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Assessment of tree carbon stock in the Bomboko Forest Reserve of the Southwest Region of Cameroon

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SUMMARY

Moist tropical forests represent a potential beneficiary of carbon credits. This research aimed to assess the tree diversity and the carbon stock capacity of the Bomboko Forest Reserve Remnant in the Southwest Region of Cameroon. To estimate the carbon sequestration of this forest, pantropical allometric equations were used in comparison with equations developed for Cameroon's forests in the estimation of tree biomass to obtain carbon stock. Five plots of 20 m × 25 m were selected with 50 m intervals. All the trees with Diameter at Breast Height (DBH) more than 5 cm were counted, and parameters such as the DBH, height, and GPS coordinates were recorded. The wood density was obtained from the wood density database. The investigation revealed a high level of tree richness (Gini-Simpson index, 0.92; Shannon-Weiner index, 4.40). Ninety trees with DBH more than 5 cm were found. Twelve families were identified, belonging to 18 species. The most represented family was the Meliaceae (25%), while the least represented included the Annonaceae and Boraginaceae, each with 3.13% of species. The most frequent tree species was *Entandrophragma angolense* (22%), whereas *Distemonanthus benthamianus* and *Khaya ivorensis* were less represented, with 2% each. All in all, the Djomo and Chave equations can be used to evaluate the biomass of moist tropical forests. A detailed inventory of the area is needed, as well as the urgent need to build site-specific allometric equations for the Southwest Region of Cameroon forests.

Keywords: Carbon Sequestration, Biomass, Allometric equation, Tropical Forest

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INTRODUCTION

The FAO defines a forest as a plot area covering over 0.5 ha and covered by trees rising at least 5 meters (FAO, 2010). According to this definition, forests are the dominant terrestrial ecosystems on Earth and are distributed across the globe, covering 4.06 billion hectares, approximately 31% of Earth's total land area, which match up to a means of 0.52 ha per person (FAO and UNEP, 2020). They are not equally distributed across the globe: 31% of Earth's total forest area is found in Asia (including Asian Russia), followed by 21% in South America, 17% in Africa, 17% in

North and Central America, 9% in Europe, and 5% in Oceania. The top five states in terms of most forest wealth, including Russia, Brazil, Canada, the USA, and China, make up more than half (54%) of the overall forest area, and two thirds (66%) of forests are found in ten countries (FAO and UNEP, 2020). Nine (9) nations have below 1% forest cover, while up to 30 countries have forest cover of merely 5% of their terrestrial zone. Forests constitute 75% of Gross Terrestrial Primary Production (GPP) (Beer et al., 2010), planet's total vegetal biomass (Kindermann et al., 2008) and contain more carbon in plants and soils than in the atmosphere, about 50% of the world's terrestrial carbon stocks (Pan et al., 2011; Newton, 2021).

The total tropical land area is near 56 million km², allocated to three main continents: South and Central America (32% of the land area), Africa (52%), and South and Southeast Asia (less than 17%) (Malhi, 2010). In line with the Global Land Cover (2000) classification, 24% of this tropical land area is sheltered by humid woodlands, 11% by deciduous woodlands, 27% by shrubs and grasslands, 15% by uncovered spaces, and 20% by agronomic, managed, or miscellany terrains. Tropical forests with a yearly precipitation of no less than 2,500 mm cover 7–10% of the worldwide land, stockpile 40–50% of carbon in earthly vegetation, as most forest carbon stocks lie within the tropics (Pan et al., 2011). They process carbon dioxide year after year by means of photosynthesis and respiration approximately six times as much as humans release from fossil fuel usage (Lewis et al., 2009) and store a ballpark 193–229 Pg of carbon in above-ground biomass (Saatchi et al., 2011; Baccini et al., 2012), or more or less 20 times the yearly emanations from combustion and land-use alteration (Friedlingstein et al., 2010).

To combat global warming, many countries signed the Kyoto Protocol in 1997 under the United Nations Framework Convention on Climate Change (UNFCCC). Cameroon ratified the protocol on 28 August 2002, which came into force on 16 February 2005. The primary goal of the Kyoto Protocol is to reduce emissions of greenhouse gases (GHGs). Countries are required to report regularly on the status of their forest resources, which necessitates detailed assessments of carbon stock over time and space (UNFCCC, 2007). Carbon stock is typically estimated from above-ground biomass, assuming that 50% of the biomass consists of carbon. The most accurate method for measuring biomass involves cutting down trees and weighing their parts. This invasive technique is often used to validate other, less destructive and costly methods, such as estimating carbon stock through non-destructive *in situ* measurements and remote sensing (Clark et al., 2001; Wang et al., 2003).

Species-specific biomass equations have been developed for temperate forests (Zianis et al., 2005). In highly diverse environments like tropical rainforests, researchers have created either specific local equations with good precision but limited applicability (Araújo et al., 1999; Basuki et al., 2009; Djomo et al., 2010) or general multispecies pantropical equations (Brown, 1997; Chave et al., 2005; Chave et al., 2014). Although these equations were not derived from data collected in Africa, Chave's pantropical allometric equations of 2005 remain the most commonly used in Central Africa (Lewis et al., 2009; Lewis et al., 2013), before they were upgraded in 2014.

In light of the recent findings on diameter-height allometry over specific biogeographical regions (Banin et al., 2012), it is puzzling that data from Africa was

excluded in construction of Chave's equations, particularly in reference to central Africa (Fayolle et al., 2013). In contrast to Chave's equations, proponents of site-specific equations formulated for African tropical rainforests may be used (Ibrahima et al., 2002; Djomo et al., 2010; Henry et al., 2010; Ebuy et al., 2011; Vieilledent et al., 2012; Fayolle et al., 2013; Djomo et al., 2016).

Currently, Fayolle's allometric equations are the only ones which are available and based on more than 30 trees with DBH greater than 10 cm, although based on a minor sample size (Ngomanda et al. 2014). There is, therefore, a problem for someone in Central Africa-whether to use a pantropical multispecies equation that is data-rich but probably biased, versus a site-specific equation that is data-poor and so presumably has greater extrapolative care. Allometric equations constructed theoretically for all types of forest might be, in fact, proven poor estimators in comparison to local ones, or instead ecosystem-specific ones (Djomo et al. 2016).

Chave's pantropical multispecies equations, originally developed for moist forests, effectively predict tree carbon stock and biomass in the forests of southeastern Cameroon. These predictions rely on diameter measurements from the forest catalog and wood-specific gravity data from a global species-level database (Fayolle et al., 2013). Additionally, Chave's equations have been enhanced by a comprehensive record of direct-harvest tree trials across tropical forests, subtropical forests, and woodland savannahs, incorporating a diverse range of vegetation types and environmental variables (Chave et al., 2014). Furthermore, allometric equations for height and biomass applicable to dry, moist, and wet forest ecosystems in Africa have also been provided (Djomo et al., 2016).

Cameroon's moist tropical forests, with a cover estimated at more than 17 million hectares (Eba'a et al., 2013), are potential beneficiaries of this carbon credit. Consequently, it is necessary to assert precise approximations of the carbon sequestered in Cameroon's forests. Scarce studies have been done in this light, with none conducted in the remnant of the Bomboko Forest Reserve (BFR) in the Southwest to evaluate the biomass and thus the carbon stock. Several reports and complaints have been received from local communities and other relevant stakeholders concerning the unsustainable use of the BFR (MINFOF, 2014). To elaborate a management strategy for the BFR, it may be necessary to evaluate the tree biomass (and thus the carbon stock), either by cutting its parts before weighing or by using allometric equations. The foremost aim of the study was to test the validity of pantropical allometric equations and compare them with equations developed for Cameroon's forests in estimating tree biomass to obtain the carbon stock of the BFR. Specifically, we identified tree species and assessed their diversity in the study area, assessed the biomass using pantropical multispecies equations developed for moist forests, and estimated the biomass using allometric equations developed for Cameroon's forests in the study area. This study is a major step in the appraisal of the biomass and carbon stockpile in the BFR, thus serving as a tool towards a better management strategy for the PSMNR-SWR (Programme for the Sustainable Management of Natural Resources in the Southwest Region).

MATERIALS AND METHODS

Location of Bomboko Forest Reserve (BFR)

The study was carried out from March to July 2015 in the BFR. The BFR is in the Mbonge Subdivision, Meme Division of the Southwest Region of Cameroon (Figure 1). It is on the northwestern slopes of Mount Cameroon and is defined by the following geographical coordinates (UTM): between latitudes 478248 and 491557, and between longitudes 510248 and 527843. It covers a surface area of about 6,000 ha.

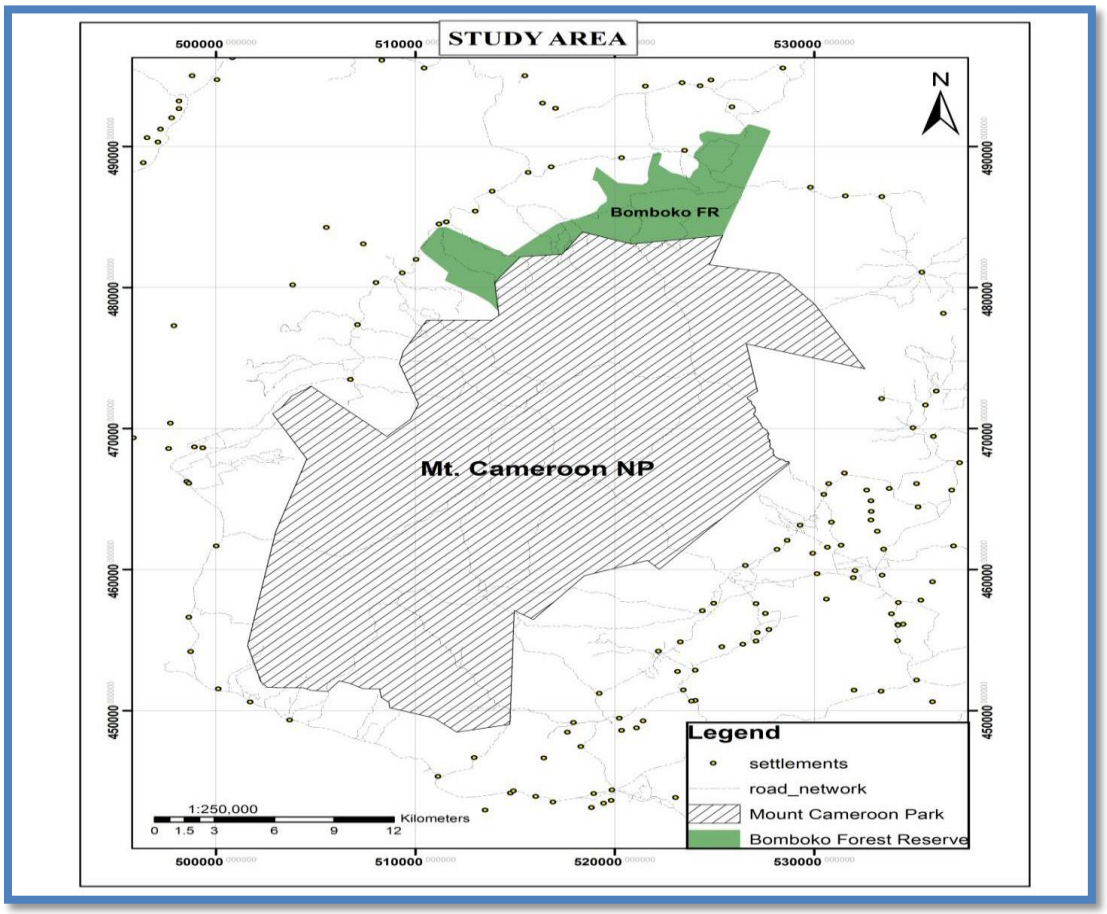

Figure 1: Map of the Study Area (Minnemeyer et al., 2005).

DATA COLLECTION METHOD AND RECONNAISSANCE SURVEY

The field work was done in two steps: the reconnaissance surveys and the field data collection proper.

The Reconnaissance survey

The reconnaissance survey took place from May 14 to 15, 2015. On the first day, we visited the Teak Plantation and Lowland Forest. On the second day, we focused on the Elephant Bush. During the survey, we observed encroachments in the Teak Plantation, where many trees had been cut down or burned to make way for cocoa

farms. Additionally, illegal timber exploitation was occurring in other forested areas of the Reserve.

The field data collection

The field data collection was conducted from 21st to 28 July 2015. We used 5 sample plots of 500 m² (20 m × 25 m) each, representing a total of 0.25 hectares along the transect line. The rectangular plots of 20 m × 25 m were located along the transect at intervals of 50 m. In the parcels, all the trees with a DBH greater than 5 cm were determined. The parameters collected included species name (scientific and/or local names), DBH, total height (H), geographical coordinates (x and y), and plot centre geographical coordinates.

Identification of tree species

Trees were identified using appropriate identification keys (Thirakul, 1983; Vivien and Faure, 1985). This identification was cross-checked by botanists from the Limbe Botanic Garden in the Southwest Region of Cameroon, the Forest Exploitation Regional Pedagogic Inspector for the Southwest, and villagers around the Reserve.

DATA ORGANISATION AND ANALYSIS

Microsoft Excel 2016 was used for data entry and analysis. Sample descriptive analyses, charts, and tables were created using SPSS 26. Line graphs were used to show comparisons between the five equations, and tables were used to display estimated biomass and carbon stocks from the five different equations. ANOVA was used to compare the mean biomass per species for each equation at a 5% significance level.

Species abundance

The abundance of species was estimated by calculating the number of individuals of a species in the area survey. The relative abundance of species was evaluated following Equation 1:

$$\mathbf{Pi} = \frac{\mathbf{ni}}{\mathbf{N}} \mathbf{X\ 100} \qquad (1)$$

With:

- Pi is species abundance
- $N = \sum n_i$
- n_i is the total number of individuals of species i in the sample

Species diversity

In order not to miss an important aspect of the numerical structure of the community, diversity index was calculated. Despite the several diversity indices available, Simpson's index and Shannon Diversity index were preferred. Simpson's index was calculated following Equation 2:

$$\mathbf{D} = \sum_{\mathbf{i=1}}^{\mathbf{S}} \mathbf{(pi)^2} \qquad (2)$$

With:

- D = Simpson's index.
- p_i = the proportion of individuals of species 'i' in the community.
- S = total number of species in the community.
- $\Sigma(pi)^2$ = sum of all the $(p_i)^2$, one for each species in the community.

Simpson's index (D) ranges from 0 to 1, where 0 indicates infinite diversity and 1 signifies no diversity. Consequently, a higher value of D corresponds to lower diversity. To convey diversity more intuitively, Simpson's index is often expressed as its inverse **(**1/D**)** or its complement **(**1-D**),** the latter being known as the Gini-Simpson index. This alternative version of the index also ranges from 0 to 1, but here, a higher value indicates greater diversity within the sample. It represents the probability that two randomly selected individuals from the sample will belong to different species.

Shannon diversity index

The Shannon Diversity index also known as Shannon-Weiner Index (Shannon, 1948) is based on the probability that a randomly selected individual fit into a specific species. It was calculated according to Equation 3:

$$\mathbf{H' = -\sum_{i=1}^{S} \frac{ni}{N} Log_2 \frac{ni}{N}} \qquad (3)$$

With:

- H': Shannon Diversity Index
- n_i: the number of individuals of species i
- S: the total number of species or taxonomic richness
- $N = \sum n_i$: the total number of individuals of all species found

Forest structure

a) Tree density

Tree density (d) was appraised by dividing the total number of trees with DBH above by the total area sampled (0.25 ha).

The Relative Density (R_d) was also evaluated using the following Equation 4:

$$\mathbf{R_d = (n_i/A) \times 100} \qquad (4)$$

With:

- n_i is the number of individuals of species i
- A is the total area sampled (0.25 ha)

b) The stand table

The stand table provides the predictable number of stems per unit area in each diameter class inside a given stand. It is desirable for the stand table to contain no less than 10 diameter classes (Van Lear and Akça, 2007). Tree diameters recorded were arranged in diameter classes. The range of tree diameters found in the area was

represented graphically, displaying tree diameters in an orderly manner with 5 cm interval differences. In total, 22 classes were established.

c) The basal area

The basal area (BA) was calculated following Equation 5:

$$\mathbf{BA} = \boldsymbol{\pi D^2} \mathbf{/ 4} \qquad (5)$$

With:

- BA, the basal area
- D, the diameter at breast height

Biomass evaluation and carbon stocks determination

a) Biomass evaluation

The most vital predictors of tree biomass encompass, in decreasing order of importance, the trunk diameter, wood-specific gravity, and total height (Chave et al., 2005). From the DBH and heights recorded in the field, we added wood densities collected from the "Global Wood Density Database" (Zanne, 2009) and "Wood Densities of Tropical Tree Species" (Reyes, 1992). In this work, we used densities instead of wood-specific gravity as specific gravity is the density of a sample normalised to the density of water; the density being the weight or mass of wood divided by the volume of the specimen at a given moisture content. Therefore, if d = ρw/ρe (with ρw as the specific gravity of wood and ρe as the specific gravity of water), and evaluated in g/cm³, then d = ρw with ρe = 1 g/cm³.

b) Estimation of carbon stocks

The assessment of carbon (C) stocked in forest ecosystems necessitates estimates of the following pools:

- Aboveground (AG): trees, lianas, understory vegetation, litter and dead wood.
- Belowground (BG): roots and soil carbon.

Carbon stocked in woody plants (C_w) is linked to the biomass (B_w) expressed in dry matter by unit of area (Mg/ha or t/ha). It is assessed by a simple relation: $C_w = k.B_w$ with $k \approx 0.50$, the conversion factor (default) (Brown and Lugo, 1992). The estimation of carbon stock or biomass is thus comparable.

i) The belowground carbon pools

Belowground biomass (BGB), which consists of roots, is regarded as the most challenging component to assess. The limited data available for Central Africa must be approached with caution, as they originate from small and imperfect samples. Consequently, the root/shoot ratio (R/S) has become a key method for estimating root biomass based on the more easily measured shoot biomass. The formula BGB = AGB * R/S (Mokany et al., 2006) offers a valuable critical review of literature regarding root/shoot ratios and provides derived values for various vegetation types as recommended by the IPCC (2006). However, there is no data specifically for Africa, and all samples referenced in this table have been measured in other regions (see Table 1).

Table 1: Root or shoot ratio values.

Vegetation type	Shoot biomass (t/ha)	Min.	Max.	R/S median	Sample size
Tropical moist forest	<125	0.092	0.253	0.205	4
	>125	0.220	0.327	0.235	10
Tropical dry forest	<20	0.281	0.684	0.563	4
	>20	0.271	0.278	0.275	2
Tropical moist woodland		0.292	0.548	0.420	7
Tropical dry woodland		0.259	0.710	0.322	6
Tropical grassland		0.380	4.917	1.887	15

***S*ource:** (Mokany et al., 2006)

ii) The aboveground carbon pools

We chose 5 equations : 01 Pantropical multispecies Equations (Chave et al., 2005); 02 Pantropical multispecies Equations (Chave et al., 2014) (including the alternative exponent one); 02 Site-specific equations (Djomo et al., 2016).

- **Chave et al. (2005) for Pantropical Forests**

Equations established for moist forests (matching to forests with a noticeable dry season and between 1500 mm and 3500 mm annual precipitation).

$$AGB = M_{AGB} = \rho Exp[-1.499+2.148\ln(D)+0.207(\ln(D))^2 - 0.0281\ln((D))^3]$$

- **Chave et al. (2014a) Pantropical Forests**

Four thousand and four (4004) trees with DBH fluctuating from 5 to 212 cm in tropical forests, subtropical forests and woodland savannahs.

$$AGB = M_{AGB} = 0.0673(\rho D^2 H)^{0.976}$$

- **Chave *et al.*, (2014b) Pantropical Forests**

This is the alternative exponent equation of Chave *et al.* (2014a). Four thousand and four (4004) trees with DBH ranging from 5 to 212 cm in tropical forests, subtropical forests and woodland savannahs.

$$AGB = M_{AGB} = 0.0559(\rho D^2 H)$$

- **Djomo *et al.*, (2016) for Moist Forests**

Four hundred and twenty (420) trees spanning 1–212 cm for DBH. Mean annual rainfall above 1500 mm with less pronounced dry season not exceeding 3 months (Vieilledent et al., 2012).

$$TB = (Mt) = Exp(-2.308+1.325\ln(D)+0.469\ln(D^2H) +0.802\ln(\rho))$$

- **Djomo *et al.*, (2016) for Wet Forests**

A total of one hundred and fifty-six (156) trees spanning 6–37 cm for DBH were assumed. The mean annual precipitation between1000mm and 1500 mm with dry season between 3 and 5 months should be considered (Vieilledent et al., 2012).

$$TB = (Mt) = Exp(-3.315 + 0.923\ln(D) - 0.156(\ln(D)^2 + 0.871\ln(D^2H) + 0.646\ln(\rho)$$

With:

- TM = Total Biomass
- M = Biomass in kg
- D = DBH in cm
- H = Height in m
- ρ = Wood Density in g/cm^3

For unknown species or those without wood density, we used $\rho = 0.58$ g/cm^3 as recommended as the default one for African tropical forests (Monssou et al., 2016), therefore:

Total Biomass = Aboveground Biomass + Belowground Biomass

RESULTS

SPECIES COMPOSITION

Ninety (90) trees with DBH ≥ 5 cm (ranging from 5 cm to 115 cm) were found, 64 trees were identified to species level while 26 could not be identified (or identified with a local name). Eighteen (18) species were identified as belonging to 18 genera and 12 families (Figure 2).

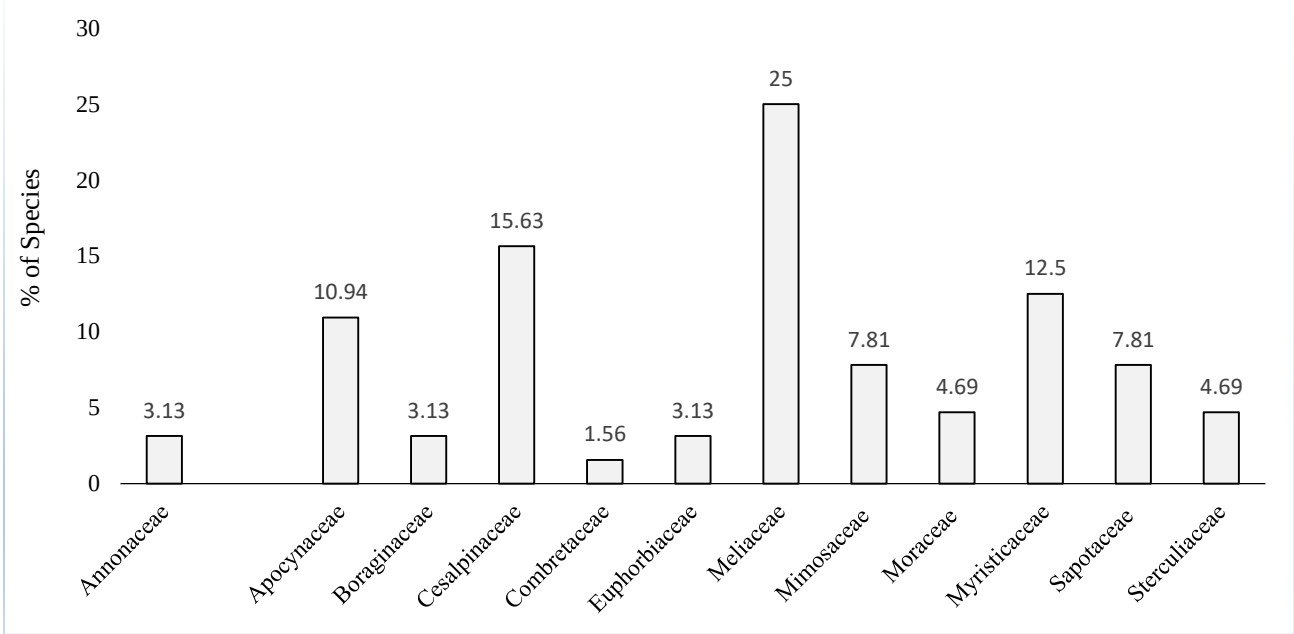

Figure 2: Tree Families in the Study Area.

The more represented family was *Meliaceae* with 25% of species; followed by *Cesalpinaceae* (15.63%) and *Myristicacaea* (12.5%). The less represented families were *Annonaceae* and *Boraginaceae* with 3.13% of species respectively. A vulnerable species (*Guarea cedrata*) was also identified. According to IUCN, a vulnerable species is not an endangered species, nevertheless, allegedly still facing a high risk of extinction in the wild in the medium-term future.

SPECIES ABUNDANCE

The most frequent tree species observed was *Entandrophragma angolense* (17.28%), followed by *Erythrophleum ivorense* (11.11%), *Pycnanthus angolensis* and *Voacanga africana* with 7.41% each. On the other hand, *Funtumia africana*, *Distemonanthus benthamianus*, *Terminalia catappa*, *Khaya ivorensis*, and *Guarea cedrata* are less represented with 1.23% each (Table 2).

Table 2: Tree relative abundance.

Species	Number (N)	Percent (%)
Enantia chlorantha	2	2.47
Voacanga africana	6	7.41
Funtumia africana	1	1.23
Cordia Millenii	2	2.47
Distemonanthus benthamianus	1	1.23
Erythrophleum ivorense	9	11.11
Terminalia catappa	1	1.23
Ricinodendron heudelotii	2	2.47
Khaya ivorensis	1	1.23
Entandrophragma angolense	14	17.28
Guarea cedrata	1	1.23
Piptadeniastrum africana	3	3.70
Albizia zygia	2	2.47
Musanga cecropioides	3	3.70
Staudia kamerunensis	2	2.47
Pycnanthus angolensis	6	7.41
Aningeria robusta	5	6.17
Pterygota macrocarpa	3	3.70
Akouk	4	4.94
Amang	3	3.70
Coffee for forest	10	12.35
Total	**81**	**100**

SPECIES DIVERSITY

Gini-Simpson index calculated was **G = 0.916**. This index is sensitive to the variation of importance for the most abundant species. Shannon-Weiner species diversity index calculated was **H = 4.395.** Both indices revealed a high degree of diversity.

TREE DENSITY

Tree density revealed 360 trees/ha for trees with DBH ≥ 5 cm. Species with high density values include *Entandrophragma angolense* (56%) and *Erythropleum ivorense* (36%) confirming the results obtained for the species abundance (Table 3).

THE STAND TABLE

The distribution of species by diameter size classes showed that the number of individuals decreases as size class increases. The highest class is found in the class [10; 15[with more than 27.78%, followed by [15; 20[with a percentage score of 8.89. On the other hand, there are size classes with no trees ([55; 60[[75; 80[[95; 100[and [105; 110[). Figure 3 below is a reverse J-shaped distribution curve of the size classes plotted against the number of individuals.

Table 3: Tree Density.

Species	Number (N)	Rd (%)
Enantia chlorantha	2	8
Voacanga africana	6	24
Funtumia africana	1	4
Cordia Millenii	2	8
Distemonanthus benthamianus	1	4
Erythrophleum ivorense	9	36
Terminalia catappa	1	4
Ricinodendron heudelotii	2	8
Khaya ivorensis	1	4
Entandrophragma angolense	14	56
Guarea cedrata	1	4
Piptadeniastrum africana	3	12
Albizia zygia	2	8
Musanga cecropioides	3	12
Staudia kamerunensis	2	8
Pycnanthus angolensis	6	24
Aningeria robusta	5	20
Pterygota macrocarpa	3	12
Akouk	4	16
Amang	3	12
Coffee for forest	10	40
Total	**81**	100

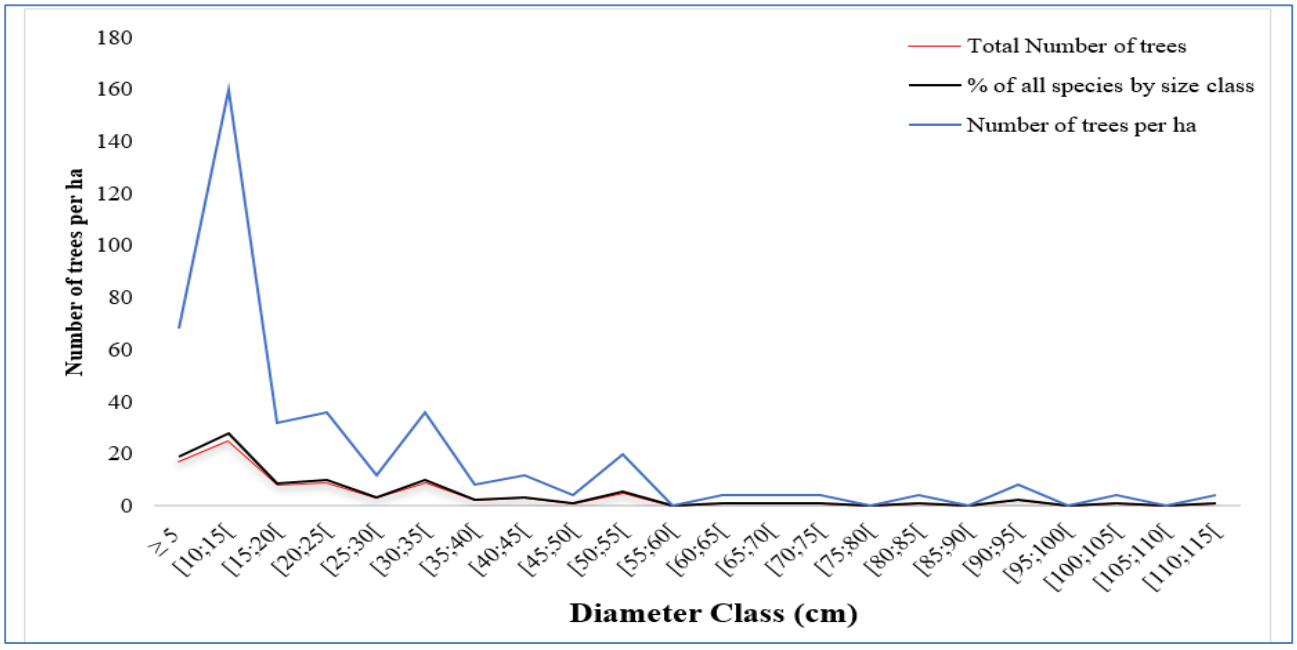

Figure 3: Curve of trees size classes charted against the number of individuals and percentage per Hectare.

THE BASAL AREA

The Basal area calculated revealed 29.199 m^2 per hectare. There is an association between the tree diameter and the basal area. The higher the diameter, the higher the basal area for this can be observed for tree numbers 32 and 26; whereas small diameters mean very low basal area as shown in tree number 5 or 86 (Figure 4).

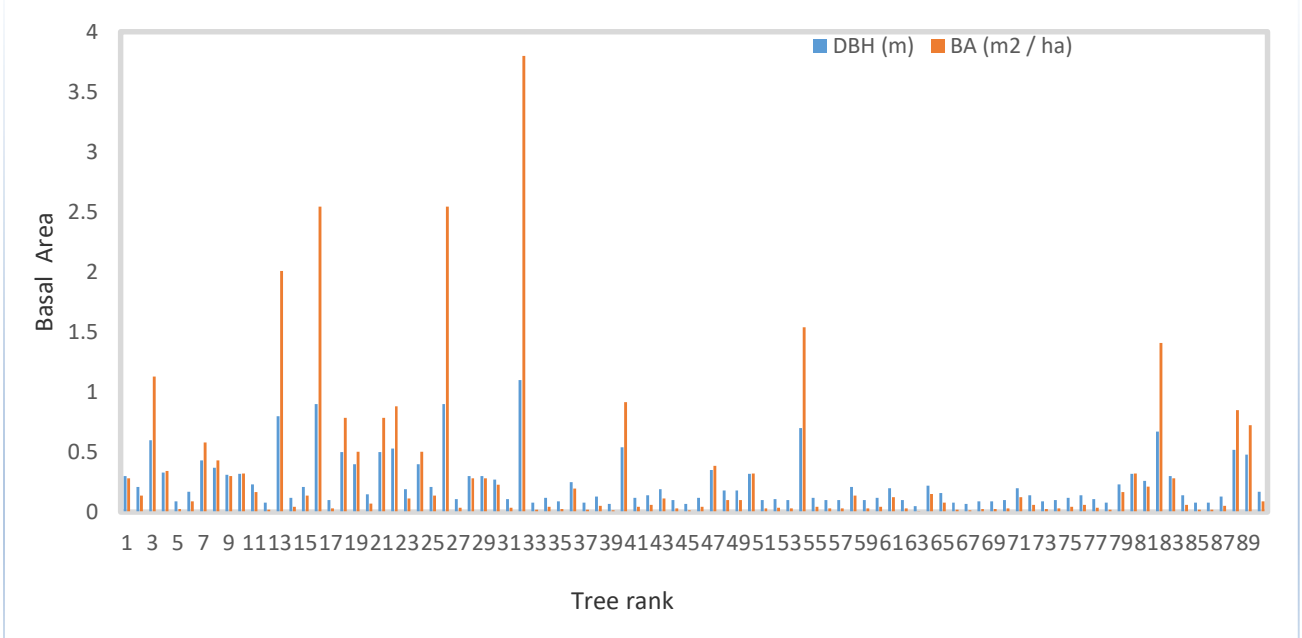

Figure 4: The Basal Area.

BIOMASS AND CARBON STOCKS

The ANOVA model revealed a significant difference ($p < 0.05$) in the mean biomass of *Ricinodendron heudelotii* in terms of the types of equations. The highest biomass (5282.8 ± 1068.4 kg) was obtained with Djomo's moist forests equation. For all the other species, there was no significant difference in the mean biomass from one equation to another (Table 4).

The carbon estimated by the five equations was above 125 tC/ha, except for that of Djomo wet forests (Table 5). It should be noted that the carbon estimated in this study is the above-ground carbon; therefore, to estimate the belowground carbon, we need the mean root/shoot ratio (R/S) = 0.205 for the Djomo (2016) equation and 0.235 for the other four equations (Mokany et al., 2006).

The biomass was evaluated on 0.25 ha and then scaled up to 1 ha to estimate the carbon stock. In Figure 5, we have a graph of the five equations plotted. The highest biomass values, in decreasing order, are as follows: Chave et al. (2005), Djomo (2016) for moist forests, Chave et al. (2014b), Chave *et* al. (2014a), and Djomo (2016) for wet forests. The discrepancy observed when comparing both equations of Djomo could be explained by the fact that we assessed the biomass in a moist forest, whereas we used both equations for moist and wet forests. Figure 6 (A, B, C, D and E) show the variations in biomass estimation with respect to the equation used.

Table 4: Biomass estimated per species with respect to the equation used.

Species	Chave (2005) Pantropical	Chave (2014a) Pantropical	Chave (2014b) Pantropical	Djomo (2016) Wet Forests	Djomo (2016) Moist Forests
Akouk	1685.2 ± 1501.3	780.4 ±777.0	824.7 ± 831.2	564.0 ± 513.7	1064.1 ± 989.8
Amang	259.1 ± 381.8	154.7 ± 210.1	157.8 ± 217.2	146.2 ± 186.9	185.6 ± 261.7
Aningeria robusta	948.1 ± 1693.2	368.1 ± 612.0	386.1 ± 652.0	283.2 ± 403.3	586.9 ± 1024.4
Coffee for forest	445.8 ± 457.3	247.6 ± 220.9	253.7 ± 231.5	227.4 ± 176.4	305.0 ± 293.5
Cordia millenii	358.8 ± 354.7	117.5 ± 94.9	117.8 ± 96.9	133.7 ± 94.9	211.7 ± 190.6
Enantia chlorantha	84.7 ± 68.7	45.7 ± 23.0	44.6 ± 22.9	56.9 ± 27.5	62.2 ± 41.0
Entandrophragma angolense	131.8 ± 128.7	69.6 ± 65.6	69.3 ± 66.4	78.7 ± 69.7	90.6 ± 86.6
Erythrophleum ivorense	2070.6 ± 4142.6	817.7 ± 1508.6	876.4 ± 1653.6	491.3 ± 691.7	1204.0 ± 2364.5
Musanga cecropioides	545.4 ± 484.5	193.8 ±151.2	197.1 ± 155.2	211.1 ± 152.7	360.6 ± 300.2
Piptadeniastrum africanum	977.2 ± 1618.5	701.8 ± 1170.3	749.5 ± 1254.7	483.5 ± 783.6	773.4 ± 1284.1
Pterygota macrocarpa	3402.1 ± 3300.9	1599.3 ± 1048.7	1708.8 ± 1139.5	1051.2 ± 537.4	2236.1 ± 1853.7
Pycnanthus angolensis	781.6 ± 1587.2	415.7 ± 808.6	440.5 ± 867.1	304.9 ± 526.7	577.8 ± 1154.7
Ricinodendron heudelotii	5125.5 ±774.0^{b}	3721.2 ± 877.1^{ab}	4044.4 ± 976.3^{ab}	2219.2 ± 390.1^{b}	5282.8 ± 1068.4^{a}
Staudtia kamerunensis	6925.8 ± 9289.2	3911.8 ± 5323.7	4318.9 ± 5898.6	1780.3 ± 2312.4	4828.9 ±6538.3
Voacanga africana	82.0 ± 70.4	47.2 ± 28.8	46.2 ± 28.8	53.3 ± 31.2	58.8 ±42.3

Values in the table represent the biomass in kg, expressed as mean ± SD

[a, b] on the same row, values carrying the same letters are not significantly different at 5% significant level.

Table 5: Carbon Stocks Estimated.

Estimation/Author	Chave (2005) Pantropical	Chave (2014a) Pantropical	Chave (2014b) Pantropical	Djomo (2016) Wet Forests	Djomo (2016) Moist Forests
ABG within 0.25 ha (tons)	89.268	46.160	49.309	30.818	62.629
ABG/ha (tons)	357.072	184.64	197.236	123.272	250.516
BGB/ha (tons)	83.912	43.390	46.350	25.271	58.871
TB/ha (tons)	440.984	228.03	243.586	148.543	309.387
Carbon stock (tC/ha)	220.492	114.015	121.793	74.272	154.694

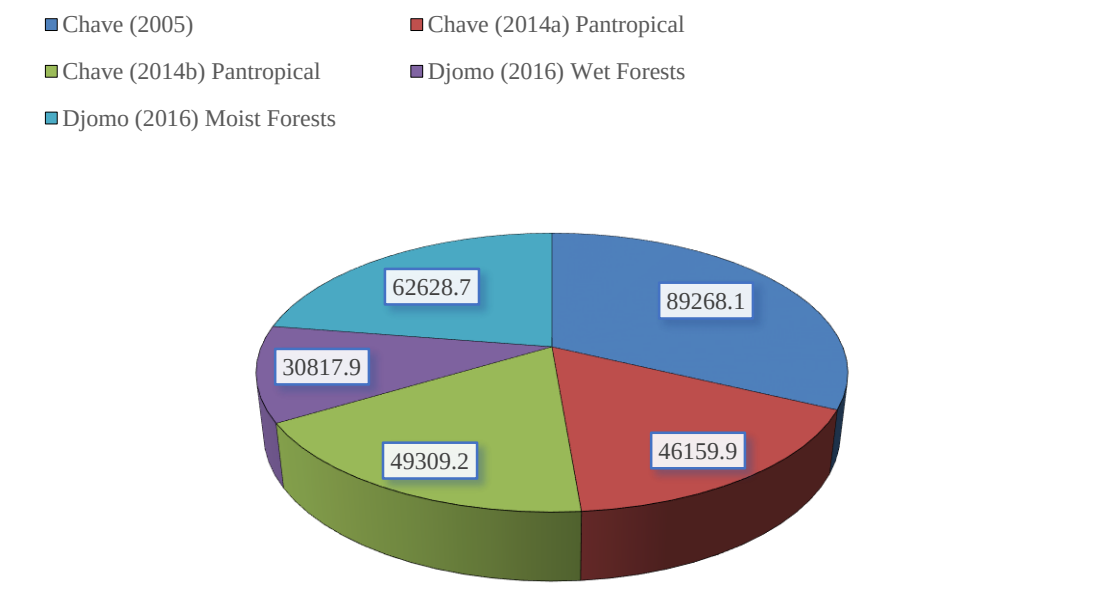

Figure 5: Total biomass of the studied forest according to the type of equation.

ESTIMATION OF POTENTIAL BENEFITS FOR THE CARBON SEQUESTRATION

Supposing that the expense of buying a credit in the voluntary market can be about $6-$8 a tonne for sequestering carbon in forests per year (Jessop, 2023), the potential benefits for the country if the Reserve is preserved, was calculated. Results are presented in Table 6.

Table 6: **Estimation of Potential Benefits for the Carbon Sequestration.**

Estimation	Carbon stock tC/ha)	Potential benefits ($)
Chave (2005) - Pantropical	220.5	1 323 - 1 764
Chave (2014) - Pantropical	114.1	684 - 912
Chave (2014) - Pantropical	121.8	731 - 974
Djomo (2016) - Wet Forests	74.3	446 - 594
Djomo (2016) - Moist Forests	154.7	928–1238

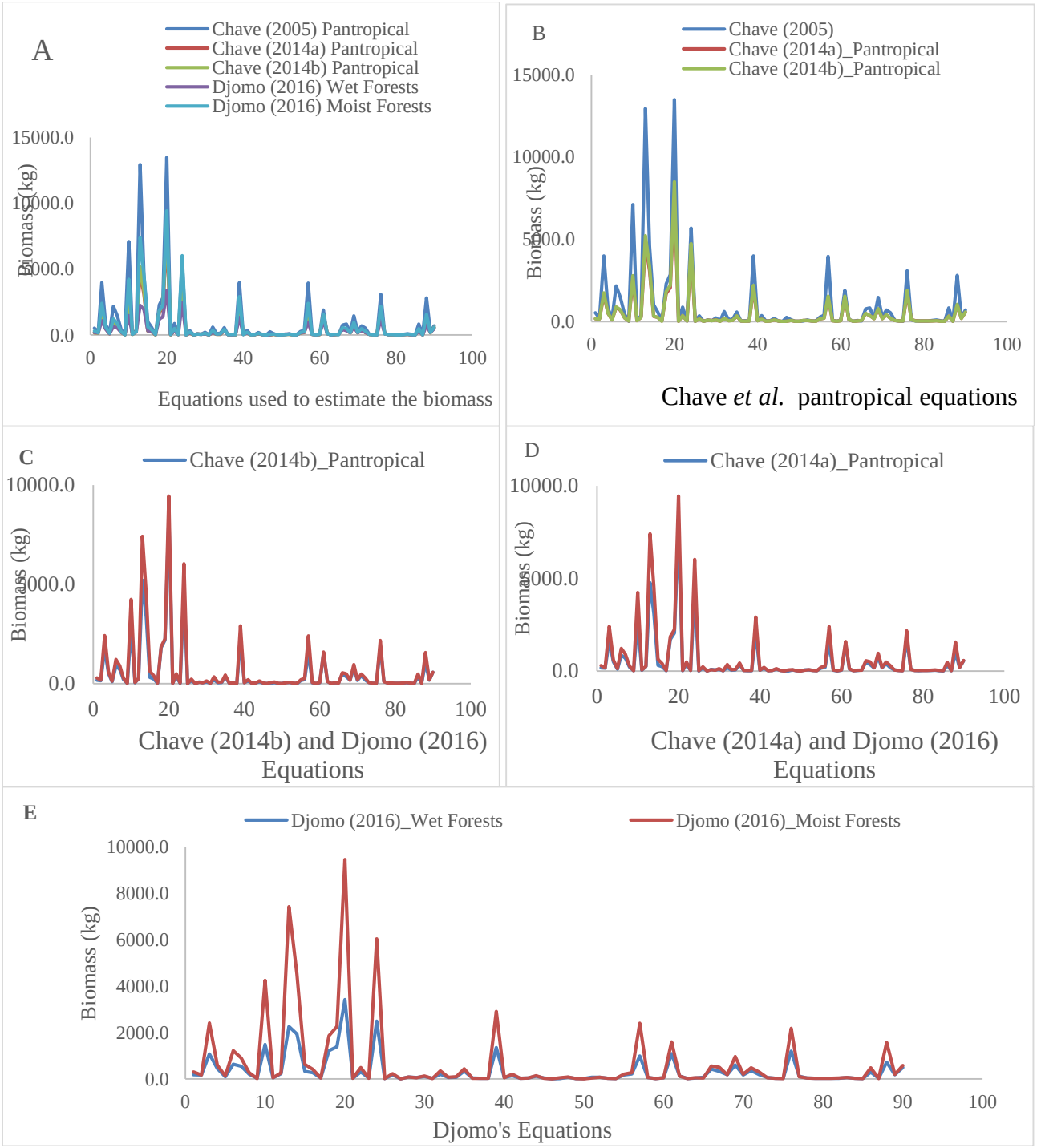

Figure 6: Variations in biomass estimation with respect to the Equation used: (A) shows the variations in the biomass with respect to the 5 equations plotted. We can observe that Chave et al. (2005) equations display the highest biomass. (B) shows Chave at al. 3 Pantropical Equations (2005, 2014a and 2014b) plotted. Chave et al. (2014b) displays higher biomass than Chave et al. (2014a). (C) and (D) show that Djomo (2016) displays higher biomass than Chave et al. (2014b) as well as than Chave et al. (2014a). In comparing both Djomo (2016) for wet forests and Djomo (2016) for moist forests, the discrepancies are enormous.

DISCUSSION

SPECIES COMPOSITION AND RICHNESS

This research aimed at assessing the tree diversity and the carbon stock capacity of the Bomboko Forest Reserve Remnant in the Southwest Region of Cameroon. The rich diversity recorded in this survey is in conformity with previous reports, according to which the forests of southwestern Cameroon are generally known to be rich in species diversity because they are located within the high rainfall zone of the Guinean equatorial tropical forest (Fonge et al., 2013). The occurrence and frequency of species in an area give a view of the spatial distribution of species in that area. In this study area, the most dominant family was the *Meliaceae* with 25% of species, followed by *Caesalpiniaceae* (15.63%) and *Myristicaceae* (12.5%). This result contradicts previous findings reporting that the *Rubiaceae* was the most dominant tree family in the Mount Cameroon Region (Ndam et al., 2001; Fonge et al., 2013). This can be explained by the small sample size studied in the area. The high value of the Gini-Simpson index in this study suggests high heterogeneity. In fact, a forest community is said to be rich if it has a Shannon Diversity value ≥ 3.5 (Kent, 2011). The Shannon index of 4.395 confirmed the high richness of the forest. Out of 18 species recorded, 1 species was a vulnerable species according to the IUCN, namely *Guarea cedrata* (Light Bossé or Scented Guarea). The Mount Cameroon area is known to be a centre of biodiversity and endemism; this probably explains the existence of such species.

THE TREE DENSITY

The tree density calculated is d = 360 trees/ha with DBH above 5 cm. The number of tree species with DBH above 10 cm in tropical forests generally ranges between 120 and 200 species per hectare (Gentry, 1988). This difference can be explained by the fact that in this study, we considered some immature trees with DBH less than 10 cm. This average falls within the range obtained in another tropical rainforest (Diangha, 2001).

THE STAND MEASUREMENT

The distribution of diameters reflects the history of the forest (Felfili, 1997). The distribution of species by diameter size classes showed that the number of individuals reduces as the size class increases. Previous reports suggested that this decrease is since, although many saplings can grow in the forest, most die off quickly, leaving only a few medium-sized trees and even fewer large and very large trees (Edwards, 1994). A small number of stems with a corresponding large basal area show that the tree species are mature with good potential for harvestable trees (Djomo et al., 2016). In contrast, many stems with a corresponding low basal area value shows that the tree species are immature. This is also confirmed by previous findings stipulating that the stand basal area of forests tends to increase with age as the trees grow (West, 2009). For young stands, or stands with very low stocking densities, stand basal areas can be close to zero. For old stands and stands with high stocking densities, it can exceed 100 m^2/ha. In this light, it was suggested that lower values of basal areas result from a

mixture of different forest types (Sonke, 1998). For virgin rainforests in Africa, basal areas of 23–37 m²/ha are considered "normal values" (Lamprecht, 1986). A population of trees with a basal area of 5 to 15 m²/ha suggests a young population, while a dense and old population has a basal area of 25–50 m²/ha (Kuuluvainen and Gauthier, 2018); this suggests that our forest is an old forest with a basal area of 29.2 m²/ha.

BIOMASS AND CARBON STOCK

The biomass generated by the different equations didn't reveal any significant difference except in the case of *Ricinodendron heudelotii* in terms of types of equations. However, there are some discrepancies in biomass estimates by different equations for Tropical Forest; this view is supported by previous reports (Fayolle et al., 2013; Ngomanda et al., 2014; Djomo et al., 2016). In general, the biomass evaluated with Chave et al. (2005)'s equation was higher than that calculated with other equations. In Chave (2005), we have 357.1 t/ha for AGB biomass, while the highest is 250.5 t/ha in Djomo (2016) for moist forest (a gap of 29.84%). Therefore, Chave *et* al. (2005)'s equation overestimates the value of the biomass; this is confirmed by other researchers who evaluated the gap to be 20.3% (Fayolle et al., 2013). With Djomo's equations, we obtained 123.272 t/ha of AGB biomass for wet forests, while it is 250.516 t/ha for moist forests (a gap of 50.79%); this confirms that ecological parameters of the area should be considered when evaluating biomass. When comparing Chave et al. (2005)'s equation with those of 2014, the difference is bigger: 357.1 t/ha of AGB biomass for Chave (2005); 184.6 t/ha (48.29% difference) and 197.2 t/ha (44.76%) for Chave (2014), respectively.

Again, in comparing both equations of Chave (2014), there is a slight discrepancy (7%). The comparison of Djomo (moist forests) and Chave (2016) gives a discrepancy of 26%. Furthermore, the biomass for the Congo Basin Forests was evaluated to be 122–192 tC/ha, with a mean of 185 tC/ha for carbon stock (Nasi et al., 2009). Both Chave et al. (2014a) and Djomo (moist forests) fall within this interval. Therefore, Djomo (2016 for moist forests) and Chave (2014a) equations can be used to assess the biomass of a moist tropical forest. Higher biomass is found in all the graphs in the interval between 20 and 22 trees. This study stresses the need to preserve forests and restore those that have been destroyed by anthropogenic pressure to reinforce the biomass and carbon stock; for this purpose the role of communities is determinant in the restoration process (Metolo et al., 2024).

CONCLUSION

The purpose of this study was to investigate tree diversity and evaluate biomass in the area using existing allometric equations. The findings revealed a high level of species richness, with the *Meliaceae* family being dominant. The most frequently observed tree species was *Entandrophragma angolense*. Additionally, various hardwood trees were identified, along with medicinal species such as *Enantia chlorantha* and *Voacanga africana*. The research documented at least 18 species of tree, including *Guarea cedrata*, which is classified as vulnerable by the IUCN. Furthermore, *the* study demonstrated that both the Djomo and Chave equations are applicable for assessing biomass in moist tropical forests. A comprehensive inventory of the area is

necessary to evaluate its potential for genetic tree diversity and overall biodiversity. There is also an urgent need to develop site-specific allometric equations for the SWR forests.

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