

Vegetation Communities of Western Niger: Physiognomy and Diversity

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Abstract

The characteristics of the plant communities inhabiting a phytogeographic area are a key indicator of its ecology. The objective of this study is to identify the main vegetation communities and quantify their phytodiversity. A forest and phytosociological inventory was conducted using stratified sampling. Thus, the vegetation of western Niger is rich and diverse in both its floristic composition and its physiognomy. Its flora comprises 441 plant species distributed across 235 genera and 80 families. It represents 19.17% of the 2274 plant species found in the Nigerien flora. There are 267 herbaceous species, 127 woody species, 20 sub-woody species, and 27 vines. Its floristic composition varies gradually from north to south across different bioclimates. In the Northern Sudanese bioclimate, it is estimated at 387 species divided into 215 genera and 76 families, compared to 208 species grouped into 122 genera distributed across 44 families in the Sahelian bioclimate. Across all sampled units and regardless of the bioclimate considered, herbaceous biodiversity is significantly higher than that of woody, sub-woody, and vine species. Eight plant communities were identified, with varying levels of alpha diversity: it is low (1.06 to 1.97) in ro-nier grove, gallery forests, and semi-aquatic grasslands; moderate (2.55 to 3.22) in savannas and fallow lands; and high (4.4) in shrublands and thickets. This status enables the sustainable management of this natural resource.

Keywords

Savanna, Thicket, Forest Gallery, Ronier Grove, Fallow Land, Grassland

1. Introduction

Vegetation exhibits varying physiognomy depending on its flora, plant communities, and the ecological conditions of the habitat in which it grows [1]. Physiognomy encompasses the structural aspects of vegetation combined with the site-specific characteristics of the environment. Most criteria for physiognomic classification of vegetation relate to the density and height of woody plants, the presence of thorns, and whether the foliage is deciduous, as well as the composition and cover of the herbaceous layer [2].

The vegetation types presented in this study are those adopted at the 1956 Yangambi conference; consequently, the synthesis written by Trochain and Aubreville in 1957 defines the typology of tropical and subtropical vegetation in Africa. The selected criteria include density, the height of the tree and shrub layers, woody cover, and grass cover. The agreements and terminology regarding physiognomic types from the Yangambi meeting are difficult to identify and define in practice, especially in the case of Sudanese and Sahelian vegetation, which is subject to severe climatic variations and the highest degree of human impact. Some of these have been revised and harmonized in the study and description of the flora and vegetation of West Africa [3]. The transition from one vegetation type to another can serve as an ecological indicator of ecosystem dynamics. Western Niger comprises three bioclimatic regions shared by farmers, agro-pastoralists, and pastoralists: western North Sudanese (A1), western South Sahelian, and western North Sahelian (CI) [4]. This land use partly determines the typology and physiognomy of its vegetation. The vegetation formations of western Niger have been poorly characterized despite their great diversity and floristic richness. This study aims to identify the distinctive vegetation formations and quantify the vegetation biodiversity of this part of Niger in order to understand their dynamics within the process of ecological succession.

2. Materials and Methods

2.1. 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 1000 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 [5]. In the Ouallam Department, the western South Sahelian climate is characterized by an alternating pattern of a very short rainy season lasting 3 to 4 months (June through September or even October) and a long dry season lasting 9 months [6]. Precipitation is erratic and sporadic, and is low or even nonexistent during years of drought. Average tem-

peratures range from 24°C to 26°C, but highs can reach 45°C between April and May; the climate is therefore hot and dry. The annual temperature range is approximately 10°C [5].

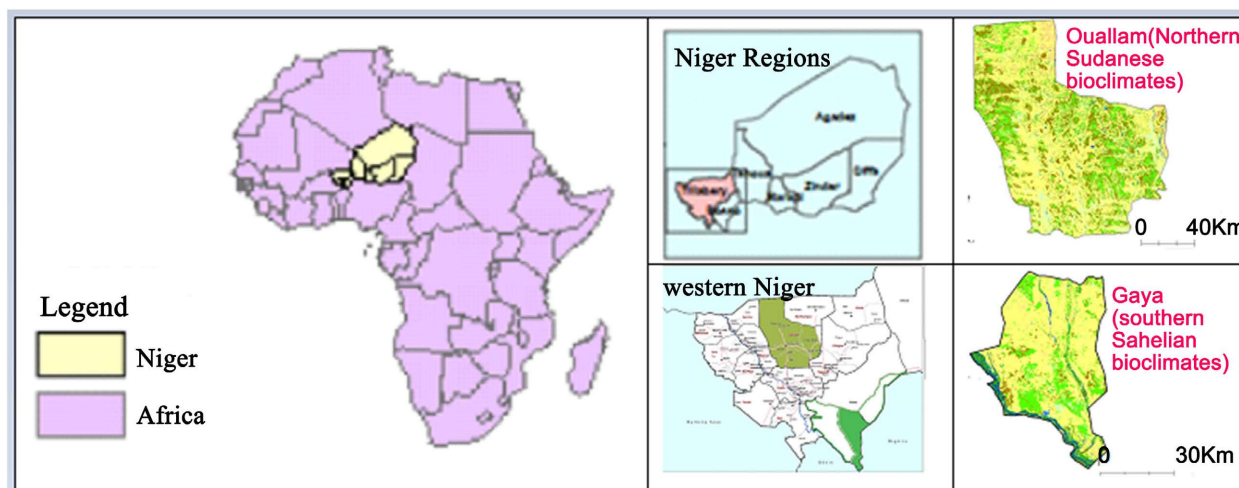


Figure 1. Location of the study area.

2.2. 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 [7]-[9]. 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 [3] [9], 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.

2.3. 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:

$$n = \left[U_{1-\alpha/2} * cv/d \right]^2 \quad (1)$$

cv = coefficient of variation of the parameter; cv = unknown $\text{P } cv = 80\%$ (worst-case scenario);

d = margin of error in parameter estimation: $5 \leq d \leq 15\%$; $U_{1-\alpha/2} \approx 1.96$ 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 N_i within each stratum i :

$$N_i = p_i * n; p_i = S_i / S \quad (2)$$

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

2.4. 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 [10]-[12]. Floristic and phytosociological surveys were conducted using the Braun-Blanquet method [13], which is based on the vegetative homogeneity of ecological stations [14]. Its objective is to understand the spatio-temporal organization of vegetation and to help describe plant communities and the species that comprise them [15]. It has been applied by several authors in the study of intertropical vegetation [16] [17]. In Niger, this approach has been adopted by numerous researchers [6] [18]-[20].

Thus, 41 transects were surveyed in the Northern Sudanese region (Gaya Department) and 8 transects in the Ouallam Department, located in the Sahelian zone. Along each transect, an average of 6 to 10 plots were surveyed. The plots are spaced 300 m, 400 m, and 500 m apart, depending on the area of the vegetation formation within which the transect is laid out. The transects consist of geomorphological units (valleys, riverbeds, shallows, glacia, plains, and plateaus), and the first plot is established at the beginning of each of these units.

The size of the plots varies from one type of vegetation community or land use to another. These empirical values for minimum plot areas are those described by [3], based on the Inter-African Agreement on the Definition of Vegetation Types in Tropical Africa [17] and discussed by [21]. The minimum plot areas selected are as follows:

- ✓ 500 m² (50 m × 10 m) in gallery forests;
- ✓ 1000 m² (50 m × 20 m) in savannas and open forests;
- ✓ 2500 m² (50 m × 50 m) in agrosystems and compacted formations (striped bush formations);
- ✓ 16 m² (8 m × 2 m) in aquatic grasslands;

Across the entire study area, 336 plots were surveyed and inventoried (Table 1).

The surveys were conducted in September and October of 2025.

Table 1. Sampling parameters.

Type of community	Number of transect	Number of plot	Plot Area (m)	Area (m ²)
Fallow Lands	14	93	50*50	232,500
Forest Galleries	4	29	50*10	14,500

Continued

Rôneraie	4	24	50*50	60,000
Semi-aquatic grasslands	4	25	8*2	400
Shrub Savanna	8	49	50*20	49,000
Tigered Bushes	7	63	50*50	157,500
Tree Orchards	4	27	50*50	67,500
Wooded savanna	4	26	50*20	26,000
Total	49	336		607,400

For each plot, the site's ecological and structural parameters are recorded: geomorphology, land-use type, vegetation type, plant community, abundance-dominance, regeneration (seeds, stump sprouts, layering, or suckers), plant 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 have been assigned to the species between 1% and 100%.

These months correspond to the plants' maturation period, and even dormant seeds are generally present. The work by [20] showed that these types of formations, environmental conditions, and floristic compositions exhibit slight interdecadal fluctuations. The scientific names of these species are verified using "The Flora of West Tropical Africa, the floras of Senegal, Adventrop: Weeds of Sudano-Sahelian Africa, and the Analytical Flora of Benin" [20].

3. Data Analysis

3.1. 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 [22]. 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

$$H_r = S - 1 \quad (3)$$

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 (H_m) is expressed by the following formula (4)

$$H_m = \sqrt{\frac{1}{n} \sum_{i=1}^n H_i^2} \quad (4)$$

where n is the number of trees in the plot and H_i is the height (in m) of tree i

Tree density is calculated using the formula below

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

- 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

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

- 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;

$$p_i = n_i / N \quad (8)$$

the ratio of the average cover of species i to the total cover of all identified species;

n_i = 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; $2.5 \leq H' < 4$ = moderate; $H' \geq 4$ = 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 [23]. 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; $0.6 \leq E \leq 0.7$ = moderate; $E \geq 0.8$ = high

The Pielou equitability index is determined by the formula below:

$$E = \frac{H'}{H_{\max}} \quad (9)$$

E = Pielou's evenness;

$H_{\max} = \log_2 S$, where S is the total number of species;

H' = Shannon index.

$E < 0.6$ = low; $0.6 \leq E \leq 0.7$ = moderate; $E \geq 0.8$ = high.

The Jaccard similarity coefficient is used to demonstrate the existence of floris-

tic similarity between two plant communities or two bioclimates being compared. It is calculated using the following formula:

$$K_{obs} = N_{ab} / [(N_a + N_b) - N_{ab}] \quad (10)$$

where: N_{ab} = number of species common to both communities; N_a = number of species in community 1; N_b = number of species in community 2.

The higher this coefficient, the more the two communities share floristic assemblages.

3.2. Biological Types

Plants adapt to the ecological conditions of the environment in which they live and reproduce. To withstand these conditions, they develop various morphological, physical, physiological, and genetic characteristics. For each species, biological types reflect the forms of adaptation to the ecological conditions of their biotope [6] [24]. According to [25], they reflect the floristic diversity within the vegetation under consideration, since isoclimatic zones may reveal different biological spectra, or different climatic zones may exhibit similar biological spectra [26]. Other authors, such as [27], propose the concept of the dominance spectrum. However, the dominance of a species in a given ecological site may reflect its competitive ability to withstand and adapt to the physical and edaphic conditions of the environment, whereas less competitive, less successful, and poorly adapted species are rare and gradually disappear over geological time. The terminology and definitions of biological types used in this study are those established by [24]. Biological types are defined based on the size of individuals and the position of their vegetative buds (growth meristems) relative to ground level during the so-called unfavorable growing season. The classification defines the following groups:

Phanerophytes (P) are woody, perennial plants whose dormant aerial buds are located more than 50 cm above the ground surface. They are subdivided into several subcategories:

- ✓ Nanophanerophytes (NnPh) are plants ranging in height from 50 cm to 2 m;
- ✓ Microphanerophytes (McPh) are plants ranging in height from 2 to 8 m;
- ✓ Mesophanerophytes (MsPh) range in height from 8 to 50 m;
- ✓ Megaphanerophytes (MPh) are plants taller than 50 m.

Chamephytes (Ch): These are subwoody plants with dormant aerial buds located above ground level at a height of less than 50 cm. These plants benefit from the unique microclimate immediately above the ground. They survive the wet season with a poorly developed stem above the ground surface. The above-ground part of the plant disappears during the dry season and resumes growth with the return of the rainy season;

Hemicryptophytes (H): are perennial plants whose dormant aerial buds are located at ground level. The aerial parts are herbaceous, with stems and flower stalks that are renewed each year;

Geophytes (Geo) are plants with very fragile aerial parts and perennial organs

buried in the soil. Geophytes can be: rhizomatous (Gr), bulbous (Gb), or tuberous (Gt). The dormant perennial organs resume activity during the growing season to produce aerial parts;

Hygrophytes (Hy): plants with very fragile aerial parts and perennial organs hidden in moist mud or even in water. This form of adaptation provides highly effective protection against drought and extreme temperature fluctuations;

Therophytes (The): their life span lasts only a few weeks to a few months. These are annual plants that survive as seeds or spores during the season unfavorable for growth.

Phytogeographic Types

Phytogeographic types will be determined based on the chorological subdivisions generally accepted by [2] [6]. Phytogeographic types show the distribution ranges of each species worldwide. The following geographic distributions are distinguished:

Widespread species:

- ✓ Cosmopolitan (Cos): species distributed throughout the tropical and temperate regions of the world;
- ✓ Afro-American (AA): species widespread in Africa and the Americas;
- ✓ Pantropical (Pan): species widespread throughout all regions of Africa, the Americas, and tropical Asia;
- ✓ Paleotropical (Pal): species found in tropical Africa, tropical Asia, Madagascar, and Australia;

Species with a distribution limited to the African continent

- ✓ African (A): These are species found only in Africa;
- ✓ Tropical Afro-Malagasy (AM): species found in Africa, Madagascar, the Comoros, and the Seychelles;
- ✓ Afro-Tropical (AT): species widespread in tropical Africa;
- ✓ Multiregional (PA): Species whose range extends across several regional centers of endemism;
- ✓ Sudan-Zambesian (SZ): Species found in both the Sudanese and Zambesian regional centers of endemism;
- ✓ Guineo-Congolese (GC): species distributed in the Guinean region;
- ✓ Sudanese (S): species widely distributed in the Sudanese regional center of endemism;
- ✓ Sudanese-Zambesian-Saharo-Sindian (SZ-Sah.S);
- ✓ Guineo-Congolese-Sudanese-Zambesian (GC-SZ);
- ✓ Saharo-Sindian (Sah.S);
- ✓ Saharo-Sindian-Mediterranean (Sah.S-Med);
- ✓ Guineo-Congolese-Sudan-Zambian-Saharo-Sindian (GC-SZ-Sah.S);
- ✓ Sudan-Zambian-Saharo-Sindian-Mediterranean (SZ-Sah.S-Med).

3.3. Vegetation Types

The North Sudanese vegetation of western Niger is characterized by a variety of

physiognomies. In terms of diversity, stand structure, and the ecological habitats of species, significant heterogeneity is observed. The objective here is to establish a physiognomic classification of the vegetation by explicitly describing the salient features or the most distinctive floristic and structural characteristics of each stand type. This classification is based on the summary of the Yanganti meeting (1956) and the work of numerous authors [2] [6] [17] [21].

4. Results

4.1. Floristic Diversity

The vegetation of western Niger is rich and diverse in both its floristic composition and its appearance. Its flora comprises 441 plant species divided into 235 genera and 80 families (**Table 2**). These include 267 herbaceous species, 127 woody species, 20 sub-woody species, and 27 vines. Its floristic composition varies gradually from north to south as one bioclimate gives way to another. In the Northern Sudanese bioclimate, it is estimated at 387 species divided into 215 genera and 76 families, compared to 208 species grouped into 122 genera distributed across 44 families in the Sahelian bioclimate. Across all sampled units and regardless of the bioclimate considered, the biodiversity of herbaceous plants is significantly higher than that of woody, sub-woody, and vine species (**Table 1**). The most prominent families are the Poaceae, with 70 species, and the Fabaceae-Faboideae, with 54 species. They are followed significantly by the Cyperaceae (19 species), Fabaceae-Mimosoideae (18 species), Fabaceae-Caesalpinioideae (17 species), Convolvulaceae (15 species), Euphorbiaceae (15 species), Malvaceae (14 species), Rubiaceae (12 species), and Acanthaceae (11 species).

In terms of the number of genera, these same families are the most widespread. Thus, the Poaceae family tops the list with 30 genera; Fabaceae-Faboideae comprises 12 genera; Fabaceae-Caesalpinioideae comprises 10 genera; Asclepiadaceae comprises 9 genera; and Fabaceae-Mimosoideae, Rubiaceae, Euphorbiaceae, Acanthaceae, Amaranthaceae, and Asteraceae each comprise 8 genera. The genera *Indigofera* (17 species), *Crotalaria* (11 species), *Ipomoea* (11 species), *Tephrosia* (10 species), and *Cyperus* (10 species) are widely distributed, with at least ten species each. They are followed by the genera *Acacia*, *Eragrostis*, *Cassia*, *Aristida*, *Brachiaria*, and *Combretum*.

Table 2. Species diversity.

Family	Number of Species	frequency %	Number of Genera	frequency %	Genus coefficient
Poaceae	70	15.87	30	12.77	42.86
Fabaceae-faboideae	54	12.24	12	5.11	22.22
Cyperaceae	19	4.31	5	2.13	26.32
Fabaceae-mimosoideae	18	4.08	8	3.40	44.44
Fabaceae-caesalpinioideae	17	3.85	10	4.26	58.82

Continued

Convolvulaceae	15	3.40	4	1.70	26.67
Euphorbiaceae	16	3.63	8	3.40	50.00
Malvaceae	14	3.17	5	2.13	35.71
Rubiaceae	12	2.72	8	3.40	66.67
Acanthaceae	11	2.49	8	3.40	72.73
Amaranthaceae	10	2.27	8	3.40	80.00
Asclepiadaceae	10	2.27	9	3.83	90.00
Asteraceae	10	2.27	8	3.40	80.00
Capparaceae	11	2.49	5	2.13	45.45
Combretaceae	9	2.04	4	1.70	44.44
Cucurbitaceae	9	2.04	6	2.55	66.67
Tiliaceae	9	2.04	3	1.28	33.33
Lamiaceae	7	1.59	4	1.70	57.14
Aizoaceae	6	1.36	5	2.13	83.33
Anarcadiaceae	6	1.36	4	1.70	66.67
Commelinaceae	6	1.36	3	1.28	50.00
Solanaceae	6	1.36	4	1.70	66.67
Caryophyllaceae	4	0.91	1	0.43	25.00
Scrophulariaceae	4	0.91	2	0.85	50.00
Apocynaceae	3	0.68	3	1.28	100.00
Areaceae	3	0.68	3	1.28	100.00
Moraceae	6	1.36	2	0.85	33.33
Onagraceae	3	0.68	1	0.43	33.33
Pedaliaceae	3	0.68	3	1.28	100.00
Sterculariaceae	3	0.68	3	1.28	100.00
Amaryllidaceae	2	0.45	2	0.85	100.00
Araceae	2	0.45	1	0.43	50.00
Bignoniaceae	2	0.45	2	0.85	100.00
Bombacaceae	2	0.45	2	0.85	100.00
Borraginaceae	2	0.45	1	0.43	50.00
Chrysobalanaceae	2	0.45	2	0.85	100.00
Hyacinthaceae	2	0.45	1	0.43	50.00
Loranthaceae	2	0.45	1	0.43	50.00
Myrtaceae	2	0.45	2	0.85	100.00
Nyctaginaceae	2	0.45	1	0.43	50.00
Nymphaeaceae	2	0.45	1	0.43	50.00
Polygalaceae	2	0.45	1	0.43	50.00
Polygonaceae	2	0.45	1	0.43	50.00

Continued

Portulacaceae	2	0.45	1	0.43	50.00
Rhamnaceae	2	0.45	1	0.43	50.00
Verbenaceae	2	0.45	1	0.43	50.00
Vitaceae	2	0.45	2	0.85	100.00
Agavaceae	1	0.23	1	0.43	100.00
Alliaceae	1	0.23	1	0.43	100.00
Annonaceae	1	0.23	1	0.43	100.00
Asparagaceae	1	0.23	1	0.43	100.00
Azollaceae	1	0.23	1	0.43	100.00
Balanitaceae	1	0.23	1	0.43	100.00
Brassicaceae	1	0.23	1	0.43	100.00
Bryaceae	1	0.23	1	0.43	100.00
Burseraceae	1	0.23	1	0.43	100.00
Celastraceae	1	0.23	1	0.43	100.00
Cochlospermaceae	1	0.23	1	0.43	100.00
Colchiaceae	1	0.23	1	0.43	100.00
Dipterocarpaceae	1	0.23	1	0.43	100.00
Ebenaceae	1	0.23	1	0.43	100.00
Liliaceae	1	0.23	1	0.43	100.00
Loganiaceae	1	0.23	1	0.43	100.00
Marsileaceae	1	0.23	1	0.43	100.00
Meliaceae	1	0.23	1	0.43	100.00
Menispermaceae	1	0.23	1	0.43	100.00
Moringaceae	1	0.23	1	0.43	100.00
Musaceae	1	0.23	1	0.43	100.00
Olacaceae	1	0.23	1	0.43	100.00
Oracaenaceae	1	0.23	1	0.43	100.00
Periplocaceae	1	0.23	1	0.43	100.00
Pontederiaceae	1	0.23	1	0.43	100.00
Rutaceae	1	0.23	1	0.43	100.00
Sapindaceae	1	0.23	1	0.43	100.00
Sapotaceae	1	0.23	1	0.43	100.00
Sphenocleaceae	1	0.23	1	0.43	100.00
Tribulaceae	1	0.23	1	0.43	100.00
Turneraceae	1	0.23	1	0.43	100.00
Typhaceae	1	0.23	1	0.43	100.00
Zygophyceae	1	0.23	1	0.43	100.00
Total	441	100.00	235	100	53.29

4.2. Biodiversity Indices

Biodiversity indices vary from one bioclimate to another along the rainfall gradient. These indices are high in the south, in the Sudanese bioclimate, where rainfall is abundant, and moderate in the Sahelian zone further north, where rainfall is low and irregular. Alpha diversity, or the Shannon index (H), is 5.12 bits in the Sudanese bioclimate, compared to 4.55 bits in the Sahelian bioclimate (**Table 3**). These values indicate remarkable species diversity within the plant communities. Pielou's evenness is at its maximum and ranges from 0.86 in the Sudanese zone to 0.85 in the Sahelian zone. This implies an even distribution of species that coexist without any particular dominance. The Jaccard similarity coefficient is low, with a value of 0.34. This indicates a distant affinity between the two bioclimates. They share 153 species—one-third of their species diversity—and are distinguished by 235 species unique to the Sudanese zone, compared to 63 species unique to the Sahelian bioclimate.

Table 3. Biodiversity indices for the study areas.

Bioclimates	Species Diversity	Alpha Diversity	H_{max}	Pielou Equitability
Northern Sudan	387	5.12	5.94	0.86
Southern Sahel	208	4.55	5.33	0.85

4.3. Biological Types

A close examination of the biological spectrum of the Northern Sudan region generally reveals a predominance of therophytes (**Figure 2**). They account for just over 46.40% of all recorded species. This biological type is followed by microphanerophytes (16.53%). It is worth noting the significant proportion of hydrophytes (6.67%). These species grow in wet or submerged habitats. Their presence indicates a well-watered area with abundant precipitation and a shallow water table. Also notable in this bioclimate is the presence of vines of all kinds (7.2%).

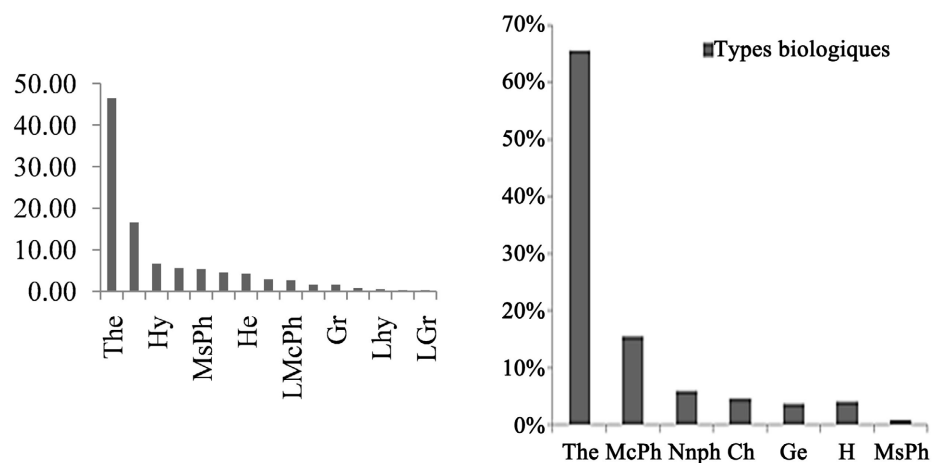


Figure 2. Biological spectra of the Sudanese bioclimate. Biological spectra of the Sahelian bioclimate.

In contrast, therophytes and microphanerophytes—accounting for 65% and 15%, respectively—make up the bulk of the flora in the southern Sahelian zone of western Niger.

4.4. Phytogeographic Types

The phytogeographic distribution reveals a predominance of species common to the African continent (**Figure 3**), which constitute half of the flora (52.11%), along with Paleotropical (17.5%) and Pantropical (17.18%) species. The other phytogeographic types are sparsely distributed. The distribution of species within African endemism zones shows a predominance of Guineo-Congolese and Sudano-Zambesian species (39.89%) and species endemic to the Sudano-Zambesian region (33.71%) (**Figure 3**). These species are accompanied by transitional species between these two regional centers of endemism and the Sahelian center of endemism. These include Sudano-Zambesian-Sahelo-Saharan species (11.24%) and Guineo-Congolese-Sudano-Zambesian and Sahelo-Saharan species (7.87%). In addition, a few Saharo-Mediterranean species are present. In the southern Sahelian bioclimate, Sudano-Zambesian species dominate (35%), followed by Guineo-Congolese-Sudano-Zambesian species (26%) and Sudano-Zambesian-Saharo-Sindian species (21%).

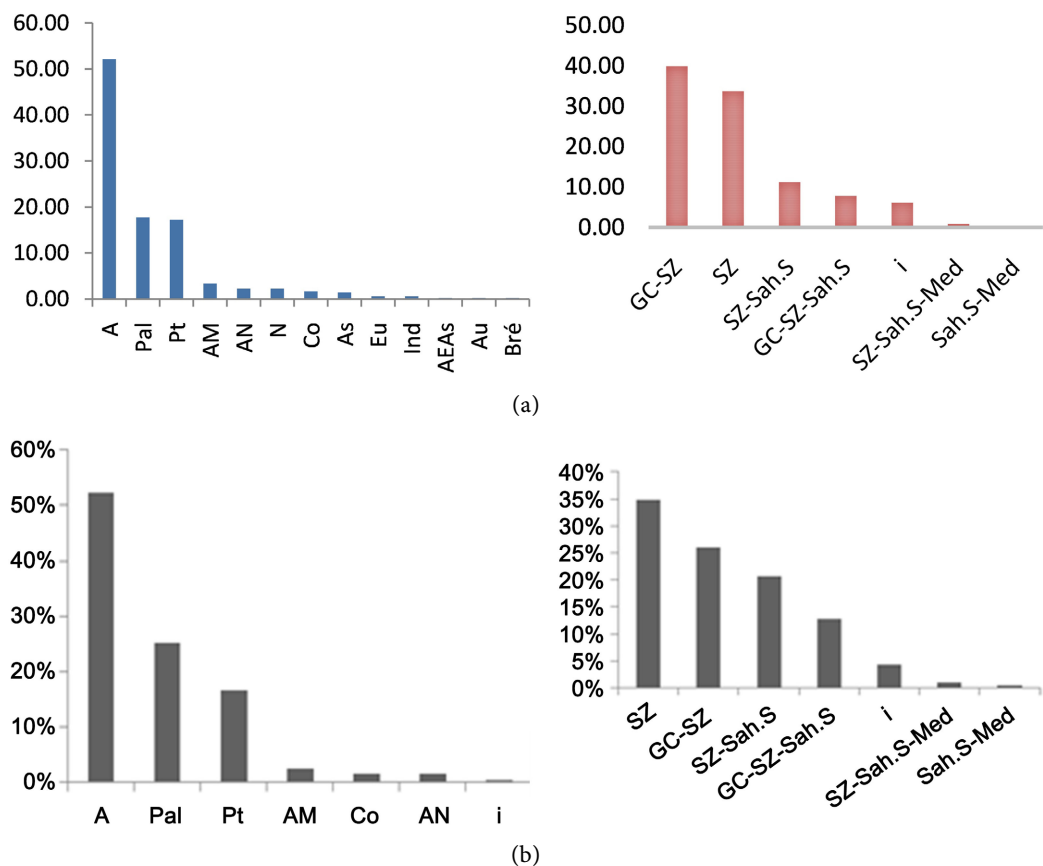


Figure 3. (a) Phytogeographic spectra of the Northern Sudanese bioclimate; (b) Phytogeographic spectra of the southern Sahelian bioclimate.

4.5. Typology of Vegetation Formations

Based on the distribution pattern of the tree layer, eight (8) major vegetation formations that are easily recognizable are presented and described in this section. These are: shrubby and thicket formations, wooded savanna, shrub savanna, gallery forest, roan tree forest, wooded parks, grasslands, and orchards.

4.6. Tigered Bushes/Thickets

Tigered thickets are generally found on stony, rocky, gravelly, and iron-rich plateaus. Sometimes they occupy the slopes of rugged depressions created by runoff water and, on occasion, glaciis. The diverse flora consists of 137 species grouped into 34 families and 85 genera. There are 27 woody species and 110 herbaceous species (Table 4). The Shannon index is 4.4 bit, and the Pielou evenness index is 0.86 in the Northern Sudanese zone. In the Northern Sudanese zone (Gaya), among the woody species associated with these thickets are:

Guiera senegalensis, *Gardenia sokotensis*, *Combretum micranthum*, *Boscia angustifolia*, *Combretum nigricans*, *Boscia senegalensis*, *Piliostigma reticulatum*, *Croton gratissimus*, *Lannea acida*, *Cassia sieberiana*, *Combretum glutinosum*, *Bombax costatum*, *Feretia apodanthera*, *Holarrhena floribunda*, *Crossopteryx febrifuga*. Les arbustes et lianes sarmenteux qu'elles abritent sont: *Acacia ataxacantha*, *Acacia erythrocalyx*, *Acacia macrostachya*, *Grewia flavescens*, *Dichrostachys cinerea*, *Strophanthus sarmentosus*, *Gymnema sylvestre* and *Asparagus africanus*. With the exception of a few species in the Combretaceae, Capparaceae, and Fabaceae-Mimosoideae families, most of the species mentioned are absent from the Sahelian (Ouallam) bioclimate plateaus, and the vegetation tends to take on the appearance of thickets or scrub. The average woody cover is 31.81%, while the herbaceous layer covers 12.44%. The remainder consists of bare patches. Shrubs cover 17.17% of the ground surface, compared to 14.64% for trees. In general, woody plants range in height from 3 to 7 m, but the average height is 8.44 ± 2.4 m for trees and 3.92 ± 1.3 m for shrubs. However, a few trees ranging from 9 m to 15 m in height are embedded among the shrubs and are found spaced far apart.

The average density of woody plants is 1121.42 individuals/ha but varies from one stand to another. It is 933.21 individuals/ha for shrubs but 185.7 individuals/ha for trees. In contrast, the density and regeneration rate are 318.92 individuals/ha and 22%, respectively. Shrubs (284.285 individuals/ha) regenerated more than trees (31.42 individuals/ha). The herbaceous layer is dominated by Poaceae. However, the Fabaceae-Faboideae, Convolvulaceae, Piperaceae, Acanthaceae, and Lamiaceae families are also significantly represented. Herbaceous species such as *Microchloa indica*, *Tripogon minimus*, *Brachiaria* sp., *Pennisetum pedicellatum*, *Zornia glochidiata*, *Triumfetta pentandra*, *Cassia mimosoides*, *Blepharis maderaspatensis*, *Englerastrum gracillimum*, *Cyanotis lanata*, *Evolvulus alsinoides*, *Stylochiton lancifolius*, *Achyranthes aspera*, *Hypoestes cancellata*, *Ipomoea* sp., and *Spermacoce* sp. are frequently recorded.

Table 4. Abundance of woody plants in the Tiger Bush.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Guiera senegalensis</i>	318.93	140.00	43.90	28.44
<i>Gardenia sokotensis</i>	303.21	74.64	23.40	27.04
<i>Combretum micranthum</i>	248.57	32.50	10.19	22.17
<i>Combretum nigricans</i>	159.29	25.00	7.84	14.20
<i>Boscia angustifolia</i>	20.36	4.64	1.46	1.82
<i>Boscia senegalensis</i>	20.00	2.14	0.67	1.78
<i>Piliostigma reticulatum</i>	11.79	14.64	4.59	1.05
<i>Croton gratissimus</i>	7.86	1.07	0.34	0.70
<i>Grewia flavescens</i>	6.07	15.00	4.70	0.54
<i>Lannea acida</i>	6.07	0.71	0.22	0.54
<i>Combretum glutinosum</i>	4.29	0.36	0.11	0.38
<i>Cassia sieberiana</i>	3.93	3.57	1.12	0.35
<i>Acacia erythrocalyx</i>	1.79	0.36	0.11	0.16
<i>Gymnema sylvestre</i>	1.79	1.43	0.45	0.16
<i>Acacia ataxacantha</i>	1.43	0.36	0.11	0.13
<i>Sclerocarya birrea</i>	1.43	0.71	0.22	0.13
<i>Acacia macrostachya</i>	1.07	0.00	-	0.10
<i>Holarrhena floribunda</i>	0.71	0.00	-	0.06
<i>Bombax costatum</i>	0.36	0.00	-	0.03
<i>Cissus quadrangularis</i>	0.36	0.00	-	0.03
<i>Crossopteryx febrifuga</i>	0.36	0.00	-	0.03
<i>Dichrostachys cinerea</i>	0.36	0.00	-	0.03
<i>Feretia apodanthera</i>	0.36	0.00	-	0.03
<i>Maerua angolensis</i>	0.36	0.00	-	0.03
<i>Pterocarpus erinaceus</i>	0.36	0.00	-	0.03
<i>Strophanthus sarmentosus</i>	0.36	0.00	-	0.03
<i>Asparagus africanus</i>	0.00	1.79	0.56	0.00
Total	1121.42	318.92	100.00	100.00

Savanna Formations

Ranging from wooded to degraded shrubland, savanna formations are primarily characteristic of the Northern Sudanese zone. Found as relict populations in protected areas (Dosso Partial Wildlife Reserve), they harbor a rich diversity of flora and retain distinctive structural features despite the anthropogenic pressures to which they are currently subjected. Savanna formations are characteristic of stony and lateritic plateaus, slopes, and sandy glacia.

Wooded Savanna

The northern Sudanese wooded savanna is a vegetation community dominated by woody plants, with an average canopy cover of 35.44%. The tree layer covers an average of 16.83% of the basal area, while shrubs have an average cover of 18.61%. The herbaceous layer, generally dominated by Poaceae and Fabaceae-Faboideae, occupies 11.94% of the area. During the rainy season, vegetation cover can reach 47.38%. Trees have an average height of 6.88 ± 3.68 m, but a few isolated individuals can sometimes reach 12 to 13 m. In contrast, the average height of shrubs is 3.30 ± 1.46 m. The total density of woody plants is 1457 individuals/ha. The average density is 707.77 individuals/ha for trees and 750 individuals/ha for shrubs. The regeneration density ranges from 185.55 individuals/ha in the tree layer to 261.66 individuals/ha in the shrub layer. Overall, the woody plant density and regeneration rate are 447.22 individuals/ha and 23%, respectively. The North Sudanese wooded savannas of Niger are home to 106 plant species, including 42 woody species, 64 herbaceous species, and 14 vines. These species are distributed across 33 families and 76 genera. The predominant families are Poaceae (14 species), Fabaceae-Faboideae (9 species), Fabaceae-Mimosoideae (7 species), Fabaceae-Caesalpinioideae, Asclepiadaceae, Convolvulaceae, Rubiaceae (6 species each), and Combretaceae (5 species). The distinctive woody species belong to the Combretaceae (*Combretum nigricans*, *Combretum micranthum*, *Guiera senegalensis*, *Combretum glutinosum*), along with *Gardenia sokotensis*, *Bombax costatum*, *Lannea acida*, *Cassia sieberiana*, and *Albizzia chevalerii* (Table 5). The herbaceous layer is dominated by *Hyptis suaveolens*, *Microchloa indica*, *Pennisetum pedicellatum*, *Eragrostis tremula*, *Tephrosia elegans*, *Zornia glochidiata*, *Spermacoce radiata*, and *Evolvulus alsinoides*. The Shannon biodiversity index is relatively low at 2.68 bits, and the Pielou evenness index is 0.57.

Table 5. Importance of woody plants in the tree savanna.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Combretum micranthum</i>	472.22	14.44	3.20	26.95
<i>Combretum nigricans</i>	419.44	161.11	35.67	23.94
<i>Gardenia sokotensis</i>	407.78	71.11	15.74	23.27
<i>Guiera senegalensis</i>	261.67	165.56	36.65	14.93
<i>Cassia sieberiana</i>	50.56	4.44	0.98	2.89
<i>Combretum glutinosum</i>	30.00	8.33	1.85	1.71
<i>Grewia flavescens</i>	18.89	6.11	1.35	1.08
<i>Acacia macrostachya</i>	12.78	0.56	0.12	0.73
<i>Bombax costatum</i>	10.56	1.11	0.25	0.60
<i>Combretum collinum</i>	8.33	1.11	0.25	0.48
<i>Boscia angustifolia</i>	7.78	1.67	0.37	0.44
<i>Ximenia americana</i>	6.67	0.56	0.12	0.38

Continued

<i>Boscia senegalensis</i>	5.56	1.11	0.25	0.32
<i>Lannea acida</i>	5.00	2.22	0.49	0.29
<i>Feretia apodanthera</i>	3.89	0.56	0.12	0.22
<i>Acacia erythrocalyx</i>	3.33	0.00	0.00	0.19
<i>Gymnema sylvestre</i>	2.78	2.22	0.49	0.16
<i>Sclerocarya birrea</i>	2.78	0.00	0.00	0.16
<i>Strophanthus sarmentosus</i>	2.78	0.00	0.00	0.16
<i>Cissus quadrangularis</i>	2.22	0.00	0.00	0.13
<i>Crossopteryx febrifuga</i>	2.22	1.67	0.37	0.13
<i>Asparagus africanus</i>	1.67	1.11	0.25	0.10
<i>Erythrophleum</i>	1.67	0.00	0.00	0.10
<i>Newbouldia laevis</i>	1.67	0.56	0.12	0.10
<i>Acacia senegal</i>	1.11	0.00	0.00	0.06
<i>Lannea microcarpa</i>	1.11	0.00	0.00	0.06
<i>Lonchocarpus laxiflorus</i>	1.11	2.78	0.62	0.06
<i>Maerua angolensis</i>	1.11	1.11	0.25	0.06
<i>Prosopis africana</i>	1.11	0.00	0.00	0.06
<i>Sterculia setigera</i>	1.11	0.00	0.00	0.06
<i>Acacia ataxacantha</i>	0.56	0.00	0.00	0.03
<i>Acacia sieberiana</i>	0.56	0.00	0.00	0.03
<i>Detarium microcarpum</i>	0.56	0.00	0.00	0.03
<i>Entada africana</i>	0.56	0.56	0.12	0.03
<i>Grewia bicolor</i>	0.56	0.00	0.00	0.03
<i>Pterocarpus erinaceus</i>	0.56	0.00	0.00	0.03
<i>Baissea multiflora</i>	0.00	1.11	0.25	0.00
<i>Piliostigma reticulatum</i>	0.00	0.56	0.12	0.00
Total	1752.22	451.67	100.00	100.00

Shrub Savanna

The shrub savanna is a type of vegetation dominated by a shrub layer.

During the growing season, vegetation cover can extend to 55.92%, of which 31.42% is woody vegetation and 24.5% is herbaceous vegetation. The average cover for the shrub layer is 18.06%, compared to 13.35% for the tree layer. The number of species recorded is 182, including 42 woody species and 140 herbaceous species. These species are distributed across 40 families and 110 genera, with a predominance of Poaceae (29 species), Fabaceae-faboideae (22 species), Fabaceae-caesalpiinoideae (11 species), Rubiaceae (11 species), Acanthaceae, Convolvulaceae, and Cyperaceae—each with 9 species—Malvaceae (8 species), and Com-

bretaceae with 7 species (Table 6). The Shannon diversity index is 3.22 bits, and the Pielou evenness index is 0.61. The dominant woody species are: *Combretum nigricans*, *Guiera senegalensis*, *Combretum glutinosum*, *Combretum micranthum*, and *Gardenia sokotensis*. However, other tree species such as *Cassia sieberiana*, *Boscia angustifolia*, *Boscia senegalensis*, *Acacia macrostachya*, *Piliostigma reticulatum*, *Bombax costatum*, *Acacia ataxacantha*, *Crossopteryx febrifuga*, *Detarium microcarpum*, *Feretia apodanthera*, *Gardenia ternifolia*, *Maerua angolensis*, and *Prosopis africana* are found sporadically. The herbaceous layer consists mainly of: *Hyptis suaveolens*, *Microchloa indica*, *Schizachyrium exile*, *Sida cordifolia*, *Penisetum pedicellatum*, *Tephrosia pedicellata*, *Cassia mimosoides*, *Tripogon minimus*, *Englerastrum gracillimum*, *Zornia glochidiata*, *Eragrostis tremula*, *Aristida adscensionis*, *Spermacoce radiata* and *Triumfetta pentandra*. Trees generally have an average height of 6.31 ± 2.02 m, while shrubs have an average height of 3 ± 1.52 m. Shrubs (1234.545 inds/ha) are three (3) times denser than trees (429.54 inds/ha), and the total density of woody plants is 1664 inds/ha. Woody regeneration stands at 667.27 individuals/ha, but varies from 160.90 to 506.36 individuals/ha for trees and shrubs, respectively. The overall regeneration rate is estimated at 29%.

Table 6. Abundance of woody plants in the Shrub Savanna.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Guiera senegalensis</i>	683.64	360.45	53.91	41.03
<i>Combretum nigricans</i>	308.86	107.27	16.04	18.54
<i>Combretum micranthum</i>	236.14	35.45	5.30	14.17
<i>Gardenia sokotensis</i>	155.45	70.91	10.61	9.33
<i>Gardenia ternifolia</i>	51.14	12.05	1.80	3.07
<i>Combretum glutinosum</i>	44.77	38.64	5.78	2.69
<i>Boscia senegalensis</i>	40.91	6.36	0.95	2.45
<i>Acacia macrostachya</i>	34.32	1.36	0.20	2.06
<i>Cassia sieberiana</i>	27.05	8.86	1.33	1.62
<i>Grewia flavescens</i>	25.91	13.86	2.07	1.55
<i>Piliostigma reticulatum</i>	17.73	1.36	0.20	1.06
<i>Boscia angustifolia</i>	9.32	2.27	0.34	0.56
<i>Acacia ataxacantha</i>	4.32	0.45	0.07	0.26
<i>Combretum collinum</i>	3.64	1.14	0.17	0.22
<i>Bombax costatum</i>	2.73	0.23	0.03	0.16
<i>Acacia erythocalyx</i>	2.27	0.23	0.03	0.14
<i>Detarium microcarpum</i>	2.27			0.14
<i>Prosopis africana</i>	1.59	0.45	0.07	0.10
<i>Strophanthus sarmentosus</i>	1.59			0.10
<i>Albizia lebbek</i>	1.36			0.08

Continued

<i>Feretia apodanthera</i>	1.36	0.45	0.07	0.08
<i>Maerua angolensis</i>	1.36	0.45	0.07	0.08
<i>Balanites aegyptiaca</i>	0.91	0.91	0.14	0.05
<i>Crossopteryx febrifuga</i>	0.91	0.91	0.14	0.05
<i>Ximenia americana</i>	0.91	0.68	0.10	0.05
<i>Burkea africana</i>	0.68	0.68	0.10	0.04
<i>Ziziphus mucronata</i>	0.68	0.23	0.03	0.04
<i>Asparagus africanus</i>	0.45	0.45	0.07	0.03
<i>Azadirachta indica</i>	0.45			0.03
<i>Lannea acida</i>	0.45	0.23	0.03	0.03
<i>Lannea microcarpa</i>	0.45	0.23	0.03	0.03
<i>Sterculia setigera</i>	0.45			0.03
<i>Stereospermum Kunthianum</i>	0.45			0.03
<i>Anogeissus leiocarpus</i>	0.23	0.23	0.03	0.01
<i>Cadaba farinosa</i>	0.23			0.01
<i>Gymnema sylvestre</i>	0.23	0.23	0.03	0.01
<i>Holarrhena floribunda</i>	0.23			0.01
<i>Lannea fruticosa</i>	0.23			0.01
<i>Monotes kerstingii</i>	0.23			0.01
<i>Pterocarpus erinaceus</i>	0.23			0.01
<i>Terminalia avicennioides</i>	0.23	0.23	0.03	0.01
<i>Calotropis procera</i>		0.23	0.03	0.00
<i>Caralluma edulis</i>		0.68	0.10	0.00
<i>Maerua crassifolia</i>		0.45	0.07	0.00
Total	1666.36	668.64	100.00	100.00

Forest Galleries

They colonize the banks of watercourses and thalwegs. Dominated by woody plants, their landscape is typically forested, with an average canopy cover of 49.17%. Compared to woody plants, herbaceous plants are underrepresented and cover only 3.61% of the area. The woody canopy (45.56) is dominated by trees, with an average canopy cover of 41.67%, compared to 3.89% for shrubs. Trees have an average height of 9.65 ± 4.6 m, while shrubs reach only 5.12 ± 1.8 m. The woody plant density is 1197.78 individuals/ha. In fact, density ranges from 581.86 individuals/ha for trees to 615.91 individuals/ha for shrubs. The regeneration density is 1244.44 individuals/ha, representing a regeneration rate of 50.95%. This rate is higher for trees (1055.28 individuals/ha) than for shrubs (189.5 individuals/ha). The relatively undiversified flora consists of 71 species, including 33 woody species, 32 herbaceous species, and 6 vines. The Shannon diversity index is 1.42 bits,

and the Pielou evenness index is 0.34. These species are distributed across 26 families and 52 genera (**Table 7**). The most well-represented families are: Fabaceae-Mimosoideae (8 species), Combretaceae and Poaceae (6 species each), Fabaceae-Caesalpinioideae, Rubiaceae, and Tiliaceae (4 species each), and Arecaceae (3 species). In the encaissant depressions of the plateaus, the woody species generally found are: *Acacia erythrocalyx*, *Acacia sieberiana*, *Azadirachta indica*, *Bombax costatum*, *Ziziphus mucronata*, *Combretum nigricans*, *Combretum micranthum*, *Combretum glutinosum*, *Combretum collinum*, *Crateva adansonii*, *Diospyros mespiliformis*, and *Piliostigma reticulatum*. Along the riparian zone are found: *Acacia erythrocalyx*, *Acacia sieberiana*, *Azadirachta indica*, *Bombax costatum*, *Borassus aethiopum*, *Diospyros mespiliformis*, *Hyphaene thebaica*, *Mitragyna inermis*, *Piliostigma reticulatum*, and *Phoenix dactylifera*. In contrast, on the banks of watercourses, the identified woody species are: *Mimosa pigra*, *Mitragyna inermis*, *Ipomoea carnea*, *Diospyros mespiliformis*, and *Acacia erythrocalyx*. The herbaceous species characteristic of gallery forests include: *Achyranthes aspera*, *Aeschynomene crassicaulis*, *Corchorus fascicularis*, *Corchorus olitorius*, *Commelina forskoalei*, *Commelina benghalensis*, *Cynodon dactylon*, *Crotalaria cylindrocarpa*, *Echinochloa stagnina*, *Heliotropium indicum*, *Hibiscus asper*, *Hyptis suaveolens*, *Indigofera hirsuta*, *Ipomoea pes-tigridis*, *Mimosa pudica*, and *Pennisetum pedicellatum*. Forest galleries are half-covered by vegetation.

Table 7. Importance of woody plants in forest galleries.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Ziziphus mucronata</i>	357.78	100.00	8.04	29.87
<i>Acacia ataxacantha</i>	337.78	135.56	10.89	28.20
<i>Borassus aethiopum</i>	206.67	131.11	10.54	17.25
<i>Azadirachta indica</i>	86.67	586.67	47.14	7.24
<i>Combretum nigricans</i>	62.22	2.22	0.18	5.19
<i>Combretum micranthum</i>	33.33	2.22	0.18	2.78
<i>Bombax costatum</i>	22.22	2.22	0.18	1.86
<i>Gardenia sokotensis</i>	22.22	0.00	0.00	1.86
<i>Acacia nilotica</i>	11.11	15.56	1.25	0.93
<i>Guiera senegalensis</i>	8.89	0.00	0.00	0.74
<i>Phoenix dactylifera</i>	8.89	46.67	3.75	0.74
<i>Acacia erythrocalyx</i>	6.67	2.22	0.18	0.56
<i>Acacia macrostachya</i>	4.44	0.00	0.00	0.37
<i>Acacia sieberiana</i>	4.44	2.22	0.18	0.37
<i>Combretum collinum</i>	4.44	0.00	0.00	0.37
<i>Combretum glutinosum</i>	4.44	0.00	0.00	0.37
<i>Albizia lebbbeck</i>	2.22	0.00	0.00	0.19

Continued

<i>Anogeissus leiocarpus</i>	2.22	0.00	0.00	0.19
<i>Diospyros mespiliformis</i>	2.22	15.56	1.25	0.19
<i>Flueggea virosa</i>	2.22	0.00	0.00	0.19
<i>Maerua angolensis</i>	2.22	0.00	0.00	0.19
<i>Mitragyna inermis</i>	2.22	60.00	4.82	0.19
<i>Piliostigma reticulatum</i>	2.22	2.22	0.18	0.19
<i>Cassia sieberiana</i>	0.00	2.22	0.18	0.00
<i>Crateva adansonii</i>	0.00	57.78	4.64	0.00
<i>Crossopteryx febrifuga</i>	0.00	2.22	0.18	0.00
<i>Ficus platyphylla</i>	0.00	2.22	0.18	0.00
<i>Hyphaene thebaica</i>	0.00	75.56	6.07	0.00
Total	1197.78	1244.44	100.00	100.00

4.7. Rôneraie

These are dense stands of *Borassus aethiopum* (Figure 4) associated with a few scattered woody plants, the most common of which are strangler figs. Rôneraias are typically found and extend along dallol valleys where the piezometric level is shallow. The flora is relatively sparse, comprising approximately 60 species belonging to 25 families (Table 8), the most widespread of which are: Arecaceae, Fabaceae-Caesalpiniodeae, Fabaceae-Mimosoideae, Poaceae, Euphorbiaceae, and Tiliaceae. The Shannon index (1.06 bits) and Pielou's evenness index (0.26) are very low. The palm grove is dominated by 48.34% by *Borassus aethiopum*, with an average density of 556.67 trees/ha and a canopy cover of 40%. Secondary species with limited density are also present: *Ficus sycomorus*, *Ficus dekdekana*, *Ficus platyphylla*, *Ficus ingens*, *Phoenix dactylifera*, *Hyphaene thebaica*, *Azadirachta indica*, *Diospyros mespiliformis*, *Tamarindus indica*, *Mitragyna inermis*, *Piliostigma reticulatum*, *Vitex doniana*, *Ziziphus mucronata*, *Maerua angolensis*, *Acacia nilotica*, *Acacia sieberiana*, *Acacia erythrocalyx*, *Albizia lebbeck*, *Crateva adansonii*, and *Flueggea virosa*. With limited coverage (3%), the typical herbaceous plants of the Rhône riverine forest are: *Achyranthes aspera*, *Aeschynomene crassicaulis*, *Corchorus fascicularis*, *Corchorus olitorius*, *Corchorus tridens*, *Cynodon dactylon*, *Vetiveria nigriflora*, *Echinochloa stagnina*, *Pennisetum americanum*, *Commelina forskoalei*, *Commelina benghalensis*, *Heliotropium indicum*, *Indigofera hirsuta*, *Ipomoea pes-tigridis*, *Cassia tora*, *Cassia occidentalis*, and *Sida rhombifolia*. Less common shrubs have a density of 356.25 trees/ha, an average cover of 3%, and a height of 4 ± 1.9 m. In contrast, the more densely occurring trees (795.41 trees/ha) reach a height of 9.6 ± 4.2 m and have a cover of 43%. Tree density and canopy cover reach 1151.66 trees/ha and 46%, respectively. Regeneration ranges from 743.33 trees/ha for trees to 120 trees/ha for shrubs, but the overall average is 863.33 trees/ha (Table 7).



Figure 4. Overview of the Rône forest.

Table 8. Proportion of woody plants in the Rône forest.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Borassus aethiopum</i>	556.67	140.00	15.85	48.34
<i>Azadirachta indica</i>	251.67	75.00	8.49	21.85
<i>Ziziphus mucronata</i>	150.00	440.00	49.81	13.02
<i>Acacia nilotica</i>	16.67	11.67	1.32	1.45
<i>Mitragyna inermis</i>	13.33	45.00	5.09	1.16
<i>Phoenix dactylifera</i>	13.33	35.00	3.96	1.16
<i>Acacia sieberiana</i>	8.33	1.67	0.19	0.72
<i>Acacia erythrocalyx</i>	5.00	0.00	0.00	0.43
<i>Diospyros mespiliiformis</i>	6.67	11.67	1.32	0.58
<i>Hyphaene thebaica</i>	23.33	56.67	6.42	2.03
<i>Crateva adansonii</i>	3.33	41.67	4.72	0.29
<i>Ficus sycomorus</i>	10.00	0.00	0.00	0.87
<i>Piliostigma reticulatum</i>	3.33	1.67	0.19	0.29
<i>Albizia lebbek</i>	1.67	0.00	0.00	0.14
<i>Ficus platyphylla</i>	3.33	1.67	0.19	0.29
<i>Flueggea virosa</i>	1.67	0.00	0.00	0.14
<i>Maerua angolensis</i>	3.33	0.00	0.00	0.29
<i>Tamarindus indica</i>	5.00	0.00	0.00	0.43
<i>Ficus ingens</i>	8.33	0.00	0.00	0.72
<i>Ficus thonningii</i>	60.00	20.00	2.26	5.21
<i>Vitex doniana</i>	3.33	0.00	0.00	0.29
<i>Bauhinia rufescens</i>	3.33	1.67	0.19	0.29
Total	1151.6667	883.33	100.00	100.00

Fallow Lands

Fallow lands are former wooded pastures that have been abandoned due to the biological and economic unproductivity of their soils. Today, Niger's rapidly growing population demands more food resources at the expense of extensive agricul-

ture, and as a result, few fallow lands remain in the western part of the country. Their biodiversity, reduced to approximately 105 plant species, includes fewer woody plants (16) than herbaceous plants (89). The Shannon diversity index and Pielou evenness index are low, at 2.55 bits and 0.54, respectively. However, vegetation cover can extend over 68.40% of their soil area. The woody canopy barely exceeds 17%. In contrast, the majority of the area is covered by grasses (51.77%). The woody density of 122 feet per hectare is higher for shrubs (100 feet per hectare) than for trees (23.7 feet per hectare). Regeneration density ranges from 10.18 plants per hectare for shrubs to 17.18 plants per hectare for trees, representing a total regeneration rate of 18.24% (**Table 9**). The average height of woody plants is 7.16 ± 2.2 m for trees and 3.28 ± 0.99 m for shrubs. The dominant woody species include: *Guiera senegalensis*, *Balanites aegyptiaca*, *Boscia senegalensis*, *Combretum glutinosum*, *Piliostigma reticulatum*, *Dichrostachys cinerea*, *Neocarya macrophylla*, *Sclerocarya birrea*, *Vitellaria paradoxa*, and *Vitex madiensis*. The herbaceous species characteristic of these areas belong to the families Poaceae, Fabaceae (Faboideae), Convolvulaceae, Rubiaceae, and Malvaceae, to name just a few. These frequently include the following species: *Cassia mimosoides*, *Zornia glochidiata*, *Tephrosia purpurea*, *Aristida sieberana*, *Eragrostis tremula*, *Mitracarpus villosus*, *Spermacoce ruelliae*, *Waltheria indica*, *Sida cordifolia*, *Digitaria horizontalis*, *Triumfetta pentandra*, *Hyptis suaveolens*, *Digitaria gayana*, *Indigofera nummulariifolia*, *Jacquemontia tamnifolia*, *Schizachyrium exile*, *Tephrosia lupunifolia*, *Brachiaria ramosa*, and *Chrozophora brocchiana*.

Table 9. Abundance of woody plants in fallow fields.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Guiera senegalensis</i>	88.36	6.91	24.68	72.32
<i>Hyphaene thebaica</i>	16.00			13.10
<i>Piliostigma reticulatum</i>	10.55	2.55	9.09	8.63
<i>Balanites aegyptiaca</i>	2.91	9.82	35.06	2.38
<i>Neocarya macrophylla</i>	1.82			1.49
<i>Vitex simplicifolia</i>	1.09	0.73	2.60	0.89
<i>Vitellaria paradoxa</i>	0.73			0.60
<i>Danielia oliveri</i>	0.36			0.30
<i>Faidherbia albida</i>	0.36			0.30
<i>Azadirachta indica</i>		0.36	1.30	0.00
<i>Boscia senegalensis</i>		0.36	1.30	0.00
<i>Combretum glutinosum</i>		5.82	20.78	0.00
<i>Combretum nigricans</i>		0.36	1.30	0.00
<i>Dichrostachys cinerea</i>		0.36	1.30	0.00
<i>Sclerocarya birrea</i>		0.73	2.60	0.00
Total	122.18	28.00	100.00	100.00

4.8. Semi-Aquatic Grasslands

Semi-aquatic grasslands are generally found in the marshy strips of unexploited dallol valleys and along the temporarily flooded banks of the river, where hydro-morphic soils are present. Very rare and not very diverse, their flora comprises approximately 45 species distributed across 17 families and 22 genera. It consists primarily of Poaceae (10 species) and a few species of Fabaceae-Faboideae, Fabaceae-Mimosoideae, and Nymphaeaceae. The Shannon diversity index and Pielou evenness index, at 1.97 bit and 0.51 respectively, are low. During the growing season, vegetation cover can reach 71.53%. It is generally dominated by herbaceous plants (71.07%) and remains very limited (0.45%) for woody plants, despite the abundance in some areas of *Mimosa pigra* and *Ipomoea carnea* (more or less vine-like shrubs). The very sparse woody layer consists of 7 species (*Borassus aethiopum*, *Ipomoea carnea*, *Mimosa pigra*, *Mitragyna inermis*, *Azadirachta indica*, *Piliostigma reticulatum*, and *Sesbania sesban*). The sparsely distributed trees have a density of approximately 27.69 feet/ha. Regeneration has a density of 29.23 trees/ha, representing a regeneration rate of 51.35%. Some species, such as *Borassus aethiopum* and *Mitragyna inermis*, can individually reach 14 m in height (Table 10). The shrub layer, dominated by *Ipomoea carnea* and *Mimosa pigra*, barely exceeds 2.4 m in height. The herbaceous vegetation includes: *Echinochloa stagnina*, *Echinochloa colona*, *Echinochloa pyramidalis*, *Vetiveria nigriflora*, *Cynodon dactylon*, *Oryza barthii*, *Mimosa pudica*, *Polygonum turgidum*, *Nymphaea lotus*, and *Nymphaea maculata*. These species are associated with numerous other herbaceous plants, including: *Aeschynomene crassicaulis*, *Azolla pinnata*, *Cyperus difformis*, *Ludwigia perennis*, and *Neptunia oleracea*.

Table 10. Abundance of woody plants in the semi-aquatic grassy meadow.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Borassus aethiopum</i>	11.69	19.38	66.32	42.22
<i>Piliostigma reticulatum</i>	4.00	0.62	2.11	14.44
<i>Azadirachta indica</i>	3.69	6.46	22.11	13.33
<i>Ziziphus mucronata</i>	3.69	2.46	8.42	13.33
<i>Mitragyna inermis</i>	3.38	0.31	1.05	12.22
<i>Sesbania sesban</i>	1.23			4.44
Total	27.69	29.23	100	100.00

4.9. Tree Orchards

Tree orchards are fruit plantations combined with vegetable and/or grain crops. This vegetation is as much the result of human activity as it is natural. Tree orchards are found in morphological units with shallow water tables, particularly within and around dallols and on the sandy plain, near villages or isolated in fields. Cultivated plant species include fruit trees (*Mangifera indica*, *Anacardium occidentale*, *Psidium guajava*, and *Carica papaya*), citrus fruits (*Citrus aurantifolia*,

Citrus grandis, *Citrus limon*, *Citrus reticulata*, *Citrus sinensis*...), vegetables (*Capsicum annuum*, *Capsicum frutescens*, *Capsicum baccatum*, *Capsicum chinense*, *Capsicum pubescens*, *Brassica oleracea*, *Brassica napus*, *Brassica rapa*, *Brassica tournefortii*, *Abelmoschus esculentus*, *Phaseolus vulgaris*, *Phaseolus coccineus*, *Solanum aethiopicum*, *Solanum lycopersicum*, *Solanum melongena*, *Solanum nigrum*, *Solanum tuberosum*, *Manihot esculenta*, melon, *Allium cepa*, *Hibiscus sabdariffa*, *Capsicum annuum*), and grains (*Oryza sativa* and *Zea mays*). There are also orchards of *Eucalyptus camaldulensis*. The diverse flora comprises approximately 125 species, including 36 cultivated species. These species are distributed across 36 families and 90 genera (Table 11). The most common species belong to the families Poaceae (25 species), Euphorbiaceae, Fabaceae-Faboideae (7 species), Rutaceae (6 species), Convolvulaceae (5 species), and Amaranthaceae (4 species). The Shannon diversity index is estimated at 2.9 bits, and the Pielou evenness index is 0.61. Vegetation cover, estimated at 78%, is more pronounced in the herbaceous layer (41.66%) than in the woody layer (23.33%). The average tree height is 3.87 ± 3.49 m. Tree density is 395 trees/ha, and the regeneration rate is very low at 1.65%. In addition to this floristic assemblage, wild species such as *Brassica oleracea*, *Cassia mimosoides*, and *Aristida mutabilis* are present.

Table 11. Proportion of woody species in the orchard.

Species	Density	Regeneration Density	SRI (%)	Frequency (%)
<i>Moringa oleifera</i>	198.33			50.21
<i>Citrus tangelo</i>	70.00			17.72
<i>Eucalyptus camaldulensis</i>	50.00			12.66
<i>Citrus sinensis</i>	35.00			8.86
<i>Manihot esculenta</i>	16.67			4.22
<i>Faidherbia albida</i>	3.33			0.84
<i>Piliostigma reticulatum</i>	3.33	1.67	25	0.84
<i>Anacardium occidentale</i>	1.67			0.42
<i>Balanites aegyptiaca</i>	1.67			0.42
<i>Citrus aurantifolia</i>	1.67			0.42
<i>Citrus grandis</i>	1.67			0.42
<i>Citrus limon</i>	1.67			0.42
<i>Citrus reticulata</i>	1.67			0.42
<i>Combretum collinum</i>	1.67			0.42
<i>Flueggea virosa</i>	1.67			0.42
<i>Mangifera indica</i>	1.67			0.42
<i>Psidium guajava</i>	1.67			0.42
<i>Stereospermum Kunthianum</i>	1.67			0.42
<i>Cadaba farinosa</i>		1.67	25	0.00
<i>Ziziphus mauritiana</i>		3.33	50	0.00
Total	395.00	6.67	100	100.00

5. Discussion

The flora of western Niger comprises 441 plant species distributed across 235 genera and 80 families. Thus, it accounts for 28% of the plant species found in the flora of Niger; according to [4], the ten phytogeographic regions comprising angiosperms are represented by 1575 species. This study shows that western Niger is particularly rich in plant diversity; moreover, the number of species recorded is very close to that recorded in the nine protected areas in Niger [28]. The Poaceae family largely dominates other families in herbaceous ecosystems due to the significance of its biomass and primary productivity [29]. The H' alpha diversity index, which indicates high diversity, is 5.12 bits in the Sudanese bioclimate compared to 4.55 bits in the Sahelian bioclimate. This value is higher than those found by several authors in Niger [18] [19] [27] [28] [30]. These values indicate remarkable species diversity within the plant communities. Pielou's equitability is at its maximum and ranges from 0.86 in the Sudanese zone to 0.85 in the Sahelian zone. This explains the even distribution of species within the bioclimates under consideration and the fact that these species coexist without any particular species dominating. The Jaccard similarity coefficient is low, with a value of 1.11. This indicates a lack of relatedness between the two bioclimates. They share 153 species—one-third of their species diversity—and are distinguished by 235 species unique to the Sudanese zone, compared with 63 species unique to the Sahelian bioclimate.

In western Niger, more than 50% of the biological types are dominated by therophytes, and more than 50% of the phytogeographic types are dominated by species common to the African continent. This highlights the unique character of this region; therophytes are annual plants that survive unfavorable seasons solely in the form of seeds [29]. Thus, the dominance of these species serves as an ecological indicator of the prolonged dry season in both the Sahelian and Sudanese regions.

The characteristics of the vegetation formations have made it possible to distinguish eight major vegetation formations (wooded savanna, shrubby savanna, thicket, gallery forest, Ronier forest, fallow land, Tree Orchards, and grassland). Characteristic parameters such as species diversity, alpha diversity, Pielou's equitability, average height, woody plant density, and regeneration rate distinguish these formations.

Thickets are dense, bushy woody vegetation consisting of a mixture of trees and vine-like shrubs that are often thorny. The shrubs generally cover 40% of the area and range in height from 3 to 7 m (author). They are usually multi-stemmed, and their main stems generally have a diameter of 10 cm or more. A few taller trees are also found, either in groups or as widely spaced individuals [2]. Shrub formations and thickets occur on rocky and stony terrain, in armored depressions on plateaus, and around anthills. In the northern Sudanese zone of Niger, some of these shrubby formations are referred to as "tiger bush" [31]. In this case, the vegetation consists of alternating dark bands—longer than they are wide—and light bands corresponding to bare ground devoid of vegetation [31]. In other

words, this consists of a monotonous repetition of a vegetated strip covered by dense, bushy woody plants, a herbaceous fringe preceding the tree-and-shrub belt, and a bare zone on a steeper slope where rainwater runs off. In the thickets, the shrubs are so tightly intertwined that they become impenetrable except along the trails carved out by animals. In any case, the floristic composition of the vegetation remains the same, with a few exceptions. This stand has an average tree height of 8.44 m, a density of 1118.92 trees per hectare, and a regeneration rate of 22%. It exhibits high diversity, with a Shannon-Weaver index of 4.4 bits and a Pielou evenness index of 0.86. Species diversity totals 137 species.

The shrub savanna is a vegetation type dominated by a tree layer distributed irregularly and associated with few shrubs. The shrub savanna of western Niger has an average tree height of 8.84 m, a density of 1457 trees per hectare, and a regeneration rate of 23%. Biodiversity is low, with a Shannon-Weaver index of 2.68 and a Pielou evenness index of 0.57. Species diversity stands at 106 species. It is slightly less diverse than the Bateké Plateau savanna in the Democratic Republic of the Congo [32] and the Lamto savanna in Côte d'Ivoire [33], where 145 and 176 species, respectively, were recorded, with trees that can exceed 32 m in height. The alpha diversity index and evenness index indicate greater diversity in Niger than in Côte d'Ivoire, where the values for these parameters are 1.217 and 0.765, respectively [33]. The spacing between tree crowns ranges from 2 to 15 m, while the distance between the bases of shrubs exceeds 15 m. Wooded cover ranges from 30% to 60% [19].

The shrub savanna is home to 182 species, with an Alpha diversity of 3.22 bits, a Pielou evenness of 0.61, an average height of 8.84 m, a density of 1664 plants/ha, and a regeneration rate of 29%. This is a vegetation type characterized by a plant community dominated by shrubs within a primary radius of 30 m. Trees are scarce, and the height of the shrubs ranges from 10 cm to 2 m. An average woody cover of 31.42% places it in the dense shrub savanna category, as shrubs dominate within a radius greater than 30 m, while trees account for only 10% of the total woody cover, which ranges from 30% to 60% [19].

A forest gallery is a topographically forested landscape that forms along the banks of watercourses and in encircling depressions (talwegs)—which are wider than they are deep—that extend from the edge of an elevated landform toward a valley or the bed of a watercourse. The forest gallery can be likened to a vegetation belt that is both rock-loving and riparian. In some cases, it consists of a dense, closed forest within which a microclimate prevails that is more humid than that of the surrounding terrain [17] [21]. This forest gallery is home to 63 species, with a diversity index of 1.42 bit and an evenness index of 0.34. The average height is 9.13 m, with a tree density of 774 trees/ha and a regeneration rate of 56%.

The Rôneraie forest has a species richness of 60 species, which is less diverse than the Dasga Rôneraie forest, which has 144 species distributed across 100 genera and 50 families [34] [35], with an alpha diversity of 1.06 and an evenness index of 0.26. The average height is 12 m, the tree density is 1151.66 trees/ha, with a

regeneration rate of 43%.

The fallow lands consist of vegetation typical of sandy slopes and valleys with sandy soils that have been leached and gradually degraded by agricultural activity and livestock grazing. Biodiversity consists of 105 plant species; the Shannon diversity index and Pielou evenness index are 2.55 bits and 0.54, respectively. The trees have an average height of 11 m, a density of 122 trees/ha, and a regeneration rate of 18.24%.

Semi-aquatic grasslands are very undiverse ecosystems, with a total of 45 species, an alpha diversity of 1.97, an evenness of 1.97, an average height of 14 m, a woody plant density of 27.69 feet/ha, and a regeneration rate of 51.35%.

6. Conclusion

The vegetation of western Niger is rich and diverse in both its floristic composition and its appearance. Its flora comprises 441 plant species divided into 235 genera and 80 families. It accounts for 19.17% of the 2274 plant species found in the Nigerien flora. There are 262 herbaceous species, 127 woody species, 20 sub-woody species, and 27 vines. Its floristic composition varies gradually from north to south as the bioclimate changes. In the Northern Sudanese bioclimate, it is estimated at 387 species distributed across 215 genera and 76 families, compared to 208 species grouped into 122 genera distributed across 44 families in the Sahelian bioclimate. Across all sampled units and regardless of the bioclimate considered, herbaceous biodiversity (262 species) is higher than that of woody (127), subshrub (20) and vine species (27). Alpha diversity varies depending on the vegetation type: it is low (in roan tree groves, riparian forests, and semi-aquatic grasslands), moderate (in savannas, Tree Orchards and fallow lands), and high in shrubby and thicket formations. Thus, human impact is a major factor in the decline of plant biodiversity.

Author Contributions

Oumarou Manirou was responsible for data collection, data processing, and writing; Amani Abdou handled data collection, data analysis, and proofreading; Ali Ado contributed to data collection, data analysis, and writing; Mahamane Ali edited and revised the draft article and selected the journal; and Saadou Mahamane proposed the research topic and refined the methodology.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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