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Woody Plant Assemblages of Recently Declared Village Land Forest Reserve in The Eastern Afromontane Biodiversity Hotspot

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Abstract

Understanding of species composition of village land forest reserves and their driving factors informs adequate development of effective restoration strategies and sustainable forest management of miombo woodlands. This study assessed the effects of human disturbance as well as environmental variables on woody plant species composition using 24 square plots of 10 x 10 m in a recently declared village land forest reserve in the Eastern Afromontane biodiversity hotspot of Tanzania. Ordination analysis technique canonical correspondence analysis was used to identify important vegetation gradients and significant factors that explain the spatial variation in species composition of woody plants. Results showed that, 779 individual woody plants were recorded, of which 379 were seedlings (48.6%), 102 saplings (13.1%) and 298 adults (38.3%). The three most dominant plant species were *Brachystegia spiciformis* (42.2%), *Diplorhynchus condylocarpon* (9%) and *B. boehmii* (8.7%), while the least were *Multidentia crassa* and *Diospyros squarrosa* with each species having less than 1% overall abundance. *Pterocarpus angolensis*, a highly protected and near-threatened tree species, was also recorded but with only very few individuals. Canopy cover and soil pH were the two most important variables explaining the spatial variation in species composition of woody plants. These results emphasise that village forests are important for preserving native and threatened tree species, and improved management should discourage all practices that change natural conditions of canopy cover and soil pH to safeguard the remaining village forests, biodiversity and rural livelihoods.

Keywords: Miombo; Human disturbance; Environmental variables; Canopy cover; Species composition.

Introduction

Village land forest reserves (VLFRs) within the miombo ecoregion are unique ecosystems with a rich composition of different native plant species that contribute greatly to the environmental conservation and socio-economic development of millions of rural dwellers (Campbell et al. 1996; Ribeiro et al. 2020). These forests are also well known for preserving water, soil, genetic resources, nutrients and cultural sites. In addition, VLFRs safeguard biodiversity from natural and non-natural (human-made) disturbances; thus VLFRs are refugia. Although no established statistics yet, VLFRs contribute considerably to the richness of flora, fauna, habitats and landscapes of the Eastern Afromontane biodiversity hotspot. The role of these forests in mitigation and adaptation to climate change impacts is increasingly acknowledged in tropical forests, especially their role in reducing emissions from deforestation and forest degradation plus (REDD+) projects (Vatn et al. 2017). Tanzania is among the leading mega-rich biodiversity hotspot countries, with 6 out of 36 global important biodiversity hotspots. Presently, there are 734 declared village forest reserves occupying a total area of 1,445,878 ha under community management in Tanzania (MNRT 2022). According to the Tanzania National Forest Resources Monitoring and Assessment (NAFORMA), woodlands cover 44.7 million ha, equivalent to 92 percent of the total forest area. Of these, miombo woodlands occupy about 44 million hectares, equivalent to 91% of the total forest area in Tanzania (MNRT 2015). It is estimated that around 60 percent of woodlands are under the village and open lands, and therefore, VLFRs are overall important for livelihood enhancement, biodiversity conservation and sustainable forest management (Vatn et al. 2017; Andrew et al. 2023).

Despite the widely appreciated importance of VLFRs for livelihood enhancement, biodiversity conservation and adaptation and mitigation to the negative impacts of climate change, these forests have continued to be threatened by, among other illegal logging, encroachments for other land uses, e.g., agriculture and human settlement, and uncontrolled fires (Jew et al. 2016, Doggart et al. 2020). Thus, deforestation and land degradation have been the two major drivers of land use/cover change and its associated changes in forest community structure. Annual deforestation was estimated at 403,000 ha in 2010 (FAO 2010), while recent data put it at 469,420 ha in Tanzania (URT 2017). Climate change poses a new conservation challenge with exacerbated forest degradation and negative impacts on forest-dependent rural livelihoods and socio-economic development (Vatn et al. 2017). To restore the community structure and functions of the VLFRs, understanding important factors that may contribute to the successful establishment and development of plant species assemblages is important in light of ongoing deforestation and intensified land degradation.

Both human activities and natural processes are known to affect plant species assemblages, especially plant species composition in tropical regions of the world (Engler and Guisan 2009). Particularly for miombo woodlands, local variation in community floristic composition is influenced by human disturbance and environmental factors (Frost 1996; Chidumayo 1997) The understanding of drivers of spatial variation in woody plant species composition is crucial to inform adequate development of effective restoration strategies and for sustainable biodiversity conservation in village forests. While there are a number of studies addressing human impact and environmental factors on the composition of woody plants in forests, few have considered wet miombo woodlands in VLFRs. Accordingly, there is limited knowledge on how to effectively restore and protect the integrity, stability and functions of these important ecosystems. Therefore, this study overall aimed to understand the potential impact of human disturbance and environmental factors on the composition of woody plant species in a Village Land Forest Reserve (VLFR) in the Southern highlands of Tanzania. Specifically, this study aimed to (1) examine the abundance, distribution and International Union for Conservation of Nature (IUCN) status of woody plant species in the recently declared VLFR as a basis for restoration planning and future monitoring work after changing the forest tenure from open to restricted access and (2) assess the association between human disturbance and environmental variables, and species composition of wet miombo woody plants. The study forest, i.e. Intake, is part of the Eastern Afromontane biodiversity hotspot that was declared VLFR in 2019. Findings reported in this work may contribute to the development of improved restoration strategies of community forests elsewhere in the world with similar political, social, economic and ecological settings.

Materials and Methods

Study area

This study was undertaken at Intake Village Land Forest Reserve (VLFR) in Ludewa district, Southern highlands Tanzania (Fig. 1). The reserve is part of the Eastern Afromontane biodiversity hotspot, one of the global biological wonders stretching from Saudi Arabia to Mozambique and Zimbabwe and occupies more than 1 million km^2. The hotspot contains more than 2,350 endemic plant species, unfortunately standing on only 15% of the protected area (https://www.cepf.net/). Administratively, Ludewa has a total area of 8,397 km^2 and a population of 151,361 in the Njombe Region (URT 2022). Different tribes are found in the district, with Wapangwa, Wakisi and Wamanda forming major groups.

Agriculture involving food (paddy, Irish and sweet potatoes) and cash (coffee, pyrethrum and sunflower) crops, as well as animal keeping, forms an important economic activity of local communities. Fishing along Lake Nyasa is also an important economic activity, providing an additional source of income and food to local communities. Ludewa is characterised with mild and generally warm and temperate climate with an average temperature of 19.2 °C and precipitation of 1215 mm per annum. November is the hottest month of the year, while the lowest average temperature is July. Intake forest reserve has an area of 5,533.3 ha and is found in Masimavalafu village Ibumi ward, about 65 km from Ludewa town.

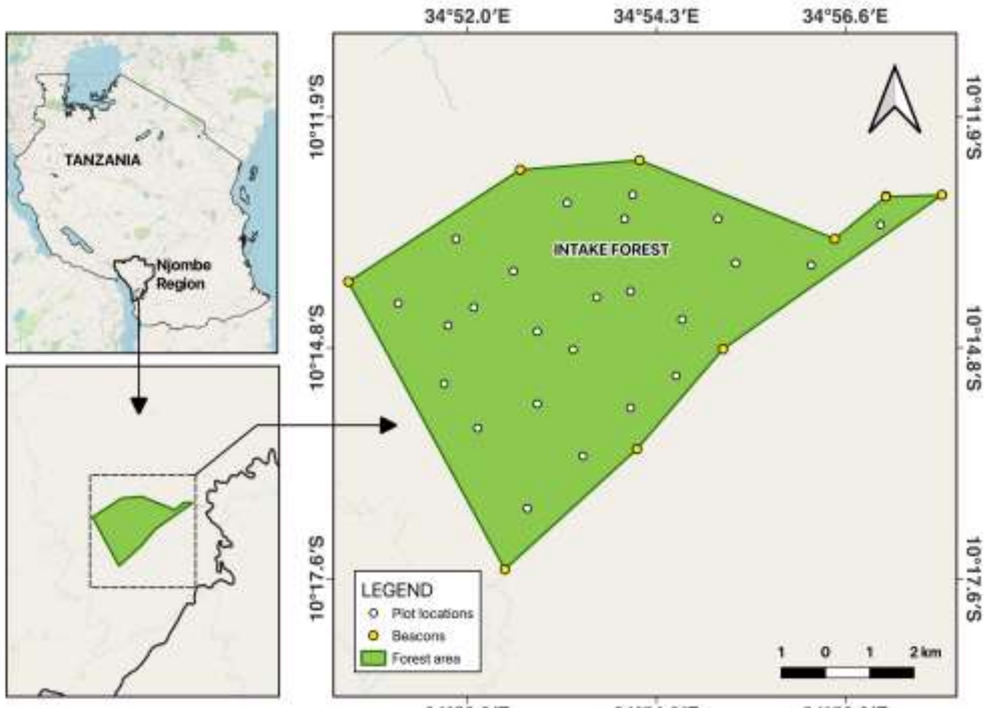

Figure 1. Map of study area showing the location of study plots in the village forest at the Southern highlands of Tanzania.

Ludewa has various vegetation types, including grasslands, miombo woodlands and plantations of Eucalyptus and Pinus species, the two dominant exotic plantation forest species. During the advent of Participatory Forest Management (PFM) in early 1990, Ludewa was not covered, and therefore, a good number of VLFRs are not protected formally. The study forest was declared VLFR in 2019 (Mombo et al. 2019), meaning that villagers were now given a full mandate to own and manage the forest with technical support from district authorities (MNRT 2007). Intake forest is an important source of water (i.e. catchment forest), is used for beekeeping and cultural activities and also provides other benefits, including timber and non-timber forest products (Andrew et al. 2023) to several ten thousand villagers in Masimavalafu and nearby villages. Soils of Intake are overall clay to sand soils derived from ancient crystalline rocks, which are part of the large Kipengere mountain ranges rising to 2961 m a.s.l. Miombo plant species characterise intake forest and hosts 72 different bird and 17 mammal species (Ludewa District Council 2019). This study reports information on woody plant assemblages and their human disturbance and environmental driving factors for Intake Village Forest for the first time.

Vegetation sampling

Before the actual field survey, a reconnaissance survey was undertaken to among other familiarise with the forest landscape (e.g. dominant features, boundaries and accessibility), vegetation characteristics, test field research tools and equipment, and sampling methods. Then, a total of 24 square plots, each measuring 10 x 10 m, were selected randomly from the forest to investigate the association between human disturbance and environmental variables and woody plant species composition. Diameter at breast height (DBH) was measured using a calliper for all stems with DBH > 1 cm in plots. The DBH is the diameter measured at 1.3 m above the ground. Woody plant species (i.e. trees, shrubs and woody climbers) with the targeted DBH were recorded for frequency and species identities in each plot. Tree seedlings (height ≤ 1.3 m and DBH ≤ 1 cm) were also enumerated in three 1 x 1 m subplots in each main plot. Sampled woody plant species were identified on-site to species level where possible with the help of field guides and a botanist. Specimens for unidentified plant species, together with specimens of the rest of the plants scored in the field, were collected, pressed, dried and brought to the Arusha National Herbarium of Tanzania (https://www.tpri.go.tz/national-herbarium-tanzania-section) for identity confirmation. Confirmation was done following standard protocols for herbaria, including matching brought-in specimens with existing collections and crosschecking with the Flora of Tropical East Africa. After confirmation, all specimens were deposited at the same herbarium for future reference and monitoring.

Human disturbance and environmental variables

Study plots were positioned at least 400 m away from each other to avoid pseudo-replication and attain independence of observations. Elevation was recorded at the centre of each plot using the standardised hand-held global positioning system. Soil samples were collected from the top 15 cm (due to relatively rich organic matter and good proportion of the fine roots) using a soil auger of 5 cm diameter to obtain soil organic carbon content, texture (clay, silt and sand) and pH. Five soil cores taken from four corners and the centre of a plot per plot were extracted and bulked into one composite sample for further processing. The collected soil sample was placed into a clearly labelled paper bag to form a composite soil sample of that particular plot. The total weight of the composite soil sample was measured by using a digital weighing scale to the nearest gram. Then, the sample was subdivided to get a sub-sample which had at least 200 g of soil for laboratory analyses. Soil pH was determined using Beckman's glass electrode pH meter after 10 g of the soil sample was suspended in 25 mL distilled water (1:2.5 ratio of soil to water). Prior to total organic carbon analysis, the soil samples were air-dried, crushed and passed through a 2-mm sieve after removing all plant materials. Soil organic carbon was determined using LECO carbon analyser after further grinding and sieving through a 0.5 mm sieve. Particle size analysis by hydrometer method was employed to characterise the size distribution of particles in the collected soil sample (or soil texture) (Gavlack et al. 2005). In this case, soil texture class was determined using USDA texture triangle where there were clay (< 2.0 µm), silt (50 – 2.0 µm) and sand (2000 – 50 µm) soils. Linear distance between a plot and the nearest footpath, which is a proxy of human disturbance, was visually estimated by three people, and the average was recorded as the true value of the distance. Similarly, canopy cover was estimated using the same procedure in plots. Soil sample analyses were conducted at the Department of Ecosystems and Conservation (https://www.cfwt.sua.ac.tz/ecosystems/), Sokoine University of Agriculture, Tanzania. Table 1 presents considered human disturbance and environmental variables in the analysis of woody plant assemblages of Intake VLFR.

Table 1: Human disturbance and environmental variables used in the analysis of woody plant species composition in the village forest in the Southern highlands of Tanzania

Variables	Code	Standard unit	Mean	Standard deviation	Minimum	Maximum
Soil pH	pH	(no.)	6.2	0.3	5.5	6.5
Soil organic carbon	SOC	(%)	1.7	0.9	0.5	3.7
Elevation	ELE	(m)	997	145	773	1273
Canopy cover	COV	(%)	45.2	13.1	20	80
Distance to foot path	DFP	(m)	21.3	8.8	8	40
Soil sand content	SSC	(%)	46.3	10	26.8	69
Soil clay content	SCC	(%)	26.3	7.8	14	48
Soil silt content	SSiC	(%)	27.4	7.3	16	39.6

Statistical analyses

Cluster analysis was employed to identify important plant communities with similar characteristics using Bray–Curtis’s distance matrix and hierarchical Ward’s minimum variance. Bray–Curtis’s distance matrix was computed using abundance data for woody plants, and using Silhouette validation, the number of important clusters was obtained with the help of ‘Nbclust’ package (Thinsungnoen et al. 2015). Detection of dominant woody plant species was conducted using indicator species analysis in ‘labdsv’ package (Roberts 2016), and the two most important species based on high synoptic cover-abundance values were used to name the dominant plant communities.

Multivariate analysis was used to understand how both human disturbance and environmental variables explain spatial heterogeneity in woody plant species composition. As opposed to univariate, multivariate analysis allows the assessment of datasets involving more than one type of measurement and uncovers hidden data structures. Consequently, multivariate analysis renders conclusions close to the real field condition. Sampled plants were categorised into growth stages based on their height and DBH: seedlings (height ≤ 1.3 m and DBH ≤ 1 cm), sapling (height > 1.3 m and dbh < 5 cm) and adult (height > 1.3 m and dbh ≥ 5 cm) for the description of forest plant assemblages. Plant species that occurred in less than three plots were regarded as rare species and were removed from the vegetation matrix before the analysis. During the analysis, all the explanatory variables (human disturbance and environmental factors) were tested against all woody plant species. Before the analysis, all explanatory variables were checked for standard assumptions of the parametric test using standard diagnostic plots in package ´ggplot2´.

Detrended correspondence analysis (DCA) is often used to evaluate the turnover in species composition as well as determine gradient length important to determine the type of multivariate analysis to undertake (Hill and Gauch, 1980). So, DCA was run to the woody plant species data matrix using the function ´decorana´ in the package ´Vegan´ (Oksanen et al. 2016). In this study, the gradient length of the first DCA axis was more than four standard deviation units, suggesting that the plant species data set had an unimodal nature. Thus, canonical correspondence analysis (CCA) was used to examine the spatial variations in species composition along human disturbance and environmental gradients following Kindt and Core (2005). Before analysis, Pearson Product Moment Correlations (*r*) was computed using ´cor.test´ function to check for multicollinearity among human disturbance and environmental variables as recommended by Økland (2007). Only variables that were not highly correlated ($r < 0.7$; Table 2) were considered in the model explaining the spatial variation in woody plants at Intake forest (Loos et al. 2014).

Table 2: Pearson correlation coefficients for the variables used to explain spatial variation in woody plant species composition in the village forest in the Southern highlands of Tanzania

Variable	ELE	COV	DFP	SOC	pH	SSC	SSiC
Elevation							
Canopy cover	-0.19						
Distance to footpath	**0.46**	-0.11					
Soil organic carbon	**0.35**	0.15	-0.06				
Soil pH	0.25	0.01	0.13	**0.32**			
Soil sand content	0.05	-0.19	-0.08	**-0.54**	-0.08		
Soil silt content	-0.26	**0.42**	-0.02	0.22	**-0.39**	**-0.63**	
Soil clay content	0.19	-0.15	0.13	**0.49**	**0.46**	**-0.69**	-0.13

Standards units for predictor variables are shown on Table 1. Statistically significant correlations ($P < 0.05$) are indicated with bold numbers. The variables displayed in the table are elevation (ELE), canopy cover (COV), distance from the footpath (DFP), soil organic carbon (SOC), soil pH (pH), soil sand content (SSC) and soil silt content (SSiC).

The multivariate analysis follows parametric statistics principles, so plant species data were log-transformed to remove skewness, improve homogeneity and reduce the influence of a few dominant plants (Borcard et al. 2011). A permutation test (iterations = 1000 and α = 5%) was applied using ´Permute´ package to test whether the CCA model was significant or not (Oksanen et al. 2016). Analysis of Variance (ANOVA) was used with 499 and 199 permutations to check for the significance of individual CCA axis and predictor variables, respectively (Oksanen 2022). All CCA analyses were carried out with the help of the ´Vegan´ package, and all graphs showing the association of woody plant species with human disturbance and environmental variables drawn with function ´ordiplot´ and ´orditorp´ with scaling = 3 settings (Oksanen et al., 2016). All analyses were done in R free software for statistical computing and graphics version 4.1.3 (R Core Team 2022).

Results

Plant community structure

A total of 779 individual plants were recorded, of which 379 were seedlings (48.6%), 102 saplings (13.1%) and 298 adults (38.3%) in this study. These individuals were distributed in 27 species, 20 genera and 18 woody plant families for all the growth stages. Thirteen species were present as seedlings, 14 as saplings and 22 as adults. The five most dominant plant species were *Brachystegia spiciformis* (42.2%), *Diplorhynchus condylocarpon* (9%), *B. boehmii* (8.7%), *Faurea saligna* (5.9%) and *B. bussei* (5.1%) while the least were *Multidentia crassa*, *Diospyros squarrosa* and *Scolopia stolzii* with each species having less than 1% overall abundance. In terms of genera, the most abundant ones were

Brachystegia (56.1%), *Diplorhynchus* (9%), *Faurea* (5.9%), *Neoboutonia* (4.4%) and *Uapaca* (3.9%). *Fabaceae* (57%), *Apocynaceae* (9%), *Proteaceae* (7.1%), *Phyllanthaceae* (6.8%) and *Euphorbiaceae (*4.4%) were the first five abundant plant families. The least families with an overall abundance of less than 1% were *Rubiaceae*, *Ebenaceae*, *Salicaceae* and *Chrysobalanaceae*. It appears that the distribution patterns of species among families were not equal in the study forest. The family Fabaceae was represented by only four species (*Brachystegia spiciformis, B. boehmii*, *B. bussei* and *Pterocarpus angolensis*), equivalent to 16.7% of all recorded woody plant species. Likewise, Myrtaceae had only three species (*Syzygium guineense*, *Syzygium spp*. and *Psidium guajava*), equivalent to 12.5% of all the field-recorded plant species. Both Combretaceae and Proteaceae were each represented by two species (*Combretum molle* and *C. zeyheri*, and *F. rochetiana* and *F. saligna*), corresponding to a total of 16.7% abundance of all encountered species. Only a single plant species accounted for the remaining 14 families (54.1%). Of all the assessed woody plants, 26 species had IUCN least concern status, meaning that their populations are still abundant in the wilderness and do not deserve special attention. Only one tree species, i.e. *P. angolensis* was discovered to have a status of near-threatened. The IUCN Redlisted near-threatened tree species *P. angolensis* had few individuals, leading to only a relative abundance of 0.9% (Table 3).

Table 3: List of woody plant species recorded during vegetation survey in the village forest at the Southern highlands of Tanzania. Relative Abundance (RA) is the ratio of individual species' total frequency and the total frequency of all species combined from all the plots

Scientific name	**Family**	**Short form**	**Presence in different growth stages**			**RA (%)**
			Seedling	**Sapling**	**Adults**	
Brachystegia boehmii	Fabaceae	Braboe	✓	✓	✓	8.7
Brachystegia bussei	Fabaceae	Brabus	✓		✓	5.1
Brachystegia spiciformis	Fabaceae	Braspi	✓	✓	✓	42.2
Bridelia micrantha	Phyllanthaceae	Brimic	✓	✓		2.7
Combretum molle	Combretaceae	Commol		✓	✓	1.9
Combretum zeyheri	Combretaceae	Comzey	✓		✓	1.5
Diospyros squarrosa	Ebenaceae	Diosqu	✓	✓	✓	0.4
Diplorhynchus condylocarpon	Apocynaceae	Dipcon	✓	✓	✓	9.0
Faurea rochetiana	Proteaceae	Fauroc		✓	✓	1.2
Faurea saligna	Proteaceae	Fausal		✓	✓	3.2
Garcinia volkensii	Clusiaceae	Garvol	✓	✓	✓	1.7
Multidentia crassa	Rubiaceae	Mulcra			✓	0.3
Neoboutonia macrocalyx	Euphorbiaceae	Neomac	✓	✓	✓	4.4
Parinari excelsa	Chrysobalanaceae	Parexc1	✓	✓	✓	0.8
Pseudolachnostylis maprouneifolia	Phyllanthaceae	Psemap		✓	✓	2.6
Psidium guajava	Myrtaceae	Psigua		✓	✓	0.4
Psorospermum	Clusiaceae	Psofeb		✓	✓	1.8

febrifugum						
[*]*Pterocarpus angolensis*	Fabaceae	Pteang	✓		✓	0.9
Scolopia stolzii	Salicaceae	Scosto			✓	0.5
Syzygium guineense	Myrtaceae	Syzgui	✓			2.3
Syzygium spp.	Myrtaceae	Syzsp		✓	✓	1.8
Uapaca kirkiana	Phyllanthaceae	Uapkir	✓	✓	✓	3.9
Uapaca nitida	Phyllanthaceae	Uapnit			✓	0.3
Vitex doniana	Verbenaceae	Vitdon	✓	✓	✓	1.3
Ximenia caffra	Olacaceae	Ximcaf		✓		1.0
Zanha africana	Sapindaceae	Zanafr			✓	0.3
Fadogia ancylantha	Rubiaceae	Fadanc			✓	< 0.1

[*]IUCN near-threatened tree species and highly protected in Tanzania

Most of the woody plant species captured were found to have Dbh ≤ 10 cm, suggesting that most of these species were regenerants to young adults. Few matured woody plant species with Dbh of > 30 cm were scored in the study forest (Fig. 2). Three plant communities were identified in the study forest (Fig. 3).

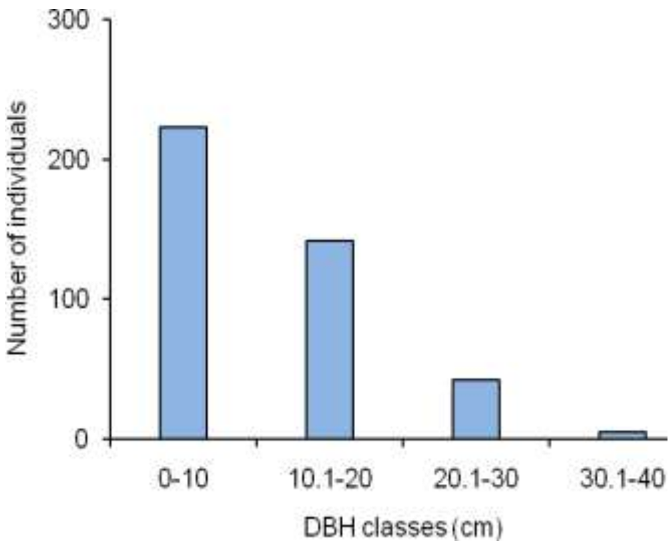

Figure 2. Diameter at breast height class distribution among woody plant species in the village forest in the Southern highlands of Tanzania (n = 24)

Gradients in plant species composition

In the present study, two environmental variables, i.e. canopy cover and soil pH were found to be the most important factors explaining significantly ($P < 0.05$) the spatial variation in woody plant species composition at Intake forest (Table 4). Soil clay content had a marginal significant effect on the spatial variation of species composition of woody plants ($P = 0.055$). Other variables, i.e. soil organic carbon, elevation, distance to the footpath, and soil and silt contents, were not important ($P > 0.05$) in explaining the spatial variation in species composition in the study forest (Table 4).

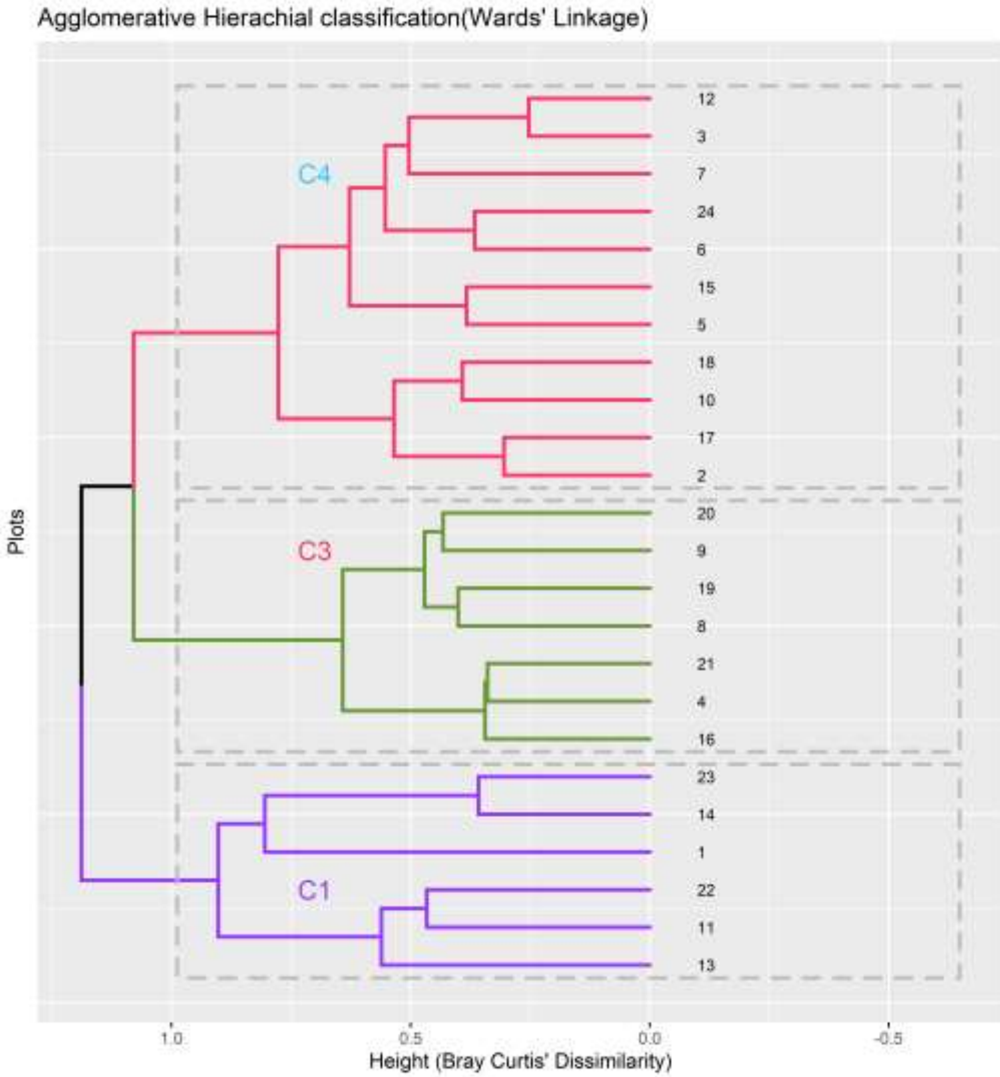

Figure 3. A dendrogram displaying plant community types in the village forest in the Southern highlands of Tanzania. The communities are named after two dominant species: C1= *Neoboutonia macrocalyx* - *Psorospermum febrifugum*, C3 = *Brachystegia spiciformis* - *Uapaca kirkiana* and C4 = *Brachystegia boehmii* - *Diplorhynchus condylocarpon* communities

Table 4: Selection of human disturbance and environmental variables explaining woody plant species composition in the village forest in the Southern highlands of Tanzania

Explanatory variable	χ^2	*F*-ratio	*P*-value
Soil pH	**0.323**	**1.674**	**0.035**
Soil organic carbon	0.209	1.086	0.345
Elevation	0.147	0.761	0.715
Canopy cover	**0.394**	**2.045**	**0.010**
Distance to footpath	0.192	0.994	0.415
Soil sand content	0.206	1.069	0.355

Soil clay content	**0.314**	**2.411**	**0.055**
Soil silt content	0.205	1.063	0.390

Standard units for different predictor variables are shown in Table 1; Variables in bold are significant at $P < 0.05$ and were considered in the final model explaining heterogeneity in species composition of woody plants.

The final CCA model had a total inertia of 4.92. However, significant explanatory variables (soil pH and canopy cover) were able to explain a total of 41.2% of the variation in species composition, equivalent to the inertia of 2.03. The first four axes explained a total of 34.3%, while the rest of the variation in species composition (i.e. 6.9%) was explained by other axes (Table 5).

Table 5: Variation in the CCA model explaining woody plant species composition in the village forest in the Southern highlands of Tanzania

	CCA ordination axes			
Attribute	**1st**	**2nd**	**3rd**	**4th**
Eigen value	0.595	0.462	0.387	0.240
Proportion explained	0.121	0.094	0.079	0.049
Cumulative proportion	0.121	0.215	0.294	0.343

Results show that the first axis ($\chi^2 = 0.595$, $F = 3.084$, $P = 0.02$) and the overall constrained ordination model ($\chi^2 = 2.025$, $F = 1.313$, $P = 0.043$) were all significant in explaining variations in species composition. This suggests that the observed patterns in the relationship between environmental variables and ecological distance are not by chance but reflect the real field situation. The total variation explained by the two canonical axes was 21.5% in woody plant composition (Table 5).

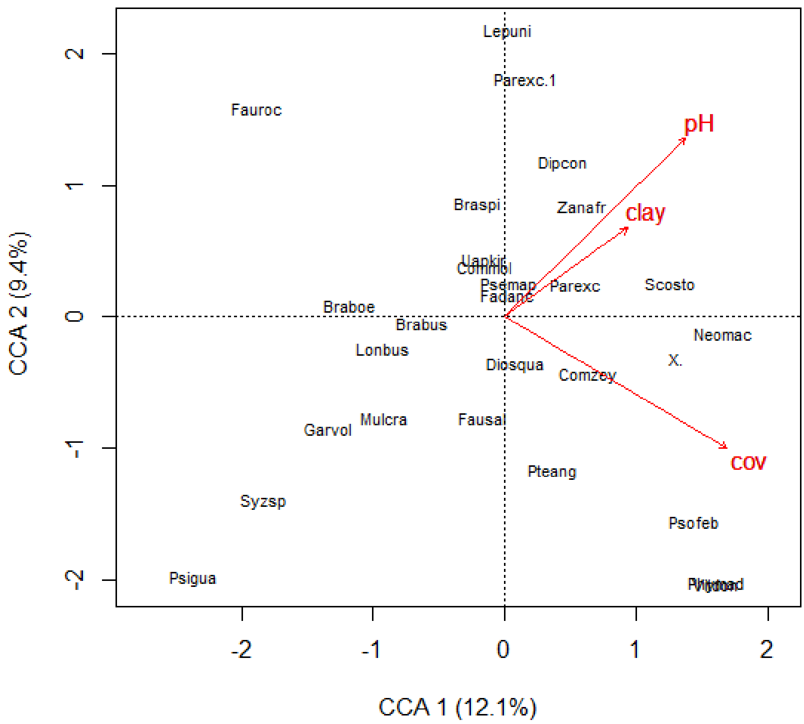

Figure 4. Canonical correspondence analysis graph for the first two axes using scaling method 3 and the human disturbance and environmental variables as constraining variables in the village forest at the Southern highlands of Tanzania. Only important constraining variables are displayed in the CCA ordination diagram: canopy cover (cov), soil pH (pH) and soil clay content (clay). Abbreviated species scientific names were curated using the first three letters from genus and species. The full names of the abbreviated plant species are shown in Table 3.

The first ordination axis correlated significantly with canopy cover (cov). In contrast, the second axis showed a strong significant correlation with soil pH (Fig. 4). This is confirmed by biplot scores for constraining variables whereby canopy cover had the score of 0.77. In contrast, pH had 0.63 both on axis 1. On axis 2, pH had a score of 0.63, while canopy cover had 0.1. Species such as *Neoboutonia macrocalyx*, *Scolopia stolzii* and *Vitex doniana* had positive species scores. In contrast, *Brachystegia bussei*, *Lonchocarpus bussei*, *Brachystegia boehmii* and *Faurea rochetiana* had negative scores both on axis 1 (Fig. 4). Plant species including *Diplorhynchus condylocarpon* and *Faurea rochetiana* were positively correlated with axis 2. In contrast, *Psorospermum febrifugum*, *Vitex doniana* and *Syzygium* species had negative scores on axis 2 (Fig. 4). *Psorospermum febrifugum* and *V. doniana* tree species related positively with canopy cover, indicating that they prefer relatively higher canopy cover (Fig. 4). On the contrary, species like *Brachystegia boehmii and Faurea rochetiana* were related negatively with the canopy cover suggesting that they prefer less of the canopy cover (Fig. 4). Soil pH related positively with *Zanha africana* and *Parinari excelsa* indicating that such tree species are favoured with the higher levels of soil pH. *Garcinia volkensii, Multidentia crassa* and *Syzygium* species related negatively with soil pH (Fig. 4), suggesting that they perform better in soils with low levels of pH. The most important canonical axes were marked by 11 woody plant species at the Intake forest (Table 6). Most of the plant species marked at least 2 axes, e.g. *V. doniana, Scolopia stolzii, Multidentia crassa* and *Faurea rochetiana* (Table 6). Only *Faurea saligna, P. angolensis* (IUCN Redlisted near-threatened tree species) and *Garcinia volkensii* marked 1 axis (Table 6).

Table 6: Woody plant species with the absolute values of the CCA axes in the village forest at the Southern highlands of Tanzania

CCA ordination axes			
1st	**2nd**	**3rd**	**4th**
Species with the largest values of canonical axes			
Vitex doniana (1.72)	*Syzygium spp.* (2.12)	*Garcinia volkensii* (2.6)	*Faurea rochetiana* (1.47)
Neoboutonia macrocalyx (1.72)	*Faurea saligna* (1.35)	*Multidentia crassa* (1.51)	*Zanha africana* (1.12)
Uapaca nitida (1.72)	*Multidentia crassa* (1.32)	*Pterocapus angolensis* (1.27)	*Uapaca nitida* (1.10)
Scolopia stolzii (1.29)	*Faurea rochetiana* (0.97)	*Scolopia stolzii* (1.16)	*Vitex doniana* (1.10)
Species with the least values of canonical axes			
Zanha africana (0.03)	*Neoboutonia macrocalyx* (0.15)	*Diplorhynchus condylocarpon* (0.17)	*Pseudolachnostylis maprouneifolia* (0.13)
Bridelia micrantha (0.02)	*Garcinia volkensii* (0.14)	*Combretum zeyheri* (0.16)	*Neoboutonia macrocalyx* (0.07)
Combretum zeyheri (0.01)	*Scolopia stolzii* (0.03)	*Pseudolachnostylis maprouneifolia* (0.13)	*Syzygium spp.* (0.10)

Discussion

Information on community structure, such as plant species composition, is important for successful restoration and establishing priority baseline information for future monitoring activities, particularly for recently protected village forests following changes in forest tenure and access to forest resources. It is, therefore, important that the status of forest plant assemblages is well established for future assessments of changes in standing stocks, forest health and resource utilisation. Plant species of the genus *Brachystegia* appear to dominate the study forest, with an overall abundance of 56.1%. Equally true, the Fabaceae family was the most dominant (57%) among all the recorded 18 plant families. These two facts confirm that, indeed, the study forest is composed of miombo woodlands with a good composition of woody plant species (Jew et al. 2016; Gondwe et al. 2020). It is widely known that miombo woodlands are composed of three genera, namely *Brachystegia, Julbernardia* and/or *Isoberlinia,* in the legume subfamily Caesalpinioideae which distinguishes it from other African savanna vegetation types (Campbell 1996; Ribeiro et al. 2020). These woodlands are estimated to cover 270 million hectares in 11 countries in eastern, southern and central Africa (Chidumayo 2019). In Tanzania, it covers about 44 million hectares, equivalent to 91% of the total forested area (Abdallah and Monela 2007; MNRT 2015). Most of the miombo woodlands are found in the village and general lands and, therefore, important for rural livelihood, including as a source of fuelwood, food, medicine, construction materials (fibre, withies, poles and timber), domestic and irrigation water and income (Luoga et al., 2004; Njana et al. 2013; Andrew et al. 2023).

The study forest has demonstrated a fair representation of individuals in different growth stages, i.e. seedlings, saplings and adults (Table 3). Also, the distribution of tree individuals among DBH size classes showed the usual reverse J shape. This distribution shows a usual trend often observed in natural forests and woodlands where stem density decreases with the increase in diameter. For matured forests, a reverse J-shaped distribution may indicate a stable and normal population and good recruitment of late-successional species. Thus, Intake Forest can be considered mature with a stable population and good recruitment of species for biodiversity conservation and sustainability. The fact that miombo covers a large area (Ribeiro et al. 2020) forms an association with mycorrhizae (Munyanziza 1994; Campbell 1996) and is resilient to human disturbances (Luoga et al. 2004) and harsh weather conditions (Chidumayo 1997) makes it have an overall good composition of woody plant species. In fact, miombo is one of the most diverse and resilient African savanna formations in plant species composition, even though the composition of canopy tree species is poor (Malmer 2007). A few individuals of the IUCN Redlisted near-threatened tree species and highly protected plant in Tanzania *P. angolensis,* were recorded, signifying that it is rare in the study forest. Of all the seventy-two 1 x 1 m subplots surveyed, only four individual seedlings and three individual adults were recorded. The likely explanations for the recorded low abundance of individuals in the study forest are intensified harvesting and a very low recruitment rate to enable the existence of higher successful populations of the species. However, since stumps of *P. angolensis* were not encountered in the field during the surveys, harvesting has not contributed to the low abundance of the concern species. It has instead been reported that a good number of valuable miombo tree species experience inherent inadequate natural regeneration (Vyamana et al. 2021). Existing empirical findings reveal that of all the fruits produced by *P. angolensis,* only 2% are able to germinate in the field (Boaler 1966). The results of the low abundance of *P. angolensis* are congruent with other studies in the miombo ecoregion. For example, studying utilisation and its effects on community structure of miombo woodlands, it was reported that despite the intensive surveys, only five seedlings of *P. angolensis* were scored (Jew et al. 2016). Also, Caro et al. (2005) studied the recruitment of *P.*

angolensis in the wild and concluded that there was low natural recruitment of *P. angolensis* even in highly protected areas like National Parks. This means that future viable wild populations of *P. angolensis* have to be secured by circumventing the low recruitment rate in natural settings, for example, by using assisted in situ conservation approaches (Chidumayo and Frost 1996; Msanga et al. 2018). Consequently, this will, on a long-term basis, safeguard the species composition of miombo woodlands and its environmental as well as socio-economic benefits.

Canopy cover and soil pH were the two most important environmental variables explaining the spatial variation in species composition of woody plants in the study system (Table 3: Fig. 4). Canopy cover provides several sets of information, including on productivity, habitat integrity and above ground biomass and is, therefore, an important attribute of forest plant species assemblages (Wu et al. 2019). Although canopy cover can reach 100% in undisturbed miombo woodlands (Campbell 1996), less cover (< 100%) provides comparative advantages for the establishment and successful development of different plant species, which enhances the overall community composition. Research has shown that canopy cover facilitates the survival of less drought-tolerant species, especially in areas of the Miombo ecoregion, which is known to have a dry period of 5-7 months (Campbell 1996; Chidumayo 2019). Ludewa is characterised by tropical climate conditions with a single rainfall season, often from November to May and a dry period from June to October (Ludewa District Council 2019). It has been found that moisture is important for the early establishment of plant species as well as growth in miombo woodlands (Chidumayo 1997; Malmer 2007). So, canopy cover is important to reduce moisture loss (through evapotranspiration) and stress for less drought tolerant species during the dry period (~5 months), consequently enriching plant species composition of Intake Forest. Canopy cover can also mediate the development of different understorey miombo tree species, such as those in *Combretum* and *Diplorhynchus* genera (Jew et al. 2016; Bulenga et al. 2021), as well as the composition of certain shrubs and small-seeded woody plant species e.g. *P. febrifugum*. A decrease in crown cover favours the growth of stunted seedlings and saplings in such ecosystems, thus creating a rich composition of miombo woody plant species (Frost 1996, Malmer 2007). In other areas, canopy cover has been demonstrated to influence nutrient availability through the production of biomass and the addition of litter to the forest soils (Økland et al., 2003).

Soil pH was the second most important variable to predict the spatial variation of woody plant species composition in the study forest. Some species, e.g. *Z. africana* and *P. excelsa*, related positively with soil pH, while others, e.g. *G. volkensii*, *M. crassa* and *Syzygium* species, related negatively. This is a true reflection of the diversity of ecological requirements to meet different species-specific physiological needs among the miombo tree species (Bulenga et al. 2021). It is well known that soil nutrients play an essential role in the formation of plant communities in tropical regions (Perroni-Ventura et al. 2006; Ribeiro et al. 2020). Soil pH is an essential nutrient factor supporting the establishment and growth of tree species, as different tree species have different optimal ranges in which they perform best. Soil pH regulates the dynamics of a number of macro and micro-nutrients important for tree establishment and growth (Schaffers 2002). Because miombo woodlands occur over extensive areas with different geology and history, tree species may establish themselves in soil groups (e.g. Acrisols, Ferralsols, Luvisols and Nitisols) with different pH ranges (Frost 1996). This study recorded a mean soil pH of 6.2 (acidic to slightly acidic with the range of 5.5 - 6.5) in the Intake Forest. Reported soil pH in the current study is comparable to pH values that have been recorded elsewhere in miombo woodlands (see, for example, Frost 1996; Chidumayo and Frost 1996; Shirima et al. 2015). Most miombo tree species occur on acidic soils with a largely common pH range of 4 to 6. This signifies that higher levels of acidity interfere with the uptake of important nutrients, whereas higher alkalinity negatively affects the growth of miombo tree species (Schaffers 2002; Riesch et al. 2018), which overall affects the plant species composition. Woody plant species composition related marginally significantly to the clay soil content (P = 0.055; Table 3) as also attested by the history of Intake Forest (Mombo et al., 2019; Ludewa District Council, 2019).

Conclusion

Although Intake Forest has recently been declared a village land forest reserve, this research has established that it has a good composition of miombo woody plant species, including one IUCN Redlisted near-threatened, and therefore, the forest is important for the conservation of plant biodiversity. The fact that a good number of native woody plant species exist in the forest is a clear demonstration that the reserve is still in good condition, something to be upheld under the new forest protection status. Different important woody plant species (i.e. trees and shrubs) were recorded, but overall, *Brachystegia* species dominated the composition, confirming that, indeed, the focal forest formation is miombo woodlands occurring in eastern, southern and western Tanzania (Abdallah and Monela 2007).

Two environmental variables, i.e. canopy cover and soil pH were important in explaining the spatial heterogeneity of the composition of woody plants. Canopy cover reduces moisture loss and stress and ensures nutrient availability via biomass accumulation and litter addition, while soil pH facilitates the uptake of different essential macro and micro nutrients by plants. The study forest is part of the Eastern Afromontane biodiversity hotspot, which is important not only for biodiversity conservation but also for other wide-reaching benefits, including socio-economic opportunities as well as ecosystem services. Intake forest has recently been given a new protection status, i.e. village land forest reserve whereby the ownership and management are devoted to the villagers, but day-to-day operations are run by the elected village environmental committee assisted with approved bylaws (MNRT 2007). The maintenance of current plant assemblages must be enhanced to ensure the sustainability of Intake Forest and the large Eastern Afromontane biodiversity hotspot in the new forest governance arrangements. Enforcement of restrictions underlined in the bylaws, e.g. harvesting of rare and near-threatened species, e.g. *P. angolensis,* as well as dampening all practices that change the natural condition of canopy cover and soil pH may facilitate recovery of such species to safeguard the remaining village forests, biodiversity and rural livelihoods.

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Data availability

The datasets analysed during the current study are available from the corresponding author upon reasonable request.

Declaration of competing interests

There is no relevant competing financial and non-financial interest to disclose.

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