

Research Article

Diversity, Population Structure, and Above Ground Biomass in Woody Species on Ngomakurira Mountain, Domboshawa, Zimbabwe

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The diversity, structure, species composition, and above ground biomass of woody plants on Ngomakurira mountain in Zimbabwe were studied. A systematic random sampling approach was adopted to establish 52 sampling plots measuring 10 × 10 m across 3 study strata in the 1266 ha study area. Woody species occurring in each plot were identified and the circumferences of trees with diameters >8.0 cm at 1.3 m height were measured. A total of 91 species belonging to 74 genera and 39 families were identified in the sample plots. A Shannon-Wiener index mean value of 3.12 was obtained indicating high species diversity on the mountain. The DBH size class distribution showed inverse J distribution patterns across the three study strata, but with only 3 individual plants with DBH > 30 cm. Mean basal area was 15.21 m² ha⁻¹ with *U. kirkiana* and *J. globiflora* contributing approximately 30% of the basal area. The estimated above ground biomass ranged from 34.5 to 65.1 t ha⁻¹. Kruskal-Wallis-*H* test showed no significant differences in species richness, stem density, basal area, above ground biomass, and evenness, across the study strata ($p < 0.05$). Ngomakurira woodland has potential to regenerate due to the presence of many stems in the small diameter size classes.

1. Introduction

The miombo ecoregion covers approximately 2.7 million km² of southern, central, and eastern Africa [1] and is one of the world's priority areas for conservation [2]. The woodlands provide ecosystem, socioeconomic, and cultural services that sustain local livelihoods [3]. Miombo woodlands contribute considerably to household livelihoods by providing fuel, construction materials, grazing, medicine, food, materials of cultural importance, and potentially supplementing incomes especially for poor communal and urban dwellers [4]. In Zimbabwe the woodlands cover approximately 42% of the country [5], but the biodiversity composition and structure are mostly poorly documented.

Miombo woodland dynamics is strongly influenced by anthropogenic factors [6–8] and most ecosystems are being threatened by the increased demand for services by the burgeoning human population [9]. Woodland ecosystems and their valuable biodiversity resources are being lost at

an accelerated rate [10–12], thereby altering ecosystem function and consequently threatening the provision of services and goods especially to poor rural communities [13].

Knowledge of the biomass of a woodland is important in estimating the carbon stocks of an area. Such information is invaluable in management for coming up with strategies for climate change mitigation [14]. Carbon stocks data can also be used to mobilise financial resources through C-based Payments for Ecosystem Services (PES) [15]. There is limited quantitative information of carbon stocks in southern African forests [15], despite the huge importance of such information. Data on carbon stocks, species composition, and vegetation structure is invaluable to forest management in designing strategies for sustainable management under different disturbance regimes [14].

Ngomakurira means “drums sounding” in the local Shona language and is a mountain located near the Domboshawa Caves, just outside of Harare in Zimbabwe. It forms part of a granitic topography with dome-shaped inselbergs

near the village of Domboshawa in the headwaters of the Mazowe river. The mountain derives its name from the traditional African drums that were played during religious festivals. The mountain is considered sacred by the local community and is used for various religious rites. Old San rock art paintings are also found in caves and on the vertical rock face of the main mountain. The mountain is protected and managed by the National Museums and Monuments of Zimbabwe to conserve its cultural and archaeological value, biodiversity and catchment value. Ngomakurira Trust, formed by the Goromonzi Rural District Council in partnership with National Museums and Monuments of Zimbabwe as well as the Environmental Management Agency (EMA), initiated the ecotourism project at Ngomakurira mountain by converting hills, used communally for grazing, fuel wood collection, and harvesting of wild fruits, into a properly managed tourist facility.

Ngomakurira mountain is surrounded by communal areas and such areas are vulnerable to anthropogenic activities and edge effects [19] as local communities continue to depend on the woodlands for sustenance. A participatory forest management approach (PFM), which involves locals in management decisions, has recently been implemented for an ecotourism project at Ngomakurira mountain. The success of the project will depend on an understanding of the woodland dynamics and especially the role of disturbance factors in shaping the woodland structure.

This study seeks to determine the following: (a) the species composition, structure, and diversity and biomass accumulation of woody plants on Ngomakurira mountain, (b) the variability of these diversity indices across the sample plots, and (c) the relationships between species diversity, richness, basal area, and above ground biomass.

2. Materials and Methods

2.1. Study Area. Ngomakurira is a large granite mountain located in the Goromonzi district, in Chinamora communal lands, approximately 30 km NE of Harare in Zimbabwe. It is located between 17°32'46.46"S–17°35'34.92"S latitudes and 31°14'21.61"E–31°15'51.89"E longitudes. Altitude varies from 1307 to 1638 metres above sea level. The total area covered by the mountain is 1266 ha.

Ngomakurira mountain is located in agroecological zone IIa [20] with rainfall fairly reliable falling from November to March/April and mean annual rainfall ranging from 750 to 1000 mm/year. Mean annual temperature range is 15–20°C. The soils are shallow and generally classified as paraferalitic soils [21]. Deep soils are found at the base of the hill, getting shallower and rocky to absent at the higher levels. Ngomakurira lies in a communal area with poor rural households mainly involved in subsistence farming, though some are involved in horticulture to supply urban markets in Harare.

The study area falls under the deciduous miombo savanna woodland [22], a vegetation type dominated by *Brachystegia* spp. and *Julbernardia globiflora*. Reference [23] described this type of vegetation as dry miombo. The vegetation on the mountain is concentrated in the lower and middle zone of

the mountain with most of the top area consisting largely of bare rock.

2.2. Sampling Design and Data Collection. Field work was conducted in February 2016. An initial study of satellite images of the study area followed by a field reconnaissance survey [24] assisted in making decisions on sampling strategy to use. From the surveys the vegetation of the mountain appears mixed with no obvious vegetation communities. We, however, divided the mountain into three sections: the vegetation at the base, middle, and top of the mountain. In each section quadrats measuring 10 × 10 m were demarcated following the methods by [25]. Random numbers were used to locate the position of plots in each stratum [24]. We sampled 15 quadrats at the base, 25 in the middle, and 12 at the top. Sample plots were distributed according to the relative sizes of the strata.

Global positioning system (GPS) measurements were taken for each sample plot using a Garmin 12XL Global Positioning System. In each plot all woody species were identified in the field and a few were collected and verified at the National Herbarium in Harare. Tree height was visually estimated, and stem circumference at 1.3 m was measured using a tape measure for plants with a circumference ≥ 8 cm [26]. For multitemmed plants, the circumferences were measured separately.

2.3. Data Analysis

2.3.1. Floristic Indices and Biodiversity. The data consisting of plot numbers, species, and circumference was entered into an Excel spreadsheet and the following parameters were calculated:

- (1) DBH = circumference/ π .
- (2) Basal area = $\pi * DBH^2$.
- (3) Relative dominance = (total basal area for a species/total basal area of all species) × 100.
- (4) Relative density = (number of individuals of a species/total number of individuals) × 100.
- (5) Relative frequency = (frequency of a species/sum of all frequencies) × 100.
- (6) Relative diversity = (number of a species in a family/total number of species) × 100.
- (7) The importance value index (IVI) = relative dominance + relative density + relative frequency.
- (8) The family importance value (FIV) = relative dominance + relative density + relative diversity.
- (9) Shannon-Wiener's index of diversity $H = -\sum p_i \ln p_i$, where $p_i = n_i/N$; n_i is the number of individual trees present for species i , and N is the total number of individuals [27].
- (10) Evenness = $H' / \ln S$, where H' is the Shannon-Wiener index and S is the total number of species
- (11) The Kruskal-Wallis H test was done using SPSS statistical package version 16.0 (2007).

TABLE 1: Allometric equations used to estimate above ground biomass.

Equation(s)	Source country	Notes	Reference
$B = 3.01D - 7.48$	Zambia	Trees < 10 cm DBH	[16]
$B = 20.02D - 203.37$	Zambia	Trees > 10 cm DBH	[16]
$B = \exp(2.516 \ln(\text{dbh}) - 2.462)$	Tanzania	For trees ≥ 5 cm DBH	[17]
$B = 0.0625 \times D^{2.553}$	Tanzania	For trees ≥ 5 cm DBH	[18]

D = DBH, B = biomass (Kg).

TABLE 2: The five species with the highest importance value index (IVI) in each stratum at Ngomakurira mountain.

Mountain strata	Species	Relative frequency (%)	Relative density (%)	Relative dominance (%)	Species important value index/300
Bottom	<i>J. globiflora</i>	8.064	25.478	22.830	56.372
	<i>L. discolor</i>	6.452	6.879	5.333	18.663
	<i>E. matabelensis</i>	2.688	9.427	6.268	18.383
	<i>U. kirkiana</i>	2.151	5.733	10.460	18.343
	<i>P. maprouneifolia</i>	3.763	3.057	8.465	15.286
Middle	<i>U. kirkiana</i>	3.833	9.269	20.665	33.767
	<i>J. globiflora</i>	6.620	11.765	11.848	30.233
	<i>B. glaucescens</i>	6.272	9.002	12.161	27.435
	<i>E. matabelensis</i>	2.091	9.804	9.896	21.790
	<i>L. discolor</i>	5.575	4.724	6.048	16.347
Top	<i>B. glaucescens</i>	6.154	18.878	19.234	44.265
	<i>J. globiflora</i>	7.692	11.905	12.374	31.971
	<i>U. kirkiana</i>	2.308	8.674	12.473	23.454
	<i>E. matabelensis</i>	3.078	10.034	6.299	19.410
	<i>S. guineense</i>	1.539	6.633	9.140	17.312

(12) The Spearman rank correlations between diversity variables were calculated in Excel 2007.

2.3.2. Classification of Sample Plots. Classification of the sample plots was done using Agglomerative Hierarchical Cluster Analysis in SPSS statistical package version 16.0 (2007). Classification was done using weighted species composition data with weighting achieved using the number of stems of each species measured in each plot. Euclidean distance was used to compute distances between plots.

2.3.3. Above Ground Biomass. Three allometric equations (Table 1) were used to estimate tree biomass. The equations show relationships between biomass and DBH. These equations are general for all species as previous studies have already shown that species specific equations are not necessary in estimating biomass [14, 28]. The equations were generated from neighbouring countries with similar ecosystems, climate, and soils. References [12, 14, 29] used a similar approach in estimating biomass. Biomass estimations were made only for trees with DBH ≥ 5 as the equations were developed to estimate biomass within these DBH ranges.

3. Results

3.1. Tree Species Composition. A total of 91 species belonging to 74 genera and 39 families were recorded (see Appendix).

In terms of the number of species, the Rubiaceae is the largest family with 11 species, followed by the Caesalpiniaceae (8 species), Phyllanthaceae (6 species), Papilionaceae and Combretaceae (5 species each), Lamiaceae, Mimosaceae and Anacardiaceae (4 species each), Burseraceae, Myrtaceae, Proteaceae, and Sapindaceae (3 species each), Clusiaceae, Dipterocarpaceae, Ebenaceae, Moraceae, Ochnaceae, and Strychnaceae (2 species each), and the remainder have one species each. The number of species were 59 at the bottom, 62 at the middle, and 48 at the top of the mountain.

Table 2 shows the five dominant species at each stratum in decreasing importance value index (IVI). *Julbernardia globiflora* dominates at the bottom, *Uapaca kirkiana* at the middle, and *Brachystegia glaucescens* at the top of the mountain. In the three strata the common dominant species were *J. globiflora*, *B. glaucescens*, *U. kirkiana*, and *Euphorbia matabelensis* with mean IVI values of 39.5, 28.43, 25.2, and 19.9, respectively.

Some species increased in dominance with increasing altitude whereas others decreased. *Combretum molle*, *Elephantorrhiza goetzei*, *Monotes engleri*, *Parinari curatellifolia*, *Strychnos spinosa*, *Zanha africana*, and *B. glaucescens* increased up the mountain whereas *C. mossambicensis*, *E. matabelensis*, *Margaritaria discoidea*, *Pseudolachnostylis maprouneifolia*, *Tapiphyllum velutinum*, and *J. globiflora* showed a decrease.

There were some species confined to only one stratum of the mountain. *Acacia goetzei*, *Afrocanthium lactescens*,

TABLE 3: Kruskal-Wallis H test results of the study variables at the bottom, middle, and top of Ngomakurira mountain (values in brackets show least values).

Variable	Median (range)			p value
	Bottom	Middle	Top	
Basal area (m^2/ha)	14.23 (4.28)	12.40 (3.38)	18.99 (6.01)	0.161
Shannon-Wiener index	3.07	3.32	2.96	0.299
Above ground biomass (t/ha)	34.49 (7.48)	46.64 (5.66)	65.17 (9.36)	0.165
Species richness	59	62	48	0.479
Evenness	0.80 (0.63)	0.86 (0.56)	0.78 (0.56)	0.115
Stem density/ha	4900 (2700)	4400 (1000)	4850 (2100)	0.646

Commiphora mollis, *Diospyros natalensis*, and *Psydrax livida* were only recorded at the top of the mountain. *Brachylaena discolor*, *Combretum apiculatum*, *Combretum collinum*, *Empogona kirkii*, *Erythrina abyssinica*, *Ficus natalensis*, *Psidium guajava*, *Rhus leptodictya*, and *Vitex payos* were found at the middle and *Cussonia arborea*, *Dombeya rotundifolia*, *Faurea rochetiana*, *Ficus sur*, *Gardenia ternifolia*, *Maesa lanceolata*, *Monotes glaber*, *Mussaenda arcuata*, *Pericopsis angolensis*, *Protea welwitschii*, *Strychnos madagascariensis*, and *Ximenia caffra* were found at the bottom. The number of species confined to a particular stratum decreased from the bottom to the top.

A number of fire tolerant species like *P. maprouneifolia*, *Pterocarpus angolensis*, *Combretum* sp., *Burkea Africana*, *Terminalia stenostachya*, and *Diplorhynchus condylocarpon* were also recorded on the mountain.

3.2. Shannon-Wiener Diversity and Evenness. Shannon-Wiener values for the bottom, middle, and top of the mountain were 3.07, 3.32, and 2.96, respectively, with a mean of 3.12 (Table 3). Kruskal-Wallis test results of the Shannon-Wiener values show no significant differences ($p > 0.05$) across the study strata. The following species contributed most to the high diversity at the mountain: *J. globiflora* (0.85), *E. matabelensis* (0.72), *B. glaucescens* (0.67), *U. kirkiana* (0.59), and *Lannea discolor* (0.46). Species evenness is highest at the middle and lowest at the top of the mountain, but no significant differences ($p > 0.05$) were observed across the study strata (Table 3).

3.3. Stem Density and DBH. A total of 2495 stems were measured in the sample plots. About a quarter of the trees (25.7%) were multitemmed and accounted for slightly over half of the stems (1770 stems). Mean stem density for stems with $\text{DBH} \geq 5$ cm was 2456 ± 1250 and 2342 ± 1286 stem ha^{-1} for $\text{DBH} < 5$ cm. For stems with a $\text{DBH} \geq 2.5$ cm stem density was highest at the bottom and least in the middle of the mountain. The mean diameter was 5.5 ± 3.6 cm, with the majority of trees (91%) with $\text{DBH} < 10$ cm. Figure 1 shows the diameter class distribution of the trees at Ngomakurira showing an inverse J distribution. Only three individual trees had $\text{DBH} > 30$ cm and these were species of *S. guineense*, *B. boehmii*, and *B. glaucescens*. *U. kirkiana* had more members in the higher size classes between 20 and 29 cm DBH.

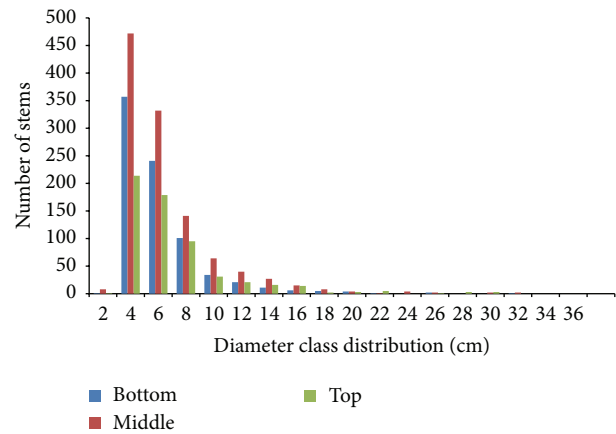


FIGURE 1: Diameter class distribution of the woody plants at the bottom, middle, and top of Ngomakurira mountain.

3.4. Basal Area. The basal area across the plots ranged from 3.38 to $41 \text{ m}^2 \text{ ha}^{-1}$ with a mean of $15.21 \text{ m}^2 \text{ ha}^{-1}$. The following species contributed most to the basal area: *U. kirkiana* (15.6%), *J. globiflora* (14.9%), *B. glaucescens* (12.4%), *E. matabelensis* (8.0%), *L. discolor* (5.5%), *S. guineense* (5.3%), *M. engleri* (4.1%), *P. maprouneifolia* (3.9%), and *B. boehmii* (3.8%).

3.5. Above Ground Biomass. Above ground biomass increased from the bottom to the top of the mountain but showed no significant difference between the study strata. Mean AGB among plots ranged from 5.7 to $134.4 \text{ tonnes ha}^{-1}$. Mean AGB ranged from 34.5 to $65.1 \text{ tonnes ha}^{-1}$ among the study strata (Table 3). The top ten trees that contributed most to the above ground biomass were *U. kirkiana* (19.5%), *J. globiflora* (13.3%), *B. glaucescens* (12.9%), *E. matabelensis* (6.6%), *S. guineense* (6.5%), *L. discolor* (5.4%), *M. engleri* (5.3%), *P. maprouneifolia* (4.3%), *B. boehmii* (4.0%), and *P. curatellifolia* (3.5%).

The AGB was highest in the 5–10 cm DBH class and least in the 20–25 cm class (Figure 2). The 5–10 cm DBH class contributed approximately 35% of the total AGB.

3.6. Relationship among the Variables. Table 4 shows Spearman's rank correlation coefficients for the different variables assessed at Ngomakurira. Basal area was positively correlated

TABLE 4: Spearman's rank correlation for diversity parameters (* indicates significance ($p < 0.05$, $df = 50$)).

	Basal area	Species richness	Shannon	AGB	Stem density	Evenness
Basal area	1					
Species richness	0.131	1				
Shannon	0.037	0.815*	1			
AGB	0.7858*	-0.035	-0.085	1		
Stem density	0.471*	0.228	0.049	0.053	1	
Evenness	0.061	0.219	0.6889*	-0.052	-0.132	1

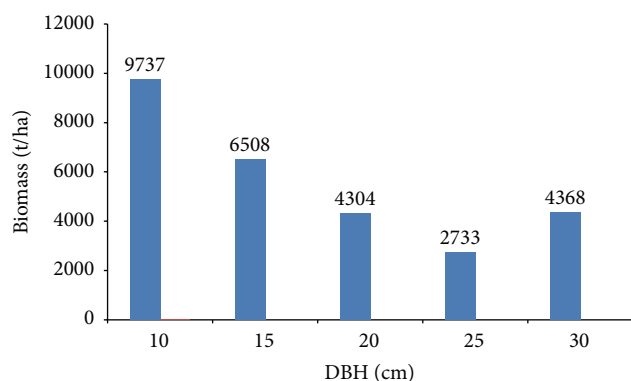


FIGURE 2: Distribution of above ground biomass of species in different DBH classes.

to all the diversity parameters. Stem density was positively correlated to basal area, species richness, diversity, and AGB. Significant correlations were found between basal area and AGB (0.79), stem density and basal area (0.47), species richness and Shannon-Wiener index (0.82), and evenness and Shannon-Wiener index (0.69). Weak correlations were found between basal area and species richness (0.13), species richness and stem density (0.23), and evenness and species richness (0.22). Negative correlations were found between AGB and species richness (-0.33), Shannon-Wiener (-0.09) and evenness (-0.05), and also stem density and evenness (-0.13).

3.7. Vegetation Communities. The dendrogram in Figure 3 shows sample plots clustering into three vegetation communities.

The vegetation communities do not correspond to the altitude strata used to sample the species as there is a mixture of plots from the three altitude ranges in each vegetation subtype. The Caesalpinoid species *B. glaucescens* and *J. globiflora* and their associated species *L. discolor*, *V. infausta*, and *Combretum molle* occur in all the three vegetations communities. In community A these common species occur mixed mainly with *E. matabelensis*, *T. velutinum*, *V. payos*, *C. mossambicensis*, and *M. discoidea*. Community B includes the common elements plus *B. boehmii*, *P. maprouneifolia*, *M. engleri*, *R. longipes*, *O. pulchra*, and *D. viscosa* whilst community C includes *U. kirkiana*, *B. spiciformis*, *P. curatellifolia*, *R. longipes*, *M. engleri*, and *P. febrifugum*.

4. Discussion

4.1. Tree Species Composition. Species diversity assessments are a way of auditing an ecosystem to understand its dynamics and quality and how disturbance factors are impacting on it [30]. The number of species obtained here compares well with those obtained in similar dry miombo woodlands in Zimbabwe [26] and elsewhere [18, 31]. Other studies have, however, recorded lower numbers; for example, [32, 33] recorded 17 species and 59 at Mapembe Nature reserve and Save Runde, respectively, in Zimbabwe and [34] recorded 69 species in Mozambique. Reference [35] recorded numbers as high as 229 from Tanzania. Differences in species richness in miombo woodlands is related to climatic, edaphic, and disturbance factors [31].

The dominance of miombo vegetation by legume families (Caesalpiniaceae, Papilionaceae, and Mimosaceae) is confirmed in this study as similarly observed in other miombo regions [12, 31]. However, observations of high numbers of woody species of the Rubiaceae are unusual as members of this family often dominate among the shrubs [31, 36]. This shows that differences in dominance patterns are possible on a local scale in miombo woodlands.

Across the study strata IVI indices show altitudinal changes in dominance patterns of a number of species. Observations of *B. glaucescens* being the dominant species at higher altitudes and *J. globiflora* at lower altitudes have also been made by [37]. The middle altitude peak in species richness observed in this study is a commonly observed phenomenon in studies on species distribution along altitudinal gradients [38]. Several hypotheses have been proposed to explain this, but all are based on the fact that species ranges vary across elevational gradients becoming narrower at the top and hence less richness is observed at those altitudes. At middle altitudes, the species ranges overlap, thereby maximising the number of species [39]. Many studies have shown that altitude is the major determinant of species composition on mountains as such related variables like temperature and edaphic factors vary with altitude [40].

The prevalence of fire tolerant species on the mountain indicates that fire is one of the drivers of species composition on the mountain. References [41, 42] made similar observations in studies of fire and elephant affected miombo regions in Zimbabwe and Mozambique, respectively.

4.2. Vegetation Communities. The 3 communities shown in the dendrogram in Figure 2 are typical miombo woodlands

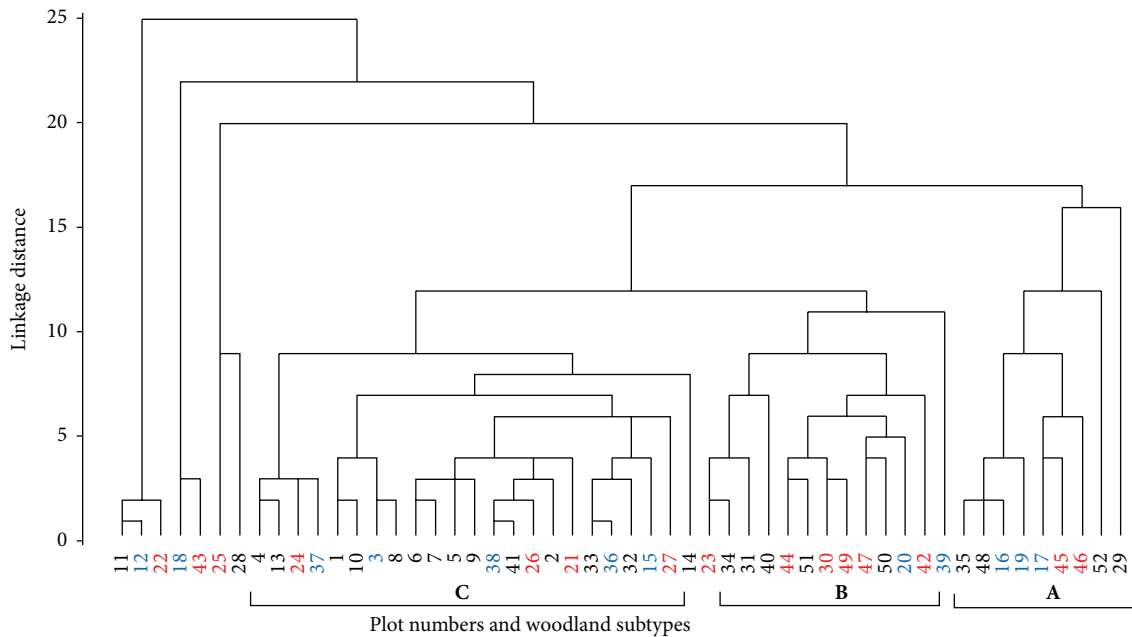


FIGURE 3: Hierarchical cluster analysis dendrogram showing classification of vegetation plots (colour of plot numbers—red: at the bottom, black: middle, and blue: the top of the mountain).

dominated by the Caesalpinoid species *B. glaucescens* and *J. globiflora* and their associated species. References [31, 43] noted that elevation was the most important factor shaping species communities in miombo woodlands. The results from this study support these observations as the spatial distribution of species like *B. glaucescens*, *J. globiflora*, and *U. kirkiana* is influenced by altitude. Presence of species confined to different strata also supports the influence of altitude in shaping communities. Altitude influences water availability, temperature, and soil characteristics which directly affect plant growth performance.

4.3. Shannon-Wiener Diversity and Evenness. The woodland at Ngomakurira mountain has high species diversity as shown by the Shannon-Wiener index values (Table 3). Reference [44] reported that Shannon-Wiener index values fall between 1.5 and 3.5 for tropical woodlands, so the value obtained here is within the expected range. Ecosystems with Shannon-Wiener values greater than 2 are regarded as medium to highly diverse in terms of species [7]. Reference [45] attributed the high species diversity in miombo woodlands to the wide diversity of habitats present. These results are comparable to those found in Zimbabwe by [26] (Shannon 3.42) and [30] (Shannon 3.28) and in Tanzania by [31] (Shannon 3.44). Our results are relatively larger than those found by [46] (Shannon 2.8) in Zambia, [29] (Shannon 1.05) in Tanzania, and [34] (Shannon 1.25) in Mozambique. Higher Shannon values have also been recorded from Tanzanian study [7] (Shannon 4.27). Differences in richness and diversity possibly result from differences in rainfall regimes [12] and disturbance history [1].

The similarity in evenness across the study strata shows that the woodland is dominated by a few species [47].

4.4. Stem Density and DBH. The multitemmed tree architecture observed at Ngomakurira mountain is indicative of a history of disturbance, particularly herbivory [48]. Herbivory is high at Ngomakurira mountain as local communities have free access to graze their animals. The mean stem density obtained in this study (2456 ± 1251 stems ha^{-1}) was much higher when compared to densities reported from other miombo woodlands ($348\text{--}1495$ stems ha^{-1}) [7, 14, 33, 34, 47]. Ngomakurira mountain is therefore well stocked. Our results, however, compare with those obtained by [31, 46] in Tanzania and Zambia, respectively.

The DBH distribution (Figure 1) shows a common trend obtained in natural forests where stem densities decrease with increasing diameter. Forests with this inverse “J” shaped curve DBH distribution pattern are generally said to show active regeneration and recruitment [12]. Recent studies have questioned reliance on inverse J distributions in forest management as they are based on a biologically unrealistic assumption of equal mortality among size classes [49]. Declining populations may also show the classic “inverse J” shape and some stable populations may not show this shape due to differences in growth rates among size classes [50]. Most of the common miombo woody species reach much larger DBH sizes in mature forests [26]. The lack of larger size classes may be due to harvesting of such trees for sale in the urban areas as evidenced by numerous stumps in the study area. Exploitation for local consumption must be minimal as studies elsewhere show preference for small size classes for firewood, poles, and house construction [44]. Fire may also be a factor as few seedlings may survive to reach mature size classes [31].

4.5. Basal Area. The estimated basal area obtained in this study ($15.21 \text{ m}^2 \text{ ha}^{-1}$) compares with that of [31] (13.55 ± 5.52) and [49] ($15\text{--}15.6$) in Tanzania and [14] (14.34 ± 0.52) in Zambia. References [25, 51] reported lower basal areas. Differences with our results may be due to species composition and site differences.

4.6. Above Ground Biomass. The AGB of woody trees is the largest carbon pool of a forest [29] and can be used to calculate the carbon stock density as 50% of AGB is assumed to be carbon [34]. The carbon stock estimate of a woodland is of importance to management for consideration of strategies that promote carbon storage. Knowledge of carbon stocks is also important in the development of a payments system to reduce emissions from deforestation and degradation [15]. The estimates for above ground biomass for Ngomakurira mountain ($34.5\text{--}65.1 \text{ t ha}^{-1}$) are comparable to those reported by [23] from Zambia and Zimbabwe (52 t ha^{-1}), [29] from Tanzania (46.4 t ha^{-1}), and [15] from Mozambique (42.2 t ha^{-1}). Any differences may be due to differences in growth conditions [42], species composition, allometric equations, and plot sizes [29]. Reference [12] in a study of sites of different utilisation levels in Tanzania reported carbon stocks of 14.6 t ha^{-1} in high utilisation sites, 33.1 t ha^{-1} in sites of medium utilisation, and 28.5 t ha^{-1} in areas of low utilisation. Using these values as a benchmark we can conclude that the woodland utilisation at Ngomakurira is low, despite the many signs of human disturbance like wood cutting and grazing. For management this means that moderate utilisation should be promoted to enhance carbon stocks. AGB of Ngomakurira mountain, however, must be higher than estimates presented here as the allometric equations used only included trees with $\text{DBH} \geq 5 \text{ cm}$, thereby excluding all trees with $\text{DBH} < 5 \text{ cm}$.

4.7. Relationship among the Diversity Variables. The positive correlation between basal area, species richness, diversity, stem density, AGB, and evenness means that to get the best basal area in a woodland each of the diversity parameters must be at its maximum. This of course is not achievable due to disturbance factors, competition among species, and variability of environmental factors. Reference [15] made similar observations in Mozambique. A significant correlation between basal area and biomass observed in this study has also been observed in similar studies elsewhere [52]. Basal area integrates both the number and size of trees and is a good predictor of biomass [52]. The correlation coefficient of 0.7858 is, however, slightly lower than expected since a positive linear relationship was expected. This variation may be a result of the fact that the allometric equations used were not generated locally or differences in species composition between our study area and the areas where such equations were generated. High correlations between Shannon and species richness and evenness were expected as these measures of diversity in a way represent the same phenomenon [53].

The observations of a negative correlation between AGB and species richness and diversity and a positive correlation

between AGB and stem density corroborate finding by [54].

5. Conclusions

The vegetation at Ngomakurira is typical miombo dominated by the species *Brachystegia glaucescens*, *Julbernardia globiflora*, and *Uapaca kirkiana*. The woodland has high species richness and diversity showing that it is in good condition. This is further supported by the DBH distribution which shows an inverse J shape typical of stable populations. This is good sign of the sustainability of the woodland stock which ensures sustainable supply of goods and services to local communities. Effects of anthropogenic effects were evident and would require management, but detailed studies on levels of resource extraction required for sustainable management of the woodland need to be carried out. This is important in conservation because humans residing next to protected areas need resources from such areas and conflicts often arise when they are prevented from accessing such resources.

Appendix

Woody Trees Recorded at Ngomakurira

Taxa

Anacardiaceae

Lannea discolor (Sond.) Engl.
Ozoroa reticulata (Baker f.) R. & A. Fern.
Rhus leptodictya Diels
Rhus longipes Engl.

Annonaceae

Hexalobus monopetalus (A. Rich.) Engl. & Diels

Apocynaceae

Diplorhynchus condylocarpon (Müll. Arg.) Pichon

Araliaceae

Cussonia arborea A. Rich.

Asteraceae

Brachylaena discolor DC.

Burseraceae

Commiphora marlothii Engl.
Commiphora mollis (Oliv.) Engl.
Commiphora mossambicensis (Oliv.) Engl.

Celastraceae

Gymnosporia senegalensis (Lam.) Loes.

Chrysobalanaceae

Parinari curatellifolia Benth.

Clusiaceae

Garcinia buchananii Baker

Psorospermum febrifugum Spach

Combretaceae

Combretum apiculatum Sond.

Combretum collinum Fresen.

Combretum molle G. Don

Terminalia brachystemma Hiern

Terminalia stenostachya Engl. & Diels

Dipterocarpaceae

Monotes engleri Gilg

Monotes glaber Sprague

Ebenaceae

Diospyros natalensis (Harv.) Brenan

Euclea natalensis A. DC.

Euphorbiaceae

Euphorbia matabelensis Pax

Fabaceae-Caesalpinioideae

Brachystegia boehmii Taub.

Brachystegia glaucescens Burt Davy & Hutch.

Brachystegia spiciformis Benth.

Brachystegia utilis Burt Davy & Hutch.

Burkea africana Hook.

Julbernardia globiflora (Benth.) Troupin

Peltophorum africanum Sond.

Senna singueana (Delile) Lock

Fabaceae-Mimosoideae

Acacia goetzei Harms subsp. *microphylla* Brenan

Albizia antunesiana Harms

Dichrostachys cinerea (L.) Wight & Arn.

Elephantorrhiza goetzei (Harms) Harms

Fabaceae-Papilionoideae

Bobgunnia madagascariensis (Desv.) J. H. Kirkbr. & Wiersema

Dalbergia nitidula Baker

Erythrina abyssinica DC.

Pericopsis angolensis (Baker) Meeuwen

Pterocarpus angolensis DC.

Flacourtiaceae

Flacourtia indica (Burm. f.) Merr.

Heteropyxidaceae

Heteropyxis dehniae Suess.

Lamiaceae

Rotheca myricoides (Hochst.) D. A. Steane & Mabb.

Tetradenia riparia (Hochst.) Codd.

Vitex mombassae Vatke

Vitex payos (Lour.) Merr.

Maesaceae

Maesa lanceolata Forssk.

Meliaceae

Turraea nilotica Kotschy & Peyr.

Moraceae

Ficus natalensis Hochst. subsp. *natalensis*

Ficus sur Forssk.

Myrtaceae

Psidium guajava L.

Syzygium cordatum Hochst. ex C. Krauss

Syzygium guineense (Willd.) DC. subsp. *afromontanum* F. White

Ochnaceae

Ochna inermis (Forssk.) Penz.

Ochna pulchra Hook. subsp. *pulchra*

Olacaceae

Ximenia caffra Sond.

Phyllanthaceae

Bridelia cathartica G. Bertol. subsp. *melanthesoides* (Baill.) J. Léonard

Flueggea virosa (Willd.) Voigt subsp. *virosa*

Margaritaria discoidea (Baill.) G. L. Webster var. *nitida* (Pax) Radcl.-Sm.

Pseudolachnostylis maprouneifolia Pax

Uapaca kirkiana Müll. Arg.

Uapaca nitida Mull. Arg. var. *nitida*

Pittosporaceae

Pittosporum viridiflorum Sims var.

Proteaceae

Faurea rochetiana (A. Rich.) Pic. Serm.
Faurea saligna Harv.
Protea welwitschii Engl.

Rhamnaceae

Ziziphus mucronata Willd.

Rubiaceae

Afrocanthium lactescens (Hiern) Lantz
Catunaregam taylorii (S. Moore) Bridson
Coptosperma neurophyllum (S. Moore) Degreef
Empogona kirkii Hook. f. subsp. *kirkii*
Gardenia ternifolia Schumach. & Thonn. subsp. *jovis-tonantis* (Welw.) Verdc.
Hymenodictyon floribundum (Hochst. & Steud.) B. L. Rob.
Mussaenda arcuata Poir.
Pavetta schumanniana K. Schum.
Psydrax livida (Hiern) Bridson
Tapiphyllum velutinum (Hiern) Robyns
Vangueria infausta Burch. subsp. *infausta*

Rutaceae

Casimiroa edulis La Llave

Sapindaceae

Allophylus africanus P. Beauv.
Dodonaea viscosa Jacq.
Zanha africana (Radlk.) Exell

Sapotaceae

Englerophytum magalismontanum (Sond.) T. D. Penn.

Sterculiaceae

Dombeya rotundifolia (Hochst.) Planch.

Strychnaceae

Strychnos madagascariensis Poir.
Strychnos spinosa Lam.

Umbelliferae-Apiaceae

Steganotaenia araliacea Hochst.

Urticaceae

Pouzolzia mixta Solms

Verbenaceae

Lantana camara L.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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