Indian Journal of Ecology (2025) 52(5) (SI): 1138-1147
DOI: https://doi.org/10.55362/IJE/2025/4626

Manuscript Number: 4626
NAAS Rating: 5.38

Assessment of Quantitative Profile of Plant Species of Forest Vegetation Along the Elevational Gradient in the Western Himalayas, India

L.S. Lodhiyal, Neelam Bisht, Vasundhra Lodhiyal[1], Neelu Lodhiyal[1] and Inder Singh Rautela

Department of Forestry, [1]Department of Botany,
D.S.B. Campus, Kumaun University, Nainital-263 002, India
**E-mail: lslodhiyal@yahoo.com*

Abstract: This study presents a quantitative ordination analysis of forest vegetation at different altitudes in the Nainital district of the western Himalayas, India. The forest sites examined were located at 29.3924° N, 79.4534° E, at elevations ranging from 400 to 2500 meters above sea level. The vegetation analysis was conducted using the quadrat method. Total 75 quadrats were randomly placed at each elevation site to assess the density, basal area, species diversity, and importance value index (IVI) of plant species. *Quercus floribunda* and *Q. leucotrichophora* dominated the higher altitude zone, while *Pinus roxburghii* and *Shorea robusta* dominated the middle. *Shorea robusta* and *Mallotus philippinensis* dominated the lower altitude zone. Species richness, density, basal area, and diversity ranged from 117-168, 580-717 individuals ha^{-1}, 52.8-69.9 m^2 ha^{-1}, and 2.4-2.1, respectively. The elevation significantly influences the forest vegetation parameters and species composition. Higher elevation remains structurally stable; middle elevation is more resilient, and lower elevation is more ecologically dynamic. Among all these elevations, the lower elevation is a more vulnerable site that requires urgent conservation and management efforts.

Keywords: Species composition, Basal area, Species diversity, Elevational gradient, Western Himalayas

Forest is defined as a plant community mainly composed of trees and other woody plants. Land covered by a tree canopy of more than 10 per cent and spanning an area greater than 0.5 hectares is considered a forest, based on the presence of trees and the lack of other dominant land uses (Laumonier et al., 2022). Forests are a primary source of biodiversity globally, offering various ecosystem services to humanity and the earth's environment. Human well-being and livelihoods heavily rely on the Earth's ecosystems and biodiversity. In recent decades, describing this reliance in terms of a set of "services" provided by ecosystems has become common. Ecosystem services are defined here as "the benefits humans derive from ecosystems" (MEA 2005a). However, recently, the decline in biodiversity threatens ecosystem stability and human well-being worldwide. In India, nearly two-thirds of the population depends directly on climate-sensitive sectors such as agriculture, fisheries, and forests (Sathaye et al., 2006). Various abiotic and biotic factors influence forest structure and its functional dynamics (Chawla et al., 2008).

In India, the Himalayan forests are very diverse and complex ecosystems in the world due to variations in altitude, topography, geographical extent, and climatic conditions (Sundariyal and Sharma,1996, Sharma et al., 2017). In this region, the dominated forest tree species are Sal, Pine, and Oak tree species in the lower, middle, and higher elevational site, respectively. The Himalayan forests support diverse ecosystem services to upstream and downstream communities (Dhyani and Dhyani 2016, Negi et al., 2018). However, the nature of forest communities largely depends on the ecological characteristics of sites, species richness, diversity, distribution, abundance, and regeneration status of species (Pandita et al., 2019). Bhat et al. (2020) stated that assessing species composition, diversity, and structure has been a primary focus of ecological forest studies. Scientists have observed that forests and other natural habitats have receded in the last few decades. Consequently, forest biodiversity and productivity have declined in many parts of the world. So, there is need to improve our understanding of these sensitive sectors at local and regional levels to gain knowledge about the physical, ecological, and social systems and reduce the pressure on vulnerability and adaptability (Mc Carthy 2001).

The degradation and disruption of forests caused by anthropogenic pressure have altered the density, diversity, basal area, and IVI (Importance Value Index) of forest species in parts of the region. The change in forest composition and structure largely takes the form of rapid shifts in resource use patterns, land use systems, and climate variability, coupled with overgrazing and resource over-exploitation. The genetic diversity of trees is being threatened and eroded by the loss of tree populations, unsustainable harvesting, overgrazing, climate change, fire, and invasive species (FAO 2014). Projected declines in the diversity and abundance of primary pollinators threaten food security, human health, and the cultural fabric and livelihoods of millions of mainly rural and indigenous communities (De Vos et al., 2015). Forest carbon stock refers to the carbon stored in forests across four pools – living biomass, dead wood, litter, and soil organic matter. Forests sequester atmospheric carbon during photosynthesis, which is stored in these four components but can also be released through processes like deforestation, fire, and decay. Consequently, forest carbon stock and its changes are critical indicators of forests' role in the carbon cycle and reflect the quality of forest management. Therefore, human society must recognize the importance of forest biodiversity for sustainable human and environmental health. Several studies on vegetation analysis have been conducted in different parts of the country . However, regarding the forests in the present study area, there is a lack of data on species structure across different vegetation layers (tree, shrub, and herb) along elevational gradients within the diverse climatic zones of the Nainital district in Uttarakhand, India. Due to numerous internal and external factors, most forested sites lack sufficient resources, as they have been heavily impacted by humans and climate change. The objectives of this study was to assess and illustrate the real-time occurrence and status of species in forest vegetation along the elevational gradient, and to examine the variation of species among different elevational forest sites..

MATERIAL AND METHODS

Study sites: The present studied forests are situated at three elevational ranges of 400-1000 m, 1000-1500 m, and 1500-2500 m, lying between coordinates 29.3924° N and 79.4534° E in Nainital. The study sites are in the nearly tropical, sub-tropical, and temperate climatic zones. The first two sites are in tropical and sub-tropical regions of the Shiwalik, while the third is in the temperate zone. The Shiwalik comprises highly degraded landmasses at elevations from 400 to 1500 m in the western Uttarakhand Himalayan region. Sal (*Shorea robusta)* forests with broad-leaved species and early successional riverine species like Shisham-Khair (*Dalbergia sissoo-Acacia catechu*) dominate the vegetation. Pine (*Pinus roxburghii*) along with other broad-leaved trees dominates the upper hill areas (Fig. 1).

The climate of the study sites is monsoon-type and influenced by temperature and rainfall patterns. The three distinct seasons—(i) dry and warm summer (mid-March to mid-June), (ii) wet and warm rainy season (mid-June to mid-September), and (iii) dry and cold winter (October to February) with frequent frost occurrences in a year. Geologically, the sites are the youngest hills, as the rocks are relatively recent and consist of sandstone conglomerate beds, quartzite, and unconsolidated segments of cobbles, shingles, pebbles, gravels, and boulders. The rocks are usually in contact with the sediments of the Indo-Ganga plain along prominent fault zones.

Meteorological information: The annual average precipitation of the study area was 1122.73 mm. Accordingly, the maximum and minimum precipitation were 326.27 mm in July and 0.0 mm in November, respectively. The highest temperature was 39.79 °C in June, and the lowest was 2.58

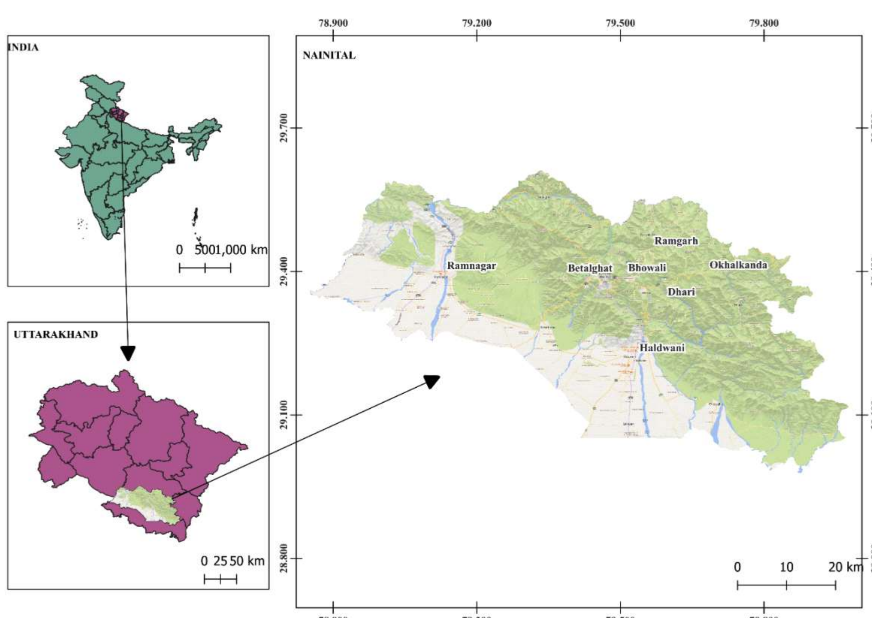


Fig. 1. Studied forest sites along the elevational gradient of western Himalaya, India

°C in December and January. The relative humidity was highest in August (86.15%), followed by September (81.59%), while the minimum was in April (28.11 %). This meteorological data for precipitation, temperature, and relative humidity illustrates climatic variation in the Nainital district (power.larc.nasa.gov 2007) (Fig. 2).

Vegetation sampling: Vegetation analysis for tree, shrub, and herb species across all three sites was conducted. The plant species were identified based on taxonomic features from literature (Osmaston, 1926) and Flora Simlensis (Collet 1971). Species analysis employed the quadrat method (Saxena and Singh, 1982, Lodhiyal and Lodhiyal, 2003). Total of 75 quadrats (25 in each sub-plot in each elevational forest site) were placed along each elevational gradient to assess the quantitative profile of plant species, including density, abundance, and frequency (Curtis and McIntosh 1950). The quadrats measured 10 m × 10 m for trees, 5 m × 5 m for shrubs, and 1 m × 1 m for herbs. Tree diameters were measured at breast height (1.37 m) using tree caliper. The diameter of shrub species was measured at 20 cm above ground to ensure accuracy during data collection. Species richness per unit area was determined (Whittaker 1972, Magurran 2013). Species diversity (H'), concentration of dominance (CD), and evenness (E) in each elevational zone were quantified using the Shannon-Wiener diversity index (Shannon and Wiener 1963), Simpson dominance index (Simpson 1949) and Pielou's evenness index (Pielou 1966). The indices were calculated as follows:

$$H' = -\sum_{i=1}^{s}\left(\frac{Ni}{N} + \ln\frac{Ni}{N}\right)$$

$$Cd = \sum_{i=1}^{s}(Ni/N)^2$$

$$E = \frac{H'}{\ln(S)}$$

Where, Ni = Total number of individuals of a species, N= Total number of individuals of all species, and S= Total number of species.

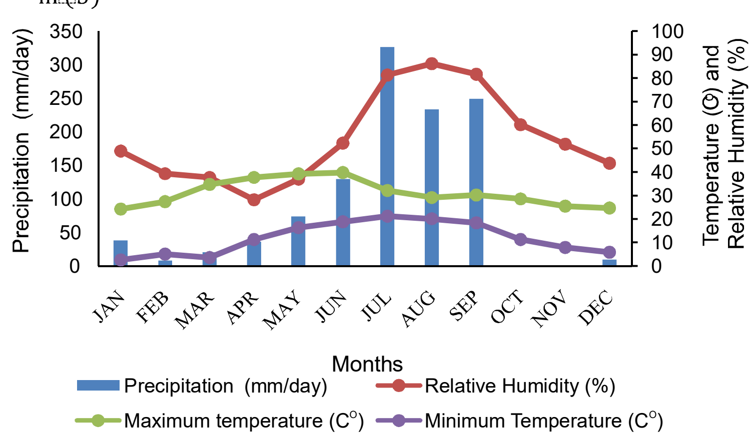
Statistical analysis: The data was statistically analyzed using correlation analysis, PCA, rank-abundance curve, and cluster analysis with the help of MS Excel and PAST software. Statistical analysis of the data was performed using correlation analysis, principal component analysis, rank-abundance curves, and cluster analysis using MS Excel and Past software. Rank-abundance curves were used to plot species dominance curves at different elevations. Cluster analysis was performed to classify the study sites based on similarity in their vegetation characteristics, revealing patterns of ecological similarity.

RESULTS AND DISCUSSION

Species richness: Total of 441 plant species were reported from the study area. Of these, 168 (38.1%), 159 (36.1%), and 114 (25.9%) species were at higher, middle, and lower elevations, respectively. The higher elevation, 52 (31.0%) trees, 33 (19.6%) shrubs, and 83 (49.4%) herbs were observed. At middle elevation, 54 (34.0%) trees, 33 (20.8%) shrubs, and 72 (45.3%) herbs were recorded. At lower elevation, 50 (43.9%) trees, 17 (14.9%) shrubs, and 47 (41.2%) herbs were identified (Fig. 3). To better represent the plant species, a hierarchical cluster was formed see (Fig. 7).

Vegetation Analysis

Tree layer: In the higher elevation forest site (1500-2500 m), total tree density was 717 individuals ha^{-1} and basal area was 69.9 m² ha^{-1}. Species diversity, evenness, and dominance concentration were 2.1, 0.3, and 0.5, respectively (Table 1). The highest IVI values were for *Quercus floribunda* (93.0) followed by *Quercus leucotrichophora*, *Rhododendron arboreum*, *Pinus roxburghii*, *Lyonia ovalifolia* and *Quercus*



Source: power.larc.nasa.gov

Fig. 2. Meteorological information of the study sites

semecarpifolia (5.3). In the middle elevation forest sites (1000-1500m), total tree density was 580 individuals ha^{-1} and basal area was 52.8 m² ha^{-1}. Species diversity, evenness, and dominance concentration were 2.2, 0.3, and 0.6, respectively. The highest IVI was reported for *Pinus roxburghii* (145.6) followed by *Shorea robusta* and *Mallotus philippinensis*, In the lower elevation forest site (400-1000m), total tree density was 640 individuals ha^{-1} and basal area was 57.3 ha^{-1}. Species diversity, evenness, and dominance concentration were 2.4, 0.3, and 0.6, respectively. The highest IVI values were observed for *Shorea robusta* (142.3) followed by *Mallotus philippinensis*, *Eucalyptus tereticornis*, *Populus deltoides*, *Acacia catechu* and *Mangifera indica* (4.4).

Shrub layer: In the higher elevation forest site, total shrub density and basal area were 1654 individuals ha^{-1} and 1.5 m^2 ha$^{-1,}$ respectively. Species diversity, evenness, and concentration of shrub dominance were 3.2, 0.04, and 0.9, respectively. The highest density was for *Hypericum oblongifolium* (210) and *Eupatorium adenophorum* (170), followed by *Arundinaria falcata* and *Daphne cannabina*. In the middle elevation forest site, total shrub density and basal area were 966 individuals ha^{-1} and 4.5 m^2 ha^{-1}, respectively. Species diversity, evenness, and concentration of shrub dominance were 3.2, 0.04, and 0.9, respectively. *Eupatorium adenophorum* (96) and Lantana camara (87) showed the highest density, followed by *Woodfordia fruticosa* (78). In the lower elevation forest site, total shrub density and basal area were 982 individuals ha^{-1} and 0.6 m^2 ha^{-1}, respectively. Species diversity, evenness, and concentration of shrub dominance were 2.6, 0.1, and 0.9, respectively. *Lantana camara* (198) and *Adhatoda vasica* (95) had the highest density, followed by *Murraya koenighii* (90).

Herb layer: In the higher elevation forest site (1500-2500 m),

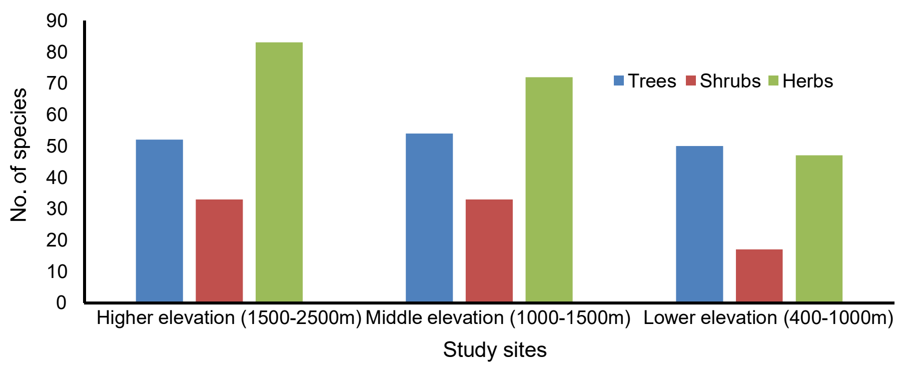


Fig. 3. Summary of plant species richness found in the study area

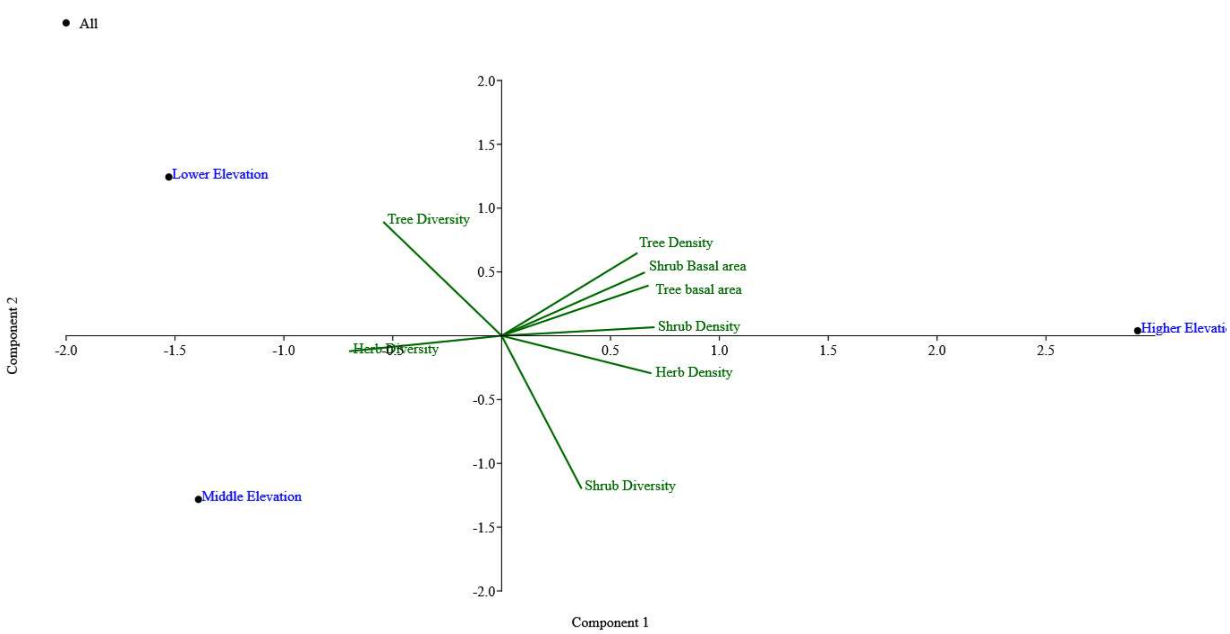


Fig. 4. PCA biplot for vegetation characteristics for different elevational gradient

the total herb density was 73.5 individuals m^2. Species diversity, evenness, and concentration of dominance of herbs were 3.4, 0.03, and 0.8, respectively. The highest density was for *Arthraxon lanceolatus* (13.5) and *Ageratum conyzoides* (11.5) followed by *Dicliptera bupleuroides*) and Justicia simplex (3.8). In the middle elevation forest site (1000-1500m), total herb density was 42.0 individuals m^2. Species diversity, evenness, and concentration of dominance of herbs were 3.7, 0.03, and 0.9, respectively (Table 1). The highest density was *Gonatanthus pumilus* (3.7) and *Geranium nepalense* followed by *Lindenbergia indica* and *Dioscorea bulbifera* . In the lower elevation forest site (400-1000m), total herb density was 27.6 individuals m^2. Species diversity, evenness, and concentration of herb dominance were 3.4, 0.03, and 0.9, respectively (Table 1). The highest density was *Wedelia wallichii* (2.9) and *Hypoxis aurea* (2.7), followed by *Barleria cristata* and *Carex condensate* (1.8).

Ordination analysis: To identify the pattern of the vegetation parameter a total of 9 vegetation characteristics of different layers i.e. (tree density, tree basal area, tree diversity, shrub density, shrub basal area, shrub diversity, herb density and herb diversity were selected for the PCA ordination analysis. The PCA biplot shown that tree density, tree basal area, shrub density, and shrub basal area was high in higher elevation. While shrub diversity was dominated at middle and herb density, and herb diversity was dominated in lower elevation respectively. While the shrub diversity and herb density were similar in all the elevation (Table 2, 3, Fig. 4).

Correlation analysis: Correlation analysis between elevation and tree density shows a positive-moderate relationship (R^2 = 0.31). While shrub and herb density show a positive-strong relationship with elevation (Fig 5A). Basal area of trees and shrubs (R2=0.50) and (R2=0.78) showed strong positive relationship with elevation (Fig 5B). whereas diversity of trees and herbs and showed strong negative correlation with elevation, while shrub shows a strong positive correlation (Fig 5C).

Rank-abundance curves: The rank-abundance curves for tree and shrub species for different elevation shows highly skewed curves showing few species were having high density and most of the species having low densities (Fig. 6A). Shrub layers middle elevation were showing more balances shrub species composition compared to higher and lower elevation (Fig. 6B). In herb species higher elevation have high dominance of few species and lower and middle elevation having evenly distributed herb layer compared to higher elevation (Fig. 6C). The species distribution pattern showing external factor i.e. environment, climate and

Table 2. Summary of PCA

PC	Eigenvalue	% variance
1	6.40313	80.039
2	1.59687	19.961

Table 3. Score for all studied sites

Elevation	PC1	PC2
Higher Elevation	2.9208	0.039171
Middle Elevation	-1.3925	-1.2828

Table 1. Vegetation parameter of studied forest sites

Vegetation parameter	Higher elevation (1500-2500m)	Middle elevation (1000-1500m)	Lower elevation (400-1000m)
Tree density (individuals ha^{-1})	717	580	640
Tree basal area (m^2 ha^{-1})	69.9	52.8	57.3
Tree diversity	2.1	2.2	2.4
Tree concentration of dominance	0.2	0.3	0.3
Tree evenness	0.5	0.6	0.6
Shrub density (individuals ha^{-1})	1654	966	982
Shrub basal area (m^2 ha^{-1})	1.4	0.2	0.6
Shrub diversity	3.2	3.2	2.6
Shrub concentration of dominance	0.04	0.04	0.07
Shrub evenness	0.9	0.90	0.92
Herb density (individuals m^{-2})	75.7	39.4	27.6
Herb diversity	3.4	4.9	4.8
Herb concentration of dominance	0.03	0.03	0.03
Herb evenness	0.8	0.9	0.9

disturbance were highly influencing the species composition in this forest.

The quantitative profile of a forest is an important indicator that gives the existing data picture about the forest health and bio-production capacity of a forest. In this context, the study was carried out in Himalayan forests at three elevational ranges *i.e.*1500-2500m (at high elevation forest site), 1000-1500m (at middle elevation forest site) and 400-

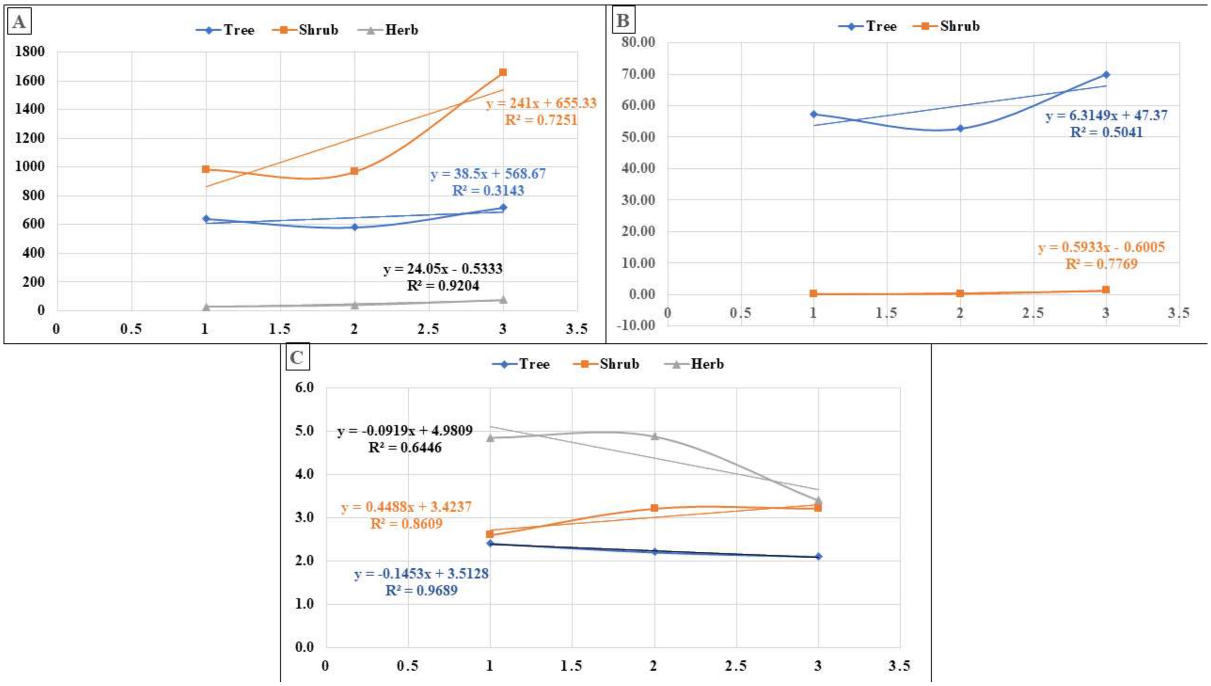


Fig. 5. Relationship of (A) tree, shrub, and herb density; (B) tree and shrub basal area; and (C) tree, shrub, and herb diversity along the elevational gradient

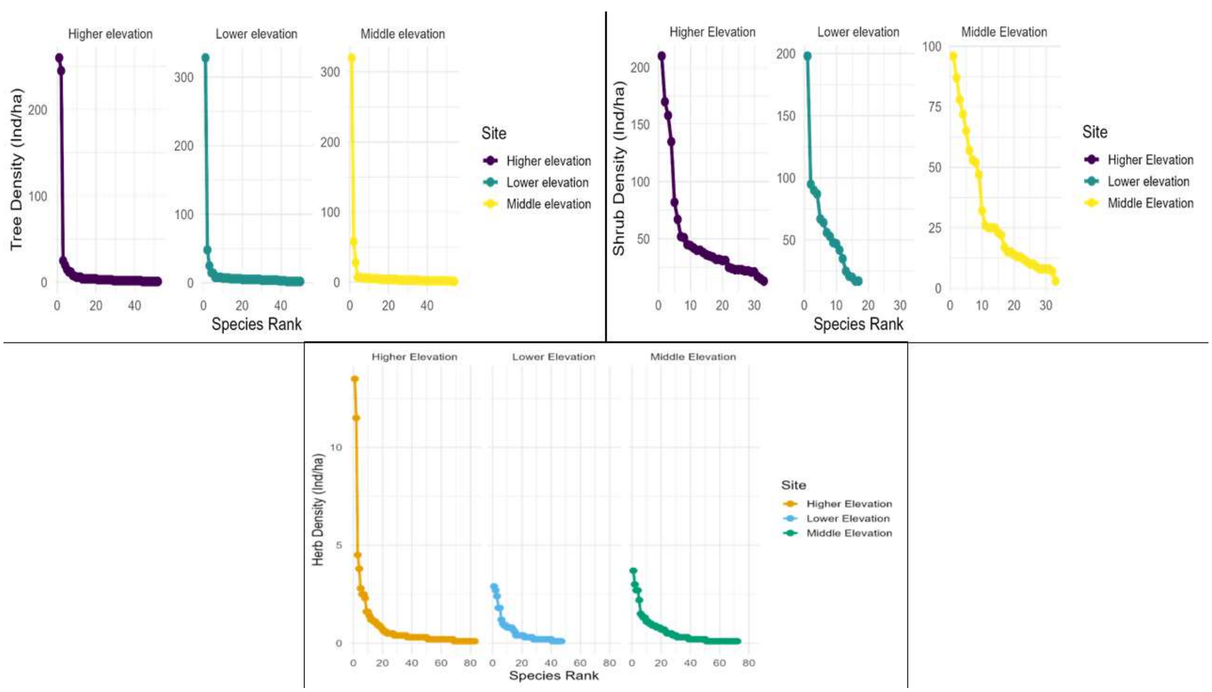


Fig. 6. Rank-abundance curves of tree, shrub, and herb species across different elevation gradient

1000m (at lower elevation forest site), these forests were fallen in the temperate subtropical and nearly tropical climate sites in the Nainital district of Uttarakhand, India.

The tree density was 717 individuals ha^{-1} recorded in the higher elevation forest site. Present value falls within the range 389-1197.5 individuals ha^{-1} reported for Indian Western and Kumaun Himalayan forests (Hussain 2008, Haq et al., 2024). The value is on the higher side than 56-490 individuals ha^{-1} reported for Central and Garhwal Himalayan Forests (Kharkwal et al., 2005, Rawat and Chandra, 2014, Ao et al., 2024), while lower side for reported for Kumaun Himalayan forests (832-2545 individuals ha^{-1}) (Bhatt and Bankoti, 2016, Bisht et al., 2025). The basal area of trees in the higher elevation forest site was 69.9 m^2 ha^{-1} which is almost like 63.6-67.7 m^{2}ha^{-1} reported for Kumaun Himalayan forests (Bhatt and Bankoti, 2016), but it is on the higher site 27.0-60.5 m^2 ha^{-1}reported for Eastern and Kumaun Himalayan forests (Ao et al., 2024, Bisht et al., 2025). The variation in basal area of forests studied by workers may be due to impacts of type of species, age group, tree girth, and disturbance regime and human activities in the forest sties. However, it can be stated that due to the presence of larger and older trees in the study forest site had been supported by good soil moisture and moisture conditions and rich nutrient availability and suitable climatic condition of forest site resulted the basal area on higher side compared to the earlier study of other forests. The shrub density in the higher elevation was 1654 individuals ha^{-1}. Present value falls within the range of 1470-1840 individuals ha^{-1} reported for Kumaun Himalaya and Garhwal Himalayan Forests (Hussain, 2008, Rawat and Chandra, 2014). The present value is on higher side than 111-132 individuals ha^{-1} reported for central Himalayan forests (Kharkwal, et al., 2005), while the value is on lower side 2027.7-10,450 individuals ha^{-1} reported for Indian central Himalayan forests (Ao et al., 2024, Yadav et al., 2024, Bisht et al., 2025). The presence of high tree density and basal area of shrubs was due to adequate availability of sunlight, soil nutrients and microclimatic conditions in the forest site. The herb density (75.7 individuals m^{-2}) in the higher elevation was on the higher side than the value reported for Garhwal Himalayan Forest (Rawat and Chandra, 2014, Bisht et al., 2025), however, on the lower side than the value of 288-414 individuals m^{-2} reported for Central Himalayan Forests (Kharkwal, et al., 2005). The present value is on the higher side than 15.1 individuals m^{-2} reported for Indian Himalayan Forest (Ao et al., 2024). The difference in herb density was due to the variation in seasonal and climate change. In this forest site, the shrub layer was in a suppressed condition, resulting in a dominant position of herbs in the forests.

The tree density (580 individuals ha^{-1}) recorded in the middle elevation falls within the range of 373.3-633.3 individuals ha^{-1} reported for forests in Kumaun Himalaya (Dhar et al., 1997, Bisht et al., 2025). The present tree density is on the higher side than 122-403 individuals ha^{-1} was reported for Indian central and eastern Himalayan forests (Kharkwal et al., 2005, Ao et al., 2024), but is found on the lower side than 1673 individuals ha^{-1} reported for Kumaun Himalayan Forest (Ralhan et al., 1982). The variation in tree density and species composition occurred due to soil

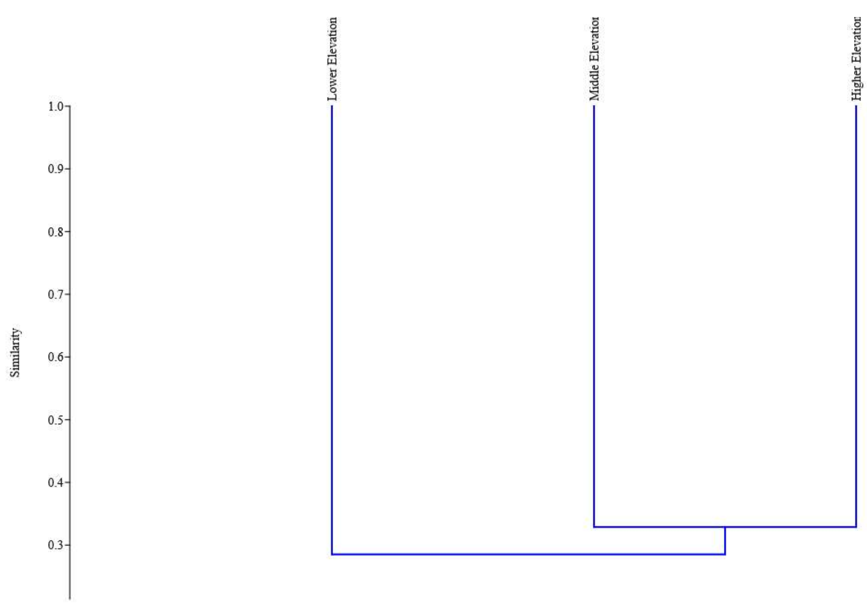


Fig. 7. Dendrogram showing clustering of plant species in forests along the elevational gradient

characteristics, nutrient status, topography, microclimate, and biotic disturbances in the forest site. The basal area of trees (52.8 $m^2 ha^{-1}$) in the middle elevation was on the higher side than the values (29.4-43.9 m^2 ha^{-1}) reported for the central and eastern Himalayan Forest by (Ao et al., 2024, Bisht et al., 2025). The shrub density in the middle elevation, 966 individuals ha^{-1}, was lower than the 2638.8-8100 individuals ha^{-1} reported for Kumaun Himalayan forests (Ao et al., 2024, Bisht et al., 2025), while the present value was higher than the 120-133 individuals ha^{-1} reported for Kumaun Himalayan Forest (Kharkwal et al., 2005). The variation occurred due to the dominant tree layer having high canopy

Table 4. Comparison of density (individual ha^{-1}), basal area ($m^2 ha^{-1}$), and diversity of higher elevation vegetation layers with other forest vegetation in Western Himalaya

Elevation	Tree density	Tree basal area	Shrub density	Shrub basal area	Herb density	Reference
1500-2500	717	69.9	1654	1.4	75.7	Present study
1500-1900m	1330-2545	63.6-135.5	-	-	-	(Bhatt and Bankoti 2016)
2050-2270	389 -832	27.0-60.5	-	-	-	(Ralhan et al 1982).
1700-2000	832-1100	35.3-67.7	8950-7850	-	-	(Dhar et al., 1997)
1710-2440	368-995	-	1470-28158	-	-	(Hussain 2008).
1600-2400	56-83	-	111-132	-	288-414	(Kharkwal et al., 2005)
2200-2500	490±30-350±20	-	1280±120-1840±80	-	6.4±0.3-8.9±0.4	(Rawat and Chandra 2014)
1800-3600	640±140.95-1197.5±199.56	-	-	-	-	(Haq et al., 2024)
1500-1900	333	30.29	10,450	-	15.1	(Ao et al., 2024)
1613-2149	1200	25.0	3120	0.2	11.9	(Bisht et al., 2025)

D-Density, BA-Basal area

Table 5. Comparison of density (individual ha^{-1}), basal area ($m^2 ha^{-1}$), and diversity of middle elevation vegetation layers with other forest vegetation in Western Himalaya

Elevation	Tree density	Tree basal area	Shrub density	Shrub basal area	Herb density	Reference
1000-1500	580	52.8	966	0.2	39.4	Present study
1300m	1673	35.3	-	-	-	(Ralhan et al., 1982).
1100-1200	586-616	29.9-43.9	5930-7800	-	-	(Dhar et al., 1997)
1000-1400	122-125	-	120-133	-	236-263	(Kharkwal et al., 2005)
1032-1053	-	-	-	-	146.6±0.14-328.40±0.33	(Thakur 2018).
1100-1500	403	36.59	8100	-	8.4	(Ao et al., 2024)
981-1282	373.3-633.3	29.4-31.9	1026.7-3789.7	0.1-0.4	9.2-14.6	(Bisht et al., 2025)

D-Density, BA-Basal area

Table 6. Comparison of density, basal area, and diversity of lower elevation vegetation layers with other forest vegetation in Western Himalaya

Elevation	Tree D (individuals ha^{-1})	Tre BA ($m^2 ha^{-1}$)	Shrub D (individuals ha^{-1})	Shrub BA ($m^2 ha^{-1}$)	Herb D (indi.m^2)	References
400-1000	640	57.3	982	0.6	27.6	Present study
400-1000	123-138	-	92-126	-	161-283	(Kharkwal et al., 2005)
809	-	-	-	-	96.40±0.96	(Thakur 2018)
710	457	38.60	-	-	-	(Kaushal and Baishya 2021)
600-900	600	-	-	-	-	(Bhardwaj et al., 2016)
450-600	462.5	-	-	-	-	(Sharma et al., 2010)
900-1000	1077-1309	-	-	-	-	(Soe and Takeda 2023)
300-1100	345-395	24.88-28.7	7350-9300	-	8.6-89000	(Ao et al., 2024)

D-Density, BA-Basal area

cover suppressing the shrub layer of the forest in the study sites. The herb density of 39.4 individuals m^{-2} in the middle elevation was higher than 146.6-328.40 individuals m^{-2} reported for the Himalayan Forest and tropical forest (Kharkwal et al., 2005, Thakur, 2018). At the same time, the value is higher than 8.4 individuals m^{-2} reported for Indian Himalayan forests (Ao et al., 2024, Bisht et al., 2025). The high density and basal area of dominance and co-dominance tree and shrub species, as well as their vegetation canopy impacts, resulted in the suppression of herbs, combined with less availability of sunlight and shading effects of the upper vegetation layer in the forest sites.

The tree density (640 individuals ha^{-1}) recorded in the lower elevation was somewhat similar to 600 individuals ha^{-1} reported for the Kumaun Himalaya forest (Bhardwaj et al., 2016). The tree density was on the higher side than (123-462.5 individuals ha^{-1}) as reported for the eastern and central Himalayan forests and the lakeside regions of Myanmar (Kaushal and Baishya, 2021, Bhardwaj et al., 2016, Sharma et al., 2010, Ao et al., 2024, Soe and Takeda 2023). The variation occurred due to differences in composition, age, and girth of tree species, as well as minimal human interference in the forest. The basal area of trees (57.3 m^2 ha^{-1}) recorded at lower elevations differs from the values (24.9-38.60 m^2 ha^{-1}) reported for eastern and Kumaun Himalayan forests (Kaushal and Baishya, 2021, Ao et al., 2024). The variation occurred due to the dominance of mature trees in the studied forest. The shrub density in the lower elevation was (982 individuals ha^{-1}), which was on the higher side than 92-126 individuals ha^{-1} for Kumaun Himalayan forests (Kharkwal, et al., 2005), while was on the lower side than (7350-9300 individuals ha^{-1}) reported for eastern Himalaya (Ao et al., 2024). The dominance of trees in the forest site had resulted in the suppressed condition of shrubs. The competition of trees for water and nutrients resulted in a lower value of shrubs. The herb density of lower elevation was 27.6 individuals m^{-2}, which was on the lower side than 96.40-283 individuals m^{-2} reported for Kumaun Himalayan Forest and tropical forest (Kharkwal et al., 2005, Thakur, 2018), however, the present value was on the higher side than 8.6-8.9 individuals m^{-2} reported for Eastern Himalayan forests (Ao et al., 2024). The deposition of forest floor biomass and the shading effects of upper-layer species resulted in a suppressed condition for herbs.

CONCLUSION

The results of the present study, conducted in the three elevational forests of the Nainital district in the western Himalayas, concluded that elevation plays a significant role in shaping the vegetation composition of these forests. Higher elevations have greater diversity of tree species, while lower elevations support more herbaceous plants. CA confirms that the tree layer dominates at higher elevations, whereas herbs are more prevalent at lower ones. Statistics show that higher elevations are structurally stable but less resilient due to lower plant biodiversity. Middle elevations are more resilient and ecologically stable because of their species richness and structural complexity. In contrast, lower elevations are more ecologically dynamic but less structurally stable due to reduced tree cover. Among all elevations, the lower zone is the most vulnerable and requires urgent conservation and management efforts, such as reforestation, strict protection, monitoring, conservation programs, and sustainable measures. The middle zone needs moderate and sustainable protection. Meanwhile, higher elevations should be preserved in their natural state to sustain plant biodiversity and ensure the longevity of the forest ecosystem.

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Received 31 July, 2025; Accepted 10 November, 2025

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