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Analysis of the structure and ecology of *Diospyros mespiliformis* in the drained area of Western Niger

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ABSTRACT: The ecology of a species is a fundamental aspect in its sustainable management. The objective is to study the ecological and floristic characteristics of plant formations with D. mespiliformis. The study was conducted in western Niger along the main tributaries of the Niger River crossing two agroecologicals compartments. Abiotic factors and forestry data where collected in 220 plots of 2500 m^2. Thus, the species is present in all types of soil in the area near streams. The area is moderately diverse with 41 woody species dominated by D. mespiliformis with 50% of Importance Value Index. The Shannon diversity index was 2.61 in Dargol and 2.19 in Goroubi and the Sorensen similarity index between the two zones was 0.62. The density of *D. mespiliformis* per hectare is 46.04 in Dargol and 33.19 in Goroubi. The demographic structure of its population of all species shows a dominance of small diameter individuals evolving into sawtooth characterized by anthropogenic pressure. These results constitute a scientific basis for the sustainable management of this food and multi-use species, which is one of the species in decline in the area.

KEYWORDS: *Diospyros mespiliformis,* ecology, structure, Niger.

1 INTRODUCTION

The Sahel environment is generally described as an area of low vegetation diversity where agriculture is the pricipal activity, especially in rural areas. In addition to this agriculture, plant resources are exploited in various ecosystem services. Among these resources there is *D. mespiliformis*. In Niger it is one of the 10 most used woody species [1]. It has been shown to be used variously in food [1-5] and in traditional medicine [1] and [6-8]. Ethnobotanical surveys at the national level [9] or in some localities where the species is one of the dominant forest species [8] show that it is in decline. Its habitat consists of Sahelo-Sudanese groves with Guinean forests, forest galleries, river banks, termite mounds and rocky hills, generally on heavy and well-drained soils [10]. In Niger its occurrence area is the southern strip of the country constituting the most watered part. Indeed, this area is also the agricultural zone of Niger but also the most densely populated [11] with consequently an increase in anthropogenic pressure on natural resources from which is D. mespiliformis. Thus, in a context of climate change before any operation tending to conservation or restoration, it is important to make a clarification on the current state of the population of species in relation to the population of the environment. Better, the climate projection to 2050 shows for the species a progressive trend in the Sudanian zone [12] and regressive in the Sudano-Sahelian zone [12]. Given its high use value and the threats it faces in Niger, it is reasonable to characterize its population for its sustainable valorization. The objective is to study ecological and floristic characteristics of plant formations with D. mespiliformis. Specifically, it involves: (i) analysing the diversity of woody flora; (ii) determine the demographic structure of the settlement and; (iii) analysize the environmental variables in D. mespiliformis occurrences area.

2 MARETIEL AND METHODS

2.1 STUDY AREA

The study was carried out in western Niger along Dargol and Goroubi which are the tributaries of the Niger River (Figure 1). These tributaries are in the two agro-climatic zones [14] of Western Niger (North-Western Sudanian compartment (A1) and the South-Western Sahelian compartment (B1)) where *D. mespiliformis* is present. In this area agriculture, livestock and fishing are the main socio-economic activities of the population. The vegetation is composed of low dry forest on the lateritic plateaus, gallery forest on the banks of the Dallols, clear forest on the southern clay terraces and in the toposequences of valleys, savannahs in dry valleys and on fixed dunes overlooking the valleys [14] in the western North Sudanian compartment (A1). While in the Western South Sahelian compartment (B1), vegetation is composed of Combretum forest on lateritic plateaus, steppes on sandy terraces, in dry valleys and on fixed dunes [14]. The tributaries of the Niger River flowed on the Liptako Gourma socle. Most of the formation is characterized by pleated volcano-sedimentary series, metamorphosed, intersected by syn and post-tectonic granites and tectonic molassic deposits [15]. Soils are non-leached tropical ferruginous types with concretions, sub-arid brown soils on clay-sandy material, hydromorphic to pseudoglay soils from calco-alkaline granites and verisols [16]. In the tributary zone, the annual average minimum and maximum temperatures are 24.45°C and 34.65°C respectively. The average annual rainfall is 518 mm (between 2002 and 2020). The Dargol is a tributary of the Niger River that passes through the departments of Gotheye and Tera for 150 km. These departments totalled 577.250 habitants, of which 49.42% were men and 50.57% women corresponding to a density of 37hts/km^2 [11]. The Goroubi is also one of the tributaries of the Niger River which crossed Say and Tororodi departments over 152 km. In these departments, 358.238 inhabitants were recorded, 51% of whom were men and 49% women, i.e. a density of 24habitants/km^2 [11].

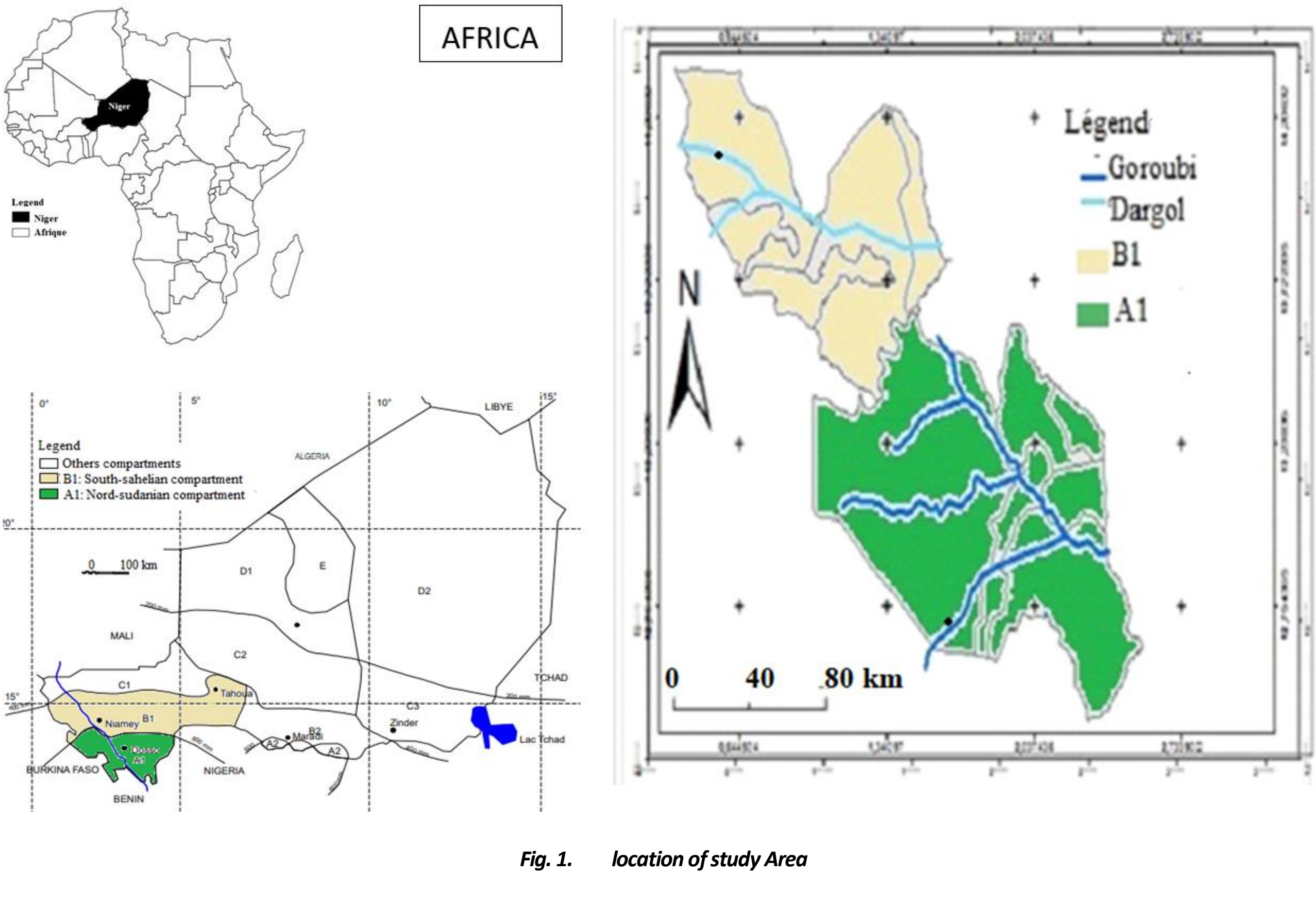

Fig. 1. location of study Area

Figure 2 shows some D. mespiliformis parklands in Dargol (Fig1.A) and in Goroubi (Fig B)

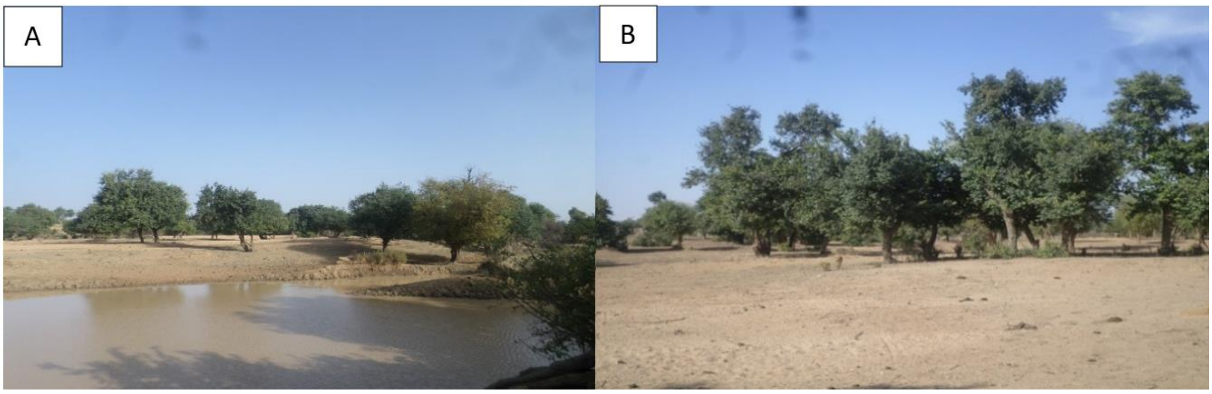

Fig. 2. population of Diospyros mespiliformis

2.2 Data Collection

Data were collected on plots measuring 50 m × 20 m (1000 m^2) along regular transects 5 km apart and perpendicular to streams taking into account geomorphology, moisture gradient and land cover types, the distance between two consecutives plots was 500 m individuated using a GPS (Figure 3). The environment of each plot was characterized by ecological descriptors such as soil type, type of plant formation, indicators of anthropogenic activities. In each plot, measurements of dendrometric parameters were made on individuals of diameter ≥ 5 cm. These measurements concerned diameter (measured at 1.3 m for trees and 0.2m for shrubs), height. Apart from these parameters, bole height was measured for the species D. mespiliformis.

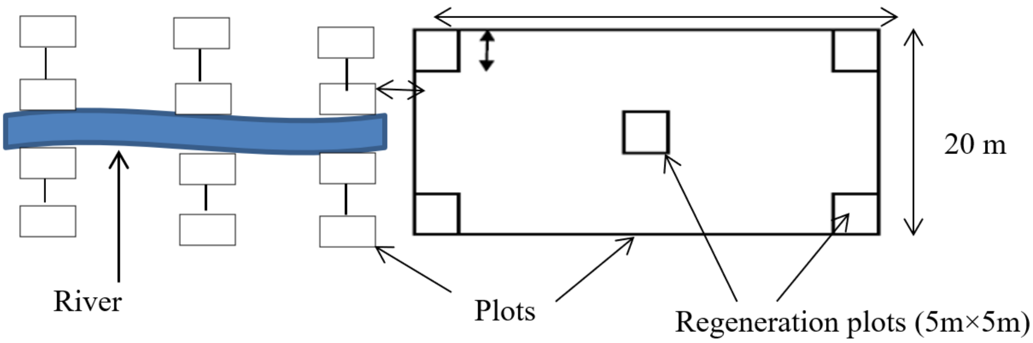

Fig. 3. Forest inventory system

2.3 Data Analysis

2.3.1 Diversity And Regularity Indices

The diversity of the flora of a territory are very useful criteria, particularly from the point of view of historical phytogeography [17]. The diversity and regularity indices are evaluated on surveys in order to assess the level of organization of the stand.

- Alpha diversity index and Piélou Equitability

The Shannon-Weaver diversity index (H') varies according to the number of species recorded and the number of each species. Diversity is low when H' is less than 3, medium if H' is between 3 and 4 and then high when H' is greater than or equal to 4 [18]. It is expressed in bits per individual and its formula is:

$$H' = -\sum_{i=1}^{s} pi\log_2 pi$$

with S being the total number of species and pi the relative frequency of the species.

The Piélou evenness index was calculated from the formula:

$$E=\frac{H'}{H'max} \text{ et } H'max=\log_2 S$$

The Piélou evenness index varies between 0 and 1. It tends to 0 when there is a dominance phenomenon and tends to 1 when the distribution of individuals between species is regular.

SORENSEN'S COEFFICIENT

Sorensen's coefficient [19] was calculated to evaluate beta diversity, which allows for comparisons between habitats. This index expresses the degree of similarity between the two sites and has the formula:

$$Is=\frac{2C}{2C+A+B}$$

with A the number of species belonging only to site 1; B the number of species belonging only to site 2 and C the number of species common to both sites.

SPECIES IMPORTANCE VALUE INDEX

The relative importance of each species is determined by calculating an Importance Value Index (IVI) of [20] which was used by [15] and [21-23]. This index is the sum of relative density, relative dominance and relative frequency of the species:

$$IVI = Dr + Cs + Fr$$

where Dr is the relative density (number of individuals of the species considered in relation to the total number of individuals, x 100), Cs is the relative basal area (basal area of the species considered in relation to the total basal area of the stand, x 100) and Fr is the relative frequency (frequency of the species considered in relation to the sum of the frequencies of all species, x 100). The IVI ranges from 0 to 300.

2.3.2 FOREST INVENTORY PARAMETERS

The assessment of dendrometric parameters of woody plants in general and for D. mespiliformis was evaluated through:

- The stem density

$$N=n/s$$

N is the average number of trees per hectare and n is the number of trees in the plot and s is the area in hectares

- The average diameter which is expressed by:

$$D_g = \sqrt{\frac{1}{n}\sum_{i=1}^{n} d_i^2}$$

n being the number of trees in the plot and di the diameter (in cm) of tree i.

- The average basal area which is expressed by the formula:

$$G = \frac{\pi}{40000\,s}\sum_{i=1}^{n} d_i^2$$

- The basal area contribution of a species which is:

$$Cs=100\frac{Gp}{G}$$

Gp: basal area of trees of a given species; G: basal area of all trees.

- The Lorey's height H_L $H_L = \frac{\sum_{i=1}^{n} gihi}{\sum_{i=1}^{n} gi}$ with gi = π/4 di^2

(gi is the basal area of tree i, h is the height of tree i, and di is the diameter of tree i).

2.3.3 DEMOGRAPHIC STRUCTURES

The woody plants were then divided into diameter classes on the one hand and height classes on the other hand through their relative frequencies.

For this purpose, 18 diameter classes of 5 cm amplitude and 18 height classes of 2m amplitude were defined. In addition, to better understand the variability of the shapes of the observed structures and to make comparisons between structures possible, an adjustment to the theoretical Weibull distribution based on the maximum likelihood method was applied with the Minitab 16.0 software. The Weibull distribution is characterized by a great flexibility of use and its probability density function has the following form [24]:

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} \exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

Where x is the diameter or height of the trees and f (x) its probability density value; a is the position parameter; b is the scale or size parameter and c is the shape parameter related to the observed structure. When c< 1 the distribution is inverted "J"; when c = 1 the distribution is a decreasing exponential function. For c > 1 the distribution is a unimodal function. If 1< c < 3.6 the distribution is positive skewed with predominance of young individuals, when c = 3.6 the distribution is approximately normal, and when c > 3.6 the distribution is negative skewed with predominantly aged individuals stands.

3 RESULTS

3.1 ECOLOGY

Data on frequencies of environmental factors in plots and species in sites were subjected to principal component analysis (PCA) and revealed that the first two axes concentrate more than 89.2% of the total variance (Figure 4). Axis 1 alone centralizes 55.8% and the second axis 33.4%. The analysis of the factorial plan shows that the environmental factors according to axis 1 brings out on the positive part the type of occupation, i.e. from garden to fields and fallow land. On the negative side, we observe the type of soil. Axis 2 highlights the geomorphological gradient from the positive to the negative part. This analysis shows that this species adapts to all textures and all types of cover land use as long as the environment is drained.

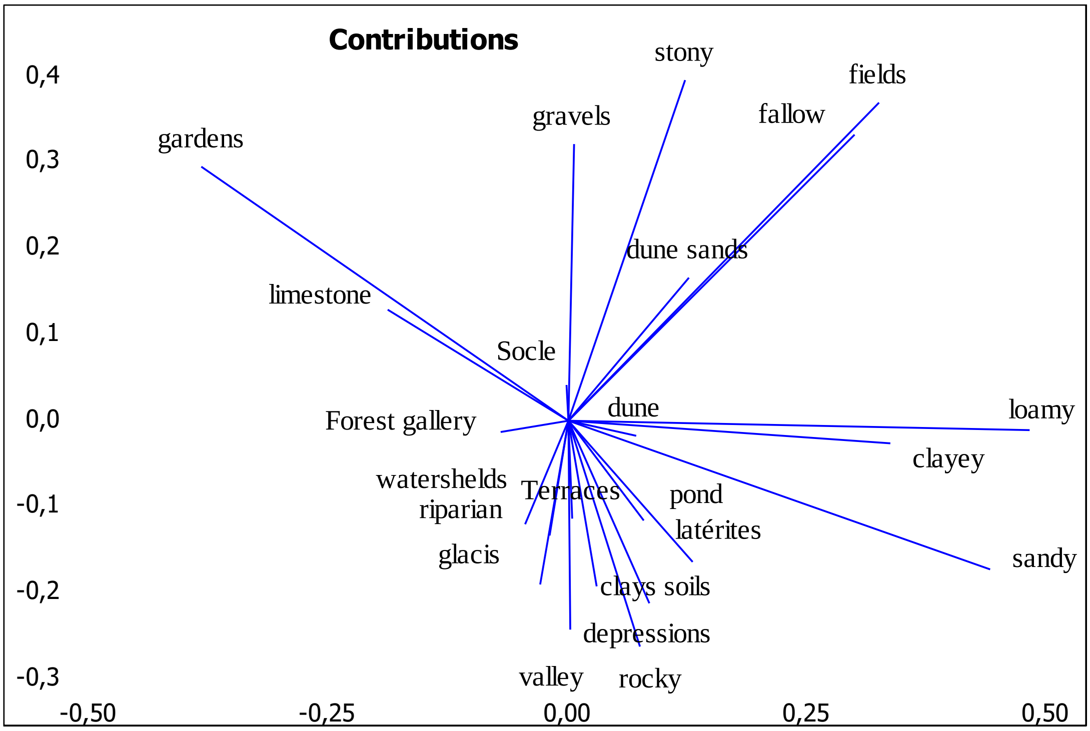

Fig. 4. Principal Component Analysis (PCA) of environmental factors

3.2 Species Richness, Diversity And Evenness Indices

Analysis of the data collected in the 220 plots shows that the flora is rich in 41 woody species belonging to 17 families. The three most represented families are Mimosaceae (11 species), Caesalpiniaceae (4 species) and Combretaceae (4 species). Figure 5 shows the percentage of each family.

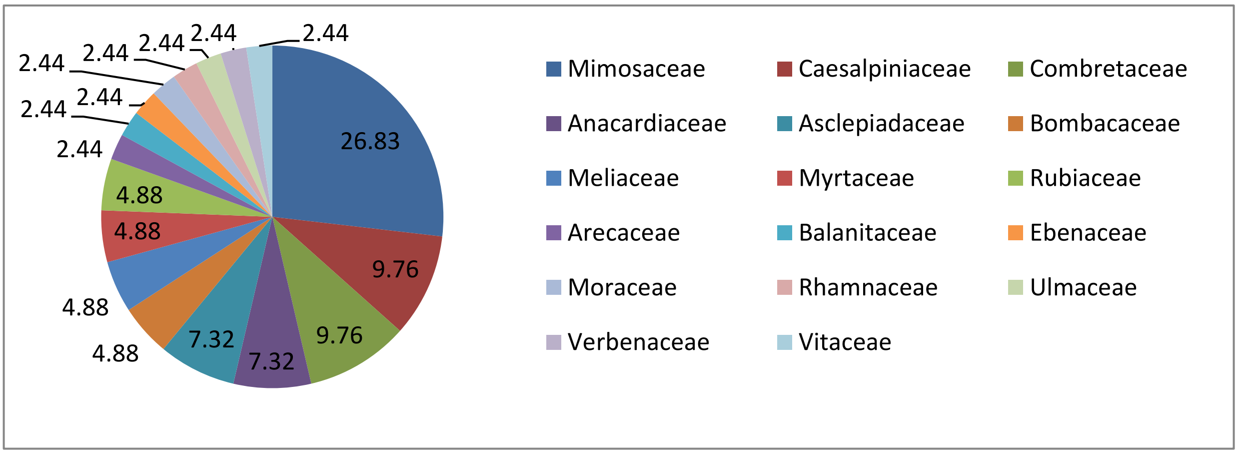

Fig. 5. The proportions of the families of all the species inventoried

The highest specific diversity was observed from Goroubi 38 species and the Alpha diversity is low along Dargol (Table 1). The specific diversity increases along the rainfall gradient. The analysis of the data shows that there is the phenomenon of dominance of a species (*D. mespiliformis*) more marked in Goroubi and a strong similarity of species between the with the index of beta diversity of 0.62.

Tableau 1. Diversity and equitability indexes values

Site	Plot	Espèce	Famille	H'	H'max	E
Dargol	100	23	23	2,61	4,32	0,6
Goroubi	120	38	17	2,19	4,8	0,45

3.3 Importance Value Index (IVI)

Along Dargol, the three species with the highest IVI (246.99) are Diospyros mespiliformis, Faidherbia albida (Del.) Chev and Mitragyna inermis (Willd.) Kuntze, of which *Diospyros mespiliformis represents* 134.23 i.e 44.74% of the IVI (Table 2).

Tableau 2. IVI of species recorded at the Dargol site

Espèce	Famille	FR (%)	DR (%)	CST (%)	IVI
Diospyros mespiliformis Hochst. ex A. Rich.	Ebenaceae	48,73	48,73	36,77	134
Faidherbia albida (Del.) Chev.	Mimosaceae	8,62	8,62	53,64	70,9
Mitragyna inermis (Willd.) Kuntze -	Rubiaceae	19,39	19,39	3,1	41,9
Combretum micranthum G. Don	Combretaceae	7,48	7,48	0	15
Ziziphus mauritiana Lam.	Rhamnaceae	3,04	3,04	0,38	6,46
Acacia nilotica (L.) Willd. ex Del.	Mimosaceae	2,22	2,22	1,32	5,76
Piliostigma reticulatum (DC.) Hochst.	Caesalpiniaceae	2,16	2,16	0,49	4,81
Acacia ataxacantha DC.	Mimosaceae	2,16	2,16	0,03	4,35
Anogeissus leiocarpus (DC.) Guill. & Perr.	Combretaceae	0,95	0,95	1,72	3,62
Azadirachta indica A. Juss.	Meliaceae	1,14	1,14	0,27	2,55
Hyphaene thebaica (L.) Mart.	Arecaceae	1,01	1,01	0,23	2,25
Tamarindus indica L.	Caesalpiniaceae	0,76	0,76	0,72	2,24
Celtis integrifolia Lam. -	Ulmaceae	0,25	0,25	0,83	1,33
Mangifera indica L. -	Anacardiaceae	0,32	0,32	0,43	1,07
Psidium guajava L.	Myrtaceae	0,51	0,51	0	1,02
Gymnema sylvestre (Retz.) Schultes	Asclepiadaceae	0,32	0,32	0	0,64
Guiera senegalensis J.F. Gmel.	Combretaceae	0,25	0,25	0	0,5
Acacia gourmaensis A. Chev.	Mimosaceae	0,25	0,25	0	0,5
Bauhinia rufescens Lam.	Caesalpiniaceae	0,13	0,13	0	0,26
Leptadenia hastata (Pers.) Decne.	Asclepiadaceae	0,13	0,13	0	0,26
Combretum glutinosum Perr. ex DC.	Combretaceae	0,06	0,06	0,04	0,16
Balanites aegyptiaca (L.) Del.	Balanitaceae	0,06	0,06	0,02	0,14
Eucalyptus camaldulensis Dehnh.	Myrtaceae	0,06	0,06	0,01	0,13

The analysis of table 3 shows that the IVI of the three dominant species (Diospyros mespiliformis, Mitragyna inermis and Piliostigma reticulatum) is 237.91 i. e 79.30% of which *Diospyros mespiliformis* is 53.06%.

Tableau 3. IVI of species found at the site of Goroubi

Espèce	Famille	FR (%)	DR (%)	CST (%)	IVI
Diospyros mespiliformis Hochst. ex A. Rich.	Ebenaceae	59,26	59,26	40,68	159,2
Mitragyna inermis (Willd.) Kuntze	Rubiaceae	15,32	15,32	26,37	57,01
Piliostigma reticulatum (DC.) Hochst.	Caesalpiniaceae	8,35	8,35	5	21,7
Khaya senegalensis (Desr.) A. Juss.	Meliaceae	3,09	3,09	5,27	11,45
Hyphaene thebaica (L.) Mart.	Arecaceae	3,15	3,15	2,18	8,48
Tamarindus indica L.	Caesalpiniaceae	1,31	1,31	3,94	6,56
Balanites aegyptiaca (L.) Del.	Balanitaceae	1,62	1,62	2,3	5,54
Mangifera indica L. -	Anacardiaceae	0,73	0,73	2,67	4,13
Albizia chevalieri Harms	Mimosaceae	0,5	0,5	2,44	3,44
Ficus sycomorus. (Miq.) C.C. Berg	Moraceae	0,21	0,21	2,57	2,99
Eucalyptus camaldulensis Dehnh.	Myrtaceae	1,31	1,31	0,21	2,83
Anogeissus leiocarpus (DC.) Guill. & Perr.	Combretaceae	0,41	0,41	1,77	2,59
Adansonia digitata L.	Bombacaceae	0,15	0,15	1,59	1,89
Azadirachta indica A. Juss.	Meliaceae	0,64	0,64	0,05	1,33
Acacia gourmaensis A. Chev	Mimosaceae	0,63	0,63	0	1,26
Vitex simplicifolia Oliv.	Verbenaceae	0,5	0,5	0,05	1,05
Acacia gourmaensis A. Chev.	Mimosaceae	0,46	0,46	0	0,92
Parkia biglobosa (Jacq.) R. Br. ex G. Don	Mimosaceae	0,09	0,09	0,7	0,88
Combretum micranthum G. Don	Combretaceae	0,23	0,23	0,35	0,81
Guiera senegalensis J.F. Gmel.	Combretaceae	0,38	0,38	0	0,76
Acacia nilotica (L.) Willd. ex Del.	Mimosaceae	0,17	0,17	0,33	0,67
Lannea microcarpa Engl. & K. Krause	Anacardiaceae	0,17	0,17	0,24	0,58
Gymnema sylvestre (Retz.) Schultes	Asclepiadaceae	0,25	0,25	0	0,5
Faidherbia albida (Del.) Chev.	Mimosaceae	0,09	0,09	0,31	0,49
Acacia seyal Del.	Mimosaceae	0,12	0,12	0,17	0,41
Ziziphus mauritiana Lam.	Rhamnaceae	0,2	0,2	0	0,4
Bombax costatum Pellegr. & Vuillet	Bombacaceae	0,09	0,09	0,18	0,36
Sclerocarya birrea (A. Rich.) Hochst.	Anacardiaceae	0,09	0,09	0,15	0,33
Prosopis juliflora (Sw.) DC.	Mimosaceae	0,06	0,06	0,2	0,32
Acacia ataxacantha DC.	Mimosaceae	0,12	0,12	0,02	0,26
Combretum glutinosum Perr. ex DC.	Combretaceae	0,06	0,06	0,14	0,26
Gardenia ternifolia Schumach. & Thonn.	Rubiaceae	0,06	0,06	0,06	0,18
Cassia sieberiana DC.	Caesalpiniaceae	0,03	0,03	0,03	0,09
Dichrostachys cinerea (L.) Wight & Arn.	Mimosaceae	0,03	0,03	0,03	0,09
Cissus quadrangularis L.	Vitaceae	0,03	0,03	0	0,06
Acacia erythrocalyx Brenan	Mimosaceae	0,03	0,03	0	0,06
Leptadenia hastata (Pers.) Decne.	Asclepiadaceae	0,03	0,03	0	0,06
Acacia ehrenbergiana	Mimosaceae	0,03	0,03	0	0,06
Total	16	100	100	100	300

3.4 DENDROMETRIC PARAMETERS

The set of stands has densities, average diameters and average heights that are significantly different. Thus, the highest values are density at Goroubi (348.9 tree/ha), mean diameter (60.14 cm) at Goulbi Maradi, mean height (10.09 m) and basal area (12.47 m^2/ha) in Dargol (Table 4). D. mespiliformis contributes more than any other species to basal area, with a greater contribution at Dargol (47.31 %). Density, mean diameter, bole height, Lorey's height, mean height and basal area of *D. mespiliformis* were significantly different between sites.

Tableau 4. Dendrometric parameters

Parameter	Dargol	Goroubi	Probabilité
	All species		
density (N/ha)	198,9±193,7b	348,9±405a	<0,010
mean diameter (cm)	44,91 46,28b	38,67 4,58a	<0,010
mean height (m)	10,09±2,88a	5,54b	<0,010
basal area (m²/ha)	12,47	11,33	
	Diospyros mespiliformis		
Contribution in basal area (%)	47,31	41,57	
density (N/ha)	46,01b	22,6a	<0,035
mean diameter (cm)	37,06±19,07 a	33,19±20 b	<0,010
bole height (m)	1,08 ±0,69a	1,28 ±0,54b	<0,010
Lorey's height, (m)	6,65	6,7	
mean height (m)	6,80±2,54a	6,23±2,26 a	<0,040
basal area (m²/ha)	5,90	4,71	

3.5 Demographic Structure

The distribution of woody species into diameter classes at the sites reveals the distribution to be unimodal (Figure 6). The shape parameter c is between 1 and 3.6 showing that the distribution is positively asymmetric with a value of 1.73 at Dargol (Figure 6A); 1.65 at Goroubi (Figure 6B).

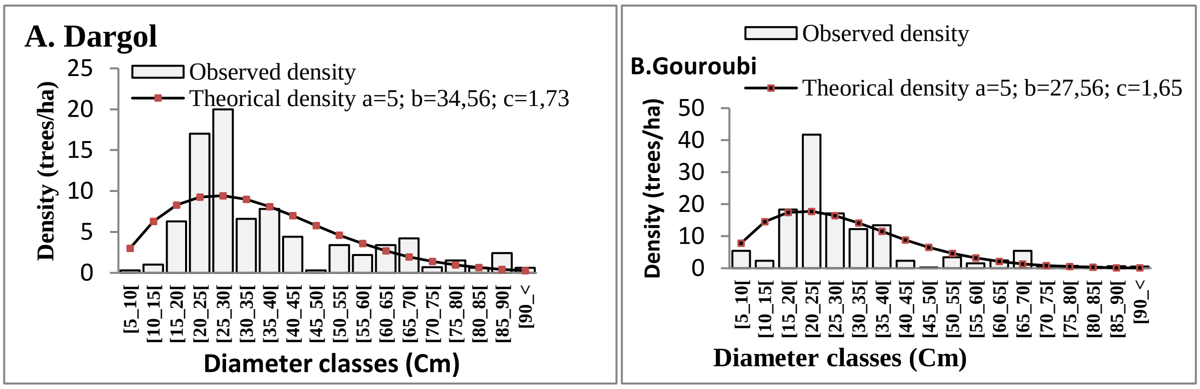

Fig. 6. Diameter class structure of the woody stand assemblage (A) Dargol, (B) Goroubi,

The distribution of individuals of the D. mepiliformis population in diameter classes at the sites reveals the distribution to a unimodal function (Figure 7). The shape parameter c is between 1 and 3.6 showing that the distribution is positively asymmetric with a value of 1.85 at Dargol (Figure 7A); 1.74 at Goroubi (Figure 7B).

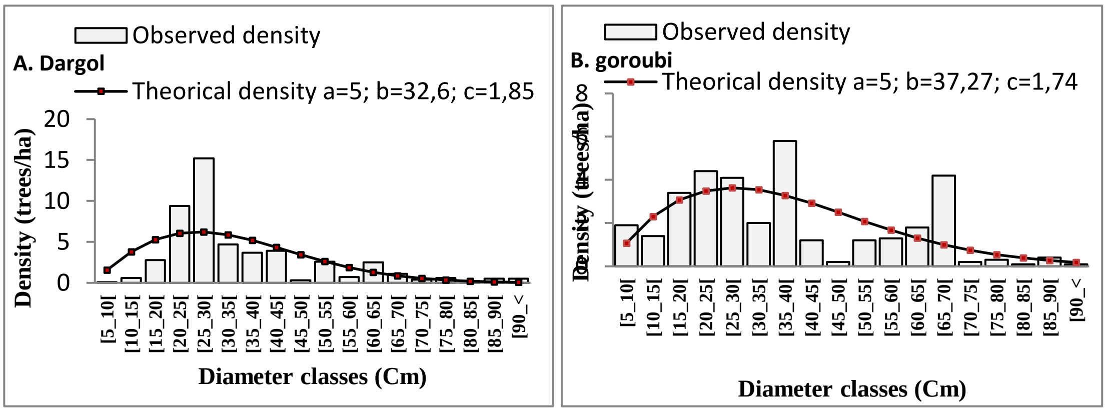

Fig. 7. Diameter class structure of D. mespiliformis population (A) Dargol, (B) Goroubi,

At the site level, the distribution of individuals in height classes shows an L-shaped distribution. It fits the theoretical Weibull distribution with the shape parameter (1 < c < 3.6), (Figure 8). This parameter takes the values 1.53 at Dargol (Figure 8A); 1.66 at Goroubi (Figure 8B).

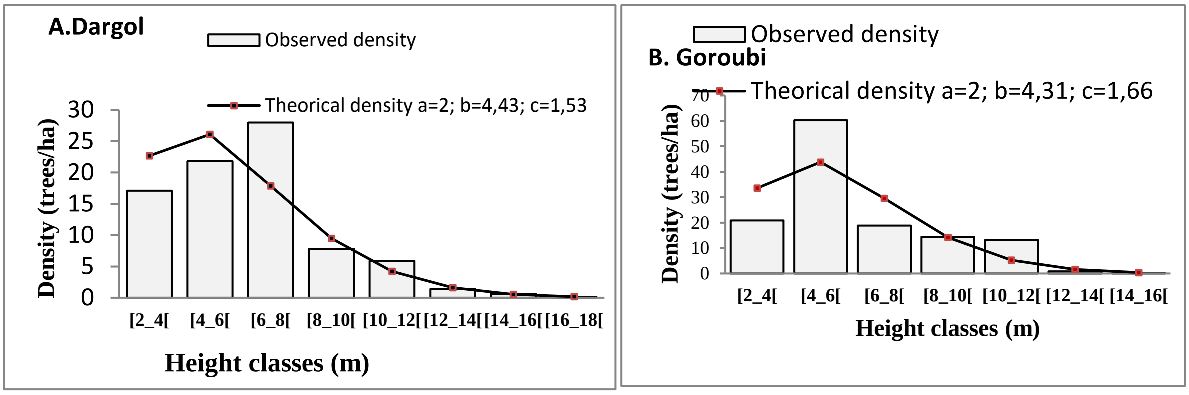

Fig. 8. Height class structure of the woody stand (A) Dargol, (B) Goroubi, (C)

At the site, the distribution of *D. mespiliformis* populations in height classes shows positive skewed distributions and a normal distribution. It fits the theoretical Weibull distribution with the shape parameter (1 < c < 3.6), (Figure 9). This parameter takes the values 2.1 at Dargol (Figure 9A); 3.63 at Goroubi (Figure 9B).

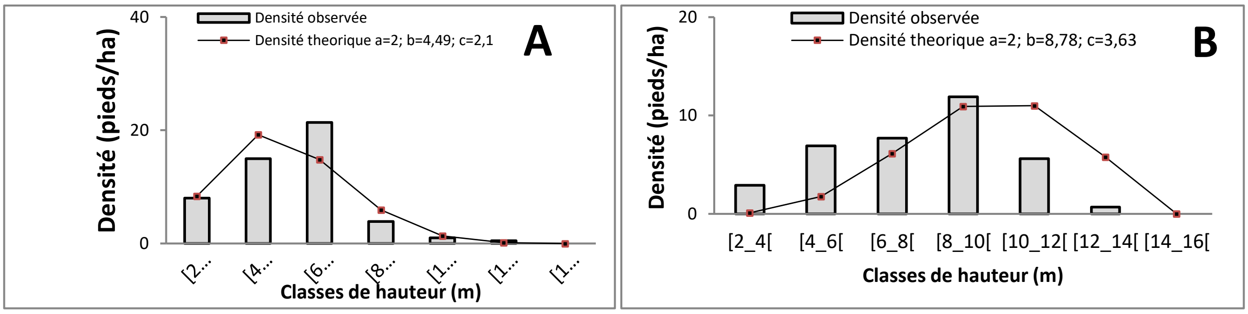

Fig. 9. Population height class structure of D. mespiliformis (A) Dargol, (B) Goroubi,

4 DISCUSSION

Western Niger in the Sahelo-Sudanian zone with a diversity of environmental factors but with a common feature that is the presence of rivers and streams constitutes a favorable habitat for D. mespiliformis. The area has a species diversity ranging from 23 to 38 trees species along Dargol and Goroubi, which is quite low compared to global diversity of Niger flora [14]. The specific diversity found by [24] in southern Niger is 19 species in Torodi, 21 in Tanda and 31 in Bana, the variation trend is the same because the specific diversity is higher in the more wettest area. The slight superiority in diversity that we obtained is due to the types of formation because the present study is carried out in forest galleries of drained environments that are areas of important diversity [14]. The diversity index is low in Dargol and medium in Goroubi. The equitability indices are from 0.45 to 0.63 showing a dominance of one species, D. mespiliformis not only by the type of sampling conditioned by the presence of this species in the plot but also by the study environments which are forest galleries and especially drained environments as [10] author showed in 2014, that this species is present in Sahelo-Sudanese groves to Guinean forests, in forest galleries, riverbanks, termite mounds, rocky hills and generally on heavy and well-drained soils. This dominance is confirmed by the indices of importance values which are close to 50% in the studied areas.

The vegetation reveals a high density of D. mespiliformis, especially in the wettest areas, with trees of large diameter and low bole height. These differences are adaptations to the environmental conditions because the wet areas present a greater availability of nutritive elements allowing the species to develop well and that the shape of the crown is determining to support the different parts of the plant whereas in arid environment the trees present a little developed trunk in response to the hydric deficits. In Niger, several studies have shown that the density of woody plants is related to the use of the species in the area, [21] in Dan kada Dodo-Dan Gado forest of south-central Niger, [23] at *P. africana* parkland, [25] on *T. indica* population., The variation in density of D. mespiliformis is in the same order as that obtained by [26] in Togo republic with a higher density reflecting the variation in density as a function of the rainfall gradient. [27] argue that the judicious interpretation of the diameter and height structures of forest stands gives a fairly accurate idea of the life conditions of the stands and allows to deduce clear management options for these stands. The diameter and height structure shows that the shape parameter (c) ranging from 1.6 to 3.6. shows a dominance of small diameter trees. This constitutes a progressive population trend of the species if only climatic conditions are the most determinant in the environment, but D. mespiliformis is a multiple-use species [8] so this information is both cause for concern given the pressure on the species.

5 CONCLUSION

The results of this work show that in these sites, which are essentially made up of forest galleries, the alpha diversity and the specific diversity increase with the increasing gradient of rainfall. The ecology of the species recorded is characterized by environmental parameters such as rupicoles and sandy-clay soils. The diversity between sites is characterized by the Sorenson index, which shows a similarity that is more important the closer the sites are geographically. The study of the demographic structures of the different populations reveals a low density of woody species, especially adults, one of the characteristics of the degraded areas as a result of anthropic actions combined with the atrocious effect of the environment factors. The structure in diameter and height of the stands, especially that of the D. mespiliformis population, reveals an instability emanating from the overexploitation of the species. Thus, the structure, composition and density of woody plant diversity are a function of ecoregions and farming practices. The absence of small-diameter trees of D. mespiliformis is an indicator of poor regeneration of the species. This requires special attention to the spread of the species and its association with other species.

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