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PHYTODIVERSITY AND CARBON SEQUESTRATION IN THE LAM FOREST RESERVE IN NORTH CAMEROON

Fawa Guidawa[1], Oumarou Haman Zephirin[2*], Nimaligui Jonas[3], Ngouvoumva Sadou Leger[3], Haiwe Bertrand Roger[4], Hubert Didier[4] and Mapongmetsem Pierre Marie[3]

[1]Department of Sciences and Techniques of Biologique Agriculture, Faculty of Science, The University of Ngaoundéré, P.O. Box 454 Ngaoundéré, Cameroon.

[2]Department of Plant Sciences, Faculty of Science, The University of Bamenda, P.O. Box 39 Bambili, Cameroon.

[3]Department of Biological Sciences, Faculty of Science, The University of Ngaoundéré, P.O. Box 454 Ngaoundéré, Cameroon.

[4]GIZ/Eco-Consult, Antenne de Garoua, Projet Forêt et Environnement (ProFE).

*Corresponding author

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ABSTRACT

The dry forests of Cameroon play an important socio-economic and ecosystemic role for local populations. The aim of this study was to assess the phytodiversity and carbon stock of the Lam Forest reserve. To achieve this, a sampling rate of 1% was used in accordance with the guidelines of the Cameroon Ministry of Forests and Fauna. Using ArsGis software, 75 concentric nested circular plots with radii of 5 and 20 metres respectively were distributed over the entire reserve, each 354 metres apart in a square grid. The floristic inventory identified 9521 individuals divided into 68 species on all the plots surveyed. The vertical structure shows that the most represented stems are regeneration and future stems. The diversity indices calculated vary according to the compartment. The total carbon stock is 55.97±0.28 tC/ha in the shrub savannah, 6.04±0.27 tC/ha in the steppe, 100.70±1.35 tC/ha in the agricultural zone with a high density of trees, 35.44±1.87 tC/ha in the agricultural zone with a low density of trees and 36.57±2.20 tC/ha in the forest gallery. Several factors are responsible for the degradation of the vegetation cover in this reserve, including the expansion of agricultural plots, pastoral activities, bush fires, logging and climate change. To remedy these problems, it would be advisable to set up a village monitoring committee, to envisage participatory management and to divide the reserve into three areas: the agroforestry area, the protection area and the restoration area.

Keywords: Floristic diversity, Forest reserve, Carbon stock, LAM, Management

1. INTRODUCTION

In Africa, protected areas offer natural resources, remnants of original formations and plant species of high socio-economic value to rural populations who depend heavily on them to meet their daily needs (Ouédraogo et al., 2010). Given the importance of plant species of high socio-economic value, forest reserves, sacred forests and several conservation areas have been set up (Boissieu et al., 2007). These local ecosystems provide forest products and are rich in biodiversity. They fulfil a number of functions, such as food security through the availability of non-timber forest products, which are sources of income for local populations (Marquant et al., 2015). Plant species provide building materials, medicinal products, fuel, habitat for wild animal species, mitigate climate change, regulate the water cycle, protect soil against erosion, etc. Around 1.6 billion people depend on forests for their livelihoods (UNDP, 2018). Despite their importance, natural resources such as dry forests are unfortunately poorly used (Abdoulaye et al., 2020). They are subject to heavy human pressure through slash-and-burn farming and extensive livestock rearing, farming systems that consume a great deal of space. The creation of vast blocks of cash crops (cotton), as well as various agro-pastoral developments and bush fires, are all factors that lead to ecological imbalances. As a result of the destruction of their habitats, overgrazing or simply abusive exploitation, certain forest and animal species are on the verge of extinction (FAO and UNEP, 2020). These actions are now threatening the sustainability of the goods and services they provide.

The rate of deforestation on the African continent is only increasing (FAO, 2012). This is also true of the LAM forest reserve. Long left to its own devices due to a lack of rational management, this forest reserve is now highly anthropised, particularly as a result of uncontrolled logging, overgrazing, the expansion of agricultural areas and the occupation of its surface area by certain village settlements (GIZ-ProFE, 2020). It is therefore important to set up a management programme for the reserve. Most forest management studies require prior knowledge of the natural heritage. However, to the best of our knowledge, the Lam Forest reserve suffers from a lack of scientific data on its floristic potential, carbon stock and the various pressures it faces. The aim of this study is to assess the floristic diversity and carbon stock of the Lam Forest Reserve.

2. MATERIALS AND METHOD

2.1. Description of the study site

The study was carried out in the Northern Region, in the Department of Mayo Louti, in the Arrondissement of Figuil, in the canton of LAM (Figure 1). The LAM Forest reserve is part of the State's permanent forest estate covering an area of 941 hectares, and lies between latitudes 09°60‘N and 10°06’N and longitudes 14°06‘E and 14°13’E. The climate is of the Sudano-Sahelian type,

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characterised by two seasons: a long dry season lasting around 7 months (November-May) and a short rainy season lasting 5 months (late May-October). Average rainfall varies between 600 and 800 mm per year (PCD, 2015).

The Northern zone is variable in terms of soils. In ascending order of surface area, there are molluscan planosols (25%), tropical ferruginous soils (35%) and hydromorphic soils or vertisols (40%) (Peltier et al., 2007). There are several types of vegetation in this zone, the most notable of which include tree/shrub savannah and steppe, forest savannah, flood plains or swamps, and herbaceous savannah. The dominant herbaceous species are grasses, including *Acacia* spp., *Azadirachta indica*, *Balanites aegyptiaca*, *Combretum* spp., *Faidherbia albida*, *Tamarindus indica* and *Terminalia* spp., the main woody species (Aubreville, 1950; Peltier et al., 2007).

Agriculture in the area is dominated by food crops such as cereals and legumes, with cash crops such as cotton, groundnuts and red millet providing the main sources of income for most of the local population. Farming is essentially traditional and extensive, with low yields (FAO, 2012). Livestock farming in the area is traditional, dominated by poultry, small ruminants, cattle and pigs (PCD, 2015). Handicrafts are well developed in the locality. It plays an important role in the lives of the people living near the reserve. It is highly diversified, with blacksmith workshops and manufacturers of vans and mats.

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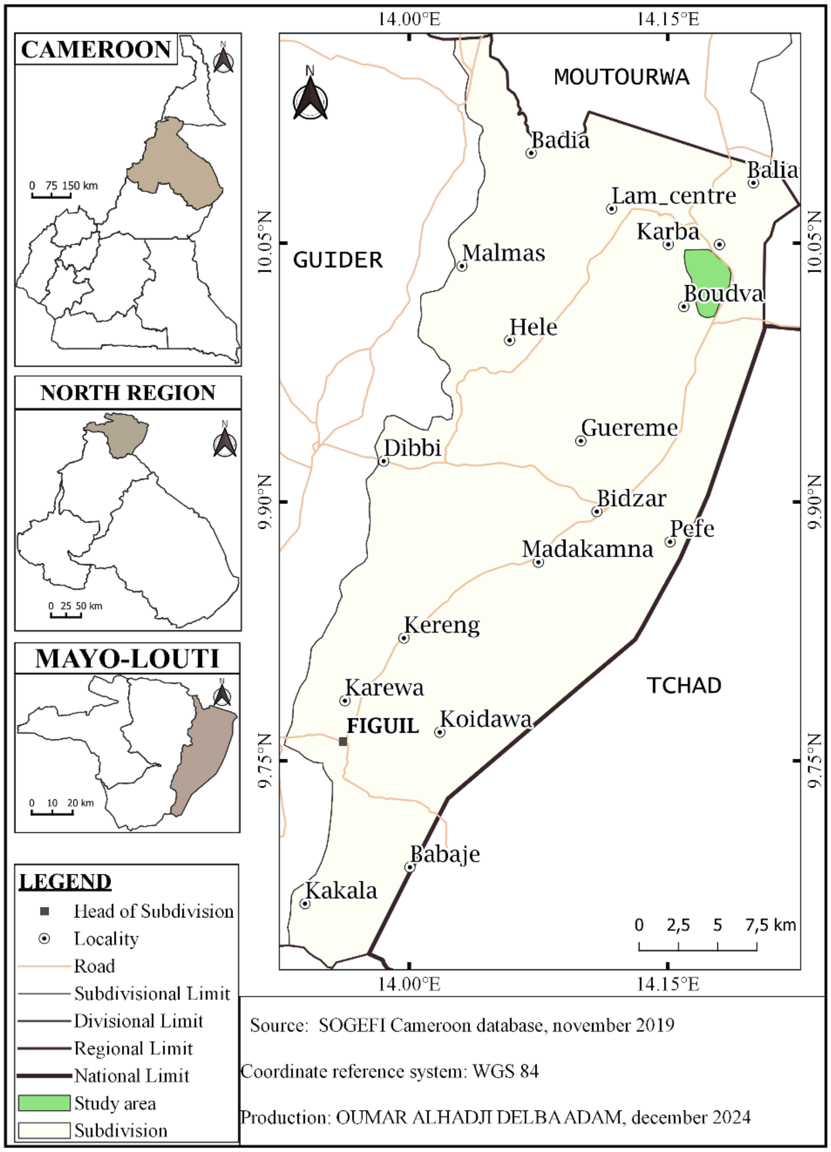

Fig. 1: Location map of the study area

2.2 Methodology

This study took place in the dry zone of Cameroon. In order to carry out the fieldwork, an inventory sheet was drawn up beforehand. It contains information describing the plot and the geographical coordinates of the area. The inventory consisted of recording all the woody species present in the plots.

2.2.1. Sampling device

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According to MINFOF (2019), for multi-resource inventories of forest formations in the dry savannah zone of Cameroon, concentric nested circular plots with radii of 5 and 20 m respectively are recommended (Figure 2). This presents a lower risk of tree positioning error both inside and outside the plots compared with other types of plot (rectangular and square shapes). The probability of finding trees on the plot boundary is reduced.

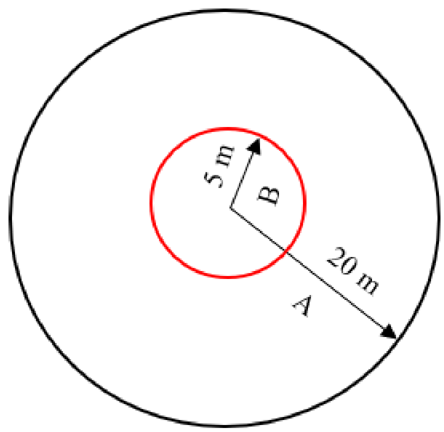

Fig. 2: Field data collection system

All species with a diameter at knee height (50 cm) of less than 5 cm are identified and counted only in compartment B with a radius of 5 m. Most of these species are the result of natural regeneration.

Trees with a diameter ≥ 5 cm at knee height (50 cm above the ground) are counted in compartment A with a 20 m radius. To facilitate plant identification, a list of forest species in the dry zone was made available to us.

The names of plants not identified in the field were collected in the local language and then determined by a specialist at the Eco-Consult office in Garoua. In each plot, all the tree species were recorded and the dendrometric parameters were measured for all the individuals: height, diameter at 1.30 m above the ground for individuals with a diameter ≥ 5 cm at knee height. The stem diameters of multi-stemmed trees (with 2 or more stems) were taken individually.

2.2.2. Plot distribution plan and sampling rate

Referring to the guidelines set up by MINFOF in 2019, to carry out inventories in dry savannah forest formations in Cameroon, in forest entities with an area > 500 ha, a minimum sampling rate of 1% is recommended to have a representative sample. Based on this information, the LAM forest reserve has a surface area of 941ha and a sampling rate of 1% is applied to carry out this inventory. A total of 75 circular plots, spaced 354 m apart in a square grid, were completely surveyed,

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representing a surveyed area of 9.75 ha. On each plot, the type of stratum (vegetation formation) was recorded according to the Yangambi typology (Aubreville, 1957). In addition to the dendrometric parameters, in each of the plot's information providing descriptive data such as soil characteristics (soil type, signs of erosion), signs of human activity (rangelands, recent fires, agricultural encroachment, pruning, wood cutting, carbonisation) was also collated.

The following formula was used to calculate the equidistance between plots: $eq=\sqrt{(s/n)}$; Where eq = distance between plot centres; s = area of the forest reserve; n = number of plots. Using ArcGIS software, the plots were distributed systematically over the entire forest reserve on a grid basis.

2.3 Data collection

2.3.1. Floristic composition

The individuals recorded were grouped into families, genus and species. For the quantitative assessment and analysis of the floristic diversity of the LAM forest reserve, it was necessary to calculate certain parameters. To carry out these calculations, the inventory sheets were first analysed manually and then entered into an Excel spreadsheet.

2.3.2. Dendrometric and structural parameters

The concepts covered include: height, diameter at breast height (1.30 m above the ground)

The height of individuals was estimated using a graduated pole. This measurement provided information on the vertical structure of the vegetation. Individuals were classified according to their height in compartment A, with a 20 m radius, and compartment B, with a 5 m radius. The diameter at breast height of individuals in compartment A was measured using the Dbh-meter. These diameters were classified into diameter classes to establish the horizontal structure (Adjonou et al., 2009; Adjonou et al., 2010).

2.3.3. Floristic diversity indices

In addition to calculating absolute density, abundance and basal area, other analysis concepts were taken into account, namely diversity indices: Shannon's index, Piélou's equitability, Sorensen's coefficient of similarity

Shannon's diversity index (ISH). $ISH = - \sum Ni/N \log2 Ni/N$ where Ni=number of species i; N=number of all species. ISH is expressed in bits. It is the most widely used and recommended index in comparative stand studies, as it enables us to assess the weight of the species in the land cover. The higher the number of species in the stand, the higher the ISH. For $ISH \leq 0.5$ = very low diversity, $ISH < 2.5$ = low diversity; $2.5 \leq ISH < 4$ = medium diversity; $ISH \geq 4$ = high diversity (Shannon, 1948).

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Piélou equitability (EQ). EQ = ISH/ log2 N, corresponds to the ratio between observed diversity and the maximum possible diversity in the number of species (N). It tends towards 0 when almost all the numbers are concentrated in one species and towards 1 when all the species have the same abundance. For EQ < 0.6 = low; 0.6 ≤ EQ ≤ 0.7 = medium; EQ ≥ 0.8 = high (Piélou, 1996).

Sorensen's coefficient of similarity. K= (2c / a + b) x 100 where a= number of species in survey 1, b= number of species in survey 2, c= number of species common to both surveys. This index evaluates the floristic affinity between two surveys. If K> 50%, then the two sites belong to the same plant community (Sorensen, 1948).

2.3.4. Ecological parameters

- **Absolute density**

Absolute density is determined according to the formula: D = N/S where N= number of species in the study environment, S= surface area occupied by the species, D= density. It indicates the average value of the number of individuals per sample unit. In this study, it was calculated per hectare according to Jiagho et al. (2016).

- **Absolute abundance**

Absolute abundance is the total number of individuals of the species out of the total number of individuals on the site studied.

- **Basal area (BA)**

This is the surface area occupied by the trunk of the tree at the diameter at breast height: Basal area (m^2/ha) = $\pi D^2/4$ with D the diameter of the individual at 1.30m from the ground. This diameter was also used to establish the distribution of trees in diameter classes (Lejoly, 1993). The basal area was used to calculate relative dominance.

- **Relative density (ReDe)**

The relative density of a species or family is the ratio of the total number of individuals of a species or family to the total number of individuals in the sample multiplied by 100 (Tiokeng et al., 2015).

Relative density of a species (**ReDe**) = n/N x 100.

Relative density of a family (**ReDe**f) = nf/N x 100.

Where n: Number of individuals of a species; nf: Number of individuals of a family; N: Total number of plots.

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- **Relative dominance (ReDo)**

Relative dominance is the ratio of the basal area occupied by a species or family to the total basal area multiplied by 100 (Adjonou et al., 2010).

Relative dominance of a species (**ReDo**) (%) = BA/BAT x100.

Relative dominance of a family (**ReDof**) = BAf/BAT x100.

Where BA: basal area of a species; BAf: basal area of a family; BAT: total basal area in the sample.

- **Relative frequency (ReFr)**

Relative frequency is the ratio expressed as a percentage between the frequency of species i and the total sum of all frequencies multiplied by 100 (Tiokeng et al., 2015).

ReFr (%) = (Frequency of species i)/ (Sum of all frequencies) x100.

ReFrf(%) = (Frequency of family i)/ (Sum of all frequencies) x100.

- **Species Importance Value Index (IVI)**

The species importance value index characterises the ecological importance of a species within the vegetation (Kent & Coker, 2003).

IVI (%) = Relative density + Relative frequency + Relative dominance

- **Family Importance Value Index (FIV)**

The family importance value index was determined using the formulae of Cottam & Curtis (1956).

FIV (%) = Relative frequency of families + Relative density of families + Relative dominance of families.

2.3.5. Estimation of carbon stock

- **Above-ground phytomass**

The non-destructure method was used in this study. It takes into account specific density, diameter and height.

To estimate above-ground phytomass, the pantropical formula for calculating above-ground biomass of Chave et al. (2005) was applied. This formula is $Y = 0.112 \times (\rho D^2H)\ 0.916$;

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where Y = above-ground phytomass of woody species in (kg), ρ = wood density (g/cm^{-3}), D = diameter at breast height (cm) and H = tree height (m). To carry out this calculation, the wood density of each species was obtained from the database of Zanne et al. (2009). The default ρ value of 0.58 g/cm3 was used for species whose density was not found in the database (Brown et al., 1989).

For Areacae, the allometric equation developed by IPCC (2003) was used:

PA = 6.666+12.826*ln (ht) 0.5*ln (ht) : PA = phytomass of Arecace, ht= total height of palms.

To estimate above-ground carbon stock, above-ground phytomass was multiplied by a conversion factor (0.47) (Mille & Louppe, 2015).

- **Underground phytomass**

Root phytomass is obtained using the equation established by Cains et al. (1997). This equation is written as BGB = exp [-1.0587+ 0.8836 × ln (AGB)]; where BGB = Woody Root Phytomass in Kg, AGB = Woody Aboveground Phytomass in Kg and ln = natural logarithm. The subterranean carbon stock is also obtained by multiplying the subterranean phytomass by the conversion factor (0.47) (Mille & Louppe, 2015).

- **Total phytomass**

The total plant mass in kg was obtained by adding the above-ground and below-ground plant mass.

The total carbon stock was obtained by multiplying the total plant mass by the factor 0.47 (Mille & Louppe, 2015).

- **CO_2 equivalent**

With regard to the stock of sequestered atmospheric CO_2, it is recognised that the atomic mass of Carbon is 12 and that of Oxygen is 16 (IPCC, 2006). The molecular mass of CO_2 is 44. The CO_2/C ratio is therefore 3.67. The equivalent atmospheric CO_2 stock was estimated by multiplying the Carbon stock from phytomass by 3.67. CO_2eq = QCtx3.67 where QCt = quantity of carbon sequestered by the plant.

The experimental design used is a completely randomised design with plant formations as the factor. The plots are the replicates.

2.3.6. Pressure factors

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Pressure factors on the reserve were observed using the method of Kagambèga et al. (2003). This consists of observing traces and counting the number of diseased plants out of the total number of plants in a plot.

2.4. Data analysis

The Microsoft Office 2010 Excel spreadsheet was used to draw the graphs. STATGRAPHICS plus 5.0 was used for the analysis of variance and Duncan's test. The Duncan's test was used to separate the significant averages for the values obtained for the different plant formations in the forest reserve.

3. RESULTS

3.1. Plant formations found in the Lam reserve

The 75 plots carried out enabled the vegetation to be grouped into five main types of plant formation with varying surface areas: the agricultural zone with a high density of trees (3.77 ha or 38.66% of the total surface area inventoried), the agricultural zone with a low density of trees (1, 56 ha or 16% of the total area surveyed), shrub savannah (3.51 ha or 36% of the total area surveyed), forest gallery or riparian gallery (0.54 ha or 5.53% of the total area surveyed), steppe (0.39 ha or 4% of the total area surveyed) (Figure 3). The sector diagram below shows the formations found in the reserve.

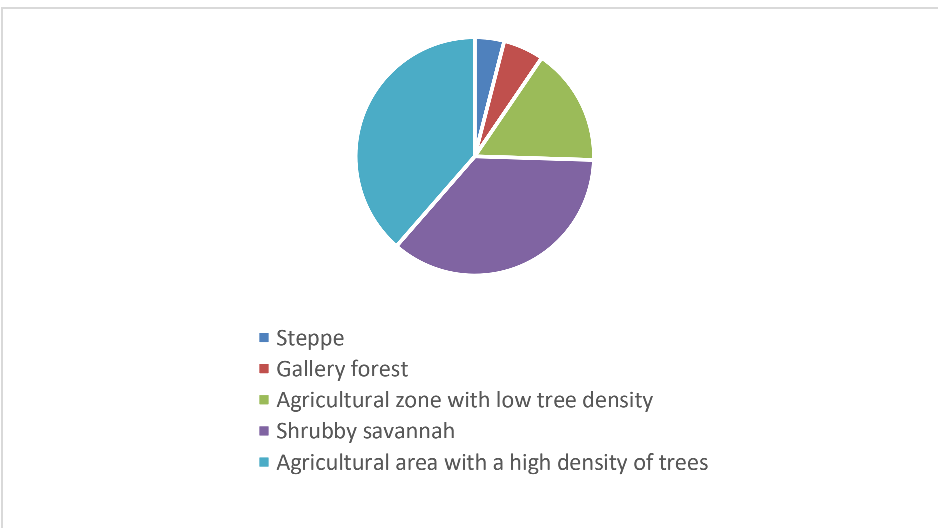

Fig. 3: Percentage of the different plant formations inventoried in the 75 plots installed in the Lam reserve.

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3.2. Floristic composition

A total of 9521 individuals in 25 families, 48 genus and 68 species were inventoried in the Lam reserve (Table 1). The most represented families are Fabaceae (18 species), followed by Combretaceae (11 species), Anacardiaceae (6 species) and Rubiaceae (3 species). Then come the Annonaceae, Apocynaceae, Burceraceae, Capparaceae, Euphorbiaceae, Meliaceae and Myrtaceae, each with 2 species. The other families each have 01 species. The inventories showed that the agricultural zone with a high density of trees is the richest plant formation in terms of phytodiversity in compartment A (53 species) and compartment B (47 species) (Table 1).

Table 1: Different species inventoried in the Lam Forest reserve

Family	Genus	Species
Anacardiaceae	Lannea	*Lannea fruticosa*
		Lannea acida
		Lannea microcarpa
		Lannea barteri
		Lannea schimperi
	Sclerocarya	*Sclerocarya birrea*
Annonaceae	Annona	*Annona senegalensis*
	Hexalobus	*Hexalobus monopetalus*
Arecaceae	Hyphaene	*Hyphaene thebaica*
Apocynaceae	Adenium	*Adenium abaesum*
	Halarrhena	*Halarrhena floribunda*
Balanitaceae	Balanites	*Balanites aegyptiaca*
Bignoniaceae	Kigelia	*Kigelia africana*
Burseraceae	Boswellia	*Boswellia dalzielii*
	Commiphora	*Commiphora africana*
Capparaceae	Capparis	*Capparis sepiaria*
	Maerua	*Maerua crassifolia*
Celastraceae	Maytenus	*Maytenus senegalensis*
Combretaceae	Anogeissus	*Anogeissus leiocarpa*
	Combretum	*Combretum molle*
		Combretum glutinosum
		Combretum adenogonium (*C. fragrans*).
		Combretum collinum
		Combretum paniculatum
		Combretum nigricans

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		Combretum aculeatum
	Guiera	*Guiera senegalensis*
	Terminalia	*Terminalia macroptera*
		Terminalia albida
Clusiaceae	Gardenia	*Gardenia aquala*
Ebenaceae	Diospyros	*Diospyros mespiliformis*
Euphorbiaceae	Bridelia	*Bridelia ferruginea*
	Hymenocardia	*Hymenocardia acida*
Fabaceae	Acacia	*Acacia gerardi*
		Acacia seyal
		Acacia albida
		Acacia hockii
		Acacia polyacantha
		Acacia ataxacantha
		Acacia amythe thophylla
		Acacia senegal
	Albizia	*Albizia lebbeck*
	Entada	*Entada africana*
		Entada abyssinica
	Dichrostachys	*Dichrostachys cinerea*
	Prosopis	*Prosopis juliflora*
	Dalbergia	*Dalbergia sosso*
	Piliostigma	*Piliostigma thonningii*
		Piliostigma reticulatum
	Pterocarpus	*Pterocarpus lucens*
	Swartzia	*Swartzia arborescens*
	Tamarindus	*Tamarindus indica*
Meliaceae	Azadirachta	*Azadirachta indica*
	Khaya	*Khaya senegalensis*
Moraceae	Ficus	*Ficus glumosa*
		Ficus trichopoda
		Ficus abutilifolia
Myrtaceae	Eucalyptus	*Eucalyptus camadulensis*
	Syzygium	*Syzygium guineense* var. *macrocarpum*
Olacaceae	Ximenia	*Ximenia americana*
Proteaceae	Protea	*Protea madiensis*

Rubiaceae	Breonadia	*Breonadia salicina*
	Crosopteryx	*Crosopteryx febrifuga*
	Feretia	*Feretia apodanthera*
Rhamnaceae	Ziziphus	*Ziziphus mauritiana*
Sterculiaceae	Sterculia	*Sterculia setigera*
Tilliaceae	Grewia	*Grewia flavescens*
Ulmaceae	Celtis	*Celtis integrifolia*
Verbenaceae	Vitex	*Vitex doniana*

Table 2: Summary of species in plant formations in the two plot compartments

	Plant formations									
	Compartiment A					**Compartiment B**				
	Ss	Step	Azhtd	Azltd	Gf	Ss	Step	Azhtd	Azltd	Gf
Families	12	6	20	11	14	13	3	13	11	13
Genus	17	7	28	13	18	20	3	22	13	18
Species	24	9	38	15	23	31	6	32	18	24

Legend: Ss = shrubby savannah; Step = steppe; Azhtd = agricultural zone with high tree density; Azltd = agricultural zone with low tree density; Gf = forest gallery or riparian gallery.

All the species in the forest reserve have Least Concern conservation status. Despite this status, these species are subject to considerable human pressure.

3.3. Characterisation of plant groups in the Lam reserve

The absolute density in the two compartments varies from one plant formation to another. It is high in the gallery forest or riparian gallery (133.33 individuals/ha and 1192.59 individuals/ha), followed by the shrub savannah (115.95 and 1128.49 individuals/ha) in compartments A and B respectively. It is low in the low tree density zone in compartment A, while in compartment B it is rather low in the steppe (Figure 4). The average density in compartment A is 79.73 individuals/ha for all plant formations. In compartment B, the average density of regenerating individuals is 871.81 individuals/ha for all the plant formations inventoried.

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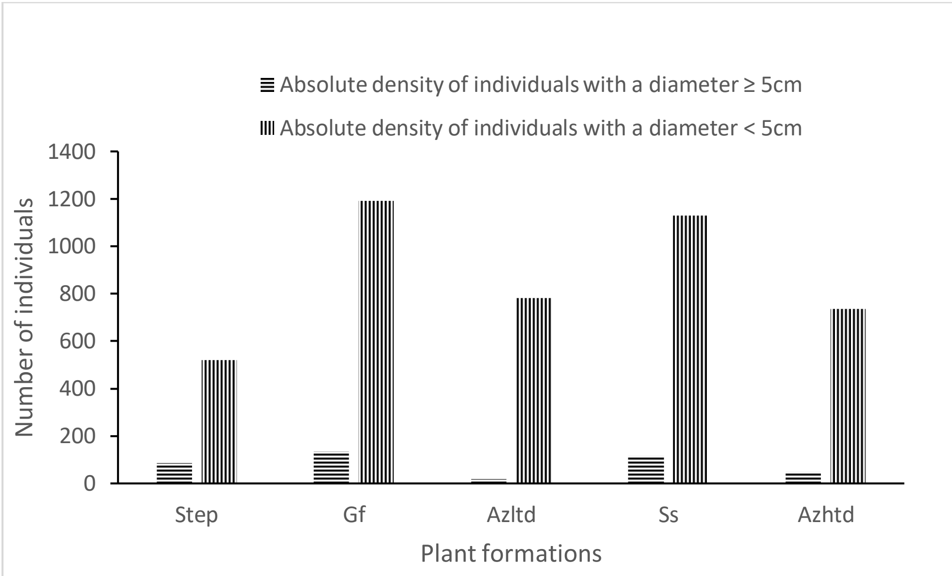

Fig. 4: Absolute density of individuals per hectare and per plant formation

Legend: Ss = shrubby savannah; Step = steppe; Azhtd = agricultural zone with high tree density; Azltd = agricultural zone with low tree density; Gf = gallery forest or riparian gallery

The density and abundance of species in the plots surveyed show that *Acacia gerardii* is the species with the highest density (21.33 individuals/ha) and abundance (43.97%), followed by *Anogeissus leiocarpa* (15.01%) and *Balanites aegyptiaca* (12.47%) in compartment A. In compartment B, the same species is the most abundant (41.25%) with an absolute density of 362.25 individuals/ha, followed by *Acacia hockii* (9.99%) and *Combretum glutinosum* (8.88%). Two species are less represented: *Feretia apodanthera* (0.38%) with a density of 3.38 individuals/ha and *Balanites aegyptiaca* (0.44%) with a density of 3.89 individuals/ha (Table 3).

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Table 3: Absolute density and abundance of species in the two compartments

Strata	Species	Absolute density (stems/ha)	Abundance (%)
Compartment B	*Acacia gerardii*	362.25	41.25
	Combretum glutinosum	78.05	8.88
	Combretum aculeatum	28	3.18
	Piliostigma thonningii	30.05	3.42
	Acacia hockii	87.79	9.99
	Ziziphus mauritiana	35.79	4.07
	Entada abyssinica	22.97	2.61
	Ximenia americana	6.76	0.77
	Dichrostachys cinerea	28.61	3.25
	Piliostigma reticulatum	32.30	3.67
	Combretum collinum	27.07	3.08
	Annona senegalensis	19.58	2.23
	Combretum molle	9.02	1.02
	Combretum adenogonium (*C. fragrans*)	9.43	1.07
	Maytenus senegalensis	40.10	4.56
	Azadirachta indica	4.51	0.51
	Terminalia albida	7.17	081

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	Albizia lebbeck	12.20	1.39
	Acacia seyal	13.94	1.58
	Balanite aegyptiaca	3.89	0.44
	Lannea schimperi	7.48	0.85
	Feretia apodanthera	3.38	0.38
	Prosopis juliflora	7.58	0.86
Compartment A	*Anogeissus leiocarpa*	7.28	15.01
	Acacia gerardii	21.33	43.97
	Azadirachta indica	5.94	12.26
	Balanite aegyptiaca	6.05	12.47
	Acacia seyal	4.30	8.87
	Entada abyssinica	3.58	7.39

3.4. Stand structure

3.4.1. Vertical structure of the stand

The trees in compartment A with a diameter greater than or equal to 5 cm and a height of at least 5 m were also divided into 4 height classes of amplitude 2 m. Most individuals are between 5 and 7 m tall. The distribution of trees in height classes shows an "L" structure, a sign of strong regeneration of young individuals in contrast to old trees (Figure 5).

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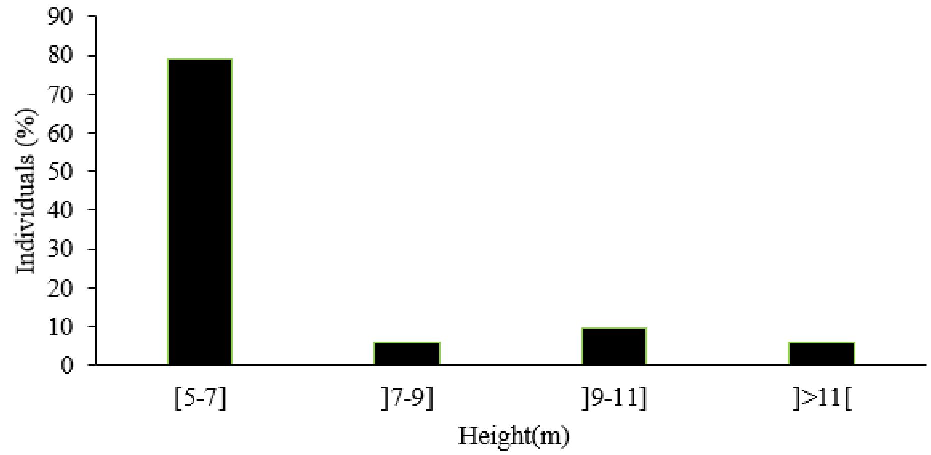

Fig. 5: Distribution of individuals by height class in compartment A

The woody species in compartment B were grouped into 3 height classes within the plant formations. This figure shows an "L" shaped structure in all the plant formations. The percentage of stems is highest in the]0-5cm] height class, which shows a very high level of regeneration, followed by the]50-100cm] class and then the height class above 100 cm for all plant formations (Figure 6).

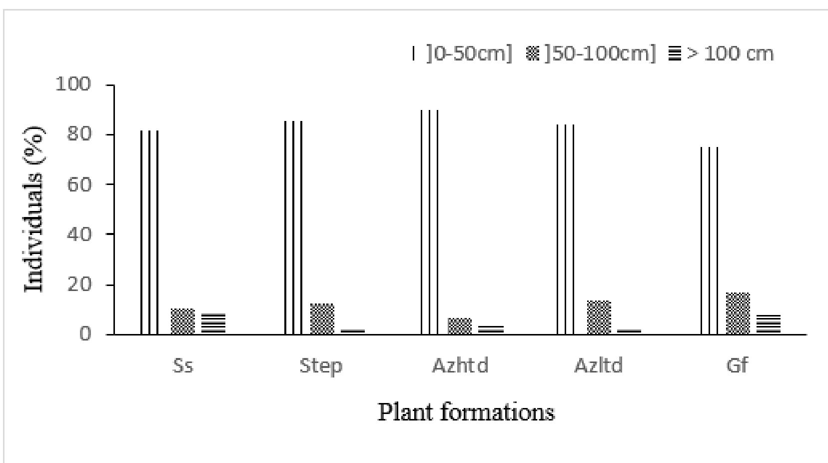

Fig. 6: Distribution of individuals by height class in compartment B

Legend: Ss = shrubby savannah; Step = steppe; Azhtd = agricultural zone with high tree density; Azltd = agricultural zone with low tree density; Gf = gallery forest or riparian gallery

3.4.2. Diameter structure of the woody stand in the Lam Forest reserve

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The diameter distribution of trees in compartment A has an "L" shaped structure. The most represented class in terms of number of individuals is [5-15] cm. This trend suggests ecological vigour and a guarantee of the longevity of young stems to replace ageing stems (Figure 7).

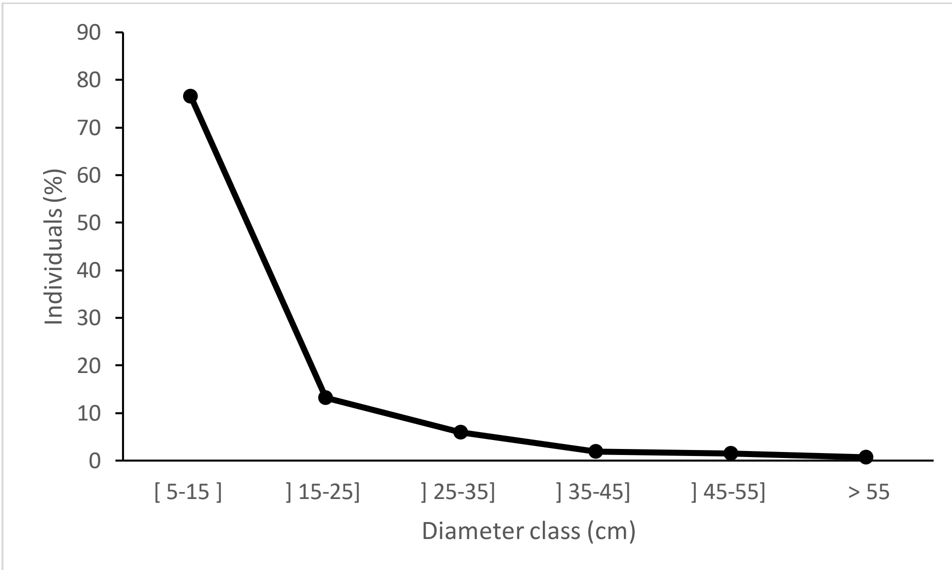

Fig. 7: Diameter class distribution of individuals

3.5 Diversity indices

Compartment A has the highest Shannon Diversity Index (1.21 bit) and Piélou Equitability (0.42) compared with Compartment B, which has the highest Shannon Diversity Index (1.05 bit) and Piélou Equitability (0.26). The Sorensen index between the two compartments (A and B) is 60% (Table 4).

Table 4: Diversity indices for the Lam Forest reserve

Indices	Compartment A	Compartment B
Shannon index	1.21 bit	1.05 bit
Piélou equitability	0.42	0.26
Sorensen similarity index	60	

3.6 Ecological importance value index

Species importance value index (IVI) was calculated for trees with a diameter of 5cm or more inventoried in the Lam Forest reserve. This calculation revealed seven (07) species in descending order whose ecological importance value indices are greater than 10%: *Acacia gerardii*,

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Anogeissus leiocarpa, *Balanites aegyptiaca*, *Azadirachta indica*, *Acacia seyal*, *Entada abyssinica* and *Tamarindus indica*. These indices range from 7.91% to 65.33% (Table 5).

Table 5: Ecological importance value index for species

Espèces	ReFr **(%)**	ReDo **(%)**	ReDe **(%)**	**IVI (%)**
Acacia gerardii	29.10	7.12	29.10	65.33
Anogeissus leiocarpa	10.16	14.29	10.16	34.63
Balanites aegyptiaca	8.35	14.50	8.35	31.22
Azadirachta indica	7.79	7.01	7.79	22.60
Acacia seyal	5.84	3.05	5.84	14.75
Entada abyssinica	4.73	4.43	4.73	13.90
Tamarindus indica	1.53	9.52	1.53	12.59
Diospyros mespiliformis	1.94	5.25	1.94	9,5
Hexalobus monopetalus	3.76	1.62	3.76	9.14
Acacia hockii	3.62	0.66	3.62	7.91
Autres espèces	23.16	32.49	23.21	78.77
Total	**100**	**100**	**100**	**300**

Legend: ReFr: Relative frequency; ReDo: Relative dominance; ReDe: Relative density

Family importance value index (FIV) ranges from 0.31% to 131.28%. The most represented families in decreasing order of importance are Fabaceae (131.28%), Combretaceae (51.13%), Balanitaceae (31.22%), Meliaceae (22.65%) and Anacardiaceae (11.91%) (Table 6).

Table 6: Ecological importance index for families

Families	ReFrf (%)	ReDof (%)	ReDef (%)	FIV (%)
Anacardiaceae	2.08	7.73	2.08	11.91
Annonacaea	3.89	1.93	3.89	9.73
Apocynaceae	0.55	0.06	0.55	1.18
Arecaceae	0.13	0.27	0.13	0.55
Balanitaceae	8.35	14.50	8.35	31.22
Bignoniaceae	0.13	0.03	0.13	0.31
Burceraceae	0.83	2.32	0.83	3.99
Capparaceae	0.13	0.73	0.13	1.01
Celastraceae	0.13	0.04	0.13	0.31
Clusiaceae	0.13	0.24	0.13	0.52
Combretaceae	16.85	17.42	16.85	51.13
Ebenaceae	1.81	4.93	1.81	8.55

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Fabaceae	50.83	29.60	50.83	131.28
Meliaceae	7.79	7.05	7.79	22.65
Moraceae	1.53	10.70	1.53	13.76
Myrtaceae	0.55	0.25	0.55	1.36
Olacaceae	1.25	0.21	1.25	2.72
Rhamnaceae	1.53	0.35	1.53	3.42
Rubiaceae	0.69	0.17	0.69	1.56
Sterculiacea	0.13	0.39	0.13	0.67
Tilliaceae	0.13	0.19	0.13	0.47
Ulmaceae	0.13	0.12	0.13	0.40
Verbenaceae	0.27	0.64	0.27	1.20
Total	**100**	**100**	**100**	**300**

Legend: ReFrf: Relative frequency of family; ReDof: Relative dominance of family; ReDef: Relative density of family

3.7 Carbon flows in the Lam reserve

3.7.1 Above-ground Carbon stock

Above-ground Carbon stock in the different plant formations ranged from 4.31±0.20 tC/ha to 75.34±1.05 tC/ha (Table 7). The highest value of above-ground carbon stock was recorded in the agricultural zone with high tree density (75.34±1.05 tC/ha). Analysis of variance shows that there is a significant difference in above-ground Carbon stocks between the different plant formations (0.0000<0.05).

3.7.2 Below-ground Carbon stock

The highest value of underground Carbon stock is found in the agricultural zone with a high density of trees (25.36±0.29 tC/ha) and the lowest value is recorded in the steppe (1.73±0.07 tC/ha) (Table 7). Analysis of variance shows that there is a significant difference in underground carbon stocks between the different plant formations (0.0000<0.05).

3.7.3 Total Carbon stock

The total Carbon stock in the different plant formations of the reserve ranges from 6.04 ± 0.27 tC/ha in the steppe to 100.70 ± 1.35 tC/ha in the agricultural zone with a high density of trees (Table 7). Analysis of variance indicates a significant difference in the total carbon stocks of the different plant formations (0.0000<0.05).

3.7.4 CO_2 levels

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CO_2 equivalent in the plant formations studied ranged from 22.16±1 tCO_2/ha to 369.57±4.95 tCO_2/ha. The maximum value is found in the agricultural zone with a high density of trees (369.57 tCO_2/ha) (Table 7). Analysis of variance shows that there is a significant difference in atmospheric CO_2 levels between the different plant formations (0.0000<0.05).

Table 7: Carbon stock and CO_2 content

Plant formations	Above-ground carbon (tC/ha)	Below-ground carbon (tC/ha)	Total carbon (tC/ha)	CO_2 content (tCO2/ha)
Ss	39.53± 0.21^{c}	16.43± 0.07^{c}	55.97±0.28^{c}	205.41± 1.03^{c}
Step	4.31± 0.20^{a}	1.73± 0.07^{a}	6.04± 0.27^{a}	22.16± 1^{a}
Azhtd	75.34± 1.05^{d}	25.36± 0.29^{d}	100.70±1.35^{d}	369.57± 4.95^{d}
Azltd	26.90± 1.45^{b}	8.54± 0.42^{ab}	35.44±1.87^{b}	130.06± 6.86^{b}
Gf	27.79± 1.75^{b}	8.77± 0.44^{ab}	36.57± 2.20^{b}	134.21± 8.07^{b}
P-value	0.0000	0.0000	0.0000	0.0000

Values in the same column followed by different letters are statistically different at the 5% threshold

Legend: Ss = shrubby savannah; Step = steppe; Azhtd = agricultural zone with high tree density; Azltd = agricultural zone with low tree density; Gf = gallery forest or riparian gallery

3.8 Socio-economic factors threatening the Lam Forest reserve

3.8.1 Agriculture

In their search for farmland, local people are moving into the Lam Forest Reserve to create or extend agricultural fields, the size of which per inhabitant varies according to the labour available. This conquest of the reserve is thought to be due partly to a shortage of arable land, drought or the population explosion in the area, partly to immigrants who have no agricultural plots and partly to the declining fertility of the soil. Agricultural production is based on family self-consumption. The most common crops are red millet, maize and groundnuts. Only cotton and surplus cereals are marketed.

3.8.2 Abusive tree felling

The people living around the reserve, particularly in the woodlands and savannahs, exploit plant resources for firewood and timber, which is considered to be one of the most damaging practices for the development of woody plants. This wood harvesting takes the form of indiscriminate

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felling, leaving the area almost devoid of woody plants. This situation is deplorable, but there are several reasons for it. On the one hand, there is the lack of an alternative source of energy, the shortage of staff responsible for supervising protected areas, the lack of an organised wood-energy industry and the poverty of the population, which leads some people to trade in firewood.

3.8.3 Charcoal production

Charcoal is produced inside the Lam reserve. The production process begins with the cutting of the wood, which takes place at least a week before it is put into the kiln. Trunks and branches over 70cm in diameter or more are separated from the smaller twigs used to light the oven, placed in a hole to limit the influence of the wind and then charred. Not all species are suitable for charcoal production. Only trees and shrubs with hard, dense, non-toxic wood, such as *Prosopis juliflora*, *Anogeissus leiocarpa* and *Combretum glutinosum*, are useful for producing good quality charcoal (slow, long-lasting combustion producing little ash).

3.8.4 Pastoral activity associated with bushfire

In the study area, pastoral activities revolve around the rearing of cattle, goats and sheep of average size per owner. Livestock grazing and trampling in the protected area also pose a threat to the health of regenerating plants and pasture soils. The transhumance during the dry season is the harshest, during which the herders cover distances that can take them from Chad to Nigeria, passing through the reserve. The result is saturation of the area due to the overloading of cattle, leading to the complete destruction of the plant cover. These pastoral activities generate other threats to the protected area, such as the early outbreak of bush fires. Pastoralists deliberately start fires at the beginning of the dry season to accelerate grass regrowth. In addition to pastoral activities, farmers and hunters are also involved in the practice of late fires. Fires have a considerable influence on the intra- and inter-annual dynamics of the plant cover, consuming almost all of the herbaceous layer and even woody plants.

4. DISCUSSION

Analysis of floristic richness identified 9521 individuals divided into 25 families, 48 genera and 68 species in all the plots surveyed in the Lam Forest Reserve. This shows that the Lam Forest Reserve is very rich in plant species. The results obtained from this study are almost similar to those of Sani et al. (2013), in the Mozogo-Gokoro National Park (62 woody species and 26 families). Our results are better than those of Jiagho et al. (2016) who obtained 52 species, 42 genera and 21 families in the periphery of Waza National Park. However, they are still lower than those of Dimobe et al. (2012), who obtained 116 woody species in 84 genera and 33 families in the Oti-Mandouri Reserve in northern Togo. The differences observed were due to strong anthropogenic pressure (bush fires, logging, overpopulation, etc.). The average absolute density

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was 79.73 stems/ha in the Lam Forest reserve. This result is much higher than those of Jiagho et al. (2016), who reported 40 stems/ha on the outskirts of Waza Park.

Fabaceae, Combretaceae and Anacardiaceae are the more dominant families. According to Dimobe et al. (2012), Fabaceae and Combretaceae are indicators of a generally dry climate. This can be explained by the low rainfall and rising temperature, which reflects the aridity of the Sudanian and Sudano-Sahelian climate.

In both compartments (A and B), the agricultural zone with a high density of trees is rich in phytodiversity compared with the other formations (shrub savannah, steppe, agricultural zone with a low density of trees). This is due, on the one hand, to the importance attached to certain plant species by the farmers and the limited threats in these zones due to the fact that they are occupied by a single farmer and, on the other hand, to the abundance of species of interest such as *Acacia gerardii* (43.97%), *Anogeissus leiocarpa* (15.01%), *Balanites aegyptiaca* (12.47%) in compartment A and *Acacia gerardii* (41.25%) followed by *Acacia hockii* (9.99%) and *Combretum glutinosum* (8.88%) in compartment B. This result is in agreement with those of Bondé et al. (2013) who stated that the woody floristic diversity of Sudanian formations is determined by an environmental gradient implied by the land use pattern.

The Shannon diversity index in compartment A (1.21 bit) and compartment B (1.05 bit) are low. This reflects low diversity in both compartments. A low value for a specific diversity index, particularly the Shannon index, is a sign of a very unstable environment. These results are lower than those of Jiagho et al. (2016) who obtained 3.44 bits in the periphery of the Waza park. This difference can be explained by the environmental conditions, which would be deficient for the regeneration of a good number of species linked to anthropogenic actions in the Lam forest reserve.

Piélou's equitability is less than 0.5 in compartments A and B. In fact, whatever the compartment, the individuals are not distributed equitably between the species.The Sorensen index between the two compartments (A and B) is 60%, which shows that the individuals in compartments A and B are almost similar from a floristic point of view, with a slight difference due to threats.

The vertical structure of individuals in compartment B shows that the most represented stems are the young stems]0-50 cm] followed by the medium stems]50-100 cm]. The least represented stems are in the height class above 100 cm in all formations. For individuals in compartment A, the stems show an exponential structure in the height class [5-15cm], with this structure decreasing as the height class increases. This figure has an "L" shaped appearance that is characteristic of an ecosystem in the process of reconstitution. Boubacar (2010) and Sani (2009) in the Sahelian zone of Niger obtained the same "L" shaped structure, but the stems least represented were the young and medium stems. These authors emphasised that this "L" shaped structure characterises a savannah with relatively small individuals.

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The diametric structure of the stand with a diameter greater than or equal to 5cm shows an exponential curve that falls very rapidly as you move from one class to the next. This curve is characteristic of a stand made up of a large number of small trees rather than large trees. This result corroborates that obtained by Jiagho (2018) in Waza Park.

The ecological importance value index makes the specific predominance in the plant formations inventoried more explicit. This index is of the order of 300 in the various plant formations. This could be explained by the strong presence of tall trees in these formations. This result corroborates that of Savadogo et al. (2016), who state that trees with large crowns contribute more to cover and, up to a certain degree of cover, they modify ecological conditions by reducing the evaporative power of the air, favouring the soil's water balance and improving fertility. *Acacia gerardii* is the species that is best represented and therefore has the best cover, and is therefore the most predominant. This means that it ranks first in terms of abundance and dominance. The Fabaceae are the best represented and therefore have the best coverage, and are therefore the most predominant. This means that they rank first in terms of abundance and dominance.

Above-ground carbon stock in the different types of vegetation varies from 4.31 tC/ha to 75.34 tC/ha. This variation in above-ground carbon stock in the different plant formations could be explained by dendrometric variability (diameter at breast height and height) and the physiognomy and architecture of the ligneous trees. The agricultural zone with high tree density (75.34 tC/ha) sequesters more carbon than the other plant formations studied because of diameter at breast height, density and basal area. The results obtained differ from the values of 40.89±1.09 tC/ha obtained by Tchobsala et al. (2016) in the tree and shrub savannas of Ngaoundéré (Adamaoua-Cameroon), and from the values of 25.89±4.58 tC/ha, 23.11±3.32 tC/ha, 10.46±2.25 tC/ha, 22.49±2.16 tC/ha obtained by Awé et al. (2021) respectively in tree, shrub, woodland and tree savannahs in the Sudano-Sahelian zone of Cameroon. This difference is justified by the counting methodology used and also the allometric model used. Our results also show that the low value of above-ground carbon stock observed in the steppe (4.31 tC/ha) could therefore be explained by the action of anthropogenic activities (excessive wood cutting, bush fires, overgrazing). This result is lower than the value (6.52 tC/ha) obtained by Wanguili (2017) in the steppes of the Sahelian zone of Cameroon.

The value of the underground carbon stock varies between 25.36 and 1.73 tC/ha in the different formations inventoried. This difference is correlated with the diameter at breast height, maturity and physiognomy of the trees in the plant formations. The agricultural zone has the highest underground carbon stock value (25.36 tCha). This result is lower than the 64.25 tC/ha obtained by wanguili (2017) in *Moringa oleifera* plantations in the Sahelian zone of Cameroon. This difference could be explained in part by the different textures and biochemical compositions of the soils and also by the sampling methods applied.

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Total carbon is variable in the vegetation formations studied (6.04 to 100.70 tC/ha). The high-density agricultural zone recorded the highest value (100.70±1.35 tC/ha), while the lowest total carbon value was recorded in the steppe. The higher total carbon stock value in the agricultural zone with high tree density would be due to the diameter at breast height of the trees, the high humus content, the density of the trees and also the limited access in this plant formation. The low value of the carbon stock in the steppe could be explained by the effect of solar radiation and the anthropogenic pressures found in this plant formation. Surroundings of Lobéké National Park (Cameroon) in the Congo Basin, Zapfack et al. (2013) worked in several land use systems including primary forest, secondary forest, wetland, old fallow, young fallow and plantations and noted a variation in the amount of carbon ranging from 94.10 ±17.30 tC/ha in plantations to 172.60 ±25.51 tC/ha in primary forest. Adamaka (2020) noted 370.77 tC/ha in the Sénegal rangeland. The difference in results could be explained by the size of the plots and other factors influencing the variability of tree biomass and soil texture.

CO_2 levels also vary in the different plant formations. This variability ranges from 22.18 to 360.60 tCO_2/ha. This variability of the CO_2 rate shows the contributory role of the different plant formations of the Lam reserve in the attenuation of greenhouse gas emissions from anthropogenic activities in the study area. The agricultural zone, with its high density of trees, captures more CO_2 (360.60 tCO_2/ha) than the other plant formations in the forest reserve. This can be explained by their high above-ground and below-ground biomass values. These results differ from the values of 249.83±12.07 tCO_2/ha, 56.37±12.09 tCO_2/ha, 143.30±12.87 tCO_2/ha and 242.82±12.06 tCO_2/ha reported by Awé et al. (2021) for tree, shrub, woodland and tree savannahs respectively in the Sudano-Sahelian zone of Cameroon. This difference is linked to the method used to count woody plants, the allometric formula used and the anthropogenic activities of the environments studied.

The observations made in the field and the distribution of our inventory plots over the whole of the forest reserve show that the main threats to the reserve are the extension of agricultural land, pastoral activity and logging. This observation is justified by the fact that of the 75 plots inventoried, 41 are in agricultural areas. The threats to the reserve would be due, on the one hand, to demographic exploitation and, on the other, to the lack of alternative energy sources accessible to the local population, poverty and the lack of fodder for livestock. This is in line with the results obtained by Wafo (2008) who worked on protected areas in the Far North of Cameroon.

5. CONCLUSION

The work carried out in the LAM forest reserve contributes to our knowledge of the floristic composition and pressure factors on the forest massif in the dry zone of Cameroon. The 75 circular plots installed in the reserve enabled us to identify five (5) plant formations, including the shrub savannah, the agricultural zone with a high density of trees, the agricultural zone with a low density of trees, the steppe and the forest gallery. A total of 9521 individuals in 25 families, 48 genera and 68 species were inventoried in the Lam reserve. The most represented families are Fabaceae (18 species), Combretaceae (11 species), Anacardiaceae (6 species) and Rubiaceae (3 species). Diversity indices vary from one compartment to another. The total carbon stock is 55.97±0.28 tC/ha in the shrub savannah, 6.04±0.27 tC/ha in the steppe, 100.70±1.35 tC/ha in the agricultural zone with a high density of trees, 35.44±1.87 tC/ha in the agricultural zone with a low density of trees and 36.57±2.20 tC/ha in the gallery forest. Investigations carried out in the reserve have identified a large number of human activities, such as logging, bush fires, agriculture and grazing. The most dominant human activity is the expansion of agricultural land. This work provides a reference framework for the sustainable management of tree species in the Lam reserve. To achieve this, the policies in charge of biodiversity conservation must integrate it into their protected area development programmes. It is also necessary to promote the conservation of species in the forest reserve, forest relics and agrosystems in the villages around the reserve.

With this in mind, it would be important to: carry out a socio-demographic survey of the local population around the reserve in order to determine precisely the main causes of the pressure on biodiversity, study the temporal dynamics of the carbon stock in the forest reserve and estimate the soil carbon stock.

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