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Structure, Alpha and Beta Diversity of Natural Forest Areas in Eco-Zones of Taraba State, Nigeria

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Abstract

To understand the health conditions and growth patterns of forest estate for environmental resilience and climate change mitigation, assessment of structure and species diversity is paramount. This study aimed at assessing the structure, alpha, and beta diversities of tree species in three ecological zones in Taraba, Nigeria for management purposes. In recent time, no research has been reported on the structure and beta diversity of the study areas. A systematic sampling design was used for data collection. Five sample plots of 50×50 m were laid in each of the six natural forest areas. The result showed a mean DBH (42.5 cm) and a tree height (15.0 m) from the forests. The forests have a structure of an inverse "J-shape," which is typical of natural forests in the tropics. The southern Guinea savanna zone had the highest mean Shannon-Weiner diversity index (2.8). The least beta diversity index (0.02) was between Baissa and Jen Gininya forest areas. Baissa and Bakin Dutse Protected Forest Areas (PFAs) contained 76.5% of the tree species. There is a high chance of all tree species to be found in these 2 forest areas. Proximity to a location influences how similar two tree species are, according to the least beta diversity index (0.02) recorded. The Federal Government's method of management for the forest, known as Gashaka Gumti National Park, may be responsible for the high beta diversity index in the Montane ecozone. Therefore, it should be strongly encouraged to practice strict oversight of natural areas, as their contributions to reducing climate change in Taraba State, Nigeria, cannot be overstated.

Key Words: diversity, ecological zone, forest ecosystems, natural areas, sustainable, tree species

Introduction

Tree species composition may vary even between two close or similar geographical areas due to different factors (human and natural factors). To assess the biodiversity of any geographical area, different diversity indices have been used (Sanders and Rahbek 2012; Hussain and Perveen 2015; Naveed and Erwin 2015; Turkis and Elmas 2018).

Often, biodiversity assessment depends on the alpha diversity index, since the indices (species diversity, richness, and evenness) are the key parameters used for the study of species diversity in ecology and forest ecosystems. Generally, in realistic conservation practises in Nigeria, beta diversity indices are seldom used when it comes to assessments of species diversity in forest ecosystems. The common alpha diversity indices used by most researchers include Shannon-Wiener (S-Weiner) diversity, Margalef, Evenness, and Chao Indices (Meer and Tella 2018; Sevda and Emire

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2018; Amonum et al. 2019a, 2019b; Bunde et al. 2019; Chenge et al. 2019). Quantifying the uncertainty in predicting species identity of an individual tree is mostly achieved by S-Weiner's diversity index (Natural Resources Biometrics (NRB) 2021). If a community has low diversity (dominated by one species), the uncertainty of prediction is low; a randomly sampled species is most likely going to be the dominant species, while if diversity is high, uncertainty is high.

Beta diversity measures similarity or dissimilarity of two or more locations of flora or fauna species in relation to an area. It quantifies the changes between diverse species within and between two or more locations in the same ecological zone or outside. Thus, a high index of beta diversity implies low similarity (dissimilarity), while a low index implies a high similarity between ecosystems within or between locations (NRB 2021).

High index of beta diversity could be due to differences in species composition variance, mostly associating with environmental gradients, elevations or topography majorly due to modification on species pool sizes; geographical variation in composition of species result to heterogeneity of habitat with increase in grain-size (Kraft et al. 2011). Beta diversity measures species variance between distinct forest areas or ecosystems situated in similar or dissimilar locations. The scales that quantify similarity or dissimilarity (beta-diversity) of species diversity range from zero to one (0-1); the higher the index, the higher the variations; and the lower the index, the higher the species similarity (Koleff et al. 2003).

Understanding species similarity or dissimilarity is paramount; and this serves as an indispensable tool for describing distinct ecological stages and modelling the functions and changes of forested areas (Singh et al. 2016; Chenge et al. 2019). The characteristics of a site's ecosystem, the stage of species regrowth, and the composition and abundance of trees all play a significant role in how a forest is structured. Assessment of alpha or beta species diversity, forest composition, and structure helps our understanding of the health status of any forest stand, regeneration needs, and species diversity for conservation management (Mishra et al. 2013). There have been few, if any, studies on the beta diversity or species composition variation between two or more forested areas within or between the same eco-zone in Taraba state, Nigeria, in the study area.

In recent time, there have been no published findings on a comprehensive study on the alpha and beta diversity of the study area, and there is a dearth of knowledge on the forest structure (growth characteristics) of the natural forest areas for management decisions (policy making). This study aimed at assessing the growth characteristics (structure) and diversity (alpha and beta) of tree species in the natural forest areas in distinct ecological zones of Taraba state, Nigeria, for sustainable forest management. Better knowledge of biodiversity status and their distribution are paramount for managing and adaption to foreign aliens, land-use changes and forest degradation; and increasing temperatures associated with climate change (Verosmarty et al. 2010; Vilmi et al. 2017).

Materials and Methods

Location of the study area

The study was carried out on six natural forest areas, namely: Gashaka Gumti National Park (GGNP), Ngel Nyaki natural forest area (PFA), Jen Giginya PFA, Baissa PFA, Bakin Dutse PFA, and Wasaji PFA. Gashaka Gumti National Park (GGNP) is one of the natural areas that have an area of approximately 6,700 km^2. It lies between Latitudes 60.917° and 110.217° North and Longitudes 80.217° and 120.183° East. Ngel Nyaki natural forest area (PFA) is situated at the Mambilla Plateau; it comprises approximately 46 km^2 of impressive sub Montane to mid altitude forest, lying between 1,400 to 1,500 m (Chapman and Chapman 2001). Jen Giginya PFA has 39.64 km^2. Baissa PFA is a lowland forest lying at 230 m above sea level on the Donga River, between Latitudes 7.233° and 10.25° North and Longitudes 10.633° and 13.517° East. The area is about 112.79 km^2 (Chapman and Chapman 2001). Wasaji PFA covers an estimated land area of 64.75 km^2. Bakin Dutse PFA has a land coverage of about 49.69 km^2 (Bunde et al. 2019).

All the forest areas are situated within the Taraba region of Nigeria. The state is situated between Latitudes 60.577° and 90.981° N and Longitudes 90.874° and 120.664° E. It occupies approximately 54, 473 km^2 of land mass; there are three distinct eco-zones: the southern guinea savanna located in the south-western part of the state, the northern guinea savanna in the northeast, and the montane forest in the southeast.

The study area has two distinct seasons: dry and rainy. The rainy period has an average period from the month of April to October; with annual mean rainfall range between one thousand and fifty eight millimeters (1,058 mm) in the North to one thousand three hundred millimeters (1,300 mm) in the South. The dry period lasts between the months of November and March. The relative humidity is as low as about fifteen percent (15%), with an annual mean temperature of about 28°C, with maximum temperatures ranging from 30°C to 35°C; the minimum temperatures range from 15°C to 23°C.

Data collection

The study area was stratified into distinct ecological zones (Northern Guinea Savanna, Southern Guinea Savanna, and Montane Forest); from each eco-zone, two uneven forest (natural) areas were purposefully sampled (based on ease of accessibility and cost-effectiveness), giving a total of six natural forest areas, namely: Bakin Dutse PFA, Baissa PFA, GGNP, Jen Giginya PFA, Ngel Nyaki PFA, and Wasaji PFAs.

A systematic sampling design was used. Prior to the field survey, QGIS (version 3.22.1) was used to plot coordinates on a map of each natural forest area. R programme software (version 4.1.0) was used to generate random numbers (between the lowest and highest coordinates plotted on QGIS). Five coordinates on each map (of the forest areas) were randomly picked to make accessing the sampling plots as simple and as quick as possible (FAO 2020). The five coordinates selected from each PFA were marked and transferred to a *Garmin e-Trex* 10 GPS for tracking on the field (Chenge and Osho 2018). On the field, each coordinate in the study area was traced, and temporary sample plots (TSP) of size 50×50 m were systematic laid exactly on the point of each coordinate, for trees assessment. Five TSP were laid in each natural area, giving a total of thirty TSP for the six natural forest areas.

Woody tree species were identified in each TSP, and the number of individuals was counted and recorded to determine species occurrence, diversity, and abundance. Using field identification aids, tree species were recognized on the spot (Neelo et al. 2015). All live trees with a diameter at breast height (Dbh) of ≥10 cm in all the TSP were identified, their Dbh and tree height (H) were measured. The Dbh of each tree was measured to the nearest 0.1 cm at 1.3 m above the ground, and the overall tree height was measured to the nearest 0.1 m (Ogana et al. 2020). DBH and H were measured using a diameter tape and a Haga altimeter, respectively (Dau et al. 2016). For leaning trees, the measurement points were obtained from the uphill sides of the trees and on the inside of the lean (Zuhaidi 2009). The measurement was taken at the sound point on the stem above the abnormality for trees with deformations of 1.3 m. To avoid measurement errors and readings, loose bark, climbers, and epiphytes were lifted above the measuring tape during the measurement (Dau and Chenge 2016).

Statistical analyses

The structure of the natural forest area was analysed using descriptive statistics (mean, standard deviation, minimum, maximum, standard error) (Amonum et al. 2019; Chenge et al. 2019). Stem diameter and tree height distributions were plotted using pivot tables on an Excel spreadsheet (2010 version) (Hammer et al. 2001), and assessed to ascertain the management effect on the tree stand structure of the study area under the protection of the Taraba State Government, Nigeria, for policy implications. A diversity index is a numerical measure of the number of distinct types (such as species) present in a community, as well as the evolutionary relationships between the individuals distributed throughout those types, such as richness, divergence, and evenness (Tucker et al. 2017). These are numerical representations of biodiversity in a variety of dimensions (richness, evenness, and dominance).

Shannon-Weiner diversity (H'), species evenness, species richness, and rarefaction indices were used to assess alpha diversity, while beta diversity indices (Simpson and Sørensen indices) (Schroeder and Jenkins 2018) were used to assess the similarity or dissimilarity of the composition, abundance, and distribution of tree species in the area. Beta diversity (b) is important to ecology and biogeography because it indicates the changes in species composition that occur across a landscape. It is also used to assess the heterogeneity of local communities (Heino et al. 2012). The Sørensen index and principal component analysis of the study area were assessed using the Paleontological Statistics software package (PAST 4.03 2001) as described in the handbook (Hammer et al. 2001). A principal component analysis of the forest areas was carried out to ascertain the natural forest area (s) with the highest number of tree species in the study area.

Shannon-weiner index (H')

The Shannon index quantifies population diversity while assuming that all species are represented in a sample and that they are sampled at random. As the community's richness and evenness increase, the Shannon index rises. The Shannon-Weiner (1949) diversity index was used to assess species diversity in the research area; the index varies based on the number of species present. When there are more species, the number is higher, suggesting greater diversity. Following Kent and Coker (1992), Magurran (2004), and Chenge et al. (2019), the Shannon-Weiner Index (H') was estimated, thus:

$$H = -\sum_{i=1}^{s} p_i \, ln \, p_i \qquad \textit{Equation} \qquad [1]$$

s is the total number of species, p_i is the proportion of individuals in the ith species, and ln is the natural logarithm.

Species evenness index

The Pielou evenness index is a number that ranges from 0 to 1 (Pielou 1969). When there is a dominating phenomenon, it is 0; when the distribution of individuals among species is homogeneous, it is 1. The Pielou evenness index was calculated as well, with the following formula (Adekunle et al. 2013):

$$E = \frac{H}{ln S} \qquad \textit{Equation} \qquad [2]$$

E is Pielou Evenness Index, H is the Shannon–Wiener function and S is the total number of species.

Species richness

The approach provided by Margalef (1951; 1968) and followed by Speller berg (1991) and Magurran (2004), as utilized by Oluwatos and Jimoh (2016), was employed to calculate species richness:

$$D = \frac{S}{\sqrt{N}} \qquad \textit{Equation} \qquad [3]$$

D is species richness index (Margalef index), S is the total number of species and N is the total number of individuals.

Simpson diversity index

This index is use to evaluate the degree of concentration when individuals are divided into groups. The measure is equal to the probability that two species chosen at random from the set of interest represent the same type (Simpson, 1949); i.e., the Simpson's Diversity Index is a measure of diversity that takes into account both the number of species present and their relative abundance. As species richness and evenness rise, so does diversity. This index ranges from 1 to 0, with 1 representing infinite diversity and 0 representing no diversity, thus:

$$SI = \frac{1}{\sum_{i=1}^{R} p_i^2} \qquad \textit{Equation} \qquad [4]$$

SI is Simpson diversity index; p_i is the proportional abundance for each species and R is the total number of species in the sample.

Rarefaction diversity index

The assessment of species richness for a given number of individual samples is possible using rarefaction, which is based on the construction of so-called rarefaction curves. The method does not take into consideration specific taxa. It looks at how many species are present in a specific sample, but not how many species are present across samples.

$$fn = K\left(\frac{N}{n}\right)^{-1} \sum_{i=1}^{k} \left(\frac{N-N_i}{n}\right) \qquad \textit{Equation} \qquad [5]$$

fn is rarefaction, N is total number of items, K is total number of groups, N_i is the number of items in group i (i is 1, ..., K).

The chao index is suited for abundance data, assumes a Poisson distribution for the number of organisms identified for a taxon and corrects for variance (Chao et al. 2005). It is useful for data sets with a high proportion of low-abundance calls, which is frequently the case with microorganisms. Thus, there was no need to estimate the chao index since it's mostly useful with microorganisms and assumes a Poisson distribution.

Results

Forest structure of natural forests in taraba state eco-zones, Nigeria

The result of this finding on the growth variables of trees in the area is presented in Table 1. Based on the result, the southern Guinea ecological zone had the highest mean DBH of 43.27 cm and 42.41 cm from the Baissa and Wasaji forest areas, respectively. Forest areas in the Montane and Northern Guinea ecological zones had a mean DBH size that ranged between 35.83 and 37.49 cm. The study areas had a minimum DBH size of 10 cm, while a maximum DBH of 420 cm and 396 cm were recorded in the northern Guinea (Jen Gininya Forest Area) and Montane (Ngel Nyaki Forest Area) ecological zones, respectively.

Mean tree height of 15.98 m was recorded in montane (Gashaka Gumti NP) eco-zone. The least mean tree height of 10.96 m was recorded in northern guinea eco-zone. All the tree stands in the study area had a narrow range (2.00-3.00 m) of minimum total height. The maximum tree height of 115 m (Gashaka Gumti National Park) and 73 m (Ngel Nyaki forest area) were from Montane eco-zone, while 35 m tree height was the least from northern guinea.

The diameter distribution trend of the study areas indicates an inverse "J-shape" pattern, which is typical of nat-

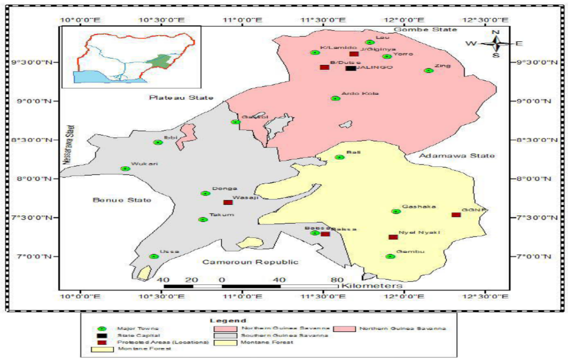

Fig. 1. Map of the six natural forest reserves in eco-zones of Taraba state, Nigeria. Source: Meer et al. (2018).

Table 1. Descriptive statistics of tree stands structure of natural forest areas in eco-zones of Taraba state, Nigeria

Eco-zones	Natural forest	Variables	n	Std. dev	C.V	Min	Mean	Max	S.E
Montane	Gashaka Gumti N.P	Dbh (cm)	392	35.86	0.09	10.00	36.43	222.00	0.30
	Ngel Nyaki PFA		1,449	43.64	0.03	10.00	36.84	396.00	0.17
Northern G.S	Bakin Dutse PFA		287	38.05	0.13	10.00	35.83	230.00	0.36
	Jen Gininya PFA		361	43.74	0.12	10.00	37.49	420.00	0.35
Southern G.S	Baissa PFA		730	43.38	0.06	10.00	43.27	325.00	0.24
	Wasaji PFA		539	44.40	0.08	10.00	41.41	262.00	0.29
Montane	Gashaka Gumti N.P	Th (m)	392	12.35	0.03	2.50	15.98	115.00	0.18
	Ngel Nyaki PFA		1,449	10.42	0.01	2.00	12.49	73.00	0.08
Northern G.S	Bakin Dutse PFA		287	6.47	0.02	2.00	11.10	35.00	0.15
	Jen Gininya PFA		361	5.80	0.02	2.50	10.96	35.00	0.13
Southern G.S	Baissa PFA		730	10.15	0.01	3.00	15.31	50.00	0.12
	Wasaji PFA		539	10.72	0.02	0.20	14.57	50.00	0.14
Montane	Gashaka Gumti N.P	B.A (m^2)	392	0.46	0.00	0.00	0.20	3.8708	0.03
	Ngel Nyaki PFA		1,449	0.77	0.00	0.00	0.26	12.3163	0.02
Northern G.S	Bakin Dutse PFA		287	0.51	0.00	0.00	0.21	4.1548	0.04
	Jen Gininya PFA		361	0.91	0.00	0.00	0.26	13.8544	0.05
Southern G.S	Baissa PFA		730	0.67	0.00	0.00	0.29	8.2958	0.03
	Wasaji PFA		539	0.65	0.00	0.00	0.29	5.3913	0.03

G.S, Guinea savanna; N.P, National park; PFA, forest natural area; C.V, coefficient of variation; S.E, standard error; n, sample (s) Dbh, Diameter at breast height; Th, tree height; B.A, basal area.

ural forests in the tropics (Fig. 1). One thousand eight hundred and two (1,802) trees had a diameter size less than 55 cm, of which the montane eco-zone had 1,089 trees in the lower DBH distribution, while the northern eco-zone had 245 individual trees in the same distribution. Two hundred and twenty two trees were recorded with Dbh distribution between 55 to 105 cm; 66 individual trees were between 105 to 155 cm class, 28 trees were found in the class of 155 to 205 cm while few trees had Dbh size above 205 cm. Tree stands in montane eco-zone had a high stock density and better structure with trees found in all Dbh distribution class.

Result on tree height distribution in the areas showed that, most of the trees (1,369) had tree height at lower class distribution (< 10.2 m). Six hundred and twenty-two (622) individual trees were identified in the middle class height distribution (10.2 to 30.2 m). However, few individual

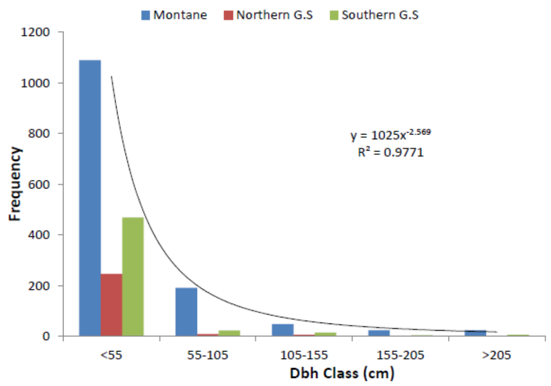

Fig. 2. Diameter distribution class of tree stands of natural forest areas in eco-zones of Taraba state, Nigeria.

trees were found in the upper-class height distribution (Fig. 2). This showed that forest areas in montane eco-zones had trees with total heights that spread across all the class distributions in the study area. Thus, forest areas in the southern Guinea savanna zone of the study area had a better tree height distribution (height structure).

Alpha and beta diversity of natural forests in taraba state eco-zones, Nigeria

A total number of 3,758 individual trees were recorded from 82 species, 73 genera, and 34 families were identified from the area. The southern Guinea savanna zone had the highest mean Shannon-Weiner index of 2.76, followed by 2.59 Shannon-Weiner indexes in the montane ecozone. The Northern Guinea Savanna Zone had a 2.48 Shannon-Weiner index. Baissa forest area had the highest species dominance index of 0.1401 (from southern Guinea savanna), followed by 0.1308 in Gashaka Gumti N.P. (Montane eco-zone), while Wasaji natural area had the least species dominance index of 0.0539 (from southern Guinea savanna).

Tree species evenness distribution among the eco-zones was closely related. A mean evenness index of 0.57 was recorded in southern guinea savanna zone, 0.56 from northern guinea zone and Montane zone had evenness distribution index of 0.522. A tree species richness index of 4.52 was the highest recorded in the Montane eco-zone, with 4.24 and 3.54 indexes from the Southern and Northern Guinea savanna eco-zones, respectively (Table 2).

The result of diversity from the study area indicates high similarity between Baissa and Wasaji PFA which had 0.12, Baissa and Bakin Dutse (0.14), Wasaji and Bakin dutse

Table 2. Tree species alpha diversity indices of natural forest areas in eco-zones of Taraba state, Nigeria

Indices	Southern G.S		Montane		Northern G.S	
	Baissa PFA	Wasaji PFA	GGNP	Ngel Nyaki PFA	Bakin Dutse PFA	Jen Gininya PFA
Taxa_S	25	32	14	51	19	24
Individuals	730	539	392	1,449	287	361
Simpson index_D	0.1401	0.0539	0.1308	0.08121	0.1036	0.1255
Shannon_H	2.446	3.078	2.241	2.945	2.495	2.459
Evenness_e^H/S	0.4615	0.6787	0.6714	0.3727	0.6378	0.487
Richness (Margalef)	3.64	4.929	2.177	6.869	3.181	3.906

G.S, Guinea savanna; N.P, National park; PFA, forest natural area.

PFAs had 0.25 beta diversity index (Table 3). The high beta diversity (Sørensen) index between Ngel Nyaki PFA and Gashaka Gumti NP was 0.57, indicating dissimilarity between the two ecosystems. Ngel Nyaki and Bakin Dutse PFAs had a 0.46 beta diversity index, while Baissa and Ngel Nyaki PFAs had a 0.34 beta diversity index. The result of the Simpson index of the study area indicates that all the PFA had a low value of the Simpson index, which ranged from 0.05 to 0.14 (Table 3). This implies that there is a low probability that two randomly sampled individuals belongs to different species.

Principal component analysis was used to visualize species distribution and overlap, the result showed that (Fig. 3), Baissa and Bakin dutse PFSs accounted for 76.5% of tree species in the study area i.e. this two PFAs housing 76.5% of the tree species identified from the six PFAs. Gashaka gumti NP accounted for 7.2% of the tree species, Jen gininya PFA had 3.2%, and Ngel nyaki and Wasaji PFAs accounted for 2.4% and 0.6%, respectively.

The species diversity indices of varied natural areas were compared using a correlation matrix (Table 4). The results indicate no significant difference ($p=0.05$) between the diversity indices of Baissa, Bakin Dutse, Gashaka Gumti, Ngel nyaki, and Jen Gininyi natural forest areas, while variation exists between Gashaka Gumti natural forest, Jen Gininya, and Ngel nyaki natural forest areas.

Discussion

Forest structure of the study area

The highest mean dbh (42.48 cm) and mean tree height (14.99 m) were recorded in the southern Guinea savanna eco-zone, while the northern Guinea area had the least mean dbh (36.75 cm) and mean tree height (11.03 m). The highest mean B.A. of 0.2900 m^2 was recorded in the southern Guinea savanna of the study area (Table 1). The mean B.A ranged from 0.2000 to 0.2900 m^2 ha^{-1}. This indicates that the study areas have occupied a low cross-sectional area at the ground level (base) of the trees. It is an indicator that the tree stands were small in size due to the frequent felling of trees with long stems for timber purposes. However, the basal area is high if compared to the basal area recorded in other guinea savannas of Nigeria (Chukwu et al. 2018; Amonum and Japheth 2019; Vange et al. 2021).

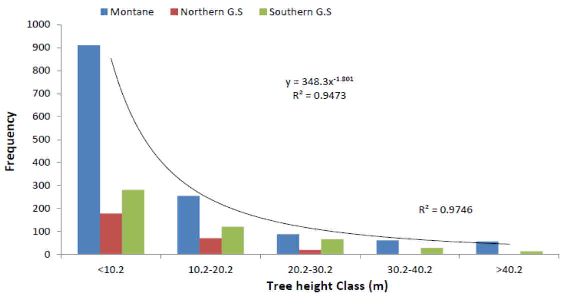

Fig. 3. Tree heights distribution class of tree stands of natural forest areas in eco-zones of Taraba state, Nigeria.

Table 3. Beta (sørensenand simpson) diversity indices of natural forests in vary eco-zones of Taraba state, Nigeria

Natural forest	Baissa PFA	Bakin Dutse PFA	Gashaka Gumti N.P	Jen Gininya PFA	Ngel Nyaki PFA	Wasaji PFA
Baissa PFA	-					
Bakin Dutse PFA	0.14	-				
Gashaka Gumti N.P	0.28	0.15	-			
Jen Gininya PFA	0.02	0.12	0.26	-		
Ngel Nyaki PFA	0.34	0.46	0.57	0.36	-	
Wasaji PFA	0.12	0.25	0.39	0.14	0.23	-
Index	Southern G.S		Montane		Northern G.S	
	Baissa PFA	Wasaji PFA	GGNP	Ngel Nyaki PFA	Bakin Dutse PFA	Jen Gininya PFA
Simpson index_D	0.14	0.05	0.13	0.08	0.10	0.13

G.S, Guinea savanna; N.P, National park; PFA, forest natural area.

Table 4. Correlation matrix of alpha diversity index of natural forest areas in eco-zones of Taraba state, Nigeria

Natural forest areas	Baissa	Bakin Dutse	Gashaka Gumti	Jen Gininya	Wasaji	Ngel Nyaki
Baissa	-					
Bakin Dutse	0.4162[a]	-				
Gashaka Gumti N.P	0.354[a]	0.114[a]	-			
Jen Gininya	0.1034[a]	0.478[a]	0.0212[b]	-		
Wasaji	0.699[a]	0.6185[a]	0.1978	0.1799[a]	-	
Ngel Nyaki	0.2405[a]	0.8842[a]	0.0482[b]	0.4702[a]	0.4162[a]	-

G.S, Guinea savanna; N.P, National park; PFA, forest natural area.
Means on the same column (between forests) with different superscript are statistically significant at 0.05 ($p < 0.05$).

The observed "inverse J" diameter distribution (stem frequencies decreased with increased Dbh) is typical of tropical forests. This indicates better development and regeneration of tree stands in the area. Natural regeneration is dependent on the availability of mother trees, favourable conditions, and fruiting patterns, as confirmed by Mohd (2012). The structure in the area indicates a high proportion of trees with a small diameter; this revealed high regeneration and recruitment, which could be due to forest exploitation as reported by Bunde et al. (2015a), who reported that the lack of trees in the middle diameter classes of forest reserves was due to the harvesting of trees for different purposes as evidenced by numerous stumps in the areas. From this finding, when regeneration occurs over a long period of time (with minimal or no disturbance), the frequency of trees would reduce from a low to a high DBH distribution. Thus, this will require sustainable management of the forest area. This result agreed with the report of Neelo et al. (2015), who reported that the status of tree populations can be revealed by way of size class distribution analyses.

Tree height distributions indicate a large population of individual tree stands in the lower height stratum (10.0 m) and a small number of tree stands in the upper (>40 m) height stratum. This could be due to the status of DBH class distributions as revealed by this study. It could also be due to competition for sunlight and open space for stem and crown diameter expansion. This is in line with the findings of Vange et al. (2017) and Amonum and Japheth (2019). It could also be due to the presence of a few individual tree stands with dominant heights over a larger population of trees in the area. The tree height distribution from this study had a similar pattern to that of the Shasha natural forest in Osun State, Nigeria, as reported by Chenge et al. (2019).

The number of horizontal layers, the height and density of each stratum, and specific characteristics (tree hollows) could make the area a good habitat structure (for bird species), which is an emergent property of vegetation. Structures alter the microclimate (e.g., shadowing lowers surface temperatures) and provide substrates for breeding, sheltering, feeding, predator avoidance, and other activities (Brown et al. 2021). In natural ecosystems, the organization of the vegetation determines the structure of the animal community (Louy et al. 2011). The composition of animal communities in agricultural systems is influenced by vegetation structure (Brown et al. 2021).

Alpha and beta diversity of the study area

Alpha diversity increased in the southern guinea savanna of the study area, but declined in the northern guinea savanna. This implies a greater abundance of tree species in the southern zone than in the northern zone of the area. The abundance of rainfall, average temperature, humidity, and sunshine could be the reason for the high diversity in the southern Guinea savanna. Suitable environmental factors (such as rainfall, temperature, wind, sunlight, and soil nutrients, among others) tend to increase the growth and development of plant species in a place. When compared to the Southern and Northern ecosystems in the research area, Shannon diversity in the Monatane zone was at its peak, which is in line with Grytnes (2003). According to Naveed and Erwin's (2015) findings in the Swat Woodlands, Pakistan, the Shannon Weiner diversity of vascular plants was at its peak at low (1,600 m) and medium (2,700 m) altitudes and at its lowest at the uppermost woodland zone (3,100 m). In the majority of the elevation gradient, it appears that the abundance of various tree species influences alpha diversity as reported by Naveed and Erwin (2015). Ohlemüller and Wilson (2000) found no link between herbaceous species richness (ground flora) and elevation in research from New Zealand.

In a tropical rainforest in Bangladesh, Nur et al. (2016) reported a Shannon-Weiner index of 3.49. When compared to the semi-evergreen forests of the Indian Eastern and Western Ghats, the tree species richness from this finding in Taraba State, Nigeria, recorded the highest number of 51 tree species and the lowest number of 14 species, which is regarded as low. Moksia et al. (2019) reported 99 species belonging to 62 genera in 32 families in two woodlands in the Sudano-Sahelian zones of North Cameroon. The number of species was distributed among the two zones explored.

Baissa and Bakin-dutse forest areas were the two principal PFAs that accounted for 76.5% of tree species found in the study; this implied that, 76.5% of all the tree species would be found in the two principal areas (Baissa and Bakin-Dutse) in Taraba state. These two natural areas house about 75% of all the tree species; therefore, the Baissa Forest area could be upgraded to a national forest reserve, botanical garden, or tree seed bank, where threatened and economically important tree species can be conserved for sustainable forest management and genetic conservation. The result of this finding showed that Gashaka Gumti, as a national park, accounted for only 7.2% of the tree species in the state. One would expect a high occurrence of trees and tree species diversity in Gashaka Gumti as a major national park in the study area, but the reverse is the situation as revealed by this finding.

The result on the beta diversity index (Simpson index) indicates that all the PFAs had low values of the Simpson index, which ranged from 0.05 to 0.14. This implies that there is a low probability that two randomly sampled individuals belongs to different species in the area. Beta diversity is essential for understanding ecosystem trends, biodiversity protection, and ecosystem management. Using the dissimilarity index, a value of 0 means that the communities have exactly the same species composition, and a value of 1 means they don't share any species.

The beta diversity index (0.02) between Baissa (Southern guinea savanna) and Jen Gininya (Northern guinea savanna) was an indication that the two areas have high similarity of tree species in the area. The similarity could also be as a result of low anthropogenic activities on tree species abundance, or/and also, elevation gradient of the forests. The southern and northern Guinea savannas of the state have similar characteristics. Ngel Nyaki PFA and Gashaka Gumti NP had a beta diversity index of 0.57, indicating an optimal beta index, i.e., both locations share optimally similar species, i.e., both sites are relatively similar. The two forest areas are situated close to each other in the same ecological zone (Montane). This finding implies that a low beta index could be influenced by location closeness. This result agreed with the finding of Condit et al. (2002), who reported that the similarity of tree species between plots (or locations) decreases as the distance between the plots (or locations) increases.

The high beta index value (0.57) of beta diversity could be due to the strictness adopted by the Federal Government to conserve the forest, which is gazetted as Gashaka Gumti NP, while Ngel Nyaki PFA is managed by an NGO (Nigerian Montane Forest Project, Christchurch, New Zealand) for efficient conservation. Therefore, management type, environmental variation, and low anthropogenic factors could be the major influences on high beta index diversity patterns in the montane eco-zone in the area.

A low beta diversity index (i.e., high similarity) was recorded between Jen-Gininya and Bakin-Dutse PFAs. This could be due to the closeness of the two forest areas located in the same ecological zone (the northern Guinea savanna). There is a high chance of having similar tree species when two or more forest areas are close, due to the migration of genetic traits dispersed by wind and birds. This finding is in line with the reports of Alahuhta et al. (2017) and Astorga et al. (2014), who reported that heterogeneity in distant locations influences beta diversity by providing a greater variety of niches or species. Species diversity in term of similarity or dissimilarity indicates the geographical variation of species composition among habitats (Anderson et al. 2011); and is importantly related to two processes (Baselga 2010): species replacement and nestedness (Alahuhta et al. 2017).

The value of Simpson index in the range of 0.10 to 0.99 had been reported for temperate forests (Turkis and Elmas

2018), Simpson index ranged of 0.47 to 0.86 in Kavakli Nature Reserve Area; and 0.55 to 0.84 in Citdere Nature Reserve Areas in Yenice Forests (Turkis and Elmas 2018). The value ranged from 0.8 to 2.3 in particular woods of the Kumaun Himalaya (Srivastava 2002). In the Kavakli and Citdere areas, an increase in species richness leads to an increase in species diversity. Temperate forests are diverse ecosystems with a lot of variation (Dudley 1992). In comparison to coniferous forests, broadleaved forests have a more diverse vascular understory (Barbier et al. 2008).

The correlation matrix indicated that there was no significant correlation between the forest ecosystems in the Montane eco-zone but that there was in the Northern and Southern eco-zones. According to Naveed and Erwin, who use polynomial regression models, total species richness followed a unimodal pattern along the elevation gradient, where tree species richness initially decreased until 2200 m, then increased, and then decreased again from 2800 m onward (Naveed and Erwin 2015). Ren et al. (2006) reported that, although the total richness of vascular plant species did not exhibit a linear elevation trend, species groups with various ecological characteristics did exhibit significant elevation tendencies. Herbs in New Zealand (Ohlemüller and Wilson 2000), trees and shrubs in South Africa (O' Brien 1993), and climbers in Mexico all change their growth forms in response to elevation (Vazquez and Givnish 1998).

An asymptotic shape or relationship was found between the number of species and occurrence, as indicated by the rarefaction curve in this study. The rarefaction curve increases relatively fast at the initiating stage and much more slowly in later samples as increasingly rare species are identified. The rarefaction curve helps in understanding diversity at higher taxonomic levels (Bunge and Fitzpatrick 1993). This method had been adopted to determine level of diversity in research many years before assessed individual species rarefaction as reported by Gotelli and Colwell (2001).

Conclusion

In the study area's southern Guinea savanna ecozone, the mean Dbh (42.5 cm) and mean tree height (15.0 m) of trees were measured. The PFAs' diameter distribution structure displayed an inverse "J-shape" pattern that is typical of tropical natural forests. As more and more rare species were added, the rarefaction curve rose relatively quickly at first and then much more slowly in later samples. Baissa and Bakin Dutse PFAs, contained 76.5% of the tree species. This finding reveals that proximity to a location influences how similar two tree species are, according to the least beta diversity index (0.02). The Federal Government's method of management for the forest, known as Gashaka Gumti NP, may be responsible for the high beta diversity index in the Montane ecozone. Therefore, in the study area, it should be strongly encouraged to practice sustainable forest management and strict oversight of natural areas, as their contributions to reducing climate change in Taraba State, Nigeria, cannot be overstated. Thus, this study provides baseline knowledge and evidence that geographically detailed analyses of the diversity of the area could be useful in conservation management or decision-making that will ensure the sustainability of tree species.

References

Alahuhta J, Kosten S, Akasaka M, Auderset D, Azzella MM, Bolpagni R, Bove CP, Chambers PA, Chappuis E, Clayton J, de Winton M, Ecke F, Gacia E, Gecheva G, Grillas P, Hauxwell J, Hellsten S, Hjort J, Hoyer MV, Ilg C, Kolada A, Kuoppala M, Lauridsen T, Li EH, Lukács BA, Mjelde M, Mikulyuk A, Mormul RP, Nishihiro J, Oertli B, Rhazi L, Rhazi M, Sass L, Schranz C, Søndergaard M, Yamanouchi T, Yu Q, Wang H, Willby N, Zhang XK, Heino J. 2017. Global variation in the beta diversity of lake macrophytes is driven by environmental heterogeneity rather than latitude. J Biogeogr 44: 1758-1769.

Amonum JI, Ikyaagba ET, Dawaki SA. 2019. Flora Diversity and Distribution in Falgore Game Reserve, Kano State, Nigeria. J Appl Life Sci Int 20: 1-13.

Amonum JI, Japheth HD. 2019. Application of Developed Crown-Bole Diameter Model to Stand Density and Stock Control on Open Grown Trees of Prosopis Africana (Guill & Perr) Taub. Appl Trop Agric 24: 32-39.

Amonum JI, Jonathan BA, Japheth HD. 2019. Structure and Diversity of Tree Species at the College of Forestry and Fisheries, University of Agriculture Makurdi, Benue State, Nigeria. Int J For Hortic 5: 20-27.

Anderson MJ, Crist TO, Chase JM, Vellend M, Inouye BD, Freestone AL, Sanders NJ, Cornell HV, Comita LS, Davies KF, Harrison SP, Kraft NJ, Stegen JC, Swenson NG. 2011. Navigating the multiple meanings of β diversity: a roadmap for the practicing ecologist. Ecol Lett 14: 19-28.

Barbier S, Gosselin F, Balandier P. 2008. Influence of tree species on understory vegetation diversity and mechanisms involved- a critical review for temperate and boreal forests. For Ecol Manag 254: 1-15.

Baselga A. 2010. Partitioning the turnover and nestedness components of beta diversity. Glob Ecol Biogeogr 19: 134-143.

Brako L, Zarucchi JL. 1993. Catalogue of the Flowering Plants and Gymnosperms of Peru. Missouri Botanical Garden, St. Louis, MO.

Brown J, Barton P, Cunningham SA. 2021. Chapter four - how bioregional history could shape the future of agriculture. In: Advances in Ecological Research (Bohan DA, Vanbergen AJ, eds). Academic Press, London, pp 149-189.

Bunde MB, Iyiola T, Saka MG, Isaac N, Solomon G, Hezel C. 2019. Sustainability, Population and Structure of Woody Species Composition of Taraba State Forests. Asian J Res Agric For 2: 1-13.

Bunge J, Fitzpatrick M. 1993. Estimating the Number of Species: A Review. J Am Stat Assoc 88: 364-373.

Canback Dangel. 2008. Canback Global Income Distribution Database (C-GIDD). https://web.archive.org/web/20120216083958/https://www.cgidd.com/. Accessed 26 Jan 2022.

Chao A, Chazdon RL, Colwell RK, Shen TJ. 2005. A new statistical approach for assessing similarity of species composition with incidence and abundance data. Ecol Lett 8: 148-159.

Chapman JD, Chapman HM. 2001. The Forests of Taraba and Adamawa States, Nigeria: An Ecological Account and Plant Species Checklist. University of Canterbury, Christchurch, pp 1-50.

Chenge IB, Chukwu O, Japheth HD, Yager GO. 2019. Tree species diversity and forest structure of a natural forest in Shasha Forest Reserve, Nigeria. In: the 41st Annual Conference of the Forestry Association of Nigeria (FAN); Abuja, Nigeria; Oct 7, 2019.

Chukwu O, Dau JH, Ogundipe OC, Wali MD. 2018. Crown ratio assessment for Prosopis africana (Guill. and Perr.) Taub species in Makurdi, Nigeria. J Res For Wildl Environ 10: 20-27.

Condit R, Pitman N, Leigh EG Jr, Chave J, Terborgh J, Foster RB, Núñez P, Aguilar S, Valencia R, Villa G, Muller-Landau HC, Losos E, Hubbell SP. 2002. Beta-diversity in tropical forest trees. Science 295: 666-669.

Dau JH, Chenge I. 2016. Growth space requirements models for Prosopis africana (Guill & Perr) Taub tree species in Makurdi, Nigeria. Eur J Biol Res 6: 209-217.

Dau JH, Vange T, Amonum JI. 2016. Growth Space Requirements Models for Daniellia Oliverii (Rolfe) Hutch and Daviz Tree in Makurdi, Nigeria. Int J For Hortic 2: 31-39.

Dudley N. 1992. Forests in Trouble: A Review of the Status of Temperate Forests Worldwide. WWF, Gland, 260 pp.

Froumsia M, Zapfack L, Mapongmetsem PM, Nkongmeneck BA. 2012. Woody species composition, structure and diversity of vegetation of Kalfou Forest Reserve, Cameroon. J Ecol Nat Environ 4: 333-343.

Gotelli NJ, Colwell RK. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol Lett 4: 379-391.

Hammer O, Harper DAT, Ryan PD, 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol Electron 4: 9.

Heino J, Grönroos M, Ilmonen J, Karhu T, Niva M, Paasivirta L. 2012. Environmental heterogeneity and β diversity of stream macroinvertebrate communities at intermediate spatial scales. Freshw Sci 32: 142-154.

Herfindahl OC. 1950. Concentration in the U.S. Steel industry. PhD thesis. Columbia University, New York, USA. (in English)

Koleff P, Gaston KJ, Lennon JJ. 2003. Measuring beta diversity for presence-absence data. J Anim Ecol 72: 367-382.

Kraft NJB, Comita LS, Chase JM, Sanders NJ, Swenson NG, Crist TO, Stegen JC, Vellend M, Boyle B, Anderson MJ, Cornell HV, Davies KF, Freestone AL, Inouye BD, Harrison SP, Myers JA. 2011. Disentangling the Drivers of β Diversity Along Latitudinal and Elevational Gradients. Science 333: 1755-1758.

Louys J, Meloro C, Elton S, Ditchfield P, Bishop LC. 2011. Mammal community structure correlates with arboreal heterogeneity in faunally and geographically diverse habitats: implications for community convergence. Glob Ecol Biogeogr 20: 717-729.

Margalef R. 1968. Perspectives in Ecological Theory. University of Chicago Press, Chicago, IL.

Meer BB, Tella I. 2018. Assessment of Woody Species Diversity in Different Ecological Zones of Taraba State, Nigeria: A Strategy for Conservation. Asian J Res Agric For 1: 1-12.

Mishra AK, Behera SK, Singh K, Mishra RM, Chaudhary LB, Singh B. 2013. Effect of abiotic factors on understory community structures in moist deciduous forests of northern India. For Sci Pract 15: 261-273.

Natural Resources Biometrics (NRB). 2021. Chapter 10: Quantitative Measures of Diversity, Site Similarity, and Habitat Suitability. https://courses.lumenlearning.com/suny-natural-resources-biometrics/chapter/chapter-10-quantitative-measures-of-diversity-site-similarity-and-habitat-suitability/. Accessed 14 Jan 2022.

Neelo J, Teketay D, Kashe K, Masamba W. 2015. Stand Structure, Diversity and Regeneration Status of Woody Species in Open and Exclosed Dry Woodland Sites around Molapo Farming Areas of the Okavango Delta, Northeastern Botswana. Open J For 5: 313-328.

Nur A, Nandi R, Jashimuddin M, Hossain MA. 2016. Tree Species Composition and Regeneration Status of Shitalpur Forest Beat under Chittagong North Forest Division, Bangladesh. Adv Ecol 2016: 5947874.

Schroeder PJ, Jenkins DG. 2018. How robust are popular beta diversity indices to sampling error? Ecosphere 9: e02100.

Simpson EH. 1949. Measurement of Diversity. Nature 163: 688.

Song X, Cao M, Li J, Kitching RL, Nakamura A, Laidlaw MJ, Tang Y, Sun Z, Zhang W, Yang J. 2021. Different environmental factors drive tree species diversity along elevation gradients in three climatic zones in Yunnan, southern China. Plant Divers 43: 433-443.

Srivastava AK. 2002. Forest vegetation and tree regeneration in a species-rich sub montane transect of central Himalaya. PhD thesis. Kumaun University, Nainital, India.

Tucker CM, Cadotte MW, Carvalho SB, Davies TJ, Ferrier S, Fritz SA, Grenyer R, Helmus MR, Jin LS, Mooers AO, Pavoine S, Purschke O, Redding DW, Rosauer DF, Winter M, Mazel F. 2017. A guide to phylogenetic metrics for conservation, community ecology and macroecology. Biol Rev Camb Philos Soc 92: 698-715.

Turkis S, Elmas E. 2018. Tree species diversity and importance value of different forest communities in Venice forests. Fresenius Environ Bull 27: 4440-4447.

Vange T, Amonum JI, Dau JH. 2018. Prediction Equations for Estimating Growth Space for Parkia biglobosa (Jacq) Benth in the Guinea Savanna Ecozone of Nigeria. Appl Ecol For Sci 3: 1-7.

Vange T, Amonum JI, Japheth HD. 2021. Crown bole diameter linear equation for Daniellia oliverii (Rolfe) Hutch and Daviz and its application to stand density control in natural stands. MOJ Eco Environ Sci 6: 22-26.

Vilmi A, Alahuhta J, Hjort J, Kärnä OM, Leinonen K, Rocha MP, Tolonen KE, Tolonen KT, Heino J. 2017. Geography of global change and species richness in the North. Environ Rev 25: 184-192.

Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Liermann CR, Davies PM. 2010. Global threats to human water security and river biodiversity. Nature 467: 555-561.

Zuhaidi YA. 2009. Local growth model in modelling the crown diameter of plantation-grown Dryobalanops aromatica. J Trop For Sci 21: 66-71.