




Biodiversity and Carbon Stock of a Tropical Montane Forest in Cameroon

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Abstract

Mountains are home to 50% of global biodiversity hotspots and support nearly a quarter of the world's forests and terrestrial biological diversity. This study aims to evaluate the floristic diversity and carbon stock of the Buea Cluster within Mount Cameroon National Park, emphasizing the role of biodiversity in climate regulation and ecosystem services. A systematic inventory approach was employed to assess tree species composition, structural parameters, and carbon stocks across three distinct plots. The research was conducted in the Buea Cluster of Mount Cameroon National Park, Cameroon. Three plots (1 ha each) were established at varying altitudes to sample trees with a diameter at breast height (DBH) ≥ 2 cm. Data collection involved measuring tree density, species richness, and calculating carbon stocks in four pools: above-ground, below-ground, soil, and litter. Statistical analyses were performed to evaluate differences in carbon stocks and diversity indices among plots. A total of 1715 individuals representing 45 tree species from 26 families were recorded. The HMF exhibited the highest species richness and above-ground biomass (900 t ha^{-1}), while the TMF had the lowest carbon stock (64.7 t ha^{-1}). Significant variations in carbon stock were observed across plots ($p < 0.05$), highlighting the ecological importance of diverse forest structures. The findings underscore the critical role of the Buea Cluster in carbon sequestration and biodiversity conservation. Effective management strategies are essential to mitigate deforestation and enhance ecosystem resilience in the region. Integrating these insights into conservation planning can significantly improve forest management outcomes.

[#]Tribute to Mr Enow. This wasn't the plan. Lucy and I still have many unanswered questions. We still miss you in the team. You are gone but never forgotten and your legacy lives on. RIP Solo.

Keywords

Biomass, Carbon Stock, Floristic Diversity, Organic Carbon, Sequestration

1. Introduction

Forests are of primordial importance considering the goods and services they provide to millions of people supporting livelihoods as they are a source of food, medicine and fuel for more than a billion people [1]. Forests contain as much as 90% of terrestrial biodiversity, with tropical forests being particularly important in terms of both species richness and their concentration of endemic species [2]. Six main vegetation types have been identified on the mountain: Lowland rainforest (0 - 800 m above sea level), Submontane forest (800 - 1600 m asl), Montane forest (1600 - 1800 m asl), Montane scrub (1800 - 2400 m asl), Montane grassland (2000 - 3000 m asl) and Sub-alpine grassland (3000 - 4100 m asl). Tropical Montane Forests (TMF) forms a major component of several of the world's biodiversity hotspots as they occur between 1500 and 4000m above sea level and represent an extremely species-rich ecosystem and endemism in the world [3] [4]. It is broadly defined as "forests that are frequently covered in cloud or mist" [5]. Tropical Montane Forest includes all types of rainforests in tropical mountains, ranging from naturally open upper montane rain forests at higher elevations (characterized by stunted growth, twisted trunks, and epiphytic mosses) to dense lower montane rain forests with tall trees and a closed canopy [3]. Mountains are therefore paramount for exploring biodiversity patterns due to the mosaic of topographies and climates encompassed over short distances.

Tropical forests, in general, are, however, highly threatened by human activities due to the growing need for an increasing population [6], which is encouraging deforestation and degradation at alarming rates and contributing significantly to the ongoing loss of biodiversity. The Food and Agriculture Organization [7] estimates that tropical mountain forests comprise about 11% of the world's tropical forest resources and suffer an annual deforestation of about 1.1%. The FAO Global Forest Resources Assessment [7] estimated that 420 million ha of forest was deforested (converted to other land uses) between 1990 and 2020 [8]. This loss in biodiversity has led the local population to shift to protected areas for their livelihood. Thus, though TMFs are supposed to be undisturbed due to the increase in altitudes, they have started losing their biodiversity as well. Also, although they are important to environmental sustainability, TMFs are one of the least studied and least understood [4] terrestrial ecosystems in the world.

The forests of Cameroon make up about 10% of the Congo Basin, the world's second largest forest ecosystem after the Amazon [9]. The establishment and management of protected areas has become the cornerstone of biodiversity conservation strategies the world over [10] with these protected areas occupying over 15% of land surface and 7% of the oceans [11]. Cameroon has equally based its biodi-

versity conservation strategy on the creation and extension of national parks, forest reserves, community forests, botanical gardens, zoological gardens, sanctuaries, and wildlife reserves [12] [13]. The Mount Cameroon National Park is an important area for plant conservation due to its rich, diverse, and unique vegetation [14] [15], which has been described in a comprehensive volume by many authors through general plant collections [14] [16]-[18]. However, tropical montane forest zones along the continental part of the Cameroon Volcanic Line [19]-[21], have few studies assessing their forest structure and composition along elevational gradients using permanent sampling plots [22] [23]. Globally, although the biodiversity of elevational gradients in the tropics has seen much attention (e.g. [24] [25]), this subject remains little studied in the Cameroon Mountains. Some studies have, however, examined changes in species composition and diversity across environmental and geographic gradients [26] [27], but the vegetational structure and composition are also influenced strongly by elevation [27] [28].

Specifically, most studies in the Mount Cameroon National Park targeted only economic species like [29], who carried out an inventory only on *Prunus africana* taking into consideration its economic benefits; or on areas below 600 m above sea level (e.g. [30] [31]). Such studies preclude examination of the potential influence of altitude, volcanism, soil, geology and human-related activities on forest dynamics. Also, most of these studies targeted plants with DBH \geq 10cm, leaving the under-storey unknown; whereas [32] in a study stated that the inventory of individual plants in DBH class of <10 cm is an indication of regeneration. Due to inadequate knowledge about the plant biodiversity of the higher altitudes of the ecosystem, there is thus growing recognition of the need for demographic studies of forests in order to evaluate the dynamics of TMFs [33]-[37] for its sustainable management.

Tropical forests store 40% - 50% of terrestrial vegetation Carbon [38] and its diversity can strongly regulate forest Carbon. Vegetation systems at different elevations on different substrates in montane ecosystems differ in biomass production and carbon storage in the fight against climate change [28]. The reductions of atmospheric CO₂ by artificial means are very expensive for African countries and so carbon sequestration by soils, oceans and plants turn out to be the simplest and most economically practical way to face the climate change crises [39]. Thus, the necessity to estimate the capacity of tropical montane forests to store carbon at the different Carbon sinks of a forest; a mitigation measure for Cameroon to combat the adverse effects of climate change. Tree species types and structure have a great influence on the accumulation of above-ground and below-ground biomass, where biomass density plays an important role in the amount of Carbon to be sequestered [40]. However, the effects of diversity on tree Carbon stock are few and scarce, especially in Africa [41] [42] in general and Cameroon specifically. Few attempts have been made in Cameroon, to determine the soil carbon pool and other sources of carbon of the MCNP like that of [43] who determined the soil Carbon of the MCNP. Also, spatial variations in above-ground tree biomass

Carbon stocks (AGC) remain poorly understood, in particular in African tropical montane forests [44], thus creating the need for forest diversity and carbon stock studies in the Mount Cameroon National Park.

Mount Cameroon offers a unique opportunity for the study of the forest biodiversity and Carbon stock in a Tropical Montane forest as it is the highest mountain in West and Central Africa, rising directly from sea level to 4095 m, with forest cover ranging from sea level to 2500 m. Mount Cameroon provides a biological mosaic that contributes to extremely high speciation and biological diversity in the Guineo-Congolian regional area of endemism, and is posited as one of the main Pleistocene refugia postulated for Africa [14] [15] [45]-[48]. Zonation is a key feature of the vegetation and in common with other massifs on the continent, it is influenced by altitude [49]. Despite having been recognized as a biodiversity hotspot in Cameroon and the existence of laws governing forests and biodiversity in Cameroon such as Law No. 94/01 of 20 January 1994 more information on floristic composition, diversity and structure of the park is required as anthropogenic activities increase around the MCNP and especially the Montane Forest zone that has more tree species that contribute to the Carbon stock of mountains.

The Mount Cameroon area is characterized by high population density of 2.6% per annum in Cameroon [50] and agriculture is the most important economic activity for both the indigenous people and local population and they control the biggest portion of farmed land, especially within the Mount Cameroon National Park (MCNP) [51] [52]. Clearance of natural vegetation to provide land poses a serious threat to the forest with much of the lowland forest already converted to industrial plantations. The collection of non-timber forest products, such as honey, medicinal plants, vegetables and spices has a considerable impact on the local economy. Due to large dependence of the population on the forest, has increased deforestation and forest degradation around the Park [51]. In this study, we aimed to evaluate how plant diversity contributes to the Carbon stock of the tropical montane forest of the Mount Cameroon National Park. Specifically, the study aimed to (1) assess the tree species composition, structure and diversity of the MCNP's Buea Cluster affected by anthropogenic activities; and (2) evaluate its Carbon stock at the different carbon pools (above ground, below ground, soil and litter). Information from this study will provide a valuable reference for appropriate forest conservation measures that will reduce deforestation and degradation and also give insight on the regeneration and Carbon stock status of a Montane forest. Two questions were therefore addressed: 1) what is the plant diversity of the Montane Forest of the Mount Cameroon National Park for sustainable forest management? 2) What is the Carbon stock potential of the MCNP in combating climate change?

2. Materials and Methods

Study Area

The study was carried out in the Buea Cluster of the Mount Cameroon National

Park (MCNP). Mount Cameroon National Park is located between 4.055° - 4.378° N and 9.031° - 9.294° E [52]. The huge volcanic mass has its long axis (about 45 km long and 30 km wide) running South West to North East between latitude $3^{\circ}57'$ to $4^{\circ}27'N$ and longitude $8^{\circ}58'$ to $9^{\circ}24'E$. The MCNP is spatially divided into four cluster conservation zones which comprise 41 villages. The Buea Cluster (**Figure 1**) in the South and parts of the East, consists of 13 villages, the Bomboko cluster in the North East and North West areas of the Park, consisting of 12 villages, the Muyuka cluster occupying the East and consisting of 9 villages, and West Coast cluster consisting of 7 villages [53].

Mount Cameroon has an equatorial climate of four seasons, the dry season runs from December-February, dry-wet season from March-May, wet season from June-August and wet-dry season from September-November. The annual rainfall ranges from 12,000 mm in the south-west of the main massif to 2000 mm in the North-East. Much of the rain is received between June and September. Mean annual temperature is $25^{\circ}C$ at sea level and decreases by $0.45^{\circ}C$ with every 100 m rise in altitude. Relative humidity averages 70% - 80% at the coast and the annual sunshine varies between 900 and 1200 hours at sea level [54].

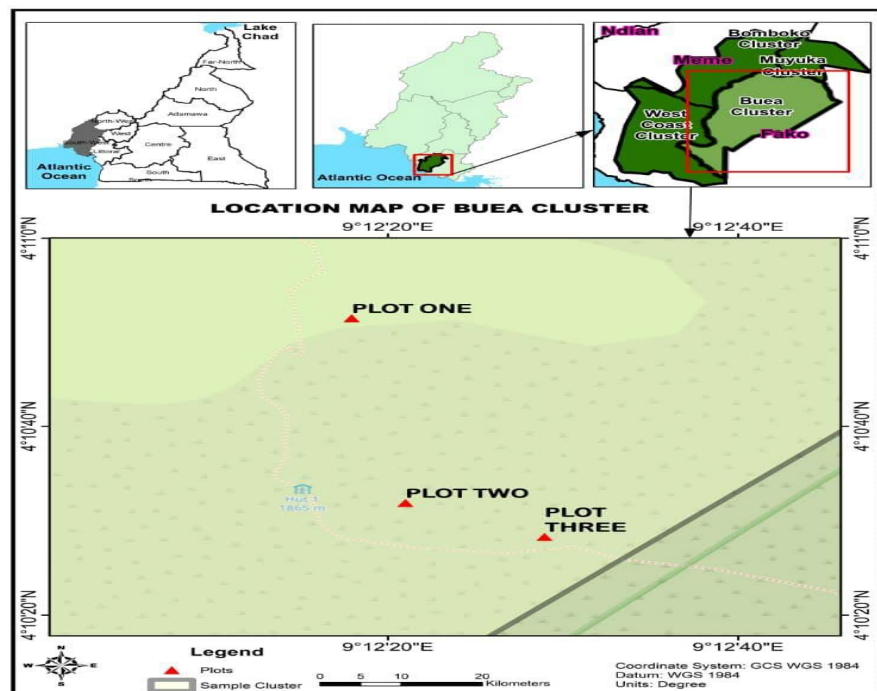


Figure 1. Map of the Mount Cameroon National Park Clusters: Priority Region for Conservation (MCNP Buea Cluster).

The area is considered Pleistocene refugia in Africa, which even during glacial periods contained rainforest, leading to extreme biodiversity of both flora and fauna with many endemics present [52]. The vegetation belongs to the lower Guineo-Congolese region [55]. It also contains a great variety of endemic and endangered flora and fauna species. The massif and surrounding foothills contain

around 4000 higher plant species and about 50 of these are endemic to Mount Cameroon [14]. This is the last area in Africa where natural vegetation remains unbroken from lowland forest at sea level to the sub-alpine grassland at the summit. The wildlife of the region is rich, with populations of Cercopitheciine primates, forest elephant (*Loxodonta africana cyclotis*) and chimpanzee (*Pan troglodytes elliotii*) [56], and at least two endemic birds [57]. The soils are non-allophanic andosols and classified as Aluandic Andosols (leptic) by [58] based on the World Reference Base system (WRB) of soil classification. The people indigenous to the area are Bakweri, Bomboko, Bakolle, Balong and Isubu [59].

Data Collection

1) Experimental design

Plot demarcation followed the protocol for permanent monitoring plots described by [60]. Three plots of 1 ha each (100 m × 100 m) were laid at different altitudes of the montane forests of the MCNP giving a total surface area of 30,000 m² (3 ha) surveyed. Each 1ha was divided into 25 quadrats of 20 × 20 m² and each 20 × 20 m² was further divided into 16 sub-quadrats of 5 × 5 m² where sampling was carried out, giving a total of 400 sub-quadrats of 5 × 5 m² per hectare. This sampling design makes it possible to cover the homogeneity of the forest units, while ensuring representativeness and exhaustiveness. Altitudinal gradient varied between 1924 m - 2050 m asl in **plot 1** (Transitional Montane Forest -TMF); 1820 m asl - 1854 m asl in **plot 2** (High Montane Forest- HMF); and 1750 m asl - 1810 m asl in **plot 3** (Low Montane Forest - LMF).

2) Tree plant enumeration

All trees with a diameter at breast height (dbh) ≥ 2 cm were taxonomically identified by their scientific name, vernacular and/or commercial names. For each tree, the dbh was measured at 1.30 m and 0.3 m above the defects (buttress). The specimens were identified at the Limbe Botanical Garden herbarium by comparing and matching specimens with existing collections and available flora and monographs. Plant classification followed species lists in the Angiosperm Phylogeny Group [61].

Determination of Stand Characteristics

The characterization of the composition, structure and diversity of tree stands found in the study area was done using multiple indices.

1) Determination of the stand composition of the Buea Cluster of the MCNP.

The absolute density (abundance) and the species richness were used to determine the stand composition of the montane forest. The abundance was determined as the number of individuals in each species in the different plots [62]. Species richness (S) was determined as the total number of species per unit area present in the population [63]. The species richness and abundance helped in the determination of other indices, such as the Important Value Index (IVI), and Family Important Value (FIV). For assessing the ecological importance of a species, the Important Value Index (IVI) [64] was used and it was calculated using

the formula:

$$IVI = SRDe + SRDo + SRF \quad (1)$$

where *SRDe* is the Species Relative Density, *SRDo* is the Species Relative Dominance, and *SRF* is the Species Relative Frequency.

The *IVI* value was calculated at the level of families and determined as the Family important value Index [65] was determined as:

$$FRDe + FRF + FRDo \quad (2)$$

where *FRDe* is the Family Relative Density, *FRDo* is the Family Relative Dominance and *FRF* is the Family Relative Frequency.

The species diversity was determined by the Fisher-alpha diversity and the Shannon diversity index. In calculating diversity only species that were identified to the species level were considered.

Fisher's alpha diversity as described by [66] was determined as;

$$S = a * \ln(1 + n/a) \quad (3)$$

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

Shannon diversity was determined as described by [67];

$$Shannon\ Index = -1(\sum pi \ln pi) \quad (4)$$

where *pi* is the proportion of individuals belonging to the *i* species in the dataset.

Species evenness which are a structural composition index reflecting the dominance of species was calculated using the Pielou's evenness index following the equation of [68];

$$J = H/H_{max} \quad (5)$$

Sorenson's quantitative index, which accounts for the relative abundance of shared species, was used to assess the degree of floristic similarity within and between the forest stands:

$$S = 2C/A + B \quad (6)$$

where *C* is the number of species they have in common in both plots while *A* is the species in *A* while *B* is the number of species in *B*.

1) Stand Structure

The forest structure was expressed through the relative density (stem density), basal area and the number of individuals in each diameter size-class. Size-class distribution was determined by the diameter size-classes, where stems of a dbh range of 5cm were grouped together in different diameter size classes for a better distribution of the species present at our different sites. These diameter size classes were distributed as follows: <5, (>5 - 10 cm), (>10 - 20 cm), (>20 - 30 cm), (>30 - 40 cm), (>40 - 50 cm), (>50 - 60 cm), (>60 - 70 cm), (>70 - 80 cm), (>80 cm). The relative density corresponds to the number of individuals on a given surface area and this was calculated by dividing the number of trees by the surface area of the sample. The basal area corresponds to the surface area of all the cross-sections of the trunks, at a height of 1.30 m, of the trees present in one hectare of forest [69]. It is expressed as:

$$BA = (\pi D^2)/4 \quad (7)$$

where: BA = basal area (m^2), D = diameter at breast height (cm) and π = pi (3.142).

2) Determination of Carbon Stock of the Buea cluster of the MCNP

• Estimation of Above-ground Carbon Stock (ACS) of the MCNP.

The diameter of all plant trees were used to estimate the biomass of trees inventoried by the non-destructive method of using the allometric equation of [70] and was determined as:

$$AGBs = \rho_s \times \exp \left[-1.499 + 2.148 \times \ln(\text{DBH}) + 0.207 \times \ln(\text{DBH})^2 - 0.0281 \times \ln(\text{DBH})^3 \right] \quad (8)$$

where DBH = diameter at breast height in centimeter, ρ_s = specific wood density. For species without wood densities, an average for the genera or family was used.

A conversion factor of 0.47 was multiplied by the above ground dry biomass to obtain above ground Carbon stock [71].

• Estimation of the Below-ground biomass Carbon (BGBC) of the Buea Cluster of the MCNP.

It makes up a significant proportion of the total forest above-ground biomass. This was calculated using the formulae of [72]:

$$Y = 0.235 \times \text{AGB} \text{ if } \text{AGBC} > 62.5 \text{ t C/ha} \quad (9a)$$

$$Y = 0.205 \times \text{AGB} \text{ if } \text{AGBC} \leq 62.5 \text{ t C/ha} \quad (9b)$$

A conversion factor of 0.47 was multiplied by the above ground dry biomass to obtain above ground Carbon stock [71].

3) Estimation of the litter Carbon stock (LCS) of the Buea Cluster of the MCNP

Within each quadrat of 5 m × 5 m, sub-quadrats of 1 m × 1 m were randomly established for the collection of litter biomass (dry leaves and twigs) and the litter samples were bulked for each plot. Each collected sample was labeled and transported to the University of Buea's Plant Biology 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 [73]:

$$LB = \frac{W_{field}}{A} \times \frac{W_{subsample(dry)}}{W_{subsample(fresh)}} \times \frac{1}{10000} \dots \quad (10)$$

where LB is leaf litter biomass in (ha), W_{field} is weight of wet field sample of litter sampled within an area of size 1 m^2 in (g), A is size of the area in which litter was collected (ha), $W_{sub-sample(dry)}$ is weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and $W_{sub-sample(fresh)}$ is weight of the fresh sub-sample of litter taken to the laboratory. Carbon stock in leaf litter biomass was computed as follows:

$$\text{LCS} = \text{LB} \times \%C \quad (11)$$

where LCS is Litter Carbon Stock in ton/ha, %C is carbon fraction determined in laboratory [73].

● Soil Organic Carbon (SOC) of the Buea Cluster of the MCNP

Soil samples were collected randomly from each quadrat at the following soil depth: 0 - 10 cm, 10 - 20 cm and 20 - 30 cm. Samples from each soil depth were composited to make one representative sample. Soil auger was used for collection of soil samples, preserved in polythene bags and later analyzed in the Life sciences laboratory of the University of Buea. The bulk density was determined by using a soil corer carefully driven into the soil as described by [74]. 50 representative samples were collected for bulk density and a total of 200 samples were analyzed for SOC. Samples were air-dried for a day in a cool environment to prevent oxidation. The samples were sieved using a 2 mm sieve and weighed with an electronic scale to get the weight (W1). Later, samples were oven-dried at 105°C for 2 days to get the dry weight (W2). The samples were then ashed at 500°C for 5 hours to get the percentage of Carbon in the samples. The SOC was determined as described by [75] as follows:

$$\text{SOC} = d \times \%C \times \text{BD} \quad (12)$$

$$\text{BD} = W2/V \text{ (g.cm}^{-3}\text{)} \quad (13)$$

where d = depth of soil; $\%C$ = percentage of Carbon; BD = bulk density (kg/ha), and V = volume of core ($\pi r^2 h$); $W2$ = weight of oven-dry sample.

● Estimation of the total Carbon stock of the Buea Cluster of the MCNP

The total biomass and Carbon stock accumulation of the MCNP's Buea Cluster was calculated by summing the biomass and Carbon stock of the different pools:

$$C \text{ (plot)} = \text{ACS} + \text{BCS} + \text{LCS} + \text{SOC} \quad (14)$$

where: $C \text{ (plot)}$ = total carbon content in the plot (tonnes/ha), ACS = Above-ground Carbon Stock (tonnes/ha), BCS = Below-ground Carbon stock (tonnes/ha), LCS = Litter Carbon stock (tonnes/ha) SOC = Soil Organic Carbon (tonnes/ha).

● Estimation of the Carbon sequestration of the Buea Cluster of the MCNP

Estimation of the Carbon sequestration potential of the different carbon pools were calculated according to [76] and [77]:

$$\text{CO}_2^{-e} = \text{TCS} \times 3.67 \quad (15)$$

where, CO_2^{-e} = carbon dioxide equivalent or weight; TCS = total Carbon stock and $44/12$ (3.67) = ratio of molecular weight of CO_2 to carbon, $\text{t CO}_2^{-e} \text{ t C}^{-1}$

Statistical Analyses

The data collected were arranged in Excel sheets and exported to other packages for statistical analysis and graphics. MINITAB was used to produce charts and to run One-Way Analysis of variance (ANOVA) which was performed after the test of homogeneity to compare the means between plots. The Tukey's Honesty Test was used to separate means of above-ground biomass and Carbon stock, which differed from one another. Paleontological Statistics (PAST) was used to calculate: Fisher's alpha diversity, Shannon's diversity and species evenness; and Sorenson's Similarity indices between plots. The Kruskal-Wallis Test was also used to determine the level of significance between soil organic Carbon and soil bulk density at different soil depths.

Results

Floristic Composition and Diversity of the Buea Cluster of the MCNP.

An inventory of the Montane forests of the MCNP's Buea cluster indicated that there is a decrease in the abundance, and species richness with an increase in altitude. We inventoried a total of 1715 individuals (DBH \geq 2 cm) belonging to 44 tree species representing 26 plant families, and 35 genera (Appendix 1). The highest number of individuals was found in the LMF (780 individuals/ha) and the least was in the HMF (463 individuals/ha) (**Table 1**). Similarly, the species richness was highest in the LMF with 33 species (19 families) and least in the TMF with 21 species (15 families).

Table 1. Tree abundance and species richness in the Buea cluster of the MCNP.

Plots/ha	Abundance (individuals/ha)	Species (S/ha)	Family/ha
TMF	472	21	15
HMF	463	32	17
LMF	780	33	19
Total/3 ha	1715	45	26
Mean/ha	571.7	28.7	17

Figures in bold indicate the highest or lowest.

The most common species were *Maesa lanceolata* with 96 individuals/ha in the TMF, *Bridelia micrantha* with 42 individuals/ha in the HMF and *Allophylus africanus* with 66 individuals/ha in the LMF. Four (4) individuals were unidentified at the species level while 3 individuals at the family level. The species *Alangium chinense* (Cornaceae), *Bridelia micrantha* (Phyllanthaceae), *Pittosporum mannii* (Pittosporaceae), *Psychotria peduncularis* (Rubiaceae) and *Vernonia auriculifera* (Asteraceae) were common in all the Plots. *Xymalos monospora* and *Satureja punctata* were found only in the TMF and *Cyathea gigantea* in the HMF.

Table 2. The most important species and families in the Buea cluster of the MCNP.

Plots	Species	Family	Level	IVI (%)	Family	FIV (%)
TMF	<i>Maesa lanceolata</i>	Primulaceae	maximum	103.75	Primulaceae	105.34
	<i>Vernonia calvoana</i>	Asteraceae	minimum	1.18	Lamiaceae	1.25
HMF	<i>Bridelia micrantha</i>	Phyllanthaceae	maximum	46.97	Phyllanthaceae	51.09
	<i>Solanum anomalum</i>	Solanaceae	minimum	0.86	Solanaceae	0.94
LMF	<i>Polyscias fulva</i>	Araliaceae	maximum	43.9	Araliaceae	44.77
	<i>Macaranga</i> sp	Euphorbiaceae	minimum	0.59	Moraceae	0.68

Figures in bold indicate the highest or the lowest.

The Importance Value iIndex (IVI) of tree species varied greatly, ranging from 0.59% to 103.75% among plots (**Table 2**). Generally, *Maesa lanceolata* (103.75%) was the most important species in the TMF while *Macaranga* sp. (0.59%) in LMF was the least important species. Specifically, the most important species was

Maesa lanceolata (103.75%) in TMF, *Bridelia micrantha* in HMF (46.97%) and *Polyscias fulva* in LMF (43.9%). Also, the most important family which denotes dominance of plant Families in the Montane forest was Primulaceae in the TMF (105.34%) and the least was found in the Moraceae in the LMF (0.68%) (**Table 2**).

The Shannon-Weaver diversity was 2.0 (TMF), 2.63 (HMF) and 2.62 (LMF) thus making HMF most diverse and TMF the least diverse (**Table 3**). Similarly, Species evenness (E), which is a measure of the equitability of spread, was maximum in the HMF (0.43), and minimum in the TMF (0.34) (**Table 3**). HMF and LMF were most similar (52.3%).

Table 3. Floral diversity and Evenness in the Buea cluster of the MCNP.

Plots	Species richness	Shannon-Weaver	Species evenness	Sorenson's Similarity (%)
TMF	1.0	2.0	0.34	30.2 (TMF&HMF)
HMF	1.50	2.63	0.43	52.3 (HMF&LMF)
LMF	1.20	2.62	0.42	29.6 (TMF&LMF)

There were five species with a total of 45 individuals/3 ha that were found in the IUCN Red list with *Tabernaemontana contorta* (38 individuals/ha) having the highest number of individuals in the LMF (**Table 4**).

Table 4. Plants in the IUCN red list in the MCNP's Buea Cluster.

Family	Species	Status	TMF	HMF	LMF
Apocynaceae	<i>Tabernaemontana contorta</i>	Near threatened	-	4	38
Asteraceae	<i>Vernonia calvoana</i>	Vulnerable	2	-	3
Meliaceae	<i>Entandrophragma cylindricum</i>	Vulnerable	-	-	1
Meliaceae	<i>Entandrophragma angolense</i>	Vulnerable	-	3	3
Rosaceae	<i>Prunus africana</i>	Threatened	1	-	-
Stilbaceae	<i>Nuxia conjesta</i>	Threatened	-	4	-
TOTAL			3	11	45

Figures in bold indicate the highest or the lowest.

Stand Structure of the MCNP's Buea Cluster

Table 5. Mean basal area of the different sites in the MCNP's Buea Cluster.

Basal Area (BA)	TMF	HMF	LMF
Number of species	21	32	33
Min BA (sq.m)	<i>Vernonia calvoana</i> 0.0005	<i>Vernonia auriculifera</i> 0.0113	<i>Cyathea gigantea</i> 0.0097
Max BA (sq.m)	<i>Maesa lanceolata</i> 2.47	<i>Polyscias fulva</i> 6.89	<i>Polyscias fulva</i> 9.68
Mean BA (sq.m)	0.29	0.93	0.83

The mean basal area for the plots ranged from 0.29 to 0.93 m²/ha. It was highest in the HMF (0.93 m²/ha) and lowest in the TMF with 0.29 m²/ha. In all three plots, the species *Polyscias fulva* had the highest basal area 9.68 m²/ha in the LMF and *Vernonia calvoana*, was least with 0.0005 m²/ha in the TMF (Table 5). The species with highest relative density was *Maesa lanceolata* (40.89%) in the TMF and the lowest was *Macaranga sp* (0.13%) in the LMF.

Diameter Size - class distribution of the MCNP's Buea Cluster

The number of individuals and mean diameters were calculated for all different diameter-size classes from 0 - ≥ 70 cm. The results indicate that the HMF had the highest mean DBH of 18.97 cm while the TMF had the lowest of 8.37 cm. An increase in DBH led to a decrease in the number of individuals, thus the highest total density of individual plant species was recorded at the <10 cm diameter size-class across the 3 plots, producing a reverse J-shaped structure (Figure 2). The individuals in the <10 cm diameter size-class contributed more than 50% of the total tree density in the montane forest. However, the number of individuals in DBH size-class > 70 increased in the HMF and LMF (Figure 2), increasing its basal area. Also there was a great difference in the plant density from ≥ 5 cm to ≥ 10 cm in the LMF.

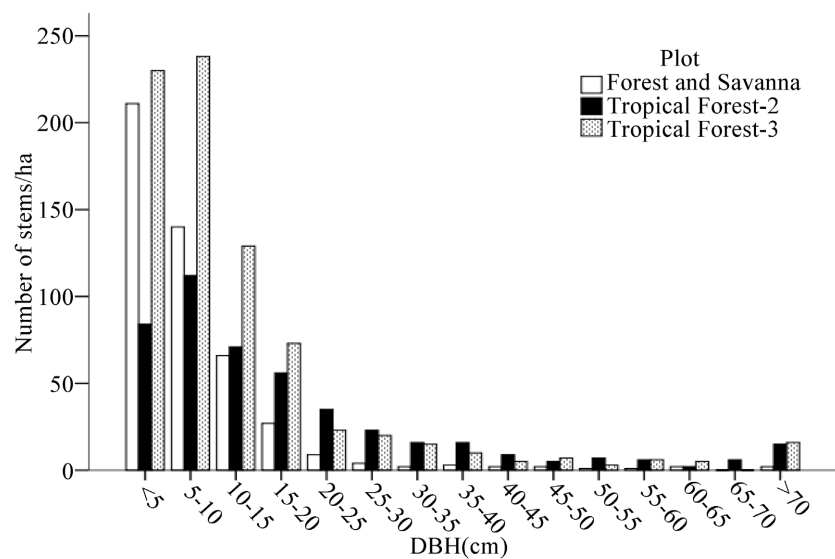


Figure 2. DBH size-class distribution and stem density in the MCNP's Buea Cluster.

Carbon stock of the MCNP's Buea Cluster

Above-ground biomass Carbon Stock (ACS) and below-ground carbon stock (BCS)

The ACS was significantly different across plots ($p < 0.000 < 0.05$). The total above-ground biomass (AGB) of the MCNP montane forest ranged from 137.7 tons ha⁻¹ in the TMF to 900 ton ha⁻¹ in the HMF (Table 6). Similarly, the mean total above-ground Biomass Carbon stock (ACS) of the MCNP montane forest ranged from 64.7 tons ha⁻¹ in the TMF to 423.9 tons ha⁻¹ in the HMF (Table 7). Similarly, the

mean BGB was 105.8 tons ha⁻¹ with a mean BCS of 49.7 tons ha⁻¹. The BGB and the BCS was highest in the HMF (189.0 tons ha⁻¹ and 88.8 tons ha⁻¹ respectively) and the lowest in TMF (28.9 tons ha⁻¹ and 13.4 tons ha⁻¹ respectively) (**Table 7**).

Litter biomass and Carbon Stock in MCNP's Buea Cluster

The mean litter biomass of 0.2 tons/ha was significantly different in all plots in the MCNP Montane forests ($P = 0.000$). The litter biomass decreases with an increase in altitude, thus the LMF had the highest litter biomass (0.3 tons/ha) and stock of Carbon (0.15 tons/ha) while the TMF and HMF were lower (0.2 tons/ha biomass and 0.09 tons/ha) (**Table 6** and **Table 7**).

Table 6. Mean AGB, BGB and LOB across the vegetation types.

Aspect (t/ha)	Vegetation Type			
	TMF (tons ha ⁻¹)	HMF (tons ha ⁻¹)	LMF (tons ha ⁻¹)	Mean/tons ha ⁻¹
AGB	137.7b	900.0a	474.0b	503.9
BGB	28.9	189.0	99.5	105.8
LB	0.2	0.2	0.3	0.2

*AGB = Above ground biomass; BGB = Below ground biomass; LB = Litter organic biomass. Means that do not share a letter are significantly different.

Table 7. Mean Carbon Stock of the different sinks in the Buea Cluster of MCNP.

Carbon pools	Carbon stock of the different Carbon Sinks			
	TMF/tons ha ⁻¹	HMF/tons ha ⁻¹	LMF/tons ha ⁻¹	Mean/tons ha ⁻¹
ACS (t/ha)	64.7	423.0	222.8	236.8
BCS (t/ha)	13.5	88.8	46.8	49.7
LCS (t/ha)	0.09	0.09	0.15	0.11

*ACS = Above ground carbon stock; BCS = Below ground carbon stock; LCS = Litter carbon stock.

Soil bulk density and Soil Organic Carbon stock (SOC) of MCNP's Buea Cluster

Soil bulk density showed a significant difference ($P = 0.000$) in all plots in the Montane Forest. There was a gradual decrease in bulk density (BD) with the increase in soil depth in the Montane forest. It was maximum in the LMF (0.30 g/cm³) and minimum in the TMF (0.23 g/cm³) (**Table 8**). For soil organic carbon stock (SOC), the maximum was recorded in the LMF (13.24 t C/ha) and the minimum was in the TMF (8.36 t C/ha). Generally, the SOC decreased with an increase in the soil depth, thus the highest amount of SOC was found at the 0 - 10 cm soil depth (top soil) (**Table 8**) in the different plots. The percentage SOC was highest in the LMF (4.91) and least in the TMF (3.50). The amount of Carbon sequestered is highest in the LMF (48.87 tons/ha) and least in the TMF (30.68 tons/ha).

Table 8. Total Soil Organic Carbon Stock (SOC) and sequestration of MCNP'S Buea Cluster.

Sites	Soil depth (cm)	BD (g cm ⁻³)	%SOC	SOC	Total soil Carbon stock (t C/ha)	TMCO ₂ ^{-e} CO ₂ /ha
TMF	10	0.08	3.79	3.03	3.86	30.68
	20	0.08	3.60	2.88		
	30	0.07	3.50	2.45		
HMF	10	0.10	4.12	4.12	11.68	42.87
	20	0.10	3.84	3.84		
	30	0.10	3.72	3.72		
LMF	10	0.10	4.37	4.37	13.24	48.59
	20	0.10	4.91	4.91		
	30	0.10	3.96	3.96		

TMCO₂^{-e} = Total molecular weight of carbon dioxide equivalent.

Total Carbon Stock and Sequestration potential of the MCNP's Buea Cluster

Table 9 summarizes the Carbon Stock of the different Carbon pools in the study area to obtain the total Carbon stock and sequestration of the study site. The highest total Carbon stock was found in the HMF (539.94 t/ha) while the least was in the TMF (86.62 t/ha). The total carbon stock of the Buea cluster of the MCNP is 319.33 t/ha. For soil organic carbon in terms of CO₂ equivalent per ha, the HMF had the highest 1981.57 CO₂/ha amount of sequestered carbon and TMF had the lowest 317.89 CO₂/ha (**Table 8**).

$$C (\text{plot}) = ACS + BCS + LCS + SOC$$

$$C (\text{plot}) = 236.8 + 49.7 + 0.11 + 32.72 = 319.33$$

Table 9. Total Carbon Stock and Sequestration potential of MCNP'S Buea Cluster.

PLOT	POOLS				TOTAL t/ha	TMCO ₂ ^{-e} CO ₂ /ha
	Above ground t/ha	Below ground t/ha	Litter t/ha	Soil t/ha		
TMF	64.7	13.5	0.09	8.33	86.62	317.89
HMF	423.0	105.7	0.09	11.15	539.94	1981.57
LMF	222.78	55.65	0.15	13.24	291.82	1070.97
Mean	236.8	58.28	0.11	10.91	306.13	1123.49

Discussion

Species composition of the Buea cluster of the MCNP

Tree species abundance and richness are important indicators for assessing the biodiversity of an environment [78]. In this study, we recorded a total of 1715 individuals, 26 families and 35 genera in the Buea cluster of the MCNP. This is similar to the results of [79] who indicated a total of 1786 individuals in the Kadjom Keku montane forest in the North west Region of Cameroon. This is how-

ever higher when compared to the results of [80] in the Rumpi Hills Forest Reserve (RHFR) who recorded 1066 individuals/25 ha in montane cloud forest (represented here as HMF and LMF giving a total of 621 individuals/ha) and 263 individuals/28 ha in transitional forest as compared to 472 individuals/ha in our study. The RHFR is part of the chain of mountains of Cameroon and Nigeria that includes the Cameroon Mountains and associated highland biomes [81] [82]. It forms part of the Lower Guinea Forest, with high levels of species richness and endemism [81] [83] [84]. The difference with the results in this study is an indication that the Buea Cluster of the MCNP still has some more individuals than its nearby forest mountains thus necessary for conservation as a national Park and an area of high endemism. The tree species' abundance and richness increased with decreasing altitude while shrubs increased with increasing altitude; that is why the transitional zone was more of shrubs while the forests had more trees. This may be due to the fact that at a higher altitude the environmental conditions do not allow for the growth of tree plants but shrubs.

The IVI of a plant indicates its ecological importance and in this study, the most important species were; *Maesa lanceolata*, *Bridelia micrantha* and *Polyscias fulva* for TMF, HMF and LMF respectively. The most important species was *Maesa lanceolata* from the Primulaceae which is also the most important family in this study. The species, *Maesa lanceolata* is a straggling shrub, 2 to 3 m tall, or a small tree with a single stem up to 9 m tall, or a rounded bushy tree with branches almost at ground level, able to withstand any environmental condition. It also has fruits eaten by only birds but poisonous to humans and mammals. The species is therefore bird-dispersed and thus can be the most important species due to its abundance [85]. This is similar to the result of [79] at the Kedjom Keku montane Forest in the Northwest Region of Cameroon, where *Maesa lanceolata* had the highest stem density.

The most important family which was the Primulaceae family (Primroses) is a large angiosperm family consisting of 22 genera and nearly 1000 species mainly distributed in the high mountains of the northern temperate zone [86] [87] where the temperatures are low. With the increase in temperatures primroses may encounter more severe survival challenges due to the rapid warming at high altitudes under global change [88]-[90]. This calls for conservation of this endemic family in the MCNP, thus this study is helpful for informing future conservation strategies about this group [91]. The most important family in the HMF which is the Phyllanthaceae is similar to the studies of [80] in the Rumpi Hills Forest Reserve as the third most important family, indicating the similarity of the MCNP and the RHFR as Cameroon mountains in the Guineo-Congolese region. The least important family which is the Moraceae in the LMF is due to the effect of anthropogenic activities in the LMF [92]. indicated that most of the species of the Moraceae family are widespread in tropical and subtropical regions, and less so in temperate climates; however, their distribution is cosmopolitan overall where anthropogenic activities take place. The reasons for the poor establishment of some families

which showed low species abundance, may be attributed to competition for nutrients, limited light by canopy trees and destruction of undergrowth during tree logging. The high level of anthropogenic activities occurring within this forest affects growth and distribution of species.

The most common families were Primulaceae, Phyllanthaceae, Araliaceae, Rubiaceae and Solanaceae. According to [26] Rubiaceae is always among the ten most species rich families in Africa, Asia and the Neotropics in a similar study in the Mono Biosphere Reserve in Togo. Stevens (2001) indicated that the family contains about 14,100 species in about 580 genera, which makes it the fourth-largest angiosperm family as Rubiaceae has a cosmopolitan distribution. These results were in accordance with the findings of [30] [93] who reported that the Rubiaceae was the most dominant tree family in the Mount Cameroon region. Likewise [79], in the Kedjom Keku Montane Forest in North West Region of Cameroon found Solanaceae was the dominant family.

Diversity of the Buea cluster of the MCNP

The diversity decreased with an increase in altitude, indicating a monotonic decrease in functional diversity along elevation across all plots. The theory predicts that the range of successful functional strategies narrows along an environmental stress gradient [94] [95]. General elevational decreases in taxonomic diversity of woody plants similar to those found in the present study have been widely reported [96]-[98], with the elevational decrease in temperature being the ultimate cause of this trend [99]. In the case of elevation, the upslope increasingly harsher and more restrictive conditions mainly in terms of temperature and resource availability [100] [101] is expected to lead to the selective survival of taxa with conservative strategies promoting storage and defense that enable them to cope with the environment, and to the cull of these with acquisitive ones enhancing photosynthesis and growth [102] [103]. This may be the reason why the most important species in the TMF is *Maesa lanceolata* which has several forms as a shrub or a small tree [85]. This pattern has been detected previously in Tropical Montane Forests both for individual functional traits including leaf size decreases [104]-[106] and wood density increases [107] [108], and for overall community functional diversity [109] [110]. This evidence has been used in support of environmental filtering as an essential driver of plant community assembly [111] [112].

However, studies have also detected a non-monotonic change in diversity along elevation, specifically a hump-shaped pattern where richness peaks at middle elevations [113]-[116]. This can be seen in this study with the HMF being the most diverse producing a bump-shaped pattern as elevation increases. This bump-shaped pattern in taxonomic diversity with elevation can be explained by the relatively stable condensation zone (cloud belt) that characterizes the middle elevations of tropical elevational gradients, which provides favourable conditions for most organisms despite the lower temperatures relative to premontane elevations [117] [118].

According to [119], a forest community is said to be rich if it has a Shannon Diversity value ≥ 3.5 . Hence, considering that all sites had Shannon Diversity index values below 3.5, the research plots were relatively poor in diversity. This is confirmed by [120] who stated that the tree species diversity of the montane forest of the Cameroon Highlands is low compared to submontane forest which has hundreds of species. This low diversity in montane forest may be firstly due to the little forest above 2000 m altitude due to the free-draining nature of its predominantly volcanic cinder substrate [14] [121] [122]. Secondly, variation in abiotic factors such as lower temperatures and shallower soils, which hinders the establishment of tree species and area effect where there is reduction of the area available for the establishment of species with increasing altitude [123]-[125]. Thirdly, the inflation of species richness or diversity in lower montane forests could be due to the higher proportion of generalist species. This also possibly indicates that the forest has ideal habitat for floral growth and reproduction [126].

Given that the Mount Cameroon National Park is located only from the montane zone in the Buea Cluster due to human habitation and farmland extensions, special conservation measures should be taken into consideration for the conservation of the few montane species found in the study as it has a number of indicator species and exhibit a floristic composition quite distinct from other lower altitudes. Human activities at these higher altitudes are less frequent due to the challenging terrain, but they still exist. Some people may venture into these areas for hunting or collection of specific resources. The transitional montane zone deserves in principle special attention regarding measures of conservation interest due to the presence of vulnerable and flagship species like, *Prunus Africana* which is almost absent in this study. Unsustainable practices like over-debarking of *Prunus africana* for medicinal purposes have been documented (29), although collaborative management approaches are being implemented to promote more sustainable harvesting. This area is where you'll find the most significant impacts from human activities. Small-scale timber and firewood exploitation, bushmeat hunting, and the harvesting of NTFPs like medicinal plants and fruits are common. The HMF was the richest and most even site, indicating a higher evenness of plant distribution. From the point of view of similarity, Sørensen's similarity index showed a high floristic similarity (Sørensen = 52.3%) between HMF and LMF, indicating sites with the same plant community. There was a low Similarity between TMF and HMF and TMF and LMF. This may be due to the altitudinal difference between the Plots that affect the vegetation type.

The structure of the Buea cluster of the MCNP

The reverse J-shape pattern obtained in the study indicated a general pattern of a normal tropical forest structure and implies the probability of a good reproduction and recruitment pattern [127]-[129]. This is an indication of ecological vigor and the guarantee of the sustainability of the population in an ecosystem. This structure is the characteristic of a stable natural forest, where small trees that make up the ecosystem tend to be denser than large trees [130]. There was a rapid de-

crease in the number of individuals from the ≥ 5 cm to the ≥ 10 cm in the TMF. This may be due to the climatic condition in the higher altitudes which enables mostly seedling and shrubs to grow in that environment. The general inverted J-shape pattern from cumulative DBH class may not represent the general trend of population dynamics and recruitment process of a single species, but analyzing DBH pattern for each individual tree or shrub species could bring the realistic and specific information to forecast the future population dynamics of the plant species [127] [131]. The highest mean DBH in HMF had the lowest stand density of 463 individuals/ha⁻¹. This is an indication that it had more matured tree species. This density of 463 individuals ha⁻¹ found in the HMF where human activities are restricted is similar to 426 and 460 individuals/ha that was found by [132] in the Dja Wildlife Reserve, thus functional as a National Park. The increase in the plant density of larger individuals in the HMF and LMF may be due to the favourable climate in the HMF for tree growth and seed trees that have been left for production and shade, or remnant cohorts that have grown after deforestation in the LMF. This area is characterized by farming activities, including the cultivation of cash crops like plantain and cassava.

Conservation status of the Buea Cluster of the MCNP.

Some taxa found in the studied area are of high conservation value and importance. They occur mostly in the montane forest, and the ecological fragility and anthropogenic pressure on the lowland forest suggest that these ecotypes are of considerable conservation value. Out of the 45 species recorded, 7 species were vulnerable according to the IUCN red list [133]; thus requires conservation efforts. Also none of the species are not endemic to the Buea Cluster of the MCNP. Finally in the montane flora of Cameroon's forest, there are 28 species based on herbarium specimens. Out of the 28, only 6 species were found in this study. Thus, the inclusion of forest remnants (native plants) within the national park and increasing collection efforts are essential for the conservation of this altitudinal zone.

Carbon Stock of the Buea cluster of the MCNP

Above-ground Carbon stock (ACS) and below-ground Carbon Stock (BCS) of the Buea cluster of the MCNP

There was generally a decrease in the AGB with an increase in altitudes due to the decrease not only in the tree abundance but also in the wood density of the trees. That is the reason why the HMF had the highest AGB (900.0 t ha⁻¹) and AGB Carbon stock (423.0 C ha⁻¹) than TMF and LMF. The difference in the AGB between HMF and LMF may be due to the fact that though both HMF and LMF had similar species diversity, in the HMF, there were larger trees than in the LMF which have been degraded by deforestation for human habitation [134]. Indicated that the above-ground biomass of all woody individuals increased with increasing plant species richness at the smallest spatial scale (0.04 ha), while this relationship weakened or even disappeared with increasing spatial scales (in this case increase in altitudes). This is an indication that the sampling size was enough for the de-

termination of a relationship between the AGB and the species richness. However the size of the trees matters as we can see no difference in the species richness between HMF and LMF but a significant difference at the level of the AGB. It is therefore safe to say that the Carbon stock is not based on the species richness, but rather on the number of trees, their DBH and wood density. In the 3 Plots sampled, the mean AGB was 503.9 t ha⁻¹ and Carbon stock 236.8 tC ha⁻¹ which is slightly low when compared to that of [135] in the Lobeké National Park with a Carbon stock of 374.2 tC/ha and [136] who found 354.73 t/ha of Carbon stock in some Cameroon's forests and values of AGB (≥ 429 t ha⁻¹) and carbon stock (≥ 249 tC ha⁻¹) documented for other Central African forests [137] [138]. Although the present study revealed that MCNP's Buea Cluster is rich in mean AGB and Carbon, exceptions were observed for some specific plots like the TMF with very low mean AGB of 137.7t ha⁻¹ and mean Carbon stock of 64.7 t ha⁻¹. This is similar with the results of [136] ABG (141.0 t ha⁻¹) in the gallery of the Kimbi-Fungom National Park. This may be due to the functional diversity of the species in this site with extreme environmental conditions reducing the abundance of the species richness. The number of trees, tree DBH, tree biomass and Carbon stock are influenced by the environmental conditions of a site. Also, tree density and tree size have strong relationships with AGB at all spatial scales which influence Carbon stock greatly [139]. Drop in ACS in LMF could be greatly due to anthropogenic activities that cause deforestation by the local population. Thus generally the high Carbon stock of this forest, may be due to its natural reserve of flora, with little or no disturbance in the HMF ecosystem. Similarly the BGB and the BCS were highest in the HMF (189 tons ha⁻¹) and least in the TMF (28.9 tons ha⁻¹), thus there was a decrease with altitude. This may be due to the downward migration of organic matter and its accumulation in the lower altitudes. similar results have been reported by [140] [141].

Litter Carbon stock (LCS) of the Buea cluster of the MCNP

The Carbon stocks of tropical litterfall in general and montane forests in particular have not received much attention in research as it constitutes a small fraction of above-ground biomass [142]. Generally the LCS increased with a decrease in altitude making LCS to be highest in LMF, and least in TMF. The total Carbon stored in litter was 0.36t ha⁻¹. This difference may be due to the increase in rain and wind blow in the higher altitudes enabling a downward migration and accumulation in the lower layers. Although some of the litter may be held in the HMF, the rain accumulation will force it down to the lower altitudes. The higher ACS than the LCS may be due to the fact that floristic composition and structural variables (basal area, height-diameter allometry, etc.) account for much of the spatial variation in Carbon stocks in African tropical forests [143]-[145].

Soil Organic Carbon (SOC) of the Buea Cluster of the MCNP

Generally there was a decrease in the SOC with an increase in soil depth in corroboration with [146]. The high concentration of biological activities particularly organic residues deposited in the top soil and organic matter tends to accu-

multate in the upper soil profiles and leads to a relatively higher SOC than in the lower soil profiles. Taking into consideration that there are very few studies that have investigated the SOC in montane forests especially in Cameroon, this study presents one of such studies with a mean total SOC of 11.1 tCha^{-1} recorded thus setting a baseline SOC for this site. Furthermore, few studies have been carried out on the different pools of Carbon in the Mount Cameroon National Park especially at altitudes above 1800 m asl. Setting the baseline is important for future SOC stock estimation and comparing the C sequestration potential of this ecosystem. In Cameroon, a national SOC database is not available and this could limit the country's ability to access funds from the Clean Development Mechanism (CDM) as proposed under article 12 of the Kyoto Protocol of the UNFCCC. Thus SOC density estimation at local levels could serve as a starting point for large scale estimations and help provide some accuracy for a national SOC data. Similar studies on SOC by [43], on different Land Uses on the lower gradient of MCNP where agricultural activities take place revealed soil Carbon stock of $225.24 \text{ tC ha}^{-1}$ which was by far higher than that obtained in this study. Also, [147] in their compilation of SOC from various sources and ecosystems in the Congo basin obtained with a mean value of 38 t/ha (range 35 to 82 t/ha).

The highest % SOC of 4.91% in the LMF is similar to the results of [148], which stood at 4 to 8% SOC on the volcanic soils at the base of Mt. Cameroon. Lower values in this study in the HMF and TMF are probably due to the high altitudes which leads to constant draining of nutrients to the lower altitudes of the mountain leading to the increase of SOC in the LMF. In the TMF, the soil is open to the atmosphere and increases the breakdown of Soil Organic Matter (SOM) to yield CO_2 . This might also be the reason for the difference in the results of [43] who have higher values in forests found at the lower altitudes of the MCNP. This higher SOC stock could be explained to be the result of basaltic volcanic soils, rich in SOM of the study area [43].

Total Carbon stock and sequestration of the Buea cluster of the MCNP

The total carbon of 319.33 t/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 [132] [136]. Similar results were found by [149] who had 278.75 t-C/ha in the Deng Deng National Park [150], in a semideciduous forest in the East region of Cameroon who recorded $283.97 \pm 51.42 \text{ Mg-C/ha}$ and [151] in a semideciduous forest in Brazil which recorded 267.52 Mg/ha of Carbon stock. These results are also similar to the values of carbon stock ($\geq 249 \text{ tC ha}^{-1}$) documented for other Central African forests [137] [138]. These results are however low when compared to that of [138] in the Lobeké National Park with with a Carbon stock of 374.2 tC/ha and [136] who found 354.73 t/ha of Carbon stock in some Cameroon's forests. The differences in the values on the total Carbon stock would depend on the type of ecosystem under study, which might not be affected by altitude as in the case of our study site. However, this calls our attention to the fact that determining the total carbon stock for a site is necessary to have a better picture of its carbon stock capacity. As we can see in this study the same sites in

Cameroon [135] [136] who had slightly higher values when considering only the AGB than our study site, later have similar results when the other carbon pools are taken into consideration. Thus though the AGB contributes more than half of the total Carbon stock, the other carbon pools do have a significant contribution to the total carbon stock required by the Bonn challenge.

The amount of Carbon sequestered in the CO₂ equivalents (CO₂ ^{-e}) are the amounts of CO₂ gas molecules sequestered by the study area from its surrounding atmosphere in the form of SOC, ACS, BCS and LCS. The organic carbon values in terms of CO₂ ^{-e} help in understanding organic Carbon relation with CO₂ gas. This is the environmental perspective which includes the removal of CO₂ from the atmosphere, the improvement of soil quality, and the increase in biodiversity [152]. Our results indicate that HMF sequestered Carbon the most, followed by LMF and the least was TMF in the transitional zone. Young individuals sequester more CO₂ for their growth [153]. More individuals were recruited in the (0 - 5 and 5 - 10) class which indicates that the MCNP's Buea Cluster has a special status of a Carbon sink in the Congo Basin for the coming decades thus offering Cameroon a place of choice in the carbon market.

3. Conclusions

The effect of elevation on the vegetation of the MCNP's Buea Cluster was observed, as it influences vegetation pattern, vegetation structure, species diversity and species composition of the area across an elevational range of 1750 m asl - 2050 m asl. This study focused on evaluating the tree species diversity, stand structures and Carbon stocks. The structural composition of this montane forest indicates that the Montane forest is still intact with deforestation taking place at the lower parts of the montane forest. However the Buea Cluster of the MCNP has more individuals than other nearby forest mountains thus necessary for conservation as a National Park and an area of high endemism.

Some species in the Cameroon flora of montane species are still present in the Buea cluster of the MCNP. Also some of the species are found in the IUCN red list of endangered species. This calls for conservation measures to be put in place in the Buea cluster of the MCNP. This study represents one of the few studies that determines the carbon stock of the different Carbon pools in a montane forest, bringing our attention to the fact that determining only the AGB does not give us a good picture of the total Carbon stock in a montane forest to combat climate change. In order to combat climate change, the Carbon stock and the CO₂ sequestration indicates that the forest of the MCNP are important reservoirs for Carbon, and they can also play a key role for mitigating the global climate change as it has the capacity to trap vast amounts of Carbon which would otherwise remain in the atmosphere as CO₂, one of the main greenhouse gases.

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Authors' Contributions

Seraphine E. Mokake was the thesis supervisor responsible for conceptual framework, research design, analyses and fine tuning of the article. Taboko Akongenow Lucy was the masters student responsible for data collection in the field, write up of thesis and writing of the draft manuscript. Nghoh M.L was incharge of the data analyses and scientific contributions to the study. Enow Solomon and Guilen-Noel Nghokapin Tataw were responsible for aiding in the data collection. Jules Priso is the academic co-supervisor of this study. All authors read and approved the final manuscript.

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Conflicts of Interest

The authors declare that they have no competing interests.

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