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Structure and Diversity of Agroforestry Parklands in the Sudano-Sahelian Zone of Cameroon

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Abstract: The general objective of the study is to characterize the woody vegetation of 05 agroforestry parkland in the Sudano-Sahelian zone of Cameroon. A total of 40 floristic surveys of 200 × 20 m were carried out. A total of 33 species in 20 families and 31 genera were recorded. The dendrometric survey method enabled us to characterize the vegetation of the agroforestry parks. The dendrometric parameters and indices calculated according to the agroforestry parks vary from one park to another. Thus, density varies from 108±2.98-223±8.01 individuals/ha, recovery from 6.11±0.21-10.12±0.31%, basal area from 6.54±1.12 to 10.05±1.87 m²/ha, biovolume from 20.09±2.22-38.54±3.76 m^3/ha, total height from 2.11±0.01-5.06±0.04 m, natural regeneration rate from 2.11±0.52-7.40±1.09%. The Shannon index varies from 1.36±0.20-2±0.29 bits, Pielou index from 0.14±0.07-0.35±0.18 and Simpson index from 0.82±0.02-0.97±0.03. The species with the highest SIV and SIR are *Combretum glutinosum*, *Combretum adenogonium*, *Sclerocarya birrea*, *Prosopis africana*, *Entada africana*, *Anacardium occidentale*, *Burkea africana*, *Maytenus senegalensis*, *Ficus glumosa*. The Mimosaceae, Caesalpiniaceae, Combretaceae show a high representativeness in relation to their family importance value. The diameter structure showed a predominance of young individuals and the height structure showed a predominance of individuals of class [4-6 m]. These results can be used as a reference in monitoring the vegetation dynamics of agroforestry parks subject to recurrent droughts and anthropogenic pressures. This study provides a better understanding of the vegetation in agroforestry parks in order to better manage these plant resources.

Keywords: Agroforestry Parklands, Structure, Floristic Composition, Cameroon

Introduction

During these two decades, the sub-Saharan Africa is facing an accelerated degradation of its plant biodiversity as a result of anthropogenic activities and naturally (FAO, 2015). The climate warming on the planet is a major challenge for developing countries (FAO, 2015; Noumi *et al.*, 2018). The populations living in these countries depend heavily on natural resources of plant and often have an adaptive capacity relatively limited (FAO, 2015). Therefore, these countries are often among the most seriously affected by climate change. In Cameroon, as in several other countries in sub-Saharan Africa, the effects of climate change are more than ever noticeable, especially in the region of Sudano-Sahelian (FAO, 2015; Victor *et al.*, 2020b). Several scientific works provide that climate change will affect the livelihoods and the plant biodiversity of significantly (Kabore *et al.*, 2013; Rabiou *et al.*, 2015).

African forest ecosystems are recognized as among the most important and richest in terms of abundance and diversity of plant species (Victor *et al.*, 2020b). They play a crucial role in sustaining life on the planet (Kabore *et al.*, 2013). They intervene in the regulation of global and regional climate systems (FAO, 2015). Despite these multiple functions, the management of natural forests, particularly in sub-Saharan Africa, is confronted with a lack of data to enable the functioning of these ecosystems to be understood in terms of floristic composition, demographic structure and regeneration (Rabiou *et al*., 2015). However, the recurrence of rainfall deficits in recent decades has caused a decline in food production based essentially on rainfed agriculture (FAO, 2015). Natural ecosystems are therefore subject to increased exploitation by a galloping population growth seeking food supplements and sources of income (Froumsia *et al*., 2012; Mouhamadou *et al*., 2013).

The Sahelian zone is characterized by an ecological fragility, an increase of the acidification for the medium and high mortality of woody plants with a decrease in biological diversity (Noumi *et al*., 2018). This area is little industrialized and populations consisting to majority of agro-pastoralists, located in the woody stratum the supplementary foods, drugs, the sources of energy, the fodder for their animals and the materials necessary for the manufacture of objects in current use. The concern for biodiversity conservation, taking into account the needs and aspirations of local populations, has become real since the Earth Summit in 1992 (Mouhamadou *et al*., 2013). Plant species in Africa are very important to human populations because of their contribution to meeting the needs for food, health, energy, income and other aspects of human well-being (Mouhamadou *et al*., 2013). Despite this recognized importance of collective consciousness, the erosion of biodiversity continues and constitutes a threat to humanity (Mouhamadou *et al*., 2013). Thus, the ligneous plants and their habitats are subjected to disturbances, linked to these anthropogenic actions and to climate change, which threaten their survival even though their ecological, morphological, genetic characterizations and the inventory of their usefulness have not been deepened (Noumi *et al*., 2018; Victor *et al*., 2020b).

Forest ecosystems are extremely rich in plant and wildlife species that are sometimes little or poorly known. However, the increasing trend in the current rate of deforestation, especially in tropical areas (FAO, 2015), may lead to the erosion of some as yet unknown forest species. Indeed, the lack of quantitative information on the abundance and distribution of tropical organisms remains a problem for biodiversity conservation and sustainable management of forest ecosystems. As a result, it becomes difficult to know which species is the most threatened (Froumsia *et al*., 2012; Mouhamadou *et al*., 2013). The alarming rate of degradation of forest ecosystems in the tropics is leading directly to the fragmentation of plant formations. Man, who has not been able to find a balance between his exploitation system and the resilience of the natural environment, remains the main agent of the regressive evolution of ecosystems (FAO, 2015). Through cultivation, forestry, the expansion of livestock farming and hunting, man is conquering an ever-increasing part of the space. The degradation of ecosystems today constitutes a threat to biodiversity, as the destruction of natural environments inevitably leads to the scarcity or even disappearance of species (Victor *et al*., 2020b). The growing needs of populations, bush fires and drought have caused an increasingly marked degradation of these habitats. This is manifested by changes in the floristic composition and structure of vegetation, poor natural regeneration of some species and bare soil due to erosion, a factor of impoverishment. However, given the relatively low level of knowledge about agroforestry parks, the question "What is the contribution of agroforestry systems to the development of rural communities" arises.

A. leiocarpus, *I. doka*, *T. laxiflora*, *P. thonningii* and *A. digitata* are agroforestry species that occupy an important place due to their multiple roles. These agroforestry parks play an important role in food and economic security, providing "fuel, food, medicinal products, fodder and various service products", while protecting the physical environment (Arbonnier, 2004). Tree densities are low to medium (discontinuous tree cover) and livestock production is sometimes associated with them. The objectives of this study are to study the diversity and structure of agroforestry parks in the Sudano-Sahelian zone of Cameroon.

Materials and Methods

Study Area

The study was carried out in the north region of Cameroon. This region is located between 9°18'N to 8°10'N latitude and 13°23'E to 12°16'E longitude (Victor *et al*., 2019a) Fig. 1. The north Cameroon region has a tropical climate in the Sudano-Sahelian type. The relief is a vast pediatric plain between the Mandara Mountains (1,442 m) in the North and the Adamawa Plateau in the South. The soil is of ferruginous type formed by degradation of sandstone from the Middle Cretaceous (Victor *et al*., 2020a). The vegetation encountered is a shrubby Sudanian savannah with a clear and degraded savannah appearance (Victor *et al*., 2020b). The fauna is rich and very diverse (Victor *et al*., 2019b). Economic activities concern: Agriculture, animal husbandry, fishing, social economy and handicrafts, transport and trade. Agriculture is the main activity of the populations of the North Cameroon region.

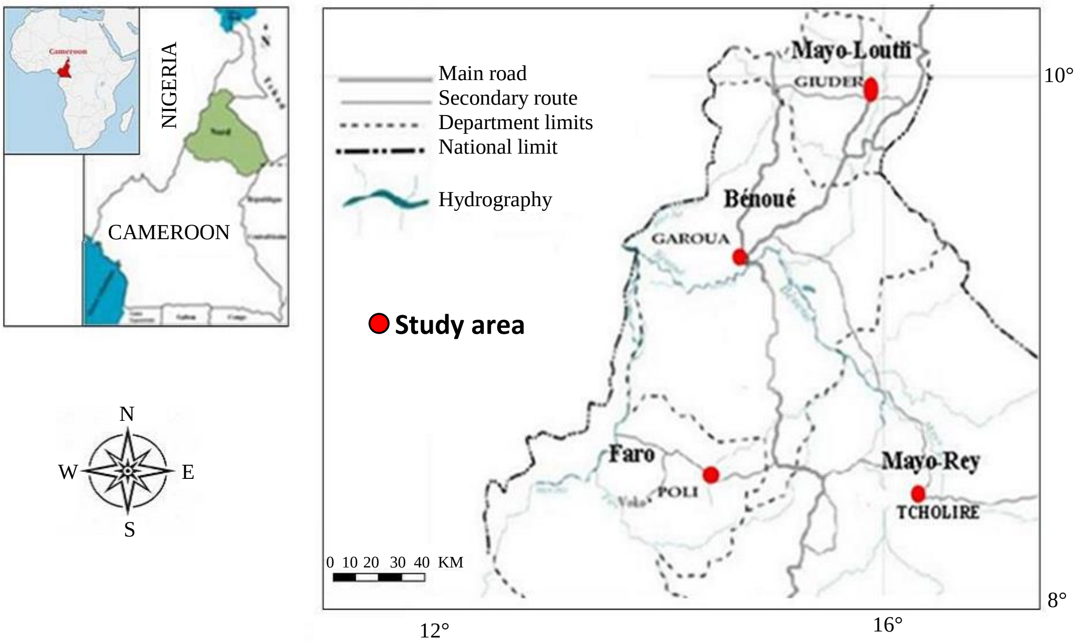

Fig. 1: Geographic location of the study area in North Cameroon Region

Data Collection

Criteria for the Selection of Agroforestry Parkland

The socio-economic and environmental importance, density, availability, topography and size of *A. leiocarpus*, *I. doka*, *T. laxiflora*, *P. thonningii* and *A. digitata* agroforestry parkland were the main reasons for the choice of these species for their structural and floristic analysis.

Sampling Methods

Sampling methods consist of transects ranging from 200 m long to 20 m wide. These transects were laid out in a north-south direction to cover most or all of the agroforestry parks studied. Sampling strips were established using wire and compass. At the ends of each strip, stakes were marked 10 m equidistant from the base. At each 10 m distance, all trees were inventoried. The geographic coordinates of each tree in the sample were collected using GPS to determine its geographic position in the field. All trees were systematically counted and measured. The dendrometric data were based on Diameter at breast height (Dbh), height and trunk size. For example, the circumference of trees was measured with a tape measure at 1.3 m from the ground for large trees and at 50 cm from the ground for shrubs and bushes. All trees that were measured by Dbh were numbered with indelible markers to facilitate their identification. Logging records (cutting, pruning, debarking, boring and bending) and the condition of the individuals measured were noted in order to inventory the pressure indicators.

Characterization of Flora and Vegetation

The analysis of the plant diversity focused on:

Specifics richness (N): $N = 2^H$; 2 is the basis of the logarithm used to calculate the Shannon-Wiener's index (H).
Shannon-Wiener's Index (H): $H = -\Sigma\ (ni/Ni) * \log_2 (ni/Ni)$

with ni = number of species i, Ni = effective of all species; H is expressed in bit.

Piélou index (E): $E = H/\log_2 N$.

with a = number of species in survey 1, b = number of species in survey 2, c = number of species common to both surveys.

Simpson's diversity index $(Ds) = 1-[(ni\ (ni-1))/(N\ (N-1)]$.

Density (D): D = N/S D: Density (in trees/ha), N: Number of trees present on the surface considered and S: surface area (ha).
Basal area (Ba): $Ba = di^2(Pi/4)$ (di = diameter, Pi = 3.14).

Biovolume $(V) = 0.53 \sum gi \times hi \times ni$ with gi: Basal area (m^2/ha). Hi: height of the barrel (m); ni: Number of individuals; V: biovolume (m^3/ha).

Relative Frequency (RFi) was determined by using the formula: $RFi = AFi/TF \times 100$ where AFi = Absolute frequency of species and TF = Total Frequency (Sum of AFi).

Relative Density (RDi) was determined by using the formula: RDi = ADi/AD ×100 where ADi = Absolute density of species and AD = Absolute density.

Relative Dominance or Cover (RCi) was determined by using the formula: RCi = BAi/TBA x100 (Manohar, 2015).

Where BAi = Basal area of species and TBA = Total basal area.

Species Importance Value (SIV) of a species was calculated by adding the Relative Frequency (RFi), Relative Density (RDi) and Relative dominance (RCi).

The Family Importance Value Index (FIV) for botanical families was calculated by adding the IVI for different species of the same family.

Specific Importance of Regeneration (SIR) in % = Number of seedlings of a species/Total number of seedlings inventoried.

Data Analysis

The data have been encoded in the excel software and then analyzed using software Statgraphics plus 5.0. Testing the significance has been achieved thanks to the test of Duncan to 5%.

Results

Floristic Composition

The total species richness recorded in the Sudano-sehalian zone is 33 species in 20 families and 31 genera Table 1. The agroforestry park based on *A. leiocarpus* is the richest in terms of floristic diversity Table 1. The most represented families in terms of number of species are respectively Combretaceae (3 to 4 species), Caesalpiniaceae (2 to 3 species) and Mimosaceae (2 to 3 species) Table 1. The average number of species per survey varies between 4.36±0.20 and 4.98±0.29 species depending on the park Table 1.

Diversity Indices and Structure

The Shannon-Weiner index and Piélou equitability values are respectively less than 2.5 bits and 0.5 bits Table 2.

Simpson's index tends towards 1 in all parks Table 2.

Recovery does not vary significantly across parks ($p>0.05$), with the highest recovery recorded in *P. thonningii* agroforestry parkland (10.12±0.31%) Table 2.

The density of individuals varies substantially between agroforestry parkland ($p<0.025$), with *A. leiocarpus* agroforestry parkland being the densest with an average of 223±8.01 individuals/ha Table 2.

Table 1: Specific richness

Agroforestry parkland	*A. leiocarpus*		*I. doka*		*T. laxiflora*		*P. thonningii*		*A. digitata*	
Number of species	22		18		19		18		21	
Number of genera	21		17		19		18		20	
Number of families	13		10		13		11		12	
Specific richness	4.98±0.29a		4.36±0.20a		4.57±0.24a		4.43±0.22a		4.76±0.27a	
Families	Nb.S	%	Nb.S	%	Nb.S	%	Nb.S	%	Nb.S	%
Anacardiaceae	3	13.64	1	5.556	2	10.53	0	0	3	14.29
Annonaceae	1	4.545	0	0	1	5.263	0	0	0	0
Balanitaceae	1	4.545	0	0	1	5.263	1	5.556	0	0
Bignoniaceae	0	0	0	0	0	0	1	5.556	0	0
Bombacaceae	1	4.545	0	0	1	5.263	0	0	0	0
Caesalpiniaceae	3	13.64	2	11.11	2	10.53	3	16.67	3	14.29
Celastraceae	0	0	0	0	1	5.263	1	5.556	1	4.762
Combreataceae	4	18.18	4	22.22	3	15.79	3	16.67	4	19.05
Euphorbiaceae	0	0	0	0	1	5.263	1	5.556	1	4.762
Fabaceae	1	4.545	2	11.11	1	5.263	0	0	1	4.762
Meliaceae	1	4.545		0	1	5.263	0	0	1	4.762
Mimosaceae	3	13.64	2	11.11	3	15.79	3	16.67	2	9.524
Moraceae	0	0	1	5.556	0	0	0	0	1	4.762
Myrtaceae	1	4.545	0	0	0	0	0	0	1	4.762
Olacaceae	0	0	1	5.556	0	0	1	5.556	0	0
Polygalaceae	1	4.545	0	0	0	0	1	5.556	0	0
Rubiaceae	0	0	2	11.11	1	5.263	2	11.11	2	9.524
Rhamanceae	1	4.545	0	0	0	0	0	0	0	0
Sapotaceae	0	0	1	5.556	1	5.263	0	0	1	4.762
Verbenaceae	1	4.545	2	11.11	0	0	1	5.556	0	0
Total	22	100	18	100	19	100	18	100	21	100

The values assigned the same letter are not statistically different ($p>0.05$; Duncan test)

Basal area and biovolume vary significantly between parks ($p<0.05$), with the highest recorded for *A. leiocarpus* agroforestry parkland (Ba = 10.05±1.87 m²/ha and V = 38.54±0.76 m^3/ha) Table 2.

The highest regeneration rate was observed in *A. digitata* agroforestry parkland with an average regeneration rate of 7.40±1.09% Table 2.

The total height of Lorey did not vary significantly ($p>0.05$) between agroforestry parkland. The highest average total height of Lory was recorded in *A. digitata* agroforestry parkland with an average of 5.06±0.04 m Table 2.

Families Importance Value (FIV)

The families with the highest FIV are respectively Combretaceae (50.32-69.91%), Mimosaceae (40-60.65%) and Caesalpiniaceae (34.89-66.4%) Table 3.

Species Importance Value (SIV) and Specific Importance of Regeneration (SIR)

In the *A. leiocarpus* agroforestry parkland, *Combretum glutinosum* and *Combretum adenogonium* have the highest values of SIV with 30.76 and 30.67% respectively and SIR with 10.22 and 8.54% respectively. However, in the *I. doka* agroforestry parks, *Sclerocarya birrea*, *Prosopis africana*, *Entada africana* and *Combretum adenogonium* have the highest SIV values with 39.19, 35.76, 32.67 and 30.76% respectively and SIR values with 12.60, 12.38, 11.38 and 8.88% respectively. On the other hand, in the *T. laxiflora* agroforestry parkland, *Prosopis africana* and *Anacardium occidentale* have the highest SIV values with 34.34 and 30.69% respectively and SIR values with 25.12 and 18.19% respectively.

Table 2: Diversity index and structure

Agroforestry parkland	*A. leiocarpus*	*I. doka*	*T. laxiflora*	*P. thonningii*	*A. digitata*
Shannon-Weiner index	2±0.05a	1.36±0.02a	1.57±0.02a	1.43±0.02a	1.76±0.01a
Piélou equitability	0.35±0.18a	0.14±0.07a	0.19±0.09a	0,19±0.09a	0.26±0.13a
Simpson index	0.87±0.02a	0.83±0.01a	0.97±0.03a	0.82±0.02a	0.88±0.02a
Average recovery	6.11±0.21a	7.02±0.25a	7.32±0.28a	10.12±0.31ab	6.76±0.23a
Density	223±8.01e	183±4.32c	151±3.72b	108±2.98a	201±6.01d
Basal area	8.54±1.45b	6.54±1.12a	8.12±1.32b	10.05±1.87c	6.76±1.20a
Biovolume	23.43±2.66ab	20.09±2.22a	22.08±2.39a	38.54±3.76c	21.66±2.37a
Specific importance of regeneration	2.11±0.52a	3.12±0.62b	2.32±0.82a	4.42±0.95c	7.40±1.09d
Height of Lorey (m)	2.11±0.01a	2.52±0.02a	4.32±0.03ab	3.12±0.02a	5.06±0.04ab

The values assigned the same letter are not statistically different ($p > 0.05$; Duncan test)

Table 3: Families Importance Value (FIV)

Agroforestry parkland	*A. leiocarpus*	*I. doka*	*T. laxiflora*	*P. thonningii*	*A. digitata*
Families	FIV	FIV	FIV	FIV	FIV
Anacardiaceae	42.12	12.43	40.87	11.00	34.72
Annonaceae	11.54	0.00	11.23	11.00	0.00
Balanitaceae	11.54	0.00	11.81	0.00	0.00
Bignoniaceae	0.00	0.00	0.00	66.00	0.00
Bombacaceae	19.54	0.00	11.11	11.00	0.00
Caesalpiniaceae	42.43	40.00	35.92	66.40	34.89
Celastraceae	0.00	0.00	11.00	11.00	12.65
Combreataceae	56.54	50.32	60.65	0.00	69.91
Euphorbiaceae	0.00	0.00	11.43	0.00	12.00
Fabaceae	15.21	39.87	11.54	48.60	12.00
Meliaceae	11.25	0.00	11.40	0.00	12.00
Mimosaceae	42.43	40.86	60.65	0.00	40.00
Moraceae	0.00	11.65	0.00	11.00	12.00
Myrtaceae	11.87	0.00	0.00	11.00	12.00
Olacaceae	0.00	12.54	0.00	42.00	0.00
Polygalaceae	12.12	0.00	0.00	0.00	0.00
Rubiaceae	0.00	39.91	11.50	0.00	36.34
Rhamanceae	11.65	0.00	0.00	11.00	0.00
Sapotaceae	0.00	12.87	10.89	11.00	11.49
Verbenaceae	11.76	39.55	0.00	11.00	0.00
Total	300.00	300.00	300.00	300.00	300.00

Table 4: Species Importance Value (SIV) and Specific Importance of Regeneration (SIR)

Agroforestry parkland	*A. leiocarpus*		*I. doka*		*T. laxiflora*		*P. thonningii*		*A. digitata*	
Species	SIV	SIR	SIV	SIR	SIV	SIR	SIV	SIR	SIV	SIR
Anacardium occidentale	20.56	6.83	0.00	0.00	30.69	18.19	0.00	0.00	11	2
Annona senegalensis	1.34	1.84	0.00	0.00	10.34	0.80	0.00	0.00	0	0
Balanites aegyptiaca	1.12	1.84	0.00	0.00	20.34	8.34	15.65	6.65	0	0
Burkea africana	23.54	6.88	25.65	6.00	0.00	0.00	30.45	11.45	38	25
Ceiba pentandra	10.43	3.84	0.00	0.00.	18.69	0.60	0.00	0.00	0	0
Combretum adenogonium	30.67	8.54	30.76	8.88	0.00	0.00	22.54	8.54	11	2
Combretum glutinosum	30.76	10.22	14.87	4.67	12.34	0.30	22.34	8.34	31	19
Dichrostachys cinerea	26.00	7.54	0.00	0.00	9.34	1.34	10.98	1.98	11	2
Entada africana	24.00	7.00	32.67	11.38	5.00	0.12	28.03	8.03	11	2
Erythrina senegalensis	4.07	1.00	0.00	0.00	11.34	1.34	0.00	0.00	11	2
Eucalyptus camaldulensis	4.04	1.84	15.00	3.74	0.00	0.00	0.00	0.00	11	2
Faidherbia albida	10.76	2.69	0.00	0.00	4.34	0.30	10.65	1.65	0	0
Ficus glumosa	0.00	0.00	22.30	5.68	0.00	0.00	20.00	10.00	30	18
Gardenia aqualla	0.00	0.00	11.87	3.00	23.00	10.00	10.47	0.47	11	2
Guieria senegalensis	10.65	5.38	11.00	2.69	0.00	0.00	20.02	8.02	11	2
Khaya senegalensis	7.20	5.00	0.00	0.00	4.34	0.30	0.00	0.00	11	2
Lannea acida	8.87	3.74	0.00	0.00	0.00	0.00	0.00	0.00	11	2
Maytenus senegalensis	0.00	0.00	0.00	0.00	10.34	0.80	30.45	11.45	11	2
Phyllanthus reticulatus	0.00	0.00	0.00	0.00	10.34	0.84	10.56	0.56	1	1
Piliostigma reticulatum	10.68	4.84	0.00	0.00	0.00	0.00	0.00	0.00	0	0
Prosopis africana	0.00	0.00	35.76	12.38	34.34	25.12	10.00	2.00	0	0
Sarcocephalus latifolius	0.00	0.00	13.65	1.50	0.00	0.00	7.41	7.41	11	2
Sclerocarya birrea	8.98	1.54	39.19	12.60	4.34	0.30	0.00	0.00	11	2
Spathodea campanulata	0.00	0.00	23.00	5.80	0.00	0.00	0.00	0.00	0	0
Strychnos spinosa	22.65	5.54	0.00	0.00	21.34	11.30	10.46	0.46	0	0
Tamarindus indica	10.65	3.84	10.02	2.88	11.00	1.50	1.13	1.13	11	2
Tectona grandis	3.65	3.84	19.67	3.00	23.34	13.40	0.00	0.00	2	1
Terminalia glaucescens	13.76	3.84	11.98	1.80	11.00	1.00	0.00	0.00	0	0
Terminalia macroptera	10.98	1.38	18.95	4.38	12.69	2.60	10.02	1.02	11	2
Vitallaria paradoxa	0.00	0.00	13.54	2.84	11.51	1.51	0.00	0.00	11	2
Vitex madiensis	0.00	0.00	18.76	3.78	0.00	0.00	0.00	0.00	11	2
Ximenia americana	0.00	0.00	0.00	0.00	0.00	0.00	19.08	10.08	0	0
Ziziphus mucronata	0.00	0.00	0.00	0.00	0.00	0.00	9.76	0.76	11	2
Total	300.00	100.00	300.00	100.00	300.00	100.00	300.00	100.00	300	100

Table 5: Anthropogenic and morphological factors

	Agroforestry parkland				
Anthropogenic factors	*A. leiocarpus*	*I. doka*	*T. laxiflora*	*P. thonningii*	*A. digitata*
Cutting (%)	8.87	34.87	18.98	65.87	20.65
Debarking (%)	5.76	1.76	45.87	1.76	40.00
Pruning (%)	3.76	9.65	5.98	6.87	12.86
Bending (%)	54.87	23.00	13.65	2.34	7.54
Brilling (%)	10.65	12.76	8.76	0.76	3.76

Next in the *P. thonningii* agroforestry parkland, *Burkea africana* and *Maytenus senegalensis* have the highest values of SIV with 30.45% each and SIR with 11.45% each, respectively. In the *A. digitata* agroforestry parkland, *Burkea africana*, *Combretum glutinosum* and *Ficus glumosa* have the highest SIV values with 38, 31 and 30%, respectively and SIR values with 25, 19 and 18%, respectively (Table 4).

The highest Cutting is recorded in the agroforestry parklands based on *P. thonningii* (65.87%). The highest Debarking is recorded in the agroforestry parklands based on *T. laxiflora* (45.87%). The highest Pruning is recorded in the agroforestry parklands based on *A. digitata* (12.86%). The highest Bending is recorded in the agroforestry parklands based on *A. leiocarpus* (54.87%). The highest Brilling is recorded in the agroforestry parklands based on *I. doka* (12.76%) (Table 5).

The diameter structure of the individuals shows that the number of individuals per diameter class decreases with increasing diameter. However, the most abundant individuals belong to the diameter class ≤10 cm. The general distribution of the studied agroecosystems shows an exponential decreasing shape (**L)** with a steep slope Fig. 2. The height structure illustrates the Gaussian "U" model. It shows a peak in the 4-6 m height class with 90% of individuals. Some individuals in the 8-10 m height class are poorly represented. On the other hand, the other height classes account for almost all individuals (8%). These appear to be homogeneous and more or less evenly distributed Fig. 3.

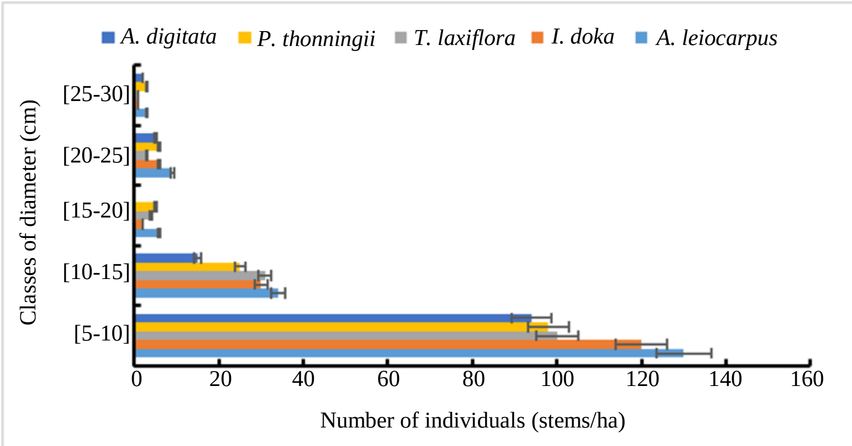

Fig. 2: Distribution by diameter class according to the number of individuals on agroforestry parkland. The values assigned the same letter are not statistically different (p > 0.05; Duncan test)

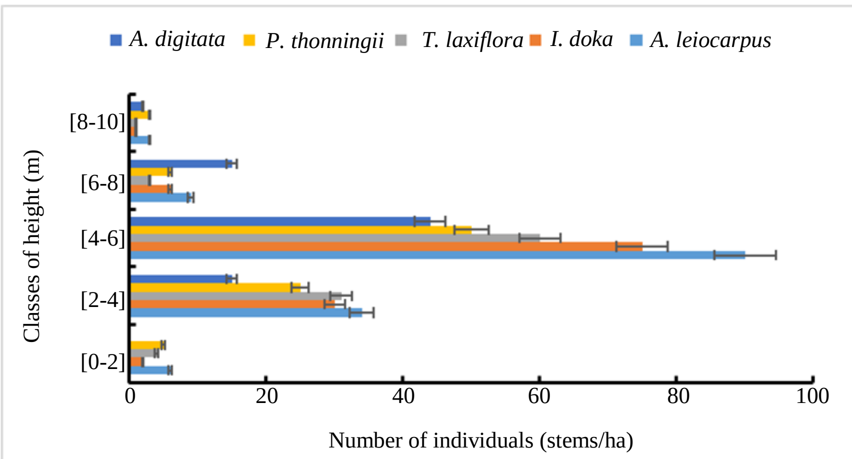

Fig. 3: Distribution by total height class according to the number of individuals on agroforestry parkland. The values assigned the same letter are not statistically different (p > 0.05; Duncan test)

Discussion

The floristic inventory identified a total of 33 woody species, divided into 31 genera and belonging to 20 families in the five agroforestry parks studied. This shows that the undergrowth in the agroforestry parks studied is very diversified. It is marked by a predominance of the family Combretaceae followed by those of Caesalpiniaceae and Mimosaceae in number of species. These results are comparable to those found by (Moussa *et al*., 2015; Morou *et al*., 2016; Manzo *et al*., 2017; Barmo *et al*., 2019; Konsala *et al*., 2020). The dominance of these families could be explained by the fact that most of the species in these families are better adapted to the climatic conditions and human activities in this Sudano-Sahelian zone. The predominance of these families in these zones could also be explained by the fact that these woody formations belong to the same climate type (Guimbo *et al*., 2010). The high floristic diversity recorded in the *A. leiocarpus* agroforestry parkland can be explained by their soil texture, which is very favourable to plant production. These results obtained during the present study are far from those of (Diedhiou *et al*., 2014) who found 54 species divided into 24 families and 43 genera in the agroforestry parks of the village of Mar Fafaco in the large island of Mar and (Kebenzikato *et al*., 2014) who found 52 species divided into 45 genera and 23 families in the *Adansonia digitata* L. (baobab) parks in Togo. They are however related to those of (Guimbo *et al*., 2010) who found 35 species in 33 genera and 20 families in the *Vitellaria paradoxa* parks, (Diatta *et al*., 2016) who found 35 species in 34 genera and 18 families in the agroforestry parks at *Cordyla pinnata* in the Southern Arachid Basin

(Senegal); (Kaou *et al*., 2017) who found 38 species in 17 families and 32 genres in the dune area of south-eastern Niger and (Félix *et al*., 2019) who found 35 species in 32 genera and 17 families in the Sahelo-Sudanian zone of Niger. In general, the reduced number of woody species observed in *I. doka*; *T. laxiflora*; *P. thonningii* agroforestry parks would be linked to the strong selection and choice of plant species to be conserved, maintained or cut during field preparation (San Emeterio *et al*., 2013; Yameogo *et al*., 2013; Sina *et al*., 2016).

The Shannon-Weiner Index ranges from 1.36±0.14 to 2±0.25. High values of the Shannon Index show that all species are well represented and low values suggest a predominance of a few species over others (Dotchamou *et al*., 2016). This may be related to the fact that some species observed on sites with low Shannon index values evolve in stands and not as isolated individuals. These indices are comparable to those obtained by (Amani, 2016) in the agroforestry parks of Tamou (1.91 bits) and Simiri (1.24 bits) in western Niger; (Barmo *et al*., 2019) (1.38-1.73 bits) in agroforestry parks adjacent to the protected forest of Baban Rafi, Niger-West Africa. However, these indices are lower than those calculated in Guidan Roumdji by (Moussa *et al*., 2015) at the park level in *Guiera senegalensis* and *Piliostigma reticulatum*. The low diversity observed in these parks would also be linked to the strong pressure exerted by the population on the one hand and the precarious climatic conditions on the other hand. The Pielou index ranges from 0.14±0.07 to 0.35±0.22 bits, reflecting an overall low woody diversity for all parklands. These results are very similar to those obtained by (Barmo *et al*., 2019) in agroforestry parkland adjacent to the protected forest of Baban Rafi, Niger-West Africa. However, these indices are lower than those calculated by (Dotchamou *et al*., 2016) (0.56 and 0.94) in forest stands in *Parkia biglobosa* in Benin. These Pielou index revealed a dominance phenomenon in all zones. This can be explained by the difference in the adaptive capacities of certain species characteristic of a given climate, enabling them to rapidly colonize natural environments (Abdourhamane *et al*., 2013). Simpson's index tends towards 1 in all parks. This reflects the fact that these parks have a homogeneous distribution of its flora and that the probability of two randomly selected individuals belonging to the same species is high in these stands. The variation in plant diversity between zones is also dependent on population density and the edapho-climatic conditions of the region (Larwanou *et al*., 2012; Félix *et al*., 2019; Garba *et al*., 2020).

The values of the average recovery rates of the parks (6.11±0.21 to 10.12±0.31%), are higher than those of the parks in *Sclerocarya birrea* (3.88%) in the Dan kada Dodo-Dan Gado classified forest complex (Abdourhamane *et al*., 2013). On the other hand, they are lower than those obtained in central southern Niger by (Moussa *et al*., 2015) in the parks at *Faidherbia albida* (29.49%) and *Prosopis africana* (15.71%). But are similar to those of (Barmo *et al*., 2019) (6.82±3.02 to 10.87±6.3%) in agroforestry parks adjacent to the protected forest of Baban Rafi, Niger-West Africa. These differences could be due to the strong pressure (excessive logging, pruning, etc.) exerted by the population on these parks on the one hand and the presence of tall trees with large crowns on the other. Agroforestry parks based on *A. leiocarpus* are the densest with an average density of 223±8.01 individuals/ha. This high density could be due to the effects of new clearings and the practice of assisted natural regeneration in the area. The lowest value is recorded at the level of agroforestry parks with *P. thonningii* (108±2.98 individuals/ha) located in the sedentary zone where these species are exploited by the populations to satisfy their daily needs.

The highest basal area and biovolume were recorded in the agroforestry parklands based on *A. leiocarpus* (Ba = 10.05±1.87 and V = 38.54±3.76 m^3/ha). This indicates the existence of large specimens of trees. Among the species in its undergrowth, some have a high shade rate. The high value of basal area (Ba = 10.05±1.87 m^2/ha) obtained in agroforestry parks based on *A. leiocarpus* is in the range 2.94±0.13-11.56±0.57 m^2/ha found by (Victor *et al*., 2019b) in savanna agrosystems in the Sudano-Sahelian zone of Cameroon. This means that these parks have an important timber potential due to their large diameters. These high biovolume values could be explained by the absence of human activities in these parks. The results obtained in this study are much lower than the 428.68; 285.57; 105.66 m^3/ha found respectively by (Kombate *et al*., 2019) in Agroforests, semi-deciduous dense forests and forest galleries and tree and shrub savannas of the Akposso Plateau in the sub-humid zone of Togo. On the other hand, are located in the ranges 30.84-202.72, 20.80-111.14, 30.05-58.11, 20.82-45.06 m^3/ha found respectively by (Victor *et al*., 2019a) to *Khaya senegalensis*, *Burkea africana*, *Anogeissus leiocarpus*, *Piliostigma reticulatum* Agroforestry parks in the Sudano-Sahelian zone of Cameroon. The highest regeneration rate was observed in agroforestry in *A. digitata* with an average regeneration rate of 10.12±0.31%. This result is higher than those obtained by (Barmo *et al*., 2019) in agroforestry parks adjacent to the protected forest of Baban Rafi, Niger-West Africa. Tree regeneration processes can be influenced by factors such as mode of spread, viability, seed dormancy and predation (Bhadouria *et al*., 2016), water stress, soil structure, temperature, insect attacks, grazing which can delay the transition from juvenile to shrub stage (Sangare *et al*., 2016). The highest mean total height of Lory was recorded in *A. digitata* agroforestry parks with 5.06±0.04 m. This result is similar to those obtained by (Barmo *et al*., 2019) in agroforestry parks adjacent to the protected forest of Baban Rafi, Niger-West Africa.

In *A. leiocarpus* agroforestry parks, *Combretum glutinosum* and *Combretum adenogonium* have the highest SIV and SIR values. However, in *I. doka* agroforestry parks, *Sclerocarya birrea*, *Prosopis africana*, *Entada africana* and *Combretum adenogonium* have the highest SIV and SIR values. On the other hand, in agroforestry parks with *T. laxiflora*, *Prosopis africana* and *Anacardium occidentale* have the highest SIV and SIR values. In the agroforestry parks of *P. thonningii*, *Burkea africana* and *Maytenus senegalensis* have the highest SIV and SIR values. In the agroforestry parks of *A. digitata*, *Burkea africana*, *Combretum glutinosum* and *Ficus glumosa* have the highest SIV and SIR values. The high SIV and SIR values of these species can be related to their high capacity of multiplication by vegetative voice and seed.

The distribution of individuals according to diameter classes varies from one park to another. It shows an inverted "J" curve in the different parks studied, reflecting a good natural regeneration of the parks' flora. This curve also shows a decrease in the number of individuals when the diameter of the individuals increases. This observation was made by in the agroforestry parks of Tamou terroir (Amani, 2016), in the *Faidherbia albida* parks of Dan Saga (Morou *et al*., 2016) and in the agroforestry parks of Baban Rafi (Barmo *et al*., 2019). The abundance of young individuals ensures the future of natural training since it allows a constant renewal of adult individuals. Such a structure is typical of stable populations that are likely to renew themselves through natural regeneration. The height class distribution has an "U" bell structure centered on the height class [4-6 m], thus reflecting a predominance of medium height individuals. This situation is observed in an unstable population characterized by an absence or a very small proportion of individuals in one or more classes (Noumi *et al*., 2018; Victor *et al*., 2020b). It may be one of the consequences of recurring droughts due to the effects of strong pressure on fodder resources (Noumi *et al*., 2018; Victor *et al*., 2020b).

Conclusion

The present study allowed to characterize the woody vegetation of 05 agroforestry parks in the Sudano-Sahelian zone of Cameroon. This study found a total of 33 species distributed in 20 families and 31 genera found in all 05 agroforestry parks. These parks present variable specific and floristic diversities. These diversities are globally low, with a dominance of Sudanian species. The families Mimosaceae, Caesalpiniaceae, Combretaceae dominate in all the parks. The structure of the stands shows a predominance of young individuals for both diameter and height classes in all the parks. This structure also reveals a strong exploitation of large-diameter individuals. In view of these observations, these parks deserve special attention from decision-makers in order to provide appropriate solutions to guarantee their sustainability and the diversity of their function. In view of their social, ecological and environmental importance, such an agroforestry system is considered a factor in local development and the fight against climate change. Agricultural development services should therefore take an interest in the development of these agroforestry parks in order to motivate local communities to develop conservation strategies so that future generations can benefit from them.

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Author’s Contributions

Awé Djongmo Victor: Designed, collected and checked the analyzed data; prepared the draft manuscript and approved the final manuscript.

Noiha Noumi Valery and Zapfack Louis: Designed research plan and supervised this study.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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