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Characterization and Carbon Sequestration Potential of Sacred Forests in the Western Highlands Cameroon

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Cameroon has a diversity of forest ecosystems, including sacred forests that have been preserved until now by traditional laws. The aim of this study was to characterize the vegetation of two sacred forests in the Western Highlands and to estimate the quantities of carbon stored by these forests. The inventories were carried out in 24 quadrats measuring 30 m x 30 m installed in the Bansoa and Baloum forests according to their surface area. Individuals with a diameter of 10 cm or more at breast height (1.30 m from the ground) were measured. Phytodiversity was assessed using the

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Shannon and Simpson indixes. The quantities of carbon stored by the sacred forests were obtained using allometric equations developed by other researchers and appropriate to the tropical zone. Overall, 50 species in 31 genera and 25 families were recorded. The diversity index values are low. They range from 1.47 to 2.52 bits per plot for the Shannon index, and from 0.70 to 0.91 for the Simpson index. *Markhamia lutea* and *Cola acuminata* are the most frequent and abundant species in the study area. The densities of individuals per hectare are 368 individuals/ha at Bansoa and 416 individuals/ha at Baloum and the basal area varies from 32.37 m^2/ha to 38.44 m^2/ha. The shrub layer dominates in both forests. Of the species recorded, 03 are Vulnerable and 02 are Endangered. Carbon sequestration was 286.84 t C/ha at Baloum and 232.44 t C/ha at Bansoa, with CO_2 uptake of 1052.12 t CO_2/ha and 853.55 t CO_2 /ha respectively. The results of this study show that despite their small size, sacred forests play a significant role in the conservation of plant diversity and also help to reduce greenhouse gases in nature.

Keywords: Biomass; sacred forests; carbon dioxide; plant diversity.

1. INTRODUCTION

Cameroon has about 22 million hectares of forests with 26,000 hectares (0.1% of the forest area) classified as plantation forests [1]. These forests are mainly tropical rainforests dominated by two types; evergreen forests (54% of the total forest area) and semi-deciduous forests (28%). The overall species diversity of the forests of Central Africa in general and the Congo Basin in particular is very high. Unfortunately, it is currently under serious threat due to the conversion of forest areas to farmland, fuelwood harvesting, infrastructure and even unsustainable and illegal logging [2]. The deforestation rate is estimated at 0.0168% in 2019 in Cameroon, i.e. around 3,628 hectares [3]. Forests provide a means of subsistence for local populations and indirectly help to feed people living in urban centers close to forested areas [4]; they also contribute 10% of Cameroon's gross domestic product and 30% of exports [5].

Anthropogenic actions in the Western Cameroon region have had a remarkably negative impact on vegetation, to the extent that it has now changed from montane forests to shrub and herb savannahs [6,7]. However, in this part of Cameroon, there are still groves of forest near chiefdoms, along watercourses or in specific places chosen by the local people. Some of these relics are sacred forests protected by traditional laws. Sacred forests are areas reserved for traditional ceremonies and magico-religious rituals [8,9,10,11,12]. They are one of the endogenous forms of biodiversity conservation in Africa, Asia and Latin America. Sacred forests have the same advantages as other categories of forest, notably their significant biological diversity and their role as carbon sinks [13,14].

In the Western Cameroon region, the scarcity of arable land is leading people to encroach more and more on the remaining relic forests, including the sacred forests. The power of the traditional authorities and other priests of the deities seems to have declined with the arrival of new religions coupled with globalization, which tends to weaken the endogenous mode of conservation of these forests [15]. Despite their small surface area, they have many endemic species and constitute a kind of nursery and genetic bank that would constitute an effective new strategy to be included in the processes of sustainable management of biodiversity [15]; in addition, they are also capable of capturing and storing atmospheric CO_2. The present study was initiated with the aim of assessing the floristic diversity, structure and carbon stock of the sacred forests of Bansoa and Baloum in the West Cameroon Highlands.

2. STUDY METHOD

2.1. Presentation of the study area

The study was carried out in the West Cameroon Highlands, specifically in the Menoua department. This department covers an area of 1,384 km2, situated between latitudes 5°11' and 5°40' North and between longitudes 9°49' and 10°21' East, with an average altitude of 1,500 m. The climate is of the humid tropical type with three facies depending on altitude: the low-lying coastal climate in the plains, with increasingly hot temperatures; the moderately cool climate in the middle altitude zones (1200 and 1600 m) and the temperate climate which becomes colder with altitude [7]. The average annual temperature is around 20°C, dropping to less than 10°C at the top of the mountain ranges. Rainfall is in the region of 1,700 to 2,000 mm per year, reaching

2,500 mm at the top of the mountain ranges [16]. The terrain is rugged and lies between 1200 m and 2200 m above sea level [8].

The village of Baloum lies at an altitude of 1900 m above sea level. The vegetation is that of mountains transformed into shrubby savannah, herbaceous plants and raffia palm (*Raphia mambilensis*) in the lowlands as a result of human activity [6,7]. The forest formations covered by this study are the sacred forests of Bansoa and Baloum in the Penka-Michel district (Fig. 1). The Bansoa village lies at an altitude of 1,665 m and the distance between the two villages is around 22.5 km.

2.2 Data Collection

The data was collected on 30 mx 30 m plots established in each sacred forest. a total of 24 plots were installed. The number per forest depended on its surface area. These plots were laid out in such a way as to cover the maximum surface area in order to better appreciate the variation in species at each site. A GPS was used to record the geographical coordinates of each plot. Within these plots, only individuals with a circumference greater than or equal to 32 cm, i.e. a diameter at breast height greater than or equal to 10 cm, were counted.

These individuals were measured using a metric tape. Any stem bifurcated before 1.30 m above the ground was considered as a secondary stem and also counted. The diameter of trees with buttresses was taken 30 cm above them. The height of individuals of each species was measured using a SUNTO clinometer/compass and, after several repetitions, an estimate was made for individuals of the other species. Some species were identified on site using morphological features such as flowers, fruit, the color of the exudation after the bark had been cut, and the presence of buttresses.

Unidentified species were collected, pressed, dried and later returned to the National Herbarium of Cameroon for identification by comparison with herbarium samples and using documents dealing with the flora of the tropical zone [9,10,11,12,13]. Letouzey's manual [14] was also used to identify certain species. The botanical nomenclature used is that of the group of the phylogenetic classification of angiosperms III (APG III).

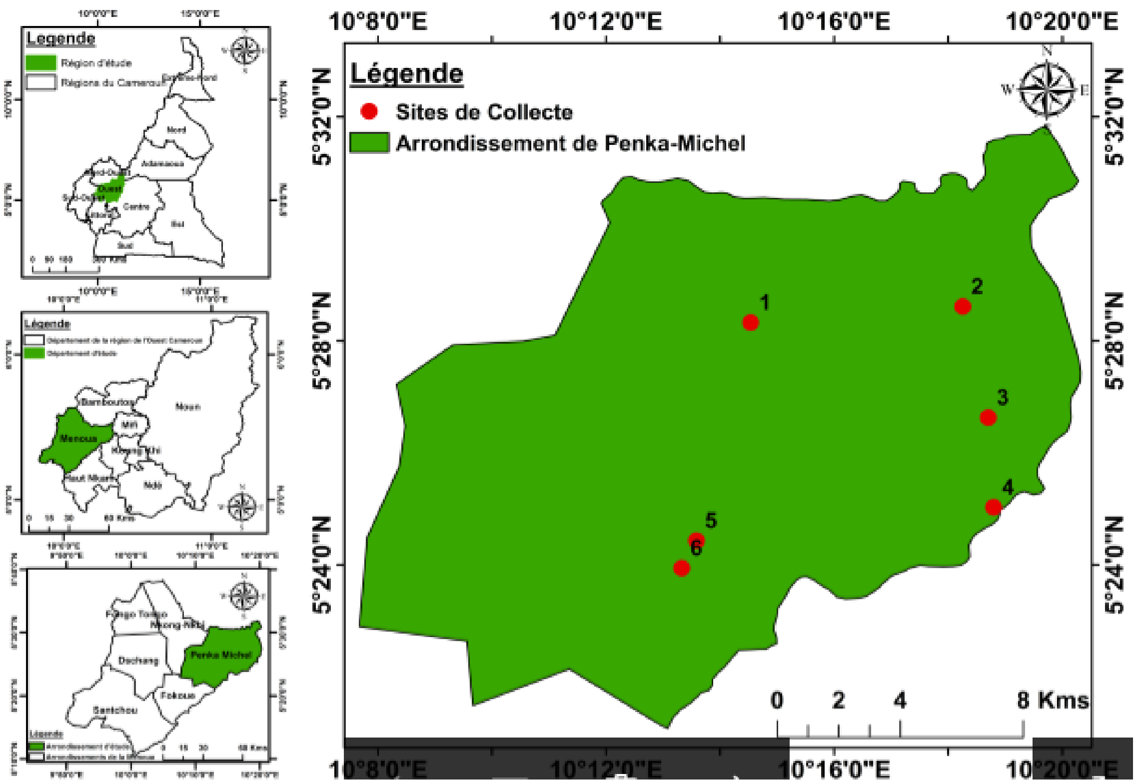

Fig. 1. Location of the study area

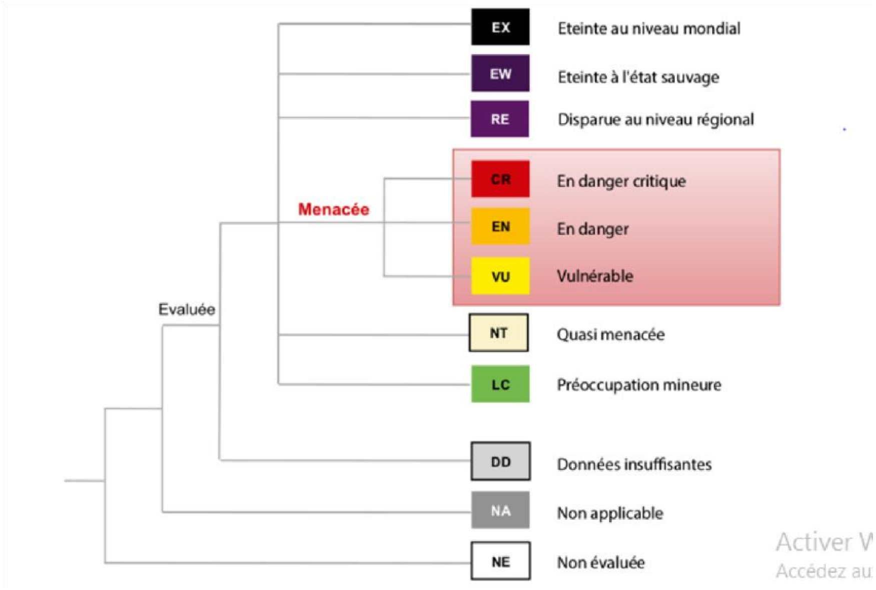

Fig. 2. IUCN Red List species status categories used at regional level (UINC, 2012)

2.3 Data Analysis

- Floristic diversity

Floristic diversity was assessed using several indexes.

Specific richness (No), which is the total number of species in the area sampled;

Shannon Diversity Index (HDI), which is expressed according to the following equation:

ISH= $-\sum \frac{Ni}{N} \times log2\,(\frac{Ni}{N})$ where Ni: number of species i and N: total number of species.

The Shannon Diversity Index (ISH) measures the uncertainty as to whether an individual taken at random from a sample belongs to a given species [15]. It is expressed as a function of the proportions of individuals of each species and varies from 0 to 5.

According to Koucthia et a. [16]., when ISH ∈ [0; 2.5], its value is assumed to be low; when ISH ∈ [2.6; 3.9], ISH is assumed to be medium. Finally, if ISH ∈ [4; 5], ISH is assumed to be high.

- Pielou Equitability index

EQ= $\frac{ISH}{Log2\ (No)}$ with ISH: Shannon Diversity Index; No : total number of species; log2 N : maximum species diversity

Pielou Equitability expresses the equitable distribution of individuals within species. Pielou values vary from 0 to 1 and tend towards 0 when almost all the individuals are concentrated in one species, reaching 1 when all the species have the same abundance [17].

-Simpson index

$$D = \sum_{i=1}^{s} \left(\frac{Ni\ (Ni-1)}{Ni\ (Ni-1)} \right)$$

With Ni: number of individuals of the given species i, i ranging from 1 to s

The Simpson index (D) measures the probability that two randomly selected individuals belong to the same species [18]. It will have a value of 0 to indicate maximum diversity and a value of 1 to indicate minimum diversity. This diversity index gives more importance to dominant species than to rare species. All these diversity indices were calculated using Past software.

-Sorensen's coefficient of floristic similarity

Sorensen's coefficient of similarity (Is) was used to assess the floristic similarity between the two forests. Is is calculated according to the following formula:

Is = $(\frac{2C}{a+b})100$

With a: The number of species in the Bansoa forest; b: The number of species in the Baloum forest and c: The number of species common to both forests.

This index varies from 0% to 100%. Is = 0 when there are no species in common between the two strata. It reaches 100% when the two forest communities are identical. When the value of Is is < 50%, the forest compared do not belong to the same plant community. When Is >50 %, the forest compared are very close and belong to the same plant community.

- Stand structure

To assess the horizontal structure of the two stands studied, the following l parameters were calculated.

Relative abundance of taxa was calculated using the formula $D_r = \frac{Ni}{N}$ x100 With Ni the number of a species and N the total number,

Frequency $Fr = \frac{Pi}{p}$ x 100 where Pi: number of surveys where species i is present; p: total number of surveys present on the surface considered and S is the surface sampled,

Dominance $Do = \frac{st}{ST} X100$
Where, ST is total basal area of all species (m^2/ha); st is the basal area of a species

Basal area $st = \sum \frac{\pi Di2}{4}$ With D: the diameter of each individual

The basal area corresponds to the cross-section of a tree and gives an idea of the surface area occupied by a species or family.

The Species Importance Value Index is expressed as a percentage (%) and is defined as the arithmetic mean, for species i, of relative density (Dr), relative frequency (Fr) and relative dominance (Dor);

$$IVI = \frac{Fr+Dr+Dor}{3}$$

Individuals were divided into diameter classes using the Letouzey method [6]**.** According to this approach, the individuals recorded are classified into the following different diameter classes: [10-20 cm [; [20-50 cm [; [50-100 cm [; ≥100 cm.

To assess the vertical structure, the recorded individuals were divides into height classes. The height classes used are as follows: [1←5 m [; [5-10 m [; [10-15m[; [15-20 m[; [20-25 m[; ≥ 25 m.

- Assessment of species conservation status

The status of the species surveyed was determined by comparing the list of registered species with the International Union for Conservation of Nature (IUCN) red list of threatened species. According to this list, there are several categories of species (Fig. 2).

- Carbon sequestered by the stand the stands

Carbon is estimated by calculating biomass. The non-destructive method was used to determine the above-ground biomass (ABS) and below-ground biomass (SB) of woody and palm trees in the two sacred forests. This method is based on the use of allometric equations pre-established by other researchers. For this purpose, the allometric equations of Fayolle et al. [18] and Brown et al. [16] were used to calculate the above-ground biomass of woody plants and palm trees respectively. These two equations take into account diameter, which is an easy variable to measure in the field, unlike height, which is sometimes difficult to measure, especially in dense forest.

- Allometric equation for trees:

$$BA = \rho \times esp(-1{,}183 + 1{,}940 \times \ln(D) + 0{,}239 \times \ln(D)^2 - 0{,}0285\ln(D)^3)$$ [18].

With ρ: specific density of wood (g/cm3) and D, the diameter of the trees.

Allometric equation for palm trees:

$$BA: \alpha + \beta(DHP0{,}5) * ln\,(DHP);$$

With α = 6.6666, = 12.826; ρ = specific density of wood (g/cm3); DBH is diameter at breast height (cm) of palms [16]

The wood density of each woody was obtained from the database of Reyes et al. [17]**.** The average density of African wood (0.65) was used for species with unknown specific density [19].

Below-ground biomass (BS) was calculated using the following formula.

BS = BA×R with AGB = above-ground biomass and R = stem/root ratio coefficient, which is 0.24 [18].

The total biomass (BT) expressed in kg Ms/ha was estimated using the following formula: BT= BA + BS where BA = above-ground biomass and BS = below-ground biomass.

To assess the carbon stock in each of the forests, the following relationship was used:

C stock = CF×BT; where C = total carbon stock, BT = total biomass and CF = Carbon Fraction (carbon ratio), the default value of which is 0.47 for all species combined [18]**.**

The quantities of CO_2 absorbed by these forests were deduced from the formula: $CO_2 = C \times 3.67$; where CO_2 = carbon dioxide and C = carbon

3. RESULTS

3.1 Floristic Composition and Diversity

The sacred forests chosen for this study have an average altitude of 1,468 m and 1,665 m respectively at Bansoa and Baloum. The inventories enabled us to count 430 individuals belonging to 37 species, 26 genera and 21 families at Bansoa and 412 individuals, divided into 38 species, 25 genera and 20 families at Baloum. The number of species inventoried in the two study sites is almost similar. However, there are species specific to each site. The species specific to Bansoa are: *Albizia adianthifolia*, *Albizia* sp., *Celtis tessmannii*, *Ficus glumosa*, *Funtumia elastica*, *Mammea africana*, *Strombosiopsis tetrandra*, *Tabernaemontana crassa* and *Trichilia welwitschii*. Those found only in the sacred forests of Baloum are: *Albizia falcataria*, *Albizia zygia*, *Alchornea floribunda*, *Antiaris africana*, *Callichilia stenosepala*, *Ceiba pentandra*, *Cola* sp. *Eucalyptus globulus*, *Ficus vogeliana*, *Macaranga assas* and *Trichoscypha acuminata*. The most species-rich families (maximum 5 species) are Moraceae, Apocynaceae , Euphorbiaceae , Fabaceae and Ulmaceae .

The average diversity indixes are low and vary from one zone to another. At Bansoa, the Shannon index is 2.15 ± 0.27 bits and 2.09 ± 0.19 bits at Baloum. Pielou equitability is 0.89 ± 0.06 in Bansoa and 0.86 ± 0.05 in Baloum. Simpson's indices are 0.85± 0.05 and 0.83± 0.05 respectively in Bansoa and Baloum. The similarity index between the two sites is equal to 66.67% .

3.2 Species Importance Value (IVI)

The ecological importance of the species shows the highest values for the species *Markhamia lutea* (54.90%) in the Bansoa forest, whereas in the Baloum forest the highest values are for *Cola accuminata* (64.79%). These two species are also the most frequent and the most abundant in Bansoa and Baloum respectively (Table 1). The densities of individuals per hectare are 368 individuals/ha at Bansoa and 416 individuals/ha at Baloum. The highest basal area values were recorded for *Ficus exasperata* and *Ceiba pentendra* in the sacred forest of Bansoa and Baloum respectively. The basal area recorded per zone was 32.37 m^2/ha and 38.44 m^2/ha in Bansoa and Baloum respectively.

3.3 Diameter Classes

The individuals surveyed were classified into 4 diameter classes (Fig. 3). The distribution of individuals according to diameter category can be seen in the shape of an inverted "J" at Bansoa.; that at Baloum is in the shape of a "bell" with a peak in the class between 20 and 50 cm. In both forests, individuals with a diameter greater than or equal to 100 are very poorly represented and sometimes absent. Overall, juvenile individuals are strongly represented in both forests.

3.4 Vertical Structure

The distribution of the number of individuals by height class shows the presence of similar strata in the two forests. These are the shrub, lower tree and middle tree strata. However, the number of individuals per stratum differed from one site to another, with a peak in the Baloum sacred forest, particularly in the 10-15 m height class (Fig. 4). Globally, the height class below 25 m is dominant.

3.5 Species conservation status

Table 2 shows the threat categories of the species in the two forests, based on the International Union for Conservation of Nature's Red List of Threatened Species. The table shows that one species is classified as "endangered", namely *Draceana arborea*. Three species have been identified as "vulnerable": *Callichilia stenosepala*, *Ficus chlamydocarpa* and *Macaranga grandifolia*. *Albizia ferruginea* and *Magnolia macrophylla* are classified as "Near Threatened".

Table 1. Basal area, frequency, relative density and importance value index for the ten most important species

		Parameters			
Forests	**Species**	**ST (m^2/ha)**	**Fr (%)**	**Dr (%)**	**IVI (%)**
Bansoa	*Markhamia lutea*	4,62	100	50,43	54,90
	Canarium schweinfurthii	2,76	92,28	42,74	47,85
	Cola accuminata	3,20	92,28	30,77	44,32
	Ficus exasperata	5,13	84,59	24,79	41,75
	Strombosia schefferi	2,29	61,52	42,74	37,11
	Ficus sp	1,39	53,83	15,38	24,50
	Polyscias fulva	0,69	61,52	9,40	24,35
	Elaeis guineensis	0,74	38,45	30,77	23,84
	Rauvolfia vomitoria	0,51	53,83	15,38	23,60
	Ficus chlamydocarpa	2,09	46,14	13,68	22,09
Baloum	*Cola accuminata*	7,55	83,84	90,91	64,79
	Ficus sur	3,32	41,41	90,91	46,99
	Persea americana	1,67	33,33	45,45	27,71
	Markhamia lutea	1,12	14,14	63,64	26,90
	Cordia cynensis	0,80	22,22	54,55	26,28
	Dracaena arborea	1,87	26,26	45,45	25,52
	Elaeis guineensis	0,54	24,24	45,45	23,70
	Strombosia schefferi	0,83	12,12	54,55	22,94
	Ceiba pentandra	8,43	10,10	27,27	19,77
	Bridelia ferruginea	0,38	11,11	45,45	19,19

ST: basal area; Fr: relative frequency; Dr: relative density and IVI: Importance Value Index

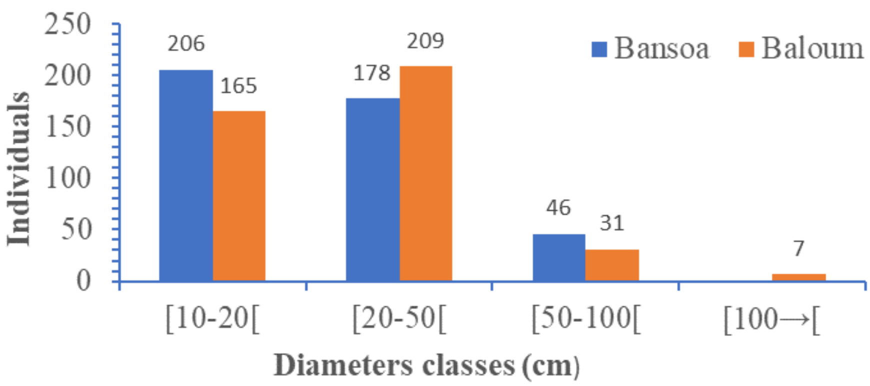

Fig. 3. Number of individuals by diameter class

3.6 Quantity of Carbon by Diameter Class

The carbon stocks obtained and classified according to diameter size show that the diameter class between 20 and 50 cm sequestered up to 106.37 t C/ha of carbon in the sacred forests of Baloum, while at Bansoa it was the class between 50 and 100 cm that had the highest carbon values (133.44 t C/ha). The lowest quantities of carbon were observed in the smallest diameter class (Fig. 6).

3.7 Carbon Sequestered by the Two Formations

Fig. 5 shows the quantities of biomass, carbon and CO_2 stored by the Bansoa and Baloum forests. The total biomass obtained in the Baloum sacred forest is 610.31 t Ms/ha and that of the Bansoa sacred forest is 499.96 t Ms/ha. The carbon values are 286.84 t C/ha and 233.94 t C/ha in Baloum and Bansoa respectively.

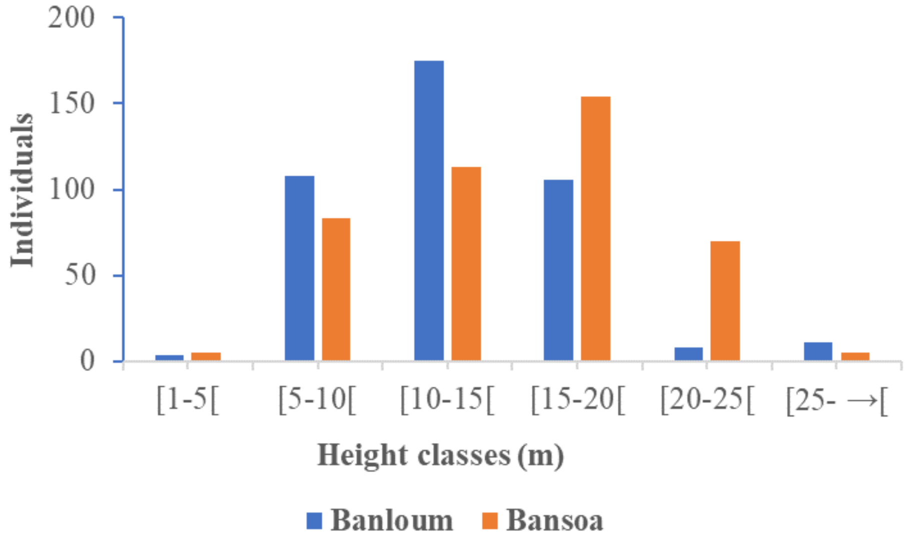

Fig. 4. Number of individuals by height class in the two forests

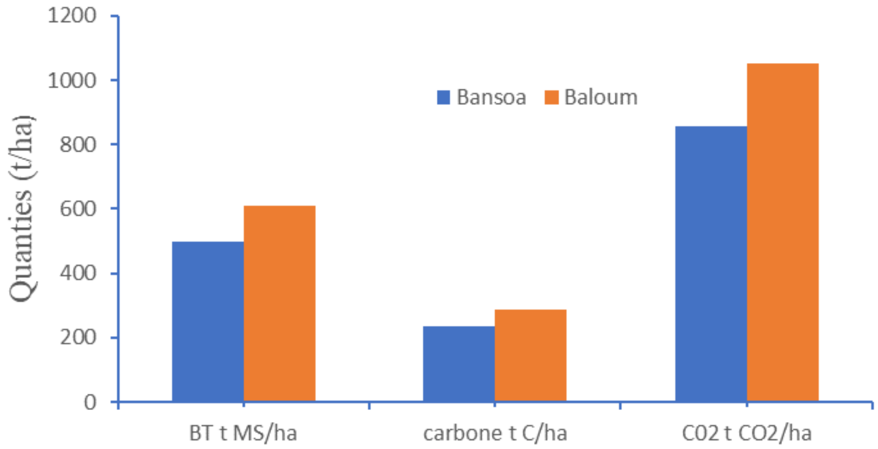

Fig. 5. Biomass, carbon and total CO_2 stored by the two forests

Table 2. IUCN status of species at the two sites

Species name	Threat category
Albizia adianthifolia	LC
Albizia falcataria	LC
Albizia ferruginea	NT
Albizia sp.	LC
Albizia zygia	LC
Alchornea cordifolia	LC
Alchornea floribunda	LC
Antiaris africana	LC
Barteria fistulosa	LC
Bridelia ferruginea	LC
Canarium schweinfurthii	LC

Species name	Threat category
Callichilia stenosepala	VU
Ceiba pentandra	LC
Celtis mildbraedii	LC
Celtis sp.	LC
Celtis tessmannii	LC
Chionanthus ramiflorus	EN
Cola accuminata	LC
Cola sp.	LC
Cordia cynensis	LC
Dracaena arborea	EN
Elaeis guineensis	LC
Eucalyptus globulus	LC
Fagara sp.	LC
Ficus chlamidocarpa	VU
Ficus exasperata	LC
Ficus glumosa	LC
Ficus sp.	LC
Ficus sur	LC
Ficus vogeliana	LC
Funtumia elastica	LC
Macaranga assas	LC
Macaranga grantifolia	LC
Macaranga spinosus	VU
Mammea africana	LC
Magnolia macrophylla	NT
Markhammia lutea	LC
Persea americana	LC
Polyscias fulva	LC
Rauvolfia vomitoria	LC
Spathodea campanulata	LC
Strombosia schefferi	LC
Strombosiopsis tetrandra	LC
Tabernaemontana crassa	LC
Trichilia welwistschii	LC
Trichoscypha acuminata	LC
Vitex grandifolia	LC

LC: Least Concern, EN: Endangered, VU: Vulnerable, NT: Near Threatened

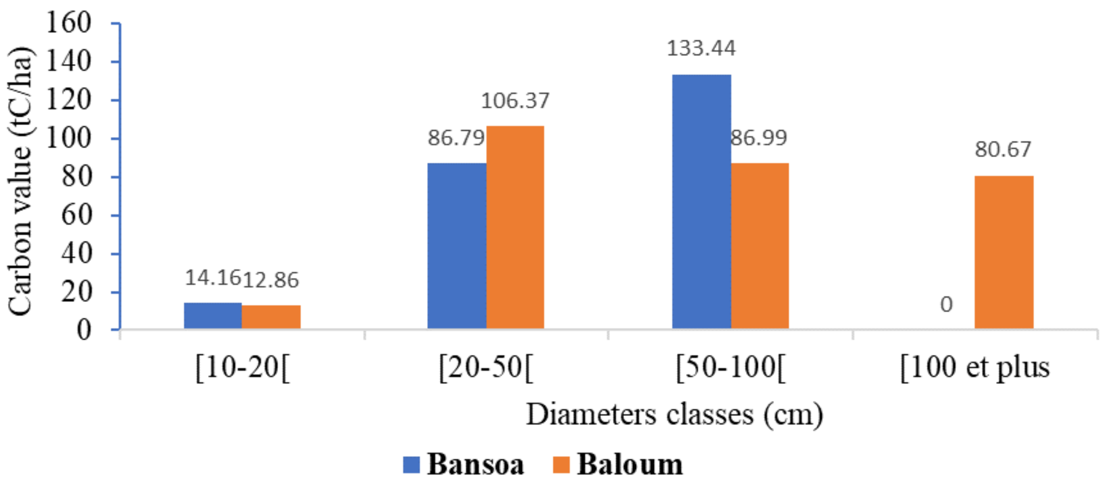

Fig. 6. Carbon stored by diameter class in the sacred forests of Bansoa and Baloum

Table 3. Total biomass, carbon and $C0_2$ of ten species that have stored the most carbon

Forest	Species	TB (t MS/ha)	Carbone (t c/ha)	$C0_2$ (t CO_2/ha)
Bansoa	*Ficus exasperata*	89,45	40,54	148,78
	Markhamia lutea	70,31	33,05	121,28
	Cola accuminata	47,86	22,49	82,55
	Canairum schweinfurthii	45,51	21,39	78,51
	Ficus chlamydocarpa	34,72	16,32	59,88
	Strombosia schefferi	31,09	14,61	53,62
	Ficus sp.	20,09	9,11	33,45
	Strombosiopsis tetrandra	17,22	7,85	28,80
	Celtis mildbraedii	12,90	5,63	20,68
	Elaeis guineensis	11,59	5,40	19,83
Baloum	*Ceiba pentandra*	179,81	84,51	310,15
	Cola accuminata	103,87	48,82	179,16
	Ficus sur	52,18	24,53	90,01
	Ficus sp.	50,68	23,82	87,41
	Dracaena arborea	23,64	11,11	40,78
	Persea americana	20,57	9,67	35,48
	Ficus vogeliana	18,10	8,51	31,23
	Markhamia lutea	15,64	7,35	26,97
	Cola sp.	14,27	6,71	24,62
	Ficus chlamydocarpa	11,71	5,51	20,21

TB:total biomass

Overall, species with large quantities of biomass also have high carbon and $C0_2$ values

3.8 Carbon Stock by Species

Many species recorded high values of biomass and, consequently, carbon (Table 3). This was the case for *Ficus exasperata* (40.54 tC/ha) and *Markhamia lutea* (33.05 tC/ha) in the Bansoa sacred forest, and *Ceiba pentandra* (84.51 tC/ha) and *Cola accuminata* (48.82 tC/ha) in the Baloum sacred forest.

4. DISCUSSION

4.1 Floristic Composition

The species richness recorded in the study site was 50 species. This low specific composition obtained in the study site could be explained by the strong presence of rocky outcrops observed in these sacred forests, which could limit the germination and growth of certain species. This value is similar to that of other researchers in sacred forests in other parts of Africa and in Cameroon. For example, Koutchia et al. [14] recorded 19 species in the sacred forests of central Benin, Ngougni [20] recorded 54 species in some sacred forests in the Menoua district and Noumi & Tagne [21] recorded 31 species in the sacred forests of Mount Oku. However, these results differ from those of Adou et al. [13] obtained in the sacred forest of Bokasso which is 188 species and by Kokou et al. [22] with 453 species recorded in the sacred forests of the Ouatchi area in south-east Togo. This difference is thought to be linked either to the area sampled or to the microclimate of each forest.

For diversity indexes, this work showed Shannon index values of 2.15 ± 0.27 bits at Bansoa and 2.09 ± 0.19 bits at Baloum. These values are low (< 3.5 bits), suggesting that the specific richness recorded in this study is low. A plant community is rich when the Shannon diversity index value is ≥ 3.5 bits [23]. These results can be explained by the unequal distribution of individuals observed within the species censused. These low values have also been found by other researchers in sacred forests [13,24].

Like the Shannon index, the Simpson index values are also low (0.15 and 0.17 respectively at Bansoa and Baloum); This could be explained by a heterogeneous stand with a low abundance of individuals within species. These results are similar to those of Tiokeng [25] who obtained Simpson indices of 0.13, 0.11 and 0.16 respectively in the sacred forests of Mbing-Mekoup, Bamendjinda and Bamendjo.

Moreover, the Piélou equitability values 0.89± 0.06 at Bansoa and 0.86± 0.05 at Baloum tend towards 1, which would mean that the number of individuals inventoried is almost identical within the species.

The coefficient of similarity between the two sites gave values of over 50%, showing that these two stands belong to the same plant community; in fact, more than 25 species out of 50 recorded are common to both forests. The strong similarity between the two sites could be explained by their almost similar geographical position.

4.2 Relative Abundance and Frequency of Species

An analysis of the relative density of each species shows that in the sacred forest of Bansoa (average altitude 1468 m), *Markhamia lutea*, *Strombosia schefferi*, and *Ficus exasperata* are the most abundant; on the other hand, in the forest of Baloum (average altitude 1665 m) we have *Cola accuminata*, *Ficus sur* and *Persea americana*. We can think of the ecological conditions that can sometimes be favorable to the development of any given species. In fact, each altitude level could have an impact on the microclimate of the environment, which would influence the regeneration and growth of the species in these biotopes. The preponderance of the species *Ficus exasperata* between 1400 and 1600 m altitude was also noted by Fomekong [26] in coffee-based agroforestry systems.

This study revealed that *Markamia lutea* was the most frequent species (100%), which brings our results into line with those of Tiokeng [13] in the sacred forests of Bamendjinda, who found that the same species was the most frequent. This observed difference could be linked to the fact that the microclimate in the sacred forests of Baloum is favorable to the development of this species.

The density of individuals was 368 individuals /ha at Bansoa and 416 individual/ha at Baloum. These results are lower than those of Tiokeng et al. [26] who obtained a density of 926 individuals per hectare in the Mbing Mekoup forest and lower than those of Vroh Bi Tra et al. [28] with 1173 individuals per hectare in the dense forests of the Azaguié Reserve (Côte d'Ivoire). These differences in density could be due to a combination of factors (soils, rainfall, competition) likely to determine the diversity and structure of the vegetation [27].

The basal area was 38.44 m^2/ha in the Baloum forest and 32.37 m^2/ha in the Bansoa forest. The variation recorded between sites is linked not only to the abundance of individuals but also to the diameter size of the individuals in each sacred forest. These results are close to those found by other researchers in sacred forests, which are of the order of 45.85 m^2/ha [25]; however, they differ from those of Noumi [29], which are 90.37 m^2/ha in the Kouoghap sacred forest.

The distribution of individuals according to diameter classes showed an inverted J shape. This could be justified by the constant natural regeneration over time of the species in this forest. In fact, this inverted J-shaped structure would reflect the dominance of sciaphilous species in the stand studied [31,31,32]. At Baloum, we have more of a bell shape. This shape is characteristic of an ageing population with a regeneration deficit. It is characterized by heliophilous species unable to develop in the forest undergrowth [33]. Similar results have been obtained in other sacred forests in Cameroon [21,31,34,35,36]. Moreover, these results differ from those of Mbaiyetom et al. [37], who found a preponderance of large-diameter individuals in the tree park in the Sudanian zone of Tchad [38-40].

The height classes of the individuals show that the Bansoa sacred forest is dominated by individuals from the lower tree stratum, whereas at Baloum, there is a marked dominance of individuals from the shrub stratum. The high representation of individuals from the shrub layer in Baloum can be explained by the exploitation of emergent trees in the forest by members of the chiefdom. Removing emergent trees would increase the amount of light under the canopy, which would favor the development and abundance of individuals in the lower strata. The result would be an increase in the density of small individuals in the forest, leading to a reduction in the height of the canopy [41,42].

4.3 Quantities of Carbon and CO_2

The quantities of carbon sequestered by the Baloum forest are 286.84 t C/ha. Those stored by the Bansoa forests are 232.44 t C/ha. The high values obtained in Baloum are justified by the higher density and basal area than in Bansoa. The fluctuations in these values can be explained by the size of the diameter of the individuals making up each forest and even the density of the wood in each individual. Biomass and carbon sequestration in an ecosystem are influenced by wood density [43,44], Fayolle et al. [30]. The quantities of carbon sequestered by the sacred forests in this study are similar to the values found by Tiokeng et al. [28] in the sacred forests of Balengou and Bangangté (286.89 tC/ha and 215.67 t C/ha respectively). These carbon values are lower than those obtained by Ngougni [58] in the Bamendou sacred forest, which are around 450 tC/ha. The type of allometric equation chosen could also be at the origin of the differences observed in these results. The value of CO_2 sequestered in the Baloum forest is 1052.12 t CO_2/ha, whereas in Bansoa it is around 853.04 t CO_2/ha. Like the quantities of carbon, the variations observed in the case of CO_2 are also attributed to the diameter and density of the trees used. The amount of carbon stored in the [20-50] cm diameter class is highest at Baloum (106.37 t C/ha). At Bansoa, on the other hand, it was the [50-100[cm] diameter class of trees that sequestered the most carbon (133.34 t C/ha). This difference could be justified by the fact that at Baloum, the greatest number of trees are in this diameter class. It could also be justified by the fact that in the Baloum forests, large-diameter trees are felled immediately, whereas in the Bansoa forests, large-diameter trees are felled very little [45-57].

5. CONCLUSION

This study shows that the sacred forests studied have low species richness. This low diversity is confirmed by the diversity index values obtained in this study. *Markhamia lutea* and *Cola acuminata* are among the most predominant species at Bansoa and Baloum respectively. The average density of individuals per hectare and their basal area sometimes differs from those regularly observed in certain sacred forests. The distribution of individuals by diameter class shows a constant natural regeneration of the species over time in the Bansoa sacred forest, but a pattern characterizing an ageing population with a regeneration deficit in the Baloum sacred forest. The carbon and CO_2 values obtained are considerable, underlining the fact that, despite the relatively small surface areas of these forest groves, they are of great importance in mitigating greenhouse gases and conserving biodiversity. These forests deserve special attention, and programs aimed at REDD+ should take account of these forests, which are sometimes somewhat neglected by decision-makers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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