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Floristic diversity and management of agroforestry parks with *Faidherbia albida* in the Maroua 1st District (Far North, Cameroon)

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Abstract

Tree parks play a crucial role in providing goods and services to rural populations. This study aims to analyze the floristic diversity of woody species found in the *Faidherbia albida* agroforestry park of Goyang and to explore sustainable management strategies. To achieve this objective, various methods were employed, including direct observations, interviews with resource persons, and floristic inventories. The floristic inventories identified 12 woody species classified into 10 families. The most representative family in the *F. albida* park is the Fabaceae (79.49%), with *F. albida* being the most dominant woody species, accounting for 77%. However, *F. albida* conservation is primarily carried out for land restoration purposes (47.8%). The highest tree density (29.7 stems/ha) and relative density (77%) were recorded for *F. albida* in the park. The species' mortality rate in the park is relatively low (0.54%). The population dynamics are positive (74.33%), driven by a high regeneration rate of woody species, estimated at 74.87% within the park. With a relative frequency of 53%, *F. albida* is the most dominant species in the park, with a relative dominance of 77.29%. The management of the Goyang agroforestry park involves multiple stakeholders, including the Directorate of the Agricultural Youth Training Center, the Ministry of Forestry and Wildlife, and the traditional chief. Several sanctions are enforced within the park to ensure its sustainable management, including resource recovery, fines, and imprisonment.

Keywords: Agroforestry Park; *Faidherbia Albida*; Sustainable Management; Biodiversity; Goyang

1. Introduction

Tree resources play a crucial role in providing goods and services to rural populations, particularly in arid zones. They supply firewood, timber, fodder, and non-timber forest products with medicinal and nutritional value while also contributing to soil fertility improvement. Additionally, trees help regulate the climate by capturing and storing large amounts of carbon in their woody biomass [1].

Millions of farmers have encouraged tree regeneration, particularly *Faidherbia albida*, known throughout the Sahel as the "fertilizer tree." Long-term research has shown that tree cover doubles the soil's organic matter content and crop yields, while also increasing fodder and firewood production [2]. *F. albida* is a key species in the agroforestry systems of the Sahel. The World Agroforestry Centre (ICRAF) defines agroforestry parks as "a land-use system in which perennial

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woody plants are deliberately retained in association with crops and/or livestock in a scattered spatial arrangement, where ecological and economic interactions exist between the woody species and other components of the system". Due to its agronomic and pastoral potential, as well as its phenological behavior, *F. albida* is one of the most valuable tree species for conservation agriculture, particularly in regions where it is ecologically suitable and socially accepted [3]. It is a highly versatile tree for agroforestry, valued not only as a firewood source but also for its ability to enhance soil fertility through nitrogen fixation [4]. *F. albida* has long been considered the ultimate agroforestry species in the Sahel due to its exceptional agronomic benefits. It improves soil fertility factors and increases agricultural yields [5].

In production systems, *F. albida* serves multiple functions. It contributes to soil fertility restoration by providing canopy cover, which protects the soil, enhances trophic levels, and supplements livestock feed [6]. Agroecologically, *F. albida* plays a crucial role in production systems. Its root system helps retain soil, protecting it from erosion, enriching it with organic matter (humus), and fixing atmospheric nitrogen. Additionally, it significantly reduces potential evapotranspiration, and its deep roots do not interfere with other plants [7].

According to [8], *F. albida* is often associated with animal droppings left by livestock resting under its canopy, which promotes organic matter formation in the soil and increases crop yields. Birds, particularly sparrows, also contribute to its fertilizing effect by depositing nutrient-rich excrement under its canopy. The integration of such tree species into traditional agricultural land use improves soil moisture and water infiltration, which helps regulate river flows throughout the year, including during the dry season when rivers often run dry [9].

Agroforestry parks form the most distinctive landscape in northern Cameroon. They consist of scattered or regularly distributed trees intercropped with cultivated fields, providing additional food sources and significant income. Farmers benefit economically from *F. albida* agroforestry parks by cultivating crops under its canopy, reducing their need for nitrogen fertilizers. Given its role in enhancing soil fertility, farmers experience increased agricultural yields, which positively impacts the economy. Local populations also generate income by collecting and selling *F. albida* pods.

However, the current state and management of the *F. albida* agroforestry park in Goyang are concerning. If the degradation continues, the park's ability to provide essential goods and services may be compromised, leading to significant economic and social consequences. It is therefore urgent to reverse this decline and adopt more effective and sustainable management strategies. This study aims to analyze the floristic diversity of woody species found in the *F. albid*a agroforestry park of Goyang and to explore sustainable management strategies.

2. Material and methods

2.1. Floristic inventory

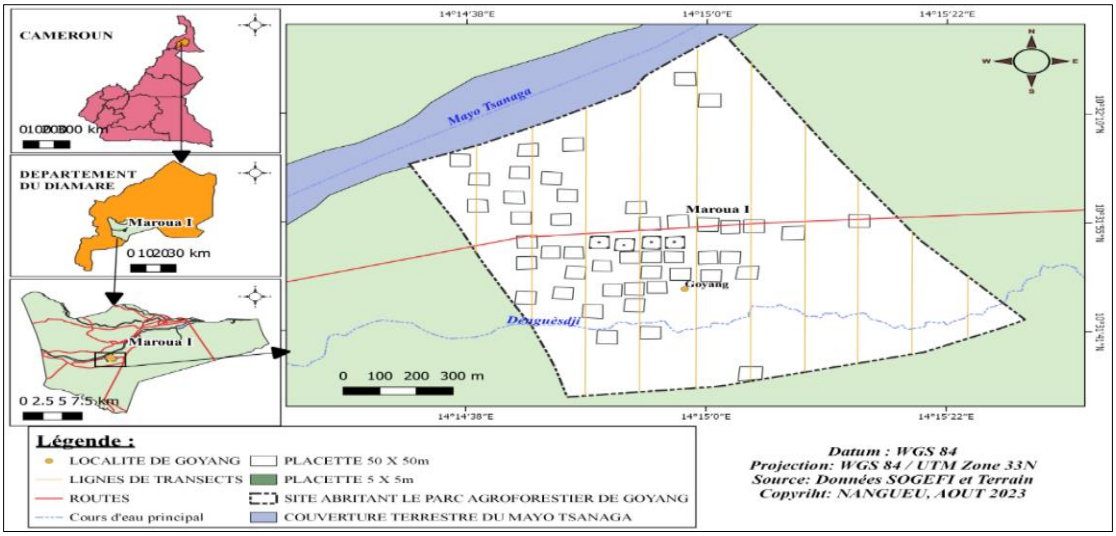

Figure 1 Materialization of transects and plots on the site housing the *F. albida* park

For this study, the inventory was conducted in the *F. albida* park of Goyang using the transect method combined with 50 m × 50 m square plots. To cover the total study area of approximately 130 hectares, 10 transects were established at 150-meter intervals (Figure 1). The geographic coordinates marking the start and end of each transect were recorded using Google Earth Pro.

Since the study site is an agroforestry system, sampling units consisting of randomly placed 50 m × 50 m square plots (covering an area of 2500 m^2), as suggested by [10], were positioned along each transect. Within these plots, the names of all recorded woody species were documented, and dendrometric parameters were measured, including the diameter at breast height (DBH) of all individuals with a diameter ≥ 5 cm at 1.30 m from the ground, as well as an estimation of tree height

2.2. Species structure analysis

To assess species composition in the sampled plots following the floristic inventory, several variables were calculated:

$$\text{Tree Density (stems/ha)} = \frac{\text{Total number of trees}}{\text{Surface area (ha)}}$$

$$\text{Relative Density of a Species (\%)} = \frac{\text{Number of individuals of the specie}}{\text{Total number of individuals}} \text{ X } 100$$

$$\text{Relative Diversity of a Species (\%)} = \frac{\text{Nomber of species in a family}}{\text{Total number of species}} \text{ X } 100$$

Species Frequency: The ratio of the number of plots in which a species is found to the total number of plots sampled.

Relative Frequency of a Species: The ratio of its frequency to the sum of all species' frequencies, multiplied by 100. It is expressed as: $Fr=\frac{Fi}{F}$; where Fr = Relative frequency, Fi = Frequency of species i, and F = Sum of all species frequencies in the sample [11].

Basal Area (G): The sum of the basal areas of all trees in the stand [12], calculated using: G (m2/ha) = D21,30 X $\frac{\pi}{4}$; where D is the diameter of an individual tree at breast height (DBH) [11].

$$\text{Relative Dominance of a Species (\%)} = \frac{\text{Territorial area of a species}}{\text{Total territorial areas of all species}} \text{ X } 100$$

$$\text{Regeneration Rate (TR)} = \frac{\text{Nomber of regenerated individuals<5cm}}{\text{Total numer of individuals}} \text{ X } 100$$

Mortality Rate (M): The percentage of dead trees relative to the total number of individuals in the study area.

Population Dynamics Rate (D): Calculated as the difference between the regeneration rate and the mortality rate. D (%) = R – M, where D = Population dynamics rate, R = Regeneration rate, and M = Mortality rate.

Diversity Analysis

Several diversity indices were computed:

Shannon Diversity Index (H'): This is the most commonly used diversity index in ecological studies. It accounts for both species' richness and abundance within a community [10]. It is calculated as:

$H' = -\sum pi * log2(pi)$ where pi is the relative frequency of species i.

The Shannon index is interpreted as follows:

Low (0 ≤ H' ≤ 2.5): Dominance of one or a few species.

Medium (2.5 ≤ H' ≤ 3.9): Moderate species diversity.

High (4 ≤ H' < 6): Species tend toward equal distribution [13].

Pielou's Evenness Index (E): Derived from Shannon's index, it measures how evenly individuals are distributed among species. It is calculated as:

E= $\frac{H'}{Hmax}$; where Hmax = log2(S) and S is the total number of species (species richness).

Pielou's evenness index is interpreted as follows:

Low ($0 \leq E \leq 0.6$): Presence of dominant species.

Medium ($0.7 \leq E < 0.8$): Moderate evenness.

High ($0.8 \leq E \leq 1$): Absence of species dominance [14].

3. Results

3.1. Floristic diversity Analysis

The analysis of inventory data from the *F. albida* agroforestry park in Goyang allowed for an assessment of the current state of woody species present in this site.

3.2. Woody species found in the park

The woody species identified in the *F. albida* agroforestry park in Goyang are listed in Table 1 below. A total of 12 woody species were recorded, grouped into 10 families. The most representative family in the park is Fabaceae (79.49%). F. albida is the most dominant species, accounting for 77%.

Table 1 List of Woody Species Found in the *F. albida* Park in Goyang

N°	Woody species	Vernacular names (Fulfuldé)	Family	Numbers	Proportion%
1	*Acacia nilotica*	Gabdé	Fabaceae	12	2.49
2	*Faidherbia albida*	Tchaski		371	77
3	*Cassia cemea*	Foré	Caesalpiniaceae	16	3.32
4	*Tamarindus indica*	Djabbé		1	0.21
5	*Adansonia digitata*	Mboki	Bombacaceae	2	0.41
6	*Azadiracthta indica*	Gagné	Meliaceae	34	7.05
7	*Balanites aegyptiaca*	Tanné	Balanitaceae	10	2.07
8	*Combretum aculeatum*	Laouni	Combretaceae	1	0.21
9	*Hyphaene thebaica*	Gellehi	Arecaceae	1	0.21
10	*Manguifera indica*	Mongoro	Anacardiaceae	4	0.83
11	*Moringa oleifera*	Gliganja	Moringaceae	1	0.21
12	*Zizifus mauritiana*	Djaabi	Rhamnaceae	29	6.02
Total				482	100

3.2.1. Distribution of species by diameter classes

The analysis of the collected dendrometric parameters made it possible to group individuals by diameter classes (Figure 2). The *Faidherbia albida* agroforestry park in Goyang is dominated by individuals with diameters ranging from 25 to 85 cm. The presence of *F. albida* across all diameter classes reflects the farmers' long-standing awareness of the importance of conserving this species.

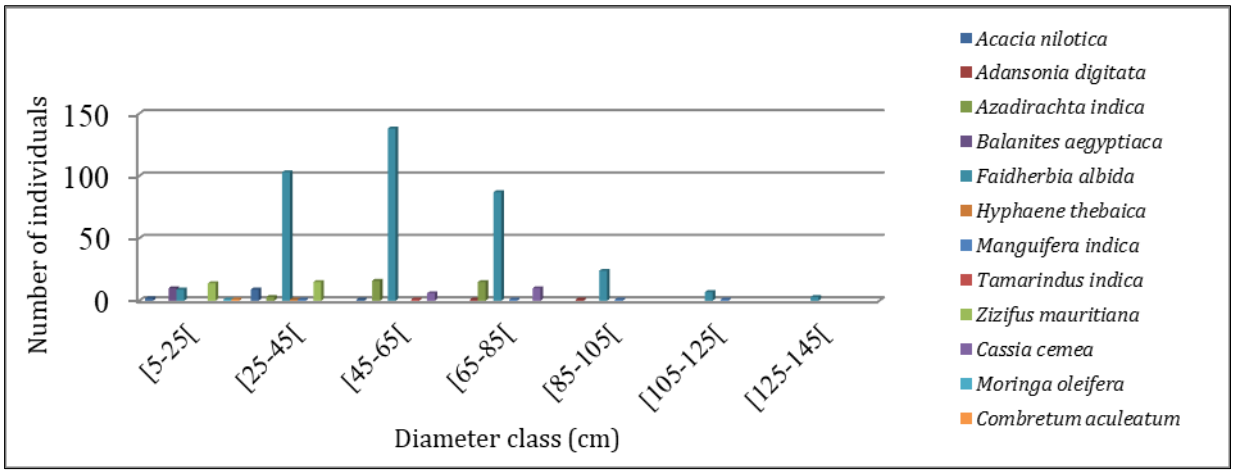

Figure 2 Distribution of Individuals by Diameter Classes

3.2.2. Structure and composition of the F. albida agroforestry park in Goyang

To understand the structure and composition of the tree population in this park, several parameters were evaluated and recorded in Table 2 below. The highest tree density (29.7 stems/ha) and relative density (77%) were observed in the species F. albida within the park. The mortality rate of species in the park is relatively low, at 0.54%, while the population dynamics are positive, reaching 74.33%. This positive trend is primarily due to the strong regeneration of woody species, evaluated at 74.87%. Notably, *Azadirachta indica* (26.47%), *Balanites aegyptiaca* (20%), and *Acacia nilotica* (16.66%) exhibit high regeneration capacities within the park. In contrast, the regeneration rates of *Ziziphus mauritiana* (6.89%) and *F. albida* (4.85%) remain very low. With a relative frequency of 53%, *F. albida* is the most dominant species in the park, holding a relative dominance of 77.29%. However, it is important to note that the dominance of F. albida is the result of farmers' conservation efforts rather than deliberate plantation initiatives.

Table 2 Analysis of Species Structure in the Tree Population

Species	N(Stem/Ha)	RN (%)	RD (%)	RF (%)	S (m2/ha)	R (%)	RR (%)	MR (%)	DR (%)
Acacia nilotica	0.96	2.49	16.66	5.3	27860.43	1.79	16.66	0	16.66
Adansonia digitata	0.16	0.41	8.33	1,1	4569.45	0.29	0	0	0
Azadirachta indica	2.72	7.05	8.33	12	124470.7	8.02	26.47	0	26.47
Balanites aegyptiaca	0.8	2.07	8.33	7.4	25197.14	1.62	20	0	20
Cassia cemea	1.28	3.32	16.66	6.3	57168.35	3.68	0	0	0
Combretum aculeatum	0.08	0.21	8.33	1,05	63.61725	0.01	0	0	0
Faidherbia albida	29.7	77	16.66	53	1199633.06	77.29	4.85	0.54	4.31
Hyphaene thebaica	0.08	0.21	8.33	1.1	3318.307	0.22	0	0	0
Manguifera indica	0.32	0.88	8.33	1.1	23532.1	1.52	0	0	0
Moringa oleifera	0.08	0.21	8.33	1.1	4778.362	0.31	0	0	0
Tamarindus indica	0.08	0.21	16.66	1.1	1452.201	0.09	0	0	0
Zizifus mauritiana	2.32	6.02	8.33	11	50360.52	3.3	6.89	0	6.89

N: Tree density (stem/Ha), RN: Relative density (%); RD: Relative diversity (%); RF: Relative frequency; S: Territorial area, DR: Relative dominance (%), RR: Regeneration rate (%), MR: Mortality rate (%), TD: Dynamism rate (%)

3.2.3. Assessment of floristic diversity in the park

The diversity of the park is highlighted through various indices, notably Shannon's Diversity Index (H') and Pielou's Evenness Index (E). Overall, the Shannon Diversity Index (H') is 0.95679 bits, which is relatively low for the park (Table 3). Meanwhile, Pielou's Evenness Index (E) is 0.1548 bits, indicating an uneven distribution of species within the park.

Table 3 Evaluation of Floristic Diversity Indices in the F. albida Agroforestry Park in Goyang

Species	Shannon Diversity Index (H')	Pielou's Index (E)
Faidherbia albida	0.201465	0.03261042
Zizifus mauritiana	0.169105	0.027372438
Acacia nilotica	0.091943	0.014882433
Tamarindus indica	0.012817	0.002074689
Moringa oleifera	0.012817	0.002074689
Cassia cemea	0.113041	0.018297486
Balanites aegyptiaca	0.080402	0.013014303
Combretum aculeatum	0.012817	0.002074689
Azadiracthta indica	0.187041	0.030275633
Manguifera indica	0.039765	0.006436563
Hyphaene thebaica	0.012817	0.002074689
Adansonia digitata	0.022758	0.00368383
Total	0.95679	0.154871862

3.3. Management Strategies for the *F. albida* Agroforestry Park in Goyang

3.3.1. Actors Involved in Decision-Making for the Sustainable Management of the Park

Understanding the different actors and their roles is crucial for the sustainable management of the park. Multiple stakeholders are involved in managing the park (Figure 3). However, despite the forest administration being considered the main authority responsible for the management and enforcement of regulations, particularly concerning certain woody species like F. albida, the Direction of the Center for Agricultural Youth Training of Goyang (CFJAG) plays the most significant role, overseeing 62% of the park's management. The CFJAG is responsible for: allocating agricultural plots to farmers through rental contracts, ensuring the protection of woody species within the site, acting as an intermediary between farmers and the forest administration.

The protection of woody species within the park is carried out by a guard, whose primary role is to prevent the felling of adult trees, especially F. albida. However, during an interview, the guard highlighted the challenges of patrolling the 130-hectare site effectively, citing his monthly salary of 40,000 FCFA as insufficient, forcing him to take on additional jobs to meet his financial needs.

Some farmers interviewed emphasized that a collaborative system has existed in the park for decades. In case of disputes, the CFJAG management informs the Djawro (Traditional leader), who then convenes the concerned parties to mediate and find solutions. If a dispute involves a violation of regulations related to the protection or management of woody species, particularly F. albida, the Traditional Chief decides on the course of action based on the severity of the offense. Depending on the situation, he may handle it himself or escalate it to the relevant administrative authority, such as the Ministry of Forestry and Wildlife (MINFOF).

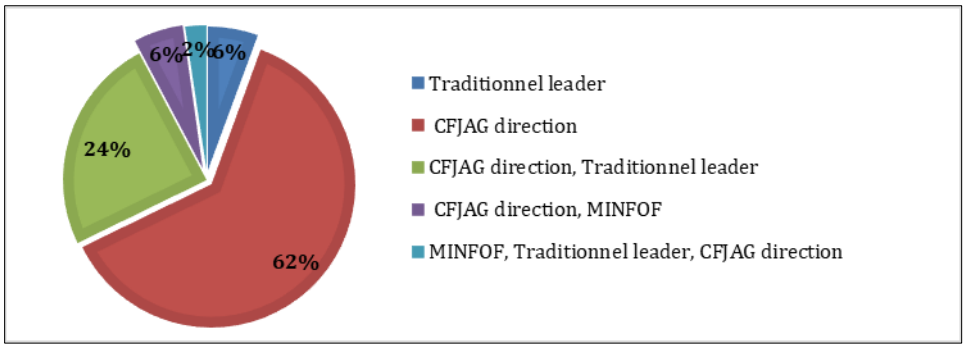

Figure 3 Actors involved in the management of the Goyang *Faidherbia* agroforestry park

3.3.2. Sanctions for Ensuring the Sustainable Management of the Park

Several sanctions are enforced in the park to ensure its sustainable management (Figure 4). 67% of surveyed farmers reported that when someone is caught cutting trees illegally or without authorization, the wood obtained from the felling is immediately confiscated by the competent authorities. 10% of farmers stated that, to prevent conflicts between herders and farmers, some nomadic herders have been prohibited from grazing their livestock in the park. Overgrazing had led to neighboring farmlands being trampled and crops destroyed by livestock. 8% of farmers highlighted the intervention of the Traditional Authority, which imposes strict measures requiring offenders to compensate for damages caused. Amendment (9%) and imprisonment (3%) are also among the sanctions applied by the forest administration to reinforce the sustainable management of the park.

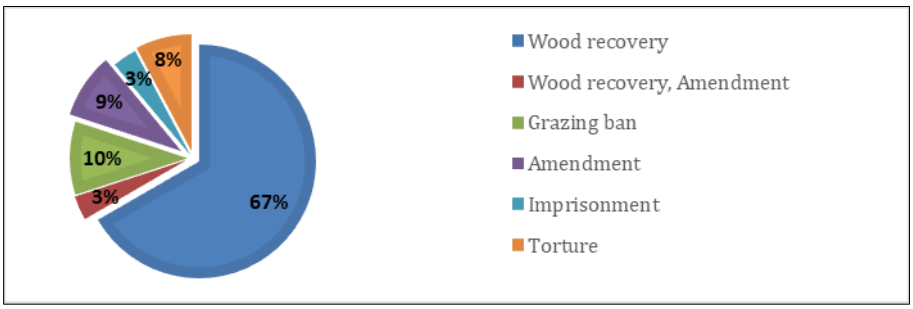

Figure 4 Sanctions Applied to Ensure the Sustainable Management of the Park

3.3.3. Human Actions Hindering the Sustainable Management and Spatial Expansion of the Park

The table below (Table 3) presents the various anthropogenic activities that impede the sustainable management and spatial expansion of the F. albida agroforestry park in Goyang.

Table 3 Anthropogenic Actions Hindering the Sustainable Management and Spatial Expansion of the *F. albida* Agroforestry Park in Goyang

Actions	**Numbers**	**Proportion %**
Absence of pruning	1	1.11
Cutting of *Faidherbia*	3	3.33
Cutting of *Faidherbia* and incorrect pruning	2	2.22
Destruction of suckers	41	45.55
Incorrect pruning	5	5.55
Lack of protection	6	6.66
Overgrazing	10	11.11
Overgrazing and excessive use of land	3	3.33

Excessive use of chemical fertilizers	4	4.44
The excessive use of land	15	16,66
Total	90	100

Human Actions Hindering the Sustainable Management and Spatial Expansion of the Park. Several human activities pose significant challenges to the sustainable management and expansion of the *Faidherbia albida* agroforestry park in Goyang: destruction of root suckers (46%); farmers report that young *F. albida* shoots are highly thorny and pose a danger during fieldwork. As a result, they are often cut down and used as firewood or dead hedges to protect fields from animals. Additionally, past forest administration policies prohibiting tree cutting have discouraged farmers from planting or preserving young shoots. Many farmers fear that the presence of protected trees in their fields could lead to land confiscation, prompting them to eliminate any young protected species they find. Excessive land use (15%): Some farmers cultivate their plots year-round (both in the rainy and dry seasons), leading to soil degradation. Overgrazing (11%): Uncontrolled livestock grazing has a negative impact on vegetation regeneration. Severe pruning (5.6%): Some farmers engage in intensive lopping, which weakens and ultimately kills trees in the park. Illegal cutting of *F. albida* (5.5%): Although cutting mature *Faidherbia* trees has been prohibited for decades, some instances still occur. Many farmers respect the tree due to its agricultural benefits and believe it is a "friend of farmers." Others hold the cultural belief that *Faidherbia* trees house spirits ("génies"), and cutting them could bring bad luck or misfortune. Limited park protection and spatial expansion (4.4%): The park's large size (130 hectares) makes it difficult to patrol effectively. A major road runs through the park, providing easy access for firewood traffickers. Land rental system (2.2%): Farmers renting plots within the park feel less invested in its long-term management and expansion. Lack of pruning (1.1%): Some believe that the absence of pruning leads to increased tree infections, negatively affecting *F. albida* and hindering sustainable park management.

4. Discussion

4.1. Floristic Diversity Analysis

A total of 12 woody species belonging to 10 families was recorded in the *Faidherbia albida* agroforestry park in Goyang. The most representative families in the park are Fabaceae, Meliaceae, and Rhamnaceae. F. albida is the dominant species (77%), highlighting its importance among local farmers. These findings align with those of [15], who reported that the conservation of *F. albida* is driven by the fact that crops particularly cereals grow better under these trees, yielding higher-quality harvests and better productivity.

The diameter distribution analysis showed that the park is dominated by trees with diameters ranging from 25 to 85 cm. The presence of *F. albida* across all diameter classes indicates a long-standing awareness among farmers regarding the importance of preserving this species. This observation is consistent with findings from [16], who also noted that *F. albida* is traditionally preserved by farmers in Cameroon due to its socioeconomic and ecological benefits.

The park has a high tree density (29.7 stems/ha), particularly for *F. albida*, reflecting farmers' enthusiasm for agroforestry conservation. The mortality rate of tree species in the park is relatively low (0.54%), while the population dynamics are positive (74.33%), indicating successful regeneration. This contrasts with the findings of [12], who observed a high mortality rate of *F. albida* in the villages studied, exceeding regeneration rates. In Goyang, the positive population dynamics are driven by strong natural regeneration, estimated at 74.87%. Notably, *Azadirachta indica* (26.47%), *Balanites aegyptiaca* (20%), and *Acacia nilotica* (16.66%) show high regeneration capacities in the park.

The park's biodiversity was assessed using Shannon's Diversity Index (H') and Pielou's Evenness Index (E). The Shannon index (H' = 0.95679 bits) is relatively low, indicating a strong dominance of F. albida. This finding aligns with Shannon et al. (1949), who stated that H' values between 0 and 2.5 indicate the dominance of one or a few species in a community. Similarly, the Pielou index (E = 0.1548 bits) confirms the dominance of F. albida, consistent with [11], who reported that E values close to 0 occur when a single species overwhelmingly dominates all others.

4.2. Park Management and Governance

The Goyang agroforestry park is managed by multiple stakeholders, including: The Center for Agricultural Youth Training (CFJAG), The Ministry of Forestry and Wildlife (MINFOF), The Traditional Chief. This multi-actor governance resembles the management model described by [17], which highlights that the exploitation of *F. albida* in Sirlawe I (Tupuri, Cameroon) requires authorization from the forest administration. To ensure sustainable management, several

sanctions are enforced, including: Resource confiscation, Fines, Imprisonment. These measures align with [18], who emphasized that agrarian regulations are enforced through prohibitions and sanctions against those who cut F. albida.

5. Conclusion

The study on the floristic diversity and sustainable management of the *Faidherbia albida* agroforestry park in Goyang recorded 12 woody species from 10 families, with *F. albida* as the dominant species (77%). Several factors hinder the park's sustainable management and expansion, including: destruction of root suckers (46%), excessive land use (15%), overgrazing (11%), land tenure issues (44%) and regulatory constraints (42%). The current state and management of the park are concerning and could compromise its ability to provide essential goods and services in the future, leading to significant economic and social consequences. To reverse this decline, it is crucial to implement more effective and sustainable management strategies, including: involving all stakeholders in decision-making, clarifying farmers' rights and obligations, enforcing sanctions, promoting regeneration initiatives, and developing effective communication strategies.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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