

# Exploring the Influence of Slope Gradient on Tree Species Richness and Forest Structure

## ABSTRACT

Slope gradient is a critical environment factor influencing the abundance, distribution and diversity of vegetation. The objective of this study was to exploring the influence of slope gradient on tree species richness and forest structure in Kpatawee forest, Liberia. Tree diameter was measured at breast height for species more than 5 cm in diameter and over 3 m in height. Tree species diversity was analyzed using Shannon diversity index ( $H'$ ). Basal area (BA) which is the cross-sectional area of tree stems was measured through the diameter at breast height that is 1.3 m above ground level. Results showed that a total of 26 tree species were identified from the total sampling area (0.36 ha). The three richest families: Moraceae, Rutaceae and Euphorbiaceae appear to be well represented in the Kpatawee forest. These families become outnumbered in the herbaceous except for the Rutaceae family, which is ranked second. This is mainly due to their adaptation potential to wider agro-ecologies. Tree species richness was higher in the lower altitude. High species abundance was recorded in the lower altitude followed by the middle and upper. The lowest Shannon diversity index value ( $H' = 1.85$ ) and the highest value ( $H' = 2.28$ ) were recorded in the upper, and the lower altitudes, respectively. Despite their values, the biodiversity did not vary greatly from altitude to altitude. Diameter class distribution showed that more species were in the lower diameter classes and decreased gradually towards the higher classes. It is recommended that further studies on the entire Kpatawee forest is needed to fully understand the species richness in the forest.

**Keywords:** Biodiversity patterns; Shannon diversity index; slope gradient; soil quality; species richness

## 1. INTRODUCTION

Topography, a crucial environmental factor, profoundly influences vegetation composition, distribution, and diversity, shaping microclimates through features like elevation, slope aspect, position, and degree (Mahari, 2014; Ang'ila *et al.*, 2023; Yao *et al.*, 2023). Scientific literature, however, exhibits considerable variability in understanding the impact of topographic factors on biodiversity patterns. Conflicting observations on soil nutrient gradients and species diversity, as well as altitude's influence on diversity, underscore the intricate nature of ecological relationships (Hiiesalu *et al.*, 2017; Hu *et al.*, 2018; Ehbrecht *et al.*, 2017; Ren *et al.*, 2018).

In arid regions, where environmental factors exert a stronger influence on vegetation and biodiversity compared to humid areas, studying these relationships becomes particularly meaningful (Li *et al.*, 2017; Yang *et al.*, 2018; Jia *et al.*, 2019; Oliveira *et al.*, 2021). Slope aspect and position play a crucial role in determining microclimates and ecological niches, particularly in hilly regions (Elisabeth *et al.*, 2015; Li *et al.*, 2020). Similarly, in mountainous areas, elevation, slope aspect, and slope angle play a pivotal role in controlling vegetation patterns (Mahari *et al.*, 2015; Mendez-Toribio *et al.*, 2016).

This study delves into the nuanced relationship between slope gradient and the intricate dynamics of tree species richness and forest structure in the biodiverse landscape of the Kpatawee forest in Liberia. Within this unique ecosystem, forests emerge as distinct entities, shaped by the intricate interplay of environmental factors, responding sensitively to the variations in topography (Gxasheka *et al.*, 2023). Specifically, montane forest ecosystems in this region exhibit a notable character, with elevation-based stratification playing a pivotal role in shaping the composition and structure of these vital ecosystems (Mi *et al.*, 2012). Understanding the broader implications of how slope gradient influences these fundamental

aspects adds a layer of insight to our comprehension of forest dynamics, contributing valuable knowledge to the broader discourse on the ecological significance of topographical features in diverse landscapes.

This research aims to contribute to the understanding of how slope gradient influences tree species richness and forest structure in a specific context, emphasizing the necessity for context-specific investigations in the fields of ecology and environmental science. The complexity of ecological relationships demands nuanced studies to unravel the intricacies of how environmental factors interact with biodiversity patterns in various ecosystems.

## **2. MATERIAL AND METHODS**

### **2.1 Study site**

The study was conducted in the Kpatawee rainforest, situated in Bong County, central Liberia. The choice of this forest area was based on its rich biodiversity, housing numerous grasses, trees, and shrub species, which are known to be part of the remaining Upper Guinean rainforest. The study site is situated at an altitude of 281 meters above sea level, precisely at 7.122° latitude and -9.641° longitude. The local climate is predominantly tropical, characterized by an annual average temperature of 25°C and an annual average rainfall of 2013 mm, which is distributed from May to October (Mahari et al., 2024). The primary soil types found in this region include latosols, lithosols, regosols, and alluvial or swamp soils. Dominant crops cultivated in the area consist of cassava, rice, and maize.

### **2.2 Experimental design and layout**

Data on tree species richness and its characteristics was collected from three slope gradients: upper, middle, and lower. The position of the sampling site was determined after elevation data was collected from both the highest and lowest slope positions. A total of nine plots (three plots from each sampling position) with an area of 20 m x 20 m and a 10-meter interval between plots were established. After demarcating the plots, careful sampling was undertaken.

### **2.3 Vegetation data collection**

The local influence of the slope gradient on the tree species richness is related to relief and hydrological dynamics, since soil properties are a direct consequence of these factors. Sampling was conducted at an undisturbed and continuous section of the forest to have a better understanding of the relationship between the relief features and the richness of Kpatawee rainforest tree communities. The tree sampling was performed on three sampling plots. According to Hu *et al.* (2018), all living trees with a diameter  $\geq 5$  cm at breast height (DBH) were recorded by species using the latest botanical classification. All tree species were assigned to their own families. A plant species identifier application was used, and the scientific names of plants were identified.

#### **2.3.1 Tree Basal area calculation**

Tree diameter was measured at breast height for species more than 5 cm in diameter and over 3 m in height. The diameter was measured using a diameter tape. According to Singh (2018), basal area (BA), which is the cross-sectional area of tree stems, was measured through the diameter at breast height, which is 1.3 m above ground level. It will help to measure the relative dominance (the degree of coverage of a species as an expression of the space it occupies) of a species in a forest. It was calculated as:

$$BA = \pi DBH^2 / 4$$

Where BA = basal area (m<sup>2</sup>), DBH = diameter at breast height (cm),  $\pi = 3.14$

### 2.3.2 Tree species diversity indices

Tree species diversity was analyzed using the Shannon diversity index ( $H'$ ) as a measure of species abundance and richness to quantify the diversity of the woody species (Liu *et al.*, 2007). Therefore, both species abundance and species richness were considered in this index.

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

Where  $s$  equals the number of species and  $p_i$  equals the ratio of individuals of species  $i$  divided by all individuals  $N$  of all species. The Shannon diversity index seldom rises above 4.5, usually falling between 1.5 and 3.5.

### 2.3.3 Dominance

Species dominance refers to the degree of coverage of a species as an expression of the space it occupies in a given area. Usually, dominance is expressed in terms of the basal area of the species. Two sets of dominance were calculated in this case: dominance (the sum of basal areas of the individuals in  $\text{m}^2\text{ha}^{-1}$ ) and relative dominance, which is the percentage of the total basal area of a given species out of the total measured stem basal areas of all species (Zeng *et al.*, 2014).

$$\text{Dominance} = \text{Total basal area/area sampled}$$

$$\text{Relative dominance} = (\text{Dominance of species A/total dominance of all species}) * 100$$

## 2.4 Statistical analysis

Descriptive statistics such as minimum, maximum, mean, and standard deviation were performed to summarize the tree species richness and their characteristics along the slope gradient in the study forest. The MS Excel 2013 package was used to perform all the statistical analyses.

## 3. RESULTS AND DISCUSSION

### 3.1 Species richness and its characteristics

The whole dataset was made up of three slope gradients: upper, middle, and lower. The position of the sampling site was determined after elevation data was collected from both the highest and lowest slope positions. A total of nine plots (three plots from each sampling position) with an area of 20 m x 20 m and a 100-meter interval between plots were established. A total of 26 tree species were collected.

### 3.2 Species richness

The three richest families in the study area were Moraceae, Rutaceae, and Euphorbiaceae, which appear to be well represented in the forest. In the herbaceous, these groups become outnumbered, with the exception of the Rutaceae family, which comes in second. In the studied area, these findings suggested that 10% of all species were from the Rutaceae family, despite the presence of some tree ferns in the woody (tree and shrub) families.

### 3.3 Relationship between species richness and slope gradients

The trees under study determined how slope gradients and species richness interacted (Table 1). Species richness decreases with increasing slope gradients for tree species. Results in Table 1 indicate that a high number of tree species were recorded on the lower slope. However, it was on the upper slope,

which indicated low species richness. The biodiversity did not vary greatly from slope to slope in the study area. A low Shannon diversity index value was obtained in the upper slope position ( $H' = 1.85$ ), whereas the highest value was obtained in the same aspect in the lower slope position ( $H' = 2.28$ ). This study is supported by Molla and Asfaw (2014), who reported 43 different woody species in natural forests. Shannon's diversity index of tree species in natural forests ( $H' = 2.76$ ).

The Shannon diversity index ranges typically from 1.5 to 3.5 and rarely reaches 4.5 (Mueller-Dombois and Ellenberg, 1974). Recently, various studies were conducted, especially on plants, to assess how the species richness of different trees is influenced by slope gradients (Zhang *et al.*, 2012). In some rare cases, researchers found the same relationship between slope gradients and species richness (unimodal or monotonic) for all the studied trees, but, more often, this relationship differs between the trees.

Some of these works have been performed on small slope gradients, and most of them in temperate climates. Here, this study showed that, in wide slope gradients in tropical Africa, the relationship between species richness and slope gradients varies from one vegetation life form to another. In a tropical African mountain, the species richness of trees and shrubs is negatively linked with slope gradients between 810 and 2760 masl, showing a monotonic decline with rising slope gradients. Eco-physiological limitations at higher slopes, such as temperature drops or CO<sub>2</sub> pressure, are undoubtedly to blame for this decline in species richness. These limitations may have an impact on photosynthetic capacity, net primary productivity, and the maintenance of living structures (Kubota *et al.*, 2004).

**Table 1.** Abundance, species richness and Shannon index of the three slope positions

Slope	Abundance	Species richness	Shannon diversity index
Lower	155	10	2.28
Middle	96	9	2.10
Upper	36	7	1.85

It was shown that there was a substantial correlation between the species richness and slope gradients of 15 families (Table 2). For the families Moraceae, Rutaceae, and Euphorbiaceae, both species richness and abundance decline with rising slope gradients. As slope gradients increase, the number of individuals in the Lauraceae and Phytocaccaceae groups rises but the number of species falls. For the other families, increased slope gradients cause either an increase or decrease in the number of species or individuals.

The species richness of a family does not always follow the pattern set by the forest that the species is found in. Some families followed the general forest trend, while others displayed a totally different trend. These various trends suggest the existence of family-specific sensitivity to changes driven by slope gradients, a variety of eco-physiological properties of each family, and family trait-based responses (William *et al.*, 2017).

For trees and shrubs, the amount of families decreasing in species richness was higher than that of families increasing along the slope gradients, but the opposite is observed in the herbaceous (Table 2). For example, woody families such as Myricaceae, Ericaceae, Monimiaceae, Myrsinaceae, Theaceae, and Podocarpaceae (Table 2) are positively correlated with slope gradients (Augusto *et al.*, 2017). This is also partially the case for Rubiaceae, which shows in both woody areas a slight increase in species as well as an increase in abundance following slope gradients, especially in the shrub. One of the most prevalent families in the understory of tropical lowland forests is Rubiaceae, but in highland forests above 2000 meters above sea level, its significance seems to be much greater (Xuluc-Tolosa *et al.*, 2003).

Families such as *Phyllanthaceae* and *Pandanaceae*, which gather many species from the *Uapaca* and *Pandanus* genus, characteristics of riverside forests that decrease with increasing slope gradients. Megathermal families that are typical of lowland tropical rainforests are the *Fabaceae*, *Meliaceae*, and

*Annonaceae* families. It is acknowledged that the *Fabaceae* family is among the wealthiest in the lowlands of Africa (Yadvinder *et al.*, 2002).

Table 2 presents a comprehensive overview of the dominant plant species in three distinct slope positions within the Kpatawee Forest. Each slope position, namely lower, middle, and upper, is characterized by a unique set of plant species, each with its species name along with their respective diameter at breast height (DBH), basal area (BA), relative dominance (RD), abundance, and species diversity metrics are provided for each species.

In the Lower slope position, the vegetation appears to consist of relatively younger or smaller trees, as indicated by the lower DBH values. *Ormosia coccinea* exhibits the lowest RD and species diversity, suggesting its lesser dominance and diversity compared to other species in this zone. Moving to the Middle slope position, *Carpinus betulus* emerges as the most dominant species with the highest RD, while *Cnidocolusa conitifolius* takes center stage in terms of BA and RD, signifying its significant canopy coverage and dominance. Notably, *Theobroma cacao* appears in both the lower and middle slopes, yet it is more prominent in the middle slope. Finally, in the upper slope position, *Goupia glabra* and *Tovomitabasilensis* exhibit the highest RD, while *Maesa lanceolata* boasts the highest species diversity, suggesting a more diverse ecosystem in this area. The presence of two *Anaxagorea* species with similar names in the middle and upper slopes highlights the importance of careful taxonomic identification. This comprehensive table offers valuable insights into the forest's composition and distribution across varying slope positions, making it an essential resource for ecological research and forest management. However, for a more in-depth understanding, additional ecological context and data may be required.

**Table 2:** Species name including their DBH, BA, RD, abundance, and diversity along the three slope positions in Kpatawee Forest

Slope	Species name	DBH (cm)	BA (m <sup>2</sup> )	RD (%)	Abundance	Spices diversity
Lower	<i>Ormosia coccinea</i>	2.23	0.0004	0.54	12	0.20
Lower	<i>Solanum lycopersicum</i>	1.91	0.0003	0.40	17	0.24
Lower	<i>Pittosporum viridiflorum</i>	2.55	0.0005	0.71	19	0.26
Lower	<i>Siparunaguianensis</i>	2.23	0.0004	0.54	22	0.28
Lower	<i>Petiveria alliacea</i>	2.55	0.0005	0.71	10	0.18
Lower	<i>Ficus benamina</i>	2.86	0.0006	0.89	14	0.22
Lower	<i>Excoecariacochinchinensis</i>	2.55	0.0005	0.71	22	0.28
Lower	<i>Tovomitabasilensis</i>	3.18	0.0008	1.10	13	0.21
Lower	<i>Apodytes dimidiata</i>	2.23	0.0004	0.54	15	0.22
Lower	<i>Theobroma cacao</i>	4.46	0.0016	2.17	11	0.19
Middle	<i>Carpinus betulus</i>	3.50	0.0010	1.34	16	0.30
Middle	<i>Anaxagorea Annonacea</i>	1.91	0.0003	0.40	10	0.24
Middle	<i>Hoya</i>	7.32	0.0042	5.84	9	0.23
Middle	<i>Theobroma cacao</i>	2.55	0.0005	0.71	13	0.27
Middle	<i>Citrus sinensis</i>	2.55	0.0005	0.71	8	0.21
Middle	<i>Bursera</i>	2.86	0.0006	0.89	3	0.11
Middle	<i>Plinia cauliflora</i>	2.55	0.0005	0.71	19	0.32
Middle	<i>Cnidocolusa conitifolius</i>	12.73	0.0127	17.68	12	0.26
Middle	<i>Ficus benamina</i>	9.55	0.0072	9.94	6	0.18
Upper	<i>Goupia glabra</i>	6.37	0.0032	4.42	7	0.32

Upper	<i>Tovomitabrsiliensis</i>	9.55	0.0072	9.94	6	0.30
Upper	<i>Ficus benjamina</i>	7.96	0.0050	6.91	5	0.27
Upper	<i>Sapiumellipticum</i>	2.86	0.0006	0.89	3	0.21
Upper	<i>Laurus nobilis</i>	2.23	0.0004	0.54	2	0.16
Upper	<i>Maesa lanceolata</i>	2.86	0.0006	0.89	9	0.35
Upper	<i>Anaxagoreadolichocar pa</i>	16.55	0.0215	29.88	4	0.25

Slope gradients in the herbaceous zone drastically reduce the number of species belonging to the Zingiberaceae and Marantaceae families; these species are primarily limited to lower slope gradients found in clearings, understory areas, and riverbanks. According to Grinand *et al.* (2017), these groups are primarily found in the tropics and are likewise megathermal. In other instances, two factors, their tendency toward microthermality and their desire for light, may be connected to the growing trend of species richness within several families.

It's possible that forests with higher slope gradients benefit from the increased light availability. For instance, *Asteraceae* species and several fern species from families like Aspleniaceae, Dennstaedtiaceae, and Lycopodiaceae. were more diversified in tropical highlands and temperate settings but were rarely found at lower slope gradients (frequently in lit areas). The structure of their daisy-like blossoms may also account for their strong occurrence in mountains (Takimoto *et al.*, 2009), which would make it easier for mountain breezes to scatter them.

**Table 3:** Summary of the structural characteristics along slope gradient of Kpataweeforest

Structure parameters	Upper slope			Middle slope			Lower slope		
	DBH (m)	BA (m <sup>2</sup> )	RD (%)	DBH (m)	BA (m <sup>2</sup> )	RD (%)	DBH (m)	BA (m <sup>2</sup> )	RD (%)
Mean	6.91	0.0055	3.93	5.06	0.0031	4.25	2.67	0.0006	0.83
Std Dev	1.93	0.0028	1.58	1.29	0.0014	2	0.23	0.0001	0.16
Min	2.23	0.0004	0.54	1.91	0.0003	0.4	1.91	0.0003	0.4
Max	16.55	0.022	9.94	12.73	0.013	17.68	4.46	0.002	2.17

Diameter at breast height (DBH), basal area (BA), relative dominance (RD)

There were more individuals in the diameter size; all individuals were distributed differently among the various DBHs (Table 3) along the slope gradient. According to Worku *et al.* (2012), the diameter at breast height distribution generally indicated that the species were more prevalent on the upper slope and gradually reduced towards the lower slope. Different patterns in the slope gradient were produced by the density distributions of some tree species in different diameter classes. *Sapiumellipticum* produced the highest DBH of trees in the middle slope (> 90 cm), whereas *Ficus sycomorus* species recorded the highest DBH (< 10 cm).

According to Bajigo and Tadesse (2015), the degree of covering of a tree species as a representation of the space it occupies in a forest is known as its relative dominance. In Table 2, RDs for every species of tree are listed. In the higher slope, *Anaxagoras dolichocarpa* (29.88%), *Cridoscolusaconitifolius* (17.68%), *Tovomitabrsiliensis* (upper slope), and *Ficus benjamina* (9.94%) were the tree species with the highest RD. There was another similar relative dominance.

#### 4. CONCLUSION

In this study, the richness and abundance of tree species were examined. The entire sampling area (0.36 hectare) yielded the identification of 26 different tree species. The three wealthiest families, the Moraceae, Rutaceae, and Euphorbiaceae, which seem to be well-represented in the woods, are

represented in all analyzed cases by decreasing species richness. In the herbaceous, these groups become outnumbered, with the exception of the Rutaceae family, which comes in second. Their capacity to adapt to larger agroecologies is primarily to blame for this. Lower altitudes showed a higher species richness of trees. The lower altitude showed the highest species abundance, followed by the medium and above elevations. In the upper and lower altitudes, respectively, the lowest Shannon diversity index value ( $H' = 1.85$ ) and the highest value ( $H' = 2.28$ ) were found. The biodiversity did not significantly change between altitudes despite their values. The distribution of diameter classes revealed that fewer species were found in the higher diameter classes, with a gradual decline in the lower diameter classes.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## AUTHORS' CONTRIBUTIONS

All authors involved in the design of the study, performed the statistical analysis, wrote the protocol, and wrote the manuscript. All authors read and approved the final manuscript.

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