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Research Article

Assessing elevational change relationships with species richness distribution and diversity of woody riparian species along Mulunguzi River in Zomba Mountain, Malawi

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ABSTRACT

Zomba Mountain has enormous plant species diversity, mainly contributed by the riparian forest along the Mulunguzi River. Most of these plant species are undisturbed remnants of natural vegetation. This study was carried out in this riparian zone, to explore the relationships for the distribution of species richness and diversity of riparian woody species (shrubs and trees) against elevational change. The nested quadrat method was used to sample woody plants with demarcated dimensions of (50m x20m) for trees, and (5m x 5m) for shrubs in their natural environment. The results portrayed the occurrence of inverse relationships between the distribution of woody species richness and its diversity with increasing elevation. These results led to a monotonic decreasing pattern of species richness and diversity, where more woody species existed in lower elevations than those in higher elevations. These results were ascertained by a single-factor analysis of variance that tested the hypothesis and discovered the existence of their relationships. Significant negative correlation relationships for woody species richness and diversity with elevational change were also supported by both simple linear regression and correlation and the Carl-Pearson correlation coefficient. This study may assist in the formulation of effective measures for the management and conservation of the forest ecosystem.

Key words: Negative correlation, Nested plots, Diversity parameters, Climatic variables, Monotonic decrease, Tolerance range

INTRODUCTION

An elevational gradient is a significant factor that influences the distribution, abundance and diversity of both plant and animal species within mountain ecosystems. It is an ecological phenomenon that is widely used to describe patterns of species richness and diversity in small geographical areas or landscapes (Bhattarai &Vetaas, 2006). It leads to an elevational diversity gradient that is caused by climate, disturbance, productivity, area, source-sink dynamics, evolutionary history and geometric constraints (Lomolino, 2001; Sanders & Rahbek, 2012).

The distribution of plants in mountain ecosystems is primarily determined by interactions of climate, topography and soil, which lead to complex patterns of structure and productivity in mountain vegetation (Lomolino, 2001). Correlations that exist between environmental variables and elevational changes are significant causes of variation in species composition and structure along elevational gradients. Climate is the most potent environmental variable that influences variations in species distribution and diversity patterns along elevational gradients, as it encompasses temperature, air pressure, precipitation and solar radiation (Vetaas & Grytnes, 2002; Wu *et al*., 2013).

The relationship between elevational gradients and the distribution of species richness and diversity in mountain ecosystems is not fully understood. It is still a puzzle that the scientific community needs to resolve, as it is affected by several factors (Sánchez-González & López-Mata 2005). This has resulted in a tug-of-war that has not been resolved among ecologists, biogeographers and biodiversity conservationists on the typical pattern of species richness and diversity that is influenced by changes in elevation gradient (Lomolino, 2001 and Whittaker, Willis & Field, 2001).

Several patterns for the distribution of species richness and diversity in mountain ecosystems have been discovered, and they are influenced by elevational change (McCain & Grytnes 2010; Berhanu *et al*., 2017). However, the most common patterns that have been revealed are monotonic decreasing and hump-shaped or unimodal patterns (Rahbek, 2005). In the monotonic decreasing pattern, the number of species and diversity declines with increasing elevation while in the hump-shaped pattern, more species and diversity exist in the middle section than at the base or top of the mountain Berhanu *et al*., 2017). Rahbek, (2005)
discovered that in tropical and sub-tropical mountains, the hump-shaped pattern is more predominant than the monotonic decrease pattern.

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Until present, few studies have been conducted on plant communities in mountain ecosystems of Malawi. These studies mostly concentrated on species composition and structure (Jackson, 1969a;1969b; Chapman & White, 1970; Dowsett-Lemaire, 2002; Byers, 2015 and Micah & Kitichate, 2024). Some of these few studies have been conducted in Zomba Mountain; the second largest mountain in Malawi, covering an area of about 130 Km^2 and reaching an elevation of 2,087 metres above sea level (Zomba District Council, 2010). These limited studies have led to a broader gap in understanding several aspects of plant communities in Malawi.

This study tried to reduce this gap by focusing on an aspect of discovering the pattern of species richness and its diversity with respect to elevational changes. The study was conducted in the riparian zone of Mulunguzi River where limited studies on its essential natural plant communities have also been conducted (Byers, 2015 and Micah & Kitichate, 2024). This riparian vegetation offers significant services to mankind such as soil and water conservation, pollution control, climate regulation and nutrient recycling.

The natural vegetation of Zomba Mountain is largely contributed by riparian vegetation that lies along the Mulunguzi River. This riparian vegetation formed the forest called Mulunguzi Riparian Forest which occurs in the mountain ecosystem of Zomba Mountain. Like any other riparian forest in the mountain ecosystem, Mulunguzi Forest is a biodiversity hotspot (Pielech, 2021 and Surmacz *et al*.,2024). It is part of mountain vegetation that plays vital roles in their ecosystems as they provide essential functions and services Rood *et al*., 2020 and Micah & Kitichate, 2024). This riparian forest is also equally affected by factors that influence the distribution of plant species in mountain ecosystems. These factors include all continuous environmental changes that greatly impact elevational changes Pielech, 2021.

This study concentrated on changes in elevation as it encompasses changes in both climatic and site conditions which significantly influence plant communities (Kharkwal *et al*.,2005). The study assessed shrubs and trees separately and combined them as woody species. Lianas were not included because only three species were discovered, and insignificant changes were observed with elevation changes. The relationship between elevational change and the distribution of species richness is best discovered in different life forms. This is because they differ in factors that cause significant variations in species richness and diversity (Bhattarai & Vetaas, 2003; Akhtar & Bergmeir, 2015; Zhang *et al*., 2016 and Cirimwami *et al*., 2019).This study would help in understanding the structure and ecology of the riparian forest community. This study hypothesizes that the relationships exist for the distribution of woody species richness and diversity along an elevational gradient.

MATERIALS AND METHODS

Study site

The study was conducted in the riparian zone that lies along the Mulunguzi River between (15°32'–15° 37' S) and (35° 31' – 35°33' E). This zone harbours the Mulunguzi Riparian Forest and occurs from the foot to the summit of Zomba Mountain in Zomba District (Figure 1A). The Mulunguzi River is about 24 km long, with a catchment area covering about 20 km^2 of the Zomba Plateau occurring only in the Zomba Forest Reserve (Dias, 2008). It stretches from the top of Zomba Plateau to Cham'mande Village, where it joins with the Likangala River near Likangala Bridge, then flows to empty its water into Lake Chilwa (Zomba District Council, 2010). The study site lies at an elevation of 900–1800m asl.

Climate

The Mulunguzi River occurs in Zomba Mountain, which has a typical highland climate in tropical Africa, as it experiences a tropical climate with three main seasons: cold-dry, hot-dry and hot-wet. These seasons range from April to July, August to October and November to March, respectively. (Happold & Happold, 1989 and Zomba District Council, 2010).

In the cold-dry season, intermittent light rain falls during "Chiperoni" weather, when the trade winds blow from the southeast. The hot-dry season has minimal rainfall, but the plateau is frequently covered in clouds and mist (Happold & Happold, 1986).

The rain-bearing system in this region is the Intertropical Convergence Zone (ITCZ). It is active between November and April, with maximum rainfall occurring in January or February. The annual rainfall in different areas of the Mulunguzi River riparian zones varies from 1,400 to 1,800mm (Dias, 2008).

The highest mean temperature, ranging from 28 –30 ^{O}C is experienced in October, during the summer period, and the lowest temperature, as low as 10 ^{O}C, is experienced either in June or July, within the winter period.

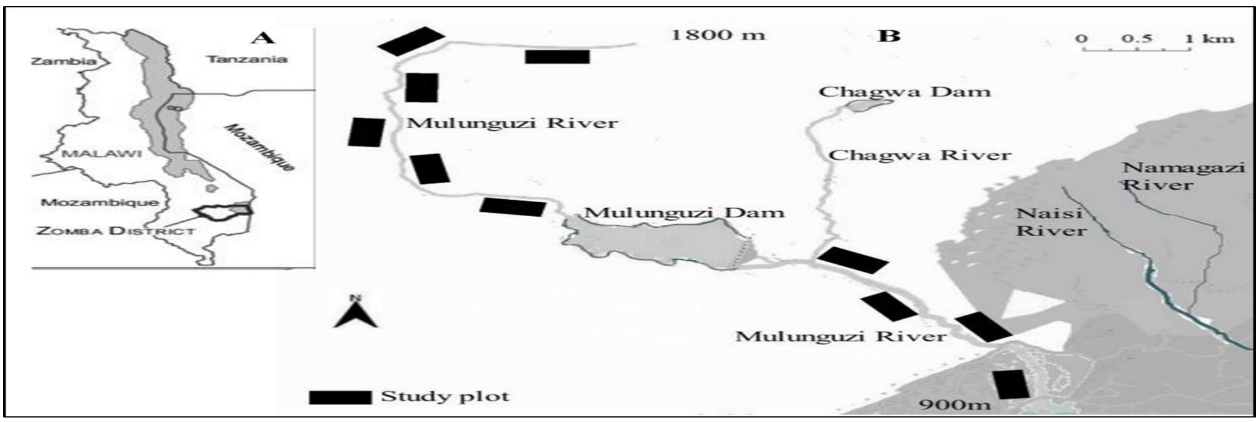

Figure 1. Map of Malawi. A. Location of Zomba District in Malawi (Source, Pullanikkatil *et al*., 2018). B. Mulunguzi River showing positions of study plots (Modified from https://latitude.to/map/mw/malawi/cities/zomba).

Vegetation Sampling Method

The nested quadrat method was used to sample vegetation on study plots (Figure 2). Ten study plots were selected at an interval difference of 100m asl on an elevational range of 900–1800m asl (Figure 1B). The study plots were purposively selected at each elevation, based on the presence of more natural remnant vegetation to maximise the discovery of more species.

On each study plot, the main quadrat covered an area of 1000 m^2 with dimensions of 50m x 20m demarcated for studying trees. This quadrat was measured by a 100m tape measure and was demarcated by strong ropes supported by poles on the corners to study trees. Four quadrats were also measured and demarcated on all corners of the main quadrat to study shrubs. Each quadrat covered an area of 25 m^2 with dimensions of 5m x 5m and was demarcated with ropes and supporting poles on its corners (Figure 2).

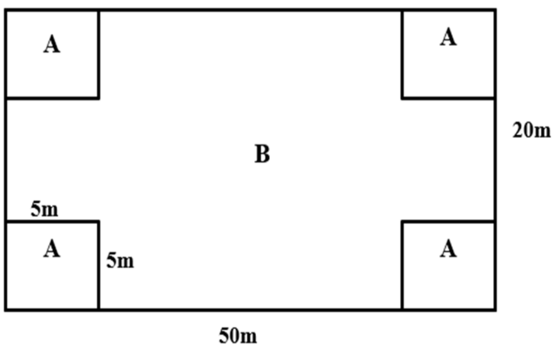

Figure 2. Arrangement of demarcated nest quadrats at a study plot. A. Nest quadrat for studying shrubs, B. Main quadrat for studying trees

Data collection

Plant surveys and data collection were carried out soon after the end of the rainy season when most species were available for easy identification. An altimeter was used to measure the elevations along riverbanks to determine the position of the study plot. At each main quadrat and nested quadrat, every individual woody plant was identified. The number of species present and their abundance were also recorded for further analysis. On the main demarcated quadrat, every tree with a diameter at breast height (DBH) greater than 10cm was selected for study. On each nested quadrat, shrubs were also selected based on their DBH, which was less than 10cm.

The identification of each plant species was done with the assistance of experts from the National Herbarium and Botanical Gardens of Malawi (NHBG).

Data analysis

Data was analysed using R Studio version 4.3.2 (R. Core Team, 2023). Simple linear correlation and regression in the R package were used to test the relationships of trees, shrubs and woody species (trees and shrubs) with elevational changes.

Single-factor analysis of variance (one-way ANOVA) was used to test the hypothesis. The hypothesis was checking the existence of any relationship between the distribution of woody species richness and diversity when elevation changes.

The plant diversity analysis was carried out by calculating the number of species, abundance, concentration of dominance, Simpson's index, Shannon-Weiner index, Pielou's evenness, Margalef index, Menhinick index, Fisher's alpha index, which was processed using Paleontological Statistics (PAST) software version 4.14.

RESULTS

Distributional relationship between riparian tree species richness and elevational change

1,810 individual trees were observed and used for this study. They belonged to 15 families and 49 species (Table 1). The Fabaceae family had the highest number of species and individual trees, followed by the Moraceae family (Table 1).

Table 1. List of riparian tree families identified in the study area with numbers of species and individual trees observed in each family.

Family	Number of Species	Number of Trees
Apocynaceae	1	29
Arecaceae	2	35
Asteraceae	2	174
Bignoniaceae	1	34
Chrysobalanaceae	2	85
Ebenaceae	1	26
Euphobiaceae	1	28
Fabaceae	21	698
Hypericaceae	2	61
Lamiaceae	2	76
Malvaceae	1	27
Meliaceae	3	157
Moraceae	8	244
Myrtaceae	1	98
Phyllanthaceae	1	38

The distribution of riparian tree species along the elevational gradient showed a slight increase in the lower elevational portion (900–1100m asl) and then declined with increasing elevation (Figure 2). The general distribution of species richness declined monotonically with a constant value ($\beta = -0.031$) across the whole elevational range. The relationship between tree species richness distribution and elevation is significant and negatively correlated ($p = 0.000012$, $r = -0.96$) as shown in Figure

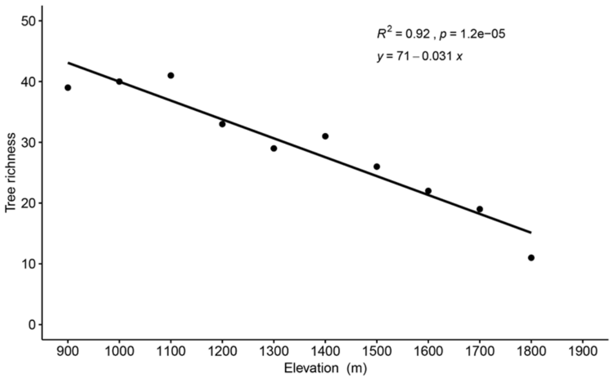

Figure 3. An elevational pattern of tree species richness of Mulunguzi Riparian Forest shows a negatively correlated relationship between elevational change and tree species richness.

Distributional relationship between riparian shrub species richness and elevational change

3,298 individual shrubs were discovered and used for this study. These shrubs belonged to 7 families and 28 species that were distributed unevenly throughout an entire elevational gradient (Table 2). The Malvaceae family had the highest number of species and individual shrubs.

Table 2. List of riparian shrub families identified in the study area with numbers of species and individual trees observed in each family.

Family	Number of Species	Number of Shrubs
Acanthaceae	5	580
Asteraceae	3	275
Euphorbiaceae	3	306
Fabaceae	2	240
Lamiaceae	5	535
Malvaceae	8	803
Rosaceae	2	559

The species richness distribution of riparian shrubs had a slight increase in the lower elevational portion (900–1000m asl); this was followed by a monotonic decrease with an increase in elevation by a constant value (β = −0.012) (Figure 3). A significant negative correlation exists between riparian shrub species richness and eleva-

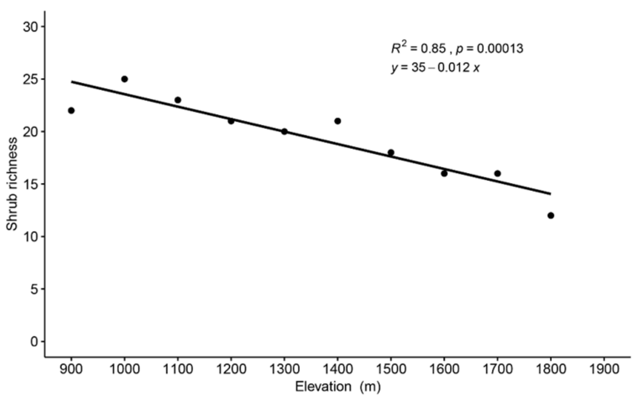

Figure 4. An elevational pattern of shrub species richness of Mulunguzi Riparian Forest shows a negatively correlated relationship between elevational change and shrub species richness.

Distributional relationship between riparian woody species richness and elevational change

5,108 individual riparian woody plants (shrubs and trees) belonging to 17 families and 77 species were observed in this study. Trees had 49 species, and the remaining 28 species belonged to shrubs.

Table 3. List of riparian woody families identified in the study area with numbers of species and individual trees observed in each family.

Family	Number of Species	Number of Trees
Acanthaceae	5	580
Apocynaceae	1	29
Arecaceae	2	35
Asteraceae	5	449
Bignoniaceae	1	34
Chrysobalanaceae	2	85
Ebenaceae	1	26
Euphobiaceae	4	334
Fabaceae	23	938
Hypericaceae	2	61
Lamiaceae	7	611
Malvaceae	9	830
Meliaceae	3	157
Moraceae	8	244
Myrtaceae	1	98
Phyllanthaceae	1	38
Rosaceae	2	559

The riparian woody species distribution in the lower elevational portion (900–1100m) had a slight increase in species richness. This was then followed by a monotonic decrease with an increase in elevation ranging from 1100–1800m asl. The relationship between species richness for riparian woody plants and elevational change is negatively correlated and significant (p = 0.000019, r = −0.95) as shown in Figure 5.

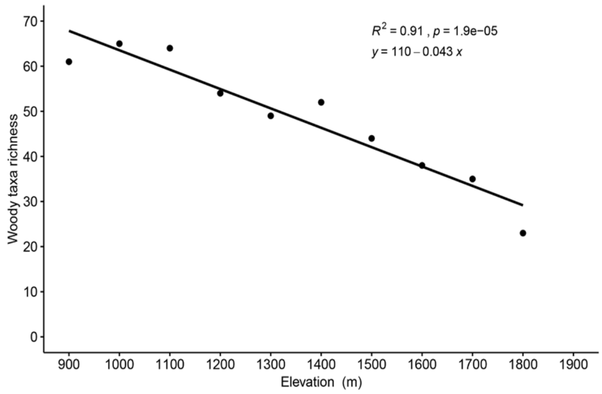

Figure 5. An elevational pattern of woody species richness of Mulunguzi Riparian Forest shows a negatively correlated relationship between elevational change and woody species richness.

Table 4. Diversity parameters at different elevational study plots for riparian shrubs, trees and woody species (combined trees and shrubs)

Lifeform and diversity Parameters	Plot 1 900m	Plot 2 1000 m	Plot 3 1100m	Plot 4 1200 m	Plot 5 1300m	Plot 6 1400 m	Plot 7 1500m	Plot 8 1600m	Plot 9 1700m	Plot 10 1800 m
Shrubs										
Number of species	22	**25**	23	21	20	21	18	16	16	12
Abundance	393	406	399	**484**	419	365	288	250	197	97
Dominance	0.061	0.058	0.054	0.059	0.062	0.06	0.065	0.072	0.067	**0.091**
Simpson index	0.939	0.942	**0.946**	0.941	0.938	0.94	0.935	0.928	0.933	0.909
Shannon index	2.94	**3.042**	3.008	2.93	2.884	2.927	2.803	2.699	2.738	2.435
Pielou's evenness	0.86	0.838	0.881	0.892	0.895	0.889	0.916	0.93	**0.966**	0.951
Menhinick index	1.11	**1.241**	1.151	0.955	0.977	1.099	1.061	1.012	1.14	1.218
Margalef index	3.515	**3.996**	3.673	3.235	3.147	3.39	3.002	2.717	2.839	2.405
Fisher's alpha	5.034	**5.885**	5.308	4.475	4.374	4.844	4.256	3.811	4.114	3.605
Trees										
Number of species	39	40	**41**	33	29	31	26	22	19	11
Dominance	0.034	0.034	0.033	0.045	0.045	0.047	0.051	0.052	0.079	**0.13**
Abundance	211	**236**	230	211	161	230	155	247	83	46
Simpson index	0.966	0.966	**0.967**	0.955	0.955	0.953	0.949	0.948	0.921	0.87
Shannon index	3.522	3.529	**3.551**	3.298	3.236	3.246	3.104	3.025	2.72	2.225
Pielou's Evenness	0.868	0.853	0.85	0.82	0.877	0.829	0.857	**0.936**	0.799	0.842
Menhinick index	2.685	2.604	**2.703**	2.272	2.286	2.044	2.088	1.4	2.086	1.622
Margalef index	7.1	7.138	**7.356**	5.979	5.51	5.517	4.957	3.812	4.073	2.612
Fisher's alpha	14.07	13.82	**14.52**	10.97	10.32	9.651	8.937	5.838	7.706	4.58
Woody species										
Number of species	61	**65**	64	54	49	52	44	38	35	23
Abundance	604	642	629	**695**	580	595	443	497	280	143
Dominance	0.03	0.028	0.026	0.033	0.036	0.029	0.034	0.031	0.040	**0.055**
Simpson index	0.97	0.97	**0.974**	0.97	0.964	0.97	0.966	0.969	0.96	0.94
Shannon index	3.79	**3.88**	3.863	3.66	3.573	3.72	3.556	3.554	3.34	3
Pielou's Evenness	0.726	0.74	0.744	0.72	0.727	0.79	0.796	**0.92**	0.807	0.87
Menhinick index	2.482	**2.57**	2.552	2.05	2.035	2.13	2.091	1.705	2.092	1.92
Margalef index	9.37	**9.9**	9.776	8.1	7.544	7.98	7.057	5.959	6.034	4.43
Fisher's alpha	16.94	**18.1**	17.82	13.7	12.77	13.7	12.14	9.575	10.56	7.75

Table 4: Summarises the change in diversity along an elevation gradient, with maximum values (bolded) occurring mostly at lower elevations, except for dominance, which has maximum values at higher elevations.

Diversity relationships between riparian trees and elevational change

The study revealed that only the concentration of dominance had a positively correlated relationship against elevational change ($r = 0.8019$, $p = 0.0053$) (Table 5) as its values increased with increasing elevation (Table 4). This positive correlation relationship was strong and significant.The rest of the diversity parameters (number of species, abundance, indices of Simpson, Shannon, Pielou's evenness, Menhinick, Margalef and Fisher's alpha) were negatively correlated to elevational change (Tables 4 and 5). However, Pielou's evenness index relationship was weak and not significant due to little variation observed at different elevational points ($r = -0.058$, $p = 0.874$) (Table 5). The other parameters with negative correlation relationships had a strong and significant relationship at different levels of significance (Table 5).

Table 5. Carl-Pearson Correlation coefficients between elevation and various diversity parameters of riparian trees

	Elevation	**No. of spp**	**Abundance**	**Dominance**	**Simpson**	**Shannon**	**Pielou's**	**Menhinick**	**Margalef**	**Fisher's**
Elevation	1									
No. of spp	-0.959***	1								
Abundance	-0.683*	0.777	1							
Dominance	0.8019**	-0.887	-0.869	1						
Simpson	-0.802**	0.887	0.869	-1	1					
Shannon	-0.911***	0.97	0.852	-0.971	0.971	1				
Pielou's	-0.058	0.023	0.424	-0.242	0.242	0.1599	1			
Menhinick	-0.87***	0.859	0.348	-0.635	0.634	0.7617	-0.312	1		
Margalef	-0.962***	0.992	0.691	-0.851	0.851	0.9463	-0.059	0.917	1	
Fisher's	-0.955***	0.967	0.596	-0.787	0.787	0.8997	-0.118	0.959	0.991	1

Correlation is significant at levels (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$).
No. of spp = number of species, Dominance = Concentration of dominance, Simpson = Simpson's index, Shannon = Shannon index, Pielou's = Pielou's Evenness index, Menhinick = Menhinick index, Margalef = Margalef index, Fisher's = Fisher's alpha index. Bolded, the relationship between Shannon diversity and concentration of dominance.
Strength of Pearson correlation coefficient (r) value: Strong when (r) is greater than 0.5 or less than -0.5, moderate when (r) occurs between 0.3 and 0.5 or between -0.3 and -0.5, and weak when (r) occurs between 0 and 0.3 or 0 and -0.3 (Shaun, 2024).

Diversity relationships between riparian shrubs and elevational change

The results that were obtained from this study showed that several diversity parameters measuring riparian shrubs had an inversely proportional relationship with elevational change. These diversity parameters include the number of species, abundance, and indices of Margalef, Fisher's alpha, Simpson's and Shannon's, which showed a general decreasing pattern with increasing elevation (Tables 4 and 6). This general decreasing pattern of these parameters resulted in reduced diversity when elevation increases. The negative correlation relationships between these parameters and elevational change were strong and significant (Table 6).

The Menhinic index, Pielou's evenness index and concentration of dominance of shrubs showed positively correlated relationships with increasing elevation (Table 6). Pielou's evenness index and concentration of dominance had a strong relationship with elevational change, which was significant ($r = 0.942$, $p = 0.00005$; $r = 0.766$, $p = 0.0097$, respectively) (Table 6). However, an insignificant and weak positive relationship exists between the Menhinick index and elevational change ($r = 0.002$, $p = 0.995$).

Table 6. Carl-Pearson Correlation coefficients between elevation and various diversity parameters of riparian shrubs

	Elevation	No. of spp	Abundance	Dominance	Simpson	Shannon	Pielou's	Menhinick	Margalef	Fisher's
Elevation	1									
No. of spp	-0.924***	1								
Abundance	-0.85**	0.887	1							
Dominance	0.766**	-0.906	-0.873	1						
Simpson	-0.766**	0.905	0.873	-1	1					
Shannon	-0.871***	0.979	0.906	**-0.973**	0.972	1				
Pielou's	0.942***	-0.924	-0.813	0.6984	-0.698	-0.8406	1			
Menhinick	0.002	0.011	-0.413	0.2367	-0.237	-0.1186	-0.079	1		
Margalef	-0.901***	0.982	0.787	-0.847	0.847	0.9389	-0.916	0.2	1	
Fisher's	-0.862**	0.941	0.688	-0.77	0.77	0.878	-0.89	0.349	0.988	1

*Correlation is significant at levels (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$).*
No. of spp = number of species, Dominance = Concentration of dominance, Simpson = Simpson's index, Shannon = Shannon index, Pielou's = Pielou's Evenness index, Menhinick = Menhinick index, Margalef = Margalef index, Fisher's = Fisher's alpha index. Bolded, the relationship between Shannon diversity and concentration of dominance.
Strength of Pearson correlation coefficient (r) value: Strong when (r) is greater than 0.5 or less than -0.5, moderate when (r) occurs between 0.3 and 0.5 or between -0.3 and -0.5 and weak when (r) occurs between 0 and 0.3 or 0 and -0.3 (Shaun, 2024).

Diversity relationships between riparian woody species and elevational change

The study's results on riparian woody species revealed that the concentration of dominance and Pielou's evenness index were positively correlated with elevational change. These relationships were strong and significant ($r = 0.7255$, $p = 0.0176$; $r = 0.7923$, $p = 0.0063$, for the concentration of dominance and Pielou's evenness index, respectively) (Table 7).

Table 7. Carl-Pearson Correlation coefficients between elevation and various diversity parameters of riparian woody species

	Elevation	**No. of spp**	**Abundance**	**Dominance**	**Simpson**	**Shannon**	**Pielou's**	**Menhinick**	**Margalef**	**Fisher's**
Elevation	1									
No. of spp	-0.954***	1								
Abundance	-0.842**	0.9	1							
Dominance	0.726*	-0.856	-0.88	1						
Simpson	-0.726*	0.856	0.8811	-1	1					
Shannon	-0.87***	0.96	0.9239	-0.965	0.964	1				
Pielou's	0.792**	-0.766	-0.659	0.442	-0.442	-0.61	1			
Menhinick	-0.8**	0.806	0.4713	-0.505	0.504	0.672	-0.7	1		
Margalef	-0.953***	0.995	0.8539	-0.826	0.826	0.941	-0.775	0.859	1	
Fisher's	-0.943***	0.977	0.7871	-0.774	0.773	0.904	-0.767	0.913	0.993	1

*Correlation is significant at levels (*** p < 0.001; ** p < 0.01; * p < 0.05). No. of spp = number of species, Dominance = Concentration of dominance, Simpson = Simpson's index, Shannon = Shannon index, Pielou's = Pielou's Evenness index, Menhinick = Menhinick index, Margalef = Margalef index, Fisher's = Fisher's alpha index. Bolded, the relationship between Shannon diversity and concentration of dominance.*
Strength of Pearson correlation coefficient (r) value: Strong when (r) is greater than 0.5 or less than -0.5, moderate when (r) occurs between 0.3 and 0.5 or between -0.3 and -0.5 and weak when (r) occurs between 0 and 0.3 or 0 and -0.3 (Shaun, 2024)

The number of species, abundance, and indices of Margalef, Menhinick, Fisher's alpha, Simpson's, and Shannon had negative correlation relationships with elevational change. (Table 7). The relationships between these diversity parameters and elevational change were strong and significant at different levels (Table 7).

DISCUSSION

Distributional relationship between riparian tree species richness and elevational change

The study discovered 49 species of riparian trees that belonged to 15 families, of which Fabaceae was predominant with 21 species and the highest number of trees (698) (Table 1). This was the case, probably due to the species' resilience and wider tolerance to environmental changes (Micah & Kitichate, 2024).

The maximum distribution of tree species (41 species) was observed at an elevation of 1100m (Figure 3 and Table 4). This is in lower elevations where most taller life forms of plants, including trees, are confined due to the availability of favourable climatic conditions that promote the existence of various tree species (Zhou *et al*., 2019). The minimum distribution of tree species (11 species) was observed at higher elevations (1800m) (Figure 3 and Table 4), likely caused by eco-physiological constraints (such as a drop in temperatures and carbon dioxide concentrations) that are not tolerated by several tree species (Cirimwami *et al*., 2019).

The study also revealed an inversely proportional relationship between the distribution of riparian tree species richness and elevational change, decreased with a constant gradient of −0.031 (Figure 3). This negatively correlated relationship is highly significant ($r = -0.96$, $p < 0.001$) across the whole elevation range. This means that when an elevation gradient increases along Zomba Mountain, the species richness distribution of riparian trees decreases and vice versa. This inverse relationship for the distribution of riparian tree species richness produced a monotonic decrease pattern with increasing elevation.

This relationship may be attributed to tree species' narrower climatic tolerance ranges, making some species fail to withstand more significant climatic variability at higher elevations (Steven, 1992 and Oommen & Shanker, 2005). Some tree species are sensitive to a reduction in wet adiabatic lapse rate of temperature (0.4 ^{O}C to 0.7 ^{O}C each 100m); as such, the number of their species decreases when moving to higher elevations due to low temperatures. On a fine scale, variations in pH and nutrients of the soils might have impacted the distribution of tree species richness along this elevation gradient (Jansen & Oksanen, 2013 and Fischer *et al*., 2014).

Several studies that were conducted worldwide concur with this discovery of an inverse correlation relationship that resulted in a monotonic decrease pattern between the distribution of tree species richness and elevational change. Some of these studies were conducted in the Democratic Republic of Congo, Cirimwami *et al*. (2019); Ethiopia, Berhanu, Woldu & Demissew (2017); China, Ren *et al*. (2006); and India, Kharkwal *et al*. (2005) and Sharma *et al*. (2009).

The results in Figure 2 also show a steeper decreasing slope of tree species (−0.031), unlike shrubs (−0.012) (Figure 4). This may probably be caused by the impact of more pressure exerted by changes in climatic and environmental factors, which is significantly experienced by tree species as compared to shrubs when elevation increases (Pausas & Austin, 2001).

Distributional relationship between riparian shrub species richness and elevational change

27 species of shrubs were discovered in this study. They belonged to 7 families, of which Malvaceae was predominant with 8 species and the highest number of shrubs (803) (Table 2). The Malvaceae family predominates in this study area due to their resilience and ability to thrive in various soils (Acharya, 2011).

Like trees, the maximum species richness distribution (25 species) occurs in the lower elevational zone (1000m asl), which offers favourable climatic conditions for diverse shrub species. Their minimum distribution (12 species) occurs in the higher elevational zone (1800m asl), which offers several eco-physiological constraints and limitations for the growth and development of several shrub species (Figure 4 and Table 4).

The study showed that the distribution of shrub species richness in the riparian zone of Mulunguzi River in Zomba Mountain was negatively correlated with increasing elevation. The correlation slope of this relationship decreased with a constant gradient of −0.012 (Figure 4). This discovered negative correlation relationship was highly significant along the whole elevation gradient ($r = -0.92$, $p < 0.001$). This relationship also leads to a monotonic pattern of species richness distribution with increased elevation, where more species were concentrated in lower elevations than those in higher elevations.

This negative correlation relationship for shrubs is thought to be brought about by a narrow climatic tolerance range, which makes shrubs thrive better in lower elevations than in higher elevations where they cannot cope with significant climatic variability (Acharya, 2011 and Zhou *et al*.,2019).

Shrub species showed a similar distributional relationship and pattern to tree species along an elevation gradient (Figures 3 and 4), likely because both are woody species with similar environmental requirements and respond similarly to environmental changes. Shrubs and trees belong to similar taller life forms of plants; due to this likeness, they co-exist well in lower elevations, as most of their species are adapted to environmental conditions present in this zone (Table 4) (Ren *et al*., 2006).

Other studies on shrubs carried out in different parts of the world discovered similar results to this study (Figure 4). They also discovered that there was an inversely proportional relationship between the distribution of shrub species richness and elevational change (Kharkwal *et al*., 2005; Ren *et al*., 2006; Cirimwami *et al*., 2019 and Berhanu *et al*., 2017).

Distributional relationship between riparian woody species richness and elevational change

The woody species comprises both trees and shrubs. The study observed 77 species of woody plants that belonged to 17 families, of which Fabaceae predominates with 23 species and 938 individual trees and shrubs (Table 3). This Fabaceae family includes 21 species of trees and 2 species of shrubs with wider tolerance to environmental changes (Micah and Kitichate, 2024).

The maximum distribution of riparian woody species (65 species) in Zomba Mountain occurred at a lower elevation of about 1000m, which offers favourable conditions for the survival of both tree and shrub species (Figure 5 and Table 4). The minimum distribution occurred at a higher elevation of about 1800m (23 species), which limits the distribution of woody species due to more significant changes in environmental conditions (Zhou *et al*., 2019).

The study discovered that the distribution of riparian woody species richness along the Mulunguzi River is negatively correlated with increasing elevation. This inversely proportional relationship is highly significant ($r = -0.95$, $p < 0.001$) and the correlation slope decreased with a constant gradient of −0.043 (Figure 5). This inversely proportional relationship leads to a monotonic decline pattern in the riparian woody species richness distribution against elevational change. This pattern may be attributed to their narrow tolerances to environmental variations when elevation increases (Steven, 1992 and Oommen & Shanker, 2005). Both tree and shrub species have a narrow tolerance to withstand more significant variations in climatic conditions at higher elevations. As such, the number of their species decreases as they move from lower elevations to higher elevations (Table 4). Variations in temperature, air pressure, solar radiation, soil pH and nutrients are most likely variables that significantly impact the distribution of their species along an elevational gradient (Kessler, 2000).

The findings for the distribution of woody species from this study agree with discoveries done by Bhattarai & Vetaas (2003) in Nepal, Ren *et al*. (2006) in China, Berhanu *et al*. (2017) in Ethiopia, Saikia *et al*. (2017) and Shooner *et al*. (2018) in India, and Cirimwami *et al*., 2019 in the Democratic Republic of Congo, who reported a monotonic decrease pattern for the distribution of riparian woody species with increasing elevation.

The results also showed that the riparian woody vegetation along Mulunguzi River consists of more tree species than shrubs along an elevational gradient of Zomba Mountain (Figures 3 and 4). This could be caused by tree species' ability to compete well with other species for resources in the same habitat, unlike shrubs that fail to compete with other species for resources under higher canopy cover and density.

It is also worth noting that the contribution of riparian tree species richness to the total riparian woody species decreased from 65% to 48%, with an elevation increase ranging from 900−1800m (Figure 3). This observation was attributed to the narrower tolerance of tree species to climatic variations along an elevational gradient that cannot be adapted by many tree species (Acharya, 2011).

Conversely, the contribution of shrub species richness to the total riparian woody species increased from 35% to 52% with an increase in elevation, ranging from 900−1800m asl. Shrubs have a wider tolerance compared to trees to changes in climatic conditions along an elevational gradient, enabling them to survive harsh conditions at specific higher elevations (Acharya, 2011).

Diversity relationships between riparian trees and elevational change

The diversity of plant communities is composed of two components: species richness, and evenness. These components are represented by different diversity indices, which are influenced by richness (Margalef's and Menhinick's indices), evenness (Pielou's evenness and Fisher's alpha indices), and both richness and evenness (Shannon's and Simpson's indices).

The concentration of dominance is the only parameter for riparian trees with a strong and significant positive correlational relationship against elevational change (Table 5). This means that when moving uphill, the concentration of dominance also increases and vice versa. However, as the values of concentration of dominance increase, the number of species (species richness) is reduced. Therefore, the diversity decreases due to reduced richness. This makes the concentration of dominance have an inverse relationship with diversity. This is also portrayed by the negative correlation relationship between the concentration of dominance and the Shannon diversity index ($r = -971$) (Table 5). This shared relationship is widely discovered in several established forests (Malik & Bhatt, 2015 and Gairola *et al*., 2011).

All other diversity parameters for riparian tree species have a negative correlation relationship with increasing elevation with different strengths and significance levels (Table 5). The number of species, indices of Shannon's, Menhinick's, Margalef's and Fisher's alpha are diversity parameters with strong and high significance inverse proportional relationships with elevational change ($r < -5$, $p < 0.001$) hence their relationships are greatly affected by changes in elevation (Table 5). Both abundance and Simpsons have strong inverse proportional relationships with elevational change but at significance levels of $p < 0.05$ and $P < 0.01$, respectively.

These strong negative correlation relationships between diversity parameters and elevational change relate to the fact that the diversity of riparian tree species along the Mulunguzi River decreases with increasing elevation. This is probably caused by the failure of most tree species to tolerate more incredible environmental changes. As such, their numbers decrease, leading to low diversity at higher elevational zones (Acharya, 2011). This, in turn, leads to a monotonic decrease pattern in diversity when elevation is increasing with maximum diversity in lower elevations (Table 4) (Kharakwal *et al*., 2005; Arya, Kumar & Rawat, 2017 and Bhat *et al*., 2020).

Pielou's evenness had a weak, insignificant negative correlational relationship with elevational change ($r = -0.058$, $p = 0.874$) due to less variability among the study plots (Table 4).

Generally, the overall relationship between the diversity of riparian tree species is inversely proportional to elevational change, and this resulted in a monotonic decreasing pattern of diversity when moving uphill (Stevens, 1992; Rahbeck,1995; Kharakwal *et al*., 2005; Arya *et al*., 2017 and Bhat *et al*., 2020).

Diversity relationships between riparian shrubs and elevational change

The analysis showed that the Menhinick index, Pielou's evenness index and concentration of dominance positively correlate with elevational changes (Table 5). However, a weak and insignificant positive correlation relationship exists between the Menhinick index and elevational change due to few variations among study plots (r = 0.002, p = 0.995).

Pielou's evenness index had a strong and significant positive relationship with elevational change (Table 5). Pielou's evenness index increased with elevation increase, symbolising diversity increase with increasing elevation because the relative abundance of different species of shrubs was almost equal when moving uphill. Although the number of species and their abundances decrease on moving uphill, the relative abundances of the species that are present get closer to each other.

The concentration of dominance for shrubs showed a common strong and significant positive correlation relationship with elevational change (Table 5). This resulted in the usual inverse proportional relationship with diversity (shown by the negative correlation relationship between the Shannon diversity index and concentration of dominance (r = –0.973) (Table 6). This decreases diversity when moving uphill.

The other parameters (number of species, abundance, indices of Simpson's, Shannon's, Margalef's and Fisher's alpha) showed strong and significant negative correlational relationships with elevational change (Table 6). These negatively proportional relationships lead to a decrease in diversity when elevation increases.

Overall diversity parameters for riparian shrubs decrease with increasing elevation, thereby leading to a monotonic decrease pattern of species diversity when moving uphill (Stevens, 1992; Rahbeck,1995; Kharakwal *et al*., 2005; Arya *et al*., 2017 and Bhat *et al*., 2020).

Diversity relationships between riparian woody species and elevational change

The riparian woody species consists of trees and shrubs. The concentration of dominance and Pielou's evenness index of woody species had a strong and significant positive correlation with elevational change (Table 7).

The positive relationship between the concentration of dominance of these woody species with elevational change causes their diversity to decrease. This decrease occurs due to reduced species richness, which happens when the concentration of dominance increases. The usual inverse correlation relationship between diversity and concentration of dominance is portrayed by the correlation relationship between the Shannon diversity index and concentration of dominance (r = –0.965) (Table 7). This discovery is supported by the findings of Gairola *et al*., (2011) and Malik and Bhatt, (2015) in the Western Himalayas.

Pielou's evenness index also had a positive correlation relationship with elevational change. An increase in Pielou's evenness index with increasing elevation represents a diversity increase caused by closer relative abundances of different species of trees when moving uphill, which increases evenness.

All other diversity parameters (number of species, abundance, indices of Simpson's, Shannon's, Menhinick's, Margalef's and Fisher's alpha) displayed strong and significant negative correlation relationships with elevational change (Table 7). The inverse proportional relationships between these parameters and elevational change for woody plants translated to reduced diversity with increasing elevation. Most woody species are adapted to survive in low elevations because of their narrow tolerance to more significant variations, which limit their existence in harsh conditions at higher elevations (Acharya, 2011).

Generally, most of the diversity indices and parameters for riparian woody species portrayed a decreasing diversity pattern with increased elevation. The decreasing diversity patterns enable the monotonic decrease pattern of diversity to be a prominent pattern observed for riparian woody species along the Mulunguzi River in Zomba Mountain. This pattern is widely accepted as the general pattern of species diversity against an increasing elevation in ecological studies (Stevens, 1992; Rahbeck,1995; Kharakwal et al., 2005; Arya *et al*., 2017 and Bhat *et al*., 2020).

CONCLUSION

This study showed that the distribution of riparian woody species richness and their diversity are significantly influenced by changes in elevation. This influence resulted in the monotonic decrease pattern of species richness and diversity, where more woody species were observed in lower elevations than in higher elevations. The outcomes of this study are supported by significant negative correlation relationships that exist between species richness and elevational change for both trees and shrubs. Their diversity also revealed a negative correlational relationship, as supported by most diversity parameters.

Further studies should be conducted regularly to assess the effects of some factors associated with elevational change on the distribution of riparian plant communities along Zomba Mountain's elevational gradients. These factors include temperature, rainfall, human disturbance, productivity and soil attributes that shape vegetation distribution and structure along an elevational gradient.

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