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# Woody vegetation and soil composition of tropical forest along an altitudinal gradient in Western Ghats, India

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**Abstract.** *Bhatt H, Gopakumar S, Bhindhu PS, Vishnu BR, Jugran HP. 2024. Woody vegetation and soil composition of tropical forest along an altitudinal gradient in Western Ghats, India. Asian J For 8: 51-62.* The altitudinal gradient significantly influences the diversity and spatial distribution of biodiversity in mountainous areas. Exploring tree species diversity patterns provides valuable insights into the factors influencing woody community structures in unexplored areas within the Western Ghats, India, a biodiversity hotspot. This study examined the floristic attributes of woody vegetation and soil composition along an altitudinal gradient (350-1450 m asl) in the tropical evergreen forest in Mankulam Forest Division, Western Ghats, Kerala, India. Along this gradient, the vegetation survey recorded 199 individuals, encompassing 88 tree species from 34 families. Species composition, tree abundance, diversity, and frequency increased with elevation while basal area decreased. *Clausena anisata* (Willd.) Hook.fil. and *Memecylon talbotianum* Brandis were dominant in the lower zone (350-900 m asl), while *Actinodaphne bourdillonii* Gamble and *Litsea keralana* Kosterm. were dominant in the higher zone (900-1450 m asl). Canonical Correspondence Analysis (CCA) revealed intricate interrelationships amongst species clustering, altitudinal spans, and soil properties. A gradual increase in species abundance was observed as the soil compositions increased along the altitude. A marked change in tree vegetation and soil concentrations was observed along this gradient, implying the distribution pattern difference across the altitudinal gradient. It is observed that under prevailing climate change conditions, any significant changes could disrupt this biodiversity hotspot and jeopardize the distinctive fauna and flora that rely on it. The study highlights the cruciality of policy development and its implementation through the forest department and policymakers to conserve and manage this rich biodiversity region.

**Keywords:** Altitudinal gradient, biodiversity hotspot, canonical correspondence analysis, Kerala, tree diversity, Western Ghats

## INTRODUCTION

Altitudinal gradients can be addressed as the most powerful natural drivers for ecological and evolutionary responses of organisms in apect to various environmental changes (Körner 2007; Sharma et al. 2018). Similarly, the adaptive and evolutionary reactions of diverse organisms, including vegetation diversity, composition and structure, are also influenced by altitudinal gradients (Cirimwami et al. 2019; Sahu et al. 2019). Globally, tropical forests cover 7% of the Earth's land area, yet they are home to over 50% of the total species of the planet (Gallery 2014). These ecosystems harbor exceptionally rich species diversity, positioning them as prime biodiversity hotspots (Admassu et al. 2016). They are often called significant carbon sinks due to their higher-standing biomass and greater productivity.

Additionally, they provide numerous ecosystem services, including prevention of soil erosion, preservation of habitat or flora and fauna, and species conservation (Armenteras et al. 2009). However, despite their importance, tropical forests are vanishing at an alarming rate, between 0.8 and 2% per annum (Sagar et al. 2003). This rapid conversion and depletion of tropical forests have resulted in an unparalleled reduction in biodiversity and the disturbance of vital ecosystem functions (Dierick and Holscher 2009).

The ecology of tropical forests is still being explored to understand their ecological systems, patterns, processes and dynamics (Anitha et al. 2010). In tropical forest ecosystems, trees are the major structural and functional components that act as vigorous indicators at the environmental scale (Brockerhoff et al. 2017). Within tropical forests, the richness of tree species exhibits variations attributable to geographic factors, habitat conditions, and degrees of disruption (Jayakumar and Nair 2013). However, the driving mechanisms influencing such high tree diversity in the tropical forest are still poorly understood.

Meanwhile, assessing species diversity encompasses a range of biota, making considering parameters of species diversity indices collectively essential. Such studies are valuable in comprehending ecosystem health and the impact of human activities and natural disruptions (Fedor and Zvaríková 2019). Given that altitude is a pivotal influencer of various life forms, it not only dictates the presence and adaptability of plant species but also provides insights into forest community structures (Körner 2007).

In India, consistent monitoring, analysis, and assessment of ecosystem components offer a potential avenue for well-informed planning and policy interventions to ensure the sustainable future of forests, including those in tropical settings. In the context of the Western Ghats, aside from factors like aspect and slope inclination, altitude also holds a significant role in molding the composition of diverse forest ecosystems and the array of woody plant species they host (USAID 2012; Rao et al. 2013).

The Western Ghats mountainous region is identified as a ‘biodiversity hotspot’ (Myers 1988) along the western coast of India (Bose et al. 2019), and around 27% of India’s overall major plant species have been documented within this region (WGEP 2011). A recorded count of 1,500 plant species endemic to this region has been documented (Ramesh 1997; Narayanan et al. 2018), though explorations are continuing. Among the evergreen tree species present, 56% are endemic (Irwin and Narsimhan 2011; Gaikwad et al. 2014).

While numerous studies on vegetation and soil change along altitude gradient have been reported for the Himalayan ecosystem (Sharma et al. 2009; Maletha et al. 2022), only very few studies are related to tree species diversity and soil compositions using multivariate analysis in tropical forests of Western Ghats (Sundrapandian and Swamy 2000; Joseph et al. 2008; Neikha and Nagaraja 2019) and Eastern ghats (Sahu et al. 2019) have been reported. Focusing on this research gap, an attempt was made to assess and describe the changes in woody vegetation and soil along an altitudinal gradient in the Mankulam Forest Division (MFD) of Western Ghats, Kerala, India. The objectives comprised (i) Phyto-sociology of woody vegetation, (ii) Assessment of the physicochemical properties of soil, and (iii) Linkages between woody vegetation diversity and soil attributes. We expect this study's results will offer pivotal insights into the status of forest tree composition along an altitudinal gradient. This information will also be instrumental in addressing the implications for managing and conserving threatened species in the Western Ghats. Additionally, the findings may guide the formulation of further policy interventions.

## MATERIALS AND METHODS

### Study area

This study was conducted in Mankulam Forest Division, Kerala, India (a forest division is an administrative entity that covers the primary forest area of the region), located between 10°0' N to 10°10' N latitude and 76°50' E to 77°0' E longitude with an altitudinal variation from 350-1,740 m asl (Figure 1). According to Champion and Seth (1968), the forest is classified as West Coast semi-evergreen forests (2A/C2) and West Coast tropical evergreen forests (1A/C4). The average yearly temperature ranges from 5.4°C to 8.0°C at minimum temperature and 22.8°C to 24.5°C at maximum temperature, with rainfall ranging between 153-232 mm in the study region (IMD 2019). This temperature variation is attributed to the varying altitudes (KFD 2014). The enhancement in rainfall along altitude depends on the windward side's specific topography, a specific feature in the Western Ghats (Muralidharan et al. 1985; Harikumar 2016). Soil rests upon Archean igneous rocks predominantly composed of gneisses and granites (Koshy 1970). This soil type is classified and reported as humic acrisol, according to FAO-UNESCO (1977) and Jose et al. (1996).

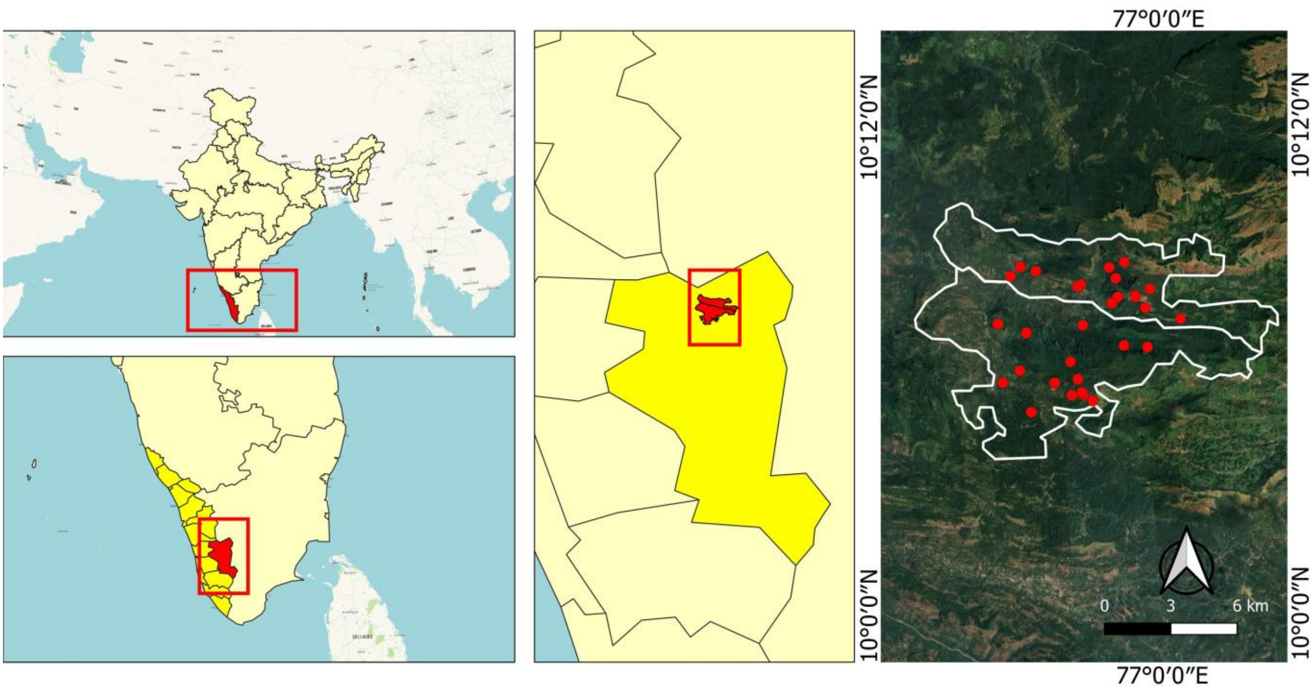


**Figure 1.** Map of the study area and sampling points in Mankulam Forest Division, Kerala, India

### Vegetation analysis

Based on preliminary and reconnaissance surveys in MFD, a suitable primary forest for vegetation sampling was selected. Forest maps and topographic sheets were utilized to validate altitude variations within the region. The study area's altitudinal range facilitated its classification into two distinct zones, i.e., (i). Zone I (350-900 masl) is the lower zone. (ii). Zone II (900-1,450 masl) is the higher zone.

A lower and higher zone primary forests were identified for detailed analysis. Fifteen sample plots measuring 10 × 10 m (100 $m^2$) located roughly 10 m apart were randomly placed along a 250 m-long transect parallel to the slope (Mota et al. 2018). The limitation of adequacy in data collection is due to the topographic limitation of the study area due to high slopes (>80°) and certain inaccessibility to the high slope areas. All the tree species (>10cm DBH) were measured at a height of 1.37 m above the ground using standard equipment, and tree height (m) was recorded using Vertex IV Hypsometer (Roby 2018).

Sampled standing tree species were individually counted and identified by referencing Sasidharan (2012) and Flora of Peninsular India (CES 2019). Relative Abundance (RA), Relative Frequency (RF), Relative Density (RD), Basal Area (BA and Importance value index (IVI) were subsequently derived from the above measurements following Phillips (1959). Species Evenness (Pielou 1966), Shannon–Wiener Diversity Index (Shannon and Weaver 1963), and the Concentration of Dominance (Simpson 1949) were also derived.

### Soil analysis

Soil samples were collected from individual 100 $m^2$ plots at two distinct depths: (i) upper (0-20 cm) and (ii) lower (20-40 cm) and then combined into composite samples. The core sampling method was used to estimate the soil bulk density (BD g $cm^{-3}$) (Abu-Hamdeh and Al-Jalil 1999). Soil pH was determined using an aqueous suspension (Jackson 1968) and a digital pH meter (model APX 175E/C). Electrical conductivity (EC d $Sm^{-1}$) was assessed using an electrical conductivity meter. Soil organic carbon (OC%) was calculated employing a titration technique developed by Walkley (1947). The content of Total nitrogen (N%) was ascertained through the Kjeldahl method (Bremner and Mulvaney 1982). Available phosphorus (P Kg $ha^{-1}$) was deduced from the soil following Olsen et al. (1954). Available Potassium content (K kg $ha^{-1}$) was determined through the neutral normal ammonium acetate method (Merwin and Peech 1951) and quantified using a flame photometer. Available soil calcium (Ca mg $kg^{-1}$) was estimated by complex metric titration using EDTA following Schwarzenbach et al. (1946).

### Statistical analysis

Employing an independent t-test and Karl Pearson correlation test, the significance of each environmental (soil) parameter with various zones was calculated. A two-tailed Pearson correlation coefficient was computed to analyze the connections among various phytosociological and soil chemical parameters using the SPSS version 25.0 software (SPSS Inc., Chicago, IL, USA) package. Canonical Correspondence Analysis (CCA) was done using R version 3.6.2 (R Core Team 2019) to establish associations between species and soil variables.

## RESULTS AND DISCUSSION

### Woody species composition and diameter distribution

This study revealed the presence of 199 individuals of 88 tree species in the lower and higher zones (Tables 1 and 2). These species were spread across 88 genera and 34 plant families. In the higher zone, there were 50 species recorded (Table 2), with Lauraceae (12 species) as the dominant family (Table 3). In the lower zone, species richness was lower (38 species) (Table 1). The higher species richness in the higher zone is due to the greater number of tropical wet evergreen species in the zone, as in these forests, tropical moist deciduous and semi-evergreen species are more numerous.

Throughout the altitudinal gradient, tree abundance and tree density were higher (67.09 and 694.23 trees $ha^{-1}$) in the higher zone compared to the lower zone (49.11 and 613.34 trees $ha^{-1}$) (Tables 1 and 2). Conversely, the lower zone had a higher tree basal area (20.3 $m^2$ $ha^{-1}$) than the higher zone (12.32 $m^2$ $ha^{-1}$; Tables 1 and 2). In the higher zone, *Vateria indica* L. had the higher Importance Value Index (24.09), whereas in the lower zone, the dominant species was *Dysoxylum malabaricum* Bedd. ex C.DC. (IVI= 34.85) (Tables 1 and 2).

The diameter distribution was in three diameter classes of 30-40, 40-50, and >100cm, with the highest contribution to vegetation composition in the lower altitudinal zone (Figure 2). While in the higher altitudinal zone, the maximum tree species were in diameter classes of 50-60, 60-80, and 80-100 cm, which significantly impacted vegetation composition.

### Dominance and diversity

The dependent relationship of dominance and diversity with altitude on tree diversity was examined (Figure 3). The Simpson Index, i.e., the concentration of dominance (Cd) and Shannon-Wiener index of tree diversity, increases with increasing altitude. The maximum values were recorded as (3.74 and 0.97) in the higher zone, followed by (3.47 and 0.96) in the lower zone. Pielou's index of Evenness was also slightly lower (0.953) in the lower zone compared to the higher zone (0.957).

**Table 1.** List of family and tree species (>10 cm DBH) and their ecological attributes in the lower zone in the Mankulam Forest Division, Western Ghats, India

| Family | Species | No. of individuals | A | D | RD | F | PF | RF | BA | RBA | IVI | RIVI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lauraceae | *Actinodaphne malabarica* N.P.Balakr. | 3 | 1.5 | 20 | 3.26 | 0.13 | 13.33 | 2.86 | 0.11 | 0.54 | 6.65 | 2.22 |
| Meliaceae | *Aglaia simplicifolia* (Bedd.) Harms | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.04 | 0.22 | 5.25 | 1.75 |
| Lauraceae | *Alseodaphne semecarpifolia* Nees | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.03 | 0.15 | 5.18 | 1.73 |
| Apocynaceae | *Alstonia scholaris* (L.) R. Br. | 3 | 1 | 20 | 3.26 | 0.2 | 20 | 4.28 | 0.03 | 0.17 | 7.72 | 2.57 |
| Phyllanthaceae | *Aporosa cardiosperma* (Gaertn.) Merr. | 2 | 2 | 13.33 | 2.17 | 0.06 | 6.67 | 1.42 | 0.05 | 0.25 | 3.85 | 1.28 |
| Moraceae | *Artocarpus hirsutus* Lam. | 3 | 1 | 20 | 3.26 | 0.13 | 13.33 | 2.86 | 0.15 | 0.71 | 6.83 | 2.28 |
| Centroplacaceae | *Bhesa indica* (Bedd.) Ding Hou | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.62 | 3.07 | 8.10 | 2.70 |
| Bombacaceae | *Bombax ceiba* L. | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 2.11 | 10.40 | 12.91 | 4.30 |
| Lauraceae | *Cinnamomum camphora* (L.) J.Presl | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.03 | 0.16 | 2.68 | 0.89 |
| Lauraceae | *Cinnamomum malabatrum* (Burm. f.) Presl | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.428 | 0.01 | 0.06 | 2.58 | 0.86 |
| Rutaceae | *Clausena anisata* (Willd.) Hook.fil. | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.01 | 0.04 | 2.56 | 0.85 |
| Meliaceae | *Dysoxylum malabarirum* Bedd. ex C.DC. | 7 | 1.4 | 46.67 | 7.61 | 0.33 | 33.33 | 7.14 | 4.08 | 20.10 | 34.85 | 11.63 |
| Elaeocarpaceae | *Elaeocarpus tuberculatus* Roxb. | 3 | 1.5 | 20 | 3.26 | 0.13 | 13.33 | 2.86 | 0.34 | 1.70 | 7.881 | 2.60 |
| Moraceae | *Ficus hispida* L. f. | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.06 | 0.28 | 5.31 | 1.77 |
| Moraceae | *Ficus tsjahela* Burm.f | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.04 | 0.22 | 2.74 | 0.91 |
| Clusiaceae | *Garcinia rubroechinata* Kosterm. | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.03 | 0.17 | 2.68 | 0.89 |
| Sapindaceae | *Harpullia arborea* (Blanco) Radlk. | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.02 | 0.10 | 2.62 | 0.87 |
| Dipterocarpaceae | *Hopea parviflora* Bedd. | 3 | 1.5 | 20 | 3.26 | 0.13 | 13.33 | 2.85 | 0.11 | 0.52 | 6.64 | 2.21 |
| Sapotaceae | *Isonandra perrottetiana* A.DC. | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.17 | 0.84 | 3.35 | 1.12 |
| Myristicaceae | *Knema attenuata* (Hook.fil. & Thomson) Warb. | 3 | 1.5 | 20 | 3.26 | 0.13 | 13.33 | 2.86 | 0.22 | 1.07 | 7.19 | 2.40 |
| Lauraceae | *Litsea bourdillonii* Gamble | 2 | 2 | 13.33 | 2.17 | 0.06 | 6.67 | 1.42 | 1.27 | 6.27 | 9.87 | 3.29 |
| Lauraceae | *Litsea floribunda* (Blume) Gamble | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.01 | 0.06 | 2.58 | 0.86 |
| Lauraceae | *Litsea wightiana* (Nees) Benth. & Hook. fil. | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.11 | 0.53 | 5.56 | 1.85 |
| Euphorbiaceae | *Macaranga peltata* (Roxb.) Müll.Arg. | 6 | 1.2 | 40 | 6.52 | 0.33 | 33.33 | 7.14 | 0.61 | 2.99 | 16.65 | 5.55 |
| Sapotaceae | *Madhuca neriifolia* (Moon) H.J. Lam | 3 | 3 | 20 | 3.26 | 0.06 | 6.67 | 1.42 | 0.75 | 3.69 | 8.38 | 2.79 |
| Magnoliaceae | *Magnolia nilagirica* (Zenker) Figlar | 4 | 1.34 | 26.67 | 4.34 | 0.2 | 20 | 4.28 | 2.33 | 11.47 | 20.11 | 6.70 |
| Euphorbiaceae | *Mallotus philippensis* (Lam.) Müll.Arg. | 4 | 1.34 | 26.67 | 4.34 | 0.2 | 20 | 4.28 | 1.39 | 6.85 | 15.48 | 5.16 |
| Rutaceae | *Melicope lunu-ankenda* (Gaertn.) T.G. Hartley | 2 | 2 | 13.33 | 2.17 | 0.06 | 6.67 | 1.42 | 0.26 | 1.28 | 4.89 | 1.63 |
| Sabiaceae | *Meliosma simplicifolia* (Roxb.) Walp. | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.02 | 0.08 | 5.11 | 1.70 |
| Melastomataceae | *Memecylon talbotianum* Brandis | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 1.36 | 6.69 | 9.20 | 3.07 |
| Calophyllaceae | *Mesua ferrea* L. | 1 | 1 | 6.67 | 1.09 | 0.06 | 6.67 | 1.42 | 0.01 | 0.06 | 2.54 | 0.86 |
| Myristicaceae | *Myristica dactyloides* Gaertn. | 7 | 2.33 | 46.67 | 7.61 | 0.2 | 20 | 4.28 | 0.60 | 2.93 | 14.80 | 4.95 |
| Sapotaceae | *Palaquium ellipticum* (Dalzell) Baill. | 2 | 2 | 13.33 | 2.17 | 0.06 | 6.67 | 1.42 | 0.89 | 4.40 | 8 | 2.67 |
| Clusiaceae | *Poeciloneuron indicum* Bedd. | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.71 | 3.48 | 8.51 | 2.84 |
| Sapindaceae | *Schleichera oleosa* (Lour.) Oken | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.22 | 1.07 | 6.10 | 2.03 |
| Bignoniaceae | *Spathodea companulata* Beauverd | 3 | 1.5 | 20 | 3.26 | 0.13 | 13.33 | 2.86 | 0.55 | 2.73 | 8.85 | 2.95 |
| Staphyleaceae | *Turpenia cochinchinensis* (Lour.) Merr. | 3 | 1 | 20 | 3.26 | 0.13 | 13.33 | 2.86 | 0.16 | 0.78 | 6.90 | 2.30 |
| Dipterocarpaceae | *Vateria indica* L. | 2 | 1 | 13.33 | 2.17 | 0.13 | 13.33 | 2.86 | 0.79 | 3.87 | 8.90 | 2.97 |
| | Total | 92 | 49.11 | 613.34 | 99.95 | | 466.66 | 99.9 | 20.3 | 100 | 300 | 100 |

Note: A: Abundance, D: Density (trees ha$^{-1}$), F: Frequency (%), RD: Relative Density (%), PF: Percent Frequency (%), BA: Basal Area (m$^2$ ha$^{-1}$), RBA: Relative Basal Area (%), RF: Relative frequency (%), IVI: Importance Value Index, RIVI: Relative Importance Value Index

**Table 2**. List of family and tree species (>10 cm DBH) and their ecological attributes in the higher zone in the Mankulam Forest Division, Western Ghats, India

| Family | Species | No. of individuals | A | D | RD | F | PF | RF | BA | RBA | IVI | RIVI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rutaceae | *Acronychia pedunculata* (L.) Miq. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.1 | 0.84 | 2.99 | 1.00 |
| Lauraceae | *Actinodaphne bourdillonii* Gamble | 3 | 1.5 | 20 | 2.80 | 0.13 | 13.33 | 2.44 | 0.11 | 0.87 | 6.11 | 2.04 |
| Lauraceae | *Actinodaphne hookeri* Meisn. | 3 | 1.5 | 20 | 2.80 | 0.13 | 13.33 | 2.44 | 0.10 | 0.83 | 6.07 | 2.02 |
| Lauraceae | *Alseodaphne semecarpifolia* Nees | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.03 | 0.23 | 2.38 | 0.79 |
| Euphorbiaceae | *Antidesma montanum* Blume | 2 | 2 | 12.37 | 1.87 | 0.06 | 6.67 | 1.22 | 0.06 | 0.46 | 3.55 | 1.18 |
| Phyllanthaceae | *Aporosa lindeliyana* (Wight) Baill. | 2 | 1 | 12.37 | 1.86 | 0.13 | 13.33 | 2.44 | 0.07 | 0.56 | 4.87 | 1.62 |
| Lauraceae | *Apollonias arnotii* Nees | 1 | 1 | 6.67 | 0.934 | 0.06 | 6.67 | 1.22 | 0.04 | 0.36 | 2.52 | 0.84 |
| Callophylaceae | *Calophyllum polyanthum* Wall. ex Choisy | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.02 | 0.20 | 2.35 | 0.78 |
| Burseraceae | *Canarium strictum* Roxb. | 4 | 1.34 | 26.67 | 3.73 | 0.2 | 20 | 3.66 | 0.42 | 3.45 | 10.85 | 3.62 |
| Lauraceae | *Cinnamomum malabatrum* (Burm. f.) Presl | 2 | 1 | 12.37 | 1.86 | 0.13 | 13.33 | 2.44 | 0.07 | 0.55 | 4.86 | 1.62 |
| Verbenaceae | *Clerodendron infortunatum* L. | 3 | 1.5 | 20 | 2.80 | 0.13 | 13.33 | 2.44 | 0.07 | 0.57 | 5.81 | 1.94 |
| Malvaceae | *Cullenia exarillata* A. Robyns | 4 | 2 | 26.67 | 3.74 | 0.13 | 13.33 | 2.44 | 0.32 | 2.59 | 8.76 | 2.92 |
| Dilleniaceae | *Dillenia pentagyna* Roxb. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.03 | 0.24 | 2.39 | 0.80 |
| Sapindaceae | *Dimocarpus longan* Lour. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.11 | 0.93 | 3.09 | 1.03 |
| Meliaceae | *Dysoxylum ficiforme* (Wight) Gamble | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.35 | 2.85 | 5.01 | 1.67 |
| Elaecarpaceae | *Elaeocarpus tuberculatus* Roxb. | 3 | 1.25 | 20 | 2.80 | 0.26 | 26.66 | 4.88 | 0.52 | 4.24 | 11.92 | 3.97 |
| Elaecarpaceae | *Elaeocarpus serratus* L. | 2 | 1 | 13.33 | 1.86 | 0.13 | 13.33 | 2.44 | 0.22 | 1.80 | 6.11 | 2.04 |
| Moraceae | *Ficus hispida* L.fil. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.02 | 0.13 | 2.29 | 0.76 |
| Theaceae | *Gordonia obtusa* Wall. | 7 | 1.75 | 46.67 | 6.54 | 0.26 | 26.66 | 4.88 | 0.98 | 7.97 | 19.39 | 6.46 |
| Anacardiaceae | *Holigarna beddomei* Wall. ex Hook. f. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.02 | 0.19 | 2.34 | 0.78 |
| Anacardiaceae | *Holigarna grahamii* (Wight) Kurz | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.02 | 0.17 | 2.33 | 0.78 |
| Dipterocarpaceae | *Hopea parviflora* Bedd. | 2 | 1 | 12.37 | 1.87 | 0.13 | 13.33 | 2.44 | 0.02 | 0.16 | 4.46 | 1.49 |
| Achariaceae | *Hydnocarpus pentandrus* (Buch.-Ham.) Oken | 2 | 2 | 12.37 | 1.87 | 0.06 | 6.67 | 1.22 | 0.09 | 0.70 | 3.79 | 1.26 |
| Myristicaceae | *Knema attenuata* (Hook.fil. & Thomson) Warb. | 2 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.07 | 0.55 | 3.64 | 1.21 |
| Lauraceae | *Litsea bourdillonii* Gamble | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.29 | 2.38 | 4.54 | 1.51 |
| Lauraceae | *Litsea coriacea* (Nees) Hook.f. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.03 | 0.21 | 2.37 | 0.79 |
| Lauraceae | *Litsea floribunda* (Blume) Gamble | 4 | 2 | 26.67 | 3.73 | 0.13 | 13.33 | 2.44 | 0.32 | 2.59 | 8.76 | 2.92 |
| Lauraceae | *Litsea keralana* Kosterm. | 2 | 1 | 13.33 | 1.86 | 0.13 | 13.33 | 2.44 | 0.07 | 0.61 | 4.92 | 1.64 |
| Lauraceae | *Litsea laevigata* (Nees) Gamble | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.03 | 0.24 | 2.39 | 0.8 |
| Lauraceae | *Litsea wightiana* (Ness) Benth. & Hook.fil. | 2 | 2 | 13.33 | 1.86 | 0.06 | 6.67 | 1.22 | 0.09 | 0.74 | 3.83 | 1.28 |
| Euphorbiaceae | *Macaranga peltata* (Roxb.) Müll.Arg. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.20 | 1.66 | 3.81 | 1.27 |
| Sapotaceae | *Madhuca longifolia* (J. Koenig ex L.) J.F. Macbr. | 2 | 2 | 12.37 | 1.86 | 0.06 | 6.67 | 1.22 | 0.15 | 1.23 | 4.32 | 1.24 |
| Myrsinceae | *Maesa indica* (Roxb.) Sweet | 2 | 2 | 12.37 | 1.86 | 0.06 | 6.67 | 1.22 | 0.58 | 4.68 | 7.77 | 2.58 |
| Sabiaceae | *Meliosma pinnata* (Roxb.) Maxim. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.03 | 0.26 | 2.41 | 0.80 |
| Sabiaceae | *Meliosma simplicifolia* subsp. *pungens* (Walp.) van Beusekom | 4 | 1.33 | 26.67 | 3.73 | 0.2 | 20 | 3.66 | 1.09 | 8.85 | 16.25 | 5.40 |
| Clusiaceae | *Mesua ferrea* L. | 2 | 1 | 12.37 | 1.86 | 0.13 | 13.33 | 2.44 | 0.19 | 1.55 | 5.86 | 1.25 |
| Icacinaceae | *Nothapodytes nimmoniana* (J.Graham) Mabb. | 4 | 2 | 26.67 | 3.73 | 0.13 | 13.33 | 2.43 | 0.07 | 0.58 | 6.76 | 2.25 |
| Sapotaceae | *Palaquium ellipticum* (Dalzell) Baill. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.54 | 4.37 | 6.53 | 2.18 |
| Lauraceae | *Persea macrantha* (Nees) Kosterm. | 2 | 1 | 13.33 | 1.86 | 0.13 | 13.33 | 2.43 | 0.08 | 0.66 | 4.97 | 1.66 |
| Rosaceae | *Photinia integrifolia* Lindl. | 2 | 2 | 13.33 | 1.86 | 0.06 | 6.67 | 1.22 | 0.15 | 1.18 | 4.27 | 1.42 |
| Rosaceae | *Prunus ceylanica* (Wight) Miq | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.02 | 0.20 | 2.40 | 2.35 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rubiaceae | *Psychotria nigra* (Gaertn.) Alston | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.03 | 0.25 | 2.40 | 0.80 |
| Rubiaceae | *Psydrax dicoccos* Gaertn. | 2 | 1 | 12.37 | 1.87 | 0.13 | 13.33 | 2.43 | 0.19 | 1.23 | 5.54 | 1.65 |
| Sapindaceae | *Schleichera oleosa* (Lour.) Merr. | 5 | 1.25 | 33.33 | 4.67 | 0.26 | 26.66 | 4.88 | 0.64 | 5.22 | 14.77 | 4.7 |
| Anacardiaceae | *Solenocarpus indicus* Wight & Arn. | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.22 | 0.03 | 0.28 | 2.41 | 0.81 |
| Sterculiaceae | *Sterculia guttata* Roxb. | 4 | 1.33 | 26.67 | 3.74 | 0.2 | 20 | 3.66 | 0.5 | 4.07 | 11.47 | 3.62 |
| Myrtaceae | *Syzigium mundagam* (Bourd.) Chithra | 1 | 1 | 6.67 | 0.93 | 0.06 | 6.67 | 1.21 | 0.05 | 0.39 | 2.55 | 0.85 |
| Meliaceae | *Trichilia connaroides* (Wight & Arn.) Bentv. | 2 | 2 | 13.33 | 1.87 | 0.13 | 13.33 | 2.43 | 0.82 | 6.62 | 10.90 | 3.64 |
| Staphylaceae | *Turpinia cochinchinensis* (Lour.) Merr. | 3 | 3 | 20 | 2.80 | 0.06 | 6.67 | 1.22 | 0.22 | 1.8 | 5.83 | 1.94 |
| Dipterocarpaceae | *Vateria indica* L. | 4 | 1.33 | 26.67 | 3.74 | 0.2 | 20 | 3.66 | 2.05 | 16.69 | 24.09 | 8.03 |
| | Total | 107 | 67.09 | 694.23 | 99.914 | | 546.69 | 99.99 | 12.32 | 99.98 | 300 | 100 |

Note: A: Abundance, D: Density (trees ha$^{-1}$), F: Frequency (%), RD: Relative Density (%), PF: Percent Frequency (%), BA: Basal Area (m$^2$ ha$^{-1}$), RBA: Relative Basal Area (%), RF: Relative Frequency (%), IVI: Importance Value Index, RIVI: Relative Importance Value Index

**Impact of altitude on vegetation**

Canonical Correspondence Analysis (CCA) also confirmed the significant impact of altitude on vegetation in the two altitudinal zones (Figures 4 and 5). The eigenvalues associated with CCA Axis 1 and 2 within the lower zone were 0.71 and 0.67, respectively. For the initial two axes of CCA, the collective percentage variance of the species-environment relationship was 34.63% (Figure 4). Axis 1 indicates a strong positive correlation, which is statistically significant, with total N (0.778), while displaying a noteworthy negative correlation with Bulk Density (BD) (-0.571), which means that the total N values showed an increasing trend with the change in altitudinal variation. In contrast, the bulk density declined with the change in altitudinal variation. Axis 2 correlated positive-significantly and strongly with soil pH (0.629) and negative-significantly correlated with Bulk Density (BD) (-0.558) (Table 6). This indicates that the soil pH values increased with elevation while bulk density declined, impacting the soil quality.

In the higher zone, the eigenvalues associated with CCA Axis 1 and 2 were 0.74 and 0.71, respectively. For the initial two CCA axes, the collective percentage variance in the species-environment relationship is 34.1 % (Figure 5). Axis 1 exhibits a robust positive correlation with N (0.764) and a negative correlation with BD (-0.679). Axis 2 correlated more positively with soil pH (0.685) and negatively with EC (-0.485) (Table 7). It shows that the edaphic factors play a significant role in delineating the species-environmental relationship.

**Soil compositions**

All the soil physicochemical properties exhibited large variations along the altitudinal gradient (Tables 4 and 5). Soil pH, OC, N, P, K, and Ca values increased along the gradient, while soil bulk density values decreased (Table 4). In the higher zone, soil depth significantly influenced soil EC values, probably due to the leaching of soluble salts and their accumulation in deeper layers (Tables 4 and 5). In the lower zone, available K exhibited a notably positive correlation with organic C (0.695), perhaps due to the abundance of species like *D. malabaricum* and *Myristica dactyloides* Gaertn. attributing better litter decomposition and humus formation. Total N negatively correlated with bulk density with the increase in soil depth and declined with an increase in soil depth, while BD increased with a decrease in soil depth (-0.551) (Table 6). In the higher zone, available K positively correlated with total N (0.700) due to well-rooted tree species that bind the soil and release N in the forest floor, while total N negatively correlated with bulk density (-0.667) (Table 7).

**Table 3**. Number of species of the ten most diverse families from two altitudinal zones in the Mankulam Forest Division, Western Ghats, India

| Lower Zone | | Higher Zone | |
|---|---|---|---|
| **Family** | **S** | **Family** | **S** |
| Lauraceae | 7 | Lauraceae | 12 |
| Moraceae | 3 | Euphorbiaceae | 3 |
| Sapotaceae | 3 | Anacardiaceae | 3 |
| Meliaceae | 2 | Rubiaceae | 2 |
| Dipterocarpaceae | 2 | Dipterocarpaceae | 2 |
| Myristicacae | 2 | Sapindaceae | 2 |
| Sapindaceae | 2 | Elaeocarpaceae | 2 |
| Rutaceae | 2 | Sabiaceae | 2 |
| Euphorbiacae | 2 | Rosaceae | 2 |
| Clusiacae | 2 | Callophylaceae | 1 |

Note: S-species richness represents the number of species within the respective families

**Table 4**. Independent t-test to investigate the influence of soil depth on soil variables at each altitudinal zone

| Altitudinal zone | Soil variables | Soil- depth 0-20 cm | Soil- depth 20-40 cm | t- value | p-value |
|---|---|---|---|---|---|
| Lower zone | pH | 4.53±0.138 | 4.61±0.183 | -0.321 | 0.751 |
| | EC | 0.91±0.08 | 0.63±0.05 | 2.56 | 0.016** |
| | BD | 0.97±0.03 | 1.05±0.04 | -1.942 | 0.147 |
| | C | 3.84±0.34 | 3.23±0.39 | 1.175 | 0.25 |
| | N | 0.13±0.018 | 0.11±0.01 | 0.874 | 0.389 |
| | P | 97.93±23.17 | 65.31±19.38 | 1.08 | 0.289 |
| | K | 854.93±38.8 | 778.84±37.53 | 1.409 | 0.17 |
| | Ca | 424±51.46 | 325.33±45.45 | 1.437 | 0.162 |
| Higher zone | pH | 4.78±0.147 | 4.63±0.107 | 0.795 | 0.433 |
| | EC | 0.68±0.06 | 0.53±0.05 | 1.85 | 0.075 |
| | BD | 0.92±0.03 | 0.98±0.04 | -1.152 | 0.259 |
| | C | 5.09±0.63 | 4.18±0.62 | 1.033 | 0.311 |
| | N | 0.22±0.02 | 0.18±0.02 | 1.141 | 0.264 |
| | P | 320.43±88.09 | 202.48±65.89 | 1.072 | 0.293 |
| | K | 990.48±84.15 | 799.71±81.22 | 1.631 | 0.114 |
| | Ca | 700±84.04 | 520±50.67 | 1.834 | 0.077 |

Note: BD: Bulk Density, pH: Soil pH, N: Total nitrogen, C: Soil organic carbon, K: Available potassium, EC: Electrical Conductivity, P: Available phosphorus, Ca: Available calcium. ** The correlation is significant at the 0.01 level with a two-tailed test

**Table 5.** Independent t-test to investigate the influence of two altitudinal zones on various soil variables at each depth

| Soil depth | Soil variables | Altitudinal zone | | t- value | p-value |
|---|---|---|---|---|---|
| | | Lower zone | Higher zone | | |
| 0-20 | pH | 4.53±0.138 | 4.78±0.147 | -1.235 | 0.227 |
| | EC | 0.91±0.08 | 0.68±0.06 | -2.061 | **0.049 |
| | BD | 0.97±0.03 | 0.92±0.03 | 1.138 | 0.265 |
| | C | 3.84±0.34 | 5.09±0.63 | -1.755 | 0.93 |
| | N | 0.13±0.02 | 0.22±0.02 | -3.074 | **0.005 |
| | P | 97.93±23.17 | 320.43±88.09 | -2.443 | **0.027 |
| | K | 854.93±38.8 | 990.48±84.15 | -1.463 | 0.159 |
| | Ca | 424±51.46 | 700±84.04 | -2.801 | **0.009 |
| 20-40 | pH | 4.61±0.183 | 4.63±0.107 | -0.145 | 0.886 |
| | EC | 0.63±0.05 | 0.53±0.05 | -1.293 | 0.207 |
| | BD | 1.05±0.04 | 0.98±0.04 | 1.166 | 0.254 |
| | C | 3.23±0.39 | 4.18±0.62 | -1.297 | 0.207 |
| | N | 0.11±0.01 | 0.18±0.02 | -2.968 | **0.006 |
| | P | 65.31±19.38 | 202.48±65.89 | -1.997 | 0.063 |
| | K | 778.84±37.53 | 799.71±81.22 | -0.233 | 0.818 |
| | Ca | 325.33±45.45 | 520±50.67 | -2.86 | **0.008 |

Note: BD: Bulk Density, pH: Soil pH, N: Total nitrogen, C: Soil organic carbon, K: Available potassium, EC: Electrical Conductivity, P: Available phosphorus, Ca: Available calcium. **: The correlation is significant at the 0.01 level with a two-tailed test

**Table 6.** Correlations among soil-related environmental variables and the CCA axis were examined in the lower zone

| Environmental variables | Axis 1 | Axis 2 | pH | EC | BD | OC | N | P | K | Ca |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | 0.163 | 0.629 | | | | | | | | |
| EC | 0.322 | -0.253 | 0.081 | | | | | | | |
| BD | -0.571 | -0.416 | -0.177 | -0.343 | | | | | | |
| OC | 0.390 | -0.558 | -0.384 | 0.281 | -.0.249 | | | | | |
| N | 0.778 | -0.340 | 0.091 | 0.542* | -0.551* | 0.658** | | | | |
| P | 0.437 | -0.042 | 0.348 | 0.214 | -0.164 | 0.353 | 0.498 | | | |
| K | 0.638 | 0.114 | 0.134 | 0.161 | -0.453 | 0.695** | 0.591* | 0.465 | | |
| Ca | 0.580 | -0.356 | 0.134 | 0.139 | -0.094 | 0.566 | 0.590* | 0.171 | 0.512 | |

Note: **: Significant at 0.01 levels (2-tailed), *: Significant at 0.05 levels, others are non-significant (2-tailed). K: Available Potassium, BD: Bulk Density, N: Total Nitrogen, EC: Electrical Conductivity, OC: Organic Carbon, P: Available Phosphorus, Ca: Available Calcium

**Table 7**. Correlations among soil-related environmental variables and the CCA axis were examined in the higher zone

| Environmental variables | Axis 1 | Axis 2 | pH | EC | BD | OC | N | P | K | Ca |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | 0.1809 | 0.685 | | | | | | | | |
| EC | 0.0284 | -0.485 | -0.379 | | | | | | | |
| BD | -0.6794 | 0.016 | 0.001 | 0.288 | | | | | | |
| OC | 0.6776 | 0.116 | 0.040 | 0.098 | -0.285 | | | | | |
| N | 0.7635 | -0.013 | -0.210 | -0.105 | -0.667** | 0.677** | | | | |
| P | -0.2850 | -0.118 | 0.087 | -0.092 | 0.244 | -0.394 | -0.198 | | | |
| K | 0.4339 | 0.320 | 0.075 | -0.278 | -0.628* | 0.311 | 0.700** | -0.106 | | |
| Ca | 0.4644 | 0.032 | 0.333 | 0.092 | -0.351 | 0.132 | 0.235 | -0.163 | 0.548* | |

Note: **: Statistically significant at the 0.01 levels (two-tailed), *: Statistically significant at 0.05 levels, others are non-significant (two-tailed). K: Available Potassium, BD: Bulk Density, N: Total Nitrogen, EC: Electrical Conductivity, OC: Organic Carbon, P: Available Phosphorus, Ca: Available Calcium

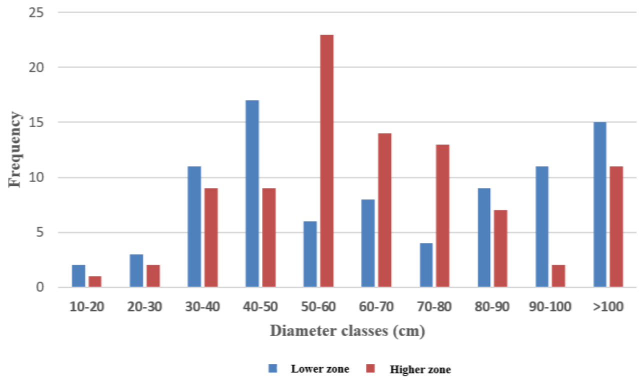


**Figure 2.** Diameter-frequency distribution in two altitudinal zones in the Mankulam Forest Division, Western Ghats, India

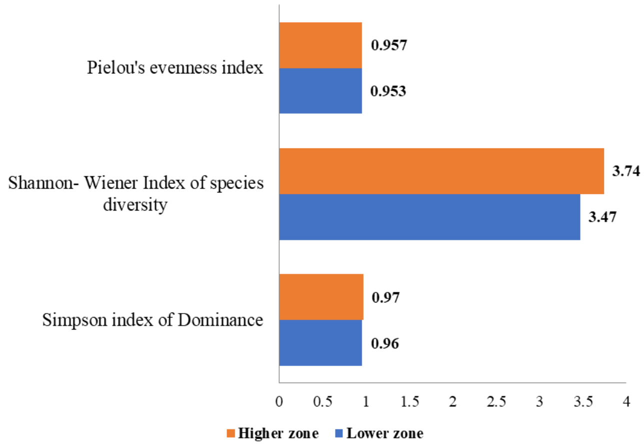


**Figure 3.** Floristic diversity indices of tree vegetation in two altitudinal zones in the Mankulam Forest Division, Western Ghats, India

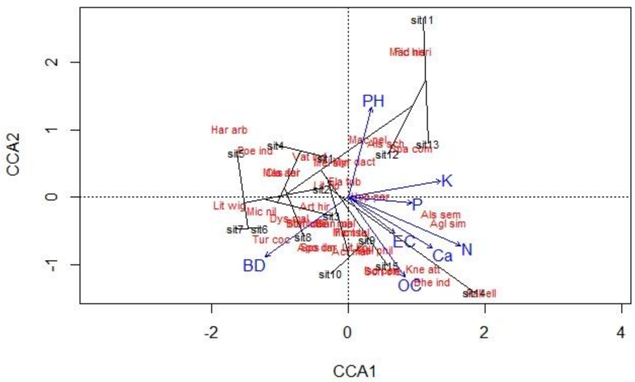


**Figure 4**. Ordination plot illustrating Canonical Correspondence Analysis (CCA) for trees in the lower zone. Variables: Bulk Density (BD), soil pH (pH), total nitrogen (N), soil organic carbon (OC), available potassium (K), electrical conductivity (EC), available phosphorus (P), and available calcium (Ca)

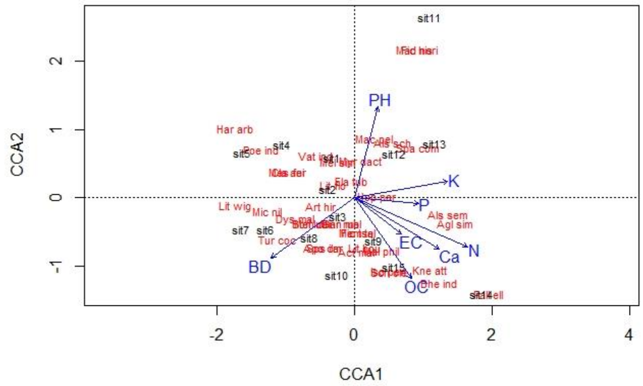


**Figure 5**. Ordination plot illustrating Canonical Correspondence Analysis (CCA) for trees in the higher zone. Variables: Bulk Density (BD), soil pH (pH), total nitrogen (N), soil organic carbon (OC), available potassium (K), electrical conductivity (EC), available phosphorus (P), and available calcium (Ca)

## Discussion

The study's findings underscore that the altitudinal gradient has a pivotal function in shaping forest communities and species richness and existence in humid tropical forests. This observation aligns with the conclusions drawn by Bacaro et al. (2008), who noted that elevation, functioning as a significant regional and local environmental factor, is a prime predictor for the diversity and spatial distribution of woody species within specific regions.

### *Species diversity pattern*

The previous investigations in diverse regions within the Western Ghats of India indicated varying levels of woody vegetation diversity (H'= 0.45-3.37) throughout different temperate forests. In this study, the significant differences in vegetation composition, diversity, and structure were discerned across the altitudinal gradient. Species richness stands out as a prominent characteristic of tropical forests. As anticipated, the higher zone exhibited elevated species richness and diversity, which aligns with the study by Singh (2016). In line with expectations, the higher zone had higher tree density (713.33 trees ha$^{-1}$) when contrasted with the lower zone (613.33 trees ha$^{-1}$), which is found to be different from the previous studies findings of 850 trees ha$^{-1}$ in Makutta Wildlife Range, Western Ghats (Neikha and Nagaraja 2019), 748 trees ha$^{-1}$ in Kodayar, Agasthyamalai hills of Western Ghats (Sundrapandian and Swamy 2000) and also in Mudumalai Wildlife Sanctuary with 232-370 trees ha$^{-1}$ (Joseph et al. 2008).

Some tree species documented in this study include dominants of higher altitudinal zones, viz., the evergreen trees *Gordonia obtusa* Wall., *Litsea floribunda* (Blume) Gamble, and *V. indica* L. (Table 2). Conversely, in the lower zones, the presence of dominant trees like *D. malabaricum*, *Macaranga peltata* (Roxb.) Müll.Arg., *M. dactyloides* were the dominant species (Table 1), possibly due to the suitable climatic factors reported by Mota et al. (2018). Invasive species like *Spathodea companulata* Beauverd and *M. peltata* were also reported in the lower zone.

In total, 88 tree species in 34 families (Tables 1 and 2) were documented in both altitudinal zones. This study recorded lower species richness compared to the studies reported in the Singara range, Nilgiri Biosphere Reserve, Western Ghats, with 181 species belonging to 115 genera and 56 families (Singh 2016), 106 tree species in 78 genera with 31 families in Nilgiri Biosphere reserve, Western Ghats (Anitha et al. 2010) and 68 tree species comprising 604 individuals of 55 genera and spanning 30 families in Makutta wildlife range, Western Ghats (Neikha and Nagaraja 2019). The lower tree species diversity in this study could be ascribed to (a) restriction of enumerations to the adult tree (>10cm DBH) following (Sundrapandian and Swamy 2000) and (b) lower sampling intensity (Sukumar et al. 1992). These species are also represented in earlier studies of forest composition and floristic studies of the Western Ghats across similar elevation ranges (Mohandass and Davidar 2009; Magesh and Menon 2011; Subashree et al. 2021).

*Basel area pattern*

The basal area of trees (20.31 $m^2$ $ha^{-1}$) was greater in the lower zone as opposed to the higher zone (12.31 $m^2$ $ha^{-1}$) (Tables 1 and 2). Nevertheless, these values were below the range reported in Mudumulai Wildlife Sanctuary with 22.3- 53 $m^2$ $ha^{-1}$ (Joseph et al. 2008) and in the Nilgiri Mountains of Southern Western Ghats with 53.33$m^2$ $ha^{-1}$ (Mohandass and Davidar 2009). Variations in the lower basal area can be ascribed to factors such as the composition of species, altitudinal variation, successional stage of a forest stand, tree age, and the extent of disturbances (Sundrapandian and Swamy 2000). The tree (>10 cm DBH) diversity index (Shannon index) was in the range of (3.47-3.74) for both altitudinal zones, which was comparatively higher (2.64 for Malayatoor Forest division near Mankulam, Western Ghats) as reported by Magesh and Menon (2011) and recorded lower (3.00-3.62) than in Amoro forest, Ethiopia (Liyew et al. 2018) and 3.9-5.26 in Mudumalai Wildlife Sanctuary, Western Ghats as noted by Joseph et al. (2008).

Meanwhile, the dominance index for the tree layer of both zones (0.96-0.97) in this study fell within the range of 0.94 recorded by Singh et al. (2016) in the Singara range of Western Ghats, India. The higher values could be attributed to largely undisturbed forests contributing to a large amount of humus and litter fall formation, resulting in higher carbon return to the ground (Gairola et al. 2012), which increases the SOC content. Pielou's index of evenness values is comparatively higher. Therefore, there is an urgent need for the sustainable management of these forest resources, which should encompass initiatives such as replenishing and restocking the forest within the Western Ghats.

*Relationship of vegetation with altitude*

Canonical Correspondence Analysis (CCA) revealed that the distribution of woody species was positively associated with various soil variables (pH, BD, EC, OC, N, P, K, and Ca). It has also revealed distinctions in soil conditions across altitudes, as reported by Mota et al. (2018). A noteworthy positive correlation between total N and Axis 1 suggests that this soil attribute significantly impacts the vegetation in lower and higher zones. Total N is an important decisive factor with increasing concentration and altitude (Shedayi et al. 2016), indicating a noteworthy positive correlation with soil pH in the present study. Present results of the soil's acidic nature are similar to those reported by Fujii (2014), who reported that organic, nitric, and carbonic acid formed by microbial activities and root favors more acidic soil in Bornean humid tropical forest Indonesia. The highest value of OC, N, P, K, and Ca was recorded in a (0-20 cm) layer in the higher zone (Table 4) with significant influence on soil EC, N, P, and Ca (0-20 cm) and in (20-40 cm) in N and Ca (Table 5). The higher soil values could be attributed to the higher abundance and density of evergreen tree species (Table 2) whose leaves and litter fall contain a higher proportion of N: P (Menéndez et al. 1988; Herna'ndez 1999; Campo et al. 2014) with leaf fall throughout the year and deeper root biomass (Osman 2013; KFD 2014) as evergreen tree species favors higher organic matter mineralization enhancing the availability of base cations in soil (McNabb et al. 1997). The lower values were observed in the lower zone with a significant influence on soil EC (Table 4) can be ascribed to the presence of a mixture of moist deciduous, semi-evergreen, and evergreen species with lower abundance and density of tree species (Table 1) as a higher proportion of moist deciduous and semi-evergreen leads to seasonal leaf fall (Osman 2013) with a lower proportion of N: P and favoring less mineralization.

This study showed variance with the prominent tree diversity pattern along the altitudes in the Western Ghats, i.e., hump-shaped patterns reported in earlier studies. It was revealed that higher zones of the Mankulam Forest Division have richer forest vegetation and better soil parameters than its lower forest zones. The higher abundance of evergreen tree species with an undisturbed forest ecosystem in the higher altitude zones shows good diversity, while the presence of invasive species due to increasing anthropogenic disturbances threatens this fragile ecosystem. The variation among altitudinal gradients also showed significant changes in vegetation dynamics. The significant properties of these forests are changing rapidly because of the multitude of influencing factors, such as climatic variations, increased demand for forest-based products, and anthropogenic disturbances. Therefore, there is an urgent need to ensure the sustainable working and management of this forest ecosystem and to conduct a detailed analysis of these coupled relationships.

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