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Stand Diversity and Carbon Stock of a Tropical Forest in the Deng Deng National Park, Cameroon

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Abstract

Tropical rainforests are crucial in maintaining about 70% of the world's plant and animal biodiversity and are also the highest terrestrial carbon reservoir. This study aimed to determine the tree species composition, structure and carbon stocks of the Deng Deng National Park which is a semi-deciduous tropical forest (plots 1 and 2 and the transition zone to the savannah (plot 3). Plots demarcation and enumeration followed standard protocols for permanent monitoring plots. The inventory of tree species ≥ 2 cm revealed a total of 5523 individuals of 64 species in 53 genera belonging to 26 families with plot 2 having the highest (2135 individuals/ha) and plot 3 the least (1291 individuals/ha). *Tabernaemontana crassa* was the most important tree species in the tropical forest and *Lecythis idatimon* in the savannah. Basal area was highest in the tropical forest and least in the savannah. The diameter distribution of trees in all forest types displayed a reverse J-pattern. Aboveground biomass was highest in the tropical forest (530.2 ± 66.4 t·C/ha) and least in the savannah (184.3 ± 20.1 t·C/ha). The carbon stock of the above ground biomass was twice as much as that of the below ground biomass, soil organic matter and litter. The total carbon stock estimated in all pools was 278.75 t·C/ha. The study site was poor in plant diversity, biomass and carbon stock, indicating a disturbed site with the absence of large trees and undergoing natural regeneration. This underlines an urgent need for efficient restoration management practices.

Keywords

Diversity, Above Ground Biomass, Below Ground Biomass, Carbon Stock,

Deng Deng National Park

1. Introduction

Tropical rainforests, with their myriad of species, play a crucial role in maintaining about 70% of the Terrestrial biodiversity with numerous plant and wildlife species [1] and are the highest terrestrial Carbon reservoir [2]. The different stands of a forest play a critical ecological role such as; storing large quantities of Carbon, dominating canopies, providing food, shelter, habitat, nesting cavities, modulating micro-climates and hydrological processes [3]. Tropical forests are thus complex ecosystems [4] that are not fully understood [5] as much debate has been conducted on the factors influencing species diversity rather than on the structural attributes on forest functioning [6] [7]. This may be due to the poor knowledge of the biological characteristics of many tropical species, notably about regeneration processes [8] as even among large trees, new species are regularly discovered [9]. This is partly due to the high botanical diversity of tropical forests which includes many endemic species. Biodiversity is a key determining factor for forests to provide effectively for ecosystem services, particularly carbon sequestration, and at the same time to maintain their resilience to disturbance, such as climate change [10]. This lack of knowledge is an obstacle to the definition of the rules for sustainable management [11].

The forests of the Congo Basin are the richest in plant species across Africa, with Cameroon being the third richest in terms of biodiversity after Democratic Republic of Congo with 8260 plant species [12] out of the 10,000 species found in the Congo Basin [13]. It is also a centre of endemism for plant and animal species [14] [15] with 150 plant species being endemic to Cameroon [16]. Although Cameroon has been better explored by botanists than most other Central African countries, its flora remains incompletely known, and several new species are described every year [17]-[22]. In addition, botanical efforts have tended to focus on some specific sites (e.g. Mt Cameroon, Mt Kupe), leaving other areas almost unexplored, especially in the North and Southeast regions of the country. Although the forest of Deng Deng has been studied, it is mostly known for its endemic fauna that it possesses [23]. Also the Flore du Cameroun series, which started in 1960 by the Muséum National d'Histoire Naturelle in Paris, and continued by the National Herbarium of Cameroon in Yaoundé, covers only about half of the families and its publications have markedly slowed down in recent years. According to Onana [24], a national checklist, numbering 7500 indigenous or naturalised species, with 600 tree species that can attain exploitable diameter [25] as against estimated 10,000 species in the Congo Basin [13].

Tropical forests absorb huge amounts of Carbon in its wood. The Carbon stored in the aboveground biomass of trees is the largest pool and is directly impacted by deforestation and degradation [26]. Thus to assess the real contribution of forests to the removal of atmospheric carbon and the magnitude of Green House Gas

(GHG) emissions in the case of deforestation, it is essential to quantify above-ground forest biomass and carbon stock [4] making it the most critical step in quantifying Carbon stocks and fluxes from tropical forests [27]. However, the carbon stock found in the dead mass of litter, woody debris and soil organic matter is also a very important parameter used for forest productivity and Carbon balance assessment [28]; making forest ecosystems contribute approximately half of global net primary production. Nonetheless, in natural forests there is great variation in the capacity of each species to accumulate biomass and store carbon, mainly due to the great diversity of species and the high variability between individuals of the same species. Therefore, tropical forests have a great influence on the terrestrial ecosystem's ability to accumulate Carbon [29]. Unfortunately, no real attempts have been made to estimate the state of biomass in most African forests, as estimating change in biodiversity and Carbon stock became difficult [30] in Africa in general and Cameroon in particular [31]; creating considerable uncertainty about the above- and belowground quantity and distribution of carbon stocks in African forests [32]. This study is one of few in Cameroon and the broader Congo Basin region that has calculated diversity, above-ground biomass, and carbon in a semi-deciduous forest [32] [33] [34] [35]; as despite the importance of this forest reserve, its biodiversity, Carbon storage capacity, the relationship between tree diversity and their ability to store Carbon remains poorly known.

In order to know and preserve the diversity of the forest, most African countries including Cameroon have based their biodiversity conservation strategy on the creation and extension of protected areas. Since the 90s, for almost two decades, globally the number and size of protected areas have seen a rise from 13% - 17%, accounting for over 651 million ha designated primarily for biodiversity conservation. In the tropics, protected areas within this same period witness an incremental addition of about 143 million ha of new forests under legal protection with huge implications for soil and water conservation [36]. In Cameroon, there has been increasing public concern about the importance of the environment and its protection. Hence, to address this, the 45% forest cover of Cameroon national territory has been divided into permanent and non-permanent forests [37]. National Parks are classified as permanent forests and thus can be considered for permanent monitoring and conservation of biodiversity. Although the National Park may seem like an unchanging climax vegetation due to the restrictions in exploitation, subtle changes actually occur in the floristic composition and structural attributes whereby continuous flux of different species of varying recruitment and mortality rates occur. The Deng Deng forest found in the East Region of Cameroon is adjacent to logging concessions, and community forests, and forms the largest conservation and most biodiverse landscape in Cameroon. The Deng Deng forest is home to the northernmost known population of the lowland gorilla, and also harbouring other threatened species including chimpanzee, elephant, hippopotamus, giant Pangolin, Yellow backed duiker [23]. The Deng Deng National Park was partly created to mitigate for the compensation of the environmental component of the construction

project of Lom Pangar Impoundment Dam [38]. It is thus no longer limited solely to the conservation of biodiversity as before, and therefore should be pruned to deforestation and degradation; as the presence of economic Operators (such as forestry exploitation companies) and external development bodies such as Cameroon Oil Transportation Company (COTCO) allowing access to hunting and poaching in the area have together led to an influx of people into the villages within the target area. This is further compounded by the fact that prices of some cash crops like cocoa and coffee have decreased in recent years, this has further resulted in the increase of illegal logging which has led to further deforestation [39]. The most significant threat is the increased fragmentation of the proposed wildlife corridor linking Deng Deng to the Dja Reserve [40]. Thus these forests might continuously decrease due to the increase in anthropogenic pressure along with the population migration for more fertile lands [41]. In most tropical forest there is lack of species dominance [42], which coupled with the high species diversity makes it very vulnerable [43], particularly for unmanaged or ill-managed forests where the forest is disturbed as a result of human activities. Forest disturbance will result in changes in the floristic composition and structure [44]. The lack of species dominance, with few individuals within a given species per hectare, implies that a forest disturbance can result in some plant species to dominate, while driving others to become extremely rare.

However, there is a knowledge gap on the vegetation compositional diversity and Carbon stock of the Deng Deng National Park (DDNP) [38]. There is thus the need for a survey of the forest to provide baseline information to contribute knowledge to the understanding of the forest ecosystem for effective forest management [45]. The main objective of this study was to determine the present diversity and Carbon stock of the Deng Deng National Park. To address this objective the following questions were asked: 1) *what is the present plant composition and structure of the DDNP*? Evaluating forest composition and structure at various spatial scales is very important for a better understanding of the terrestrial forests and this will provide baseline information which will enable better management and sustainability of the forest. 2) *What is the carbon stock of the DDNP*? Evaluating the biomass and Carbon stock of the forest will broaden our horizon on the forest's potential to sequester carbon for climate change mitigation. Following the global effort on the sustainable management of tropical ecosystems, this study contributes towards national and regional responsibility to characterise local forest biodiversity in the region hence highlighting the importance of the DD forest as a biodiversity rich zone and being part of a continuous block in the Congo Basin. This study thus provides insights into the rich diversity and carbon stock of the study area and also emphasises the importance of protecting the biodiversity of protected transitional zones.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Deng Deng National Park located between lati-

tudes 5˚8' and 5˚32'N and longitudes 13˚22' and 13˚36'E. Its altitude ranges between 600 m and 800 m above sea level (Figure 1). The forest has a Type A wet equatorial climate (Guinea type climate) with relatively high humidity and cloud cover and yearly precipitation ranging from 1500 - 2000 mm except in the extreme eastern and northern portions, where it is slightly less [46]. The soil type is primarily ferralitic and characterised by high leaching and poor nutrients [38] [47]. The forest flora is dominated by commercially valuable *Triplochiton scleroxylon* and is heavily targeted for exploitation. Some other important economic plant resources present in the park include; *Entandrophragma cylindricum*, *Terminalia superba*, *Entandrophragma utile*, *Erythrophleum suaveolens*, *Eribroma oblonga*, *Guarea cedrata*, *Pterocarpus soyauxii* and *Enantia chlorantha* [47]. The presence of forest savannah transition zones makes the flora unique with both savannah and forest species coexisting as the forest transitions into savannah which supports plant species unique to this habitat type.

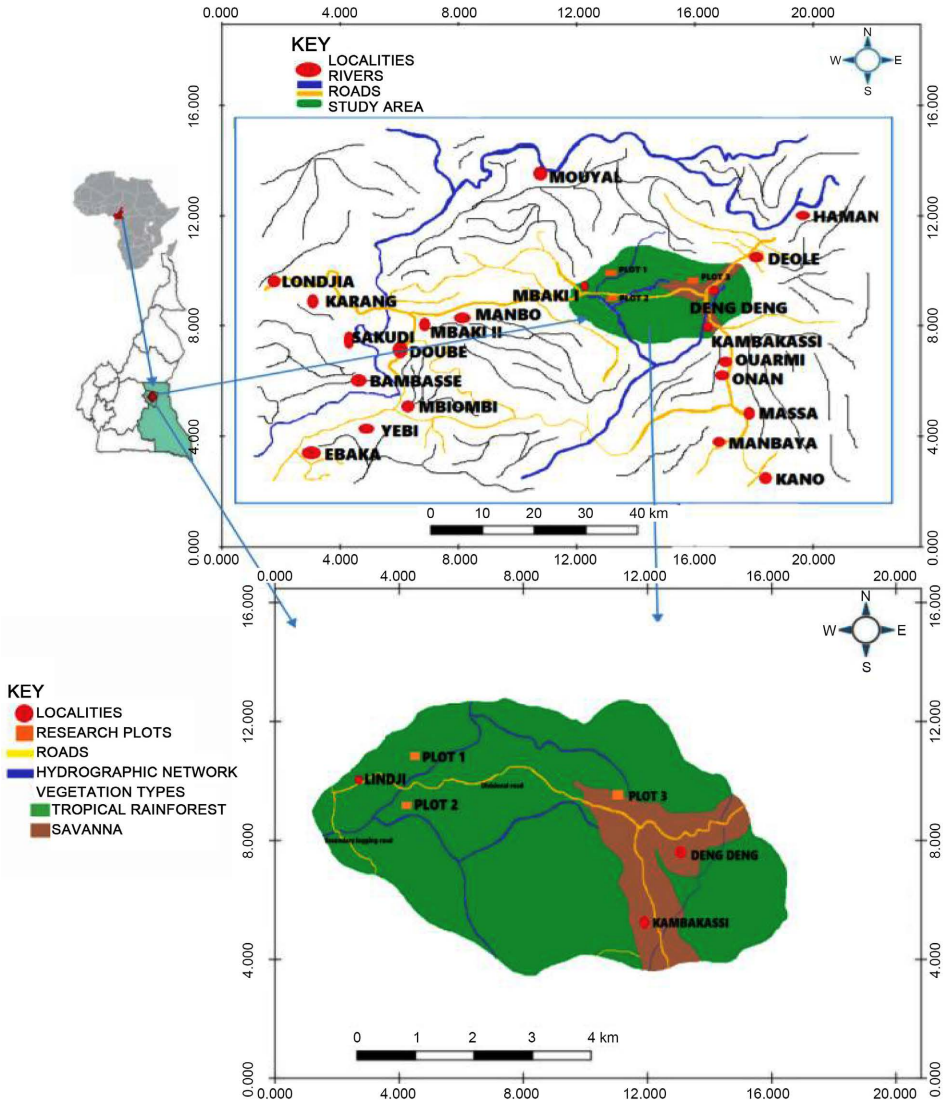

Figure 1. Location of study sites in the Deng Deng National Park.

The park size is 52,347 ha [38], and consists of three blocks; two of which are in the tropical forest zones highly rich in biodiversity experiencing high rainfall, relatively high temperatures, and high humidity, while the third is located within a transitional zone spanning from the forest into the savannah. This zone is characterised by shrubs and smaller trees, and nutrient-poor soils.

2.2. Field Design and Sampling Methodology

2.2.1. Plot Demarcation

Three plots of 1-ha size each were systematically established out across the three main blocks of the national park. These locations were selected in the three blocks to capture most of the flora diversity of the park with Plots 1 and 2 found in the forest and Plot 3 found in the savannah transition zones. Each selected plot location was registered with the help of a Garmin model GPS. Plot demarcation followed the Condit [48], method of permanent sampling plot. Hence, each 1-ha plot was divided into 25, 20 m × 20 m quadrats whose corners were marked with painted permanent poles. Each 20 m × 20 m quadrat was subdivided into 16, 5 m × 5 m subquadrats using temporary markers at 5 m intervals; giving a total of 400 (5 m × 5 m) subquadrats per ha (**Figure 2**).

2.2.2. Tree Species Enumeration

All tree species with a diameter at breast height (dbh) ≥ 2 cm were measured at 1.3 m from the ground except for those that have buttresses which were measured 30 cm from the end of the buttress. We used the Timber Cruising Handbook [49] proposed guide for measurement. The DBH of all trees ≤ 6 cm was measured with a vernier calliper while trees with DBH ≥ 6 cm were measured with a diameter tape. The location of each plant within each 5 m × 5 m subquadrat was determined by measuring the X and Y coordinates.

Plant identification was carried out by a field botanist. Most of the trees enumerated lacked fertile materials, so we used vegetative characters like colour, odour, and texture of bark slash; and colour of exudates from bark to segregate morphospecies. Unidentified voucher species were collected in triplicates and their identification was confirmed at the Yaounde National Herbarium.

2.3. Data Analyses

2.3.1. Determination of Stand Characteristics

Determination of the stand composition

Species richness and abundance were used to evaluate the stand composition. These stand parameters were used to estimate the Importance Value Index (IVI), Family Importance Value (FIV), and Fisher's alpha diversity.

Species richness was determined by tallying all extant species [50].

Species abundance was determined by a simple count of the number of individuals of all the different species [51].

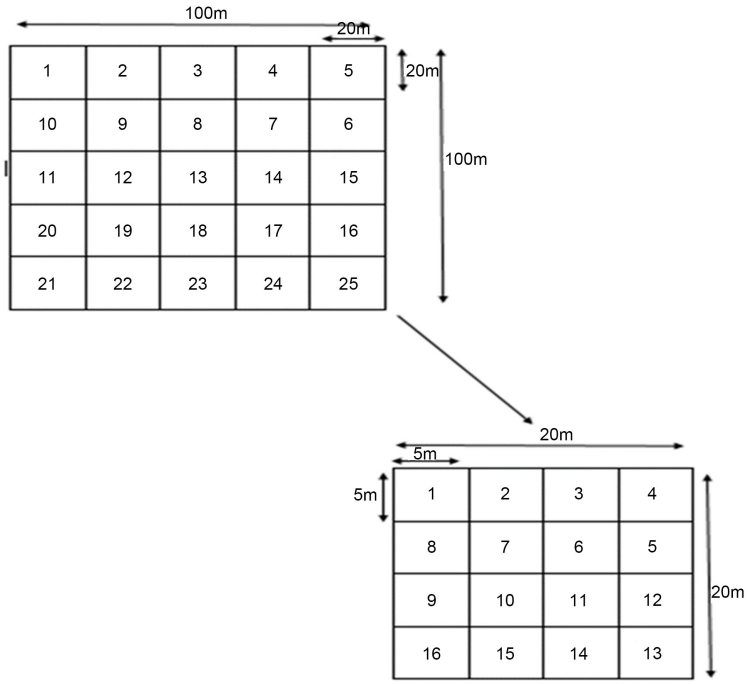

Figure 2. Plot design of the study sites in the Deng Deng National Park. The numerical numbering of the quadrats and subquadrats follows movement during tree species enumeration.

Species Importance Value Index (IVI): The IVI was obtained by summation of the relative percentage values of frequency, density and dominance [52]

$$\mathrm{IVI} = \mathrm{SRDe} + \mathrm{SRF} + \mathrm{SRDo} \tag{1}$$

where SRDe = Species Relative Density which is

$$\mathrm{RDe} = \frac{\text{number of individuals of that species}}{\text{total number of individuals}} \times 100$$

SRDo = Species Relative Dominance which is

$$\mathrm{RDo} = \frac{\text{Basal area of that species}}{\text{total basal area}} \times 100$$

SRF = Species Relative Frequency which is

$$\mathrm{RF} = \frac{\text{number of quadrats with that species}}{\text{total number of quadrats for all species}} \times 100$$

Family important value index (FIVI): It was calculated as described by Mori *et al.* [53]:

$$\mathrm{FIVI} = \mathrm{FRDe} + \mathrm{FRF} + \mathrm{FRDo} \tag{2}$$

where FRDe = Family Relative Density which is

$$\mathrm{RDe} = \frac{\text{number of individuals of that family}}{\text{total number of families}} \times 100$$

FRDo = Family Relative Dominance which is

$$\text{RDo} = \frac{\text{Basal area of that family}}{\text{total basal area}} \times 100$$

FRF = Family Relative Frequency which is

$$\text{RF} = \frac{\text{number of quadrats with that family}}{\text{total number of quadrats for all families}} \times 100$$

The diversity of trees was determined using Fisher's alpha diversity and Shannon diversity indices:

Fisher's alpha diversity: It was determined as described by Fisher *et al.* [54];

$$S = a^x \ln\left(1 + n/a\right) \tag{3}$$

where S is the number of taxa, n is the number of individuals and a is the Fisher's alpha.

Shannon diversity: It was determined as described by Shannon [55]:

$$\text{Shannon index} = -1\left(\sum pi * \ln pi\right) \tag{4}$$

where pi is the proportion of individuals belonging to the i species in the data set.

In calculating diversity, only species that were identified to the species level were considered. In the PAST statistical package, we ran a Jaccard test for similarity and a principal component analysis (PCA) test to determine species similarity across plots and the distance of each plot from one another based on its composition of species.

2.3.2. Stand Structure of the Deng Deng National Park

Stand structural characteristics were based on DBH measurements represented here by the number of stems per DBH class for the size class distribution. Multiple stemmed plants were considered as single individuals for the calculation of stem density, and the basal area (G) of all stems were summed for the calculation of basal area (m^2/ha). Tree density was calculated as the number of individuals divided by sample area. Basal area and densities were determined on a per hectare basis [44] [56]. The basal areas of the stems were summed up and converted to basal areas per hectare. The mean basal area per hectare was calculated, using the individual values obtained from the forest stands. The densities of trees were also calculated on a per hectare basis for each stand and used to calculate the mean number of individuals/ha.

2.3.3. Determination of Carbon Stock of the Deng Deng National Park

1) Soil Organic Carbon (SOC)

Soil sampling was determined according to FAO [57]. Nine quadrats of 1 m × 1 m were randomly selected in all the 3 plots and cored soil samples carefully collected and placed in polythene bags at 0 - 10 cm, 10 - 20 cm and 20 - 30 cm, giving a total of 27 samples/plot. The soil samples of the different soil depths for the different plots were bulked together, labelled, and representative samples taken. The soil samples were air-dried to prevent oxidation and sieved using a 2

mm sieve in order to separate the fine and coarse materials. Soil samples were weighed (W_1) using a scale balance and oven-dried at 105˚C for 2 days to get the dry weight (W_2). The samples were ashed at 500˚C for 5 hours to get the percentage of Carbon (%C) present in the sample (W_3). The Soil organic Carbon was determined by the formulae:

$$\text{Soil Organic Carbon}(\text{SOC}) = d \times \%\text{C}(W_3) \times \text{BD} \tag{5}$$

where d = depth of soil, W_1 is the weight of soil sample before drying, W_2 is the weight of soil sample after drying, %C = percentage of carbon (W_3) and BD = bulk density (kg/ha).

To determine the bulk density, a soil corer was used to collect soil samples with a known volume. The fresh weight (W_1) was determined by weighing scale and this was oven dried at 105˚C for 48 hours to have the dry weight (W_2). This was later used to determine the bulk density of the soil.

$$\text{Bulk density} = W_2 / V\left(\text{g} \cdot \text{cm}^{-3}\right) \tag{6}$$

where V = volume of the soil corer = $\pi r^2 \times h$.

2) Litter Carbon Stock (LCS)

Litter was collected from ten random 1 m × 1 m quadrants per plot and for all three plots. The litter samples were bulked for each plot. The litter samples included leaves, tree barks, branches and woody roots. Each collected sample was labelled and transported to the University of Buea Life Sciences Laboratory. The samples were then weighed (W_1) using a scale to obtain their masses and oven-dried at 105˚C to constant weight (W_2). Litter dry weight was determined as described by Timothy *et al.* [58]:

$$\text{Carbon stock of litter}\left(\text{t} \cdot \text{C/ha}\right) = \frac{\text{Total dry weight}\left(\text{meter square}\right) \times 0.5}{\text{Sample area}\left(\text{m.sq.}\right)} \tag{7}$$

3) Above Ground Biomass (ABG) and Carbon stock

The diameter obtained during the floristic inventory was used to evaluate the Above Ground Biomass (AGB) of the Deng Deng National Park. The allometric equation developed by Chave *et al.* [59] was used for the assessment of Above Ground Biomass without tree heights:

$$\begin{aligned}\text{AGBs} = \rho_s \times \exp\Big[&-1.499 + 2.148 \times \text{In}\left(\text{DBH}\right) + 0.207 \times \text{In}\left(\text{DBH}\right)^2 \\ &- 0.0281 \times \text{In}\left(\text{DBH}\right)^3\Big]\end{aligned} \tag{8}$$

where DBH = diameter at breast height in centimetres, ρ_s = specific wood density extracted from CIRADs database [60] and FAO database 2 [30]. For species without wood densities, an average for the genera or family was used.

The estimation of the Carbon stock for the Above Ground Biomass, was determined as described by Zapfack *et al.* [61]: This approach basically estimates the amount of carbon by multiplying the obtained biomass by 0.47.

4) Below Ground Biomass (BGB) and Carbon stock

The belowground biomass constitutes a considerable share of the total forest

biomass. Cairns *et al.* [62]), Litton *et al.* [63], Lima and Leão [64] all indicated that the BGB represents up to 40% of the total biomass. The BGB was then estimated as 40% of the total AGB. The estimation of Carbon stock of dead organic matter was determined as described by the Global Forest Resource Assessment [65]:

$$C = B \times \%\text{C organic} \tag{9}$$

where:

C = carbon content from biomass (kg)

B = total biomass (kg) = 40% of the AGB

$$\%\text{ C organic according to Zapfack } et\ al. \text{ [61]} = \text{AGB} \times 0.47 \tag{10}$$

The estimation of the total carbon stock with respect to the different carbon pools studied, was evaluated as described by Hairiah *et al.* [66]:

$$C(\text{plot}) = C(\text{AGB}) + C(\text{BGB}) + C(\text{LCS}) + C(\text{SOC}) \tag{11}$$

where:

C (plot)—total carbon content in the plot (ton/ha).

C (AGB)—total carbon content of AGB per hectare in the plot (ton/ha).

C (BGB)—total carbon content of BGB per hectare in the plot (ton/ha).

C (LCS)—total carbon content of the litter biomass per hectare in the plot (ton/ha).

C (SOC)—total carbon content of soil per hectare in the plot (ton/ha).

2.4. Statistical Analyses

With the aid of MINITAB statistical package version 17, One-Way Analysis of Variance (ANOVA) was used to compare the plot means after a test of homogeneity. The Turkey's Honesty Test was used to separate means of Above Ground Biomass and Carbon stock which differed from one another. Also, a non-parametric Kruskal-Wallis Test was used to separate levels of Soil Organic Carbon and soil bulk density at different soil depths. Diversity indices (Fisher alpha and Shannon-Weiner) and Jaccard similarity were all computed in PAST statistical package.

3. Results

3.1. Forest Composition

Stem Density and Tree Species Composition

We sampled three plots covering an area of 3 hectares and observed a total of 5523 individual tree species. Plot 2 recorded the highest stem density with over 2135 stems/ha, followed by Plot 1 and Plot 3 with 2097 stems/ha and 1291 stems/ha respectively (**Table 1**). There were 64 species belonging to 53 genera in 26 families (Supplementary **Table S1**). Plot 1 had the highest species richness (49 species); while plot 3 had the least (30 species). Plot 1 had the highest number of families while Plot 2 had the least number of families (**Table 1**).

The most common tree species with the highest abundance was *Tabernae-*

montana crassa with 1453 individuals/ha representing 26.3%, *Voacanga africana* with 523 individuals representing 9.5% and *Polyalthia suaveolens*with472 individuals/ha representing 8.5% of the total number of individuals (Table 2).

The species with the most dominance across all the plots is *T. crassa* (26.49). However, in Plot 1, *P. africanum* recorded the highest dominance (10.74), while *T. crassa* and *L. idatimon* recorded highest in Plot 2 and 3 respectively (Table 3). Hence the species with the highest Important Value Index (IVI) recorded for Plots 1 and 2 was *T. crassa* with values 29.50 and 70.98 respectively while in Plot 3 *L. idatimon* recorded the highest IVI with a value of 41.53 (Table 3). Thus, the most important tree species were *Tabernaemontana crassa* for plot 1 and plot 2, and *Lecythis idatimon* for plot 3. The most important tree species in each plot are shown in Table 3; Supplementary Table S2).

The FIV indicates the most important family. The most important family in this study was Apocynaceae for plot 1 and plot 2, and Lamiaceae for plot 3. The least important family was Olacaceae for plot 1, Euphorbiaceae for plot 2 and Urticaceae for plot 3 respectively (Table 4).

Table 1. Stem density and species richness of tree species of the Deng Deng National Park.

Plot	Number of stems	Number of species	Number of families
1	2097	49	22
2	2135	33	18
3	1291	30	21
Total	**5523**	**64**	**26**
Mean/ha	**1841**	**21**	**20**

Table 2. Tree species with the most number of individuals of the Deng Deng National Park.

Species	Family	Abundance (%)
Tabernaemontana crassa	Apocynaceae	1453 (26.3)
Voacanga africana	Apocynaceae	523 (9.5)
Polyalthia suaveolens	Annonaceae	472 (8.5)
Diospyros melocarpa	Ebenaceae	448 (8.1)
Tabernaemontana sp	Apocynaceae	339 (6.1)
Anonidium mannii	Annonaceae	328 (5.9)
Baillonella toxisperma	Sapotaceae	273 (4.9)
Lecythis idatimon	Lamiaceae	249 (4.9)
Coelocaryon preussi	Myristicaceae	228 (4.1)
Albizia ferruginea	Fabaceae	222(4.0)

Table 3. The IVI of the five most important tree species in Deng Deng National Park.

Plot #	Species	RDo	RDe	RF	IVI
1	*Tabernaemontana crassa*	5.21	19.46	4.83	29.50
	Anonidium mannii	8.04	11.40	5.34	24.79
	Tabernaemontana sp	4.03	6.91	4.58	15.52
	Piptadeniastrum africanum	10.74	1.19	2.29	14.22
	Voacanga africana	2.50	6.10	5.09	13.69
2	*Tabernaemontana crassa*	26.49	37.94	6.54	70.98
	Voacanga africana	6.42	11.29	6.54	24.25
	Piptadeniastrum africanum	13.72	3.23	5.61	22.56
	Polyalthia suaveolens	4.54	10.26	6.54	21.34
	Tabernaemontana sp	6.82	7.45	5.30	19.57
3	*Lecythis idatimon*	17.28	16.65	7.60	41.53
	Albizia ferruginea	14.94	14.65	7.60	37.18
	Ceiba pentandra	16.53	5.78	6.38	28.69
	Diospyros melocarpa	5.56	11.33	7.60	24.49
	Ficus exasperata	5.34	8.40	7.29	21.04
Where: **RDo:** Relative Dominance		**RDe:** Relative Density		**RF:** Relative Frequency	

Table 4. Five most important families in the Deng Deng National Park.

Plot	Family	Apocynaceae	Annonaceae	Fabaceae	Malvaceae	Celastraceae
1	FIV	93.05	31.71	28.17	17.46	16.80
	# of Genera	5	1	5	6	1
	# of Species	6	1	6	7	1
	Family	Apocynaceae	Fabaceae	Magnoliaceae	Sapotaceae	Cannabaceae
2	FIV	125.97	33.67	25.27	19.14	14.87
	# of Genera	3	4	1	3	1
	# of Species	4	5	1	4	1
	Family	Lamiaceae	Sapotaceae	Fabaceae	Ebenaceae	Magnoliaceae
3	FIV	48.71	36.97	36.14	27.95	21.95
	# = number of	1	2	2	1	1
	# of Species	1	2	2	1	1

= number.

1) Diversity

There was a high diversity of tree species as revealed by the indices of Fisher and Shannon-Wiener (Table 5(a)). These gave a mean diversity of 0.67 and 2.50 respectively. Plot 1 was the most diverse (0.98) while plot 3 was the least diverse (0.54). Plots 1 and 2 were more even as compared with plot 3. Plot similarity in the study area showed Plot 2 and Plot 3 to be very similar in species

composition and Plot 1 to be highly dissimilar from Plot 2 and Plot 3 (Table 5(b)). This was confirmed by PCA to compare plots distance, thus we observed a marked difference in plot distribution across axes (PC axis 1: eigenvalue = 18.83, percentage variance = 75.33; PC axis 2: eigenvalue = 6.17, percentage variance = 24.68).

3.2. Stand Structure

3.2.1. Basal Area of Tree Species

Basal area estimates were calculated from both the stem diameter and the density of the species and this varied among plots. The mean basal area for all plots was 24.98 m^2/ha. Plot 1 recorded the highest mean basal area (29.80 m^2/ha) followed by Plot 2 (25.33 m^2/ha) and Plot 3 with (19.98 m^2/ha).

3.2.2. Stem Distribution and Diameter Size Classes

The number of trees and mean diameters were calculated for all different diameter-size classes from 0 - ≥80 cm. The survey revealed that the number of individuals decreased with an increase in the diameter-size class; indicating that the diameter-size class of 0 - 10 cm had the highest number of individuals. The diameter size class distribution of trees thus followed the reverse "J" shape pattern (Figure 3). The diameter-size class with the least number of individuals was the 65 - 75 cm DBH-size class in all plots (Figure 3). Also, plot 1 had more individuals in the 0 - 5 cm diameter size class than the other plots. The largest diameters of tree species in all forest plots were as follows: *Cylicodiscus gabunensis (*180.0 cm) for plot 1, *Piptadeniastrum africanum* (130.0 cm) for plot 2 and *Entandrophragma cylindricum* (80.9 cm) for plot 3.

Table 5. (a) Plot diversity and evenness in the Deng Deng National Park; (b) Similarity indices among plots in the Deng Deng National Park.

(a)

Plots	Fisher alpha diversity	Shannon-Weiner diversity (H)	Shannon-Wiener Evenness (e^AH/S)
1	0.98	2.66	0.29[a]
2	0.54	2.28	0.30[a]
3	0.49	2.57	0.44[b]
Mean	**0.67**	**2.50**	**0.34**

Values with the same letters in a column represent means which are significantly the same; while different letters represent means which are significantly different.

(b)

Plot	Jaccard similarity index
Plot 1 - Plot 2	0.32
Plot 1 - Plot 3	0.21
Plot 2 - Plot 3	0.44

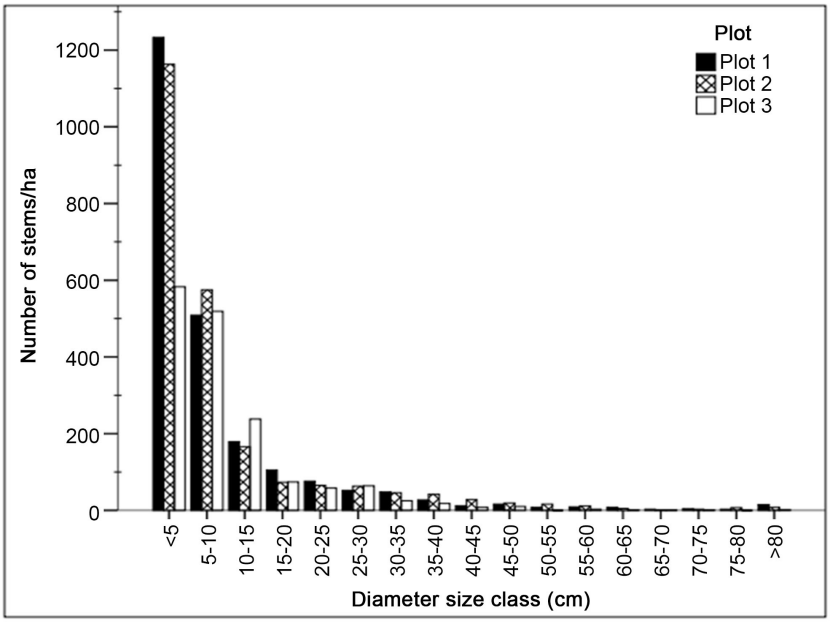

Figure 3. Diameter size class distribution of trees of the study site in the DDNP.

3.3. Carbon Stock of the Deng Deng National Park

3.3.1. Above Ground Biomass (AGB) and Carbon Stock

The Above Ground Biomass and Carbon stock varied significantly among the three plots ($P < 0.05$). The mean AGB and Carbon stock for the 3 forest plots were 387.4 t/ha and 193.7 t·C/ha respectively. The AGB and Carbon stock were both highest in plot 1 and lowest in plot 3 (Table 6). There was no significant difference in AGB and carbon between Plot 1 and Plot 2. However, both Plot 1 and Plot 2 had significantly higher AGB (F-value = 13.5, P-value = 0.0001) and carbon (F-value = 13.5, P-value = 0.0001) than Plot 3 (Table 6).

3.3.2. Belowground Biomass (BGB) and Carbon Stock of the Deng Deng National Park

Similarly, the mean BGB was 154.9 t/ha and the mean Carbon stock contained in the root biomass was 75.0 t·C/ha. The BGB and Carbon were both highest in plot 1 and lowest in plot 3 (Table 7).

1) Soil bulk density and Soil Organic Carbon (SOC) of the Deng Deng National Park

The soil bulk density in all the plots increased with soil depth, while soil carbon decreased with soil depth (Table 9). A simple regression fit indicates a linear relationship between soil bulk density and soil carbon with soil depth (F-value = 19.49, P-value < 0.0001), hence as soil depth increases, bulk density increases with a decrease in soil carbon. A non-parametric Kruskal-Wallis test used to compare between plots showed no significant difference for bulk density (H = 4.67 DF = 2 P = 0.097) and soil carbon (H = 5.12 DF = 2 P = 0.077) across plots. However, Kruskal-Wallis test showed significant differences when comparing soil bulk density and soil carbon with depth; registering H = 16.99 DF = 2 P = 0.0001 and H = 18.25 DF = 2 P = 0.0001 respectively.

The soil bulk density and SOC was significantly different in all plots ($P < 0.05$). The mean soil bulk density and SOC was 0.38 (g/cm^3) and 10.23 (t·C/ha) respectively. The soil bulk density was highest in plot 3 (0.39 g/cm^3) and least in plot 1 (0.37 g/cm^3) while the SOC was the reverse with the highest in plot 1 (11.64 t·C/ha) and lowest in plot 3 (8.37 t·C/ha; Table 8).

Similarly, the Soil bulk density and the SOC were significantly different at the different soil depths ($P < 0.05$). The soil bulk density increased with an increase in soil depth while SOC decreased with an increase in soil depth (Table 9).

Regression Equation

Depth (cm)

0 - 10 Carbon stock (t·C/ha) = −11.17 + 66.5 Bulk density (g/cm^3)

10 - 20 Carbon stock (t·C/ha) = −13.59 + 66.5 Bulk density (g/cm^3)

20 - 30 Carbon stock (t·C/ha) = −18.8 + 66.5 Bulk density (g/cm^3)

Table 6. Above Ground Biomass (AGB) and carbon stock of the Deng Deng National Park.

Plots	AGB (t/ha)	Carbon (t·C/ha)
1	$530.2^a \pm 66.4$	$265.2^a \pm 33.2$
2	$447.6^a \pm 43.2$	$223.8^a \pm 21.6$
3	$184.3^b \pm 20.1$	$92.2^b \pm 10.1$
Mean	**387.4 ± 43.2**	**193.7 ± 21.6**

Tukey pair-wise comparison used to separate means in letters. Similar letters indicate not significant while different letters indicate significant.

Table 7. Belowground biomass (BGB) and carbon stock of the Deng Deng National Park.

Plots	BGB (t/ha)	Carbon (t·C/ha)
1	212.1 ± 26.7	106.1 ± 13.4
2	179.1 ± 17.3	89.5 ± 8.7
3	73.7 ± 8.4	29.5 ± 4.2
Mean	**154.9 ± 17.5**	**75.0 ± 8.8**

Table 8. Soil bulk density and Soil Organic Carbon (SOC) of the Deng Deng National Park.

Plots	Soil bulk density (g/cm^3)	SOC (t·C/ha)	Percentage Soil Carbon
1	0.37 ± 0.01^a	11.64 ± 0.92^a	2.90
2	0.38 ± 0.01^b	10.69 ± 0.57^b	2.51
3	0.39 ± 0.01^c	8.37 ± 0.64^c	2.29
Mean	**0.38 ± 0.01**	**10.23 ± 0.71**	**2.57**

Values with different letters in a column represent means which are significantly different.

Table 9. Soil depth, soil bulk density and soil organic carbon in the DDNP.

Plots	Soil depth (cm)	Soil bulk density (g/cm^3)	Soil organic carbon (t·C/ha)
1	0 - 10	0.38 ± 0.00^a	14.17 ± 0.35^a
	10 - 20	0.39 ± 0.00^b	12.37 ± 0.94^b
	20 - 30	0.41 ± 0.01^c	8.40 ± 0.74^c
2	0 - 10	0.36 ± 0.00^a	14.27 ± 0.35^a
	10 - 20	0.37 ± 0.00^b	12.17 ± 0.94^b
	20 - 30	0.40 ± 0.00^c	8.42 ± 0.74^c
3	0 - 10	0.35 ± 0.01^a	10.63 ± 0.17^a
	10 - 20	0.36 ± 0.01^b	9.20 ± 0.42^b
	20 - 30	0.39 ± 0.01^c	7.00 ± 0.50^c
	Mean	**0.40 ± 0.01**	**13.02 ± 0.29**

Values with the same letters in a column represent means which are not significantly different.

2) The total dry weight and Litter Carbon Stock (LCS) of the Deng Deng National Park

The total dry weight and Litter Carbon Stock (LCS) were estimated for all 3 plots. The mean dry weight of litter recorded was 3.6 kg/ha; while the mean total Carbon stock recorded was 0.00182 ± 0.00009 t·C/ha. The total dry weight was highest in plot 1 (4.6 kg/ha) and least in plot 2 (2.6 kg/ha). Similarly, the Carbon stock of litter was highest in plot 1 (0.0023 ± 0.00015 t·C/ha), and least in plot 2 (0.00133 ± 0.00003 t·C/ha; Table 10).

3.3.3. The Total Carbon Stock of the Deng Deng National Park

The total Carbon stock of the Deng Deng National Park from the aboveground biomass (AGB), belowground biomass (AGB), soil organic Carbon (SOC) and the Litter Carbon stock (LCS) is estimated as shown in Table 11.

The total carbon stock was calculated as seen below:

$$\begin{aligned} C_{(\text{plot})} &= C_{(\text{AGB})} + C_{(\text{BGB})} + C_{(\text{litter})} + C_{(\text{soil})} \\ &= 193.7 + 75.0 + 0.00182 + 10.23 \\ &= 278.75\left(\text{t}\cdot\text{C/ha}\right) \end{aligned}$$

A mean total of 278.75 (t·C/ha) was present in the four pools of Carbon in the Deng Deng National Park.

4. Discussion

This study was carried out in the Deng Deng National Park, East Region of Cameroon. The species abundance and richness were higher in the tropical forest vegetation (Plots 1 and 2) than in the forest savannah transition vegetation (Plot 3). The total species richness of 64 species belonging to 53 genera in 26 families found in this study is similar to other studies in Africa like those obtained by

Table 10. The total dry weight and carbon stock of litter of research plots in the DDNP.

Plots	Total dry weight of litter (kg/ha)	Carbon stock of litter (t·C/ha)
1	4.6 ± 0.3^{a}	0.0023 ± 0.00015^{a}
2	2.6 ± 0.1^{c}	0.00133 ± 0.00003^{c}
3	3.5 ± 0.2^{b}	0.0018 ± 0.00012^{b}
Mean	**3.6 ± 0.3**	**0.00182 ± 0.00009**

Values with the same letters in a column represent means which are significantly the same; while different letters represent means which are significantly different.

Table 11. The total Carbon stock of the Deng Deng National Park.

Plots	AGB (t·C/ha)	BGB (t·C/ha)	SOC (t·C/ha)	LCS (t·C/ha)
1	265.2	106.1	11.64	0.0023
2	223.8	89.5	10.69	0.00133
3	92.2	29.5	8.37	0.0018
Mean	**193.7**	**75.0**	**10.23**	**0.00182**

Khaine *et al.* [67] who recorded 75 species and 31 families in a tropical forest in Myanmar and Pappoe *et al.* [68] in the Kakum National Park in Ghana who had 73 species, 6 genera and 28 families. These results are however low when compared to those obtained from other studies in Cameroon like Ntonmen *et al.* [34] in the Mindouru community forest in the East region of Cameroon who recorded 186 species, 93 genera and 38 families, Kabelong *et al.* [38], who worked in the periphery of the Deng Deng National Park with 187 species distributed in 43 families, Djomo *et al.* [69] who found 105 species in the Yokadouma District in the East Region and Sainge *et al.* [70] in the Kimbi-Fungom National Park in Cameroon who recorded 178 species, 110 genera and 42 families. Similarly, the mean tree species richness of 25.1 species/ha is very low in comparison to other National Parks in Cameroon like 43.1 species/ha in Kimbi-Fungom National Park (KFNP) [70], the rainforests of the Rumpi Hills (lowland forest 117.5 species/ha, submontane forest 75 species/ha) [71] and Korup National Park lowland rain forest (88.5 species/ha) [72] [73] [74] [75] [76]. The mean species richness of 25.1 species/ha in our study is however comparable to 37 species/ha [77] and 28 species/ha [44] in Ghana. Taking into consideration that the species richness was low when compared to other studies in Cameroon, and other studies having similar results were carried out in disturbed sites [77] who recorded in a disturbed semi-deciduous forest in Ghana), this therefore infers that the study site is disturbed and the low alpha diversity in this study can be ascribed to the anthropogenic activities around the study site.

These differences might be firstly due to the sampling size which was only 3 hectares in this study but higher in other studies leading to an increase in the number of species. Secondly, the sampling for this study was from 2 cm which therefore excluded most of the species found in the <2 cm diameter size class in

the savannah plot thereby decreasing the number of species. Ntonmen *et al.*, [34] studied the understorey of the Mindourou community forest, Kabelong *et al.* [38] carried out a study in the periphery of the Deng Deng National Park and Sainge *et al.* [70] worked on the species from ≥1 cm in the Kimbi-Fungom National Park. The periphery of the Deng Deng National Park is highly associated with anthropogenic activities and the presence of nearby primary forests which thus allows for the implantation of new species and individuals along the periphery of the National Park thus a higher species richness. Thirdly, the difference could be explained by the fact that these authors worked in a forest type (evergreen) that according to the literature is more floristically rich than the semi-deciduous evergreen forests [78]. However these results are also different from those obtained by Sonke and Couvreur [79]), who assessed tree species ≥ 2 cm and identified 312 species belonging to 54 families in the nearby Dja Reserve. This difference could be due to the sampling size of 22.5 ha in the Dja reserve.

The Important Value Index (IVI) is often used in ecological studies to indicate the ecological importance of a species in a given ecosystem, thus prioritising species conservation [80]. The dominance of the members of the family Apocynaceae in plots 1 and 2 (*Tabernaemontana crassa*) may be due to the fact that, the Apocynaceae are mostly abundant in tropical zones with about 1500 species in 180 genera worldwide [81]. Similar results of IVI were obtained by Temgoua *et al.* [82], who indicated that Apocynaceae was ranked in the 20 most dominant families in the Cobaba community forest in Cameroon. Also, the Apocynaceae was amongst the dominant families found in the Korup National Park [74]. This is an indication that plots 1 and 2 are natural tropical forests. The Lamiaceae are mostly small trees, herbs and shrubs comprising about 3200 species in 200 genera. The dominance of members of the Lamiaceae family (*Lecythis idatimon*) could account for their dominance in the savannah transitional zone. High ecological status of these species in our study, as evidenced by the IVIs, may be attributed to dominance by certain species, which suggests negative interactions among the tree species. This is indicated in this study in plot 2 where the species *Tabernaemontana crassa* had a 70.98% of IVI. In other words, resource spaces are not shared thus negative species interactions and some plants cannot obtain resources with relative ease [83]. This is confirmed by the presence of the savannah vegetation which will have a lower relative density than plants in the tropical forest vegetation. These plants that cannot acquire resources with ease thus require conservation in order not go extinct. The high IVIs may also imply that most of the species in this forest are rare [52] [84]. This can be confirmed by the fact that 67.3% of the plants are rare and a Shanon index of 2.66 which shows a rich floristic diversity of the study site. This is similar to the results of Chimi *et al.* [33].

In this work, stand structure relates to the basal area of trees, density of trees, and their distribution into various diameter-size classes. The basal area of tree species in the tropical forest vegetation was larger than the basal area in the Savannah vegetation. This is to be expected since semi-deciduous forest is closer to lowland or mid-elevation rainforest with large trees than the open grassland and

woody Savannah that are prone to fire annually. This is similar to the results obtained by Sainge *et al.* [70] in the Kimbi-Fungom National Park. The mean basal area of 24.98 m^2/ha is also similar to that obtained by Cummings *et al.* [85] (average 24, 28, and 24 m^2/ha for open, dense, and ecotone forests, respectively), in the rainforests of South western Brazilian Amazon.

The mean tree basal area of 24.98 m^2/ha is however low as compared to that of 37.5 m^2/ha in the Rumpi Hills Forest Reserve in the South West Region of Cameroon [71], 41.6 m^2/ha in a semi deciduous forest in the East region of Cameroon [33] 37.5 and 30.5 m^2/ha found by Djuikouo *et al.* [86] respectively in forests dominated by *Gilbertiodendron dewevrei* and in the mainland forests of the Dja reserve, and with 35.3, 35.8 and 30.3 m^2/ha found in the communal forests of Yokadouma, Campo-Ma'an National Park and some tropical African forests respectively by Djomo [69], Lewis *et al.* [76] and Day *et al.* [87]. This might be due to the fact that these studies were carried out in only semi-deciduous tropical forest.

This study however, confirms that the basal area increases with tree diameter. Thus due to the small diameter classes, and the abundance of the number of stems/ha, the basal area is low and inversely for high diameter classes that have a low number of stems/ha this value increases [69]. Low basal area is a characteristic of a disturbed forest stands and serves as a reflection of low performance of the trees. The low basal area has an implication for the forest stand as this means the absence of big trees which suppress the growth of small plants by intercepting much of the solar radiation that might otherwise reach the forest floor. In fact, when the ecosystem is more disturbed, the number of stems per hectare in the lower classes increases [88]. This result thus indicates that the forest is in a state of natural regeneration [44] [78] [89] from disturbance.

This is confirmed by the reverse J-shaped obtained in both vegetation types as the number of individuals decreased with an increase in the diameter-size class. This pattern indicates that stands are developing and regeneration is occurring in the forest, indicating a high potential for species substitution when mature trees in the dominant species die [90]; which is a characteristic of a natural tropical rainforest. This result is consistent with the findings of various authors in the tropics: [91] [92] [93] [94]. Similar results have been obtained by different authors in the Cameroonian forest ecosystems [69] [87] [88] [95].

An estimation of the aboveground biomass is an essential aspect of carbon stocks and the estimated carbon pools in different forest types can be used in making decisions about carbon management within forests [96]. The AGB was higher in the tropical forest than in savannah due to the presence of large trees in the tropical forest. While the low carbon content in the woody savannah may be attributed to the scanty tree vegetation and/or anthropogenic activities. Other factors such as rainfall, duration of wet season, and topography can also influence net primary productivity of tropical dry forest [97]. An AGB of 278.75 t·C/ha is similar to results obtained by Sainge *et al.* [70] who had a mean total

AGB by vegetation type of 203.8 t/ha in mixed vegetation forest, 72.0 t/ha in grassland/woody savannah, 141.0 t/ha in gallery forest, 167.7 t/ha in secondary forest, and 321.5 t/ha in semi-deciduous forest. This result reaffirms the assertion that higher species richness could be associated with higher carbon storage in some forests [70] [98]; thus a need for reafforestation of the Savannah.

Though this study was carried out in just three 1ha plots, a 100% inventory was carried out with a mean total AGB of 387.4 ± 43.2 (t·C/ha) that tended to be higher than that obtained from large-scale inventory plots on acrisols in two concessions of Central Africa Republic (286.8 ± 104.1 Mg/ha for DBH ≥ 10 cm, n = 329 plots supposedly undisturbed [60], and from Central African permanent plots on acrisols of the AfriTRON network (338.5 ± 103.9 Mg /ha for DBH ≥ 10 cm, n = 6 plots [76]. This different results from undisturbed and permanent plots, thus indicates that the study site is disturbed. The mean total AGB was also higher than that found in the Kimbi-Fungom National Park of 149.2 t/ha and carbon of 74.6 t·C/ha [70]. These differences could be explained by the difference in the wood densities of forest species, the location of forests, species found in the different forests and the great variability of the carbon stocks of deadwoods in tropical zones [2]. This can be seen from the fact that these results were similar to that of Sainge *et al.* [70] who had a mean total AGB 321 t/ha in some plots in the Kimbi-Fungom National Park, Cameroon and Cummings *et al.* [85] who had a mean total AGB of 341 Mg/ha from 20 forest sites in the Brazilian amazons, to some values obtained in Africa (374.5 ± 58.2 Mg ha 21) in Central Africa [91] in the Democratic Republic of Congo), (398.5 ± 111.1 Mg ha 21 [99] in the tropical rainforest of Congo); (395.7 ± 117.4 Mg ha 21 [76] in Central Africa). They tended to be lower than the values obtained in Central African countries (434.4 ± 90.5 Mg/ha, n = 36 plots located in Cameroon, the Democratic Republic of Congo and Gabon) [60].

This thus calls for the need for the use of site and species specific allometric equations in the calculations of the AGB of tropical forests taking into consideration the rich diversity of the forest. The AGB had the highest Carbon stock in this study. Similar results were obtained by Hubert *et al.* [35] in the Dimako communal forest in the East region of Cameroon. Vahedi *et al.* [100] indicated that the trunk biomass is higher than the other compartments of the tree. According to FAO [36], the aboveground biomass includes all biomass in living vegetation, both woody and herbaceous, above the soils including stems, stumps, branches, barks, seeds and foliage; while carbon stock is the quantity of carbon contained in a reservoir or system which has the capacity to accumulate or release carbon. Ploton *et al.* [101] indicated that the mean crown biomass alone represents 36% of the aboveground biomass compared to 64% for the trunk biomass. Similar results were obtained by Dantas *et al.* ([102] in Brazil where the AGB indicated 63.22% of the total biomass.

Djomo *et al.* [88], when analysing an African moist tropical forest, found over three times more carbon in the aboveground biomass than in the soil. Ngo *et al.*

[41] indicated that the contribution of the different compartments to total carbon stock varies markedly between primary and secondary forests. In primary forest, the dominant compartment is the aboveground biomass, and the soil contributes less due to a greater number of trees with larger diameters, while the opposite is true in secondary forest. In this study however, the carbon content of the BGB, SOC and LCS is almost half of the carbon content of the AGB indicating that the forest is in a state of natural regeneration towards a natural forest. This is similar to the results obtained by Gibbon *et al.* [103] who found twice as much carbon in soil than in AGB in a Peruvian Montane forest. According to Dixon *et al.* [104], in tropical forests, approximately 50% of the total carbon is stored in AGB, and 50% is in the layer extending from the soil surface down to 1 m.

The BGB component of trees is still poorly known because it needs labour and is time-intensive [105]. However, belowground biomass constitutes a significant share of the total forest biomass. Cairns *et al.* [62] and Litton *et al.* [63] have maintained that belowground biomass may represent up to 40% of the aboveground biomass. This is confirmed by Mokany *et al.* [106] who indicated that the belowground biomass which are most often neglected in biomass estimation studies due to difficulties in field sampling, represent about one-quarter of total forest biomass, similar to the results of this study.

The soil bulk density increased with an increase in soil depth which can be explained by the presence of more organic matter in the upper layer [107]. Generally, there is a negative relationship between soil density and depth as a result of the high organic matter content at the surface because organic matter is less dense than mineral grains [108]. These results are similar to those of Dantas *et al.* [102] in a tropical forest in Brazil. Their Bulk density was however higher (0.89 $g \cdot cm^{-3}$ in the topsoil) than that found in our study. This may be due to the differences in the decomposition rate in the study sites.

The SOC on the other hand decreased with an increase in soil depth from 14.17 ± 0.35 t·C/ha to 7.00 ± 0.50 t·C/ha. Juhwan *et al.* [109] and Dantas *et al.* [102] indicated that the SOC decreased with an increase in soil depth which is similar to the results of this study. This is partly due to the accumulation of organic material at the soil surface, and the increased rate of organic matter decomposition in the tropics. Higher levels of organic carbon in the surface soil in forest environments are due to the presence of the organic litter and by the higher density of fine roots at the upper surface of the soil [110]. Therefore, the addition of organic litter is responsible for the accumulation of carbon in the topsoil layer because it is humidified, which increases the nutrient cycling in the upper layers of the soil profile [111]. The Soil Organic Carbon was, however, low when compared to studies by Dantas *et al.*, [102] in Brazil (55.05 to 32.63 Mg/ha). It can be inferred that the differences in SOC observed between these studies are related to the type of forest cover as well as the climatic and soil conditions of each area. Also according to Sayer *et al.* [112] the amount of resistant and highly resistant SOC was unaffected by litter addition.

The total amount of Carbon stored in this study (278.75 t·C/ha) is similar to the results of other authors who indicated that in the Congo Basin Tropical Forests, the carbon stored varies from 100 to more than 300 t·C/ha [86] [95]. Similar results were found by Zekeng *et al.* [32] in a semideciduous forest in the East region of Cameroon who recorded 283.97 ± 51.42 Mg·C/ha and Dantas *et al.* [102] in a semideciduous forest in Brazil which recorded 267.52 Mg/ha of Carbon stock. However slight differences in the amount of Carbon stock might be due to the fact that in this study, the Chave *et al.* [59] biomass estimate equation was used for the calculation of the Carbon stored in a transition zone.

5. Conclusion

The forest of the Deng Deng National Park is generally poor in plant diversity, biomass and carbon, indicating a high level of disturbance site with the absence of large trees undergoing natural regeneration. This study therefore provides information on the tree species composition, stem diameter variation and carbon stock to provide baseline information for the sustainable management of the Deng Deng National Park. This work underlines an urgent need to implement efficient management practices to restore the forest of the Deng Deng National Park.

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Author's Contribution

Seraphine E. Mokake: In charge of the research design, supervision of field work and data collection, guided analysis and interpretation, and reviewed manuscript. Babila K. Weyi: Masters student at the University of Buea responsible for data collection, analyses, interpretation and wrote the manuscript. Neculina Anyinkeng: Academic co-supervisor. Contributed in research concept and design and reviewed the manuscript. Lyonga M. Ngoh: Analysed data collected, contributed in the research concept and design and methodology. Also contributed in data interpretation and review of manuscript. Obenarreyneke E. Berkeley: Contributed in field work, data collection and review of article. Egbe E. Andrew: Academic supervisor who suggested the topic and the research design, contributed in perfecting the methodology and analyses and reviewed the manuscript.

Data Availability Statement

Data are available within the article and/or its supplementary materials.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Supplementary Sheets

Table S1. Species list.

Family	Scientific Name
Annonaceae	*Anonidium mannii*
	Polyanthiasuaveolens
Apocynaceae	*Alstonia boonei*
	Funtumia elastic
	Rauvolfia caffra
	Tabernaemontana brachantha
	Tabernaemontana crassa
	Voacanga africana
Arecaceae	*Elaeis guineensis*
Bombacaceae	*Ceiba pentandra*
Burseraceae	*Santiria trimeria*
Cannabaceae	*Celtis tessmannii*
	Celtis zenkeri
Combretaceae	*Terminalia ivorensis*
	Terminalia superba
Ebenaceae	*Diospyros melocarpa*
Euphorbiaceae	*Alchornea latifolia*
	Maracanga assas
	Macaranga spilosa
Fabaceae	*Albizia anplianthifolia*
	Albizia ziglia
	Angylocalyxpynaertii
	Cylicodiscus gabunensis
	Distemonanthus benthamianus
	Erythrophleum ivorense
	Piptadeniastrum africanum
	Pterocarpus indicus
	Pterocarpus soyauxii
Irvingiaceae	*Desbordesia glaucescens*
	Irvingia gabonensis
	Klainedoxa gabonensis
Lamiaceae	*Lecythis idatimon*
	Vitex grandifolia
Lecythidaceae	*Petersianthus macrocarpus*

Continued

Malvaceae	*Adansonia digitata*
	Corchorus capsularis
	Eribroma oblonga
	Mansonia altissima
	Theobroma cacao
	Triplochiton scleroxylon
Meliaceae	*Carapa paviflora*
	Entandrophragma cylindricum
	Lovea trichiloides
Moraceae	*Ficus exasperata*
	Milicia excelsa
Myristicaceae	*Coelocaryon preussi*
Olacaceae	*Strombosia postulata*
Rubiaceae	*Isertia speciformis*
	Tricalysia lasiodephys
Rutaceae	*Zanthoxylum clava-hercules*
	Zanthoxylum heitzii
Sapindaceae	*Allophylus africanus*
Sapotaceae	*Planchonella reseoloba*
	Baillonella toxisperma
	Pouteria guianensis
Urticaceae	*Sterculia rhinopetalia*
	Musanga cecropoides
	Myrianthus arboreus

Table S2. Important Value Index for all species per plot.

Plot 1

Species	Rel Dom	Rel Den	Rel Freq	IVI
Tabernaemontana crassa	5.21	19.46	4.83	29.50
Annona montana	8.04	11.40	5.34	24.79
Tabernaemontana sp	4.03	6.91	4.58	15.52
Piptadeniastrum africanum	10.74	1.19	2.29	14.22
Voacanga africana	2.50	6.10	5.09	13.69
Albizia anplianthifolia	5.91	3.53	3.82	13.26
Cylicodiscus gabunensis	8.92	0.72	2.80	12.43
Diospyros melocarpa	1.22	6.68	4.33	12.22
Magnolia grandifolia	2.10	4.77	4.07	10.94

Continued

Mansonia altissima	3.19	3.34	3.56	10.09
Coelocaryon preussi	0.88	3.86	5.34	10.09
Baillonella toxisperma	1.08	3.77	4.58	9.43
Tabernaemontana crassa	1.22	5.63	1.78	8.63
Celtis zenkeri	2.06	2.48	3.56	8.10
Allophylus africanus	1.53	2.10	3.82	7.45
Santiria trimeria	1.84	1.76	3.56	7.17
Annona montana	3.26	1.48	1.02	5.75
Celtis zenkeri	2.82	1.29	1.53	5.63
Adansonia digitata	5.32	0.05	0.25	5.62
Corchorus capsularis	3.85	0.38	0.76	5.00
Terminalia superba	3.84	0.14	0.25	4.23
Coelocaryon preussi	0.22	2.43	1.27	3.92
Pterocarpus soyauxii	2.33	0.24	1.02	3.58
Terminalia superba	2.22	0.24	1.02	3.47
Voacanga africana	0.15	1.48	1.53	3.15
Cylicodiscus gabunensis	2.42	0.10	0.51	3.03
Entandrophragma cylindricum	1.08	0.57	1.27	2.92
Tabernaemontana sp	0.47	1.10	1.27	2.84
Zanthoxylum sp	0.24	0.52	2.04	2.80
Ficus exasperata	0.58	0.38	1.53	2.48
Milicia excelsa	1.61	0.10	0.51	2.21
Baillonella toxisperma	0.18	0.72	1.27	2.16
Musanga cecropoides	0.93	0.43	0.76	2.12
Baillonella sp	0.16	0.38	1.53	2.07
Elaeis guineensis	0.81	0.19	0.76	1.77
Mansonia altissima	0.05	0.33	1.27	1.65
Triplochiton scleroxylon	0.11	0.24	1.27	1.62
Isertia speciformis	0.72	0.19	0.51	1.42
Corchorus capsularis	1.08	0.05	0.25	1.38
Allophylus africanus	0.12	0.19	1.02	1.33
Pterocarpus indicus	0.57	0.10	0.51	1.18
Pterocarpus soyauxii	0.69	0.14	0.25	1.08
Entandrophragma cylindricum	0.06	0.24	0.76	1.06
Alchornea latifolia	0.40	0.10	0.51	1.00
Ficus exasperata	0.36	0.10	0.51	0.96
Santiria trimeria	0.02	0.14	0.76	0.93

Continued

Pterocarpus indicus	0.03	0.38	0.51	0.92
Maracanga assas	0.59	0.05	0.25	0.89
Zanthoxylum sp	0.02	0.10	0.76	0.87
Alstonia boonei	0.22	0.10	0.51	0.82
Magnolia grandifolia	0.08	0.19	0.51	0.78
Planchonella reseoloba	0.12	0.14	0.51	0.78
Vitex grandifolia	0.39	0.10	0.25	0.74
Milicia excelsa	0.33	0.14	0.25	0.72
Celtis tessmannii	0.07	0.10	0.51	0.67
Macaranga spilosa	0.05	0.10	0.51	0.66
Albizia anplianthifolia	0.25	0.14	0.25	0.65
Zanthoxylum clava-hercules	0.20	0.05	0.25	0.50
Dicorymia guianensis	0.13	0.05	0.25	0.43
Funtumia elastica	0.12	0.05	0.25	0.42
Lovea trichiloides	0.07	0.05	0.25	0.37
Irvingia gabonensis	0.06	0.05	0.25	0.37
Carapa paviflora	0.05	0.05	0.25	0.36
Klainedoxa gabonensis	0.02	0.05	0.25	0.33
Theobroma cacao	0.02	0.05	0.25	0.32
Desbordesia glaucescens	0.02	0.05	0.25	0.32
Mansonia sp	0.02	0.05	0.25	0.32
Eribroma oblonga	0.01	0.05	0.25	0.31
Strombosia postulata	0.01	0.05	0.25	0.31
Baillonella sp	0.00	0.05	0.25	0.31
Desbordesia glaucescens	0.00	0.05	0.25	0.31
Lovea trichiloides	0.00	0.05	0.25	0.30
Pteleopsis hylodendron	0.00	0.05	0.25	0.30

Plot 2

Species	Rel Dom	Rel Den	Rel Freq	IVI
Tabernaemontana crassa	26.49	37.94	6.54	70.98
Voacanga africana	6.42	11.29	6.54	24.25
Piptadeniastrum africanum	13.72	3.23	5.61	22.56
Magnolia grandifolia	4.54	10.26	6.54	21.34
Tabernaemontana sp	6.82	7.45	5.30	19.57
Celtis zenkeri	4.78	4.45	6.23	15.46
Albizia anplianthifolia	2.83	3.75	6.54	13.12
Baillonella toxisperma	2.72	3.70	6.54	12.96

Continued

Coelocaryon preussi	2.29	3.75	5.92	11.96
Diospyros melocarpa	2.14	3.75	5.30	11.19
Annona montana	3.58	1.87	5.61	11.06
Entandrophragma cylindricum	4.21	1.45	4.98	10.65
Santiria trimeria	4.37	1.41	4.36	10.14
Cylicodiscus gabunensis	3.73	0.75	3.12	7.59
Zanthoxylum sp	0.63	1.36	4.36	6.35
Corchorus capsularis	2.01	0.75	2.18	4.94
Musanga cecropoides	2.35	0.61	1.87	4.82
Baillonella sp	0.27	0.37	1.87	2.52
Alstonia boonei	0.77	0.33	1.25	2.35
Pterocarpus soyauxii	1.03	0.14	0.93	2.10
Desbordesia glaucescens	0.34	0.19	1.56	2.09
Pouteria guianensis	1.09	0.14	0.62	1.85
Planchonella reseoloba	0.29	0.23	1.25	1.77
Eribroma oblonga	1.37	0.05	0.31	1.73
Allophylus africanus	0.03	0.19	0.93	1.16
Terminalia ivorensis	0.19	0.09	0.62	0.91
Macaranga spilosa	0.53	0.05	0.31	0.89
Baillonella sp	0.02	0.09	0.62	0.74
Zanthoxylum clava-hercules	0.14	0.09	0.62	0.86
Adansonia digitata	0.11	0.05	0.31	0.47
Pterocarpus indicus	0.11	0.05	0.31	0.47
Ficus exasperata	0.04	0.09	0.31	0.45
Terminalia superba	0.00	0.05	0.31	0.36
Mansonia altissima	0.00	0.05	0.31	0.36

Plot 3

Species	Rel Dom	Rel Den	Rel Freq	IVI
Lecythis idatimon	17.28	16.65	7.60	41.53
Albizia fetruginea	14.94	14.65	7.60	37.18
Ceiba pentandra	16.53	5.78	6.38	28.69
Diospyros melocarpa	5.56	11.33	7.60	24.49
Ficus exasperata	5.34	8.40	7.29	21.04
Planchonella reseoloba	5.48	8.25	7.29	21.02
Magnolia grandifolia	4.92	8.71	6.38	20.01
Petersianthus macrocarpus	12.50	2.47	3.95	18.92
Baillonella toxisperma	3.64	6.01	5.47	15.12

Continued

Voacanga africana	1.22	6.17	6.69	14.07
Zanthoxylum clava-hercules	2.62	2.62	4.86	10.10
Corchorus capsularis	2.38	1.77	4.26	8.41
Entandrophragma cylindricum	0.48	1.23	3.95	5.66
Celtis zenkeri	0.82	0.93	3.34	5.09
Santiria trimeria	0.51	0.85	3.04	4.40
Erythrophleum ivorense	2.64	0.31	0.61	3.55
Sterculia rhinopetalia	0.43	0.62	1.82	2.87
Adansonia digitata	0.70	0.39	1.52	2.61
Tabernaemontana sp	0.10	0.46	1.82	2.38
Allophylus africanus	0.04	0.31	1.82	2.17
Zanthoxylum heitzii	0.18	0.23	1.22	1.63
Vitex grandifolia	0.57	0.23	0.61	1.41
Anthonia macrophylla	0.02	0.23	0.91	1.16
Annona montana	0.07	0.15	0.91	1.14
Desbordesia glaucescens	0.16	0.46	0.30	0.93
Zanthoxylum sp	0.02	0.15	0.61	0.78
Terminalia ivorensis	0.31	0.15	0.30	0.77
Ceiba pentandra	0.30	0.08	0.30	0.68
Terminalia superba	0.24	0.08	0.30	0.62
Santiria trimeria	0.01	0.08	0.30	0.39
Myrianthus arboreus	0.01	0.08	0.30	0.39
Tabernaemontana crassa	0.00	0.08	0.30	0.38
Mansonia altissima	0.00	0.08	0.30	0.38