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Phytodiversity and Characteristics of Dendrometric Parameters in Parklands of Western Niger

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ABSTRACT

They have a rich plant diversity consisting of 266 plant species. The Shannon index and Pielou's evenness index are 2.94 bits and 0.52, respectively. Distributed across 62 families and 187 genera, these species include 77 woody specimens and 110 herbaceous species. The scattered woody species have a limited ground cover (9%), generally dominated by the tree layer (6%), while shrubs in the form of regeneration account for only 3%. Herbaceous plants, which are more numerous during the rainy season, cover 29% of the area. This extensive herbaceous cover is associated with the growth of Poaceae (Pennisetum americanum and Sorghum bicolor) and Fabaceae-Faboideae (Vigna unguiculata, Arachis hypogaea, etc.). The average tree height is 12 m, and some shrubs can reach 3 m. The relatively low woody plant density (58.38 feet/ha) is higher for trees (34.13 feet/ha) than for shrubs (24.25 feet/ha). The total regeneration rate and density are 59% and 84.33 feet/ha, respectively. However, at this level, shrubs (48.83 feet/ha) regenerate more than trees (35.50 feet/ha). Forest parks are diverse in terms of both typology and vegetation structure and community composition. Thus, the following agroforestry parks include 10 parks characterized by their dominant species (Balanites aegyptiaca, Borassus aethiopum, Daniellia oliveri, Guiera senegalensis, Hyphaene thebaica, Mitragyna inermis, Neocarya macrophylla, Sclerocarya birrea, Tamarindus indica, and Vitellaria paradoxa).

Keywords: *parklands, diversity, density, natural plant regeneration.*

Introduction

Agricultural production is one of the primary strategies for human subsistence and resilience in the environment. In sub-Saharan Africa, smallholder farming practices date back more than 2,000 years [1]. Agriculture has profoundly influenced and shaped the landscape, as well as the structure and floristic composition of natural vegetation. The distribution of trees within agricultural areas gives the vegetation a distinct appearance from its native form. This distinctive feature of agroforestry landscapes is the basis for the concept of "tree-lined parks" [2]. The presence of trees in fields benefits crops because certain plants—particularly legumes—capture atmospheric nitrogen and fix it in the soil. They fertilize the soil, improve the mineral nutrition of crops and agricultural productivity, and contribute to better management of arable land [3-4]. Under scattered trees of the species Faidherbia albida, Albizzia lebbeck, and Parkia biglobosa, herbaceous and agricultural yields are double those of open land [5]. In humid and fertile areas (valleys), a high density of woody plants increases crop productivity [6-7]. Cereal production under tall trees—which are less dense and less closely spaced—is higher than that on open land [8-9].

However, certain tree species of the genera Eucalyptus, Casuarina, Leucaena leucocephala, Prosopis juliflora, and Tectona grandis limit the production of cultivated plants. These tree species produce chemical inhibitors that hinder crop growth. In all cases, farmers demonstrate remarkable skill in selecting useful trees and shrubs to retain within cultivated areas. Most woody plants are cleared and burned. However, the intensification of farming and the shift toward a sedentary lifestyle are always accompanied by a decline in woody plants, which are increasingly being cut down and are gradually disappearing. For several decades, the North Sudanese wooded areas of Niger have been subject to this intense degradation resulting from population growth and land overexploitation [10-12]. The objective here is to establish a physiognomic classification of the vegetation by explicitly describing the salient features and the most distinctive floristic and structural characteristics of each park.

I. Materials and Methods

1.1 Study Area

The study area is located in western Niger between longitudes 0° and 4° East and latitudes 10° and 15° North.

It covers the Gaya Department in the southern part of the Dosso Region and the northern portion of the Tillabéry Region in the Ouallam Department (Figure 1). The Gaya Department, located in the Sudanese zone, lies at a relatively low altitude and has no pronounced topography. It is characterized by annual precipitation ranging from 700 to 800 mm. In exceptional cases, rainfall can reach 1,000 mm, but the annual average is always above 600 mm. The rainy season lasts about 4 to 5 months, from June to September, and the longer dry season extends from October to May [13].

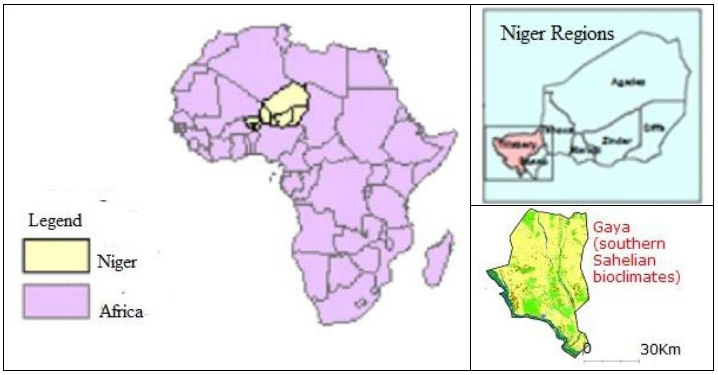

Figure 1 : Location of the study area

1.2. Sampling

The study of flora and vegetation is conducted by analyzing the necessary data through a forest and phytosociological inventory. However, given the study area's large size and diversity, it is not feasible to survey the entire area; instead, extrapolation must be used. Vegetation formations are often too vast to be subject to an exhaustive inventory. Therefore, the floristic inventory of the vegetation was conducted using a sampling method [14-16]. It is therefore convenient to select inventory units within the study area at which floristic and ecological variables will be observed and collected. To this end, the stratified random sampling method, as described by [16,17], was chosen. This methodological approach depends on the types of vegetation communities or land use. Within each inventory unit, transects or lines along which the plots are arranged were selected based on the toposequence and extent of the vegetation community.

Sample Size

In order to provide a comprehensive and accurate description of the flora and vegetation in a study area, it is advisable to determine the sample size, or the minimum number of units to be surveyed. This number is proportional to the area's size. The sample size is calculated using the following formula:

$n = [U_{1-/2} * cv/d]^2$ (1)

cv = coefficient of variation of the parameter; cv = unknown Þ cv = 80% (worst-case scenario);

d = margin of error in parameter estimation: 5 ≤ d ≤ 15%; U1-a/2 » 1.96. Since vegetation in the Sudano-Sahelian zone does not follow a normal distribution—that is, it is not homogeneous along the rainfall and topographic gradients—it seems more appropriate to calculate the sample size for each stratum type (forest, savanna, striped bush, open field, etc.). The formula below is used to determine the sample size Ni within each stratum i:

Ni=pi*n ; pi = Si/S (2)

Let S be the area of stratum i and S be the total area of the study area.

1.3. Forest and Phytosociological Inventory

The forest and phytosociological inventory is a key tool for the descriptive study of vegetation and for decision-making regarding appropriate measures for the protection and management of natural resources [18-20]. Floristic and phytosociological surveys were conducted using the Braun-Blanquet method [21], which is based on the vegetative homogeneity of ecological stations [22]. Its objective is to understand the spatio-temporal organization of vegetation and to help describe plant communities and the species that comprise them [23]. It has been applied by several authors in the study of intertropical vegetation [24-25]. In Niger, this approach has been adopted by numerous researchers [26-29].

The 2 500 m^2 plots (50 m × 50 m) are spaced 300 m, 400 m, and 500 m apart, depending on the area of the vegetation unit within which the transect is laid out.

In each plot, the ecological and structural parameters of the site are recorded: geomorphology, land-use type, vegetation type, plant community, abundance-dominance, regeneration (seeds, stump sprouts, layering, or suckers), individual height, and threats to the species and their habitat. Abundance-dominance reflects the number of individuals of a given species and their degree of coverage. The following abundance-dominance coefficients were assigned to the species :

+ species present as isolated individuals (very low abundance and coverage) covering less than 1% of the survey area, corresponding to an average coverage of 0.5%;

1 species present as a small number of individuals and occupying less than 5% of the area, corresponding to an average coverage of 3%;

2 species present in large numbers, covering 5 to 25% of the area, corresponding to an average coverage of 15%;

3 species with coverage between 25% and 50%, corresponding to an average coverage of 37.5%;

4 species with a coverage of between 50 and 75%, corresponding to an average coverage of 62.5%;

5 species with a coverage of between 75 and 100%, corresponding to an average coverage of 87.5%.

II. Data Analysis

2.1. Estimation of Biodiversity

- **Species Richness**

The simplest index for measuring biodiversity is the number S of categories (species, genera, and families) minus one (1), so that a collection comprising a single category has zero biodiversity [30]. The estimation of species diversity is based on both qualitative (presence or absence) and quantitative (abundance-dominance) criteria.

It is given by the following formula

Hr = S – 1 (3)

Where S is the number of species (genera or families).

The category index provides insight into the richness of a plant community. A high species index indicates a diverse plant community—that is, one with a large number of species, genera, or families. The dendrometric parameters calculated are:

- The average height (Hm) is expressed by the following formula (4)

$$H_m = \sqrt{\frac{1}{n}} \sum_{i=1}^{n} Hi^2$$

Where n is the number of trees in the plot and Hi is the height (in m) of tree i

- Tree density is calculated using the formula below.

$$\boldsymbol{D} = \frac{\text{total number of trees in the plot}}{\text{area S}} \quad (5)$$

- The specific regeneration index (SRI) is the ratio of the number of young plants of a given species to the total number of young individuals counted, expressed as a percentage.

$$SRI = \frac{\text{Number of young plants of a species}}{Total\ number\ of\ young\ plants\ counted} * 100 \quad (6)$$

- The Shannon index provides insight into how species are distributed within a stand. In a sense, it reflects the degree of landscape fragmentation at the observation site level. A very low value (≤1) for this index indicates the dominance of one or a few species within the stand. Conversely, a high to very high value indicates an almost homogeneous distribution of species.
- The Shannon index (Shannon, 1949) is estimated using the following formula:

$$H' = -\sum_{i=1}^{n} p_i \, Log_2 p_i \quad (7)$$

S is the total number of species ;
p_i = ni/N (8):
the ratio of the average cover of species i to the total cover of all identified species;
ni = the average cover of the species within the sampling unit;
N = the sum of the covers of all species ;
H' = the Shannon index.
H' < 2.5 = low diversity ; 2.5 ≤ H' < 4 = moderate ; H' ≥ 4 = high diversity.
Pielou's Equitability Index (E) and Jaccard Similarity Coefficient
The Shannon index is often used in conjunction with Pielou's equitability index, also known as the equipartition index [31]. It reflects the pattern of species distribution within a stand. It reflects the degree of diversity achieved relative to the maximum possible.

Pielou's equitability index ranges from 0 to 1. It approaches 0 when a single species dominates the stand and takes the value 1 when nearly all species are unevenly distributed and each has the same number of individuals.
E < 0.6 = low ; 0.6 ≤ E ≤ 0.7 = moderate ; E ≥ 0.8 = high
The Pielou equitability index is determined by the formula below :

$$E = \frac{H'}{Hmax} (9)$$

E = Piélou's evenness ;
Hmax = log2S, where S is the total number of species ;
H' = Shannon index.
E < 0.6 = low ; 0.6 ≤ E ≤ 0.7 = moderate ; E ≥ 0.8 = high.

3. Results

The study identified 10 parklands

3.1. *Balanites aegyptiaca* (L.) Del. Parkland

The Balanites aegyptiaca forest is found primarily around ponds, in the Dallol valleys with clay soil, and on sandy plains where it is associated with Guiera senegalensis. This is a stand in which Balanites aegyptiaca constitutes 44.3% of the tree layer (table 1). In this stand, the overall density of woody plants is 98.88 trees/ha, of which 35.11 trees/ha are mature trees and 63.77 trees/ha are young trees. The density of Balanites aegyptiaca is 64.22 trees/ha (15.55 for mature trees and 48.66 for regeneration). The average height of the tree layer is 7.4 ± 2.7 m, and the average diameter at breast height is 24.5 ± 10.2 cm. Woody cover is low (13.88%), while herbaceous vegetation covers 16.83%. The TRP of 64.49% indicates that the Balanites aegyptiaca stand is expanding rapidly. The species contributing most to this TRP are Balanites aegyptiaca (ISR of 76.3%), Borassus aethiopum (ISR of 10%), Piliostigma reticulatum (ISR of 2.4%), and Guiera senegalensis (ISR of 2.1%). This park contains 96 species, 19 of which are woody, the main ones being : Balanites aegyptiaca, Borassus aethiopum, Guiera senegalensis, Piliostigma reticulatum, Tamarindus indica, Diospyros mespiliformis, Azadirachta indica, and Mitragyna inermis. Its diversity index is 4.63 bits, and its Pielou's evenness is 0.67. The main activity is rain-fed and/or dry-season irrigated rice cultivation. Okra is sometimes grown here as well.

Table 1: Importance of woody species in the parkland, with Balanites aegyptiaca (L.) Del

Species	Number of Adults	Number of Rejects	Density of adults/ha	ISR	Frequency
Balanites aegyptiaca	70	219	15,56	76%	44,3%
Borassus aethiopum	26	23	5,78	8%	16,5%
Guiera senegalensis	19	7	4,22	2%	12,0%
Piliostigma reticulatum	12	4	2,67	1%	7,6%
Tamarindus indica	8	1	1,78	0%	5,1%
Diospyros mespiliformis	5		1,11	0%	3,2%
Azadirachta indica	4	11	0,89	4%	2,5%
Daniellia oliveri	3		0,67	0%	1,9%
Mitragyna inermis	3	1	0,67	0%	1,9%
Vitex doniana	3	2	0,67	1%	1,9%
Acacia erythrocalyx	1		0,22	0%	0,6%
Acacia seyal	1	8	0,22	3%	0,6%
Combretum glutinosum	1	1	0,22	0%	0,6%
Cordyla pinnata	1		0,22	0%	0,6%
Ziziphus mucronata	1		0,22	0%	0,6%
Combretum nigricans		1	0,00	0%	0,0%
Dichrostachys cinerea		1	0,00	0%	0,0%
Hyphaene thebaica		2	0,00	1%	0,0%
Sclerocarya birrea		6	0,00	2%	0,0%
Total	**158**	**287**	**35,11**	**100%**	**100%**

3.2. Borassus aethiopum Mart. Parkland

This is a forested area dominated by Borassus aethiopum (36%) along with various other tree species : Neocarya macrophylla (13%), Piliostigma reticulatum (13%), Balanites aegyptiaca (5%), Azadirachta indica (7%), Hyphaene thebaica (5%), Sclerocarya birrea (4%), and occasionally Vitellaria paradoxa (3%) (Table 2). Depending on the woody species accompanying Borassus aethiopum, this park exhibits varying woody facies : the Borassus aethiopum and Balanites aegyptiaca facies, the Borassus aethiopum and Diospyros mespiliformis facies, the Borassus aethiopum and Hyphaene thebaica facies, the Borassus aethiopum and Piliostigma reticulatum facies, and the Borassus aethiopum and Vitellaria paradoxa facies. The Borassus aethiopum forest is found in the Dallol valleys and on the sandy soils of the lower terraces of the Niger River valley. It is characterized by a tree density of 67.82 individuals/ha, of which 32.58 are adults and 34.24 are young trees.

The stand's regeneration rate is 51.24% (which indicates the good health of this stand). The density and specific regeneration index (SRI) of Borassus aethiopum are 33 trees/ha and 62.39%, respectively. The average height of the woody stratum is 13.9 ± 2.5 m, and the average diameter at breast height is 33.9 ± 5.2 cm.

The average canopy cover is 19.76%. This cover consists of 3.87% woody vegetation and 19.76% herbaceous vegetation. On average, this park is home to 142 plant species, including 32 woody species. The Shannon diversity index is 3.2 bits, with a Pielou evenness index of 0.65. This attests to its high species biodiversity. Among the herbaceous species characteristic of the park are: Eragrostis tremula, Pennisetum pedicellatum, Cassia mimosoides, Corchorus trident, Sporobulus eoclados, Tephrosia linearis, Mitracarpus villosus, Evolvulus alsinoides, Sida cordifolia, Striga hermonthica, and Waltheria indica. The most commonly cultivated crops during the rainy season are millet, sorghum, cowpeas, and peanuts.

Table 2 : Importance of woody plants in the Borassus aethiopum Mart. Stand

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Borassus aethiopum.	120	219	11,71	62,39	35,93
Neocarya macrophylla	45	-	4,39	-	13,47
Piliostigma reticulatum	45	1	4,39	0,28	13,47
Azadirachta indica	25	12	2,44	3,42	7,49
Balanites aegyptiaca	16	25	1,56	7,12	4,79
Hyphaene thebaica	16	78	1,56	22,22	4,79
Sclerocarya birrea	12	4	1,17	1,14	3,59
Vitellaria paradoxa	9	-	0,88	0,00	2,69
Acacia sieberiana	6	2	0,59	0,57	1,80
Gardenia ternifolia	6	-	0,59	0,00	1,80
Vitex doniana	5	2	0,49	0,57	1,50
Danielia oliveri	4	-	0,39	-	1,20
Acacia nilotica	3	-	0,29	-	0,90
Combretum micranthum	2	-	0,20	-	0,60
Dichrostachys cinerea	2	-	0,20	-	0,60
Ficus sycomorus	2	-	0,20	-	0,60
Stereospermum Kunthianum	2	-	0,20	-	0,60
Acacia seyal	1	1	0,10	0,28	0,30
Adansonia digitata	1	-	0,10	-	0,30
Calotropis procera	1	-	0,10	-	0,30
Cassia sieberiana	1	-	0,10	-	0,30
Combretum glutinosum	1	1	0,10	0,28	0,30
Combretum paniculatum	1	-	0,10	-	0,30
Diospyros mespiliformis.	1	1	0,10	0,28	0,30
Faidherbia albida	1	1	0,10	0,28	0,30
Feretia apodanthera	1	-	0,10	-	0,30
Flueggea virosa	1	-	0,10	-	0,30
Mitragyna inermis	1	2	0,10	0,57	0,30
Prosopis juliflora	1	-	0,10	-	0,30
Psidium guajava	1	-	0,10	-	0,30
Tamarindus indica	1	-	0,10	-	0,30
Acacia seyal	-	1	-	0,28	-
Ficus dekdekena	-	1	-	0,28	-
Total général	**334**	**351**	**32,59**	**100**	100,00

3.3. Combretum nigricans parkland

The Combretum nigricans parkland is rare and is characterized by low species diversity (32 species) and a meager cover rate (23.5%) (table 3). This forest has a Shannon diversity index of 3.16 bits and a Pielou evenness index of 0.96. Its flora comprises seven (7) woody species, the most characteristic of which belong to the Combretaceae family (Combretum nigricans, Guiera senegalensis, Combretum micranthum, and Combretum glutinosum). In this park, the density of mature woody plants is 76.8 trees/ha, compared to a regeneration rate of 48.2 trees/ha, resulting in a net regeneration rate (NRR) of 38.56%. The dominant species, Combretum nigricans, accounts for 43.49% of the mature tree stand. Its density is 33.4 trees/ha, and its ISR is a modest 1.42%.

The trees have a sparse canopy cover, barely exceeding 8.5%, and an average height of 5.3 ± 2.24 m. Their diameter averages around 11 ± 2 cm. The herbaceous species frequently recorded in this stand include : Achyranthes aspera, Pennisetum pediccelatum, Peristrophe bicalyculata, Sporobulus festivus, Schizachyrium exile, Tephrosia linearis, Triumfetta pentandra, and Waltheria indica.

Table 3: Abundance of woody plants in the Combretum nigricans var. elliotii (Engl. ex Diels) Aubrev. Parkland

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Combretum nigricans	167	3	33,4	1,24	43,49
Guiera senegalensis	110	150	22	62,24	28,65
Combretum micranthum	80	68	16	28,22	20,83
Combretum glutinosum	20	6	4	2,49	5,21
Boscia angustifolia	4	1	0,8	0,41	1,04
Azadirachta indica	3	11	0,6	4,56	0,78
Balanites aegyptiaca		2	0	0,83	0,00
Total général	**384**	**241**	**76,8**	100	100,00

3.4. Guiera senegalensis J.F. Gmel. Parkland

The Guiera senegalensis parkland (table 4) is a shrub stand resulting from the recent clearing of thickets, Combretaceae thickets, or shrubby savanna. In this stand, dominated by Guiera senegalensis (94.28%), the density of woody plants ranges from 152 trees/ha for mature individuals to 486.85 trees/ha for regeneration. Its high regeneration rate is estimated at 76.20%. The density of Guiera senegalensis reaches 136.6 trees/ha with an ISR of 95.65%. The vegetation cover rate is 41.42%, of which 13.14% is accounted for by the tree canopy. Its flora, which is poor in woody specimens (7), comprises 73 species, giving it a diversity index of 2.17 bits. Piélou's equitability of 0.49 indicates vegetation with a uniform appearance dominated by a single species (Guiera senegalensis). The average height of woody plants is 3.5 ± 0.5 m, and the majority of individuals have a diameter between 3 and 6 cm. The main woody species accompanying Guiera senegalensis in this stand are : Combretum micranthum, Combretum nigricans, Combretum glutinosum, Piliostigma reticulatum, Balanites aegyptiaca, and Boscia senegalensis.

Table 4: Abundance of tree species in the Guiera senegalensis J.F. Gmel. Parkland

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Guiera senegalensis	478	1630	136,6	96	94,28
Piliostigma reticulatum	40	14	11,4	1	2,42
Combretum glutinosum	-	32	-	2	1,43
Combretum nigricans	-	16	-	1	0,72
Balanites aegyptiaca	14	-	4,0	-	0,63
Combretum micranthum	-	10	-	1	0,45
Boscia senegalensis	-	2	-	-	0,09
Total	**532**	**1704**	**152,0**	**100**	**100**

3.5. Hyphaene thebaica (L.) Mart. Parkland

The main woody species comprising this stand are : Hyphaene thebaica (66.67%), Piliostigma reticulatum (10.98%), Neocarya macrophylla (6.27%), Balanites aegyptiaca (2.35%), Borassus aethiopum (1.96%), Vitellaria paradoxa and Faidherbia albida (1.57%) (table 5). The dominant herbaceous plants include : Cassia mimosoides, Sporobulus eoclados, Vetiveria nigritana, Pennisetum pediccelatum, Cynodon dactylon, Waltheria indica, Corchorus tridens, and Eragrostis tremula. This park exhibits two major vegetation types : one dominated by Hyphaene thebaica and Piliostigma reticulatum, and the other by Hyphaene thebaica and Neocarya macrophylla. It has a species richness of 162 species, including 31 woody species. The Shannon index is 3.54 bits, with a Pielou evenness index of 0.69. The overall tree density is 53.68 trees/ha, while the regeneration density is 108 trees/ha, representing a TRP of 66.79%. The density of Hyphaene thebaica is 35.78 trees/ha, with a specific regeneration index of 79.33%. This species has a canopy cover of 8.78%, which is approximately 73.73% of the woody canopy cover, which averages 11.92%. The average height of woody trees is 7.78 m. The average diameter of the tree stratum measured at breast height is 18.38 cm. However, the average diameter for the park's characteristic species is 14.37 ± 4.30.

Table 5: Importance of woody plants in the parkland with Hyphaene thebaica (L.) Mart

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Hyphaene thebaica	170	407	35,79	78,72	66,67
Piliostigma reticulatum	28	18	5,89	3,48	10,98
Neocarya macrophylla	16	30	3,37	5,80	6,27
Balanites aegyptiaca	6	26	1,26	5,03	2,35
Vitellaria paradoxa	5		1,05	-	1,96
Borassus aethiopum	4	3	0,84	0,58	1,57
Faidherbia albida	4	1	0,84	0,19	1,57
Adansonia digitata	3		0,63	-	1,18
Gardenia ternifolia	3		0,63	-	1,18
Guiera senegalensis	3	2	0,63	0,39	1,18
Acacia nilotica	2	2	0,42	0,39	0,78
Acacia sieberiana	2	2	0,42	0,39	0,78
Azadirachta indica	2	4	0,42	0,77	0,78
Acacia senegal	1	2	0,21	0,39	0,39

Albizia chevalieri	1	1	0,21	0,19	0,39
Danielia oliveri	1		0,21	-	0,39
Euphorbia balsamifera	1		0,21	-	0,39
Mitragyna inermis	1	2	0,21	0,39	0,39
Sclerocarya birrea	1	1	0,21	0,19	0,39
Stereospermum Kunthianum	1		0,21	-	0,39
Calotropis procera		1	-	0,19	-
Annona senegalensis.		1	-	0,19	-
Combretum aculeatum		1	-	0,19	-
Crateva adansonii		1	-	0,19	-
Dichrostachys cinerea		6	-	1,16	-
Ficus platyphylla		1	-	0,19	-
Ficus sycomorus		1	-	0,19	-
Feretia apodanthera		1	-	0,19	-
Flueggea virosa		1	-	0,19	-
Ziziphus mauritiana		1	-	0,19	-
Ziziphus mucronata		1	-	0,19	-
Total	**255**	**517**	53,68	100	100,00

3.6. Mitragyna inermis (Willd.) O. Kuntze parkland.

The Mitragyna inermis parkland (table 6) is generally found along riverbanks and in the low-lying depressions of Dallol valleys that are temporarily flooded and used for rain-fed and/or irrigated rice cultivation. It is a floristically poor and sparsely vegetated park, as indicated by the Shannon diversity index (1.84 bits). Its relatively undiversified flora comprises 41 plant species, including eleven (11) woody species. The Pielou evenness index is 0.49, and the average vegetation cover is 72%. The values of these last two parameters indicate a dominance of Oryza sativa, a species of the Poaceae family that is continuously cultivated. Woody plants have a density of 48 plants/ha and can reach a height of 8.75 ± 0.35 m. Their diameter rarely exceeds 40 ± 5 cm. In contrast, the low cover and density of Mitragyna inermis are 7.25% and 16 plants/ha, respectively. This species accounts for only 33% of the woody stand and regenerates very little (2 trees/ha). Its specific regeneration index is 1.44%. The park's overall TRP averages 73.91%.

Table 6: Importance of woody species in the parkland relative to Mitragyna inermis

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Mitragyna inermis	64	1	16	1%	33%
Piliostigma reticulatum	42	28	10,5	41%	22%
Diospyros mespiliformis	22	3	5,5	4%	11%
Azadirachta indica	18		4,5	0%	9%
Acacia sieberiana	11	1	2,75	1%	6%
Acacia nilotica	10		2,5	0%	5%
Balanites aegyptiaca	7		1,75	0%	4%
Ziziphus mucronata	8	16	2	23%	4%
Acacia seyal	6		1,5	0%	3%
Ficus platyphylla	3		0,75	0%	2%
Borassus aethiopum	1	20	0,25	29%	1%
Total	**192**	**69**	**48**	**100%**	**100%**

3.7. Neocarya macrophylla (Sabine) Prance parkland

This is area dominated by Neocarya macrophylla (table 7), with an average canopy cover of up to 9.64% and a density of 63.63 trees per hectare. Neocarya macrophylla accounts for 63% of the park's woody stratum and has an ISR of 56%. Its companion species are: Hyphaene thebaica, Borassus aethiopum, Sclerocarya birrea, Guiera senegalensis, Balanites aegyptiaca, and Piliostigma reticulatum. This allows for the distinction of two facies types in this park: the Neocarya macrophylla and Hyphaene thebaica facies, and the Neocarya macrophylla and Borassus aethiopum facies. This association with the Arecaceae family is linked to its ecology in the low-lying areas of the Dallols valleys, where rainwater converges and groundwater sometimes resurfaces. The Neocarya macrophylla park has a flora comprising 98 species, including 13 woody species with a low average cover of 13.14%. The diversity index is 2.95 bits, and the Pielou's evenness index is 0.64. The total density of woody plants is 67.82 trees/ha, with a low regeneration rate (24.21%), including for Neocarya macrophylla (17.14 trees/ha). The height of the tree layer is 6.48 ± 4 m. These low values for species biodiversity, density, and regeneration rate in the Neocarya macrophylla forest are related not only to agricultural use but also to the harvesting and collection of fruits from most of the woody species that make up the forest, which prevents their regeneration. Furthermore, Neocarya macrophylla provides dense shade that inhibits the growth of the herbaceous layer.

Table 7: Importance of Woody Species in the Neocarya macrophylla Forest

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Neocarya macrophylla	111	30	63,43	56%	63%
Hyphaene thebaica	13	13	7,43	24%	12%
Borassus aethiopum	16		9,14	0%	7%
Sclerocarya birrea	3	8	1,71	15%	5%
Guiera senegalensis	8		4,57	0%	4%
Balanites aegyptiaca	6		3,43	0%	3%
Piliostigma reticulatum	4	2	2,29	4%	3%

Azadirachta indica	3		1,71	0%	1%
Bombax costatum	2		1,14	0%	1%
Acacia nilotica	1		0,57	0%	0%
Combretum glutinosum	1		0,57	0%	0%
Flueggea virosa		1	0,00	2%	0%
Prosopis africana	1		0,57	0%	0%
Total	**169**	**54**		**100%**	**100%**

3.8. Sclerocarya birrea (A. Rich.) Hochst. Parkland

The Sclerocarya birrea parkland is a low-density tree stand (30 trees/ha) in which Sclerocarya birrea accounts for 40% of the woody individuals (table 8). It has a species richness of 50 species. The Shannon index is 2.41 bits, and the Pielou evenness index is 0.61. Nine (9) woody species characterize this park, the main one being Sclerocarya birrea, which has a low density of 12 trees/ha. The overall regeneration density of the park is high (194 trees/ha), representing a regeneration rate of 85%. Regeneration is dominated 71% by Guiera senegalensis. However, the dominant tree species regenerates poorly, with an ISR of 1.02%. The average tree height in this stand is 8.5 m, and the diameter is 37 ± 5 cm for Sclerocarya birrea. Tree cover is 11.25%, but the overall cover is 48% for all vegetation layers.

Table 8: Importance of woody species in the Sclerocarya birrea (A. Rich.) Hochst. Park

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Sclerocarya birrea	154	1	12	1%	40%
Sterculia setigera	145	9	10	9%	33%
Azadirachta indica	118		4		13%
Faidherbia albida	19		2		7%
Piliostigma reticulatum	19	3	2	3%	7%
Boscia angustifolia		1		1%	
Combretum glutinosum		10		10%	
Guiera senegalensis		70		71%	
Hyphaene thebaica		3		3%	
Stereospermum Kunthianum		1		1%	
Total	455	98	30	100%	100%

3.9. Tamarindus indica parland

The Tamarindus indica parland (table 9) is found in the dallol valleys and has a coverage of 42.62%, with the herbaceous layer (38.5%) showing greater coverage than the woody layer (4.25%). Its floristic composition consists of 11 woody species but is generally low in species diversity (19 species). The Pielou diversity index and evenness are relatively low, at 0.68 bits and 0.23, respectively. The density of individuals per hectare is 51 trees for adults and 7.5 trees for regeneration. The average height of the tree layer is approximately 11.8 ± 3.4 m, with a diameter at breast height (1.3 m) of 43.75 ± 8.5 cm. The regeneration rate in this park is fairly good (TRP = 57.7%). The density of Tamarindus indica averages 16.9 trees/ha, and it accounts for 33.14% of the woody stand. This species regenerates very little (ISR = 1.03%), and as a result, its stand is aging. The only species that regenerate well are Diospyros mespiliformis (ISR = 38.56%), Piliostigma reticulatum (ISR = 20.57%), and Azadirachta indica (ISR = 14.14%). Special attention must be paid to the conservation of this park, as it is home to numerous species of socioeconomic importance: Acacia seyal, Balanites aegyptiaca, Diospyros mespiliformis, Tamarindus indica, and Ficus sycomorus. he main human activity in this park is rain-fed and seasonally irrigated rice farming.

Table 9: Importance of woody plants in the park, based on Tamarindus indica L

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Tamarindus indica	169	4	16,9	1,03	33,14
Diospyros mespiliformis	152	150	15,2	38,56	29,80
Acacia seyal	50	34	5	8,74	9,80
Balanites aegyptiaca	46	37	4,6	9,51	9,02
Mitragyna inermis	33	24	3,3	6,17	6,47
Capparis tomentosa	30	3	3	0,77	5,88
Ficus sycomorus	11	-	1,1	-	2,16
Ziziphus mucronata	10	-	1	-	1,96
Azadirachta indica	9	55	0,9	14,14	1,76
Entada africana		2		0,51	
Piliostigma reticulatum		80		20,57	
Total	**510**	**289**	**51**	100,00	100,00

3.10. Vitellaria paradoxa parkland

The Vitellaria paradoxa parkland (table 10) is a very open tree stand typical of the sandy soils found in fossil valleys, with a vegetation cover of approximately 25.35%. Vegetation cover is 5.03% for the woody canopy and 20.32% for the herbaceous layer. The tallest trees in this stand can reach 12.88 m in height with an average diameter of 47.69 cm. In contrast, for Vitellaria paradoxa, the diameter reaches 61.42 ± 16 cm. With significant species diversity (144 plant species), the Vitellaria paradoxa forest harbors 36 woody species, the most characteristic of which are Vitellaria paradoxa (21.69%), Piliostigma reticulatum (16.54%), Balanites aegyptiaca (6.62%), Borassus aethiopum (5.88%), and Hyphaene thebaica (4.41%). The low woody plant density is comparable to that of the Borassus aethiopum and Hyphaene thebaica stand. It stands at 34 mature trees/ha and 32.12 saplings/ha.

The regeneration density of 32.12 trees/ha is low for Vitellaria paradoxa (1.25 trees/ha). The overall regeneration rate of 48.58% indicates an aging stand, particularly with regard to Vitellaria paradoxa, which has an ISR of 3.89%. The most common herbaceous species in this park are Poaceae of the genera Aristida, Eragrostis, Sporobulus, and Pennisetum, as well as Fabaceae, specifically Cassia mimosoides and Tephrosia sp.

Table 10: Importance of woody plants in the parkland with Vitellaria paradoxa C. F. Gaertn

Species	Number of Adultes	Number of Rejects	Density of adults/ha	ISR	Frequency
Vitellaria paradoxa	236	10	7,38	3,89	21,69
Piliostigma reticulatum	180	69	5,63	26,85	16,54
Stereospermum Kunthianum	152	42	4,75	16,34	13,97
Balanites aegyptiaca	72	23	2,25	8,95	6,62
Borassus aethiopum.	64	16	2,00	6,23	5,88
Hyphaene thebaica	48	1	1,50	0,39	4,41
Dichrostachys cinerea	36	2	1,13	0,78	3,31
Combretum glutinosum	28	12	0,88	4,67	2,57
Feretia apodanthera	28	9	0,88	3,50	2,57
Sclerocarya birrea	28	12	0,88	4,67	2,57
Acacia seyal	24	10	0,75	3,89	2,21
Faidherbia albida	24	8	0,75	3,11	2,21
Azadirachta indica	20	4	0,63	1,56	1,84
Gardenia ternifolia	20	2	0,63	0,78	1,84
Guiera senegalensis	20	12	0,63	4,67	1,84
Acacia senegal	12	4	0,38	1,56	1,10
Combretum collinum	12	3	0,38	1,17	1,10
Mangifera indica	12	-	0,38	-	1,10
Tamarindus indica	12	-	0,38	-	1,10
Adansonia digitata	8	-	0,25	-	0,74
Annona senegalensis	8	-	0,25	-	0,74
Mitragyna inermis	8	1	0,25	0,39	0,74
Acacia sieberiana.	4	-	0,13	-	0,37
Anacardium occidentale	4	-	0,13	-	0,37
Detarium microcarpum	4	-	0,13	-	0,37
Diospyros mespiliformis	4	-	0,13	-	0,37
Maytenus senegalensis	4	-	0,13	-	0,37
Prosopis africana	4	4	0,13	1,56	0,37
Vitex madiensis	4	1	0,13	0,39	0,37
Ziziphus mauritiana	4	4	0,13	1,56	0,37
Ziziphus mucronata	4	1	0,13	0,39	0,37
Boscia angustifolia		2	-	0,78	-
Lannea acida		1	-	0,39	-
Maerua angolensis		2	-	0,78	-
Neocarya macrophylla		1	-	0,39	-
Parinari curatellifolia		1	-	0,39	-
Total	**1088**	**257**	**34**	100,00	100,00

4. Discussion

The vegetation west of the Niger River is characterized by a variety of physiognomies. There is considerable heterogeneity in terms of species diversity, stand structure, and the ecological habitats of the species. This classification is based on the summary of the Yanganbi meeting of 1956 and the work of numerous authors [1, 29,32-33]. Based on the distribution pattern of the tree layer, their floristic richness, and habitat, ten (10) agroforestry parks are described in this section. Based on the dominant tree species, these are : Balanites aegyptiaca park, Borassus aethiopum park, Daniellia oliveri park, Guiera senegalensis park, Hyphaene thebaica park, Mitragyna inermis park, Neocarya macrophylla park, Sclerocarya birrea park, Tamarindus indica park, and Vitellaria paradoxa park. The spatial distribution of trees gives the landscape distinctive features. A scattered distribution of trees at low density creates the appearance of a savanna park or a very open stand. In western Niger, the average height of the stands ranges from 3.5 meters in the Guiera senegalensis stand to 13.9 meters in the Borassus aethiopum stand. In Africa, in regions south of the Sahara, agroforestry groves are the result of agricultural activity dating back 2,000 years [1] and largely cover the landscape.

In this type of vegetation, spatially scattered perennial woody species are deliberately maintained in association with crops and/or livestock [2,34]. In the northern Sudanese zone of Niger, due to long-standing sedentarization, these agrosystems cover vast areas and constitute the most widespread vegetation type.

Wooded parks are stands of trees found in heavily human-altered areas where the natural vegetation has been completely removed [35]. The only trees found there are naturally propagated species of socio-economic importance. This structure gives them the appearance of a savanna park [1]. In these systems, tree density and canopy cover are very low and vary from one field to another (from 16 to 152 trees/ha). The highly diverse herbaceous layer is sparse. Tree-covered areas are continuously used for growing annual crops. Once the soil is depleted, these lands are abandoned to make way for grazing areas. At that point, they are referred to as fallow lands. These fallow lands are characterized by a few scattered trees and regularly pruned shrubs. The herbaceous cover is most often dominated by invasive species and a few grasses that are eaten by livestock.

Species diversity ranges from 162 species in the Hyphaene thebaica park to 19 species in the Tamarindus indica park.

Alpha diversity is low in four parks (Hyphaene, Vitellaria, Borassus, Neocarya), moderate in four others (Neocarya, Combretum, Borassus, Hyphaene), and high in two parks (Combretum, Tamarindus). This species diversity is significantly higher than that of agroforestry parks in the Northern Sudanic zone of Burkina Faso, as reported by [36] in Senegal (54 tree species with alpha diversity ranging from 1.94 to 3.34 bits) as well as by [37], where tree diversity was 66 species and alpha diversity was 1.34 bits in the best-case scenario. In agroforestry parks, human impact appears to be the determining factor in biodiversity variation. In fact, agricultural practices shape the vegetation that appears in an area because, when agriculture is practiced on fallow land, the soil becomes increasingly poor, leading to ecological succession—that is, a shift from one dominant vegetation type to another. Thus, soil fertility in agrosystems may vary inversely alpha plant diversity. The work by [38] on protecting the savanna from bushfires has the benefit of promoting vegetation dynamics. This process begins with a grassy state and progresses to a forest dominated by woody species, leading to soil restoration, the provision of ecosystem services, and the mitigation of climate change. Similarly, the work by [12] shows that the degree of human impact on parks varies inversely with the rainfall gradient.

Another factor distinguishing the parks is tree density. In this study, density ranges from 152 trees/ha in the Guiera senegalensis park to 16 trees/ha in the Mitragyna inermis park; these densities are very low compared to those reported by [12] in natural formations—notably the Kouré Plateau, the Guittodo Plateau, and the Gorou Bassounga Protected Forest—but higher than that reported by [37]. Although the difference is very large and depends on the types of agrosystems, the finding is that protected areas and agrosystems are subject to degradation linked to the use of these resources.

Regeneration is an indicator of the health of the ecosystem and is also a key factor in ensuring the renewal of the populations that inhabit the parks. In this study, eight of the ten parks surveyed showed vegetation with a natural regeneration rate exceeding 50 percent, which implies rapidly expanding populations if the same conditions are maintained. This observation is broadly consistent with that made by [37]. Thus, in these parks, hopes rest on how human populations manage these ecosystems ; in most cases, human activity exerts pressure combined with other constraints that hinder the transition of juveniles to adults, as demonstrated by [12, 39] in western Niger within protected areas, but especially by [40], in agrosystems. The stands of V. paradoxa and C. micrantum show a natural regeneration rate of less than 50%, indicating a declining population, as do the dominant species, which are : Vitellaria paradoxa, Piliostigma reticulatum, Stereospermum kunthianum, Combretum nigricans, Guiera senegalensis, and Combretum micranthum are all experiencing a decline in their populations. [39-41] have already reported low densities of these species, even within protected areas. This situation may be linked either to the failure of stocks to replenish due to seed harvesting—which reduces the availability of hypothetical diaspores in the soil—or to difficulties in seed germination, or even to a lack of fruit production, particularly among the Combretaceae family. According to [37], the V. paradoxa stand has a TRP of 64.67%, which once again demonstrates the influence of human activities on the dynamics of agrosystems. The total seedling density did not show any significant differences based on latitudinal position or species in Burkina Faso across different agroecological zones.

Although some species—G. senegalensis, C. glutinosum, C. micranthum, and C. nigricans exhibit germination rates ranging from 70–100% in nurseries [42], when water conditions are very favorable and combined with terrace farming techniques, these species are suitable for restoring plateau lands [43,44] reported that the structure of the parks is strongly influenced by human activities, as farmers preserve forest species but also introduce fruit trees for food, medicinal purposes, timber production, and soil fertility improvement. Ethnobotanical investigations conducted by [45] in agroforestry parks with Vitellaria paradoxa and Neocarya macrophylla revealed that several multi-purpose tree species are in decline due to climatic, anthropogenic, and biotic factors.

Conclusion

This study highlighted a diversity of ten (10) stands, including a Balanites aegyptiaca stand, a Borassus aethiopum stand, Daniellia oliveri groves, Guiera senegalensis groves, Hyphaene thebaica groves, Mitragyna inermis groves, Neocarya macrophylla groves, Sclerocarya birrea groves, Tamarindus indica groves, and Vitellaria paradoxa groves. Significant heterogeneity is observed in terms of species diversity, stand structure, and the ecological habitats of the species. This classification distinguishes the stands by an average tree height of 12 m and an average shrub height of 3.5 m. The relatively low woody density (58.38 trees/ha) is higher for trees (34.13 trees/ha) than for shrubs (24.25 trees/ha). The total regeneration rate and density are 59% and 84.33 feet/ha, respectively. However, at this level, shrubs (48.83 feet/ha) regenerate more than trees (35.50 feet/ha). Differences are also observed in terms of plant diversity, density, and average height across the parks. The most common characteristic of agroforestry parks is the high natural regeneration rate, indicating that vegetation can renew itself under ecologically favorable conditions. This study serves as a wake-up call to local officials in these areas regarding the management of these agrosystems, so that they can continue to provide the ecosystem services for which they are intended.

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