The TVC in general had an inflection of the curve with the increase of the sampling surface, reflecting the inventory of flora in almost all of the TVC of the Dja Wildlife Reserve. The sampling effort was not the same in all the different TVC identified in the Dja Wildlife Reserve (Fig. 3). This sampling effort does not seem to be achieved for the DHS CHP d, DHS CHP b and MIT so the accumulation curves continue to grow. Thus, new species could be inventoried if additional inventories were to be made.

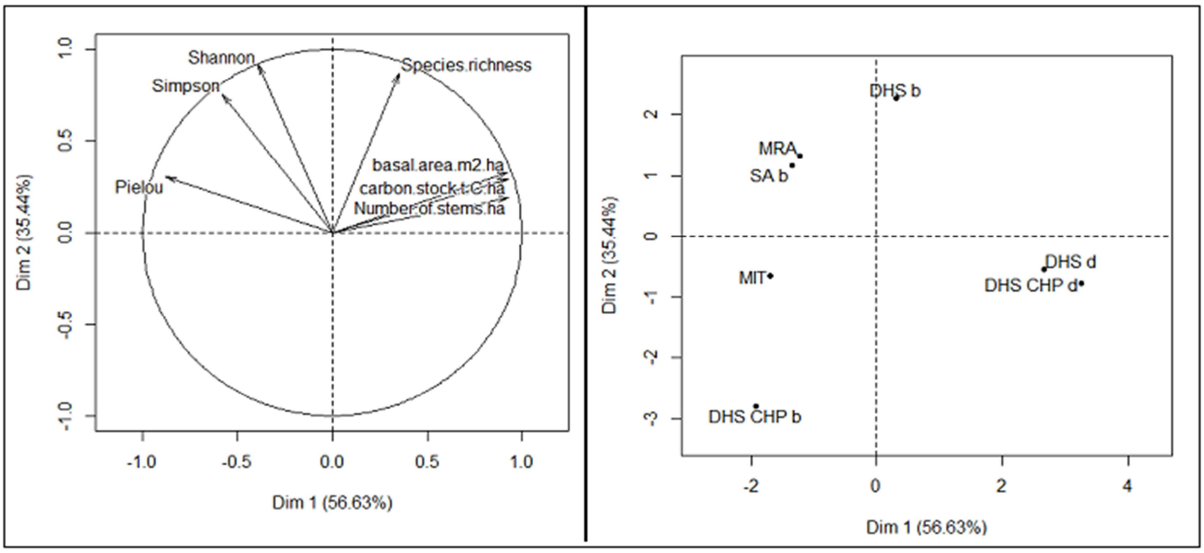


Fig. 6. Results of Principal Component Analysis of carbon stocks, diversity index and structural characterisation in function of types of vegetation cover.

Structures of Vegetation Cover Types

This study reveals a very high IVI for the different taxa identified. These vary between families from 1% to just over 135% in the study forest. For families, IVI = 135.38% for Fabaceae and IVI for slightly more than 117% for Phyllanthaceae. At the species level, they range from 0.2 to 101.73%. *Petersianthus macrocarpus* and *Uapaca guineensis* are the species with high ecological importance in the forest studied with IVI of 101.73 and 101.31% respectively. These values, both at the level of families and species are much higher than those obtained in the forests of Ngovayang in southern Cameroon (Gonmadje *et al.*, 2011). These authors obtained the highest values at the level of families in the Fabaceae (IVI = 34.35%) and an IVI of 17.39% in *Coelocaryon preussii* for the species level.

The average basal area obtained in this work was 26.12m²/ha. This value is very low compared to those obtained in the Democratic Republic of Congo (30.5 m²/ha) by Amani *et al.* (2013) and in the Dja Wildlife Reserve (Sonké, 2004, Djuikouo *et al.*, 2010). This difference could be explained by the fact that large individuals that contribute significantly to land use are poorly represented in this forest, which could be proof that this forest is in full regeneration with regard to the abundance of small diameter tree species.

According to Doucet (2003), basal area varies between 30 and 35 m²/ha in the African rainforests for dbh ≥ 10 cm. For different types of vegetation cover, it is higher in DHS CHP b (30.85 m²/ha)unlike what we would have. This contrast could be accounted for by the density of stems per hectare which is amplified by a high prevalence of pioneer sun-loving species that colonize gaps and disappear over time leaving room for sciaphile species. In this TVC, a strong contribution of *Musanga cercropioides* amounted to almost 0.98 m²/ha. Stem density/ha is also high in DHS CHP d (351 stems/ha) and is explained by the same fact. The average density of stems is 260 stems/ha for the studied forest and remains lower than those obtained by Sonké (2004) and Djuikouo *et al.* (2010) which are respectively 498 and 420 stems/ha in the same reserve. These differences would be natural phenomena (wind throw and natural dead) that have occurred in the Dja Wildlife Reserve ecosystems over time and show the dynamics of the forest.

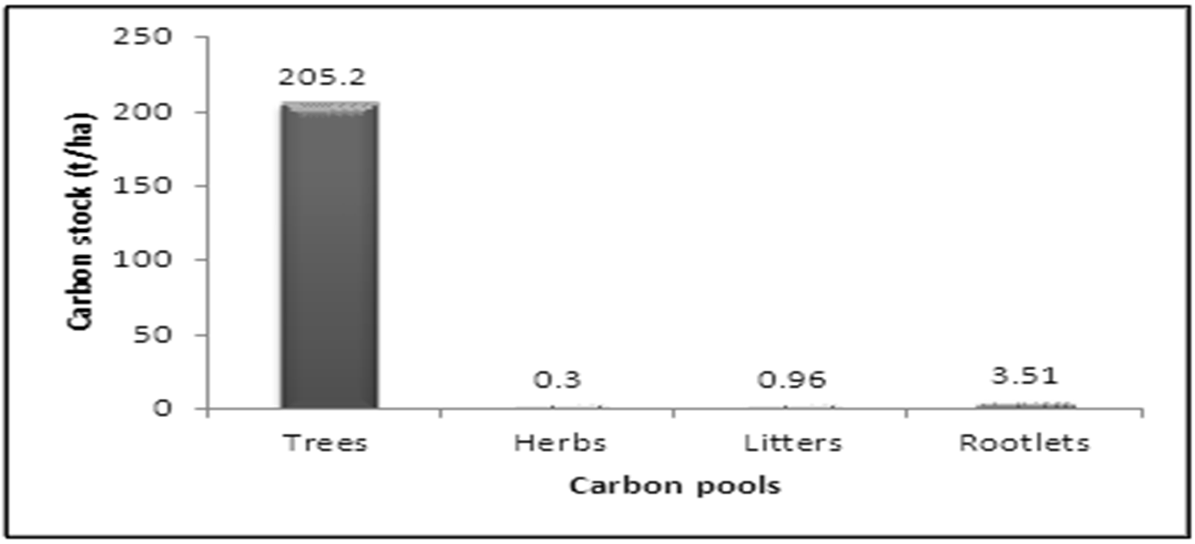


Fig. 7. Carbon Storage per pool (tC/ha).

Carbon Stock

The studied forest stored an average of 209.97 tC/ha. These stocks include the hypogenous carbon and with very small variation between the TVC and do not show any significant difference (ANOVA, p> 0.05). This could result from the high specificity in TVC and also because stem density does not considerably influence carbon storage. In addition, it is clear that the diameter-dependent basal area is the key factor in carbon stock change in the Dja Wildlife Reserve as shown by the PCA.

In this work, the obtained carbon stock (165.48 t/ha) is close to the results obtained in West African forests (152 tC/ha) by Lewis *et al.* (2013) and in Mount Kilimanjaro in Tanzania where Ensslin *et al.* (2015) found 180.1 tC /ha.

On the contrary, this carbon stock is far below other estimates made in tropical forests of Africa where carbon stocks were estimated at 214.5 tC/ha by Lewis *et al.* (2013) and 209 tC/ha by Slik *et al.* (2013). In Nordic Forests in Limpopo Province, South Africa, Mensah *et al.* (2016) obtained an average of 358.1 tC/ha. Zapfack *et al.* (2016) in the Lobeké National Park in Cameroon obtained carbon stocks of 374.2 tC/ha; in the Democratic Republic of Congo, carbon stocks were estimated at 270 tC/ha (Chave *et al.*, 2008); in the Parc de Monts de Cristal in Gabon, Day *et al.* (2013) estimated the carbon stock at 214.32 tC/ha. Still in the Dja Wildlife Reserve, Djuikouo *et al.* (2010) obtained 216.2 t/ha whereas Tabue *et al.* (2016) found 354.73 t/ha.Still in Cameroon's forests, Ngueguim *et al.* (2010) obtained 328.52 tC/ha in the Mangombe forest station.

However, this value remains much higher than those obtained in the tropical forests of South America (135.36 tC/ha) by Slik *et al.* (2013), in East African forests (137 tC/ha) by Lewis *et al.* (2013) and Cameroon where Day *et al.* (2013) had 125 tC/ha at the Campo Ma'an National Park.

At the level of carbon storage pools, trees constituted the most efficient carbon storage pool in all ecosystems. However, it is noted in this study that they store much less carbon (205.2 tC/ha) than in the Lobéké National Park where Zapfack *et al.* (2016) recorded 363.14 t/ha. The same trend was observed for the other carbon pools with 0.6 tC/ha for the grass, 3.1 tC/ha for the litter and 7.3 tC/ha for the small roots in the Lobéké National Park against 0.3

tC/ha for herbs, 0.96 tC/ha for litter and 3.51 tC/ha for small roots in the Dja Wildlife Reserve. These observed differences are due to the high density of trees in Lobéké National Park.

The differences observed could be due to the variability of the formulas used for biomass estimation. However, floristic composition and structural variables (basal area, height-diameter allometry, etc.) account for much of the spatial variation in carbon stocks in African tropical forests (Djomo *et al.*, 2011, Marshall *et al.*, 2012, Bastin *et al.*, 2014, Ekoungoulou *et al.*, 2015, Shirima *et al.*, 2015 and Fayolle *et al.*, 2016).

Conclusion

This work permitted us to map the vegetation of the Dja Wildlife Reserve which presents 11 types of vegetation cover. The seven major types of vegetation cover that were characterized showed a high species richness with a total of 270 species, 187 genera and 50 families. The dominant taxa are essentially the same in all types of vegetation cover.

The analysis of the flora of all characterized types of vegetation cover led to the determination of an average basal area of 26.12m²/ha, an abundance in the diameter class [10-40] individuals in which tree individuals represented 82.8% of the total number of plant individuals. This reserve stores an average of 220.45 tC/ha. These stocks vary from 171 to 236 tC/ha respectively in DHS CHP b and DHS d. Principal component analysis showed that these carbon stocks are strongly related to basal area and floristic diversity and weakly related to stem density per hectare.

Since young individuals sequester more CO2 for their growth which is the opposite for senescent subjects, the fact that more than 82.8% of individuals are recruited in the [10-40] class confers to Dja Wildlife Reserve a special status of carbon sinks living in the Congo Basin for the coming decades thus offering Cameroon a place of choice in the carbon market.

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References

Adingra OM, Kassi NJ. 2016. Dynamique De La Végétation De Bamo Et Stocks De Carbone Dans La Mosaïque De Végétation. European Scientific Journal **12(18),** p359-374.

Amani A, Milenge CK, Héritier, Lisingo J, Nshimba H. 2013. Analyse floristique et impact du déterminisme édaphique sur l'organisation de la végétation dans les forêts de l'ile Kongolo (R. D. Congo). International journal of tropical geology, geography and ecology **37(2),** 255-272.

Bastin JFO, Barbier N, Couteron P, Adams B, Shapiro A, Bogaert J,Canniere DC. 2014. Aboveground biomass mapping of African forest mosaics using canopy texture analysis: toward a regional approach. Ecological Application **24(8),** 1984–2001.

Bocko YE, Ifo SA, Loumeto JJ. 2017. Quantification Des Stocks De Carbone De Trois Pools Clés De Carbone En Afrique Centrale : Cas De La Forêt Marécageuse De La Likouala (Nord Congo). European Scientific Journal **13(5),** 438-456.

Brown S. 1997. Estimating biomass and biomass change of tropical forests. FAO, Rome, 134 p.

Brown S, Gilespie AJR, Lugo AE. 1989. Biomass estimation methods for tropical forest with application to forest inventory data. Forest Science **35,** 881-902.

Chave J, Rejou-Mechainn M, Burquez A, Chidumayo E, Colgan SM, Delitti BCW, Vieilledent G. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology **20,** 3177–3190.

Chiabai A, Travisi C, Markandya A, Ding H, Nunes PALD. 2011. Economic assessment of forest ecosystem services losses: cost of policy inaction. Environmental and Resource Economics **50,** 405–445.

Dajoz R. 1982. Précis d'écologie. 4è édition. Bordas, Paris, 503 p.

Day M, Baldauf C, Rutishauser E, Sunderl TC. 2013. Relationships between tree species diversity and above-ground biomass in Central African rainforests: implications for REDD. Environmental Conservation **41(1),** 64-72.

Devineau JL, Lecordier C, Vuattoux R. 1984. Évolution de la diversité spécifique du peuplement ligneux dans une succession préforestière de colonisation d'une savane protégée des feux (Lamto, Côte-d'Ivoire). Candollea **39(1),** 103-134.

Dibi N'da H, Adou YCY, N'guessan KE, Kone M, Sagne YC. 2008. Analyse de la diversité floristique du parc national de la Marahoué, Centre-Ouest de la Côte d'Ivoire. Afrique Science **4(3),** 552 - 579.

Djuikouo KMN, Doucet J-L, Nguembou KC, Lewis SL, Sonke B. 2010. Diversity and aboveground biomass in three tropical forest types in the Dja Biosphere Reserve. African Journal of Ecology **48,** 1053–1063.

Dorvil W. 2010. Evaluation de la biomasse et des stocks de carbone sur des placettes forestières en forêts tropicales humides de Guadeloupe. Master, Université des Antilles et de Guyane, 45 p.

Doucet JL. 2003. L'alliance délicate de la gestion forestière et de la biodiversité dans la forêt du centre du Gabon. Thèse de doctorat, Gembloux Agro-Bio Tech, 390 p.

Doucet JL. 2003. L'alliance délicate de la gestion forestière et de la biodiversité dans la forêt du centre du Gabon. Thèse de doctorat, Gembloux Agro-Bio Tech, 390 p.

Durot C. 2013. Evaluation et comparaison des stocks de carbone des systèmes agroforestiers à base de cacaoyers du Centre Cameroun Cas de l'arrondissement de Bokito. Mémoire de fin d'étude. Groupe ISA et Montpellier SupAgro. 83 p.

Ekoungoulou R, Niu S, Loumeto JJ, Ifo SA, Bocko YE, Koula Mikieleko FE, Mpane Guiekisse ED, Senou H, Xiaodong L. 2015. Evaluating the Carbon Stock in Above-and BelowGround Biomass in a Moist Central African Forest. Applied Ecology and Environmental Sciences **3(2),** 51-59.

Ensslin A, Rutten G, Pommer U, Zimmermann R, Hemp A, Fischer M. 2015. Effects of elevation and land use on the biomass of trees, shrubs and herbs at Mount Kilimanjaro. Ecosphere **6(3),** p 45.

Fahey TJ, Siccama TG, Driscoll CT, Likens GE, Campbell J, Johnson CE, Battles JJ, Aber JD, Cole JJ, Fisk MC, Groffman PM, Hamburg SP, Holmes RT, Schwarz PA, Yanai RD. 2005. The biogeochemistry of carbon at Hubbard Brook. Biogeochemistry **75(1),** 109–176.

FAO. 2007. Situation des forêts dans le monde. Annexe, tableau. Rapport COMIFAC, FAO, Rome, p 18.

FAO. 2016. Situation des forêts du monde 2016 : les forêts et l'agriculture – défis et opportunités de l'utilisation des terre. FAO, Résumé. 36 p.

Fayolle A, Loubota Panzou GJ, Drouet T, Swaine MD, Bauwens S, Vleminckx J, Biwole A, Lejeune P, Doucet JL. 2016. Taller trees, denser stands and greater biomass in semi-deciduous than in evergreen lowland central African forests. Forest Ecology Management **374,** 42–50.

Frontier S, Pichod-Viale D. 1993. Ecosystèmes : structure, fonctionnement, évolution. Coll. écologie **21.** (2e Ed.). Masson, Paris, 448 p.

Gone Bi ZB, Kouame D, Kone I, Adou Yao CY. 2013. Diversité végétale et valeur de conservation pour la Biodiversité du Parc National du Mont Péko, une aire protégée, menacée de disparition en Côte d'Ivoire. Journal of Applied Biosciences **71,** 5753– 5762.

Gonmadje CF, Doumenge C, McKey D, Tchouto GPM, Sunderland TCH, Balinga MP B, Sonké B. 2011. Tree diversity and conservation value of Ngovayang's lowland forests, Cameroon. Biodiversity and Conservation **20,** 2627–2648.

Gotelli NJ, Colwell RK. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecology Letters **4,** 379-391.

Guedje MN, Nkongmeneck BA, Lejoly J. 2002. Composition floristique et structure des formations à Garcinia lucida dans la region de Bipindi, Akom II (Sud Cameroun). Acta Botanica Gallica **149(2),** 157-178.

Imani G, Boyemba F, Lewis S, Nabahungu NL, Calders K, Zapfack L, Riera B, Balegamire C, Cuni-Sanchez A. 2017. Height-diameter allometry and above ground biomass in tropical montane forests: Insights from the Albertine Rift in Africa. PLoS ONE **12(6),** p e0179653.

Kokou K, Adjossou K, Hamberger K. 2005. Les forêts sacrées de l'aire Ouatchi au sud-est du Togo et les contraintes actuelles des modes de gestion locale des ressources forestières, VertigO – la revue électronique en sciences de l'environnement **6(3),** p 5.

Lebœuf A, Samson MP, Paquet A. 2015. Guide d'interprétation des mosaïques d'images satellite landsat. Dépôt légal-Bibliothèque et archives nationales du Québec 2013 ISBN pdf : 978-2-550-68461-9.

Lejoly J, Sonke B, Van Essche K. 1995. Utilisation de la méthode du transect en vue de l'étude de la biodiversité dans la réserve de Faune du Dja (Cameroun). The biodiversity of African plants. Proceeding XIVth AETFAT Congress 22-27 August 1994, Wageningen, The Netherlands, p 150-154.

Letouzey R. 1985. Notice de la carte phytogéographique du Cameroun au 1:500.000. Institut de la Carte Internationale de la Végétation, Toulouse, p 240.

Letouzey R. 1968. Etude phytogéographique du Cameroun. Edition Paul Lechevalier, Paris, p 511.

Lewis SL, Sonke B, Sunderl T, Zemagho L. 2013. Aboveground biomass and structure of 260 African tropical forests. Philosophycal Transactions of the Royal Society of London **368(1625),** http://dx.doi.org/10.1098/rstb.2012.0295.

Lu D, Chen Q, Wang G, Moran E, Batistella M, Zhang M, Laurin GV, Saah HD. 2015. Aboveground Forest Biomass Estimation with Landsat and LiDAR Data and Uncertainty Analysis of the Estimates. Publishing Corporation International Journal of Forestry Research. http://dx.doi.org/10.1155/2012/436537,16p.

Lu D, Moran E, Hetrick S. 2011. Land-cover classification in a moist tropical region of Brazil with Landsat Thematic Mapper imagery. International Journal of Remote Sensing **32(23),** 8207–8230.

Lu D, Chen Q, Wang G, Moran E, Batistella M, Zhang M, Laurin GV, Saah D. 2012. Aboveground Forest Biomass Estimation with Landsat and LiDAR Data and Uncertainty Analysis of the Estimates. International Journal of Forestry Research. http://dx.doi.org/10.1155/2012/436537,16p.

Madountsap TN, Zapfack L, Chimi DC, Kabelong BLP, Forbi PF, Tsopmejio TI, Tajeukem VC, Ntonmen YAF, Tabue MRB, Nasang JM. 2018. Carbon storage potential of cacao agroforestry systems of different age and management intensity, Climate and Development, http://dx.doi.org/10.1080/17565529.2018.1456895

Marshal AR, Willcock S, Platts PJ, Lovett JC, Balmford A, Burgess ND, Latham JE, Munishi PKT, Salter R, Shirima DD, Lewis S. 2012. Measuring and modelling above-ground carbon and tree allometry along a tropical elevation gradient. Biological Conservation **154,** 20-33.

Marshal AR, Willcock S, Platts PJ, Lovett JC, Balmford A, Burgess ND, Latham JE, Munishi PKT, Salter R, Shirima DD, Lewis SL. 2012. Measuring and modelling above-ground carbon and tree allometry along a tropical elevation gradient. Biological Conservation **154,** 20-33.

Mendelsohn R, Balick MJ. 1995. "The Value of Undiscovered Pharmaceuticals in Tropical Forests." Economic Botany **49,** 223-228.

Mensah S, Veldtman R, Ben du Toit, Glèlè Kakaï R, Seifert T. 2016. Aboveground Biomass and Carbon in a South African Mistbelt Forest and the Relationships with Tree Species Diversity and Forest Structures. Forests **7(79),** 17 p.

Miller K, Tangley L. 1991. Trees of life: saving tropical forests and their biological wealth, World Resources Institute Guide to the Environment, Beacon Press, Boston.

Mokany K, Raison RJ, Prokushkin A. 2006. Critical analysis of root: shoot ratios in terrestrial biomes. Global Change Biology **12,** 84-96.

Momo SMC, Kamga YB, Nguetsop VF, Tiokeng B, Avana-Tientcheu ML, Kemeuze VA. 2017. Diversité Floristique Et Variation Altitudinale De La Structure Des Formations A Gnidia Glauca (Fresen) Gilg. Dans Les Forêts Communautaires De Kilum-Ijim (Nord-Ouest Cameroun). European Scientific Journal **13(6),** 12 p.

Muoghalu IJ. 2014. Vulnérabilité des systèmes biophysiques et socioéconomiques des savanes et formations boisées d'Afrique occidentale et centrale au changement climatique. African Forest Forum **2(14),** 35 p.

Ngueguim JR, Zapfack L, Youmbi E, Riera B, Onana J, Foahom B, Makombu JG. 2010. Diversité floristique sous canopée en plantation forestière de Mangombe-Edea (Cameroun). Biotechnologie, Agronomie, Sociétéet Environnement **14(1),** 167-176.

Nnah NS, Klaus M. 2014. Déforestation, REDD et le Parc national de Takamanda au Cameroun: une étude de cas. Forest Peoples Programme Charity No. 1082158.

Paquette A, Messier C. 2011. The effect of biodiversity on tree productivity: from temperate to boreal forests. Global Ecology Biogeography **20,** 170-180.

Pearce D. 1987. Economic Value and the Natural Environment. London Environmental Economics Centre,London, Paper 87-08.

Pearce RB. 1999. Forest products biotechnology. Journal of Chemical Technology and Biotechnology **74(5),** 472-474.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Richardson AD, Hollinger DY, Dail DB, Lee JT, Munger JW, O'Keefe J. 2009. Influence of spring phenology on seasonal and annual carbon balance in two contrasting New England forests. Tree Physiology **29(3),** 321–331.

Salle JC, Monfort A. 1999. Evaluation de la composante Cameroun du projet de Conservation et d'Utilisation Rationnelle des Ecosystèmes Forestiers en Afrique Centrale (ECOFAC). AGRIFOR Consult. Wavre, Belgique. 111P+Annexes.

Shirima DD, Ørjan T, Munishi, Pantaleo KT,Stein RM. 2015. Relationships between tree species richness, evenness and aboveground carbon storage in montane forests and miombo woodlands of Tanzania. Basic and applied ecology **16,** 239-249.

Siccama TG, Fahey TJ, Johnson CE, Sherry TW, Denny EG, Girdler EB, Likens GE, Schwarz PA. 2007. Population and biomass dynamics of trees in a northern hardwood forest at Hubbard Brook. Can. Journal of Forestry Research **37(4),** 737–749.

Slik JWF, Paoli G, McGuire K, Zweifel N. 2013. Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics. Global Ecology and Biogeography **22,** 1261-1271.

Smith LA, Eissenstat DM, Margot WK. 2017. Variability in aboveground carbon driven by slope aspect and curvature in an eastern deciduous forest, USA. Canadian Journal of Forest Research **47,** 149–158.

Sonké B, Lejoly J. 1998. Biodiversity study in Dja fauna reserve (Cameroon): using the transect method. in C.R. Huxley, J.M. Lock and D.F. Cutler (editors). Chorology, Taxonomy and Ecology of the Floras of Africa and Madagascar **11,** 155-170.

Sonké B. 1998. Etude floristique et structurale des forêts de la réserve de faune du Dja (Cameroun). Thèse de doctorat, Université libre de Bruxelles. 267 p.

Sonké B. 2004. Forêts de la réserve du Dja (Cameroun). Etude floristique et structurale. Meise, Jardin Botanique National de Belgique. 144 p.

Sullivan MJP, Talbot J, Phillips OL, Qie L. Zemagho L. 2017. Diversity and carbon storage across the tropical forest biome. Nature, Scientific Reports **7,** 39102. http://dx.doi.org/10.1038/srep39102.

Sunderland CHT, Comiskey JA, Besong S, Mboh H, Fowebon J, Abwe Dione M. 2003. Vegetation Assessment of Takamanda Forest Reserve, Cameroon. Takamanda: the Biodiversity of an African Rainforest. SI/MAB 8, 19-53.

Tabue MRB, Zapfack L, Noiha NV, Nyeck B, Meyan-Ya DRG, Ngoma LR, Kabelong BL-P, Chimi DC. 2016. Plant Diversity and Carbon Storage Assessment in an African Protected Forest: A Case of the Eastern Part of the Dja Wildlife Reserve in Cameroon. Journal of Plant Sciences **4(5),** 95-101.

Tayo GYK. 2014. Dynamique de la biodiversité ligneuse et des stocks de carbone dans les systèmes agroforestiers à base de cacaoyer au centre Cameroun: cas de Ngomedzap (Cameroun). Mémoire de Master, Université de Dschang, p 91.

Tchoumi NF. 2001. Contribution à l'étude écologique et structurale des forêts somitales du massif du Mbam Minkoum (région de Yaoundé). Mémoire de maitrise : Université de Yaoundé I. 56 p.

Torquebiau EF. 2002. Les associations agroforestières et leurs multiples enjeux. Bois et Forêts des Tropiques 271, 23-34.

Vandermeer J, Cerda IGDL, Boucher D, Perfecto I, Ruiz J. 2000. Hurricane disturbance and tropical tree species diversity. Science 290, 788-791.

Vroh BTA, Adou YCY, Kouamé D, N'Da DH, N'Guessan KE. 2010. Diversités Floristique et Structurale sur le Site d'une Réserve Naturelle Volontaire à Azaguié, Sud-est de la Côte d'Ivoire. European Journal of Scientific Research **45(3),** 411-421.

Waring RH, Landsberg JJ, Williams M. 1998. Net primary production of forests: a constant fraction of gross primary production. Tree Physiology **18(2),** 129–134.

Waring RH, Landsberg JJ, Williams M. 1998. Net primary production of forests: a constant fraction of gross primary production. Tree Physiology **18(2),** 129–134.

Wilson MA, Carpenter SR. 1999. Economic valuation of freshwater ecosystem services in the United States: 1971– 1997. Ecological Applications **9,** 772–783.

Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis S, Miller RB, Swenson NG, Wiemann MC, Chave J. 2009. Global wood density database. Dryad. Identifier: http://hdl.handle.net/10255/dryad.235.

Zapfack L, Noiha NV, Tabue MRB. 2016. Economic estimation of carbon storage and sequestration as ecosystem services of protected areas: a case study of lobéké National Park. Journal of Tropical Forest Science **28(4)**, 406–415.

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(2),** 78-86.