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Floristic and structural diversity of woody vegetation in the Sudano-guinean zone of Larmanaye, Chad

Béré NANGNDI[1,4], Marie Louise AVANA TIENTCHEU[1*], Junior Baudoin WOUOKOUE TAFFO[2], Alex Bruno ETCHIKE DONG[3], Dodorom Téblé WOLWAI[4] and Théophile FONKOU[3]

[1]Department of Forestry, Faculty of Agronomy and Agricultural Sciences, University of Dschang, P. O. Box 222 Dschang, Cameroon.
[2]Department of Biological Sciences, Faculty of Science, University of Maroua, P. O. Box 814 Maroua Cameroon.
[3]Department of Plant Biology, Faculty of Science, University of Dschang, P. O. Box 67 Dschang, Cameroon.
[4]Department of Biological Sciences, Faculty of Science and Technique, University of Doba, P. O. Box 03 Doba, Chad.

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This study was carried out in the Larmanaye ecological landscape in the Sudano-guinean zone of Chad. The objective was to analyse the floristic and structural diversity of different woody-vegetation types. Floristic and dendrometric data were collected in 92 plots of 2500 m² to assess woody species with diameter greater than 5 cm, and 460 plots of 25 m² for the assessment of regeneration. The composition, diversity, diameter and height structure, density, species and family importance value of the woody species were described, evaluated and compared among vegetation types. A total of 80 species belonging to 63 genera and 25 families were recorded with 64, 61, 52 and 46 species respectively in tree-based savannah, gallery forest, croplands, and shrubby savannah. The families of Fabaceae and Combretaceae were the richest and abundant in the all woody-vegetation types. Shannon diversity index varied from 3.23 in the gallery forest to 2.72 in the tree-based savannah whereas the Pielou evenness index varied from 0.95 in the tree-based savannah to 0.91 in croplands. The distribution of stems of the main species in classes of diameter and height showed an "L" shaped curve. Mean density varied from 24.70 stems/ha in the tree based savannah to 9.65 stems/ha in the shrubby savannah. The levels of regeneration were low with seedlings proportion of 18.75, 15.83, 10.05 and 9.18%, respectively in croplands, tree-based savannah, gallery forest and shrubby savannah. Protection systems and appropriate management were therefore recommended in order to ensure the sustainability of the forest resources in Larmanaye ecological landscape.

Key words: Floristic diversity, Larmanaye-Chad, regeneration, structure, woody vegetation type.

INTRODUCTION

Forest resources constitute a major component of the environment. In sub-Saharan Africa, forest zones contain more biodiversity, constituting a significant potential for socio-economic development (Ouédraogo, 2006). However, most of the forested landscapes are being transformed by human activities to satisfy their socio-

economic needs (Tankoano, 2017).

In Chad, the main factors driving forest resource degradation are population growth coupled with the effects of climate change (which pushes farmers to look for new agricultural lands), overexploitation of woody species for fuelwood and overgrazing (Ngaryo et al., 2010; Mbailassem, 2012). Consequently, there is a reduction of woody species density in cultivated areas, fragmentation and reduction of forests and other natural environments (Béchir and Zoungrana, 2012). The transformation of natural landscape into agricultural and urban areas is an important factor in vegetation degradation and destruction as well as loss of biodiversity and ecosystem functions (Ngaryo et al., 2010; Khan et al., 2020).

The natural ecological landscape of Larmanaye is one of the Sudano-guinean zones in Chad known as a home to an exceptionally rich biodiversity, many of which are poorly documented and threatened (Brugière and Scholte, 2013).

In addition, the area constitutes an attractive zone for many nationals and foreigners involved in transhumance, due to its high agroecological potentials (Mbailassem, 2012).

Today, under the combined effect of increased population and their need for cultivable lands, Larmanaye landscape is being transformed to traditional land-use systems such as shifting cultivation, extensive livestock grazing, fuelwood collection and harvesting of timber and non-timber forest products. Thus, there has been a large-scale transformation of vast and continuous expanses of natural vegetation formations into grazing lands, settlements, farmlands and fallow lands. These vegetation types constitute potential sites of pasture and habitats for fauna (Brugière and Scholte, 2013) as well as areas for the settlement of incoming populations. Some studies have been carried out on the functional and structural aspects of the woody-vegetation types in different areas of Chad (Melom et al., 2015; Madjimbe et al., 2019; Mbaiyetom et al., 2021). However, very little information exists on the floristic and structural characteristic of the Sudano-guinean area of the Larmanaye zone of Chad. Understanding the afore-mentioned is pertinent as it will enable to comprehend the evolution of the vegetation and to develop well informed strategies for sustainable management of this unique landscape.

The aim of this study was therefore to assess the floristic diversity and structural characteristics of woody-species in the vegetation types of Larmanaye ecological landscape.

MATERIALS AND METHODS

Study site

The study was carried out in Larmanaye, Monts de Lam Division, Logone Oriental Region of Chad. The study area is located between latitude 7°48'- 8°24' N and longitude 15°18'- 15°36'E (Figure 1). The climate is defined as the Sudano-guinean type. The annual average rainfall varies between 800 to 1300 mm. The annual average temperature is 26°C (DREM- Tchad, 2016). The predominant soils are red ferralitic soils (clayey-sandy) and hydromorphic soils (Atlas, 2012). The vegetation is characterized by savannahs (trees, shrubs and grasses), open forest and gallery forest. According to Baohoutou (2007) some plant genera dominate including *Burkea*, *Prosopis*, *Parkia*, *Pterocarpus*, *Isoberlinia*, *Daniellia*, *Combretum*, *Terminalia*, *Anogeisus* and *Sclerocarya*.

Data collection

Sampling was done during the peak period of plants flowering (October-November 2019), using the quadrat method for inventory of the flora. The stratified sampling method was used. Inventory was done in plots of 50 m × 50 m. In order to identify most of the species, plots were established about 400 m away from each other. The surface area occupied by each vegetation type in the ecological landscape of Larmanaye was the main criteria for choosing the number of plots per vegetation type. A total of 92 plots of 2500 m² were established with 7 in the gallery forest, 39 in tree-based savannah, 30 in shrubby savannah and 39 in cultivated areas and fallows. In total, 23 hectares was sampled. All plots geo-localised using a GPS. Within each plot, all trees with diameter at breast height (DBH) ≥ 5cm and all shrubs were systematically recorded and their diameter measured at 20cm of height. Trees with diameter smaller than 5 cm were considered as regeneration (Mahamane and Saadou, 2008). For the inventory of regeneration, 5 sub-plots of 5 m x 5 m were established in each plot of 2500 m², one each placed at all the four corners and at the centre of the plot. The measurements of natural regeneration were taken on the seedlings with height ≤ 50 cm from the ground. Scientific identification of the most common species was done directly in the field whenever possible. Herbarium specimens were collected on unidentified species in order to authenticate scientific names in the herbarium of the Laboratory of Veterinary and Zootechnical Research of N'Djaména. Angiosperms phylogenic group classification was adopted (APG IV, 2016).

Data analysis

The species composition of the different woody-vegetation types was described using the following parameters:

(i) The relative frequency (RFr) of species i is given by the formula: RF = (Ai/B) *100, where Ai=Number of plots containing the species i

*Corresponding author. E-mail: avanatie@yahoo.fr. Tel: (+237) 677653225.

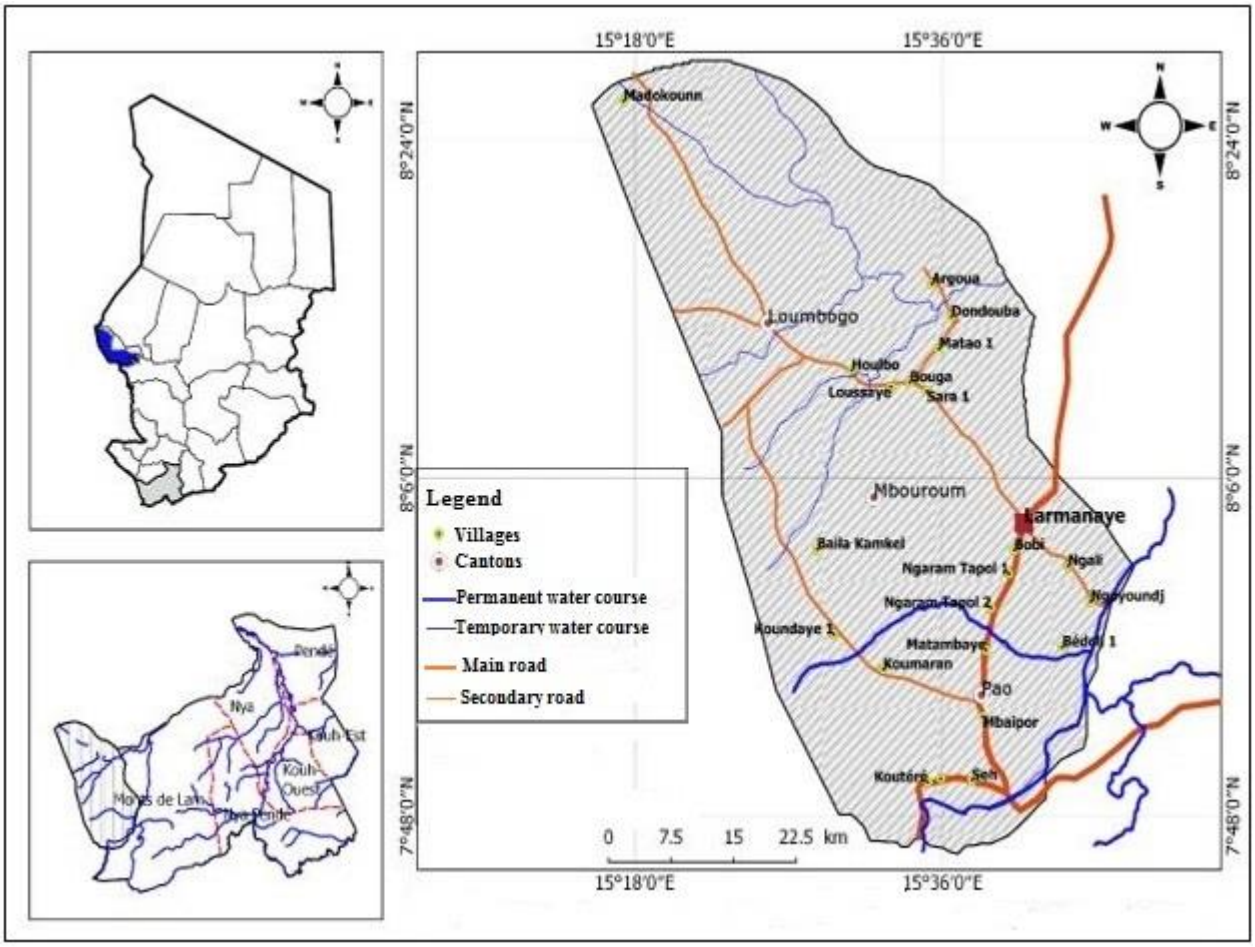

Figure 1. Location of Larmanaye.

and B=total number of plots sampled.
(ii) Relative dominance (RDo) represents the recovery area for the species i of one population. It is given by the follow formula: RDo= $\pi Di^2/4$, RD = relative dominance; Di = diameter at breast height of the specie i; π=3.14. (iii) Relative density (RDe) of species was calculated according this formula: RDe = Pi*100, where Pi=ni/N, ni is the number of individuals belonged to taxon i and N is total number of individuals of all sampled plots.
(iv) Relative diversity (RDi) is given by the formula: RDi = number of species of one family*100/ total number of species.
(v) Density (stems/ha) of each species were calculated according to this formula: D = ni/A where ni is the number of individuals belonging to species i and A is the area in hectares.
(vi) Basal area (BA) is given by the formula (Mbaiyetom et al., 2021): BA= $(\sum \pi Di)^2/4$, where D is diameter at breast height and S in m^2/ha.
(vii) Important Value Index (IVI) is given by the relation: IVI= relative density + relative frequency + relative dominance.
(viii) Family Important Value (FIV) is given by the relation (Mbaiyetom et al., 2021): FIV= relative density + relative diversity+ relative dominance.

Specific diversity of the site was described using the following indices: Shannon and Weaver (1949) index is calculated according to the formula: $H' = \sum ni/N \log_2 ni/N$. The equitability index of Pielou (1975) is calculated according to the formula: Eq= H'/Hmax=H'/lnS. The dynamics of species renewal was evaluated using regeneration rate such as seeds germination and rejections. XLStat 16.02 was used for data analysis.

RESULTS

Floristic characteristics

In the study area, 2298 individuals with DBH ≥ 5 cm belonging to 80 species, 63 genera and 28 families were recorded. The most represented families in terms of species were: Fabaceae (32 species), Combretaceae (12 species), Moraceae (6 species), Phyllanthaceae (6 species) and Anacardiaceae (5 species) (Figure 2). The remaining families were represented by less than 3

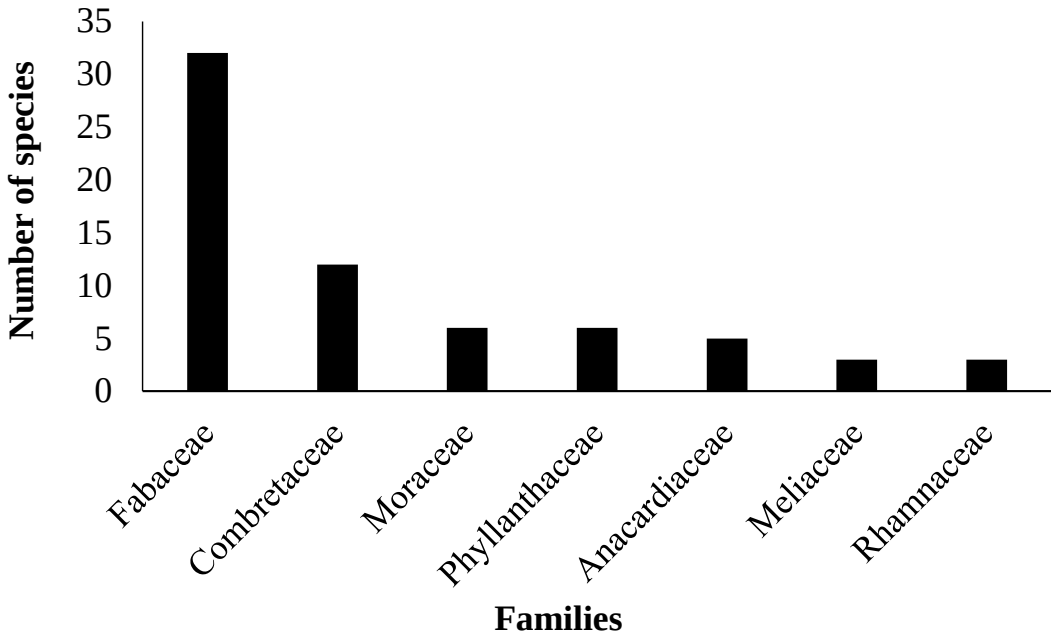

Figure 2. Richest families in the ecological landscapes of Larmanaye, Chad.

Table 1. Diversity indices in the different woody-vegetation types in the ecological landscape of Larmanaye.

Diversity indices	Woody-vegetation formations			
	Gallery forests	Croplands	Tree-based savannah	Shrubby Savannah
Species richness	61	52	64	46
Maximum diversity	4.11	3.95	4.16	3.83
Shannon-Weaver index	3.23	3.06	2.72	3.22
Pielou evenness index	0.93	0.91	0.95	0.92

species. Species richness was higher in tree-based savannah with 64 species belonging to 25 families, followed by gallery forests with 61 species belonging to 22 families and croplands with 52 species regrouped into 48 genera and 18 families (Table 1). The lowest species richness was in shrubby savannah (46 species belonging to 17 families).

Specific diversity

The diversity indices varied between woody-vegetation types. Shannon-Weaver diversity index was higher in the gallery forest (3.23), followed by shrubby savannah (3.22) (Table 1). This indicates a moderate floristic diversity of these wood vegetation. The Piélou evenness index (E) was higher for the tree-based savannah (0.95) and lower in croplands (0.91).

The similarity index of Jaccard was higher than 50% between gallery forests and croplands, gallery forests and shrubby savannah, gallery forests and tree-based savannah, tree-based savannah and croplands (Table 2). This index was lower than 50% between shrubby savannah and croplands. Indices higher than 50% mean that the two woody-vegetation types are floristically similar.

Ecological importance indices

The ecological importance of species was determined by the Importance Value Index (IVI). It was variable for each woody-vegetation types according to species but the variability was not statistically significant (p=0.167). In the gallery forests, species with high ecological importance (IVI) were: *Isoberlinia doka* (13.11), *Terminalia*

Table 2. Similarity index within different vegetation types.

Plant formations	Gallery forest	Cultivated area and fallows	Shrub savannah	Tree savannah
Gallery forest	100			
Cultivated area and fallows	**57.3**	100		
Shrub savannah	**57.5**	43.2	100	
Tree savannah	54.9	53.5	47.5	100

Table 3. Family importance value of different woody-vegetation types in the ecological landscape of Larmanaye.

Families	Family importance value of different woody formations			
	Gallery forest	Croplands	Tree-based savannah	Shrubby savannah
Fabaceae	77.60	80.68	67.64	90.47
Combretaceae	42	41.63	40.89	39.80
Phyllanthaceae	16.72	22.67	21.22	13.70
Sapotaceae	10.19	14.97	14.04	29.36
Meliaceae	15.50	4.82	16.20	24.26
Moraceae	12.30	18.68	13.56	7.47
Burseraceae	19.74	9.28	13.44	
Malvaceae	11.64	7.64	8.85	12.33
Ebenaceae	6.76		9.83	21.88
Ochnaceae	8.83	11.89	7.31	10.22
Rosaceae	8.20	13.27	7.20	6.82
Annonaceae	5.95	13.85	3.50	11.37
Rubiaceae	4.92	10.90	5.22	8.76
Anacardiaceae		15.71	12.71	
Olacaceae	6.67	6.76	6.89	6.35
Rhamnaceae	8.10	6.36	5.73	5.38
Myrtaceae	9.33	8.99	5.56	
Ulmaceae	19.13			
Bombacaceae			15.17	
Loganiaceae	3	6.69	5.07	
Polygalaceae	2.79	5.21	3.35	2.96
Zygophyllaceae	1.56		4.42	6.23
Clusiaceae	7.50		4.13	
Tiliaceae	1.56		3.57	2.65
Hypericaceae			3.13	
Loranthaceae			1.39	

macroptera (10.50), *Pterocarpus lucens* (10.11) whereas in the tree savannah species with high IVI were *Daniellia oliveri* (22.45), *Vitellaria paradoxa* (17), *Parkia biglobosa* (16.27), *Combretum glutinosum* (11.42), *Terminalia schimperiana* (10.64) and *Annona senegalensis* (10.48). In croplands, species with high ecological importance characterized by high IVI were: *A. senegalensis* (13.97), *P. biglobosa* (12.68), *Hymenocardia acida* (11.33) and *D. oliveri* (10.96) whereas in the shrub savannah, species with high IVI were: *Bridelia ferruginea* (11.43), *D. oliveri* (10.86) and *T. schimperiana* (10.59). The analysis of variance showed that there was no significant difference (p=0.167) between IVI of the different woody-vegetation types. These species characterized the woody-vegetation physiognomy of the Larnanaye landscape.

The ecological importance of families was determined by the family important value (FIV) (Table 3). These values were variable for each woody-vegetation type

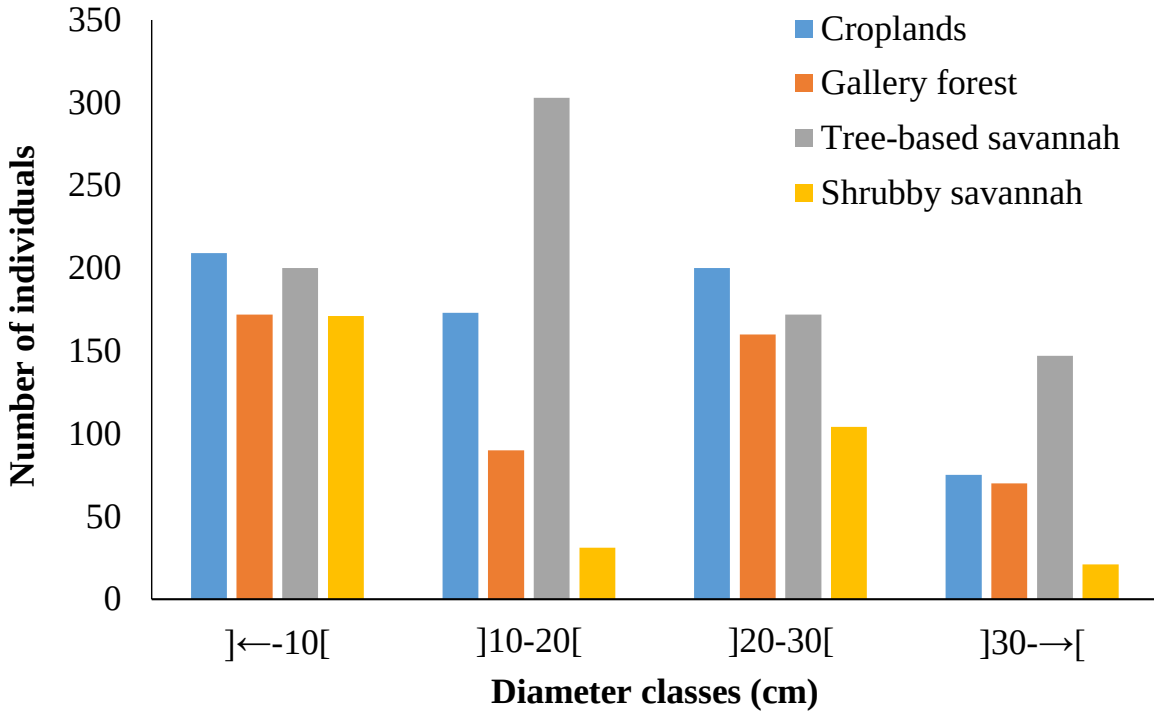

Figure 3. Distribution in diameter classes of individuals in the woody-vegetation types of Larmanaye ecological landscape.

according to families but the difference was not significant (p=0.993). In the shrubby savannah, families with high ecological importance (FIV) were: Fabaceae (90.47), Combretaceae (39.80) and Sapotaceae (29.36) whereas in croplands, families with high FIV were Fabaceae (80.68), Combretaceae (41.63) and Phyllanthaceae (22.67). In the gallery forests, families with high FIV were Fabaceae (77.60), Combretaceae (42), Phyllanthaceae (16.72) and Burseraceae (19.74) whereas in the tree-based savannah, families with high FIV were Fabaceae (67.64), Combretaceae (40.89) and Phyllanthaceae (21.22).

Diametral structure of woody-vegetation types

The distribution of individuals in diameter classes in different woody-vegetation types showed a structure in ‘‘L’’ shape. The greatest number of individuals were in the lower diameter class [←- 10[cm in croplands, gallery forests and shrubby savannah whereas in the tree-based savannah, the greatest number of individuals was observed in the diameter class [10-20[cm. The smallest proportions of individuals was observed in the diameter class [30- →[cm for all woody-vegetation types (Figure 3). Mean diameter was highest in gallery forests (22.21 cm) followed by tree-based savannah (17.24 cm), shrubby savannah (11.03 cm) and lowest in croplands (9.76 cm).

Vertical distribution

The distribution of individuals with respect to their height in the different woody-vegetation types showed a structure in ‘‘L’’ shape (Figure 4). The individuals with highest length of 15 m were rare in the studied woody-vegetation types. It was noted that, the individual’s height did not exceed 15 m in the shrub savannah and, croplands. Mean height was higher in the gallery forests (6.65 m), followed by tree savannah (5.54 m), shrub savannah (3.60 m) and croplands (3.23 m).

Density and basal area

In total, 2298 woody plants (DBH ≥ 5 cm) were recorded in 23 ha with mean density of 67.87 stems/ha. Mean density varied from 24.70 stems/ha in the tree-based savannah, 18.35 stems/ha in the gallery forests, 15.17 stems/ha in croplands, and 9.65 in shrubby savannah.

The species with high stem density were: *D. oliveri*

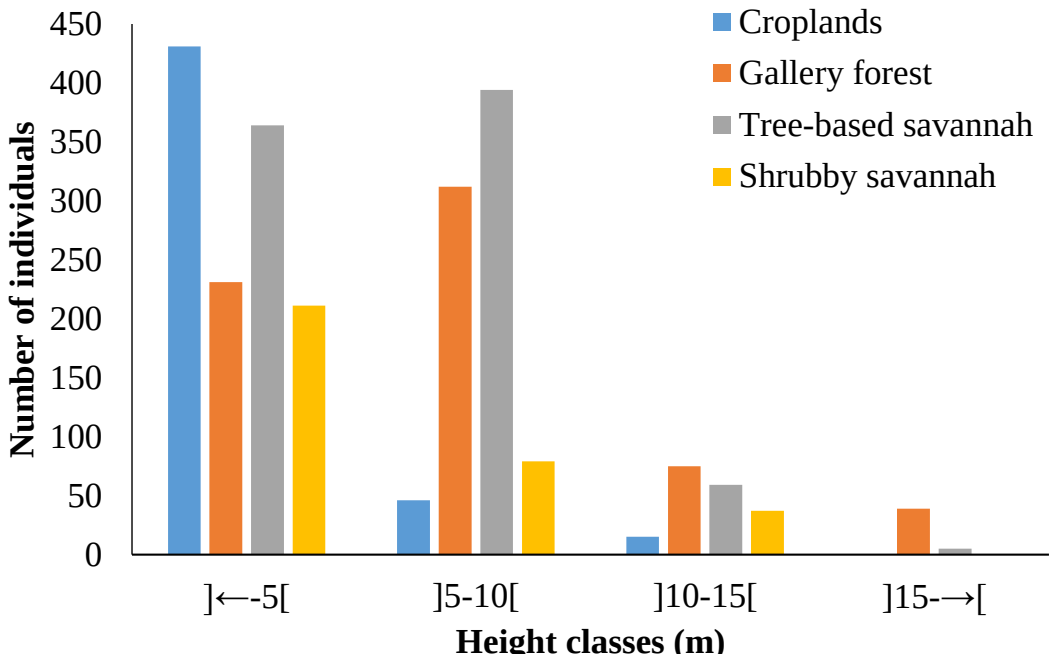

Figure 4. Distribution of individuals stems according to height classes in the vegetation types of the Larmanaye ecological landscape.

(5.70 stems ha^{-1}), *A. senegalensis* (4.96 stems ha^{-1}), *T. schimperiana* (4.91 stems ha^{-1}), *Terminalia macroptera* (4.71 stems ha^{-1}), *Isoberlinia doka* (4.48 stems ha^{-1}), *B. ferruginea* (3.52 stems ha^{-1}) and *Detarium microcarpum* (3.48 stems ha^{-1}).

Basal area was highest in the gallery forests (31.42 m²/ha), followed by tree-based savannah (18.74 m²/ha), shrubby savannah (8.63 m²/ha) and lowest in the croplands 6.43 m²/ha. The most represented species was *P. biglobosa* in all the woody-vegetation types with 17.35 m^2/ha of basal area, followed by *Canarium schweinfurthii* (13.50 m^2/ha), *Khaya senegalensis* (10.58 m^2/ha), *Afzelia africana* (8.73 m^2/ha) and *Celtis toka* (8.56 m^2/ha).

Regeneration potential

In the study area, a total number of 1237 seedlings and saplings were counted as regeneration in the woody-vegetation types. The global rate of regeneration for the woody species sampled was 53.82% with a rate of 18.75% in croplands, and 15.83, 10.05 and 9.18%, respectively in the tree-based savannah, gallery forests, and shrubby savannah. Species with the highest regeneration capacity and greatest density of regeneration were: *D. oliveri* (6.65 seedlings ha^{-1}), *A. senegalensis* (3.52 seedlings ha^{-1}), *T. schimperiana* (2.96 seedlings ha^{-1}), *D. microcarpum* (2.74 seedlings ha^{-1}) and *H. acida* (2.52 seedlings ha^{-1}).

DISCUSSION

Floristic characteristics of the woody vegetation types in the Larmanaye ecological landscape

The number of species, genera and families recorded in all the woody-vegetation types was 80 species belonging to 63 genera and 28 families. These results were similar to those of Savadogo et al. (2007) who recorded a total of 89 species representing 66 genera and 29 Families in the Tiogo forest, Burkina Faso. In the same line, Froumsia et al. (2012) recorded 86 woody species representing 58 genera and 28 families in the Kalfou Forest Reserve, Cameroon, and Madjimbé et al. (2019) recorded 87 species belonging to 56 genera and 22 families in the Manda park, Chad. However, the studies of Mbaiyetom et al. (2021) in the Sudanian zone of Chad found fewer number of species with 29 species belonging to 29 genera and 18 families. The differences observed in these studies could be attributed to the difference in the level of anthropogenic pressures such as agricultural activities, overgrazing, population growth and bush fires (Jhariya et al., 2012). The relatively high species richness in the present study area could be due to the lower anthropogenic pressure associated with the high diversity

of woody species found in the existing vegetation types studied which include gallery forest, tree savannah, shrub savannah and cultivated areas and fallows. The difference in species composition among different vegetation types may be due to micro-site factors.

The most represented families based on number of species were: Fabaceae, Combretaceae, Moraceae, Phyllanthaceae, Anacardiaceae. The zone can be described as a shrubby zone dominated by thorny species constituted of Fabaceae and Combretaceae. The Fabaceae, Combretaceae families were also the most represented in the Ngazobil (Joal-Fadiouth) reserve in Senegal (Diatta et al., 2009), in the Manda national park in Chad (Madjimbé et al., 2019). These two families also dominated the Guidan Roumdji vegetation in Niger) (Ousmane et al., 2017), as well as the Sudano-sahelian zones of North Cameroon (Froumsia et al., 2019).

The Shannon-Weaver diversity index was greater than 3 except in tree-based savannah. These values indicate that the woody-vegetation types have a high diversity (Wouokoue et al., 2017). The higher value of Shannon-Weaver diversity index obtained in the croplands could be due to the high number of plots laid out in vegetation type dominating the study area. Piélou evenness index was high in all woody-vegetation types. These values mean that the distribution of individuals across species is very equitable in all woody-vegetation types studied. These results were similar to those of Madjimbé et al. (2019) in the Manda park of Chad who found Shannon diversity indices higher than 3.12, 5.23 and 4.74 for the different vegetation types sampled and Zampaligré et al. (2020) who obtained Shannon index of 4.5 for tree-based savannah and 4.21 for shrubby savannah in the Dinderesso vegetation in Burkina Faso.

Diametral and height structure of the vegetation types of the Larmanaye ecological landscape

The height and the diameters of the different woody species in all the sampled vegetation types showed a structure in the form of an ‘‘L’’ shaped curve. This structure results from frequent wood collection which puts pressure on exploitable stems of the vegetation. It was found that a high proportion of stems of thee woody species surveyed had smaller height and diameter for the all the woody-vegetation types indicating a good regeneration within the landscape. Woody stems with large diameter were rare. A great number of stems were recorded within the diameter smaller diameter class (]←-10[cm), indicating the high number of small trees and their contribution to the shrubby vegetation type. According to Whitmore (1990), the high densities of low diameter classes ensured the future of natural vegetation while the low densities of larger classes trees resulted from natural selection. This stem class is in fact constituted of the seed-bearers which ensured the sustainability of the woody cover. Similar results were found by Froumsia et al. (2012) in Kalfou Forest Reserve, Cameroon and Mbayngone et al. (2017) in the Massenya natural vegetation in Chad. Human disturbance in must vegetation types was shown through stumps from cut stems, bush fires, overgrazing and other factors, that influenced biodiversity by reducing the number of stems, and affecting species diversity and their abundance (Kabre et al., 2009; Wouokoue et al., 2020).

In terms of distribution with respect to height of the stems, the structure showed a high number of individuals in the lower height class ([←-5] m) as observed in gallery forest, shrubby savannah and, croplands whereas in the tree-based savannah, the medium height class ([5-10]m) presented the greatest number of individuals. The high number of seedlings showed a good natural regeneration. The great number of individuals with height less than 5 m showed either the predominance of shrubby species, or the influence of anthropogenic activities dominated by cutting of individuals for fuelwood which contributed enormously to the height reduction of individuals. In savannah ecosystem, trees rarely reach 10 m of height. It is therefore imperative under these conditions to take measures that favour conservation and the sustainable management of woody-species formations (Jhariya et al., 2019).

Density and basal area Larmanaye ecological landscape

The stem density in the present study was higher than the one (28.52 stems ha^{-1}) recorded by Mbaiyetom et al. (2021) in the Sudanian parklands of Chad. The difference in the results lies on the fact that the present study was carried out in several woody-vegetation types. Basal area was in relation to the individual diameter and the species density. The values of basal area in different woody-vegetation types were higher than those of Mbaiyetom et al. (2021) who recorded a basal area of 4.07 m^2/ha in the Sudanian parkland of Chad, but similar with those obtained by Mbayngone et al. (2008) in Pama reserve Burkina Faso and Adjonou et al. (2009) in the Oti- Kéran national park of Togo.

Regeneration potential in the different vegetation types of the Larmanaye ecological landscape

The high regeneration potential observed in the present study could be considered as a testimony of the renewal of woody resources in the Larmanaye ecological landscape. Diatta et al. (2009) in the reserve of Ngazobil

(Joal-Fadiouth) in Senegal, observed significant regeneration potential. Species with high regeneration and the greatest density of seedlings were: *D. oliveri, A. senegalensis*, *T. schimperiana*, *D. microcarpum* and *H. acida*. The processes of tree regeneration could be influenced by certain factors such as the dissemination mode, viability, dormancy and the predation of seeds (Condit et al., 2000). This good regeneration also indicates that the anthropogenic pressure such as bush fire and overexploitation and seed bearers stems still have less impact on the vegetation dynamics in the studied landscape. Earlier studies has shown that regeneration of many woody species was made difficult by the harmful action of bush fires and grazing (Thiombiano et al., 2003).

Conclusion

The ecological landscape of Larmanaye had a large number of woody species with a high diversity. The woody flora was dominated by shrubs with the predominance of Fabaceae and Combretaceae families. The most important species in terms of importance value index (IVI) found in all woody-vegetation types were: *D. oliveri, P. biglobosa, V. paradoxa, A. senegalensis* and *T. schimperiana*. Structural parameters showed a very high proportion of individuals with small diameter and height. The renewal of species through regeneration was good. It is imperative to develop strategies for the management of seedlings to ensure availability of wood products and services for the surrounding and growing populations. The floristic potential of the zone showed the need for preservation of these natural resources, which can only be achieved through a sustainable management of the woody-vegetation for the benefit of future generations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

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AUTHORS' CONTRIBUTIONS

BN and DTW collected data in the field. BN, MLAT, JBWT, ABED and FT drafted the manuscript. BN, MLAT and JBWT analysed the field data. MLAT and TF supervised the work. All authors read and approved the final manuscript.

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