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Adeboyin Funmi Aderounmu[1], Oluwatoyin Opeyemi Akintola[2], Tunde Adeniran[3], Emmanuel Abodunrin Kolawole[4], Festus Olakunle Agboola[5], Bolanle Lisa Olajiire-Ajayi[6]

INTEGRATING DIVERSITY INDICES AND MULTIVARIANCE ANALYSIS TO ASSESS TREE COMMUNITY STRUCTURE IN LANLANTE FOREST RESERVE, SOUTHWESTERN NIGERIA

Abstract: Tropical forest reserves in Nigeria are under increasing pressure from plantations, farming, and community use, leading to shifts in tree species composition and structure. This study assessed tree community structure in Lanlante Forest Reserve, Southwestern Nigeria, using diversity indices and multivariate analysis. Tree inventory from eight plots were analyzed using Shannon-Weiner, Simpson's index, Evenness and Dominance, while principal component analysis (PCA) was used to identify major ecological patterns.

Results showed moderate diversity (H' = 2.43; Simpson = 0.85) with high evenness (0.90) despite the dominance of *Tectona grandis*. Principal component analysis revealed three components explaining 72% of total variance: PC1 represented plantation versus indigenous species, PC2 highlighted agroforestry-related rare species, and PC3 reflected other uncommon species. Overall, the reserve shows structural stability but is compositionally skewed toward plantations. Management should focus on reducing plantation dominance, enhancing indigenous species, and strengthening community-based conservation.

Keywords: tree diversity, Shannon index, PCA, plantation, agroforestry

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[1] Forestry Research Institute of Nigeria, Nigeria. ORCID ID: https://orcid.org/0009-0003-0538-2714, email: afaderounmu@gmail.com

[2] Federal College of Forestry, Ibadan, Forestry and Environmental Technology Department, Ibadan, Nigeria, ORCID ID: https://orcid.org/0000-0003-1556-9008, email: toyinakintola73@gmail.com

[3] Federal College of Forestry, Ibadan, Horticulture Technology Department, Ibadan, Nigeria, ORCID ID: https://orcid.org/0000-0002-4080-3663, email:tundekingus@yahoo.com

[4] Federal College of Forestry, Ibadan, Forestry and Environmental Technology Department, Ibadan, Nigeria, ORCID ID: https://orcid.org/0009-0006-0206-4798, email: emanuelkolawole@gmail.com

[5] Federal College of Forestry, Ibadan, Horticulture Technology Department, Ibadan, Nigeria, ORCID ID: https://orcid.org/0009-0001-7934-0125, email:agboolafestus@yahoo.com

[6] Federal College of Forestry, Ibadan, Forestry and Environmental Technology Department, Ibadan, Nigeria, ORCID ID: https://orcid.org/0000-0004-4291-2940, email: jiirebolanle@gmail com

Introduction

Tropical forests are important for biodiversity conservation, climate adaptation and provision of ecosystem services that are crucial in supporting rural communities. Forest reserves in Nigeria are momentous natural habitat for both flora and fauna, however, they are increasingly threatened by agricultural expansion, timber harvesting, plantation and community usage (Akindele & Lemay, 2006; Hooper et al., 2012; Moores et al., 2015). These often lead to changes in species composition and structural dynamics, resulting to a mix of native species alongside exotic trees like *Tectona grandis* and *Gmelina arborea* (Chukwuone & Okeke, 2012). Knowing these dynamics is fundamental for effective forest management and biodiversity preservation. Evaluation of forest structure needs quantitative methods that can perfectly reflect both species diversity and ecological gradients affecting tree composition.

Diversity indices such as Shannon entropy (H′) and Simpson's index are mostly used in tropical forestry to assess specie richness, evenness and dominance patterns (Magurran, 2013; Adekunle, 2006). Nonetheless, depending mainly on univariate indices may not passably address the intricacies of species–environment interactions. Multivariate approaches, such as Principal Component Analysis (PCA), can further give insights by revealing ecological gradients, species relationships, and the effects of management practices on forest communities (Eni et al., 2012; Akwaji et al., 2024). In Nigeria, several researchers have employed the diversity indices to assess specie composition and structure, however Eni et al. (2012) indicated the use of principal component analysis (PCA) in differentiating soil and vegetation relationships while Akwaji et al. (2024) highlighted climatic and edaphic factors as major impacts on species distribution in his study. Despite these, there is scarcity of research that has employed the integrated diversity indices and multivariate analysis to assess the structural diversity of reserves.

This study thus employed diversity indices and Principal Componemt Analysis (PCA) to evaluate tree community structure within Lanlante Forest Reserve in Southwestern Nigeria. Specific objectives are to assess species richness, diversity and evenness using Shannon and Simpson indices; ascertain the dominant ecological gradients that influence species composition through PCA and suggest recommendations for accomplishing a balance between plantation establishment and conservation of indigenous species.

Materials and methods

Study area description. Lanlante Forest Reserve which lies between Latitude $7^{0}43'0''$ N and Longitude $3^{0}37'0''$ E is located along Eruwa within Ibarapa East Local Government Area of Oyo State (Fig. 1). Eruwa has a total area of 836km^2 and it is bounded by Iseyin Local Government in the eastern side, Ogun State to the south, Ibarapa Central and East LGAs to the western side. Lanlate Forest Reserve which belongs to Oyo State government was established in 1999 during the much rush for teak wood by Chinese and Lebanese businessmen. The reserve is surrounded by villages such as Alawure, Alapa, Opoogede, Afayasoro, Aba panu, Panlati, Abule guard, and Yanko (Fig. 2).

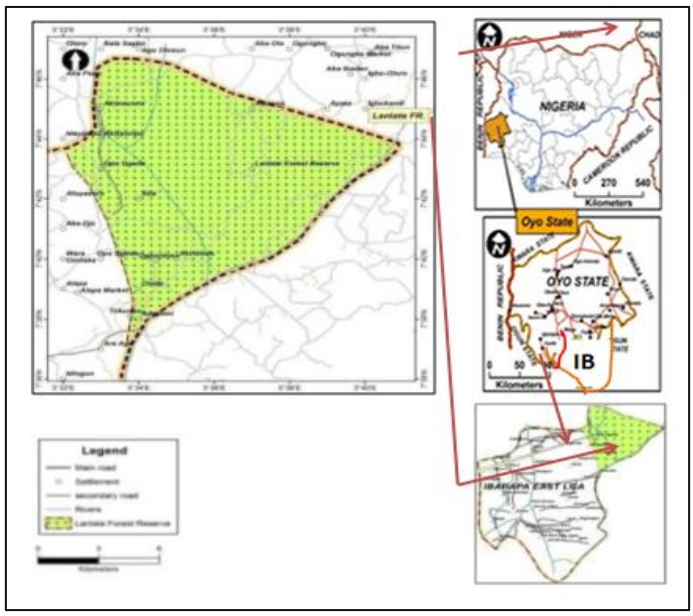

Fig. 1. Location map of the study area
Source: Own elaboration

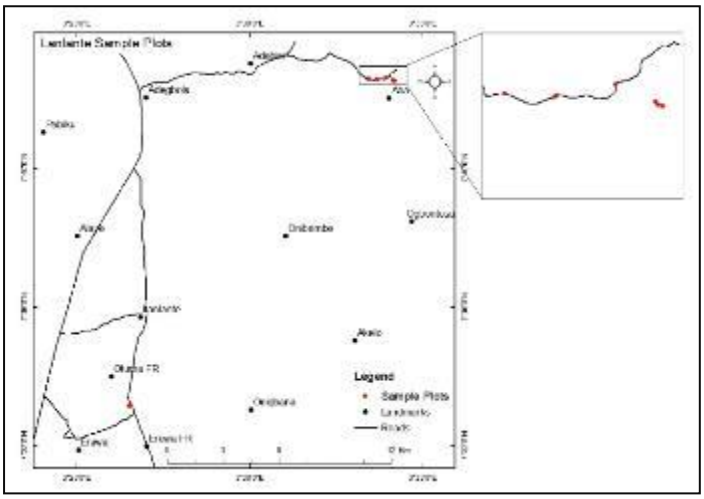

Fig. 2. Location map of the reserve showing the sampling plots
Source: Own elaboration

The reserve covers a land area of 75.07km^2 (7507Ha). The extent of depletion and deforestation caused by illegal logging and the encroachment of forest reserves in the state, has reduced the area extent reported for the study area (Sanwo et al., 2015; Ige, 2017). The climate is marked by a wet season that spans from April to October and a dry season from November to March, with annual rainfall varying between 1,300 and 1,500 mm and an average humidity of approximately 65%. The average temperature is about 26°C.

The climate and vegetation in the study area are conducive for the cultivation of primarily food crops, along with some tree crops such as cocoa, oil palm, and cashew. The original rainforest vegetation is being converted into derived savanna due to centuries of subsistence farming practices that include bush burning (Alabi et al., 2023).

Ogundele et al. (2012) identified the essential flora in the study area as savanna tree species including *Parkia biglobosa*, *Piliostigma reticulata* and *Vitellaria paradoxa*. The predominant grasses are *Panicum maximum, Imperata cylindrica* and *Andropogon tectorum.* The topography of the study area is characterized by undulating terrain, with average elevation levels reaching 192 meters above sea level.

Sampling procedure. Sampling technique employed in this study was systematic cluster sampling as employed by Akindele (2013). It involved establishment of a cluster in the Reserve. The cluster consisted of a 500 meters base line with 200 meters square transect at either end (Fig. 3). A distance of 100 meters therefore separated the two transects in the cluster. Each transect contained within its corners four sample plots of 50m x 50m. This is to cover as much as possible, the variations observed within the reserve. Thus, a total of 8 sample plots in the study area (Fig. 3) within a total area of 20000m^2 (i.e. 2ha) were established.

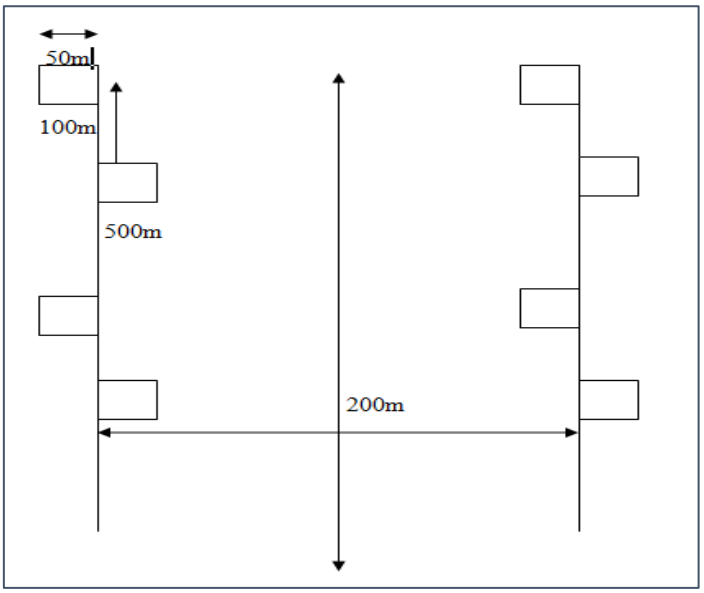

Fig. 3. Plot layout with systematic line transects sampling technique
Source: Own elaboration

Botanicals specimen collection and identification. Different species of trees were identified and counted in – situ where possible and by comparison with voucher specimen from the Forest Herbarium Ibadan (FHI), Forestry Research Institute of Nigeria, Ibadan. Flora species enumerated were categorized into families and frequency of the species was used to determine species composition.

Data collection Measurement of tree growth variables such as Diameter at breast height (DBH), Diameter at 0.5 cm, 0.7cm and 0.9cm, Crown diameter (cm), Height (m), Density of trees (tree/ha)were assessed in situ.

Data analysis. Data were subjected to descriptive statistics. Volume of trees and basal area were determined as indicated in equation 1 and 2 respectively. Data were also analyzed using both univariate diversity indices and multivariate techniques. Species diversity were determined using Shannon-Wiener index(H'), Simpson's diversity

index (1-D), Pielous's evenness (J'), and dominance index as shown in Equation 3 to 7 respectively. These gave adequate measurement of species richness, evenness and extent of their dominance within the reserve.

The basal area of all the trees in the sample plots were calculated using the formula in equation 1:

$$BA = лD^2/4 \quad (1)$$

Where BA = Basal area (m^2), D = Diameter at Breast Height (Cm) and л = 3.142

The volume of each tree was calculated in every plot using Newton's formula (Hush et al., 2003) as follows:

$$V = \left(\frac{H}{6}\right)(Ab + 4\,Am + At \quad (2)$$

Where V – Volume of trees (m^3), Ab, Am and At = tree cross-sectional area at the base, middle and top merchantable height, (m^2) and h in m respectively. The plot volumes were obtained by adding all the volumes of the trees in each plot.

Shannon-Wiener index (H') was calculated as:

$$H' = \sum_{i=1}^{S} Pi\ ln\ (Pi) \quad (3)$$

Where sis the number of species, $Pi = \frac{ni}{N}$ is the amount of individuals in the **i**th species, n**i** is the number of indivisuals of species **i** and N is the total number of individuals

Simpson's diversity index (1-D) was estimated as:

$$D = \sum_{i=1}^{S} P^2\ ;\ 1 - D \quad (4)$$

Where D represents probability that two individuals randomly selected from a sample from the same species, 1-D shows probability that they belong to different species (Shannon & Weaver, 1949; Magurran, 2013).

Evenness (J') was computed after Pielou (1966):

$$J' = \frac{H'}{In\ (S)} \quad (5)$$

This is used to standardize Shannon diversity (H') against maximum possible diversity for given number of species.

Dominance index (D) was estimated as:

$$D = \sum_{i=1}^{s} P_i^2 \quad (6)$$

Where higher values indicated greater dominance by one or few species (Simpson, 1949).

Principal component transforms correlated variables into uncorrelated orthogonal axis, each with an eigen value representing variance explained as stated by (Joliffe, 2002; Legendre & Legendre, 2012) and shown in Equation 7 and 8.

$$Z = XW \quad (7)$$

Where X is the standard data matrix, W is the Eigen vector matrix (Component loadings), and Z is the transformed component scores. Eigen values were used to evaluate important components:

$$\lambda = \frac{Var\ (Z)}{Var(X)} \quad (8)$$

Components with Eigen values > 1 were retained (Kaiser's criterion) and scree plots were used to confirm the optimal dimensionality of the output.

Results and discussion

Species composition. A total number of 257 trees representing 15 species and 7 families were identified in the reserve. The Fabaceae family was represented by six distinct tree species, followed by the Lamiaceae family with three different tree species, while the Combretaceae family included two different tree species. The most abundant species was *Tectona grandis* (68) while the least was *Funtumia elastic* (2) as shown in Table 1.

Table 1. Number of Trees, Species and Families in Lanlate Forest Reserve

Tree species	Family	Frequency
Burkea Africana	Fabaceae	11
Tectona grandis	Lamiaceae	68
Vitex doniana	Lamiaceae	15
Gmelina arborea	Lamiaceae	26
Parkia biglobosa	Fabaceae	10
Vitellaria paradoxa	Sapotaceae	21
Anogeissus leiocarpus	Combretaceae	12
Cola millenii	Malvaceae	5
Afzelia aficana	Fabaceae	9
Albizia zygia	Fabaceae	18
Funtumia elastic	Apocynaceae	2
Acacia Senegal	Fabaceae	11
Daniellia oliveri	Fabaceae	10
Azadirachta indica	Meliaceae	22
Terminalia senegalensis	Combretaceae	17

Source: Own elaboration

The average basal area and volume of the trees encountered in the study area were presented in Table 2. Plot 2 gave the highest basal area and volume with an average value of 16.45m^2 and 34.86m^3 respectively. This was followed closely by trees in plot 6 with an average basal area and volume of 15.22m^2 and 32.59 m^3 respectively. The least basal area and volume were recorded for trees in plot 3 with an average value of 9.43 m^2 and 12.37m^3 respectively. However, the overall mean values of basal area and volume of trees assessed are 2.12m^2 and 14.30m^3 respectively.

Table 2. Basal area and Volume estimation in Lanlate Forest Reserve

Plots	Basal Area (m^2)	Volume (m^3)
1	12.67	28.13
2	16.45	34.86
3	9.43	12.37
4	8.62	19.45
5	11.37	21.99
6	15.22	32.59
7	13.97	27.22
8	14.30	23.90
Mean	2.12	14.30

Source: Own elaboration

Diversity indices. Shannon – Weiner (H') of 2.43 demonstrated a moderate level of diversity, with various species contributing to the overall structure, while Simpson's index of 0.88 suggests a high likelihood that two randomly chosen trees are from different species (Table 3). High evenness index (J'=0.90) indicate a relatively balanced distribution of individual among species despite the strong dominance of *Tectona grandis* while dominance index (D=0.12) confirmed low overall dominance, reflecting the contribution of various species to make up the structure.

Table 3. Diversity indices

Indices	Values
Shannon – Weiner Index (H')	2.43
Simpson's index (1-D)	0.88
Evenness (J')	0.90
Dominance index (D)	0.12

Source: Own elaboration

Community structure. The rank-abundance curve (Fig. 4) shows a steep preliminary slope indicating teak dominance, followed by a steady waning, unswerving with moderately disturbed stands dominated by one species with many others.

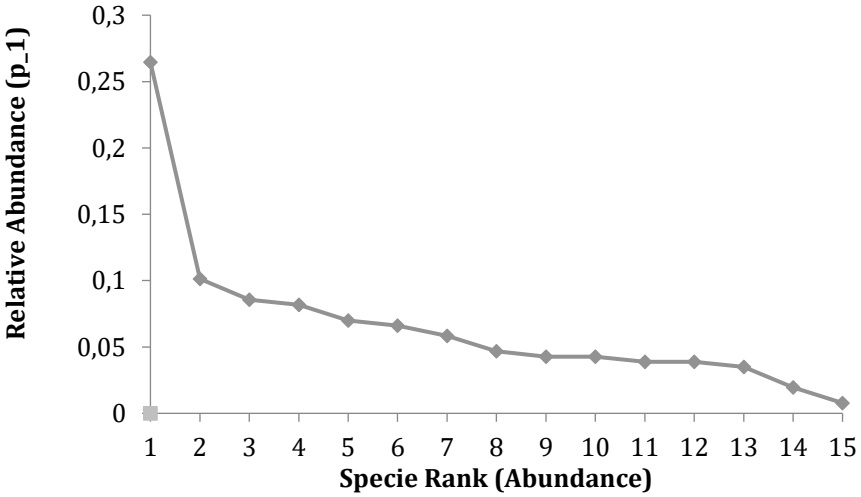

Fig. 4. Rank Abundance curve
Source: Own elaboration

Lanlate Forest Reserve displays reasonable structural diversity but is subjugated by *Tectona grandis* which is a replication of historical plantation establishment and selective logging of indigenous species. Similar studies have been reported in other reserves experiencing anthropogenic pressure (Sanwo et al., 2015; Ige, 2017). The high evenness suggests that while one exotic species dominates, sub-dominant species still persist, offering opportunities for ecological restoration.

Principal component analysis (PCA). Three components were extracted with eigenvalue, >1 for PC1(6.32). PC2(2.71) and PC3(1.80) with cummulative total variance of 72% (Table 4). Principal Component analysis shows strong ecological composition of the study area (Table 5).

Table 4. Eigenvalues and Variance Explained by Principal Components

Principal Components (PCs)	Eigenvalues	Variance explained (%)
PC1	6.32	42.0
PC2	2.71	18.0
PC3	1.80	12.0
PC4	0.95	6.3
PC5	0.72	4.8
PC6	0.51	3.4
PC7	0.38	2.6
PC8+	<0.30	<2.0 each

Source: Own elaboration

Table 5. Principal Component Loading of Tree Species in the Study Area

Species	PC1(plantation / indigenous species	PC2 (native rare species)	PC3(rare species)
Tectona grandis	+0.71	-0.12	0.08
Gmelina arborea	+0.63	-0.15	0.10
Azadirachta indica	+0.58	-0.11	-0.06
Afzelia aficana	-0.41	+0.09	0.12
Albizia zygia	-0.39	+0.54	-0.07
Vitellaria paradoxa	-0.05	+0.66	0.04
Parkia biglobosa	-0.12	+0.59	-0.02
Anogeissus leiocarpus	0.21	+0.27	-0.05
Burkea Africana	-0.18	+0.32	-0.01
Terminalia ivorensis	-0.10	+0.29	0.06
Cola millenii	-0.08	-0.03	+0.44
Funtumia elastic	0.02	0.07	+0.46
Acacia Senegal	-0.16	+0.22	-0.05
Daniellia oliveri	-0.19	+0.25	-0.04
Vitex doniana	-0.22	+0.18	-0.06

Source: Own elaboration

The PCA (42%-plantation-indigenous species) was strongly and positively correlated with *Tectona grandis* (+0.71), *Gmelina arborea* (+0.63) and *Azadirachta indica* (+0.58) confirming the dominancy of exotic plantation species. The negative loadings reflects the indigenous species of *Alfezelia Africana* (-0.41) and *Albizi azygia* (-0.39) indicating their difference with plantation dominated plots. This is followed by PC2 (18%) capturing agroforestry-rare native species such as *Vitellaria paradoxa* (+0.66), *Parkia biglobosa* (+0.59) *and Albizia zygia* (+0.54) while the third component PC3 (12%) showed the contribution of few rare species where *Funtumia elastic* (+0.48) and Cola *millenii* (+0.44) evolving as the major contributors (Table 5). Though their effect on general structure was trivial, their positive loadings advocate ecological significance in terms of niche diversity and genetic conservation.

In general, these loadings indicate that the structure of the reserve is shaped by a plantation of indigenous species (PC1), an agroforestry component of native species

(PC2), and a component of rare native species (PC3), leading to an observed variation of 72% in species composition.

The scree plot (Fig. 5) additionally established that the first two components apprehended the ecological evidence, followed by other components which gave little explanation about the reserve. This is in line with findings of Eni et al., (2012) and Akwaji et al., (2024) where they indicated that first two components were sufficient to reveal the foremost soil/vegetation and climatic chauffeurs of forest composition. This further showed that plantation to indigenous, and agroforestry – native species are the dominant structural governing species distribution in the reserve.

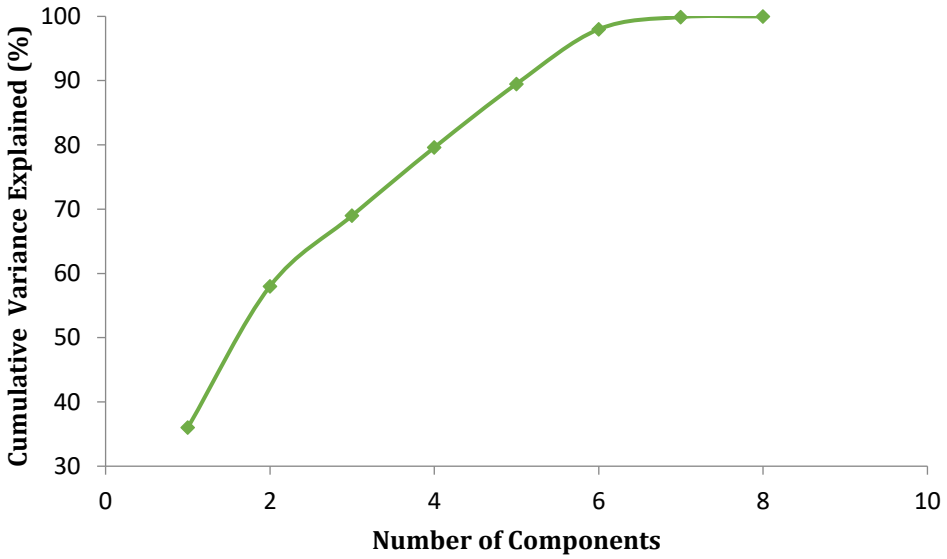

Fig. 5. Scree plot
Source: Own elaboration

Conclusions

This study presents a comprehensive evaluation of tree structural diversity in Lanlante Forest Reserve, Southwestern Nigeria, by incorporating diversity indices and multivariate analysis. Shannon-Weiner and Simpson indices showed a moderate species diversity with evenness irrespective of *Tectona grandis* dominance.

The PCA indicated two major ecological gradients, a plantation-indigenous species (PC1) showing the establishment of *Tectona grandis Gmelina arborea* plantation and an agroforestry – rare domain (PC2) emphasizing the impact of socio-cultural species like *Vitellaria paradoxa, Parkia biglobosa and Albizi a zygia*.

The results have shown that while exotic plantations silhouette the structural shape of the reserve, indigenous species maintain the integral culture and balance of the ecosystem. Thus, there is need to reduce plantation dominance through steady diversification of stand composition by enriching them with important ecological and economically native species such as *Vitellaria paradoxa, Afzelia africana Parkia biglobosa and Albizia zygia.*

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