International Journal of Ecology and Environmental Sciences 50: 467-479, 2024
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2024.0066

Effect of Slope Aspect on Tree and Shrub Diversity of Lesser Himalaya of Garhwal Region, Uttarakhand, India

DHARMENDRA SHAH*, SHUBHAM CHAUHAN AND A. K. NEGI
Hemvati Nandan Bahuguna Garhwal University, Srinagar (Garhwal), 246174, Uttarakhand, India
E-mail: shahdharm850@gmail.com, shubhamforestry1996@gmail.com, aknsilvic@rediffmail.com
***Corresponding author**

ABSTRACT
A research study was conducted in the Garhwal region of the lesser Himalaya to explore the impact of topographical aspects on vegetation species diversity. The research was conducted for two years, from January 2021 to December 2022. Randomly placed sampling plots of 20 x 20 m were used for trees and 5 x 5m for shrubs in different slope directions (E, NE, N, NW, W, SW, S, SE) for vegetation analysis. The study revealed the presence of 28 tree species and 17 shrub species. The north-western slope aspect had the highest diversity of tree species (H'=2.14), while the south-western slope aspect had the highest number of shrub species (H'=2.06). The CD values for trees in the south-western slope aspect (0.41) and shrubs in the northern slope aspect (0.23) were the highest. The study found that an area's topographical aspects significantly impact plants' diversity and spatial distribution. For trees, the north-western slope aspect had the highest evenness value (0.86) and the western slope aspect had the highest species richness (2.92). On the other hand, for shrubs, the northern slope aspect had the highest evenness value (0.96), and the north-eastern slope aspect had the highest species richness (2.18). In conclusion, the north-western slope aspect was more diverse for trees, while the south-western slope aspect was more diverse for shrubs.

Key words: Diversity; Distribution; Evenness; Lesser Himalaya; Richness; Topographical aspect.

INTRODUCTION

The Garhwal region is an integral part of the Western Himalaya in Uttarakhand, comprising several types of forests that change with altitude. Other factors like topography, slope inclination, slope aspect, and soil type also determine the forest's composition as the altitude increases (Shank and Noorie 1950, Holland and Steyn 1975, Sharma et al. 2009). Depending on the slope and aspect of a site, insolation periods at different elevations vary, creating a diverse range of microclimates across various landscapes. Recent research suggests that the middle of soil nutrient gradients typically has the highest species diversity (Song et al. 2008). Some argue it evolved in the most fertile locations (Gentry 1988). However, several studies have shown that as altitude increases, species diversity decreases (Hao et al. 2002). On the other hand, others have discovered that areas with reasonable elevation occupied the most excellent species variety due to optimal hydrothermal conditions (Li et al. 2002). In hilly terrain, slope aspect and slope position significantly influence plant variety but little on plant assemblage (Zeng et al. 2014). The slope and altitude factors greatly influence the temperature regime of each location (Yang et al. 2020). Additionally, the two distinct topographical aspects shift the patterns and orientation of vegetation structure and composition (Chmura 2008).

The phytosociological study aims to describe and comprehend the features and functions of vegetation. It provides information on the makeup of trees, shrubs, herbs, and climbers (Rawat and Chandra 2014). Although studies on the diversity of vegetation and forest composition have been conducted in various parts of the Himalaya, there is a need for more analysis of plant compositions and diversity in the Lesser Himalayan region of Garhwal Himalaya. Therefore, we have analyzed the hypothesis that topographical aspects impact plant compositions and diversity along the altitudinal gradient.

MATERIALS AND METHODS

Study area

The study was conducted in the Garhwal region between Lansdowne (29°50'03.11''N and 78°41'38.38''E) the highest point, and Kotdwar (29°44'00.03'' N and 78°31'55.53'' E) the lowest

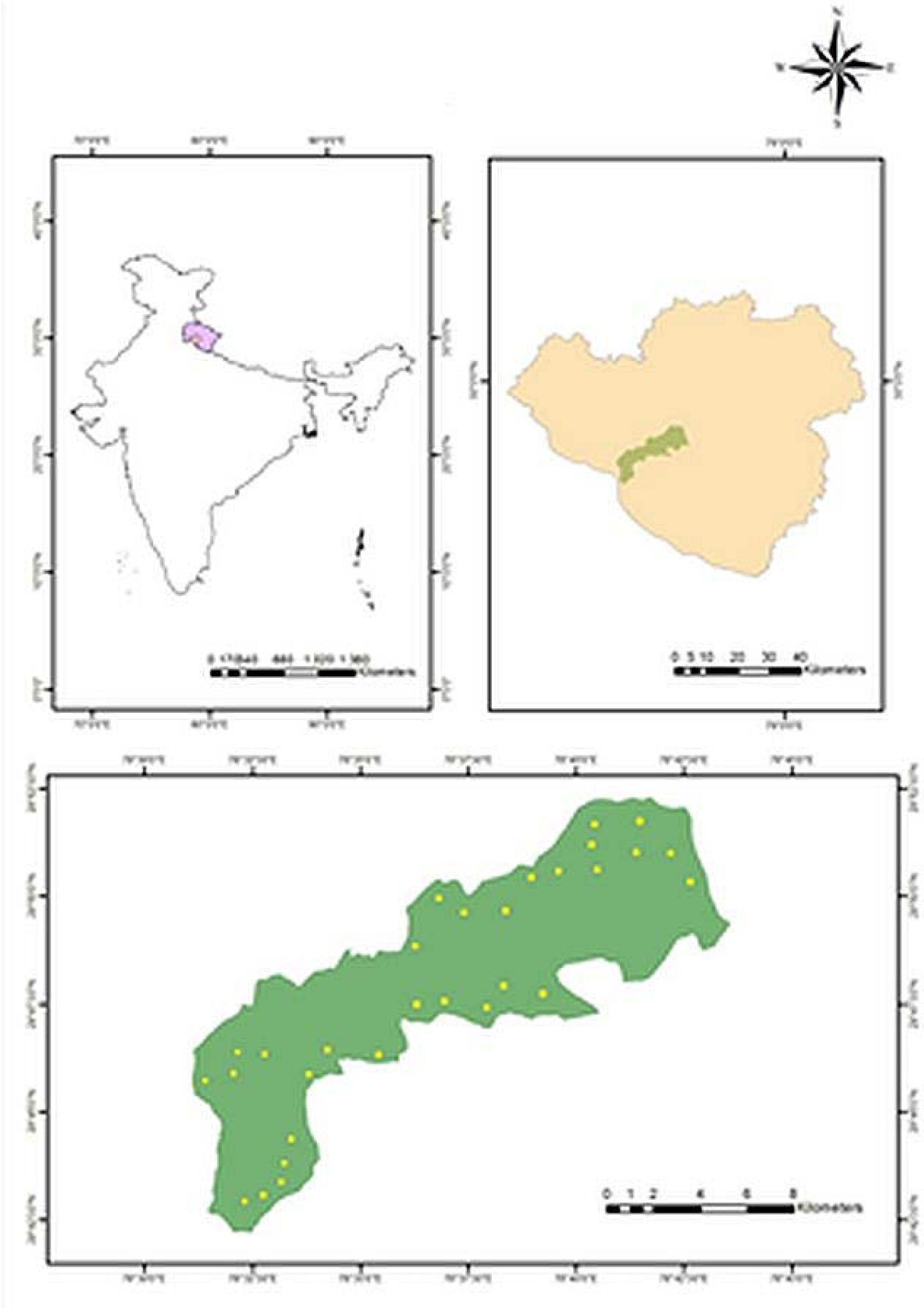


Figure 1. Map of study site

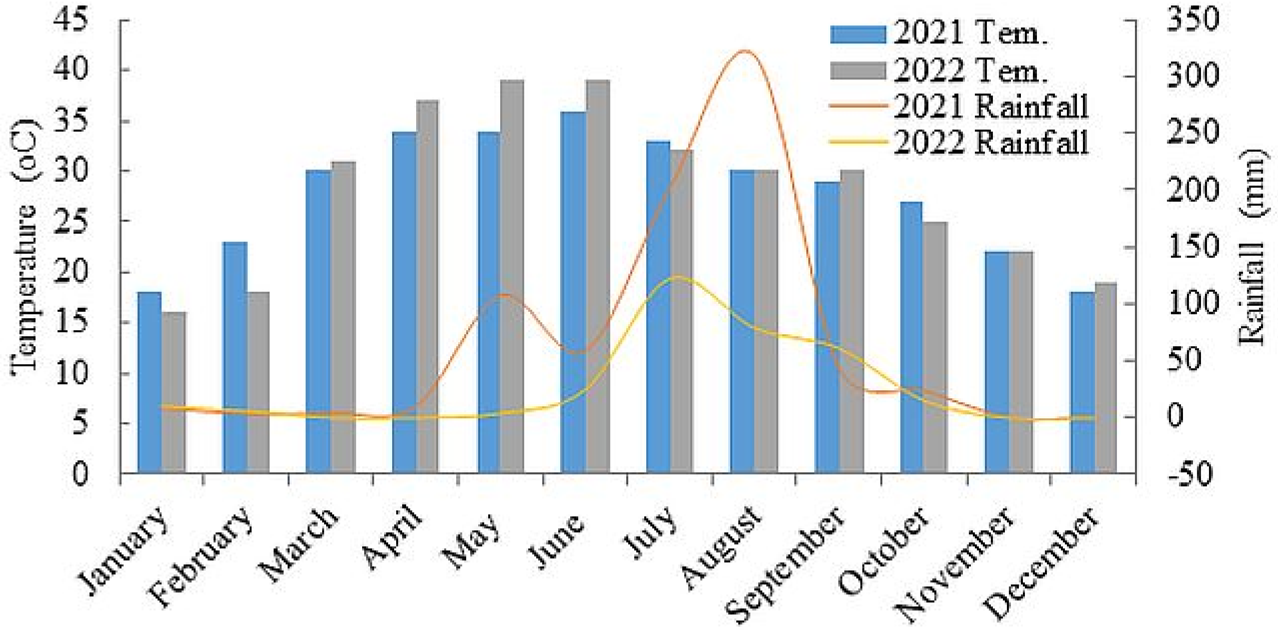


Figure2. Meteorological data of study site

point, along the Kho river (Fig. 1). This area is located in the Lesser Himalayan range, which is the outermost range of the Himalaya. The study area is between two well-known protected regions of Uttarakhand, the Corbett National Park and the Rajaji Tiger Reserve, home to various flora and fauna. The altitude of the study area ranges from 350 to 1550 m amsl. The mean annual temperature of the study area ranges from 18^{o}C in January to 39^{o}C in June (Fig. 2). The annual average rainfall is 218 cm, with 90% concentrated during the monsoon season and the relative humidity varies between 54 and 63% (Anonymous 2016).

With varying altitudinal zones and climatic variations, tree and shrub species also vary; most species are deciduous. The lower altitudinal zones-I (350-650 m) have dominant shrub species such as *Lantana camara, Murraya koenigii, Clerodendrum infortunatum,* and *Glycosmis pentaphylla* associated with tree species *of Adina cordifolia, Tectona grandis, Cassia fistula, Wrightia tinctoria, Bombax ceiba* and *Schleichera oleosa.* However, the middle to higher altitudinal zones-II, III, IV (650-1550 m) are dominated by *Eupatorium adenophorum, Rhus parviflora, Maesa montana, Inula capa, Berberis aristata* and *Rubus ellipticus* with the *Shorea robusta, Pinus roxburghii, Myrica esculenta, Quercus leucotrichophora* and *Rhododendron arboreum* tree species. Some shrub species were common across the study area, such as *Lantana camara* and *Eupatorium adenophorum.*

Methodology

To ensure a comprehensive analysis of the vegetation in the area, the sampling was conducted across different altitudinal zones and topographic aspects (E, NE, N, NW, W, SW, S, and SE) along with altitudinal gradients. Given the steep slopes and varying landscapes, 40 quadrats of 20 x 20 m for trees and 5 x 5 m for shrubs were randomly laid out to cover the sampling area. The identified tree and shrub species were listed, and quantitative analysis was done. To determine the frequency, relative frequency, relative density, relative dominance, importance value index (IVI), and basal area, the standard procedures presented by Curtis and McIntosh (1950) were used. Species diversity (H') was calculated using Shannon and Wiener's method (Shannon and Wiener 1963), while Simpson's index (Simpson 1949) was used to determine the concentration of dominance (CD). Species richness was determined by Margalef's index (MA) (Margalef 1958), and the evenness index (J) was calculated using Pielou's formula (Pielou 1966). Additionally, correlation analysis was performed using the PAST software package version 4.0.

Table 1. Frequency (%), density (individuals ha^{-1}), IVI of tree layer

		Eastern			North-eastern			Northern			North-western			Western			South-western			Southern			South-eastern		
Tree species	**Family**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**
Pinus roxburghii	*Pinaceae*	60	145	136.4	40	65	73							20	70	43.06	40	125	91.73	40	105	91.34	60	195	136.93
Quercus leucotrichophora	*Fagaceae*	40	35	45.4																					
Rhododendron arboreum	*Ericaceae*	20	10	18.0																					
Myrica esculenta	*Myricaceae*	20	5	14.3																					
Shorea robusta	*Dipterocarpaceae*	40	80	85.9	60	180	134	80	175	143.1	20	75	53.8	20	5	26.88	80	160	165.87	60	120	115.51	20	20	34.78
Mitragyna parvifolia	*Rubiaceae*																						20	10	35.13
Schleichera oleosa	*Sapandaceae*				20	5	11																		
Holoptelea integrifolia	*Ulmaceae*				20	20	21				40	35	41.6	40	15	26.17				20	15	31.12	20	5	14.33
Cassia fistula	*Caesalpiniceae*				20	10	12							40	20	29.45							40	15	27.30
Albizia lebbeck	*Mimosaceae*				20	5	10																		
Albizia procera	*Mimosaceae*													20	5	17.04							20	5	16.94
Lannea coromandelica	*Anacardiaceae*				20	5	11	20	5	11.4	20	10	12.03							20	5	12.20			
Sapium insigne	*Euphorbiaceae*				20	5	11													20	5	11.45			
Toona ciliate	*Meliaceae*				20	5	16																		
Semicarpus anacardium	*Anacardiaceae*							20	10	17.8							20	5	14.26	20	5	11.90			
Wrightia arborea	*Apocynaceae*													40	30	29.37									
Mallotus philippensis	*Euphorbiaceae*							40	20	28.2	40	15	19.96	40	25	26.21	20	5	14.47	20	10	14.01			
Acer oblongum	*Aceraceae*							40	90	81.7															
Bombax ceiba	*Bombacaceae*													20	0	15.56									
Terminalia tomentosa	*Combretaceae*							20	10	17.9	20	10	16.04				20	5	13.66						
Aegle marmelos	*Rutaceae*																			20	5	12.48			
Moringa oleifera	*Moringaceae*										20	5	10.77												
Adina cordifolia	Rubiaceae										40	30	59.58	40	15	41.00							20	15	23.25
Erythrina suberosa	*Fabaceae*										40	30	28.31	20	5	13.76									
Tectona grandis	*Verbenaceae*										20	5	11.64	20	15	21.18									
Cassine glauca	*Celastraceae*										20	5	10.08	20	5	10.32							20	5	11.35
Diospiros montana	*Ebenaceae*										20	10	10.91												
Anogeissus latifolia	*Combretaceae*										20	20	25.26												

RESULTS AND DISCUSSION

The study examined the composition and structure of trees and shrubs in different topographical aspects. In the present study we enumerated, 438 individual trees belonging to 28 species and 24 families and 474 individual shrubs belonging to 17 species and 13 families and analyzed quantitatively.

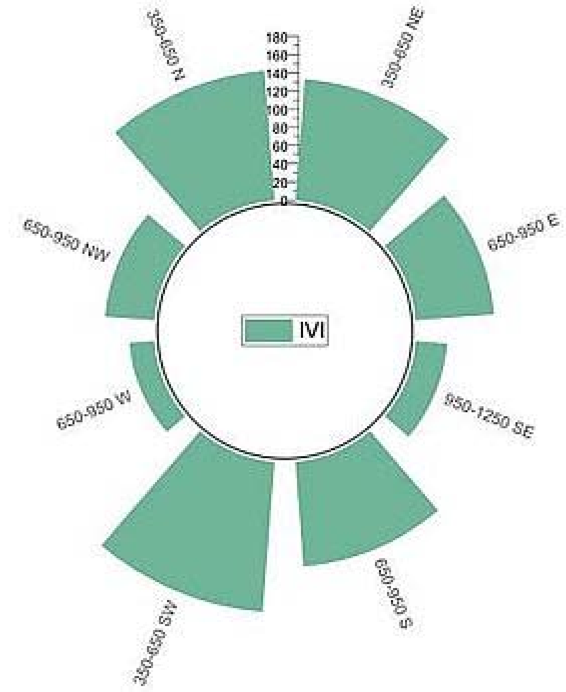
Vegetation association with altitude and slope aspect

The study examined the composition and structure of trees and shrubs in different topographical aspects. Tables 1 and 2 present phytosociological data of the trees and shrubs in each altitudinal zone and topographical aspect, respectively. *Shorea robusta*, commonly known as Sal, exhibits a broad altitudinal distribution ranging from 350 to 1250 m, encompassing all topographical aspects of the lesser Himalayan region (Fig. 3a). It attains highest dominance in the South-western aspect at elevations between 350 and 650 m, with an impressive dominance ratio (IVI) of 165.87. Its dominance gradually extends to the Western and North-western aspects, reaching prominence in the Northern (IVI 143.1) and North-eastern (IVI 134) within the same altitudinal range. However, Sal's dominance diminishes above 650-950 m in the western and North-eastern aspects. *Mallotus philippensis* is identified as an associated species of *Shorea robusta*, displaying an altitudinal range of 350-950 m asl, with higher IVI values in the Northern (IVI 28.2) and Western (IVI 26.21) aspects within the 350-650 m altitudinal distribution (Fig. 3c). The distribution of *Pinus roxburghii* spans an altitudinal range of 350-1250 m (Fig. 3b), with dominance in the Eastern (IVI 136.4) and South-eastern (IVI 136.9) aspects above the 950-1250 m altitudinal range. Concurrently, *Acer oblongum* (IVI 81.17) demonstrates a notable association with the Northern aspect within the 650-950 m elevation range.

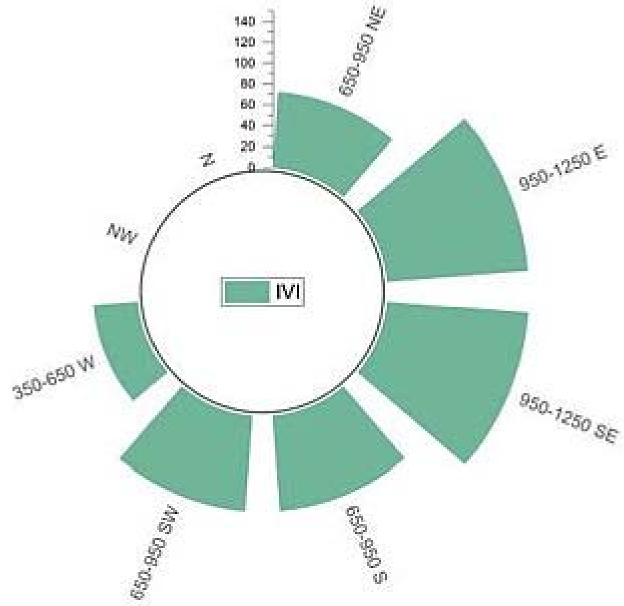
Among shrub species, it is observed that *Murraya koenigii* and *Lantana camara* exhibit a random distribution across the entire area, spanning altitudes from 350 to 1250 m and all topographical aspects (Figs. 3e, f). The highest IVI value for *Murraya koenigii* is in the altitudinal range of 650-950 m, specifically in the Northern aspect (100.96), followed

Table 2. Frequency (%), density (individuals ha^{-1}), IVI of shrub layer

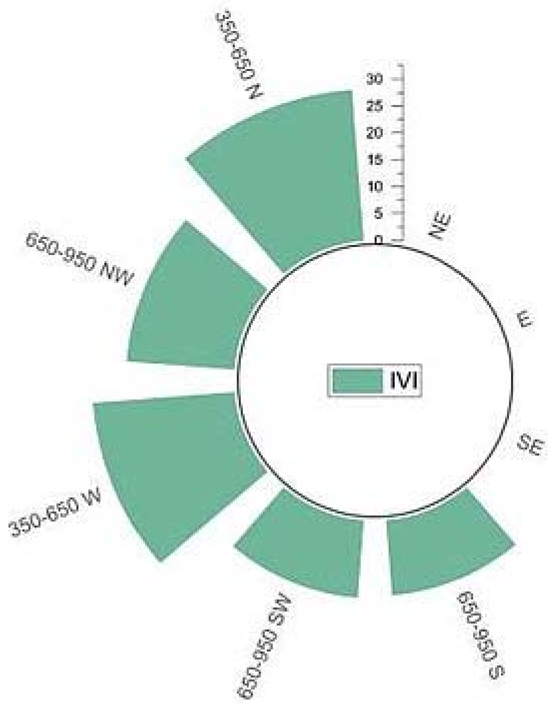
		Eastern			North-eastern			Northern			North-western			Western			South-western			Southern			South-eastern		
Shrub species	**Family**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**	**F**	**D**	**IVI**
Murraya koenigii	Rutaceae	20	0.40	11.07	40	1.00	33.79	80	4.20	100.96	80	3.00	83.47	60	1.00	50.06	20	0.80	14.7	40	0.60	27.86	40	1.20	53.71
Clerodendrum infortunatum	Lamiaceae	20	0.60	13.45				40	3.20	60.96	60	1.40	37.87	60	1.40	53.26				20	0.60	22.48	40	0.80	24.22
Glycosmis pentaphylla	Rutaceae										20	0.40	10.87												
Eupatorium adenophorum	Asteraceae	60	4.20	63.88	40	2.00	36.63	40	1.80	37.02	40	2.20	44.36				60	2.60	42.76	20	0.20	10.38	60	3.00	48.59
Colebrookea oppositifolia	Lamiaceae				20	0.60	12.12				20	1.00	23.9	20	0.60	24.62	20	0.40	14.54	40	1.40	44.66	20	2.00	29.92
Lantana camara	Verbenaceae	20	0.40	20.59	60	2.40	64.64	60	2.40	63.37	40	2.00	62.27	60	3.60	83.57	60	1.00	36.53	20	0.40	21.95	60	1.60	48.45
Rhus parviflora	Anacardiaceae	60	3.20	74.33	40	3.60	69.21										40	3.40	69.51	60	3.00	96.8	20	0.80	19.71
Justicia adhatoda	Acanthaceae				20	0.40	15.45				20	1.00	22.14	20	0.40	12.51				20	0.40	24.42	20	0.20	11.33
Senna occidentalis	Fabaceae										20	0.40	15.12	20	0.80	16.86									
Maesa Montana	Primulaceae	40	1.60	39.05	40	1.20	33.26	20	0.12	37.68							20	1.40	42.35				40	3.00	64.07
Inula cappa	Asteraceae				20	0.40	9.76										20	0.80	13.28	20	1.00	27.2			
Woodfordia fruticosa	Lythraceae				20	0.40	10.3													20	1.20	24.26			
Berberis aristata	Berberidaceae	20	0.40	10.53													20	0.40	10.12						
Rubus ellipticus	Rosaceae	40	1.80	44.67										20	1.20	31.81	20	2.20	37.13						
Cestrum aurantiacum	Solanaceae	20	0.60	22.44																					
Carissa opaca	Apocynaceae				20	0.40	14.83																		
Pogostemon beghalensis	Lamiaceae													40	0.60	27.31	20	0.60	19.08						



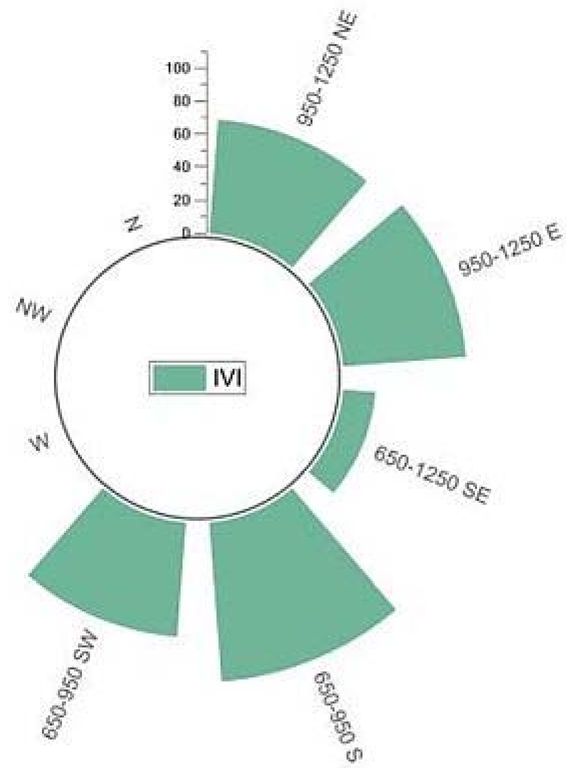
Shorea robusta



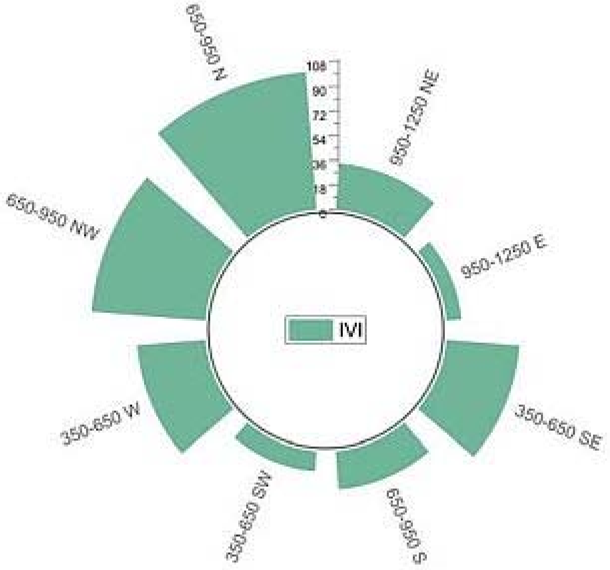
Pinus roxburghii



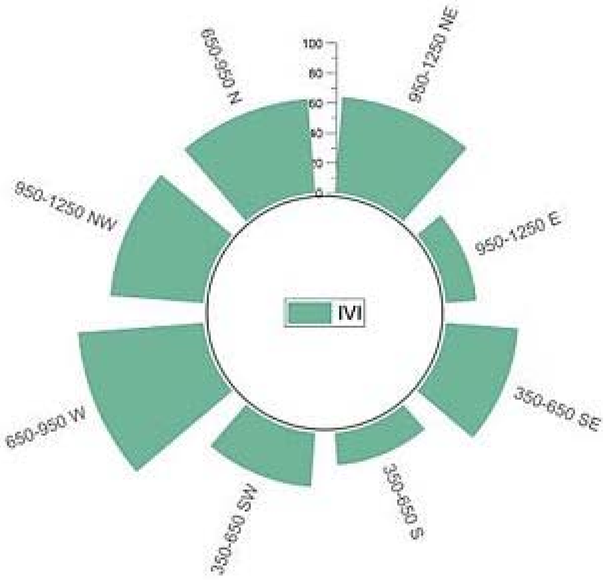
Mallotus philippensis



Rhus parviflora



Murraya koenigii



Lantana camara

Figure 3. Elevation wise dominance of tree and shrub species

by the North-western aspect (83.47). In contrast, the lowest IVI value is in the Eastern aspect (11.07) within the 950-1250 m altitudinal range. *Lantana camara*, a shrub associated with *Murraya koenigii*, exhibits its highest IVI value in the Western aspect (83.57) within the 650-950 m, while the lowest value (20.59) is observed in the 950-1250 m altitudinal range, specifically in the Eastern aspect. Within the upper altitudinal zone, *Rhus parviflora* is found to coexist with the dominant shrubs *Lantana camara* and *Murraya koenigii,* occupying an altitudinal range of 650-1250 m and varying slope aspects (Fig. 3c). *Rhus parviflora* is notably absent from the Western, North-western, and Northern aspects, exhibiting dominance in the Southern aspect (IVI 96.8) within the 650-950 m altitudinal range and extending toward the South-east (IVI 19.71) and South-western aspects (IVI 69.51). Other shrub species, including *Eupatorium adenophorum, Colebrookea oppositifolia, Clerodendrum infortunatum*, and *Maesa montana*, demonstrate a widespread distribution across multiple topographical aspects.

The study found that tree density ranged from 210 to 310 individuals ha^{-1} (Table 1), with the highest density found in the Northern aspect and the lowest in the Western aspect, followed by the North-western, Southern, and South-eastern aspects. Meanwhile, shrub density (Table 2) ranged from 8.8 to 13.6 individuals 25 m^{-2} in the southern and southwestern areas. Rawat and Rawat (2010) and Pala et al. (2011) reported similar density of 193 to 324 individuals ha^{-1} for trees and a density of 12.8 individuals 25 m^{-2} for the shrub layer in the forest of Garhwal Himalaya. The Shannon and Wiener (H'), Margalef's (Ma), Pielou (j), and Simpson diversity (CD) indices for vegetation varied significantly among the aspects ($p<0.05$). The present study recorded highest tree diversity (Table 3) in the North-western aspect (H'= 2.14, D= 0.14, CD= 0.10, J= 0.86), and richness in the Western aspect (Ma= 2.92). In contrast, lowest tree diversity was found in the South-western aspect (H'= 0.90, Ma= 0.98). Singh et al. (2016) also reported similar values of (1.27 - 1.86) tree diversity.

Maximum diversity of shrubs was in the south-western aspect (H'= 2.06, Ma= 2.13, D= 0.14), and the lowest in the northern aspect (H'= 1.55, Ma= 0.95, D= 0.21). Zeng et al. (2014) revealed that Shannon-Weiner (H') and Margalef (Ma) indices in the southern slopes were substantially higher (1.44 and 1.06) than those in the northern slope. Similarly, Bhat et al. (2020) reported diversity values of 2.09-3.37 for trees and 2.62-4.20 for shrubs in the Western Himalaya, while Pokhriyal et al. (2009) reported diversity values of 0.74-0.77 for trees and 0.67-0.76 for shrubs for the forests of Garhwal Himalaya. Akash et al. (2018) reported the diversity of shrubs

Table 3. Diversity indices

	Slope aspects							
	Eastern	North-east	Northern	North-west	Western	South-west	Southern	South-east
Trees								
Shannon and Wiener Index (H')	1.15	1.27	1.15	2.14	2.11	0.90	1.31	1.06
Simpson Index (D)	0.37	0.40	0.40	0.14	0.15	0.45	0.34	0.53
CD	0.32	0.27	0.32	0.10	0.12	0.41	0.26	0.26
Richness (SR)	1.00	1.95	1.21	2.81	2.92	0.98	1.75	1.75
Evenness (E)	0.71	0.58	0.64	0.86	0.84	0.56	0.62	0.51
Shrubs								
Shannon and Wiener Index (H')	1.83	1.99	1.55	1.89	1.83	2.06	1.91	1.88
Simpson Index (D)	0.19	0.16	0.21	0.16	0.19	0.14	0.17	0.16
CD	0.16	0.15	0.23	0.17	0.17	0.14	0.17	0.15
Richness (SR)	1.91	2.18	0.95	1.73	1.81	2.13	2.11	1.69
Evenness (E)	0.83	0.86	0.96	0.91	0.88	0.90	0.87	0.90

is (H') 1.89 in the subtropical moist deciduous forest of the Rajaji Tiger Reserve as also reported by Malik et al. (2015). The value of species diversity (H') in various forest types varies between 1.22 to 2.46 for shrubs (Semwal et al. 2010). These minor variations in diversity values could be attributed to the protected status and broader geographic characteristics such as altitude, aspect, and fertile soil. Verma et al. (2004) revealed that species diversity is governed by long-term factors, particularly community stability and evolutionary time because the variety of micro- and macro-climate influences diversification among various communities. This study reported the higher evenness (J) values for shrubs (0.83- 0.96) which is similar to those reported by (Akash et al. 2018) and (Uniyal et al. 2010).

Dominance-diversity curve

The dominance-diversity curve for shrub and tree layers is presented in Figures 4 and 5 which shows geometric series pattern. As per Whittaker (1965), the log-normal series illustrates the partitioning of realized niche space over various species and is the outcome of the evolution of specific species diversity along the niche parameters. Additionally, Raturi (2012) reported that the dominance-diversity curve for all forest types' tree and shrub layers was similar to the geometric series based on an importance value index (IVI).

Relationship between variables and topographical aspect

Pearson's correlation test for tree species distribution among different topographical aspects indicated that diversity (H') had a significantly strong positive correlation with species richness ($r = 0.924$; $p<0.01$), Simpson index of dominance ($r = 0.950$; $p<0.01$), while it had a strong negative correlation with Simpson's index ($r = -0.950$; $p<0.01$) and Concentration dominance ($r = -0.947$; $p<0.01$). Additionally, species dominance showed a strong negative correlation with the Simpson index ($r = -1.000$; $p<0.01$), Concentration dominance ($r = -0.817$; $p<0.05$), and significant positive correlation with Richness ($r = 0.781$; $p<0.05$) (Table 4). Similarly, for shrub species distribution among different topographical aspects, diversity (H') had a significant strong positive correlation with species richness ($r = 0.925$; $p<0.01$), Simpson dominance (r

Table 4. Relationship among the variables along with topographical slope aspect for tree layer

	Shannon_H	Simpson	CD	Evenness	Richness	Dominance
Shannon_H	1					
Simpson	-.909** (0.002)	1				
CD	-.933** (0.001)	.815* (0.014)	1			
Evenness	-0.531^{NS} (0.176)	0.184^{NS} (0.662)	0.651^{NS} (0.081)	1		
Richness	.925** (0.001)	-0.701 (0.053)	-.875** (0.004)	-.772* (0.025)	1	
Dominance	.921** (0.001)	-.987** (0)	-.866** (0.005)	-0.243 (0.562)	.711* (0.048)	1

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).

Table 5. Relationship among the variables along with topographical slope aspect for shrub layer

	Shannon_H	Simpson	CD	Evenness	Richness	Dominance
Shannon_H	1					
Simpson	-.950** (0)	1				
CD	-.947** (0)	.817* (0.013)	1			
Evenness	-0.292^{NS} (0.482)	0.522^{NS} (0.185)	0.047^{NS} (0.913)	1		
Richness	.924** (0.001)	-.781* (0.022)	-.960** (0)	-0.105 (0.804)	1	
Dominance	.950** (0)	-1.000** (0)	-.817* (0.013)	-0.522 (0.185)	.781* (0.022)	1

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).

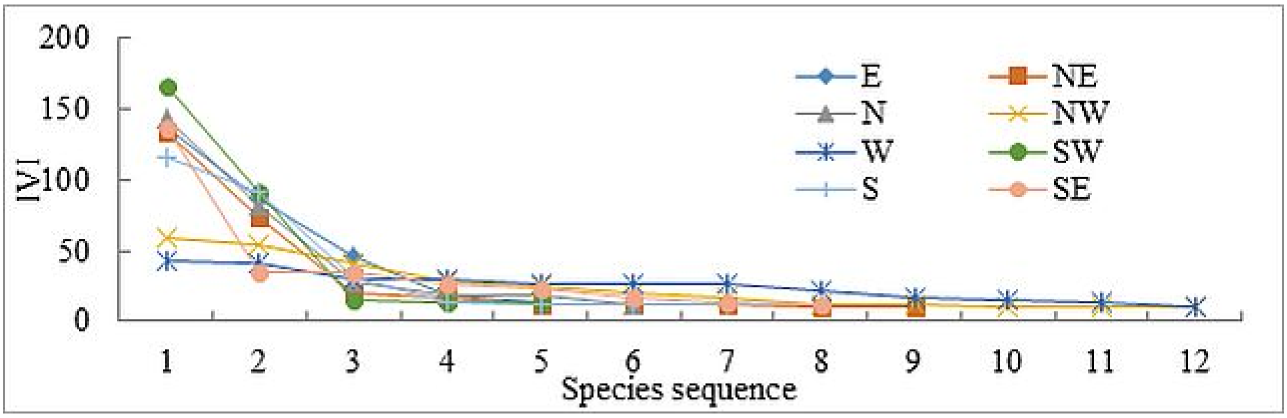


Figure 4. Dominance-diversity curve of tree species in different slope aspects

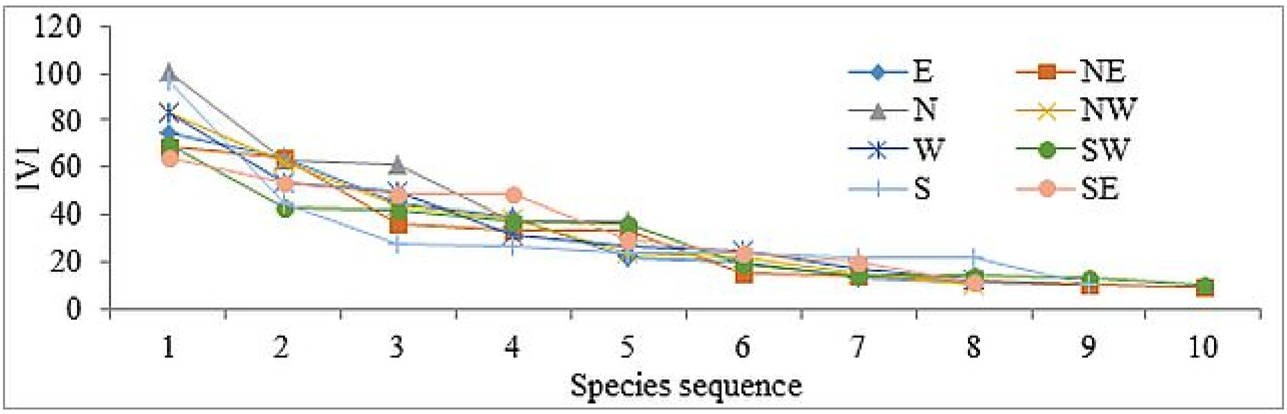


Figure 5. Dominance-diversity curve of shrub species in different slope aspects

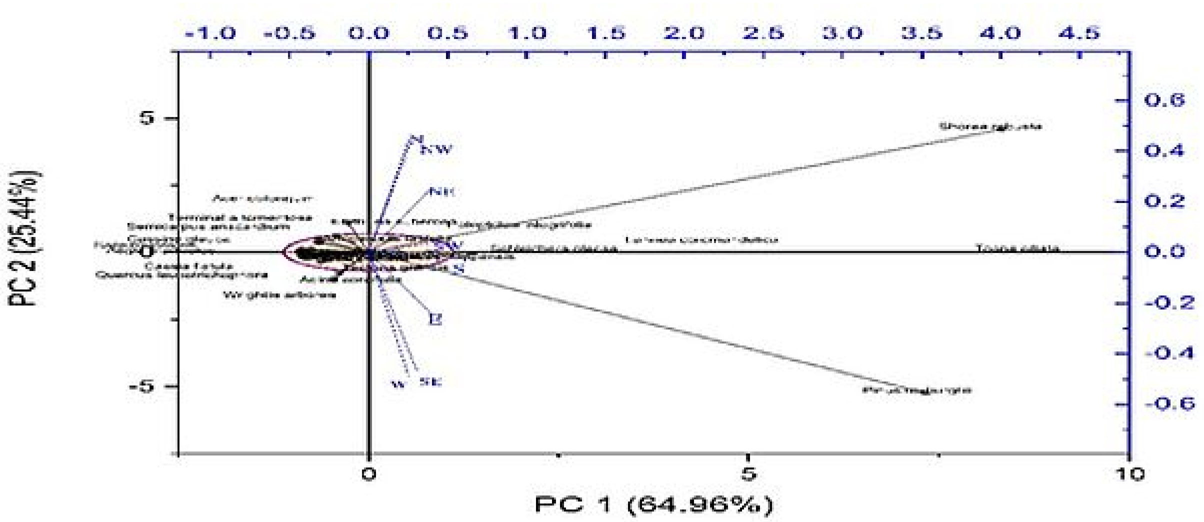


Figure 6. Principal component analysis (PCA) biplot for tree species

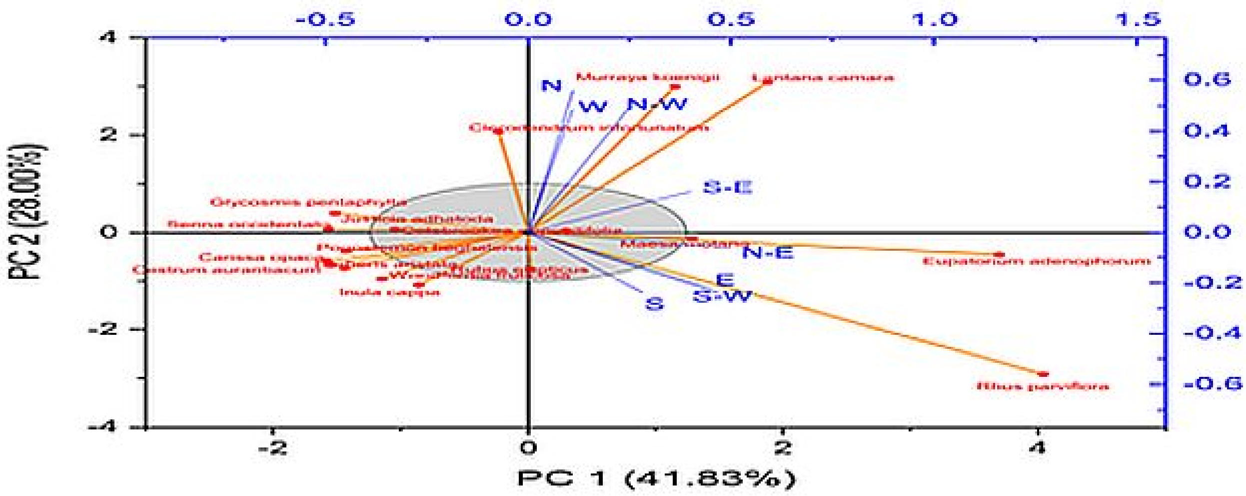


Figure 7. Principal component analysis (PCA) biplot for shrub species

= 0.921; p<0.01), while it had a strong negative correlation with Simpson's index (r = -0.909; p<0.01) and Concentration dominance (r = -0.933; p<0.01). In addition, species dominance is strongly negatively correlated with the Simpson index (r = -0.987; p<0.01), Concentration dominance (r = -0.866; p<0.01), and positively significant with Richness (r = 0.711; p<0.05) (Table 5).

Principal component analysis

The tree PCA plot (Fig. 6) revealed that the northern, north-western, north-eastern, and south-western slope aspects formed cluster I, while, the southern, south-eastern, eastern, and western slope aspects formed the cluster II. Species distributions such as *Shorea robusta, Lannea coromandelica, Schleichera oleosa, Toona ciliate*, and *Holoptelea integrifolia* were present in cluster I. Similarly, the PCA plot for shrubs (Fig. 7) showed that the northern, western, north-western, and south-eastern slope aspects formed cluster I, while the north-eastern, eastern, south-western, and southern slope aspects formed cluster II. *Murraya koenigii* and *Lantana camara* showed strong affinity with cluster I, and *Eupatorium adenophorum, Rhus parviflora*, and *Maesa montana* showed strong affinity with cluster II. Both cluster I and II of trees showed strong affinity with cluster I and II of shrubs, respectively.

Shorea robusta and *Pinus roxburghii* were the dominant trees. At the same time, *Murraya koenigii* and *Lantana camara* were the most dominant shrubs in the majority of the topographical aspects, followed by *Rhus parviflora*. The diversity of vegetation was not evenly distributed across different slope aspects. Tree species diversity was more in the north-western aspect (H'= 2.14) and western aspect (H'= 2.11), followed by north-eastern aspect (H'= 1.27) and northern aspect (H'= 1.15) as also reported by Sharma et al. (2010) for tree diversity (1.81) in the northern aspect. The higher diversity of shrubs was reported in the south-western aspect (H'= 2.06), followed by the north-eastern aspect (H'= 1.99), while the northern aspect (H'= 1.55) reported the lowest diversity. The southern aspect exhibited higher shrub species diversity, as also reported by Zeng et al. (2014). The direction of a slope plays a significant role in determining the diversity of plant species that can grow in an area. This is because different slopes receive varying amounts of sunlight, warmth, moisture, and soil nutrients, creating unique environmental conditions that support diverse plant communities.

South-facing slope aspects receive maximum sunlight and are usually warmer and drier than other slope aspects Cantlon (1953). These conditions make them ideal for plant species adapted to hot, dry conditions. In particular, south-facing slopes support predominantly shrub species, although some tree species may also survive in these conditions. The southern slope aspect is also known for its rich diversity of plant species, which makes it an essential area for conservation efforts. On the other hand, north-facing slopes receive the minimum sunlight and are usually colder and moist than other slope aspects Searcy et al. (2003). These environmental conditions support plant species adapted to more moist conditions. In particular, most trees grow well on north-facing slopes and have a rich diversity of plant species.

East-facing slopes receive morning sun and are more-cooler in the afternoon, while west-facing slopes receive midday sun and are warmer in the afternoon. These environmental conditions create microclimates that support unique plant communities Singh (2018). For instance, east-facing slopes may be cooler and moister, keeping plant species adapted to these conditions, while west-facing slopes may be warmer and drier, supporting plant species adapted to hot and dry conditions Zeng et al. (2014). Understanding the impact of topographical aspects on plant communities is essential for developing sustainable ecosystems that support diverse plant species and promote a healthy environment.

CONCLUSIONS

The study concludes that the variance in species variety along altitudinal gradients is an essential area of ecological research. The factors that affect the species' structure and composition include history, habitat heterogeneity, biotic interaction, productivity, and climate. With the altitudinal rise, species structure and composition are affected due to altitudinal co-factors such as topography, aspect, slope inclination, and soil. We can develop conservation strategies that protect unique plant communities and encourage biodiversity by considering the specific environmental conditions that different slope aspects provide.

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to Department of Forestry and Natural Resource, HNBGU for the invaluable support and assistance throughout the course of this research. We also thank the State Forest Department in Uttarakhand, India, for permitting the research.

Authors' contributions: All authors contributed equally.

Conflict of interest: The authors declare no conflicts of interest.

REFERENCES

Akash., Navneet. and Bhandari, B.S. 2018. Phytosociological studies, biodiversity conservation in a sub-tropical moist deciduous forest of Rajaji Tiger Reserve; Uttarakhand, India. International Journal of Research and Analytical Reviews, 5(3), 39-51.

Anonymous. 2016. EIA (Environmental impact assessment Report). District Environment Impact Authority, Pauri Garhwal, Uttarakhand, India.

Bhat, J.A., Kumar, M., Negi, A.K., Todaria, N.P., Malik, Z.A., Pala, N.A., Kumar, A. and Shukla, G. 2020. Species diversity of woody vegetation along the altitudinal gradient of the Western Himalayas. Global Ecology and Conservation, 24, e01302. https://doi.org/10.1016/j.gecco.2020.e01302

Cantlon, J.E. 1953. Vegetation and microclimates on north and south slopes of Cushetunk Mountain, New Jersey. Ecological Monographs, 23, 241-270. https://doi.org/10.2307/1943593

Chmura, D. 2008. The slope aspect affects the heterogeneity and growth of ground vegetation in deciduous temperate forests. Polish Journal of Ecology, 56, 463-470.

Curtis, J.T. and McIntosh, R.P. 1950. The Interrelation of certain analytic and synthetic Phytosociological characters. Ecology, 31, 434-455. http://doi.org/10.2307/1931497

Gentry, A.H. 1988. Changes in plant commodity diversity and floristic composition on environmental and geographical gradients. Annales of Misauri Botanical Garden, 75, l-34. https://doi.org/10.2307/2399464

Hao, Z.Q., Yu, D.Y., Yang, X.M. and Ding, Z. 2002. Alpha diversity of communities and their variety along altitude gradient on northern slope of Changbai Mountain. Chinese Journal of Applied Ecology, 13, 785-789. http://www.cjae.net/EN/Y2002/V/I7/785

Holland, P.G. and Steyn, D.G. 1975. Vegetational responses to latitudinal variations in slope angle and aspect. Journal of Biogeography, 2, 179-183. https://doi.org/10.2307/3037989

Li, Q.H., Yang, L.W. and Zhou, J.X. 2002. Comparative analysis on species diversity of hill closed afforested plant community in Beijing Jiulong Mountain. Chinese Journal of Applied Ecology, 13, 1065-1068.

Malik, Z.A. and Bhatt, A.B. 2015. Phytosociological analysis of woody species in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India. Journal of Forest and Environmental Science, 31(3), 149-163. https://doi.org/10.7747/JFES.2015.31.3.149

Margalef, R. 1958. Information theory in ecology. General Systems, 3, 36-71.

Pala, N.A., Negi, A.K., Gokhale, Y. and Todaria, N.P. 2011. Species composition and phytosociological status of Chanderbadni Sacred forest in Garhwal Himalaya, Uttarakhand India. NeBIO, 2(4), 52-59.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. Journal of Theoretical Biology, 13, 131-144. https://doi.org/10.1016/0022-5193(66)90013-0

Pokhriyal, P., Naithani, V., Dasgupta, S. and Todaria, N.P. 2009. Comparative studies on species, diversity and composition of *Anogeissus latifolius* mixed forests in Phakot and Pathri Rao watersheds of Garhwal Himalaya. Current Science, 97(9), 1349-1355. https://www.jstor.org/stable/24109730

Raturi, G.P. 2012. Forest community structure along an altitudinal gradient of district Rudraprayag of Garhwal Himalaya, India. Ecologia, 2, 76-84. http://doi.org/10.3923/ecologia.2012.76.84

Rawat, V.S. and Chandra, J. 2014. Vegetational diversity analysis across different habitats in Garhwal Himalaya. Journal of Botany, 2014, Article ID 538242. https://doi.org/10.1155/2014/538242

Rawat, Y.S. and Rawat, V.S. 2010. Van panchayats as an effective tool in conserving biodiversity at local level. Journal of Environmental Protection, 1, 278-283. https://doi.org/10.4236/jep.2010.13033

Searcy, K.B., Wilson, B.F. and Fownes, J.H. 2003. Influence of bedrock and aspect on soils and plant distribution in the Holyoke Range, Massachusetts. Journal of the Torrey Botanical Society, 130, 158-169. https://doi.org/10.2307/3557551

Semwal, D.P., Uniyal, P.L. and Bhatt, A. 2010. Structure composition and dominance – diversity relations in three forest types of a part of Kedarnath Wildlife Sanctuary, Central Himalaya, India. Notulae Scientia Biologicae, 2(3), 128-132. https://doi.org/10.15835/nsb234655

Shank, R.E. and Noorie, E.N. 1950. Microclimate vegetation in a small valley in eastern Tennessee. Ecology, 11, 531-539. https://doi.org/10.2307/1931571

Shannon, C.E. and Wiener, W. 1963. The Mathematical Theory of Communication. University of Illinois press, Urbana.

Sharma, C.M., Baduni, N.P., Gairola, S., Ghildiyal, S.K. and Suyal, S. 2010. Effects of slope aspects on the forest composition, community structure and soil nutrient status of some major natural temperate forest types of Garhwal Himalaya. Journal of Forestry Research, 21, 331-337. https://doi.org/10.1007/s11676-010-0079-y

Sharma, C.M., Suyal, S., Gairola, S. and Ghildiyal, S.K. 2009. Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. Journal of American Science, 5(5), 119-128. https://www.sciencepub.net/american/0505/15_0937_mauscript_ am0505.pdf

Simpson, E.H. 1949. Measurement of Diversity. Nature, 163, 688. https://doi.org/10.1038/163688a0

Singh, S., Malik, Z.A. and Sharma, C.M. 2016. Tree species richness, diversity, and regeneration status in different oak (*Quercus* spp.) dominated forests of Garhwal Himalaya Indian. Journal of Asia Pacific Biodiversity, 9, 293-300. https://doi.org/10.1016/j.japb.2016.06.002

Singh, S. 2018. Understanding the role of slope aspect in shaping the vegetation attributes and soil properties in Montane ecosystems. Tropical Ecology, 59(3), 417-430. https://tropecol.org/pdf/open/PDF_59_3/3%20Shipra%20Singh.pdf

Song, C.Y., Guo, K. and Liu, G.H. 2008. Relationships between plant community's species diversity and soil factors on Otingdag sand land. Chinese Journal of Ecology, 27, 8-13.

Uniyal, P., Pokhriyal, P., Dasgupta, S., Bhatt, D. and Todaria, N.P. 2010. Plant diversity in two forest types along the disturbance gradient in Dewalgarh Watershed, Garhwal Himalaya. Current Science, 98(7), 938-943. https://www.jstor.org/stable/24111551

Verma, R.K., Kapoor, K.S., Subramani, S.P. and Rawat, R.S. 2004. Evaluation of plant diversity and soil quality under plantation raised in surface mined areas. Indian Journal of Forestry, 27(2), 227-233.

Whittaker, R.H. 1965. Dominance and diversity in land plant communities. Science, 147, 250-260. http://dx.doi.org/10.1126/science.147.3655.250

Yang, J., El-Kassaby, Y.A. and Guan, W. 2020. The effect of slope aspect on vegetation attributes in a mountainous dry valley, Southwest China. Scientific Reports, 10, 16465. https://doi.org/10.1038/s41598-020-73496-0

Zeng, X., Zhang, H., Wan. J., Song, Y.G. and Shen, H.T. 2014. Slope aspect and slope position have effects on plant diversity and spatial distribution in the hilly region of Mount Taihang, North China. Journal of Food, Agriculture & Environment, 12(1), 391-397.

Received: 18th December 2023
Accepted: 10th February 2024