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TREE SPECIES DIVERSITY AND DISTRIBUTION PATTERNS OF PROTECTED AREAS OF SAVANNA ECOSYSTEM OF NORTHERN NIGERIA

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ABSTRACT

Savanna ecosystems are shaped by complex interactions among disturbances, climate extremes, and management, yet quantitative assessments of their structural and floristic characteristics in Nigeria remain limited. This study therefore examined the present status of protected areas (PAs) within the savanna ecological zone of Northern Nigeria, focusing on tree species diversity, abundance, stand structure, density, and distribution patterns with the view of providing information for management and conservation purposes. Data were collected from five randomly selected PAs: Yankari Game Reserve and Sumu Wildlife Park (Bauchi State), Kainji Lake National Park and Borgu Game Reserve (Niger State), and Marhai Forest Reserve (Nasarawa State). A systematic line-transect sampling technique was used, with four 50 m × 50 m plots established at 250 m intervals in alternate directions within each site. All trees with DBH ≥10 cm were measured and identified. A total of 1,051 trees, 71 species and 22 families were recorded. Tree density ranged from 68 to 275 trees ha^{-1}. Combretaceae and Fabaceae were the most dominant families, while *Combretum micranthum*, *Anogeissus leiocarpa*, and *Vitellaria paradoxa* were the most frequent species. Despite low population density, *Adansonia digitata* contributed substantially to basal area and volume. Kainji recorded the highest Shannon index (3.21), evenness (0.95) and Margalef's index of species richness (6.87). Tree density and height varied significantly ($p<0.05$), but basal area and DBH did not differ. Strong correlations between structural variables and diversity indices highlight the need to conserve and protect large-tree growth in the Nigerian savanna.

Keywords: Biodiversity Assessment, Protected Area, Savannas, Tree Density, Ecosystem Function

INTRODUCTION

Savanna ecosystems dominate the Nigerian landscape and represent one of the most extensive and ecologically important biomes in sub-Saharan Africa. Characterized by a dynamic mixture of grasses and widely spaced woody species, these systems form a complex vegetation mosaic shaped by climate variability, fire regimes, soil conditions, and human influence. Structurally, savannas are defined by the coexistence of a continuous herbaceous layer and discontinuous tree canopies, a pattern that supports diverse ecological niches and sustains high levels of biodiversity (Sankaran et al., 2005). In northern Nigeria, savanna landscapes provide essential ecosystem services, including carbon storage, soil protection, microclimate regulation, and the supply of timber and non-timber forest products essential to rural livelihoods (Wakawa et al., 2017; Adeniji et al., 2021).

Despite their ecological and socio-economic value, Nigerian savannas are increasingly subjected to anthropogenic pressures. Expansion of agriculture, fuelwood harvesting, charcoal production, grazing, and infrastructural development have intensified land-use change, resulting in habitat fragmentation and vegetation degradation (Shuaibu, 2014; Egbinola, 2015; Shuaibu et al., 2021). Charcoal production, in particular, has emerged as a major driver of woody biomass removal in the northern savanna, linking rural extraction zones to growing urban energy demands. The cumulative impacts of anthropogenic disturbances have altered significantly species composition, reduce tree density, and modify stand structure, thereby weakening ecosystem functioning and resilience (Zankan et al., 2019; Nabaloum, et al., 2022).

Tree species in the savanna zone, though often undervalued in conventional timber markets, play indispensable ecological and socio-cultural roles. Species such as *Khaya senegalensis*, *Parkia biglobosa*, *Vitellaria paradoxa*, *Adansonia digitata*, *Daniellia oliveri*, and *Lophira lanceolata* contribute to nutrient cycling, habitat provision, food, medicine, and income for local communities (Wakawa et al., 2017). The diversity and structural arrangement of tree species strongly influence ecosystem productivity, stability, and resistance to disturbance (Nabaloum, et al., 2022; Hooper et al., 2005; Leishangthem & Singh, 2018).

Protected areas in northern Nigeria are therefore vital biodiversity strongholds for conserving floristic diversity and maintaining ecological processes in the savanna biome (Adeniji et al., 2021). However, even these areas face varying degrees of anthropogenic influence, making it essential to assess current vegetation composition and structure. Understanding floristic diversity, structural characteristics, and distribution patterns of trees provides critical baseline data for biodiversity conservation, sustainable management, and restoration planning (Adekunle, 2022; Bassey et al., 2025). This study aims to evaluate these attributes within protected savanna ecosystems of northern Nigeria, thereby contributing to evidence-based strategies for safeguarding ecological integrity in a rapidly changing environment.

MATERIALS AND METHODS

The Study Area

This study was conducted within the northern savanna ecological zone of Nigeria, which encompasses the Sudan and northern Guinea savanna of the ecoregion. Geographically, the savanna region of Nigeria extends from latitudes 7°N - 13°N and longitudes 3°E - 14°E (Nwaigbo, 1989). The vast area includes grasslands with scattered trees, transitioning from the wetter Sudan savanna in the south-central north to drier Sudan and semi-arid zones in farther north (Modibbo & Shahidah, 2018). The five selected sites PAs for this study are, Yankari Game Reserve (9°45′N–10°05′N, 10°30′E–10°50′E) and Sumu Wildlife Park (9°50′N–10°10′N, 10°18′E–10°50′E) in Bauchi state; Kainji Lake National Park (9°40′–10°30′N, 3°30′–5°50′E) and Borgu Game Reserve (10°0′N–10°20′N, 3°50′E–4°15′E) in Niger state and Marhai Forest Reserve (9°06′N–9°20′N, 8°42′E–8°77′E) located in Nasarawa state.

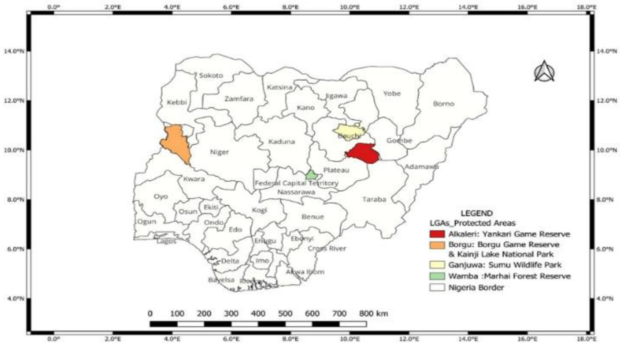

Figure 1: Map of Nigeria showing the Local Government Areas of the Selected PAs

Sampling Procedure and Data Collection

In each of the study sites, data were collected using the systematic line transect sampling method. The line transect method involved the centrally laying of a 1000m transect line in each of the study sites, along which four equal sized sample plots (50 m × 50 m or 0.25ha) were established at intervals of 250m according to Ijeoma et al., (2022). Within each sample plot, all trees with DBH ≥ 10 cm were tagged, measured, identified, and classified on a family basis, and their frequency of occurrence was also obtained to ascertain tree species diversity.

Data Analysis

Basal area and volume were calculated for each measured tree to quantify stand structure and growing stock within the study areas.

Basal Area Calculation

$$BA = \frac{\pi D^2}{4}$$

Where: BA= Basal Area; π= 3.142 and D= Diameter at breast height. The total BA for each plot was obtained by adding all tree BA in the sample plot.

Volume Computation

The volume of individual trees was estimated using the Newtons' formula (Husch et. al., 2003)

$$V = \frac{\pi h}{24}(Db^2 + 4Dm^2 + Dt^2)$$

Where: V = Tree volume (m^3); D_b , D_m and D_t = Diameter at the base, middle and top (cm) respectively and H = height (m). Plot volume was also obtained by adding the volumes of all trees in the plot

Tree Species Diversity Indices

For comprehensive assessment and comparison of tree species diversity, the following indices were employed:

(i) Species relative density (RD). This was calculated according to Brashears et al. (2004) equation:

$$RD = \left[\frac{n_i}{N}\right] \times 100$$

Where n_i = Number of individual species I; N = Total number of individuals in the entire population.

(ii) Species relative dominance (RDo) was calculated following Curtes and McIntosh (1950);

$$RDo = \left(\frac{\sum BA_i \times 100}{\sum BA_n}\right)$$

Where: BA_i = Basal area of individual trees belonging to a particular species i and BA_n = Stand basal area.

(iii) Relative frequency (RF) was obtained using the formula according to Oduwaiye et. al (2002):

$$RF = \frac{\sum F_i \times 100}{F_n}$$

Where F_i = frequency of i species and F_n = Total frequency of all species.

(iv) Shannon- Wiener diversity index was calculated following Shannon, 1948

$$H' = -\sum_{i=1}^{s} piLn(pi)$$

Where: S = Total number of species in the community; P_i = the proportion of a species to the total number of plants in the community and Ln = the natural logarithm

(v) Species evenness (E) was computed according to Pielou (1966):

$$E = \frac{H'}{Ln(S)}$$

(vi) Margalef's Index of species richness was calculated according to Margalef (1958)

$$D = \frac{S-1}{Ln\ N}$$

(vii) Simpson's Diversity index according to Simpson (1949)

$$D = 1 - \sum\left[\frac{n_1}{N}\right]^2$$

(viii) Number 1 of Hill diversity index was calculated according to Hill (1973)

N1= Exp (-∑pi (Lnpi))

RESULTS AND DISCUSSION

A total of one thousand and fifty-one (1,051) trees were encountered across the five selected Protected Areas (PAs) in the northern savanna ecological zone of Nigeria. This is represented in twenty (20) Families and seventy-one (71) numbers of species (Table 1). Across the sites, *Combretum micranthum* recorded the highest N/ha (168) followed by *Anogeissus leiocarpa* (116 stems/ha) and *Vitellaria paradoxa* (82 stems/ha), while species of *Parinari curatellifolia*, *Combretum nigricans*, *Terminalia schimperiana*, *Diospyros Mespiliformis*, *Azanza garckeana*, *Ficus platyphylla*, and *Gardenia aqualla* each recorded one (1) stand which makes them the species with the least number of occurrence across the study areas. Basal area and stand volume provided further insight into species' roles in shaping stand structure. *Adansonia digitata* recorded the highest Basal Area (8.81 m²/ha) and volume (40.90 m³/ha), attributable to its large stem diameters despite its low population density. It was closely followed by *Anogeissus leiocarpa* with basal area and volume of 5.85 m²/ha and 28.18 m³/ha respectively. This pattern, where few large individual trees account for a disproportionate share of biomass, is typical of savanna woodlands (Adeniji et al., 2021). *Combretum micranthum*, and *Vitellaria paradoxa* likewise contributed substantially to Basal area and volume, confirming their ecological importance.

Family and Family Importance Value (FIV) of trees in selected PAs were presented in Table 2. The result revealed that Combretaceae and Fabaceae emerged as the most ecologically dominant families, with the highest Family Importance Values of 85.95 and 81.59 respectively. These findings are consistent with many savanna studies that identified Combretaceae and Fabaceae as key structural and functional components of the ecosystem, largely due to their resistant to fire, drought, and herbivory (Zankan et al., 2019; Attua & Pabi, 2013; Wakawa et al., 2006). The dominance of Fabaceae highlights their ecological flexibility and key functional role, such as nitrogen fixation, which contribute to community assembly and the provision of ecosystem services (Attua & Pabi, 2013).

The Summary of phytosociological results and biodiversity indices of the selected PAs are presented in Table 3. The results show significant variation in stand structure and growth characteristics of the study sites. Tree density ranged from a low value (68 trees/ha) in Kainji to a high value (275 trees/ha) in Marhai. Species richness varied across the five PAs, with Yankari, Sumu, Borgu, Kainji and Marhai recording 13, 21, 28, 30 and 26 species respectively. When compared with the previous studies in similar landscapes, tree species richness obtained across the selected PAs are within the range obtained by Bello et al., (2022) who recorded 25 species in Rabadi Forest Reserve, Jigawa State, Nigeria. However, the values are lower than 50 tree species reported by Zankan et al., (2019) in the Jemaa Local Government Area of Kaduna State, Nigeria. These observed variations reflect both natural ecological differences and the influence of varying management practices among the PAs. The comparatively low number of trees, families, and species recorded in the study areas, compared with tropical rainforest ecosystems such as the Ologbo Forest Concession in Edo State where Ogunjemite (2015) recorded 630 stems representing 71 species in 24 families, and the Strict Nature Reserve 1 in Akure Forest Reserve, Ondo State where Adekunle et al. (2013) reported 387 stems per hectare belonging to 94 species and 30 families, reflects a typical characteristic of savanna ecosystems in which tree species are sparsely distributed across the landscape.

Results of biodiversity indices demonstrated clear spatial variation among sites. Kainji recorded the highest Shannon–Wiener diversity (H′) of 3.21, evenness (0.94), and Simpson index (0.95), indicating both rich species composition and equitable distribution. In contrast, Yankari exhibited lower diversity and evenness, suggesting dominance by a few species. The highest Margalef's index of species richness was recorded in Kainji (6.87), reflecting larger species pool despite lower tree density. Differences in diversity indices reflect variations in disturbance regimes, soil conditions, and conservation histories across protected areas (Magurran, 2004).

Table 1: Tree Species Diversity, Abundance and Growth Characteristics in Selected PAs of the Nigerian Savanna

S/N	FAMILY	SPECIE	N/ha	Ba/ha (m^2)	Vol./ha (m^3)	RD	Rdo	Pi	LnPi	H[1]
1	Anacardiaceae	*Lannea acida A.Rich.*	10	0.60	2.79	0.95	1.18	0.01	-4.65	-0.04
2		*Lannea schimperi (Hochst. ex A.Rich.)Engl.*	3	0.31	1.06	0.29	0.60	0.00	-5.86	-0.02
3	Araliaceae	*Cussonia arborea Hochst. Ex A. Rich.*	2	0.09	0.42	0.19	0.17	0.00	-6.26	-0.01
4	Burseraceae	*Boswellia dalzielii Hutch*	7	0.24	1.18	0.67	0.48	0.01	-5.01	-0.03
5	Calastraceae	*Maytenus senegalensis (Lam.) Exell*	3	0.06	0.31	0.29	0.12	0.00	-5.86	-0.02
6	Chrysobalanaceae	*Maranthes glabra(Oliv.) Prance*	2	0.07	0.33	0.19	0.13	0.00	-6.26	-0.01
7		*Parinari curatellifolia Planch.ex Benth*	1	0.03	0.12	0.10	0.06	0.00	-6.96	-0.01
8		*Parinari excelsa Sabine*	15	0.32	2.49	1.43	0.63	0.01	-4.25	-0.06
9	Combretaceae	*Anogeissus leiocarpa (DC.) Guill. & Perr.*	116	5.85	28.18	11.06	11.50	0.11	-2.20	-0.24
10		*Combretum glutinosum Perr.ex DC*	63	1.51	7.63	6.01	2.97	0.06	-2.81	-0.17
11		*Combretum micranthum G.Don*	168	5.12	34.15	16.02	10.06	0.16	-1.83	-0.29
12		*Combretum molle R.Br ex.G Don*	24	1.37	6.40	2.29	2.68	0.02	-3.78	-0.09
13		*Combretum nigricans Lepr. ex Guill. & Perr.*	1	0.01	0.04	0.10	0.02	0.00	-6.96	-0.01
14		*Terminalia avicennioides Guill. & Perr.*	5	0.15	0.73	0.48	0.29	0.00	-5.35	-0.03
15		*Terminalia glaucescens Planch.ex Benth.*	51	1.00	5.31	4.86	1.97	0.05	-3.02	-0.15
16		*Terminalia macroptera Guill. & Perr.*	23	0.34	1.86	2.19	0.67	0.02	-3.82	-0.08

S/N	FAMILY	SPECIE	N/ha	Ba/ha (m^2)	Vol./ha (m^3)	RD	Rdo	Pi	LnPi	H^1
17		*Terminalia schimperiana Hochst.*	1	0.01	0.04	0.10	0.02	0.00	-6.96	-0.01
18	Ebenaceae	*Diospyros barteri Hiern*	2	0.06	0.31	0.19	0.12	0.00	-6.26	-0.01
19		*Diospyros Mespiliformis Hochst. ex A.DC.*	1	0.19	0.83	0.10	0.36	0.00	-6.96	-0.01
20	Euphorbiaceae	*Bridelia ferruginea Benth*	11	0.19	1.24	1.05	0.37	0.01	-4.56	-0.05
21	Fabaceae	*Acacia gourmaensis A. Chev*	3	0.07	0.25	0.29	0.13	0.00	-5.86	-0.02
22		*Acacia hockii De Wild*	5	0.09	0.47	0.48	0.18	0.00	-5.35	-0.03
23		*Acacia polyancantha Willd*	2	0.09	0.34	0.19	0.18	0.00	-6.26	-0.01
24		*Acacia senagal (L.) Willd.*	50	1.73	8.52	4.77	3.41	0.05	-3.04	-0.15
25		*Acacia seyal Delile*	9	0.18	0.97	0.86	0.36	0.01	-4.76	-0.04
26		*Afzelia africana Sm. ex Pers*	14	0.99	4.32	1.33	1.95	0.01	-4.32	-0.06
27		*Burkea africana Hook*	12	0.44	2.14	1.14	0.86	0.01	-4.47	-0.05
28		*Cassia sieberiana DC*	3	0.13	0.61	0.29	0.25	0.00	-5.86	-0.02
29		*Daniellia oliveri (Rolfe) Hutch. & Dalziel*	6	0.45	2.25	0.57	0.89	0.01	-5.16	-0.03
30		*Detarium micocarpum Guill. & Perr.*	23	0.80	5.18	2.19	1.58	0.02	-3.82	-0.08
31		*Dichrostachys cinerea (L) Wight & Arn*	12	0.47	2.31	1.14	0.93	0.01	-4.47	-0.05
32		*Diphysa floribunda Peyr.*	3	0.53	6.99	0.29	1.04	0.00	-5.86	-0.02
33		*Entada africana Guill. & Perr*	3	0.06	0.29	0.29	0.11	0.00	-5.86	-0.02
34		*Isoberlinia doka Craib & Stapf*	6	0.30	1.48	0.57	0.59	0.01	-5.16	-0.03
35		*Leucaena leucocephala (Lam.) de Wit*	7	0.17	1.55	0.67	0.34	0.01	-5.01	-0.03
36		*Parkia biglobosa (Jacq.) R.Br. ex G Don*	8	1.25	6.70	0.76	2.45	0.01	-4.88	-0.04
37		*Pericopsis laxiflora Benth. ex Baker*	3	0.13	0.65	0.29	0.26	0.00	-5.86	-0.02
38		*Piliostigma reticulatum (DC.) Hochst.*	5	0.47	2.21	0.48	0.92	0.00	-5.35	-0.03
39		*Piliostigma thonningii (Schumach.)Milne-Redh.*	16	0.26	1.43	1.53	0.51	0.02	-4.18	-0.06
40		*Prosopis africana (Guill. & Perr.) Taub.*	17	0.74	3.85	1.62	1.45	0.02	-4.12	-0.07
41		*Pterocarpus erinaceus Poir.*	19	1.09	5.22	1.81	2.14	0.02	-4.01	-0.07
42		*Senna alata (l.) Roxb*	2	0.06	0.31	0.19	0.12	0.00	-6.26	-0.01
43		*Tamarindus indica L.*	26	2.22	10.66	2.48	4.36	0.02	-3.70	-0.09
44	Lamiaceae	*Gmelina arborea Roxb.*	10	0.72	3.95	0.95	1.42	0.01	-4.65	-0.04
45		*Vitex doniana sweet*	2	0.12	0.58	0.19	0.24	0.00	-6.26	-0.01
46	Loganiaceae	*Strychnos elongata K. Schum*	1	0.01	0.05	0.10	0.02	0.00	-6.96	-0.01
47		*Strychnos spinosa Lam.*	3	0.03	0.16	0.29	0.05	0.00	-5.86	-0.02
48	Lythraceae	*Lagerstroemia lanceolata Wall. ex C.B.Clarke*	2	0.04	0.18	0.19	0.09	0.00	-6.26	-0.01

S/N	FAMILY	SPECIE	N/ha	Ba/ha (m^2)	Vol./ha (m^3)	RD	Rdo	Pi	LnPi	H¹
49	Malvaceae	*Adansonia digitata L.*	9	8.81	40.90	0.86	17.32	0.01	-4.76	-0.04
50		*Azanza garckeana F.Hoffm.(Exell & Hillc.)*	1	0.01	0.07	0.10	0.03	0.00	-6.96	-0.01
51		*Bombax costatum pellegr. & Vuillet*	8	0.52	2.48	0.76	1.02	0.01	-4.88	-0.04
52		*Grewia mollis Juss.*	13	0.17	0.75	1.24	0.33	0.01	-4.39	-0.05
53		*Sterculia setigera Delile*	18	0.65	3.18	1.72	1.27	0.02	-4.07	-0.07
54		*Triplochiton scleroxylon K. Schum*	3	0.03	0.14	0.29	0.05	0.00	-5.86	-0.02
55	Meliaceae	*Azadirachta indica A.Juss*	34	1.68	8.08	3.24	3.31	0.03	-3.43	-0.11
56		*Ekebergia senegalensis A. Juss*	2	0.17	0.80	0.19	0.33	0.00	-6.26	-0.01
57		*Khaya senegalensis (Desr.) A. Juss.*	4	0.61	2.81	0.38	1.20	0.00	-5.57	-0.02
58		*Pseudocedrela kotschyi (Schweinf.) Harms*	4	0.11	0.54	0.38	0.21	0.00	-5.57	-0.02
59	Moraceae	*Ficus platyphylla Delile*	1	0.03	0.13	0.10	0.05	0.00	-6.96	-0.01
60		*Ficus sycomorus L.*	7	0.26	1.61	0.67	0.51	0.01	-5.01	-0.03
61	Myrtaceae	*Eugenia uniflora L*	7	0.14	0.73	0.67	0.28	0.01	-5.01	-0.03
62	Ochnaceae	*Lophira lanceolata Tiegh. ex Keay*	3	0.06	0.31	0.29	0.11	0.00	-5.86	-0.02
63	Phyllanthaceae	*Bridelia ferruginea Benth*	3	0.07	0.24	0.29	0.13	0.00	-5.86	-0.02
64		*Hymenocardia acida Tul.*	27	0.42	2.77	2.57	0.83	0.03	-3.66	-0.09
65	Polygalaceae	*Securidaca longipedunculata Fresen*	13	0.20	1.07	1.24	0.40	0.01	-4.39	-0.05
66	Rubiaceae	*Crossopteryx febrifuga (Afzel. ex G.Don)Benth.*	10	0.19	0.97	0.95	0.38	0.01	-4.65	-0.04
67		*Gardenia aqualla Stapf & Hutch.*	1	0.01	0.03	0.10	0.02	0.00	-6.96	-0.01
68		*Mitragyna inermis (Willd.) Kuntze*	8	0.24	1.44	0.76	0.47	0.01	-4.88	-0.04
69		*Nauclea latifolia Smith.*	7	0.23	1.10	0.67	0.46	0.01	-5.01	-0.03
70	Sapotaceae	*Vitellaria paradoxa C.F. Gaertn*	82	5.06	25.01	7.82	9.95	0.08	-2.55	-0.20
71	Simaroubaceae	*Quassia undulata (Guill.&Perr.) D. Dietr.*	3	0.06	0.23	0.29	0.12	0.00	-5.86	-0.02
	Grand Total		1051							

N/ha- Number of stem per hectare, BA- Basal area per hectare (m^2), VOL. –Volume per hectare (m^3), RD- Spp. Relative density, RDo- Relative dominance of each Spp, H¹- Shannon-Weiner diversity index

Table 2: Family and Family Importance Value of Trees in Selected PAs of the Savanna Ecosystem, Nigeria

S/No	FAMILY	N/ha	NS	Ba/ha (m^2)	Vol./ha (m^3)	Rdo (%)	RD	RF (%)	FIV
1	Anacardiaceae	13	2	0.90	3.85	1.24	1.78	2.82	5.83
2	Araliaceae	2	1	0.09	0.42	0.19	0.17	1.41	1.77
3	Burseraceae	7	1	0.24	1.18	0.67	0.48	1.41	2.55
4	Calastraceae	3	1	0.06	0.31	0.29	0.12	1.41	1.81
5	Chrysobalanaceae	18	3	0.42	2.94	1.72	0.82	4.23	6.76
6	Combretaceae	452	9	15.36	84.34	43.09	30.18	12.68	85.95
7	Ebenaceae	3	2	0.25	1.14	0.29	0.49	2.82	3.59
8	Euphorbiaceae	11	1	0.19	1.24	1.05	0.37	1.41	2.83
9	Fabaceae	254	23	12.71	68.70	24.21	24.99	32.39	81.59
10	Lamiaceae	12	2	0.85	4.53	1.14	1.66	2.82	5.62
11	Loganiaceae	4	2	0.04	0.21	0.38	0.07	2.82	3.27

S/No	FAMILY	N/ha	NS	Ba/ha (m^2)	Vol./ha (m^3)	Rdo (%)	RD	RF (%)	FIV
12	Lythraceae	2	1	0.04	0.18	0.19	0.09	1.41	1.69
13	Malvaceae	52	6	10.19	47.52	4.96	20.02	8.45	33.43
14	Meliaceae	44	4	2.57	12.23	4.19	5.05	5.63	14.88
15	Moraceae	8	2	0.29	1.74	0.76	0.56	2.82	4.14
16	Myrtaceae	7	1	0.14	0.73	0.67	0.28	1.41	2.36
17	Ochnaceae	3	1	0.06	0.31	0.29	0.11	1.41	1.81
18	Phyllanthaceae	30	2	0.49	3.01	2.86	0.96	2.82	6.63
19	Polygalaceae	13	1	0.20	1.07	1.24	0.40	1.41	3.05
20	Rubiaceae	26	4	0.68	3.54	2.48	1.33	5.63	9.44
21	Sapotaceae	82	1	5.06	25.01	7.82	9.95	1.41	19.17
22	Simaroubaceae	3	1	0.06	0.23	0.29	0.12	1.41	1.82

N/ha- number of stem per hectare, BA- Basal area per hectare (m^2), VOL –Volume per hectare m^3), RD- Spp. Relative density, RDO - Relative dominance of each Spp, RF- Relative Frequency, FIV- Family Importance Value.

Table 3: Summary of Phytosociological Results and Biodiversity Indices of the Selected Pas

	Location					
Indices	**Yankari**	**Sumu**	**Borgu**	**Kainji**	**Marhai**	**All Location**
No of Individual tree/ha (Ni)	220	218	270	68	275	1051
No of Species (NS)	13	21	28	30	26	71
No of Families (NF)	6	10	14	12	14	22
Shannon-Weiner Index (H')	2.12	2.39	2.88	3.21	2.13	3.41
Shannon's Maximum Diversity Index	2.56	3.04	3.33	3.4	3.25	4.26
Pielou's Evenness Index (E)	0.82	0.78	0.86	0.94	0.65	0.80
Margalef's Index of Species Richness	2.22	3.71	4.82	6.87	4.45	10.6
Simpsons' Index	0.84	0.86	0.92	0.95	0.74	0.94
Number 1 of Hill diversity Indices (N1)	8.33	10.93	17.95	24.78	8.45	30.54

The comparative summary of growth variables revealed significant differences among the selected PAs (Table 4). Basal area and volume followed a similar trend, with Yankari recording the highest values of 17.44 m^2 and 82.96 m^3 respectively, while Kainji had the lowest basal area (3.54 m^2) and volume (16.27m^3). Yankari also exhibited substantial Mean DBH (24.33cm) and mean height (23.25m), whereas Marhai had the lowest mean DBH (16.33m^2) and kainji the lowest mean height (8.53m). Patterns of tree size distribution strongly influence stand productivity and structural complexity (Maiguru & Akpan, 2023). The higher basal area and volume recorded in Yankari and Sumu indicate greater biomass and forest maturity, consistent with trends observed in other tropical forest assessments (Parresol, 1995; Sankaran et al., 2005).

Table 4: Summary of Growth Variables Across the Selected PAs

	Location					
Growth Variable	**Yankari**	**Sumu**	**Borgu**	**Kainji**	**Marhai**	**All Location**
N/ha	220	218	270	68	275	1051
BA (m^2)	17.44	14.08	9.09	3.54	6.77	50.92
Vol (m^3)	82.96	67.39	44.83	16.27	53.15	264.60
Mean Dbh (cm)	24.33	26.73	18.61	21.66	16.33	21.09
Mean Ht (m)	23.25	27.23	10.57	8.53	9.03	16.13
Dominant Dbh (cm)	49.13	43.25	33.42	42.80	26.50	39.41
Dominant Ht (m)	36.41	44.88	18.58	13.30	14.13	33.00

ANOVA results that compared differences in tree growth variables among the five selected PAs revealed significant differences in tree density and mean tree height among the five study sites, with F-values of 20.923 and 19.192 and p-values < 0.05. However, diameter at breast height, basal area, and tree volume did not differ significantly (Table 5).

Results of Duncan's multiple range test is presented in Table 6. The results revealed no significant difference between Yankari, Sumu, Borgu, Marhai, and while Kainji showed significant difference. This suggests lower stand density or higher level of disturbance in Kainji. On the other hand, basal area, Volume and Mean DBH did not differ significantly among locations. The significant differences that exist in tree density but not in BA, volume and DBH suggests that trees of similar size classes are present across sites, but vertical growth varies, likely due to light availability, soil fertility, and competition.

Table 5: Comparison Between Differences in Tree Growth Variables among the Five Selected PAs using ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Nha	Between Groups	7068.300	4	1767.075	20.929	0.000*
	Within Groups	1266.500	15	84.433		
	Total	8334.800	19			

		Sum of Squares	df	Mean Square	F	Sig.
Ht	Between Groups	1298.742	4	324.685	19.192	0.000*
	Within Groups	253.769	15	16.918		
	Total	1552.511	19			
Dbh	Between Groups	300.089	4	75.022	1.826	0.176
	Within Groups	616.229	15	41.082		
	Total	916.319	19			
BA	Between Groups	31.222	4	7.805	1.699	0.202
	Within Groups	68.899	15	4.593		
	Total	100.121	19			
Vol	Between Groups	630.084	4	157.521	1.455	0.265
	Within Groups	1624.019	15	108.268		
	Total	2254.103	19			

**Significance (P<0.05).*

Table 6: Follow up Analysis to Compare Tree Growth Variables of the Selected PAs

	Location					
Growth Variable	**Yankari**	**Sumu**	**Borgu**	**Kainji**	**Marhai**	**All Location**
N/ha	220a	218a	270a	68b	275a	1051
BA (m^2)	17.44a	14.08a	9.09a	3.54a	6.77a	50.92
Vol (m^3)	82.96a	67.39a	44.83a	16.27a	53.15a	264.60
Mean Dbh (cm)	24.33a	26.73a	18.61a	21.66a	16.33a	21.09
Mean Ht (m)	23.25a	27.23a	10.57b	8.53c	9.03c	16.13
Dominant Dbh (cm)	49.13a	43.25a	33.42a	42.80b	26.50b	39.41
Dominant Ht (m)	36.41a	44.88a	18.58a	13.30a	14.13a	33.00

Means followed by similar alphabets in a row are not significantly different (P<0.05).

The relationship among tree growth variables and diversity indices in the selected PAs was examined using the Pearson correlation coefficient**.** The results revealed a very strong positive correlation between BA and Volume (0.96), Shannon-Weiner diversity index and Simpson's index (0.93). A strong positive relationship was also demonstrated by tree Height and DBH (0.84), DBH and Volume (0.80), Evenness and Margalef (0.80).

Table 7: Correlation Matrix of Growth Variables and Diversity Indices in Selected PAs

	Nha	*Ht*	*Dbh*	*BA*	*Vol*	*H'*	*S I*	*Evenness*	*Margalef*
Nha	1								
Ht	0.47	1							
Dbh	0.70	0.84	1						
BA	0.19	0.66	0.78	1					
Vol	0.27	0.63	0.80	0.96	1				
H'	0.39	0.10	0.22	0.07	0.06	1			
S I	0.39	0.21	0.27	0.02	0.03	0.93	1		
Evenness	0.17	-0.39	-0.05	-0.03	0.00	0.27	0.41	1	
Mangalef	-0.17	-0.66	-0.37	-0.24	-0.26	0.05	0.13	0.80	1

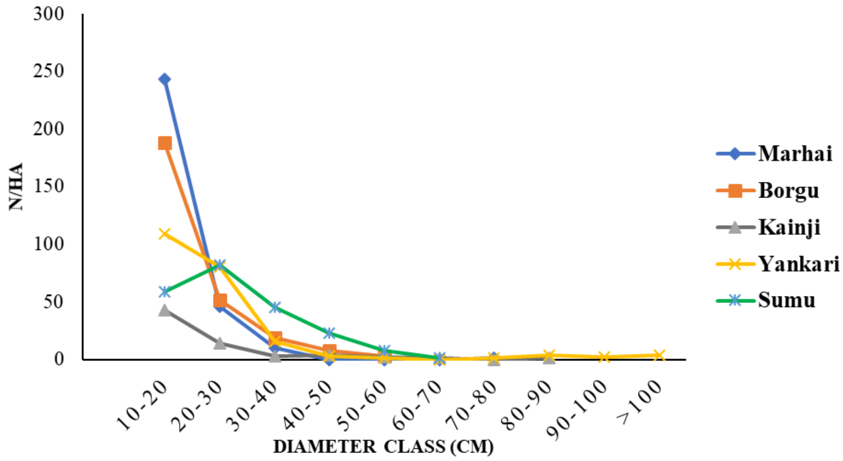

Figure 2: Diameter Class Distribution Curves of all Individual Selected PAs

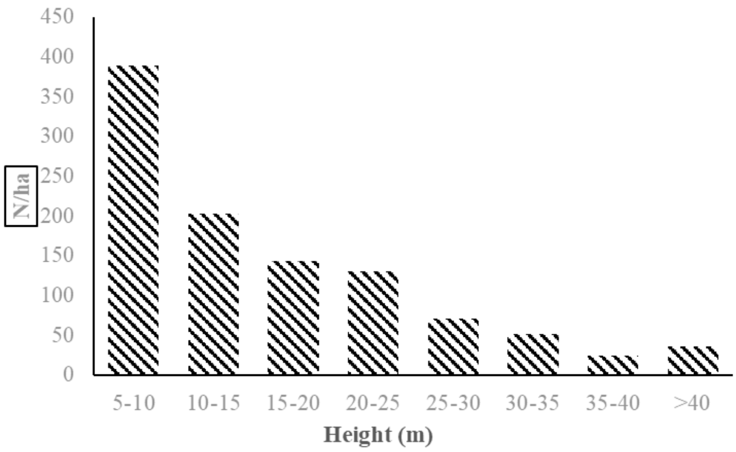

Figure 3: Height Distribution of Trees in all the Selected PAs in the Savanna Ecosystem

The diameter distribution curves for the selected individual PAs are presented in Figure 2. The curves followed the inverted J-shaped expected of any natural forest, indicating the availability of many small stems and relatively fewer large stems across all sites and typical of savanna undergoing natural regeneration and moderate disturbance (Adeniji et al., 2021). The results revealed that approximately 47% of species were represented by ≤ 5 trees/ha across all sites, highlighting the dominance of rare species. According to Bond and Parr (2010), such a structure has important implications for ecosystem function, as the low number of individuals reaching large size classes may restrict long-term carbon storage and compromise structural complexity.

Figure 3 revealed the height distribution of trees in all selected PAs. Trees height distribution falls mainly within the height class of 5– 40m. This structural pattern is similar to that obtained by Adenıjı et al. (2021) in the Southern Guinea savanna, which is typical of uneven-aged, naturally regenerating savanna woodlands under moderate disturbance. The presence of a few large trees across the study sites shows reduced structural complexity, carbon storage, and ecosystem resilience. Therefore, safeguarding large trees and facilitating the transition of mid-sized classes into the upper canopy can support structural complexity, biodiversity conservation, and ecosystem carbon accumulation.

CONCLUSION

This study assessed tree species composition and distribution patterns across five protected areas in the northern Nigerian savanna ecosystem. The findings reveal that vegetation patterns are influenced by environmental conditions, disturbance regimes, and conservation practices. A total of 71 species from 22 families indicates considerable floristic diversity, although species distribution was uneven, with many occurring at low densities; reflecting the heterogeneous nature of savanna ecosystems. Structural variations among sites were evident, with significant differences in tree density and height suggesting variations in regeneration processes and disturbance intensity, while similar basal area and DBH indicate comparable size-class structures.

The inverted-J diameter distribution across sites confirms active regeneration but also indicates limited recruitment into larger size classes, with implications for long-term biomass accumulation and ecosystem resilience. The dominance of Combretaceae and Fabaceae highlights their adaptive capacity and ecological importance, while large-stem species such as *Adansonia digitata* contribute significantly to biomass storage. Effective conservation strategies should therefore focus on reducing disturbance pressures, protecting large trees, and promoting the transition of mid-sized trees into upper canopy classes to enhance biodiversity conservation, carbon storage, and overall ecosystem stability.

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