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Community structure and drivers of wet miombo woodlands in the Eastern Afromontane biodiversity hotspot

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Abstract

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Despite their ecological and socio-economic importance, wet miombo woodlands in Eastern Afromontane biodiversity hotspots are increasingly threatened by anthropogenic disturbances and changes in natural environmental conditions affecting their ecosystem services provisioning and environmental sustainability. Understanding of key factors driving wet miombo community structure in village forests is vital for restoring ecosystem's functions and integrity. The study used standard ecological methods to examine important human disturbance and environmental variables that determine wet miombo woody plant species total abundance, richness, evenness and diversity using 24 (10 m × 10 m) plots and 72 (1 m × 1 m) subplots in Intake village land forest reserve Southern Tanzania. The forest scored Shannon-Wiener diversity index (H′) of 2.3 (± 0.4 SD) and Pielou's species evenness index (*J*′) of 0.7 (± 0.14). Species total abundance was positively ($P < 0.05$) related to soil pH and soil sand content but negatively ($P < 0.05$) related to elevation. Of all the human disturbance and environmental variables assessed, only canopy cover was associated positively ($P < 0.05$) with *J*′ and H′ of woody plants. None of the tested human disturbance variables could explain significantly ($P > 0.05$) the spatial variation in total abundance, richness, evenness and diversity, suggesting that environmental variables have relatively more influence on the study woodlands. Maintenance of present soil pH, soil sand content and canopy cover facilitates the restoration of plant diversity in wet miombo woodlands of Eastern Afromontane biodiversity hotspots for biodiversity protection, environmental sustainability and broad reach enhanced socio-economic benefits.

Keywords

biodiversity, diversity, ecosystem services, richness, woody species, Tanzania

Introduction

Miombo woodlands are one of the most extensive tropical savanna biomes spanning ten countries in central and southern Africa (Dziba et al., 2020). Despite its extensiveness (about 3.6 million km^2) covering different habitats, landscapes and countries, the woodlands are floristically characterized by the unique presence of three major genera i.e. *Brachystegia*, *Julbernadia* and *Isoberlinia* (White, 1983). It comprises about 8,500 plant species (Assédé et al., 2020), including rare, endemic, unique, flagship and threatened species of local, national, regional and global importance. The woodlands are essential not only for plant biodiversity but also as reliable critical habitats for a diversity of many iconic wildlife, including the big five, birds, reptiles, amphibians and the array of insect species (Ribeiro et al., 2020). It has been estimated that nearly 100 million people across Southern Africa depend on miombo woodlands for direct and indirect ecosystem goods and services, including foods (e.g. fruits, wild vegetables and mushrooms), fuelwood (firewood and charcoal), medicine, income, construction materials and water (Ryan et

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al., 2016; IPBES, 2020). Because of permanency, extensive coverage, and ecological integrity, miombo woodlands have recently received added attention in national efforts to Reduce Emissions from Deforestation and Land Degradation plus (REDD+) in the region (Katani et al., 2015; Mwakalukwa and Andrew, 2024).

Present statistics show that around 70% of the rural and urban dwellers depend on biomass energy in the form of charcoal and firewood from the miombo ecoregion (Nyamoga and Solberg, 2019) due to availability and affordability. Unfortunately, global trends show clearly that prices of non-biomass energy sources have increasingly risen with no promising signs of stabilizing soon, meaning that people might be forced to continue relying on or embarking on biomass energy, threatening further the sustainability of the remaining miombo woodlands (Vyamana et al., 2023; Andrew et al., 2023) such as wet miombo in the Eastern Afromontane biodiversity hotspot. Experience shows that miombo woodland areas have fallen victim to unplanned land use land cover changes such as small to large scale agricultural expansion and large infrastructure developments e.g. railway lines, major roads and mining and industrial sites, negatively affecting the plant community structure, including species abundance, richness and diversity (Dziba et al., 2020; Montfort et al., 2021). If this trend is left unchecked, it might have far-reaching implications, including a reduced supply of ecosystem goods and services (Appiagyei et al., 2023), consequently affecting the environment, and natural resources dependent on rural livelihoods and the economy. It is therefore important and with urgency that miombo woodlands are restored to preserve the ecosystem structure, functions and integrity.

In efforts to restore the miombo woodlands, many studies have been undertaken to understand the key factors that potentially drive miombo woodlands plant community structure, including species composition, richness and diversity during the last decades (see e.g. Mangora, 2005; Mwakalukwa et al., 2014; Bulenga et al., 2021; Njoghomi et al., 2021). Unfortunately, most of these studies were carried out in areas receiving rainfall less than 1,000 mm per annum (dry miombo) due to among other factors good protection and easy accessibility, while on the contrary miombo woodlands in areas receiving more than 1,000 mm per annum (wet miombo) have remained little studied (Jew et al., 2016; Mwakalukwa and Andrew, 2024). However, wet miombo woodlands have more complex plant community structure (e.g. higher species richness, higher canopy height and tall grasses) due to high supply of growth resources including moisture and nutrients as opposed to dry miombo woodlands (Malmer, 2007; Timberlake and Chidumayo, 2011). Accordingly, this means that successful restoration of wet miombo woodlands requires better understanding of dynamics of community structure and key drivers, which is unfortunately limited at the moment (Jew et al., 2016; Gumbo et al., 2018). Also, wet miombo woodlands are more prone to encroachments for agricultural expansion due to high rainfall, potential fertile soils, and more human disturbances through illegal harvesting of high-value timber species and charcoal production due to remoteness (Andrew, 2023). Among all the miombo studies on the dynamics of plant community structure and driving factors, none has focused on recently protected areas such as Village Land Forest Reserves (VLFRs). Such protected areas need more ecological knowledge to accelerate recovery from the threats and be able to provide sustainably anticipated ecosystem goods and services to rural and urban communities. This study was designed to i) determine plant community structure in terms of species abundance, richness, evenness and diversity, and ii) assess human disturbance and environmental variables that potentially influence the miombo community structure as an entry point for restoration and resilience building. This study reports for the first time factors that potentially influence species total abundance, richness, evenness and diversity within wet miombo woodlands of Intake Village Land Forest Reserve in Ludewa District, Tanzania. The generated information assists in the effective implementation and realization of the Eastern Afromontane biodiversity hotspot objectives, including sustainable forest management, biodiversity conservation and enhanced rural livelihoods.

Materials and methods

Study area

This research was carried out in a remote landscape within the Eastern Afromontane biodiversity hotspot of Ludewa Tanzania. Ludewa is between 34°10’E−35°21’E and 09°30’S−10°36’S and occupies a total surface area of 8,397 km^2 distributed into 6,325 km^2 of terrestrial and 2,072 km^2 of aquatic areas. Due to large size, good soils and favourable climate in terms of rainfall and temperature, the district has high potentials for commercial production activities including agriculture, livestock keeping and fishing (Haule et al., 2013; Andrew, 2023). Njombe Rural and Makete Districts border Ludewa on the north, while to the southeast by the Ruvuma Region and southwest by Malawi across Lake Nyasa, a transboundary lake. There are three major ethnic groups Wapangwa, Wakisi and Wamanda, who contribute to the cultural diversity of people in Ludewa District. Ludewa experiences mild and generally warm and temperate climates with average temperature of 19.2 °C per annum (Mwakalukwa and Andrew et al., 2024). July experiences the lowest average temperature whereas November is the hottest month of the year. The rain season starts in mid-December and continues until April with an average precipitation of 1,215 mm per annum (Haule et al., 2013).

The focus of the study was Intake village land forest reserve found about 65 km from Ludewa town in Ibumi Ward, Masimavalafu village (Fig. 1). Significant portion of Ludewa is sitting on the large Kipengere mountain ranges which rise up to around 2,961 m asl. Although soils of Ludewa are variable, Intake forest is dominated by clay to sand soils (Andrew, 2023). These soils are originated from the ancient crystalline rocks which are part of the

Kipengere ranges. At Intake, hills, mountains and valleys characterize the topography. Declared village land forest reserve in 2019 Intake forest has an area of ca. 5,533.2 ha and is important for providing timber and non-timber forest products (Andrew, 2023). The forest hosts 17 important species of mammals including *Panthera pardus* (Vulnerable), *Aonyx capensis* (Near threatened), *Cephalophus harveyi*, *Hystrix africaeaustralis*, *Potamochoerus larvatus* and *Tragelaphus strepsiceros*. Seventy-two (72) important bird species, including *Oriolus larvatus*, *Stephanoaetus coronatus*, *Legonosticta ribricata*, *Oriolus auratus*, *Chloropicus namaquus* and *Halcyon albiventris*, have been reported in the Intake forest (Nyanghura, 2017). No wonder the Intake forest is part of the Eastern Afromontane biodiversity hotspot − one of the earth's biodiversity hotspots. Masimavalafu (where Intake forest is found) is among the few villages with Community Based Forest Management (CBFM) governance arrangement in Ludewa. There are no available recent official data for village population yet, but Ibumi ward has 2,637 people and 639 households (URT, 2022). Following the declaration, access to the forest and utilization of forest resources is regulated by Village Council through village level CBFM committee (MNRT, 2007). Intake forest is bordered with Mhambalasi River to the west and several important streams to the east and north. Thus, the forest was named 'Intake' as it is the major source of domestic and irrigation water (catchment forest) to thousands of villagers living in the Masimavalafu village and beyond (Ludewa District Council, 2019; Andrew et al., 2023). The dominant vegetation in Masimavalafu is wet miombo woodland on hilly and upland areas, wooded or bushed grassland on undulating landscapes and grasses and bushes on floodplains. According to White (1983) miombo woodlands have been categorized into wet (i.e. average rainfall of ≥1,000 mm per annum) and dry (average rainfall of <1,000 mm per annum) (White, 1983) and therefore the study forest is the wet miombo woodlands, which are generally understudied (Jew et al., 2016; Andrew et al., 2023).

Data collection

A pre-survey was conducted to familiarize with the Intake forest environment, including boundaries, topography, dominant vegetation type and accessibility with the help of local field guides. The same was also carried out to test field methods including field equipment e.g. caliper and global positioning system (GPS, Garmin 76cx), and plants survey protocol adopted from National Forest Resources Monitoring and Assessment Field Manual for Biophysical Survey 2010 (MNRT, 2010). Following field experience, some adjustments were made on the equipment and survey protocol to best fit the real situation on the ground. To study species abundance, richness, evenness and diversity of woody plants, a random sampling nested design was adopted whereby 24 plots of 10 m × 10 m (for saplings and adult trees and shrubs) and 72 subplots of 1 m × 1 m (for seedlings) were surveyed between 2015 and 2016 in Intake forest, southern Tanzania. Within each designated plot all woody plants i.e. seedlings, sapling and adults were enumerated (i.e. species identity and Diameter at Breast Height – DBH) accordingly. In measuring DBH all forked trees below the breast height (i.e. 1.3 m above the ground) were treated as separate individuals, while those that were forked above 1.3 m were considered as one individual. In cases where the individual was swollen, injured or had

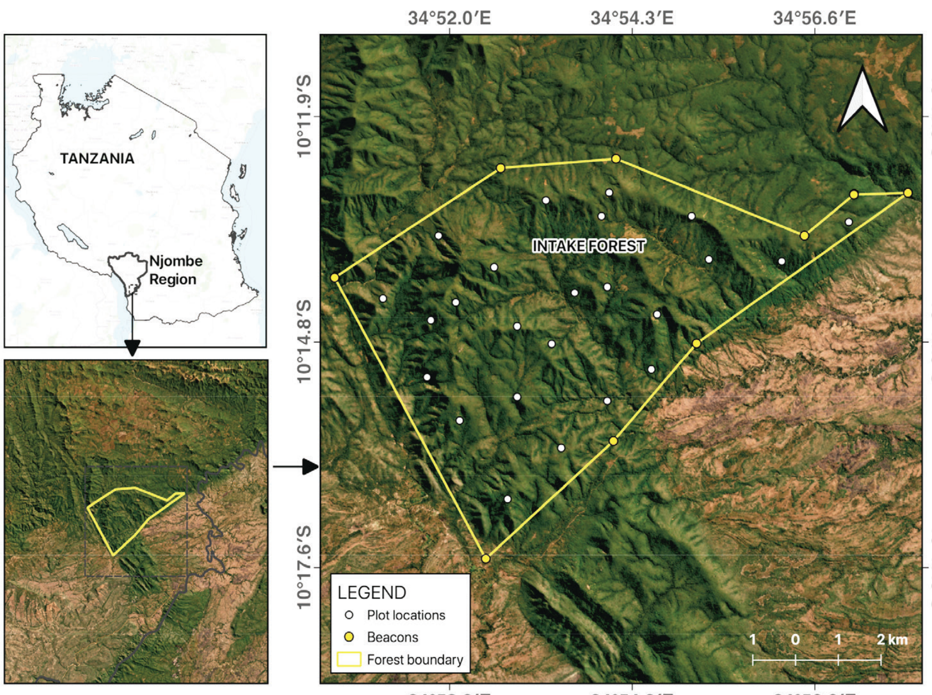

Fig. 1. A map showing the location of study area in Tanzania.

Table 1. Important human disturbance and environmental variables considered during the analysis of community structure at Intake village land forest reserve, Ludewa, Tanzania

Predictor variable and (unit)	Mean ± SD	Confidence interval (95%)	Minimum	Maximum
Elevation (m)	997 ± 145	938.99–1,055.01	773	1,273
Distance to footpath (m)	21.3 ± 8.8	17.78−24.82	8	40
Soil pH (no.)	6.2 ± 0.3	5.90−6.32	5.5	6.5
Soil clay content (%)	26.3 ± 7.8	23.18−29.42	14	48
Soil silt content (%)	27.4 ± 7.3	24.48−30.32	16	39.6
Soil sand content (%)	46.3 ± 10	42.30−50.30	26.8	69
Soil organic carbon (%)	1.7 ± 0.9	1.34−2.06	0.5	3.7
Canopy cover (%)	45.2 ± 13.1	39.96−50.44	20	80

deformities at 1.3 m measurements for DBH were done either above or below to avoid over- or underestimation of the actual value of DBH (MNRT, 2010). Seedlings (height ≤ 1.3 m and DBH ≤ 1 cm) were enumerated in each plot using randomly positioned three 1 × 1 m subplots. A caliper was used to measure DBH of all individuals with DBH > 1 cm and frequency and species identities were recorded in each plot. To avoid spatial autocorrelation in abundance, richness, evenness and diversity surveyed plots were positioned around 450 m apart (Andrew, 2023). The distance between plots also ensured that a wide range of human disturbance and environmental gradients were captured. All scored woody plants were identified using field guides (Mbuya et al., 1994; Smith and Allen, 2004) whenever possible, and those that could not be identified in field voucher specimens were collected, processed and deposited at the Arusha National Herbarium of Tanzania for identity confirmation. The naming of all sampled woody plant species follows Flora of Tropical East Africa.

Eight human disturbance and environmental variables considered to be important for plant community structure in wet miombo woodlands were measured (Table 1). Geographical location and elevation readings were taken at the centre of each plot using a handheld GPS (Mwakalukwa and Andrew, 2024). To estimate linear distance between plot and nearest footpath (human disturbance indicator) a researcher and 2 research assistants estimated visually the distance separately and the average was recorded. Soil samples were collected from the top layer (15 cm) to obtain data for soil pH, soil texture (silt, clay and sand) and soil organic carbon content using a 5 cm diameter soil auger (Bulenga et al., 2021; Andrew, 2023). Four soil samples were collected from the four corners and at the plot's centre, then aggregated to obtain a composite sample for analysis at Sokoine University of Agriculture (SUA), Morogoro, Tanzania. The pH was determined using Beckman's glass electrode pH meter, soil organic carbon using LECO carbon analyser, and soil texture using particle size analysis by hydrometer assisted with the USDA texture triangle. The same procedure used in linear distance estimation was also used in the assessment of canopy cover in a plot.

Data analysis

Woody plant species accumulation curve (SAC) was generated using function 'specaccum' in the package 'Vegan' (Oksanen et al., 2013) to check whether the main sample size used (n = 24) was sufficient to adequately characterize the woody plant community in Intake forest. Analysis was done to understand the relationship between the abundance (*Ab*), richness (*S*), Pielou's species evenness index (J') and Shannon-Wiener diversity index (H′), and human disturbance and environmental variables in Intake forest reserve. Dependent and independent variables were separately computed per plot before the actual analysis. In this case dependent factors were *Ab*, *S*, J' and H′, whereas independent variables were human disturbance and environmental factors (Table 1). Because soil sand content related with soil clay content ($r = -0.69$; $P < 0.05$) and soil silt content ($r = -0.63$; $P < 0.05$), only soil sand content was considered in the subsequent analysis. Species abundance was the total number of all individual trees and shrubs from different species and species richness was the total number of species per plot. Shannon-Wiener diversity index given as

$$H = -\sum_{i=1}^{n} p_i \cdot \ln >(p_i)$$

where H′ is Shannon diversity index, s is number of species in a plot and Pi is proportion of individuals of the i^{th} species expressed as a proportion of total abundance in the plot and ln is natural logarithm, was computed using the 'Diversity' function in the package 'Vegan' (Oksanen et al., 2013). In this work H′ was chosen because it integrates well richness and evenness, it is affected little by sample size and is also widely used in ecological studies (Krebs, 1989; Magurran and McGill, 2011; Barna and Mihál, 2024). Pielou's species evenness index which shows the relative distribution of individuals among plant species in a plot was calculated as $J' = H'/\ln S \equiv H'/H'_{max}$ (Pielou, 1975) where J', H′ and S are as explained above and H'_{max} is maximum value of H′. Generalized linear models (GLMs) were used to evaluate how independent variables influence dependent factors using appropriate link functions and distribution following Crawley (2012). Therefore, GLMs for species total abundance and richness were run using logarithmic link function and Poisson distribution. In contrast, species evenness and diversity models were run using the identity link function and normal distribution of errors. Backward elimination of non-significant independent variables was used to build GLMs starting with the full models, with the help of Akaike information criterion and alpha (α) (Crawley, 2012). In all the analysis, the significance level (α) was considered to be ≤ 0.05

for all the significant relationships. Final models were validated using standard diagnostic plots and all the analyses were performed in R 4.1.3 (R Core TEAM, 2022).

Results

Plant species richness and diversity

The species-area curve indicated the rate of encountering new species whereby the number of species against the area sampled increased sharply at first up to the 20^{th} plot and then slowed down as the rare species were increasingly added up to asymptote at around the 24^{th} plot (Fig. 2). This trend confirms that the number of plots laid was sufficient to adequately characterize the whole range of woody plant species in the study forest. Intake forest had an average number of individuals reaching 32.5 (± 10.9 SD) in a plot, whereas the total number of species or species richness was 7.6 (± 1.9). The average for Shannon-Wiener diversity index (H′) was 2.3 (± 0.4), and Pielou's species evenness index (*J′*) was 0.7 (± 0.14) in a plot. The lowest number of individuals in a plot was 20, whereas the highest was 57. The smallest number of species in a plot was 5, whereas the highest was 14.

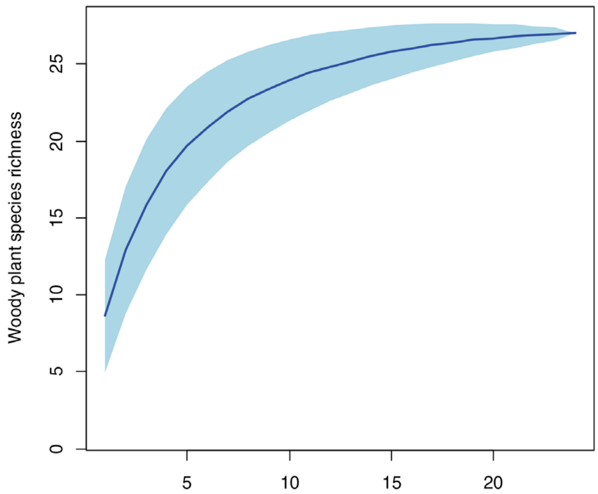

Fig. 2. Woody plant species accumulation curve for the Intake village land forest reserve, Ludewa, Tanzania (n = 24).

Effects of human disturbance and environmental variables

There was a significant ($P < 0.05$) negative relationship between species total abundance and elevation (Table 2; Fig. 3a). Species total abundance was positively significantly ($P < 0.05$) related with the soil pH and soil sand content (Table 2, Fig. 3b and c). No relationships existed between species total abundance and distance from footpath and soil organic carbon (Table 2). Species richness for woody plants was not significantly ($P > 0.05$) related to any of the independent variables tested. Of all the independent variables assessed, only canopy cover related positively significantly ($P > 0.05$) to the Pielou's species evenness index (Table 3, Fig. 3d) and Shannon-Weiner diversity index of woody plants (Table 4, Fig. 3e).

Discussion

Plant species sampling and diversity

It is widely known that sample size (n) is an important attribute to consider in ecological studies to be able to draw meaningful conclusions for the study population. In this study, a total of 24 (10 m × 10 m) plots and 72 (1 m × 1 m) subplots were used to understand the relationship between community structure (i.e. species total abundance, richness, evenness and diversity), and human disturbance and environmental variables in wet miombo woodlands. Species-area curve has demonstrated that indeed, the number of main plots considered (n = 24) was adequate to characterize the Intake forest and that even if more plots could have been sampled, there would be no significant additional woody plant species scored (Fig. 2). Accordingly, future related ecological studies may consider using comparable plot number and sizes to arrive to the equivalent findings. The distribution of tree individuals among DBH size classes showed 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 (Shirima et al., 2011; Andrew, 2023).

Table 2. The relationship between woody plant species total abundance and human disturbance and environmental variables for Intake village land forest reserve, Ludewa, Tanzania

Predictor variable	Estimate	Std. error	t-value	P-value
Intercept	**−30.64**	**9.885**	**−3.099**	**0.002**
Elevation	**−0.001**	**0.001**	**−2.117**	**0.034**
Canopy cover	−0.008	0.073	−0.153	0.204
Distance from footpath	0.007	0.006	1.325	0.185
Soil organic carbon	−0.007	0.067	−0.110	0.912
Soil pH	**0.742**	**0.197**	**3.766**	**<0.001**
Soil sand content	**0.308**	**0.095**	**3.262**	**0.001**

Units for predictor variables are shown in Table 1. Significant variables are shown in bold.

Table 3. The relationship between species evenness and human disturbance and environmental variables for Intake village land forest reserve, Ludewa, Tanzania

Independent variable	Estimate	Std. error	t-value	P-value
Intercept	13.93	7.717	1.805	0.091
Elevation	0.001	0.001	1.485	0.158
Canopy cover	**0.006**	**0.002**	**2.248**	**0.040**
Distance from footpath	−0.005	0.004	−1.247	0.232
Soil organic carbon	−0.005	0.049	−0.096	0.925
Soil pH	−0.266	0.151	−1.754	0.099
Soil sand content	−0.119	0.073	−1.626	0.125

Units for predictor variables are shown in Table 1. Significant variables are shown in bold.

Table 4. The relationship between species diversity and human disturbance and environmental variables for Intake village land forest reserve, Ludewa, Tanzania

Independent variable	Estimate	Std. error	t-value	P-value
Intercept	14.623	22.649	0.646	0.528
Elevation	0.001	0.001	0.982	0.342
Canopy cover	**0.016**	**0.007**	**2.217**	**0.043**
Distance from footpath	−0.008	0.012	−0.674	0.511
Soil organic carbon	−0.040	0.142	−0.282	0.782
Soil pH	−0.354	0.444	−0.796	0.438
Soil sand content	0.117	0.215	−0.546	0.593

Units for predictor variables are shown in Table 1. Significant variables are shown in bold.

This study has revealed that Intake forest has a good variety of woody plant species or species diversity (H´ = 2.3). It has been reported that H´ often ranges between 1.5 and 4.5 and rarely exceeds 5 (Magurran and McGill, 2011; Barna and Mihál, 2024), thus the study woodlands have medium diversity including variety of typical miombo plant species such as *Brachystegia spiciformis*, *B. boehmii* and *Diplorhynchus condylocarpon*. The value of species diversity reported for Intake (2.3, average rainfall 1,215 mm year^{-1}) is higher than those reported from other wet miombo woodlands within the region such as Nyanganje forest reserve (average of 2.05, average rainfall 1,400 mm year^{-1}, Shirima et al., 2011) and Iwuma forest reserve (1.3, average rainfall 1,450 mm year^{-1}, Mwampashi, 2013), both in Tanzania. It is lower than the values reported from Chunya District in Tanzania (3.2, average rainfall 1,199.5 mm year^{-1}, Jew et al., 2016) and Copperbelt Province in Zambia (2.8, average rainfall 1,450 mm year^{-1}, Kalaba et al., 2013). Observed differences in the species diversity might be due to variations in methodology, including sample size used (n) and size of trees measured, disturbance histories, and presiding environmental conditions (Gumbo et al., 2018; Montfort et al., 2021). Nevertheless, reported species diversity in this and compared studies are within the reported ranges of miombo woodlands in sub-Saharan Africa.

Effects of human disturbance and environmental variables

Species total abundance related negatively to the elevation variable in this study (Table 2, Fig. 3a). The elevation is a complex physiographic variable that may relate to temperature and rainfall. In this study, it ranged from 773 to 1,273 m asl. The negative relationship perhaps shows also that some miombo plant species in the study woodlands prefer intermediate elevation to optimize utilization of available growth resources such as nutrients and moisture. The other probable explanations for such a relationship could be that as the elevation increases, tough terrains and remoteness increases too, creating a safe environment for illegal harvesting of preferred woody species (Andrew et al., 2023; Andrew, 2023) which certainly in return reduces the total abundance.

Species total abundance was related positively with soil pH and soil sand content in the studied woodlands (Table 2, Fig. 3b, c). Miombo woody plants, like other tropical plant species occur and perform optimally under a certain range of soil acidity and alkalinity reported to be 4.2–6.9 in most areas of central and southern Africa (Frost, 1996; Malmer, 2007). Positive relationship conceivably shows that increasing pH favours the total abundance of woody plant species through enhanced availability and uptake of essential nutrients such as N, P and K (Kumar et al., 2010; Ribeiro et al., 2020; Bulenga et al., 2021). Soil pH generally mediates chemical reactions involving essential nutrients, which support the establishment and development of different plant species (Riesch et al., 2018; Andrew, 2023). It is also known that a substantial number of miombo species form associations with vesicular-arbuscular mycorrhizae for mutual benefits, including taping essential nutrients from the soil and nutrition provisioning through photosynthesis (Campbell, 1996; Syampungani et al., 2020). Thus, in this case, maintenance of soil pH may also be important to uphold the favourable environmental conditions for such a beneficial relationship to successfully function with good outcomes on the increased abundance of woody plants. A positive association observed may also

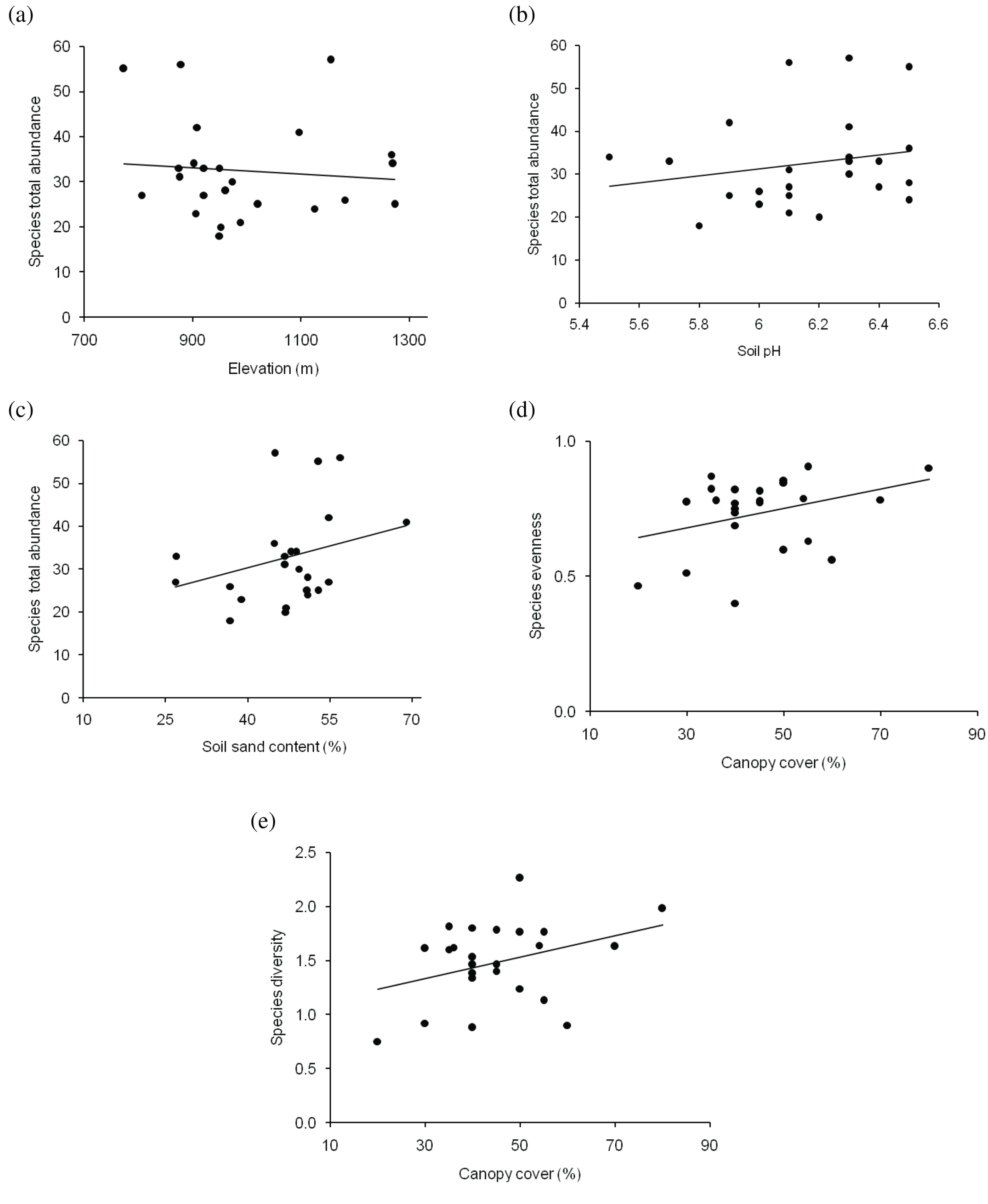

Fig. 3. The relationship between species total abundance, evenness and diversity and human disturbance and environmental variables for Intake village land forest reserve, Ludewa, Tanzania. Only statistically significant associations ($P < 0.05$) from generalized linear models multiple regressions are shown.

mean a wide range of pH needed to meet different physiological requirements of highly diverse miombo woody plant species covering different habitats and landscapes (Chidumayo, 1997; Ribeiro et al., 2020). Research developments in the ecology of miombo woodlands highlight that miombo tree species are widely distributed over different soil types including clay and sandy soils in central and southern Africa (Frost, 1996; Campbell, 1996). Soils of Intake are generally clay-to-sand soils derived from ancient crystalline rocks. As reported elsewhere, the existing miombo species appear to perform best in the sand soils of Intake forest reserve (Ludewa District Council, 2019).

Species evenness and diversity were positively related to canopy cover at Intake forest reserve (Table 3 and 4, Fig. 3d and e), suggesting that the canopy cover enhances the two community properties in various ways. One likely way is to improve survival of less drought tolerant woody plant species, especially during prolonged dry periods. It is known that the dry period in miombo ecoregion is often between 5 to 7 months (Malmer, 2007; Ribeiro et al., 2020) and Ludewa experiences a dry season associated with hot days for at least six months (Ludewa District Council, 2019; Andrew et al., 2023) which affects the development of plants negatively. As a result, during this period, moisture loss (and stress) through evapotranspiration is reduced due to the shading effect, thereby enhancing the survival of a variety of woody plant species, which promotes diversity (Campbell et al., 1996; Syampungani et al., 2015). It has also been reported that canopy cover plays a role in moderating the growth of understorey vegetation (e.g. those from Rubiaceae family) and small seeded plants, including small trees and shrubs, which enriches the woodlands without few species dominating (Chidumayo, 1997; Bulenga et al., 2021; Njoghomi et al., 2021). Canopy cover may also influence species evenness and diversity through enhanced fertility and moisture availability by adding organic litter into the soils (Økland et al., 2003). Added litter acts as a mulch to conserve soil moisture, reduces competing weeds, and adds fertility to the soils once incorporated, thus promoting germination of different new species and growth of existing ones with fair distribution of individuals among miombo species (Timberlake and Chidumayo, 2011; Syampungani et al., 2020).

Conclusions and recommendations

This study was initiated with the overall objective of determining plant community structure and assessing important human disturbance and environmental variables that could explain spatial variation in species total abundance, richness, evenness and diversity for Intake miombo woodlands. This work has reported a diversity index to be 2.3, signifying that the forest has medium species diversity, but has the potential to improve. The analysis has shown that elevation, soil pH and sand soil content were essential variables to predict the total abundance of miombo woody plant species. In contrast, canopy cover was important for species evenness and diversity. These results have broad implications, including providing important information for restoration, developing improved management plans, and monitoring Intake and other village forests with comparable socio-ecological and governance settings. Distance from the sampling plot to the footpath, a proxy for human disturbance, was insignificant when regressed with the computed community properties. While these results may pervasively suggest that human disturbance has little or no effect on the species total abundance, richness, evenness, and diversity, care should be taken when interpreting these results as indicated by an elevation in this paper and Andrew et al. (2023). It is well established that human disturbance affects the composition and structure of woody plant communities, negatively impacting miombo ecosystem stability, integrity and functions (Timberlake and Chidumayo, 2011; Ribeiro et al., 2020). Miombo woodlands are generally adaptive and resilient to human disturbance and environmental perturbations. Accordingly, these results may suggest that the Intake forest may be at an intermediate disturbance. It is recommended that the village and district authorities initiate joint monitoring of Intake forest to watch out for any changes in the plant community structure and offer the support needed. Also, current management of the forest should be intensified to allow the recovery of the newly protected village forest reserve for biodiversity protection, sustainable forest management and enhanced rural livelihoods per the objectives of establishing the Eastern Afromontane biodiversity hotspot. Further research in other village forests with wet miombo woodlands is recommended to strengthen reported findings.

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Data availability

Datasets used for the present study are available from the corresponding author upon reasonable request.

Declaration of competing interests

There are no relevant competing financial and non-financial interests to declare.

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