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Ecological Structure, Diversity and Floristic Composition of Woody Plant Communities in the Chari Department (Chad)

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Abstract

This study investigates the floristic diversity, taxonomic structure, and ecological organization of four woody vegetation communities exploited for fuelwood in the Chari Department of Chad. A total of 24 species belonging to 23 genera and 12 families were recorded across wooded savanna, open forest, gallery forest, and shrub savanna. The dominant families (Fabaceae, Combretaceae, Rhamnaceae) reflect the typical Sudano-Sahelian signature of the region. The findings indicate that the wooded savanna (H′ = 2.55; J = 0.87) and the shrub savanna (H′ = 2.50; J = 0.85) represent the most diverse and structurally balanced habitats. The open forest shows moderate diversity (H′ = 2.30) and relatively high evenness (J = 0.83). Conversely, the gallery forest exhibits lower diversity (H′ = 2.23) and reduced evenness (J = 0.76), signalling the dominance of a limited number of species. The gallery forest exhibited lower evenness due to hyper-dominance of *Balanites aegyptiaca* and *Acacia nilotica*. Principal Component Analysis (PCA) highlighted strong ecological gradients between dry and humid formations, emphasizing the role of moisture availability and disturbance regimes. These findings provide critical insights for sustainable management of woody resources in the Chari Department.

Keywords

Diversity, Plant Communities, Abundance, Structure, Woody, Chad

1. Introduction

Woody plants play a leading role in food, health, habitat, and even in terms of financial income for populations [1]. They are sources of non-timber forest products, including leaves, flowers, fruits, seeds, bark, sap, roots, tubers, and fibers [2];

[3]. However, these woody resources are subject to anthropogenic disturbances combined with the detrimental effects of climate change, threatening their survival despite still limited knowledge about their in-depth ecological and socioeconomic contributions [4].

In Chad, around major urban areas, woody resources are present and exploited in different types of spaces with very different potentialities and access rules, namely fields, fallow lands, and forest areas, whose boundaries are not defined and which practically refer to all uncultivated spaces, wooded or not. For more than three decades, Chad, like other Sahel countries, has faced two major constraints that hinder its socio-economic development. On one hand, there is a political conjunctural crisis since the early years of its independence, and on the other hand, there is a almost-permanent climate crisis that disrupts the functioning of agro-sylvo-pastoral activities. The concentration of the population has created a strong demand for wood energy. The consumption of woody fuel in N'Djamena, as domestic energy, is not a choice but a necessity, as in terms of availability and cost, it remains the most accessible. The Agency for Domestic Energy and the Environment [5] estimates wood energy requirements at around 464,589.61 m^3. Local populations depend mainly on natural resources for their livelihoods and energy needs. However, over the last decade, several factors have contributed to the significant deterioration of woodland cover in connection with the demand for wood energy [6]. To meet this high demand for energy, which seems to exceed the immediately available resources, an economic sector has emerged. It connects various professionals and urban consumers. The pressure exerted on existing "forest areas" by operators has resulted in numerous pockets of deforestation in peri-urban areas and, increasingly, in rural farming areas.

Poverty appears to be a factor in ecological degradation, as poor people must turn to the fundamental natural resources on which they depend [7].

This study aims to characterize the habitats of Sahelian woody plants exploited in the wood energy supply basin in Chad, with a view to the rational and sustainable use of forest resources.

2. Methods

2.1. Study Area

The work was conducted in the Chari Department. It is one of the three departments comprising the Chari-Baguirmi province in Chad. Its capital is Mandalia, located between 12˚03′ North and 15˚18′ East (**Figure 1**). The climate is Sahelian. It is characterized by alternating long dry seasons from October to April and short rainy seasons. The lowest temperatures are recorded from December to February, with average lows ranging from 23˚C to 25˚C. The hottest temperatures are recorded from March to April, with average monthly highs of 36˚C to 39˚C.

The vegetation is of the shrub savanna, tree savanna, open forest, and gallery forest type. Agriculture, livestock breeding, and trade are the main activities of the populations. The soil is clayey or sandy with occasional vertisols. In the exondated areas, two soil variants are noted: the hydromorphic-vertisol soil complex and the hydromorphic-holomorphic soil complex [8].

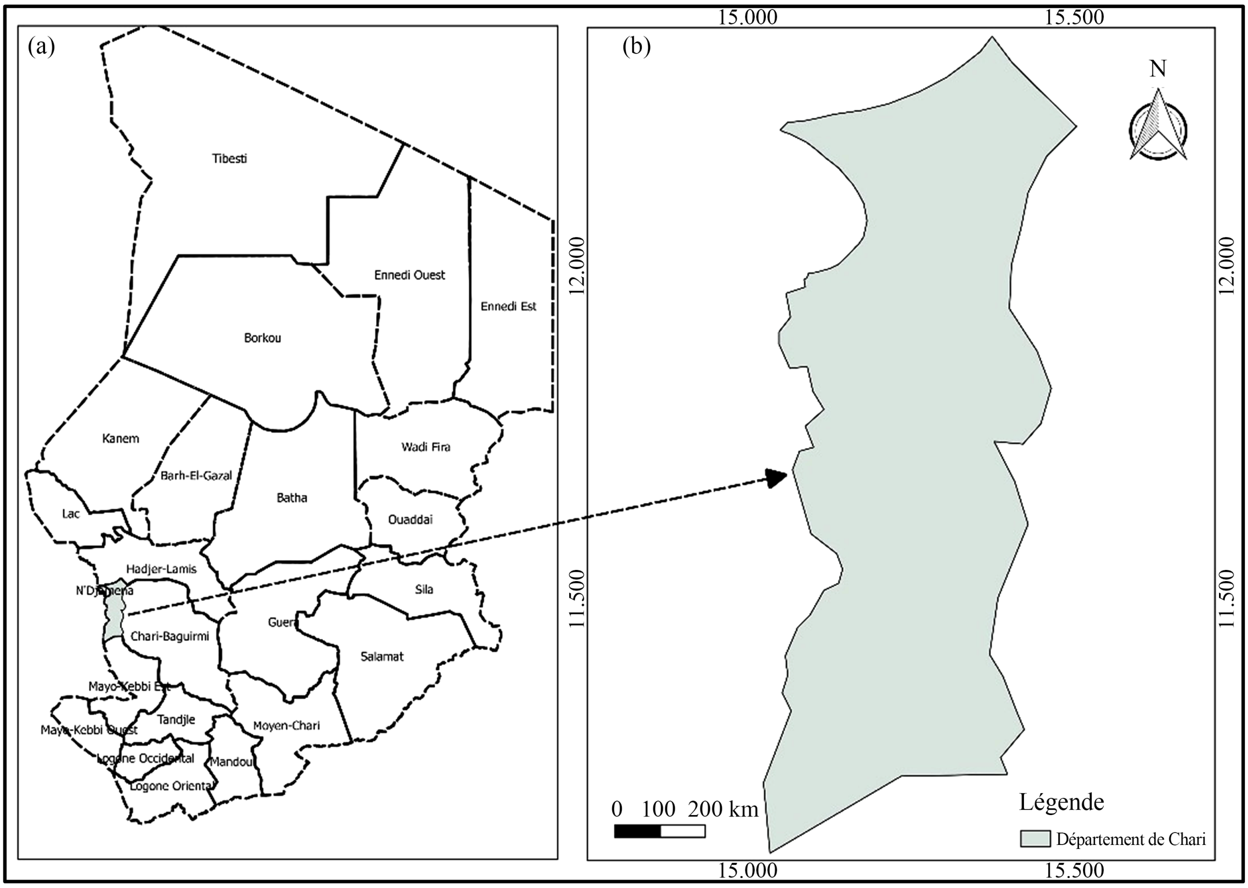

Figure 1. Location of the study area.

2.2. Floristic Inventory Method

Sampling was stratified based on types of plant formations. The representativeness of woody species at the local level was one of the main criteria for selecting the sampling site and plant formations. Special consideration was given to certain areas and sites likely to harbor unusual or rich flora. The physiological and floristic homogeneity of the facets of each plant formation formed the basis for establishing the various floristic survey points.

The inventory of the flora was carried out using a transect based on the classical method of Brun-Blanquet. The classical Braun-Blanquet phytosociological method consists of conducting floristic surveys within homogeneous vegetation units, where each recorded species is assigned an abundance-dominance coefficient based on its relative cover. This semi-quantitative approach enables the description of floristic composition and the identification of dominant, characteristic, or indicator species. Its relevance lies in its ability to capture true floristic diversity, including rare species, while providing a reliable assessment of vegetation structure. It also facilitates the detection of ecological gradients, vegetation dynamics, and environmental disturbances such as grazing, degradation, and land-use changes.

Thirty sampling points per vegetation formation were established every 200 meters along 2 km transects oriented North-South and East-West in order to account for the essential floristic and ecological diversity [9] [10]. The plots, whose central coordinates had been previously recorded, were located using the GARMIN 64S GPS.

2.3. Data Processing

To simultaneously quantify the taxonomic richness and distribution of taxa within a plant community, we calculated the Shannon and Simpson diversity indices and species richness. These indices are calculated from floristic inventory data. The Shannon-Weaver index, **H′**, measures the structure of populations and species. H' is calculated using the following formula:

$$\mathbf{H}' = -\sum_{i=1}^{S} \boldsymbol{pi}.\boldsymbol{log}2(\boldsymbol{pi})$$

S is the number of species, **ni** is the number of individuals of species **i**, **N** is the number of individuals of all species, and **pi** is the proportion of individuals of each species in the total **(pi = ni/N).** The value of **H′** varies between 1 and 5.

The Shannon index is often accompanied by Pielou's evenness index (E), also called the even distribution index. The evenness index relates observed diversity to the maximum theoretical diversity or the even distribution of populations among the S species present. This index takes into account the distribution of individuals among the species. The index can range from 0 to 1. It is maximal when species have identical abundances in the stand and minimal when a single species dominates the entire stand.

$$\mathbf{E = H'/(log2(S))}$$

This index therefore varies between 0 and 1. If it tends towards E = 1, then the species present in the plant communities have identical abundances. If it tends towards E = 0, then we are dealing with an imbalance where a single species dominates all the plant communities. The various parameters recorded were subjected to Principal Component Analysis (PCA) using XLStat version 2009.3.02 in order to establish a typology of the plant communities.

3. Results

3.1. Floral Diversity and Composition of the Chari

The analysis of the results of the woody vegetation inventory of the Chari Department through the 4 studied plant formations is rich in 24 species belonging to 23 genera and 12 families. **Figure 2** shows that the Fabaceae, Combretaceae, and Rhamnaceae are the most represented families with 42% and 14% respectively. They are followed by Arecaceae, Bignoniaceae, Caparaceae… which are poorly represented.

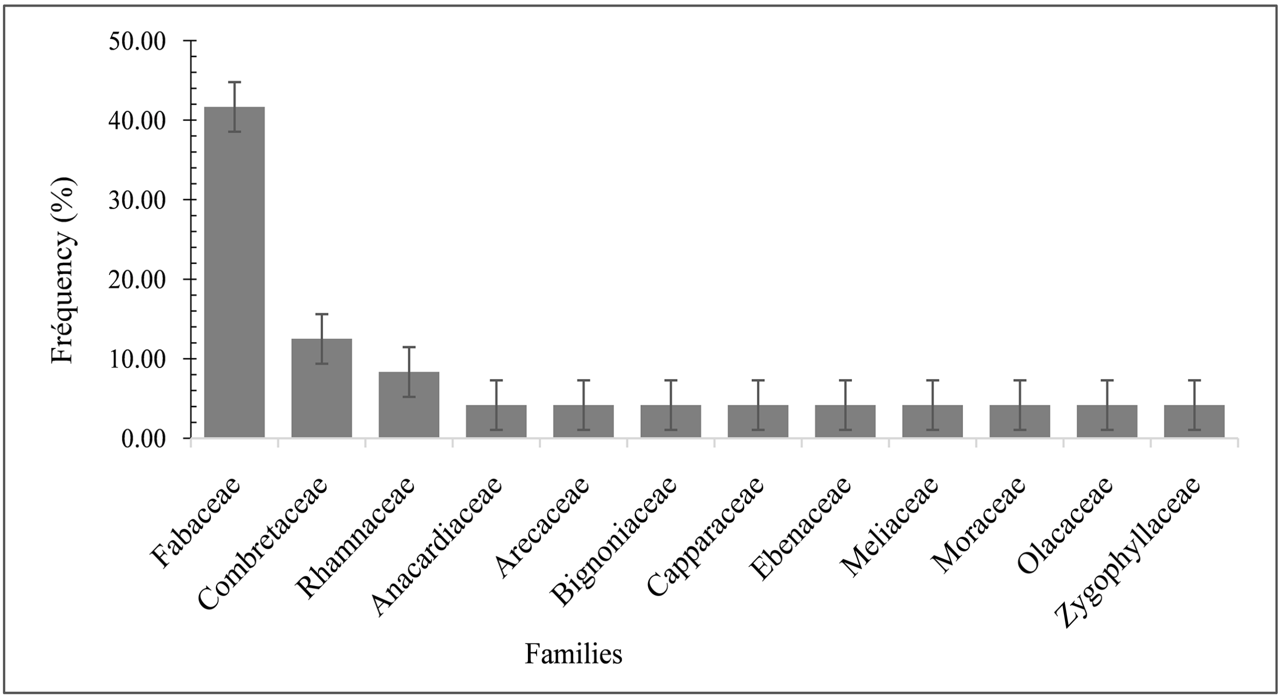

Figure 2. Proportion of the families of species inventoried in the Chari Department.

3.2. Abundance of Woody Plants

The wooded savannah of the Chari site is dominated by *Acacia nilotica* (17%), *Guiera senegalensis* (28%), *Acacia senegal* (13%), *Balanites aegyptiaca* (10%). The woody *Kigelia aethiopica* (1%), *Sclerocarya birrea* (1%), *Bauhinia rufescens* (0.5%) are the least represented (**Figure 3(A)**). The open forest (**Figure 3(B)**) is characterized by *Acacia nilotica* (21%), *Acacia senegal* (21%), *Guiera senegalensis* (13%), *Balanites aegyptiaca* (9%). *Zizyphus mucronata* (1.49%), *Anogeisus leiocarpus* (0.67%) and *Prosopis africana* (0.67%) are the least abundant woody species in the same light forest formation. The gallery forest (**Figure 3(C)**) is dominated by *Balanites aegyptiaca* (26%), *Acacia nilotica* (24%), *Boscia senegalensis* (10.22%), *Kigelia aethiopica* (9.60%), *Sesbania sesban* (6.50%), *Acacia senegal* (4.95%) and *Guiera senegalensis* (4.95%). The least represented species are: *Terminalia glaucescens* (0.62%), *Prosopis africana* (0.31%) and *Zizyphus mucronata* (0.31%). The shrub savannah (**Figure 3(D)**) is dominated by *Acacia nilotica* (17.86%), *Acacia senegal* (15%), *Balanites aegyptiaca* (12%), *Guiera senegalensis* (11.43%) and *Hyphaene thebaïca* (9.29%). The least represented species are *Kigelia aethiopica* (0.71%), *Prosopis africana* (0.71%) and *Sclerocarya birrea* (0.71%).

3.3. Ecological Index

Analysis of **Table 1** shows that the four plant communities exhibited high species richness, ranging from 16 to 19 species. The high Shannon and Piélou values indicate relatively diverse and balanced communities, although differences exist between open Sahelian formations and more closed, humid formations.

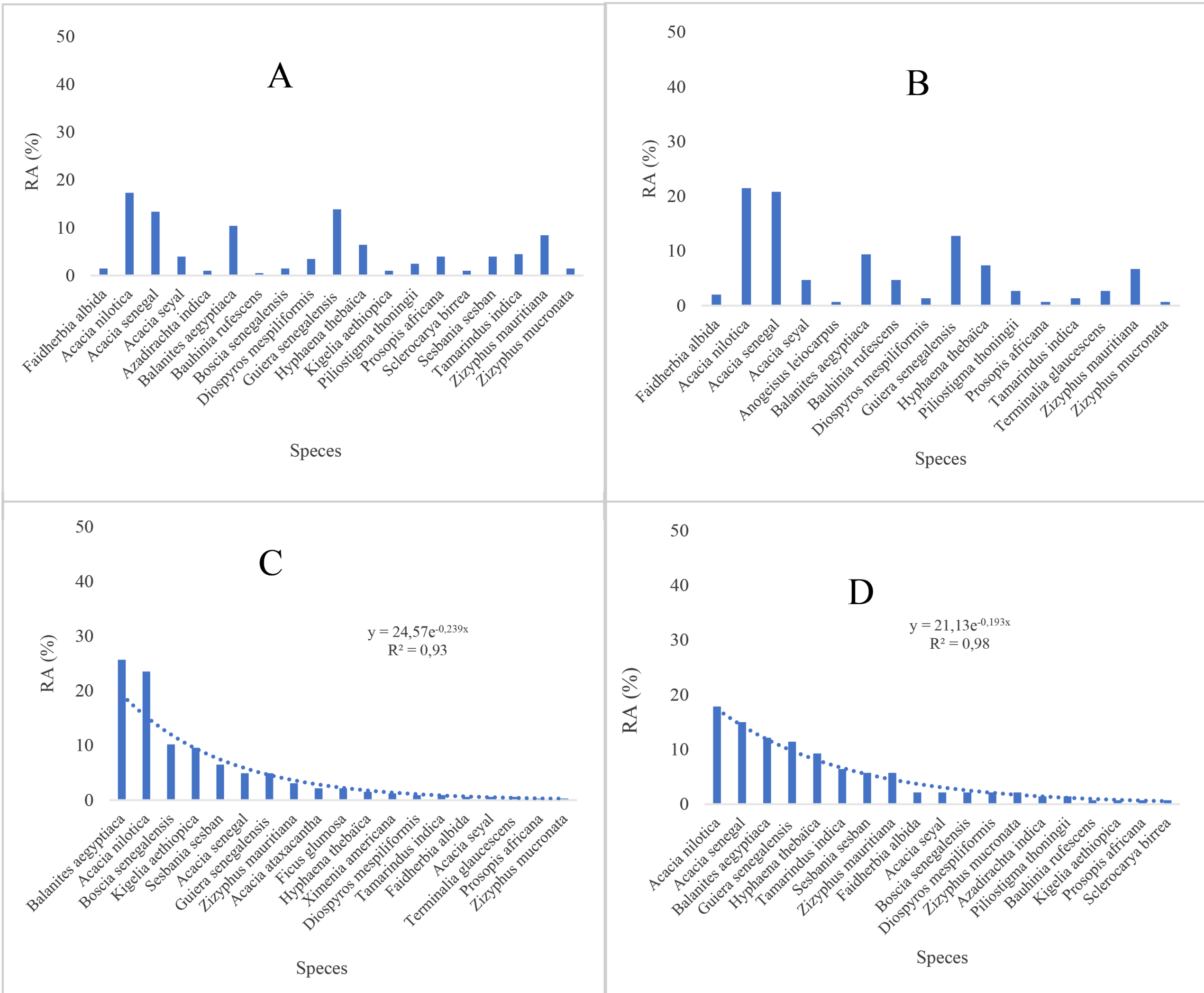

Figure 3. Abundance of species according to the type of plant communities of the Chari ((A) = Wooded savanna, (B) = Open forest, (C) = Gallery forest, (D) = Shrub savanna and RA = Relative Abundance).

Table 1. Specific richness according to the plant communities of the Chari.

Plant communities	Specific richess	Relative abundance	Shannon Index (H')	Piélou Index (J)
Wooded forest	19	202	2.55	0.87
Open forest	16	149	2.30	0.83
Gallery forest	19	323	2.23	0.76
Shrub savanna	19	140	2.50	0.85

Statistical analyses based on the number of individuals and relative abundances per plant communities showed that the gallery forest exhibited the highest values in terms of both average and variance, demonstrating significant heterogeneity among the individuals. In all four plant communities, the percentages of relative abundance averaged around 10%.

The wooded forest (H′ = 2.55) and the shrub savanna (H′ = 2.50) are among the most diverse environments. As for the gallery forest, the Shannon index shows moderate diversity (H′ = 2.30) despite its high population density. This indicates strong species dominance.

3.4. Comparison of the Specific Diversity and Evenness of the Plant Communities

Figure 4(A) shows that wooded forest and shrub savanna have the highest values. This explains their greater floristic diversity, high species richness, and better distribution of abundance among species. Open woodland has slightly lower diversity than savannas. There are fewer abundant species and more dominance by a few species. Gallery forest, despite a large number of species, has the lowest index. It is dominated by one or two very abundant species, such as *Balanites aegyptiaca*.

The wooded forest (J = 0.87) and shrub savanna (J = 0.85) exhibit the highest evenness, characterized by species with similar abundances (Figure 4(B)). No single species dominates the population. These are the most balanced communities. The open forest (J = 0.83) shows reasonable but slightly lower evenness, with some species more abundant than others, but dominance remains moderate. The gallery forest exhibits the lowest evenness (J = 0.76) with its highly unbalanced structure. One or two species are strongly dominant: this is the case for *Balanites aegyptiaca* or *Acacia nilotica*. The other species are present in small numbers.

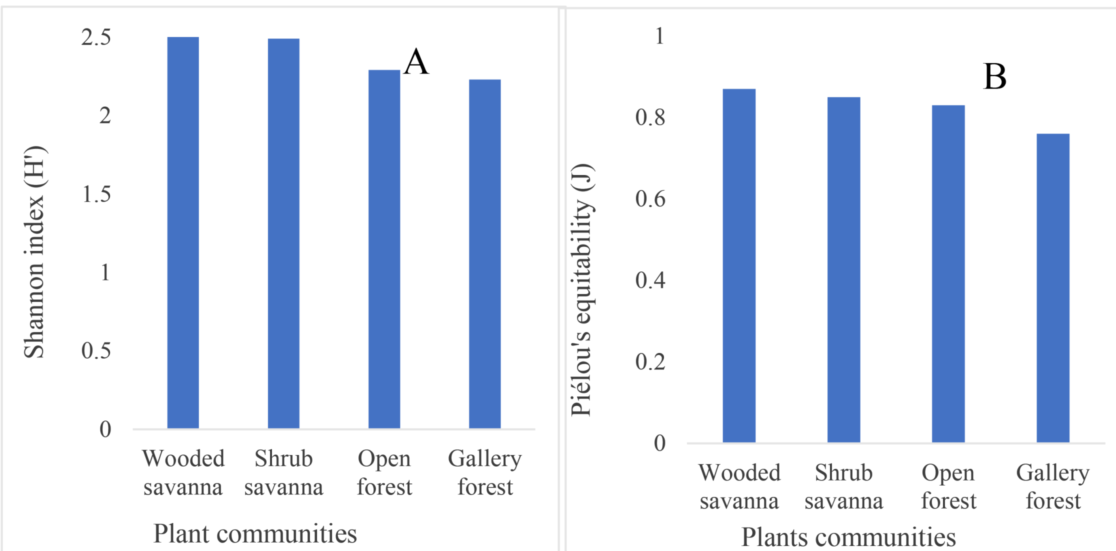

Figure 4. Variation in the diversity index (A) and evenness index according to plant communities (B).

3.5. Principal Component Analysis (PCA) of Plant Communities

PCA performed on the species abundance matrix allows for the representation of plant communities in a low-dimensional space. The first axes (PC1: 58.4% of the variance and PC2: 28.5%) account for a significant portion of the information (86.9%).

Axis PC1 (horizontal axis, 58.4%) represents the gradient from savanna to gallery forest, with gallery forest on the right and wooded savanna on the left. This axis expresses a strong contrast between gallery forest and wooded savanna. The gallery forest is strongly characterized by *Balanites aegyptiaca* with a very high abundance (83 individuals), followed by *Acacia nilotica* (76 individuals), *Boscia senegalensis* (33 individuals) and *Kigelia aethiopica* (31 individuals). These species pull the grouping strongly to the right. This reflects a more humid, more linear (riparian) environment, often marked by deeper soils, a more accessible water table, and anthropogenic influence (logging, grazing) favoring *Balanites* and *Acacia*. In **Figure 5**, the wooded savanna is pulled to the left by *Acacia nilotica* with an abundance of 35 individuals, *Guiera senegalensis* (28 individuals), and *Acacia senegal* (27 individuals).

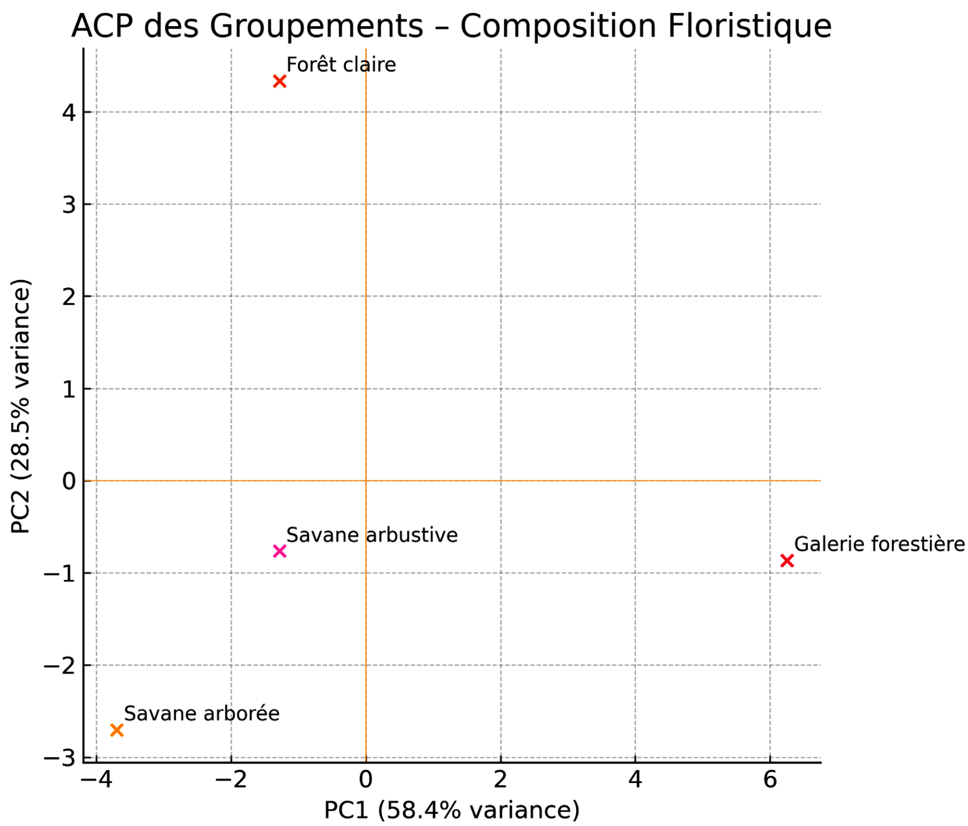

Figure 5. PCA diagram of the 4 plant groups and their floristic composition.

4. Discussion

4.1. Floristic Diversity and Taxonomic Composition

The floristic inventory conducted across the four vegetation types of the Chari Department revealed an overall high taxonomic richness. A total of 24 species, distributed among 23 genera and 12 families, were recorded. This richness is similar to that reported by [11] in their inventory of woody species exploited as fuelwood in the Baguirmi Department (Chad). Comparable results were also recorded by [12], who identified 31 species belonging to 23 genera and 15 families.

The flora of the Chari Department is largely dominated by Fabaceae, Combretaceae, and Rhamnaceae, a pattern consistent with observations from Sahelian ecosystems where these families constitute the core of woody vegetation in dry savannas [13] [14]. The predominance of Fabaceae, particularly the genus *Acacia*, reflects their strong adaptability to nutrient-poor soils, hydric stress, and anthropogenic disturbances, in line with the conclusions of [15].

The species richness recorded across communities (16 to 19 species depending on the plant communities) confirms that these formations represent ecological mosaics characteristic of the Sudano-Sahelian zone [16], despite a harsh climatic context.

4.2. Community Structure and Relative Abundance

Relative abundance revealed strong dominance patterns across all plant communities, although the intensity varied among vegetation types.

4.2.1. Open Formations (Wooded Savanna and Shrub Savanna)

These environments showed moderate dominance, mainly driven by *Acacia nilotica*, *Guiera senegalensis*, and *Acacia senegal*. Such patterns characterize relatively balanced and resilient communities adapted to drought, a finding consistent with [17], who described the structural stability of African savannas.

4.2.2. Open Forest

The open forest of the Chari Department appears as a transitional formation, with intermediate diversity and moderate dominance. This type of vegetation is generally influenced by edaphic conditions and moderate anthropogenic disturbances [18].

4.2.3. Gallery Forest

The gallery forest exhibited the highest total abundances but the lowest evenness, due to the hyper-dominance of *Balanites aegyptiaca* and *Acacia nilotica*. Such patterns are typical of degraded Sudano-Sahelian riparian woodlands subjected to sustained human pressure [19]. This results in moderate diversity despite high richness, indicating structural imbalance in the community.

4.3. Ecological Index: Diversity, Evenness, and Structure

The computed ecological indices confirm relatively high diversity across all four vegetation communities, with Shannon values ranging from 2.23 to 2.55, and Pielou's evenness between 0.76 and 0.87. These values are similar to those reported for other Sudanian savannas [20] [21].

The wooded savanna and shrub savanna exhibited the highest diversity and evenness ($H' > 2.5$; $J > 0.85$), indicating stable communities with low species dominance and good ecological resilience.

The open forest showed slightly lower values ($H' = 2.30$; $J = 0.83$), reflecting a mild increase in dominance and confirming its transitional position.

The gallery forest exhibits the lowest Shannon index (H′ = 2.23) and the lowest evenness (J = 0.76), despite a high number of individuals. This confirms a strong dominance of competitive species in this hydromorphic environment. These results are consistent with the findings of [22], who emphasized that a high total abundance does not necessarily lead to higher diversity when species dominance is pronounced. This author described the Shannon index (H'), the Simpson index (D, 1/D, 1 − D), Pielou's evenness index (J), observed and estimated richness, as well as rank-based diversity indices.

4.4. Spatial Organization of Vegetation Types: Contribution of PCA

The Principal Component Analysis (PCA) revealed a clear separation among vegetation groups following a gradient extending from the wooded savanna to the open forest, and from the shrub savanna to the gallery forest. PC1 (58.4% of the variance) primarily distinguished dry environments from humid ones dry communities included *Acacia nilotica*, *Guiera senegalensis, Acacia senegal*. Humid communities (gallery forest) were characterized by *Balanites aegyptiaca*, *Boscia senegalensis* and *Kigelia aethiopica*. This ecological gradient is typical of Sudano-Sahelian ecosystems, where soil moisture availability and soil depth strongly structure communities [23] [24].

4.5. Ecological Dynamics and Management Implications

4.5.1. Strong Structural Variability among Formations

Savannas show high diversity with low dominance, reflecting relative stability but vulnerability to anthropogenic pressures such as fuelwood extraction and grazing. These pressures were also reported by [12] in the Chari-Baguirmi region.

In contrast, the gallery forest—though species-rich—shows a pronounced floristic imbalance, indicating possible degradation or selective exploitation.

4.5.2. High Ecological and Socio-Economic Value

Dominant species such as *Balanites aegyptiaca*, *Guiera senegalensis*, and several Acacia species play key roles in: food security, traditional medicine, soil stabilization and erosion control. The dominance of *Balanites aegyptiaca* observed in the studied plant communities can be attributed to its notable ecological advantages. *B. aegyptiaca*, beyond its resilience supported by stable population structures in grazing areas [25] demonstrates a high regeneration capacity. Such traits provide the species with a competitive edge in environments subjected to both natural and anthropogenic pressures. This strong regenerative potential not only facilitates its persistence but also promotes its expansion within these ecosystems, thereby shaping community composition and influencing overall vegetation dynamics.

4.5.3. Need for Differentiated Management

Strengthened protection of gallery forests, which are fragile linear habitats. Controlled pastoral management in savannas to prevent overdominance of tolerant species.

4.5.4. Limitations of Our Study

The limitations of our study stem primarily from the temporal and methodological constraints associated with conducting floristic inventories at the beginning and end of the rainy seasons. This restricted sampling window may have reduced the detection of short-lived or seasonally dependent species, leading to a potential underestimation of true species richness, particularly in ecologically sensitive habitats such as the gallery forest. Interannual climatic variability between 2021 and 2022 may also have influenced species emergence, regeneration, and abundance, thereby affecting the calculated diversity and evenness indices. Furthermore, the spatial representativeness of the sampling plots, possible edge effects, and the semi-quantitative nature of the Braun-Blanquet method may have introduced biases in species detection and abundance estimates. These limitations should be considered when interpreting the observed differences in floristic diversity and structural balance among the studied habitats.

5. Conclusions

The analysis of woody plant communities in the Chari Department reveals a diversified but increasingly fragile vegetation mosaic shaped by ecological gradients and human pressures. The four plant formations—wooded savanna, open forest, gallery forest, and shrub savanna—harbor significant floristic richness, yet their structural and ecological integrity differs markedly. While wooded and shrub savannas maintain high diversity and balanced species distribution, the gallery forest shows clear signs of imbalance, characterized by the dominance of a few highly competitive species. This structural homogenization is likely driven by hydromorphic conditions combined with intensive exploitation for fuelwood.

The PCA confirms that environmental factors such as soil moisture, habitat type, and disturbance regimes strongly influence the spatial organization of plant communities. The contrasting diversity patterns observed across habitats provide clear guidance for fuelwood management. The wooded and shrub savannas, being the most diverse and balanced systems, allow for regulated and rotational harvesting, while the open forest requires selective cutting to avoid destabilizing its structure. In contrast, the gallery forest, characterized by low diversity and reduced evenness, should be strictly protected and prioritized for ecological restoration. Strengthening natural regeneration, supporting community nurseries, and promoting responsible harvesting practices are essential to ensure the long-term sustainability of woody resource.

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Conflicts of Interest

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

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