ZONATION OF WOODY VEGETATION AND SOIL ALONG AN ALTITUDE GRADIENT IN MANKULAM FOREST DIVISION, KERALA

By

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(2018-17-014)

THESIS

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DECLARATION

I, hereby declare that the thesis entitled **"Zonation of woody vegetation and soil along an altitude gradient in Mankulam Forest Division, Kerala"** is a bonafide record of research done by me during the course of research and that this thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that the thesis, entitled "**Zonation of woody vegetation and soil along an altitude gradient in Mankulam Forest Division, Kerala**" is a record of research work done independently by **Honey Bhatt (2018-17-014)** under my guidance and supervision and that it is not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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HONEY BHATT

Dedicated to......

"To the martyrdom of soldiers who lost their lives defending the sovereignty of the nation"

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INTRODUCTION

Our nation has around 71.23 M ha (21.67 percent of India's total geographical area) of forests (FSI, 2019). It is also one of the 12 mega-diverse countries in the world. It comprises five different types of forest namely, tropical forests, sub-montane tropical forests, temperate montane forest, subalpine and alpine forest.

Tree species diversity is an elementary constituent of overall biological diversity in several ecosystems as trees are basic ecosystem producer that provide habitat and resources for almost all other organisms in the forest (Huston, 1994). In a tropical forest, tree species diversity differs mainly by various habitat variable, geography, and levels of interference. In tropical forest ecosystems major structural and functional basis is formed mainly by trees and can set out as vigorous indicators at the environment scale (Whitmore, 1992).

The richest biological group on earth is tropical forests and these have been identified to anchorage a remarkable section of world biological diversity (Baraloto *et al.* 2013).Trees an important element of vegetation, must be monitored and managed to straight successional processes for managing species and habitat diversity (Attua and Pabi, 2013)

The Western Ghats is a mountain range extends to a length of 1490 km from Kanyakumari in extreme south to Tapi valley in north. It runs parallel to the southwestern coast of peninsular India. It is known as one of the hottest hot spots of biodiversity in the world out of the eight (Myers *et al*. 2000), listed among the 200 globally most important ecoregions (Olson and Dinerstein, 1998). The Western Ghats accounts for some of the best representatives of non-equatorial tropical evergreen forests in the world. It harbors tropical humid forests, known to be amongst the most diverse, most productive and most threatened biological communities around the world. A total of around 5000 flowering plants or we can say 27 % flowering plants species were recorded in India with 2,200 genera. Out of all these, about 645 tree species of evergreen forest around 56% is endemic specific to Western Ghats, making it unique among other ecosystems in the world

(WGEP, 2011). Kerala as a part of Western Ghats holds 3,800 species of flowering plants and 1,272 Southern Western Ghats endemics (Ramesh, 2001). Distinct climatic zone which varies along with varying altitude makes mountain ecosystems as epicenter of biodiversity. The slopes of mountain ranges is flourished by thick forests but the composition and forest types vary along with climatic and altitudinal variations.

It is familiar that various characteristic of tropical forest differ with an increasing altitude. It is necessary to assign and describe this altitudinal difference through vegetational zones (Hamilton, 1975). Altitude gradient is being increasingly recognized to offer many characteristics that make it more suitable for uncovering the underlying causes of spatial variation in diversity. It plays an important role in regulating species richness patterns (Sanders and Rahbek, 2012). The soil properties vary along with altitude according to the vegetation pattern and climate. To determine soil quality organic matter is an important key factor and serves as a major fount of nutrients for ameliorating the biological and physical properties and productivity of soils (Divya *et al*. 2016).

Forest stands in protected higher elevation sites are reservoirs of native, endemic, and critically endangered species. It is an accepted fact that elevation has a strong impact on the formation of the vegetation. However, there are different schools of thought regarding species diversity trends along gradients. Ecologists have proclaimed that species diversity will either increase or decrease with rising elevation or will summit at an intermediate elevation. This inconclusiveness in opinions is because vegetation structure depends mostly on concrete patterns of interconnection among plant groups, species, soil and environmental factors. Due to these contradictory conclusions, disparity in species diversity along gradients is still vital subject of ecological study in tropical forests.

Phytosociological studies provide information on the diversity, associations, structure, and dynamics of a forest. Through such studies, one can also set up the conceptual basis that hold up the preservation of genetic resources, the preservation of indistinguishable areas and the retrieval of areas graded as forest fragments, committing considerably to its management (Lima *et al*. 2012). Such studies along altitudinal gradients are considered one of the most robust'natural experiments' for evaluating ecological and evolutionary reaction of biota to much geophysical impact, including low temperature. Woody vegetation, particularly trees, also modifies the soil moisture regime through evapotranspiration processes and also provides root cohesion to the soil mantle. Soil depth and texture are strong determinants of nutrient content, which subsequently influence plant species diversity and long-term species persistence. Soil depth is also a major driver of vegetation structure and plant community composition. Soil depth, thus, influences resource availability and competitive ability of species, vegetation recovery following disturbance, and can determine which species become dominant within a plant community. The trending of the soil parameters along a gradient is also a matter of intense interest for forest ecologists. However, published information on these ecological phenomena in different forest ecosystems of the tropics is scanty.

The Western Ghats are acclaimed biodiversity hotspots in the world (Myers, 2000). The forest in the Mankulam Forest Division is part of the southern-western Ghats and is well known for its high degree of endemism (Jose *et al*. 1996). Like elsewhere, here too are various proofs of huge changes in the forest structure and dynamics over time exists. Thus, there is a need for a well-planned analysis of tree community and soil physico-chemical properties along an altitudinal gradient in this ecosystem. The data gathered will help us to throw light on the tree species diversity, composition and soil characteristics which will further our understanding of the community life of plants, including their associations, endemism, etc. No organized studies on these lines have been taken up in Mankulam Forest Division, which will also help us to understand whether tree diversity will peak at an intermediate elevation (humped distribution hypothesis) and whether the soil properties will also have peak values at the intermediate elevation.

It was in this background, that this study was proposed with the following objectives

1. To study the floristic composition, diversity and vegetation structure of typical tropical forest along an altitudinal gradient
2. To investigate the physico-chemical properties of soil along this gradient

The data generated from this study will be of benchmark value for the forest department as well as forest ecologists and can later be used to monitor the changes in both vegetation and soil, especially in the context of a changing climate. For researchers, data generated will be useful for comparisons with those obtained from comparable ecosystems and to deduce trends.

REVIEW OF LITERATURE

2.1. TROPICAL FOREST ECOLOGY

Forest is a major resource and plays a vital role in maintaining the ecological balance and environmental setup. Tropical forests are unique in several aspects – structurally complex, genetically rich, diversified into several subtypes and highly productive in terms of biomass (Roy *et al.* 2002). These forests are among the most species-rich and structurally complex plant communities on earth (Myer *et al.* 2000).Tropical forests contain high biomass compared to other forest ecosystems, with approximately half of the total living biomass of the world's major ecosystem.The diversity of tree species in tropical forests is fundamental to total forest biodiversity because trees provide resources and habitats for almost all other forest species (Cannon *et al.* 1998).

Acknowledging vegetation and tree species diversity patterns are foundational for the preservation of natural areas and these patterns have regularly been the centre of many ecological studies (Muhumuza and Byarugaba, 2009). For the proper management of forest and its biodiversity, awareness and clear knowledge regarding the structure and function of the ecosystem has got immense significance. A composite of components regulates the community configuration and structure, and the associated tree species diversity, of mountain vegetation (Schmidt *et al*. 2006). The elevation is sole principal factor (McVicar and Korner, 2012), which employ a strong impact on the composition of the flora in most mountains in the world (Zhang *et al*. 2006). The elevation gradient is investigated as a conclusive component for creating the spatial patterns of tree species diversity even as it is directly corresponded with diverse environmental variables and provides new distinct ecological environment (Lomolino, 2001).

Species diversity along elevational gradients keeps on changing, and has been the focus of several studies (Fetene *et al*. 2006). Some ecologists stated a "humped" distribution, that shows highest species diversity near the mid of the gradient (Zhang and Ru, 2010). However, Bruun *et al*. (2006) supported the fact that a humped pattern emerges when the elevation gradient corresponds with productivity gradient. They went on to test Grime's (1973) suggestion of a relationship between general productivity and diversity. Bruun and co-workers (2006) also discussed a possible fluctuation in natural disturbance and disturbance due to various grazing animals (Grime's, 1973) "intermediate disturbance hypothesis". However, some scholars have proposed several exceptions to the humped pattern (Stevens, 1992; Pausas, 1994). Some have argued whether species diversity increases or decreases with increasing elevation or whether it peaks at an intermediate elevation. It depends mainly on specific arrays of interactions among the plant communities, species, and environmental factors (Korner, 2007). The considered view is that further tests of the hypothesis in different mountains are needed (Kikvidze *et al*. 2006; Zhang and Chen, 2007).

The study of general pattern and search for a common cause of species richness along the spatial and environmental gradients become important in recent years for biogeographical research. Among the spatial patterns, the latitudinal gradient in species richness is the most consistent and relatively well studied (Begon *et al*. 2006).

2.2. ALTITUDINAL EFFECTS ON VEGETATION

Shibu *et al*. (1996) carried out a study in peninsular India on a high altitude tropical forest (shola forest), to scrutinize the changes in floristic composition (mainly woody species regeneration) along the edge to an interior gradient concerning changes in both edaphic as well as micro environmental factors. Species inventory was taken in 25 m^2 plots, recognized at 10 m intervals along the edge to interior transects. They observed that edge effects prevailing in these high altitude forests pierce to a distance of 15-30 m. Furthermore, edaphic factors have a significant effect on woody species regeneration, perhaps even more than the micro environmental factors. This implies that the disturbances in the bare forest floor is due to lowering of soil moisture and fluctuating soil nutrient status, which can harmfully affect the regeneration of many shola species.

Parathasarathy (2001) studied the changes in abundance, woody species composition and forest stand structure in the low, medium and high elevation of tropical wet evergreen forest in Sengalthari, Western Ghats, India. Total of 3.14 ha, 2673 stems of $\geq$ 30 cm girth at breast height casing 125 species (range: 64 to 82 species per site) were computed in Three ha plots established each in selectively-felled, undisturbed, and moderately disturbed sites, situated 2 to 4 km apart . Changes in abundance, woody species composition, and stand structure revealed that tree density and species richness varied judiciously among the sites. It was observed that changes are related to natural site variations and anthropogenic impacts.

Sundrapandian and Swamy (2000) explored the forest ecosystem structure and composition in deciduous and evergreen forest ecosystems along an altitudinal gradient (250-1150 m) at Kodayar, in the Western Ghats, South India. they recorded a total of 58, 77,125 and 105 plant species belonging to 30, 28, 52 and 45 families in moist deciduous forests (MDF, sites I & II), an evergreen forest (EF, site III) and a forest at a higher elevation (HEF, site IV) respectively. *Terminalia paniculata*, *Pterocarpus marsupium*, and *Aporosa lindleyana* were the dominant species in the moist deciduous forests, whereas *Hopea parviflora*, *Vateria indica* and *Xanthophyllum flavescens* dominated in the evergreen forest. In that "L" shaped curve of different DBH classes of trees and saplings indicated good regeneration status in these forests. The changes in species composition are mainly due to changes in vegetation types influenced by anthropogenic pedoturbations and other abiotic factors.

Joseph *et al*. (2008) explored the distribution of plant communities along the topographic (elevation, slope, aspect and drainage density) and climatic (temperature and precipitation) gradients in Mudumalai Wildlife Sanctuary with relation to species richness, a central part of the Nilgiri Biosphere Reserve, (southern India). They studied 90 sample plots (19 semi-evergreen, 17 moist deciduous, 36 dry deciduous, and 18 thorny forest plots) and recorded, 498 plant species out of which 154 were trees with > 5 cm DBH. Species richness exhibited a unimodal distribution about elevation gradient. Lesser species richness and diversity were witnessed in lower (<800) and higher (>1000) elevation zones, while higher species richness and diversity were noted in medium elevation zones (800-1000 m). They found that due to highly exposed sanctuary to human burden in lower elevation, while various climatic restraints (e.g. extreme cold and wind speed) are quite persistent in the higher altitude zones leads to lower species richness. Similar kind of observations was recorded in Neotropical sites: rise in diversity initially with altitude, and later declined at higher elevation (Leigh, 1999). In this study slope and species richness were negatively correlated; i.e. species richness decreased with the increased in slope mainly due to steep slopes at higher elevations, resulting in poor nitrogen and phosphorous.

Studying the vegetation composition, structure and diversity concerning with the characteristics of soil in temperate mixed broad-leaved forest along an altitudinal gradient in Garhwal Himalaya, India, Sharma *et al*. (2009) observed community diversity to be highest (3.140) at the higher altitude while at middle and lower altitudes it was 3.09 and 2.10 respectively where the concentration of dominance followed the opposite trend of the diversity. At higher altitude, the concentration of dominance and maximum diversity (0.0354 and 0.45) values were recorded for *Quercus leucotrichophora*. At middle altitude, the concentration of dominance and highest diversity values (0.0493 and 0.48) were recorded for *Daphniphyllum himalayense.* At a lower altitude the maximum concentration of dominance and diversity values (0.2643 and 0.49) were observed for *Quercus leucotrichophora*.

Gairola *et al*. (2008) explored vegetation diversity in forest along an altitude gradient in three different sites namely Tunganath, Lata and Pindari of the subalpine zone of Garhwal and Kumaon region of west-Himalaya, Uttarakhand. Two vertical transects were laid in three elevation zone (viz. <2800m, 3000-3200, >3200 m) and a total of 54 sample plots 10× 10 m were established for analyzing species richness and other vegetation parameters. In their study, they observed a decrease in total basal area and total tree density with apparent increase in elevation. At an altitude between <3000m *Acer caesium* (IVI- 85.88), *Pinus wallichiana* (IVI – 210.08) and *Quercus semecarpifolia* (IVI-166.91) dominate in Pindari, Lata, and Tungnath respectively. In between 3000 – 3200 m, *Abies pindrow* (IVI-49.32), *Pinus wallichiana* (IVI-123.18) and *Abies pindrow* (IVI- 96.49) dominate in Pindari, Lata, and Tungnath respectively.In altitude between >3200 m altitude *Betula utilis* (IVI- 88.80), *Betula utilis* (IVI-222.5) and *Abies pindrow* (IVI -90.08) dominate in Pindari ,Lata and Tungnath respectively.In all three different sites, the mid-altitude elevation (3000 – 3200 m) displayed high species diversity proper ecophysiological conditions, aspect topography and high soil fertility resulting in high species richness. Due to this, the mid-altitude strata (3000-3200 m) may be recognized as most representative for long term monitoring of forest ecosystem elements in the Sub-alpine forest in West Himalaya.

Kukshal *et al*. (2009) analyzed the life form pattern of grazing lands and phytosociology under pine canopy in the temperate zone, northwest Himalaya, India. They studied the life form pattern, phytosociology, and vegetation analysis of such grazing land between 1100-1400 MSL through the altitude gradient and variable slopes. The composition of grazing land differs significantly with the intensity of biotic factors; soil moisture and altitude.They reported that the dominant species among the under-canopy vegetation in *Pinus* forest was *Capillipedium parviflorum* irrespective of altitudinal gradient and aspect. However, in most of the sites co-dominance species were different because of definite microclimatic requirements by these species. The main factors responsible for disturbance of native vegetation are overgrazing and forest fire.

Rao *et al*. (2013) studied the changes in vegetation along an altitude gradient varying from coast to Deccan plains in human-disturbed forests of Uttara Kannada, Central Western Ghats. The study was carried out in different agroclimatic zones – coast, hilly and plains with 10 different sectors. They documented a total of 146 species of shrubs and 134 species of trees by using transect based survey. It was observed that sectors 6, 7 and 8, lying in the Western Ghats section, had semi-evergreen to evergreen forests and showed the highest percentage endemism, percentage evergreen, and species diversity. The sectors 9 and 10 in eastern plains comprised of dry deciduous forests dominated mainly by teak. The moist deciduous forests in the coastal sectors were affected more by human disturbances except for a patch of a sacred grove. They concluded that major causes behind the transformation of once evergreen forests into deciduous forests are anthropogenic activities and habitat fragmentation.

Tree inventory along the altitudinal gradients with elevation between 900 to 2150 m above mean sea level (MSL) in Singara Range of Nilgiri Biosphere Reserve, Western Ghats, India was studied by Singh (2016). In their study, a total of 60 quadrats were laidout, each of 10×50 m size in the forest across five elevational ranges with an interval of l250-meter. A total of 115 Genera & 56 Families were recorded with 181 species. The most dominant species across the whole study area was *Anogeissus latifolia*. Lower elevation (900-1150) comprises mainly evergreen trees and shrub due to climatic and topographic variation. Deciduous trees were mostly present in the middle zone B, C, and D while zone E (1900-2150) comprised of Shola vegetation. It was present at the higher altitudes of the Western Ghats including the Singara range in NBR.This vegetation was found only at the upper elevational undisturbed zone due to lack of resistance and tolerance to environmental changes. The present study revealed that altitudinal variations play a very crucial role in shaping the forest community.

Mohandass *et al*. (2016) provide descriptive information of the floristic composition, forest structure and effects of disturbance on forest structure of mid-elevation (≥ 1800 ≤ 2100 m above MSL) tropical montane evergreen forests (sholas) in the Nilgiri Mountains, southern India. Five species, namely *Litsea glabrata, Lasianthus venulosus, Meliosma simplicifolia, Daphniphyllum* *neilgherrense*, and *Neolitsea fischeri* were dominant species and influenced the forest structure; disturbance influences tree species richness density, liana density, and basal area, in addition to forest structure and changes species composition.

Thakur and Chawala (2019) explored the functional diversity along altitudinal gradients in the high altitude vegetation of the western Himalaya. They laid eleven altitudinal transects in high altitude region of western Himalaya; in each transect, sampling of the vegetation randomly at every 200 m elevation to estimate species rarity, niche width and different FD indices [community-weighted mean traits (CWM), functional richness (FRic), functional divergence (FDiv), functional dispersion (FDis) and functional specificity (FSpe)]. They observed a total of 418 plant species; most of them have a narrow niche and distribution. Whereas a higher proportion of species with a narrow niche is more profound at higher elevations, 36.5% species were rare with 17% were endemic to Himalaya.CWM plant height, FDiv, FRic, FSpe, and FDis were found to be significantly decreasing with increasing elevation. Natural gradients influence i.e. aridity (aspect) and decreasing temperature (elevation) on functional diversity and species distribution prefer that functioning of high altitude communities is very likely to be affected in the future under climate change.

Mota *et al*. (2018) evaluated that the changes in life forms, vegetation structure, and species composition along an elevational gradient of rupestrian grasslands in south-eastern Brazil. At each elevation, thirteen plots of size 10 m^2 were laid in seven sites at 100-m elevation intervals (800–1400m). Significant changes were observed along an elevation and soil attributes showing differences indiversity, vegetation structure, species composition, richness and frequency of each life form. A total of 9672 individuals belonging to 278 species were identified across the elevational gradient. The floristic composition also varied along with an altitude. The result finally indicated that soil pH, hydrogen + aluminum, solution equilibrium P,base saturation, K, and organic matter act as an important factor of community change along the altitude gradient in the rupestrian grasslands.

Kulge and Kessler (2010) observed that under the stressful conditions (frost at high elevations anddrought at low elevations) of environment, epiphytic fern assemblages tended to be clustered for trait characteristics, which suggested environmental filtering in Braulio Carrillo National Park Costa Rica, Central America.

2.3. PROFILE DIAGRAM

In plant ecology, profile diagrams are considered to be a very useful instrument for studying and comparing physiognomic structures of forests. In their study, Ralhan *et al*. (1982) prepared a profile diagram at six different sites in and around forests of Nainital, Kumaon Himalayas, India. For including the majority of the species an area of $200m^2$ was selected. They recorded the maximum average height for *Quercus floribunda* and a minimum of *Quercus launginosa* in strata A and strata B. Whereas, in strata C and Strata D P. *roxburghii* exhibited the highest average tree and *Quercus foribunda* forest as lowest. The average of shrub stratum was recorded maximum in *Quercus leucotrichophora* and *Quercus foribunda* and minimum in *Pinus roxburghii*.

Cooray (1974) prepared profile diagram of the dominant tree canopy of tree species (*Acacia koa*). He also studied the advance growth of *Mestosideros collina* with 'gap phase'. Both of the profile diagram was taken from same forest in Montane rainforest, Hawaii.George *et al*. (1993) made vegetation profiles of 80 × 10 m strip transects at 2 locations to describe stand physiognomy in the 15 yr old secondary forest is an abundant *Eucalyptus tereticornis* plantation in the Western Ghats.Profile diagrams of representative 10 × 40 m strip were drawn in the four vegetation types of Kuruva Island by Vidyasagaran *et al*. (2000). Four district strata were identified in the river rain forests as well as moist deciduous of forest in the Island.

Lemos *et al*. (2001) had drawn a profile diagram for comparing the vegetation of two adjoining areas: an area on the top of a small hill and on quaternary sandy terrain in Cardosa Island, Brazil. A 2× 60 m transect was laid in each of the area and diameter at base of stem of every tree, shrub or liana was recorded and drawn. They concluded that profile diagram is a useful instrument for physiognomic structures and comparison of forests.

A profile diagram was used in the management of mixed stands in the urban woodlands of Denmark (Nielsen and Nielsen, 2005).The study was mainly focused on planning and development of a long term management for two young mixed stands for recreational use.

Zhu (2006) studied the forest vegetation of Xishuangbanna, South China. In his study in ravine seasonal rain forest, a (50 × 50 m) strip was taken for analysing vegetation profile diagram. It is usually stratified with three layers of trees, reaching up to a height of 35–45 m in top layer and has coverage of 25%–30%.In second tree layer, continuous crowns reaches up to 18–30 m high and is wholly evergreen. The lower layer of tree reaches up to a height of 6–18 m with a coverage of less than 50%. *Terminalia myriocarpa*, *Pometia tomentosa* was found to be the dominant trees in Ravine seasonal rain forest.

2.4. ALTITUDINAL EFFECTS ON SOIL

Climate is the most critical factor in shaping the range of plant communities; the edaphic factors are also responsible for limiting its occurrence. The physical, chemical and biological relation of the soils to forest growth is extremely complex. Several other workers have made attempts to examine the interrelations between soil and vegetation (Chiarucci *et al*. 1998)

Balagopalan and Jose (1995) explored the properties of soils in the natural forest in the Trivandrum Forest Division revealed that the soils of evergreen and semi-evergreen forests are sandy loam whereas in a moist deciduous forest was loamy sand. Similarly, the soils in evergreen forest and moist deciduous forest of Malyattoor division are sandy loam and loamy sand (Balagopalan, 1995).

Studying the vegetation diversity, composition, and structure in relation with soil characteristics present in the temperate mixed broad-leaved forest along an altitudinal gradient in Garhwal Himalaya, India, by Sharma *et al*. (2009). The physicochemical properties of soils in their study displayed the presence of higher nitrogen contents (0.36% at higher and 0.38% at middle altitudes), availability of higher average organic carbon (3.91% at higher and 3.61% at middle altitudes) and higher average moisture contents (15.57% at higher and 16.01% at middle altitudes) in the soils of 2100m and 1700m altitudes respectively. The soils found in the forests of *Quercus leucotrichophora*, extending from 1550 to 2100m elevations were slightly acidic to almost neutral in reaction with a pH range of 5.7 to 6.6, which was presumed to be the promising range for availability of nutrients for this species. They concluded that the occurrence of higher diversity at higher elevations is due to its relation with higher total nitrogen, available potassium, organic carbon, and available phosphate.

Sheikh *et al*. (2009) analyzed the variation present in the soil organic carbon stock along an altitude in subtropical coniferous and temperate broadleaf forests in Tehri Garhwal Himalaya, Uttarakhand, India. In their study, three sites were selected with varying altitudes in two different types of forest. *Pinus roxburghii* forest at an altitude of 700 m (site-I), 900 m (site-II), 1100 m (site-III) and three sites in *Quercus leucotrichophora* forest at altitudes of 1700 m (site-I), 1900 m (site-II) and 2100 m (site-III). They observed that the soil organic carbon (SOC) stocks were found to be decreasing with altitude: from 185.6 to 160.8 t C ha^{-1} in temprate (*Quercus leucotrichophora*) forests and from 141.6 to 124.8 t C ha^{-1} in subtropical (*Pinus roxburghii*) forests. The result of their study reported that the increase in carbon density with decreasing altitude may be due to better stabilization of Soil organic carbon at the lower altitudes.Gahlod *et al*. (2018) observed the influence of altitude on soil organic carbon in the land use system of Uttarakhand state. They estimated the SOC stocks (0-25 cm soil) along the altitudinal gradient viz., low mountain (<1250 m), middle mountain (1250-

2500m) and upper mountain (>2500m) in the agricultural associated forest, plantations, and grassland uses in-state using the geospatial technique.

Singh *et al*. (2010) studied the pattern of distribution of Pine and Oak along altitudinal gradients in Garhwal Himalaya. They concluded that nitrogen availability and SOC showed reducing trends with altitudes in both the forests. It might be due tothe total basal cover and reducing density of the trees with elevations.

Gairola *et al*. (2012) analysed soil chemical properties with respect to forest composition in moist temperate valley slopes of Garhwal Himalayas, Uttarakhand, India. Various diversity and phyto-sociological parameters, i.e., tree species richness (SR), stem density (Nha^{-1}), total basal cover (Gha^{-1}), Shannon–Wiener diversity index (H) and Simpson concentration of dominance were calculated for each forest type. Soil chemical properties, i.e., organic carbon (C), total nitrogen (N), C:N ratios, available phosphorus (P), available potassium (K) , pH and soil organic matter (SOM) were calculated for three different depths viz. Upper (0–10 cm), Middle (11–30 cm), and Lower (31–60 cm) in all the selected forest types.Values of K, P, N, C, pH, SOM, and C: N ratio and ranged from 40.67 to 261.17 ppm, 2.73 to 20.17 ppm, 0.17 to 0.45 %,2.29 to 4.31 %,5.47 to 6.67, 3.95 to 7.43 % and 8.12 to 14.49 respectively. P was negatively correlated with altitude and positively with C and was higher in soil of lower horizon. K was positively correlated with N, C and altitude. pH was slightly acidic in all the forest types. C content decreased with soil depth and showed no relationship with altitude due to different forest composition along altitude gradient. In this study soil chemical properties in most of the forest types were found on the higher end than the values recorded for other similar region. The main possible reason was undisturbed and luxuriant vegetation of these forest types, which is due to presence of higher values of diversity and other phytosociological parameters.

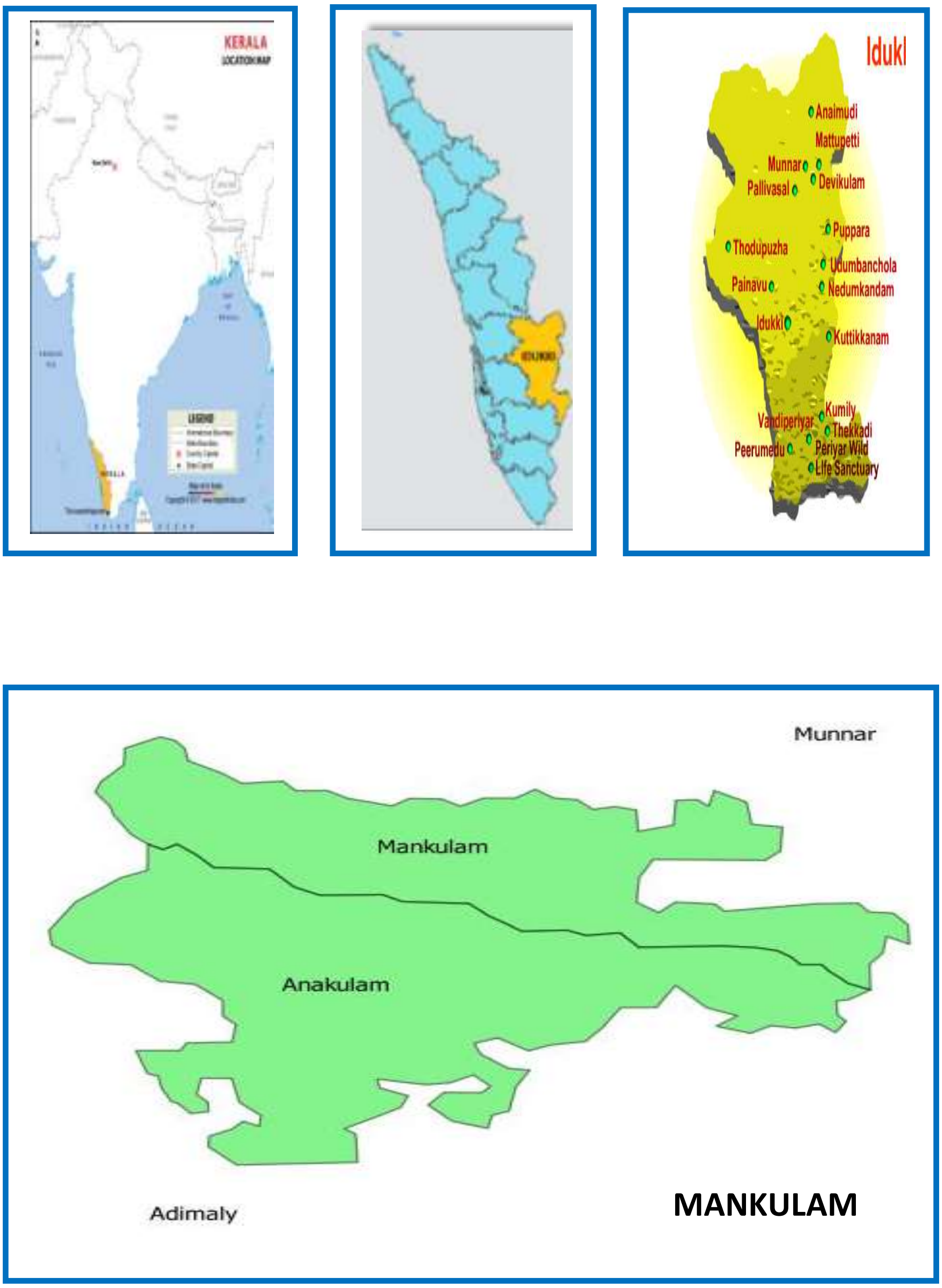
Debnath *et al*. (2012) studied the physicochemical properties and water holding capacity of cultivated soil along an altitude gradient in south Sikkim, India. They analysed that the porosity, bulk density, particle density, water in air-dry soils and volume expansion ranged from 36.25 to 57.72 percent, 1.08 to 1.53 gm/cc, 2.15 to 2.76 gm/cc, 0.68 to 4.32 percent, and 2.94 to 11.9 percent respectively.The effect of different physical and chemical properties on water holding capacity concerning altitudes indicates that the organic carbon, the content of clay and sand and porosity directly influence water holding capacity of the soil. In slopping land, the water holding capacity of the soil decreases with increasing altitude. This helps the farmers to schedule irrigation for their crops.

Choudhury *et al.* (2016) studied the impact of land use change, altitudinal gradient and agro-physical variation (bulk density, soil texture, mean temperature, and annual rainfall) on soil organic carbon (SOC) in north eastern Himalayan region. They observed that non -agricultural land uses (forestsand grasslands) registered significantly higher SOC stock (35·2–42·1 Mg ha^{-1}) and SOC concentration (2·20 to 2·51%) compared with horticulture, plantation and agriculture land uses (lowlands and settled-up and shifting) (SOC stock, 27·4 – 28·4 Mg ha^{-1}; SOC concentration, 1·44 to 1·63%). SOC concentration varied mainly by altitudinal gradient and finer fractions of separates (silt and clay) leads to climatic variables (temperature and rainfall) variation. Trend analysis resulted in the increase of SOC with an increase in rainfall and clay content and decreased with mean temperature and soil bulk density. Along the altitudinal gradient (6 to 1,000 MSL), increase instock, silt + clay SOC concentration and annual rainfall observed was not same throughout. However, the respective increase was linear beyond 1,000 MSL.

Divya *et al*. (2016) analysed the nutrient status of the soil (N, P, and K) about the forest types of southern Western Ghats region falling mainly under the northeastern region of Idukki district, Kerala, India. In their study, ten stations with varying altitudes of the region from 150 to 2000 m above mean sea level were selected. The vegetation of that area comprises of evergreen, hilltop evergreen, semi-evergreen, dry deciduous, sandalwood, moist deciduous, grasslands, and shola (tropical montane forest). They observed that higher nutrient (especially N and K) status in shola forest i.e station 6 Eravikulam

National Park (1915 m) while lower values were in dry deciduous forest i.e Station 10 Chinnar (481 m). The status of N, P, and K in forest soils varies from 0 to 1.09%, 0.04 to 0.92% and 0.56 to 3.81% respectively. A decreasing trend was reflected by N and P with the increasing soil depth and K show almost the same values throughout the entire depth of 1 m length soil profiles. They concluded that soils of the study area are generally sand and clay dominant compared to silt.

Sahu *et al.* (2019) studied the distribution of tree species, their diversityand nutrient status of soil along an altitudinal gradient of Saptasjya hill range, Eastern Ghats, India. A total of thirty quadrats of size 10m×10m size were laid for trees across the altitude ranging between 81m and 450m. Field sampling were conducted at 3 different elevation sites of the hill range. The 3 different elevation sites were Site 1- Low Elevation Forest (LEF), Site 2- Middle Elevation Forest (MEF) and Site 3- High Elevation Forest (HEF). The MEF possessed highest SOC and HEF contained the lowest. The nitrogen content (%) was highest in MEZ (0.29±0.01) and lowest in HEF (0.26±0.01).The phosphorus content was observed highest in MEF (0.15±0.01) followed by LEF (0.12±0.01) .Soil analysis of all the three sites recorded that highest concentration of N,C, and P were highest in MEF than LEF and HEF.Tree diversity index and species richness were positively correlated with pH (r=0.829 andr=0.743 respectively; p <0.05), whereas tree density was negatively correlated with organic carbon (r= - 0.543), phosphorous (r= -0.401), tree diversity index (r= - 0.364),and pH (r= - 0.597).



(Source: GOK, 2014)

Fig. 1 Location Map of the study

MATERIALS AND METHODS

The present study was carried out during 2019-20 to enumerate the tree community and soil physico-chemical properties along with an altitudinal gradient of selected zones in west coast tropical evergreen forests (1A/C4) ecosystem of Mankulam Forest Division. The details of the study area and the methods of investigation followed are described below.

3.1. STUDY AREA

3.1.1. Name, Location, and Extent

The entire area of the Mankulam Forest Division falls within Mankulam Village of DevicolamTaluk, Idukki District, Kerala. It lies within the geographical range between 10˚0' and 10˚ 10' N latitude and 76˚ 50' and 77˚ 0' E longitude. The division was formed on April 16, 1980, and covers an area of about 9005.82 ha (KFD, 2014). It is enwrapped by a portion of Eravikulam National Park on the north; Kadalar, Cholamala, Nallathanni, Kallar, and Latchmi estates in the east; areas of Adimaly Range of Munnar Division in south; Munnar and Malayattur Division in the west. The division comprises of two forest ranges namely, Mankulam and Anakulam (KFD, 2014).

3.1.2 Terrain

The altitude of the Mankulam forest division varies between 340 m and 2102 m above MSL with highly undulated and rugged terrain. The highest peak Sankumala (2102m) is situated in Mankulam range.

3.1.3. Climate

3.1.3.1 Rainfall

The forests of the division receive rain from both South Westand North East monsoons. The South West monsoon commences with the pre-monsoon showers by the middle of April. Southwest monsoon results in continuous precipitation starting from the end of May and lasts till the middle of August. The

North-East monsoon is also conspicuous during October and November. The average rainfall received in this division varies from 2,500 mm to 3,000 mm.

3.1.3.2 Relative Humidity

The mean relative humidity ranges from 50 percent to 90 percent and reaches high during the monsoon periods.

3.1.3.3. Temperature

Mankulam forest division enjoys a salubrious climate. The winter in the high altitudes of above 1,400m is characterised by extremely cold nights with normally bright days. The mean annual temperature in the tract ranges from 5˚C to 30˚ C. The variation in temperature is mainly due to altitude.

3.1.3.4. Wind

Normally, during Southwest monsoons, wind does not cause much damage to the tree growth. But the Northeast rains are usually accompanied by strong winds from the northeast, which often causes some injury to the tree growth.

3.1.4. Hydrology

The study area comprises of Ethashola, Karinthiri and Menachery rivers which are perennial and are the main source of drainage from Mankulam. The Karinthiri river flows through the middle portion of the Mankulam resumed land. Cholamala and Pampadumpara are its main tributaries. The tributaries of Menachery originate in the forests of Kankattumala and Lakshmi mala. The Menachery River flows towards the west and joins Karinthiri River near Anakulam.

3.1.5 Geology, Rock and Soil

The division consists of pre-cambrian rocks of Archean age comprising of gneisses and granites. Charnockites, sillimanite, granites, gneiss, magnetite, and biogenesis are widely present in the division. The laterites are formed due to laterization process under tropical humid humid conditions, which is reddish-brown with irregular pockets.The soils of Mankulam Division are mainly of four types (a) Forest loam (b) Riverine alluvial (c) Laterite and (d) Red loams (KFD, 2014). Forest loams are formed by the weathering of crystalline rocks under the forest cover. They are dark reddish to black with loam to silty loam texture. Riverain alluvial soils occur mostly along the riverbanks. They are very deep with surface texture ranging from sandy loam to clayey loam. Laterites are typical weathered products of gneissic and granitic rocks, developed under humid conditions and are commonly found within the foothills than on the higher ridges. Red loams are found in degraded areas and are deficient in organic matter and plant nutrients.

3.1.6 Vegetation

The majority of the area in this division is under natural forest i.e. 8083.55 ha excluding the area leased to KFDC (265.50 ha), tribal settlement area (381.70 ha) and the existing plantation area (274.97ha). Floristically, the tract is one of the richest areas in the country harbouring around 3800 species of angiosperms (27% of flowering plants). The forest types as per Champion and Seth (1968) are West coast tropical evergreen forests (1A/C4) and West coast semi-evergreen forests (2A/C2). Apart from these, Grasslands (11A/C1/DS2) and Southern Montane Wet Temperate Forest (11A/C1) are also there at higher altitudes.

3.1.6.1 West Coast Tropical Evergreen Forests (1A/C4)

The tropical evergreen forest is dense and evergreen. It covers an area of 5252.36 ha of natural forests in the division. It comprises of lofty trees characterized by the presence of a large number of species occurring together to form a closed multi-storied canopy. It has climatic climax vegetation. As per the classification, areas with high elevation type are associates of *Cullenia excelsa, Mesua ferrea* and *Palaquium ellipticum.* Top canopy comprises of *Mesua ferrea, Calophyllum tomentosum, Vateria indica, Hopea parviflora, Dysoxylum malabaricum*. Species like *Holigarna species, Cinnamomum malabaricum, Elaeocarpus serratus*, etc. are present in middle canopy. Trees in lower canopy are *Aporusa lindleyana,* and *Sterculia nobilis*. *Ancestrocladus heyneanus, Bridelia scandens* etc. are common climbers found in this division.

3.1.6.2 West Coast Semi-Evergreen Forest (2A/C2)

Tropical semi-evergreen forest occurs in the area adjacent to evergreen forests and areas once cleared by tribals and encroachers. It covers an area of about 2831.19 ha of natural forests in the division. It is closed high forests, with a heterogeneous mixture of evergreen and deciduous species with the preponderance of evergreen species in the lower storey. They occur in localities where annual rainfall is 2000-2500mm. The dominant species regenerate under its shade. Top canopy comprises of *Hopea parviflora, Mesua ferrea, Vateria indica, Elaeocarpus tuberculatus, Solenocarpus indicus*. Species like *Cinnamomum malabatrum, Hydnocarpus pentandra, Olea dioica*, etc. are there in the middle canopy. Trees in lower canopy are *Aporusa lindleyana, Sterculia nobilis.* The common climbers found in this division *Ancestrocladus heyneanus, Myxopyrum serratulum, Spatholobus roxburghii*, etc.

3.1.6.3 Grass Lands (11A/C1/DS2)

Grassland patches are occurring interspersed with patches of the shola forest (Montane temperate type forest). The grassland is seen in areas like Pampadumpara, adjacent areas of Eravikulam National Park, Kozhimottapara, Otallu, Pullumdi areas and southern side of Kadalar. Predominant species are *Andropogon percusa, Arndinellia sp., Ischaemum sp, Pilosum sp., Themeda sp., Cymbopogon sp., Engrostisrigram, Pennisetum sp.* and *Dicanthium sp.*

3.1.6.4 Southern Montane Wet Temperate Forest (11A/C1)

Southern montane wet temperate forest type is usually present on the higher hills above 1500 Mts. It is usually seen in the depression of valleys, glens and between hillocks of Pampamdumpura adjacent to Eravikulam National Park and southern side of Kadallar. Main species of vegetation are *Cinnamomum sp, Elaeocarpus species, Eugenia gardneri, Bauhinia racemosa, Rhododendron sp.,* *Michelia species.* The undergrowth consists of *Arundinaria sp.*, *Rhamnus sp.*, *Strobilanthus sp.*. Climbers like *Rosa sp.* and *Rubus sp.* are also there.

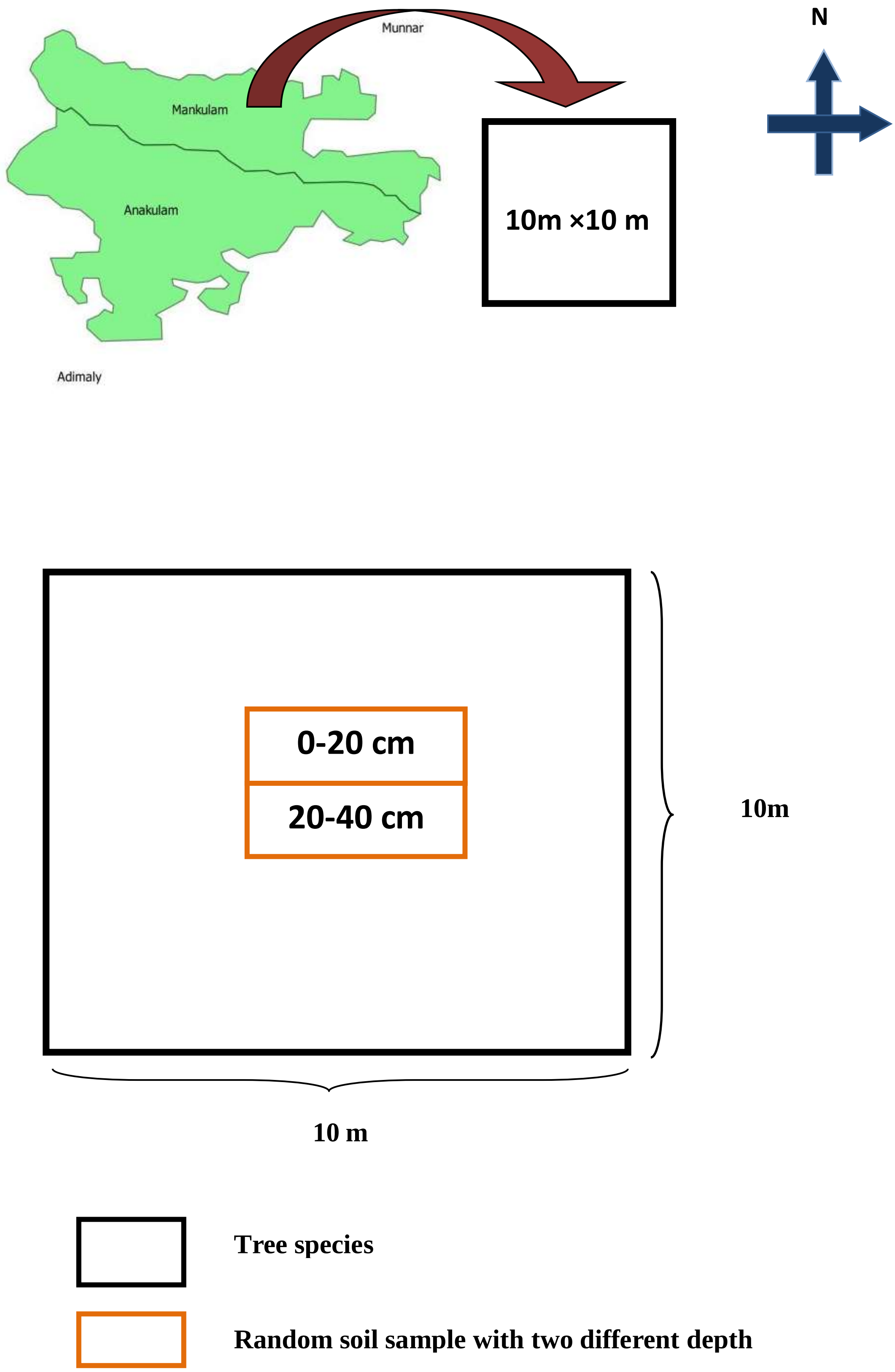


Fig. 2 Diagrammatic representation of sampling method adopted

3.2. METHODS

3.2.1. Experimental Site

According to the Working Plan, the Mankulam Forest division is distributed from 340 m to 2102 m above MSL. Two altitudinal zones, namely Zone I (between 350-900 above MSL) and Zone II (between 900-1450 above MSL) with forest cover were first identified for detailed study. A total of 0.30 hectares of forest area located along these three zones was assessed. For carrying out the vegetation analysis, fifteen sample plots (0.15 ha in extent) were established in each of the three altitudinal zones. The quadrats of size 10 × 10 m were established on the ground using pegs outlined by coloured nylon ropes. Initially, two pegs were driven into the ground at a distance of 10 m (baseline). Perpendicular lines were taken at both ends of the baseline and a distance of 10 m was measured and marked using pegs.

3.2.2 Vegetation Analysis

3.2.2.1. Tree Height and Girth

In the sample plots, all the trees (above 10cm GBH) were enumerated. All the tree species individuals standing in the plot were identified by referring to published sources such as Gamble and Fisher (1915-1935), Sasidharan and Sivaraman (1996), Pascal and Ramesh (1987), KFRI's Flowering plants of Kerala Version 2.0 (Sasidharan, 2012), Western Ghats Tree ID (Ramesh *et al.*,2010),Flora of Peninsular India by IISc's ,Centre for Ecological Sciences (2019) and also by consulting plant taxonomists and dendrologists.The height of all trees were measured by using Vertex IV Hypsometer and recorded in meter. All trees girth was measured at a height of 1.37m from the ground level (Girth at Breast Height) by using Tailor's tape and recorded in centimeters (Chaturvedi and Khanna, 1982).

3.2.2.2. Phytosociological analysis

The analysis of tree vegetation in the study area was carried out using phytosociological methods (Goldsmith *et al*. 1986). The vegetation was quantitatively analyzed for their abundance, frequency, density, and their relative values and Importance Value Index (Curtis and McIntosh, 1950). To determine the quantitative relationship between trees species, the following parameters were determined (MOEF, 2014).

$$\text{Density (D)} = \text{Number of individuals/hectare}$$

$$\text{Relative Density (RD)} = \frac{\text{Number of individuals of the species} \times 100}{\text{Number of individuals of all species}}$$

$$\text{Abundance (A)} = \frac{\text{Total number of individuals of the species}}{\text{Number of quadrats of occurrence}}$$

$$\text{Frequency (F)} = \frac{\text{Number of quadrats of occurrence} \times 100}{\text{Total number of quadrats studied}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Percentage frequency of individual sps} \times 100}{\text{Sum percentage frequency of all sps}}$$

$$\text{Basal Area} = \frac{\text{GBH}^2}{4\pi}$$

$$\text{Relative Basal Area (RBA)} = \frac{\text{Basal area of the species} \times 100}{\text{Basal area of all species}}$$

$$\text{Importance Value Index (IVI)} = \text{RD+RF+RBA}$$

$$\text{Relative Importance Value Index (RIVI)} = \frac{\text{IVI}}{3}$$

3.2.2.3 Floristic diversity

In addition to the quantitative analysis, α- diversity of tree species was also calculated using Shannon-Wiener index, Simpson index and Pielou index of

Evenness index.The following formula were used for determining the diversity of tree species individuals.

The dominance of concentration of vegetation was measured by application of Simpson Index (Simpson, 1949)

$$\text{Simpson index } D = 1 - \Sigma (n_i/N)^2$$

Where,

n_i = Number of individuals of the species

N= Total number of individuals in the plot,

D=Diversity

The diversity of species was calculated by application of Shannon-Weiner's index (Shannon and Weaver, 1963)

a.$H' == 3.3219 (\text{Log } N - 1/N \sum n_i \text{ Log } n_i)$

Where,

n_i = Number of individuals of the species

N= Total number of individuals in the plot

S- Total number of species

b. $H_{max} = 3.3219 \log_{10} S$

Where, H_{max} is the maximum dispersion taking into account the number of species present in the plot.

Pielou's Index of Evenness (J') expresses how evenly the individuals are distributed among the different species. It is calculated by application of Pielou's evenness index (Pielou, 1966)

$J' = H'/Hmax$

Where, $H'\ max = 3.3219 \log 10\ S$

S= Total number of species

H'= Shannon-Weiner's index

3.2.2.4 Profile diagram

Profile diagram is a physical, size to scale, pictorial transactional representation of a representative segment of the forest land (Richards, 1952). A strip of 80 m x 10 m was selected from each altitude zone for linear representation of this strip was made in a size to scale graph ignoring the width of the strip. Positions of each tree were marked on the line. Total height and height to the first branch forming crown were recorded using an altimeter. The crown diameter was measured by tracing it on the ground with the help of two long rods. The vertical projection of the crown shape of each tree was drawn by hand in the field. From these pictorial and quantitative data obtained, the profile diagram was made, keeping the measurements to scale.

The samples collected were packed in sealed plastic cover and brought to the laboratory. The soil was kept for air drying for one week. The air-dried soil samples were sieved through 2 mm sieve and stored in a polybags for analysis of various physico-chemical parameters.

3.2.3.3. Physical properties

3.2.3.3.1. Bulk density

The bulk density (BD) of soil was estimated by using a core sampler method. The soil collected was transferred into an air tight container and the weight of the soil (both wet and dry) was estimated.

Bulk density= Mass of soil/core volume

3.2.3.4. Chemical properties

Soil chemical properties like Soil pH, electrical conductivity, soil organic carbon, Total Nitrogen, available potassium and available calcium were estimated by using standard analytical methods and are discussed below.

3.2.3.4.1. Soil pH

The pH of soil was determined by using the aqueous suspension method (Jackson, 1958). Soil pH was obtained potentiometrically with the help of a pH meter in 1:2.5 soil/water suspensions. For this, an air-dried soil sample of 10 g was taken in a beaker of 50 ml to which 25 ml distilled was added and repeatedly stirred for 20-30 minutes. The pH meter was used for obtaining the value of pH of the soil suspension.

3.2.3.4.2. Electrical conductivity

The determination of electrical conductivity (EC) of soil was done by calibrating electrical conductivity meter in 1:2.5 soil/water suspensions (Jackson, 1958). Air-dry soil of 10g was taken in a beaker of 50 ml to which 25 ml distilled water was added and conductivity is measured in the supernantant of the soil water suspension prepared for pH.

3.2.3.4.3. Soil organic carbon

Soil organic carbon (C) was estimated by Walkley and Black method (Walkley and Black, 1934). The soil samples were dried and fine-grained using mortar and pestle and to pass through 0.5mm sieve. The 0.5 g sieved soil samples were transferred into a conical flask of 500 ml to which 10 ml, 1 N $K_2 Cr_2 O_7$ (Potassium dichromate) was mixed thoroughly. 20 ml of Concentrated $H_2 SO_4$ was introduced to the conical flask and then was kept for 30 minutes for oxidation. Then, 100 ml distilled water was added with two drops of ferroin indicator. It was titrated against 0.5 N $FeSo_4$ solutions until dull green colour changed to chocolate dull red colour. A blank was also run simultaneously and readings were noted.

$$\text{Soil organic carbon (\%)} = \frac{(BV\text{-}TV) \times 10 \times \text{Amount of 1 N } K_2 Cr_{27} \text{ used} \times 100}{BV \text{ x weight of sample g}}$$

Where,

BV- Blank value

TV – Titre value

The determination of Soil organic matter was done by multiplying the value of organic carbon by 1.724 (Van Bemmelen factor).pestle and to pass through 0.5mm sieve. The 0.5 g sieved soil samples were transferred into a conical flask of 500 ml to which 10 ml, 1 N $K_2 Cr_2 O_7$ (Potassium dichromate) was mixed thoroughly. 20 ml of Concentrated $H_2 SO_4$ was introduced to the conical flask and then was kept for 30 minutes for oxidation. Then, 100 ml distilled water was added with two drops of ferroin indicator. It was titrated against 0.5 N $FeSo_4$ solutions until dull green colour changed to chocolate dull red colour. A blank was also run simultaneously and readings were noted.

Soil organic carbon (%) = (BV-TV) ×10×Amount of 1 N $K_2 Cr_{27}$ used ×100

3.2.3.4.4. Total Nitrogen

Total Nitrogen (N) was estimated by by semi-micro Kjeldahl method. The organic and nitrate nitrogen is converted to ammonium sulfate. In soil was converted to ammonium sulfate by digestion with conc sulphuric acid.

The ammonium liberated by distillation is collected in boric acid and determined by titrating with 0.01N HCl.

Percentage of N in the sample = (T.V-B.V) ×0.01×0.014× dilution factor ×100/W

Where, T.V= Sample titration value

B.V= Blank titration value

W= Weight of soil sample

3.2.3.4.5. Available potassium

Available potassium (K) in the soil samples was extracted with natural ammonium acetate and estimated using flame photometer (Jackson, 1958).

Available K in soil (ppm) = R× Volume of extractant/ wt of soil

Available K in soil (Kg/ha of soil) = Available K in soil (ppm) × 2.24

Where, R = flame photometer reading

3.2.3.4.6. Available phosphorus

Bray's extract No.1 reagent was used for extraction of available phosphorus (P) from a known quantity of soil (Bray and Kurtz, 1945). Phosphorus was estimated calorimetrically based on reduced molybdate ascorbic acid method using a spectrophotometer (Watanabe and Olsen, 1965). The intensity of colour was read using a red filter at 660 nm.

$$\text{Available P in soil (ppm)} = \frac{\text{R} \times \text{(volume made} \times \text{volume of extranct)}}{\text{(Aliquot taken} \times \text{Weight of soil)}}$$

$$= \text{R} \times 50$$

$$\text{Available P in soil (kg ha}^{-1}\text{)} = \text{R} \times 50 \times 2.24$$

Where, R= Concentration in PPM from standard curve

3.2.3.4.7. Available Calcium

Available calcium (Ca) was estimated by complexometric titration using EDTA.Five gram of soil was extracted with 25ml of neutral normal ammonium acetate. The Ca ions in the extract at high pH (this was achieved by NaOH solution to attain pH (>12) was titrated with standard 0.01N ethylene diaminetetraacetic acid by using murexide as an indicator. The color of the solution changed from pink to violet.

Available Ca (m. equivalent per 100g)

$$= \frac{\text{Titre value} \times \text{N of EDTA} \times \text{volume made} \times 100}{\text{Weight of soil} \times \text{Aliquot taken}}$$

Available Ca (mg/Kg) = Exchangeable Ca (m.equivalent per 100g) × 200

3.2.4. Statistical analysis

The experimental data of two elevational zones was subjected to statiscally analysis using the independent t- test to determine influence of different soil depth and different elevation on various soil parameters and Simple correlation analysis was carried out to find the significance of each soil parameters with varioussites studied in each elevation zone and alsowith soil parameters for both elevational zonesby using SPSS V.25.0 and Biodiversity R Ver.3.6.2. The floristic diversity of both elevation zones was done by using PAST (PAleontological STatistics) version 4.03 software. Rank abundance curve, to determine species abundance in both elevation zone Non-metric multidimensional scaling (NMS) and to relate the soil parameters with species diversity in both elevation zone Cannonical Correspondence Analysis (CCA) were done using BiodiversityR Ver.3.6.2 (Kindt and Coe, 2005).

RESULTS

The current study was conducted during 2019-2020 to understand the floristic composition, diversity and vegetation structure of typical tropical forest along an altitudinal gradient and to investigate the physico-chemical properties of soil along the gradient in two altitudinal zones i.e. zone I (350-900m above MSL) and zone II (900- 1450 m above MSL) of Mankulam Forest Division. The results obtained from the study are given below.

4.1 Vegetation analysis

4.1.1. Species composition (>10cm GBH)

All individuals having a GBH above 10cm were recorded species wise for each altitudinal zone.

A total of 38 tree species with around 92 individuals were identified from the sampled 0.15-hectare area in zone I (300-900 above MSL).Around 6 species were observed as Endangered as per IUCN red list (Table 1).

In Higher zone (900-1450 above MSL) a total of around 50 tree species having 107 individuals were identified from the sampled 0.15-hectare area. Around 11species were recorded as Endangered as per the IUCN Red list (Table 2).

Table1.List of tree species (>10 cm GBH) recorded in zone I (350-1450m above MSL

SI No.	Scientific Name	Family	Remarks
1.	*Actinodaphne malabarica*	Lauraceae	Vulnerable (VU)
2.	*Aglaia simplicifolia*	Meliaceae	Near Threatened (NT)
3.	*Alseodaphne semecarpifolia*	Lauraceae	Data Deficient (DD)
4.	*Alstonia scholaris*	Apocynaceae	Least concern (LC)
5.	*Aporosa cardiosperma*	Phyllanthaceae	Vulnerable (VU)
6.	*Artocarpus hirsutus*	Moraceae	Vulnerable (VU)
7.	*Bhesa indica*	Centroplacaceae	Least Concern (LC)
8	*Bombax ceiba*	Bombacaeae	Least concern (LC)
9.	*Cinnamomum camphora*	Lauraceae	Not Evaluated (NE)
10.	*Cinnamomum malabatrum*	Lauraceae	Least concern (LC)
11.	*Clausena anisata*	Rutaceae	Endangered (EN)
12.	*Dysoxylum malabaricum*	Meliaceae	Endangered (EN)
13.	*Elaeocarpus tuberculatus*	Elaeocarpaceae	Near Threatened (NT)
14.	*Ficus hispida*	Moraceae	Not Evaluated (NE)
15.	*Ficus tsjakela*	Moraceae	Not Evaluated (NE)
16.	*Garciniarubro- echinata*	Clusiaceae	Vulnerable (VU)

17.	*Harpullia arborea*	Sapindaceae	Least Concern (LC)
18.	*Hopea parviflora*	Dipterocarpaceae	Endangered (EN)
19.	*Isonandra perrottetiana*	Sapotaceae	Not Evaluated (NE)
20.	*Knema attenuata*	Myristicaceae	Least Concern (LC)
21.	*Litsea bourdillonii*	Lauraceae	Not Evaluated (NE)
22.	*Litsea floribunda*	Lauraceae	Not Evaluated (NE)
23.	*Litsea wightiana*	Lauraceae	Not Evaluated (NE)
24.	*Macaranga peltata*	Euphorbiaceae	Not Evaluated (NE)
25.	*Madhuca neriifolia*	Sapotaceae	Endangered (EN)
26.	*Magnolia nilagirica*	Magnoliaceae	Vulnerable (VU)
27.	*Mallotus philippensis*	Euphorbiaceae	Not Evaluated (NE)
28.	*Melicope lunu-ankenda*	Rutaceae	Least Concern (LC)
29.	*Meliosma simplicifolia*	Sabiaceae	Not Evaluated (NE)
30.	*Memecylon talbotianum*	Melastomataceae	Endangered (EN)
31.	*Mesua ferrea*	Calophyllaceae	Not Evaluated (NE)
32.	*Myristica dactyloides*	Myristicaceae	Lower risk (L)
33.	*Palaquium ellipticum*	Sapotaceae	Not Evaluated (NE)
34	*Poeciloneuron indicum*	Clusiaceae	Not Evaluated (NE)
35	*Schleichera oleosa*	Sapindaceae	Not Evaluated (NE)
36	*Spathodea companulata*	Bignoniaceae	Least Concern (LC)
37	*Turpenia cochinchinensis*	Staphyleaceae	Not Evaluated (NE)
38	*Vateria indica*	Dipterocarpaceae	Critically Endangered(CE)

Table 2.List of tree species (>10 cm GBH) recorded in Zone II (900 – 1450m above MSL)

Sr. No	**Scientific Name**	**Family**	**Status**
1.	*Acronychia pedunculata*	Rutaceae	Least Concern (LC)
2.	*Actinodaphne bourdillonii*	Lauraceae	Not Evaluated (NE)
3.	*Actinodaphne hookeri*	Lauraceae	Not Evaluated (NE)
4.	*Alseodaphne semecarpifolia*	Lauraceae	Not Evaluated (NE)
5.	*Antidesma montanum*	Euphorbiaceae	Least Concern (LC)
6.	*Aporosa lindleyana*	Euphorbiaceae	Not Evaluated (NE)
7.	*Apollonias arnottii*	Lauraceae	Not Evaluated (NE)
8.	*Calophyllum polyanthum*	Callophylaceae	Not Evaluated (NE)
9.	*Canarium strictum*	Burseraceae	Critically Endangered (CE)
10.	*Cinnamomum malabatrum*	Lauraceae	Not Evaluated (NE)
11.	*Clerodendron viscosum*	Verbenaceae	Not Evaluated (NE)
12.	*Cullenia exarillata*	Malvaceae	Vulnerable (VU)
13.	*Dillenia pentagyna*	Dilleniaceae	Not Evaluated (NE)
14.	*Dimocarpus longan*	Sapindaceae	Near Threatened (NT)
15.	*Dysoxylum malabatrum*	Meliaceae	Endangered (EN)
16.	*Elaeocarpus tuberculatus*	Elaecarpaceae	Not Evaluated (NE)
17.	*Elaeocarpus serratus*	Elaeocarpaceae	Endangered (EN)

18	*Ficus hispida*	Moraceae	Least Concern (LC)
19.	*Gordonia obtusa*	Theaceae	Least Concern (LC)
20.	*Holigarna beddomei*	Anacardiaceae	Endangered (EN)
21.	*Holigarna grahamii*	Anacardiaceae	Vulnerable (VU)
22.	*Hopea parviflora*	Dipterocarpaceae	Endangered (EN)
23.	*Hydnocarpus macrocarpa*	Achariaceae	Vulnerable (VU)
24.	*Knema attenuata*	Myristicaceae	Least Concern (LC)
25.	*Litsea bourdillonii*	Lauraceae	Not Evaluated (NE)
26.	*Litsea coriacea*	Lauraceae	Not Evaluated (NE)
27.	*Litsea floribunda*	Lauraceae	Not Evaluated(NE)
28.	*Litsea keralana*	Lauraceae	Endangered (EN)
29.	*Litsea laevigata*	Lauraceae	Not Evaluated(NE)
30.	*Litsea wightiana*	Laraceae	Not Evaluated(NE)
31.	*Macaranga peltata*	Euphorbiaceae	Not Evaluated(NE)
32.	*Madhuca longifolia*	Sapotaceae	Not Evaluated(NE)
33.	*Maesa indica*	Myrsinceae	Not Evaluated(NE)
34.	*Meiliosma pinnata*	Sabiaceae	Not Evaluated(NE)
35.	*Meliosma simplicifolia*	Sabiaceae	Near Threatened(NT)
36..	*Mesua ferrea*	Clusiaceae	Endangered (EN)
37	*Nothapodytes nimmonia*	Icacinaceae	Endangered (EN)
38.	*Palaquium ellipticum*	Sapotaceae	Not Evaluated (NE)
39.	*Persea macarantha*	Lauraceae	Endangered (EN)

40.	*Photinia integrifolia*	Rosaceae	Least concern (LC)
41.	*Prunus ceylanica*	Rosaceae	Endangered (EN)
42.	*Psychotria nigra*	Rubiaceae	Not Evaluated (NE)
43.	*Psydrax dicoccos*	Rubiaceae	Vulnerable (VU)
44	*Schleichera oleosa*	Sapindaceae	Least Concern (LC)
45	*Solenocarpus indicus*	Anacardiaceae	Vulnerable(VU)
46	*Sterculia guttata*	Sterculiaceae	Least Concern (LC)
47	*Syzigium mundagam*	Myrtaceae	Vulnerable (VU)
48	*Trichilia connaroides*	Meliaceae	Not Evaluated (NE)
49	*Turpinia cochinchinensis*	Staphyleaceae	Not Evaluated (NE)
50	*Vateria indica*	Dipterocarpaceae	Critically Endangered (CE)

4.1.2. Height – frequency distribution

Tables 3-4 and Figures 1 depicts the height- frequency distribution of the vegetation in the two altitudinal zones.

4.1.2.1.Zone I (350-900m above MSL)

The height frequency of tree species individuals was highest in 10-15 m height class with 34 individuals, followed by 5-10 m height class with 29 individuals. However, other classes were also well represented (Fig.3 and Table 3).

4.1.2.2.Zone II (900-1450m above MSL)

The highest number of individuals was recorded in 0-5 and 5-10m height classes (Fig. 1 and Table 4). The highest frequency of 40 tree species individuals was observed in 5-10 m height class, followed by 34 tree species individuals in 0-5 m (Fig. 3 and Table 4) class.

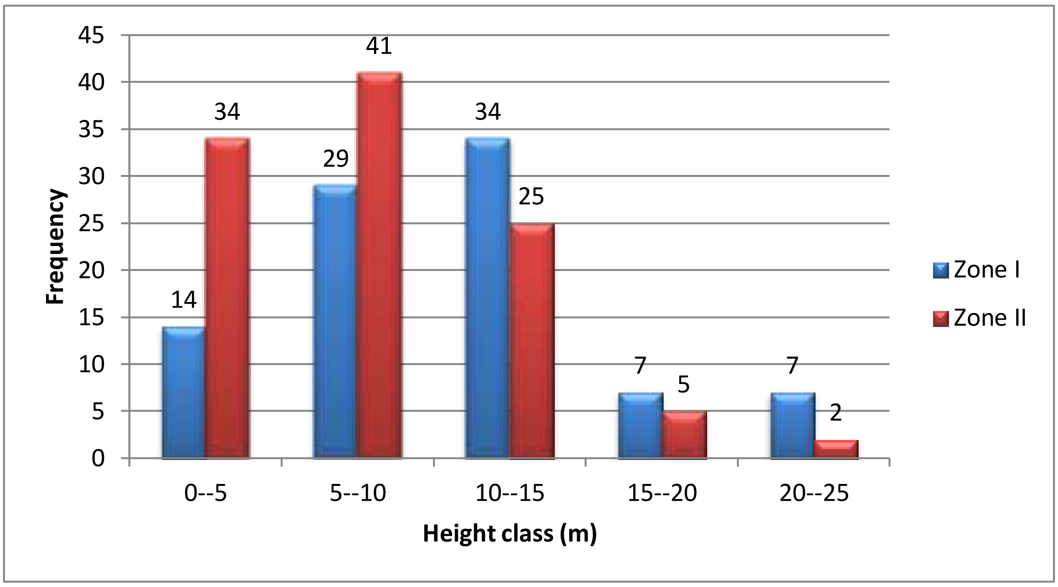


Fig. 3 Height- Frequency distribution in two altitudinal zones of Mankulam Forest Division.

Table 3. Height – Frequency distribution in zone I (350-900m above MSL)

SI No :	Species	Height class (m)					Total
		0-5	5-10	10-15	15-20	20-25	
1.	*Actinodaphne malabarica*	2	1	0	0	0	3
2.	*Aglaia simplicifolia*	0	1	1	0	0	2
3.	*Alseodaphne semecarpifolia*	2	0	0	0	0	2
4.	*Alstonia scholaris*	2	0	1	0	0	3
5.	*Aporosa cardiosperma*	1	1	0	0	0	2

6.	*Artocarpus hirsutus*	0	2	1	0	0	3
7.	*Bhesa indica*	0	2	0	0	0	2
8.	*Bombax ceiba*	0	0	1	0	0	1
9.	*Cinnamomum camphora*	0	1	0	0	0	1
10	*Cinnamomum malabatrum*	0	1	0	0	0	1
11.	*Clausena anisata*	0	1	0	0	0	1
12.	*Dysoxylum malabaricum*	0	0	4	2	0	6
13.	*Elaeocarpus tuberculatus*	0	1	2	0	0	3
14.	*Ficus hispida*	1	0	1	0	0	2
15.	*Ficus tsjahela*	0	0	0	1	0	1
16.	*Garcinia rubro- echinata*	0	0	1	0	0	1
17.	*Harpullia arborea*	0	0	0	0	1	1
18.	*Hopea parviflora*	0	0	1	1	1	3
19.	*Isonandra perrottetiana*	0	0	1	0	0	1
20.	*Knema attenuata*	0	1	2	0	0	3
21.	*Litsea bourdillonii*	0	0	2	0	0	2
22.	*Litsea floribunda*	0	1	0	0	0	1
23.	*Litsea wightiana*	0	0	2	0	0	2
24.	*Macaranga peltata*	1	4	1	0	0	6
25.	*Madhuca neriifolia*	2	1	0	0	0	3
26.	*Magnolia nilagirica*	0	3	1	0	0	4
27	*Mallotus philippinensis*	0	2	2	0	0	4
28.	*Melicope lunu-ankenda*	0	0	2	0	0	2

29.	*Meliosma simplicifolia*	2	0	0	0	0	2
30.	*Memecylon talbotianum*	0	1	0	0	0	1
31	*Mesua ferrea*	0	0	0	0	1	1
32.	*Myristica dactyloides*	0	1	2	3	1	7
33.	*Palaquium ellipticum*	0	0	0	0	2	2
34	*Poeciloneuron indicum*	0	0	1	0	1	2
35	*Schleichera oleosa*	0	1	1	0	0	2
36	*Spathodea companulata*	1	2	0	0	0	3
37	*Turpenia cochinchinensis*	0	1	2	0	0	3
38	*Vateria indica*	0	0	2	0	0	2

Table 4. Height- Frequency distribution in zone II (900-1450m above MSL)

SI No:	Species	Height class (m)					Total
		0-5	5-10	10-15	15-20	20-25	
1.	*Acronychia pedunculata*	0	1	0	0	0	1
2.	*Actinodaphne bourdillonii*	2	1	0	0	0	3
3.	*Actinodaphne hookeri*	0	2	1	0	0	3
4.	*Alseodaphne semecarpifolia*	1	0	0	0	0	1
5.	*Antidesma montanum*	1	1	0	0	0	2
6.	*Aporosa lindleyana*	1	0	1	0	0	2
7.	*Apollonias arnottii*	0	1	0	0	0	1
8.	*Calophyllum polyanthum*	0	1	0	0	0	1

9.	*Canarium strictum*	0	0	2	1	1	4
10.	*Cinnamomum malabatrum*	1	1	0	0	0	2
11.	*Clerodendron viscosum*	2	1	0	0	0	3
12.	*Cullenia exarillata*	0	2	2	0	0	4
13.	*Dillenia pentagyna*	0	1	0	0	0	1
14.	*Dimocarpus longan*	0	0	1	0	0	1
15.	*Dysoxylum malabaricum*	0	0	1	0	0	1
16.	*Elaeocarpus tuberculatus*	0	1	0	2	0	3
17.	*Elaeocarpus serratus*	0	2	0	0	0	2
18.	*Ficus hispida*	1	0	0	0	0	1
19.	*Gordonia obtusa*	2	3	2	0	0	7
20.	*Holigarna beddomei*	0	0	0	1	0	1
21.	*Holigarna grahamii*	0	0	1	0	0	1
22.	*Hopea parviflora*	0	0	2	0	0	2
23	*Hydnocarpus macrocarpa*	2	0	0	0	0	2
24.	*Knema attenuata*	1	1	0	0	0	2
25.	*Litsea bourdillonii*	1	0	0	0	0	1
26.	*Litsea coriacea*	1	0	0	0	0	1
27	*Litsea floribunda*	1	2	1	0	0	4
28	*Litsea keralana*	2	0	0	0	0	2
29.	*Litsea laevigata*	0	1	0	0	0	1
30.	*Litsea wightiana*	1	1	0	0	0	2
31.	*Macaranga peltata*	0	1	0	0	0	1

32.	*Madhuca longifolia*	0	1	1	0	0	2
33.	*Maesa indica*	2	0	0	0	0	2
34.	*Meliosma pinnata*	0	1	0	0	0	1
35.	*Meliosma simplicifolia*	2	2	0	0	0	4
36.	*Mesua ferrea*	0	1	1	0	0	2
37.	*Nothapodytes nimmonia*	3	1	0	0	0	4
38.	*Palaquium ellipticum*	0	0	0	1	0	1
39	*Persea macarantha*	0	1	1	0	0	2
40	*Photinia integrifolia*	0	1	1	0	0	2
41.	*Prunus ceylanica*	0	1	0	0	0	1
42.	*Psychotria nigra*	1	0	0	0	0	1
43	*Psydrax dicoccos*	2	0	0	0	0	2
44.	*Schleichera oleosa*	1	2	2	0	0	5
45.	*Solenocarpus indicus*	0	1	0	0	0	1
46.	*Sterculia guttata*	0	2	2	0	0	4
47.	*Syzigium mundagam*	1	0	0	0	0	1
48	*Trichilia connaroides*	0	1	1	0	0	2
49	*Turpinia cochinchinensis*	1	1	1	0	0	3
50.	*Vateria indica*	0	0	2	1	1	4

4.1.3. Vegetation structure

4.1.3.1. Stratification

The percentage distribution of tree species occupying different storey's (<10, 10-20, >20 m) in two altitudinal zones is given in Table 5.

4.1.3.1.1. Zone I (350-900m above MSL)

In the lower elevation, 46.73 percent of the trees were present in the first storey (< 10m).The second (10-20 m), and third storey (>20 m) had 41.3 and 7.60 percent of individuals (Table 5).

4.1.3.1.2. Zone II (900-1450m above MSL)

In the higher zone, the percentage distribution of trees was highest in the first storey (69.15%) and second storey (28.97%). Third story had poor stocking (1.86 percent) (Table 5).

Table 5.Percentage distribution of individuals occupying different storey in the two altitudinal zones

Altitudinal zone	No. of Individuals (N)	Percentage distribution		
		First storey (<10m)	Second storey (`10 -20 m)	Third storey (>20m)
Lower Zone	92	46.73	41.3	7.60
Higher Zone	107	69.15	28.97	1.86

4.1.4. Diameter-frequency distribution

4.1.4.1. Zone I (350-900 above MSL)

The diameter-frequency distribution (Table 6 and Fig. 4) showed that maximum tree species individuals were mainly in three diameter classes (i.e.30-40, 40-50, and >100cm) had the highest contribution in the composition of vegetation The diameter classes of Zone I showed a reverse J shaped pattern from 50-60 cm class.

4.1.4.2. Zone II (900-1450 above MSL)

The diameter- frequency distribution (Table 7 and Fig. 4) was highest in the main three diameter classes (i.e. 50-60, 60-80, and 80-100 cm). The inverted J shaped curve is visible from 50-60 cm diameter class onwards (Fig. 2).

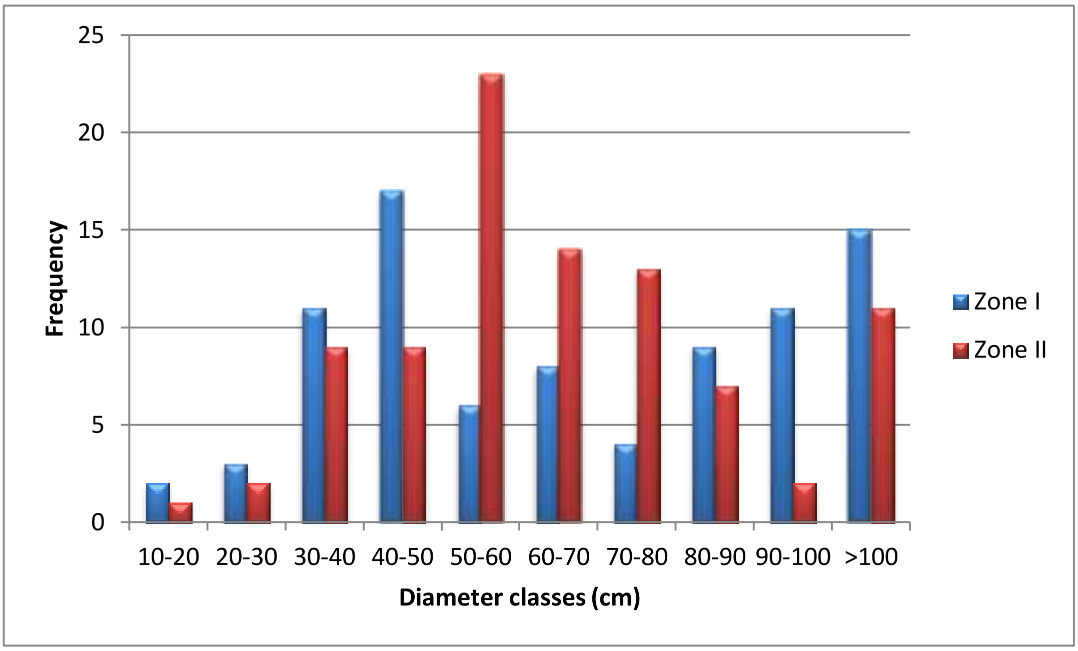


Fig.4 Diameter-Frequency distribution in two zones of Mankulam Forest Division

Table 6. Diameter- frequency distribution of tree species (>10cm GBH) in Zone I (350-900m above MSL)

Sr No.	Species	Diameter class (cm)										Total
		10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	>100	
1.	*Actinodaphne malabarica*	0	0	0	2	1	0	0	0	0	0	3
2.	*Aglaia simplicifolia*	0	0	1	1	0	0	0	0	0	0	2
3.	*Alseodaphne semecarpifolia*	0	1	2	0	0	0	0	0	0	0	2
4.	*Alstonia scholaris*	1	0	2	0	0	0	0	0	0	0	3
5.	*Aporosa cardiosperma*	0	0	1	1	0	0	0	0	0	0	2
6.	*Artocarpus hirsutus*	0	0	0	2	1	0	0	0	0	0	3
7.	*Bhesa indica*	0	0	0	0	0	0	0	0	1	1	2
8.	*Bombax ceiba*	0	0	0	0	0	0	0	0	0	1	1
9.	*Cinnamomum camphora*	0	0	0	0	1	0	0	0	0	0	1

Table 6 continued…

10.	*Cinnamomum malabatrum*	0	0	1	0	0	0	0	0	0	0	1
11.	*Clausena anisata*	0	0	1	0	0	0	0	0	0	0	1
12.	*Dysoxylum malabaricum*	0	0	0	0	0	0	1	2	3	1	7
13.	*Elaeocarpus tuberculatus*	0	0	0	0	0	2	0	1	0	0	3
14.	*Ficus hispida*	0	0	0	1	0	0	0	0	0	0	2
15.	*Ficus tsjahela*	0	0	0	0	0	0	1	0	0	0	1
16.	*Garcinia rubro- echinata*	0	0	0	0	0	1	0	0	0	0	1
17.	*Harpullia arborea*	0	0	0	0	0	0	0	1	0	0	1
18.	*Hopea parviflora*	0	0	0	1	0	0	0	0	0	0	3
19.	*Isonandra perrottetiana*	0	0	0	0	0	0	0	0	0	1	1
20.	*Knema attenuata*	0	0	0	1	1	1	0	0	0	0	3
21.	*Litsea bourdillonii*	0	0	0	0	0	0	0	0	1	1	2
22.	*Litsea floribunda*	0	0	0	1	0	0	0	0	0	0	1

Table 6 continued…

23.	*Litsea wightiana*	0	0	2	0	0	0	0	0	0	0	2
24.	*Macaranga peltata*	0	0	0	0	0	0	0	2	3	1	6
25.	*Madhuca neriifolia*	0	0	0	0	0	0	0	0	0	3	3
26.	*Magnolia nilagirica*	0	0	0	0	0	0	0	0	2	1	4
27	*Mallotus philippinensis*	0	0	0	0	0	0	3	0	0	1	4
28.	*Melicope lunu-ankenda*	0	0	0	0	0	0	0	0	1	1	2
29.	*Meliosma simplicifolia*	1	1	0	0	0	0	0	0	0	0	2
30.	*Memecylon talbotianum*	0	0	0	0	0	0	0	0	0	1	1
31	*Mesua ferrea*	0	0	0	1	0	0	0	0	0	0	1
32.	*Myristica dactyloides*	0	1	2	2	2	0	0	0	0	0	7
33.	*Palaquium ellipticum*	0	0	0	0	0	0	0	0	1	1	2
34	*Poeciloneuron indicum*	0	0	0	0	0	0	0	0	1	1	2
35	*Schleichera oleosa*	0	0	0	0	0	0	1	0	1	0	2
36.	*Spathodea campanulata*	0	0	0	0	0	0	0	1	2	0	3

Table 6 continued…

37.	*Turpenia cochinchinensis*	0	0	0	2	1	0	0	0	0	0	3
38.	*Vateria indica*	0	0	0	0	0	0	0	0	1	1	1

Table 7. Diameter- frequency distribution of tree species (>10cm GBH) in Zone II (900-1450m above MSL)

Sl No.	**Species**	**Diameter class (cm)**										**Total**
		10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	>100	
1	*Acronychia pedunculata*	0	0	0	0	0	0	0	0	0	1	1
2	*Actinodaphne bourdillonii*	0	0	1	0	1	0	0	0	0	0	3
3	*Actinodaphne hookeri*	0	0	2	1	0	0	0	0	0	0	3
4	*Alseodaphne semecarpifolia*	0	0	0	0	1	0	0	0	0	0	1
5	*Antidesma montanum*	0	0	1	0	1	0	0	0	0	0	2
6.	*Aporosa lindleyana*	0	0	0	1	1	0	0	0	0	0	2

7.	*Apollonias arnottii*	0	0	0	0	0	0	1	0	0	0	1
8.	*Calophyllum polyanthum*	0	0	0	0	1	0	0	0	0	0	1
9.	*Canarium strictum*	0	0	2	0	0	0	2	0	0	0	4
10.	*Cinnamomum malabatrum*	0	0	1	0	1	0	0	0	0	0	2
11	*Clerodendron viscosum*	1	1	0	0	1	0	0	0	0	0	3
12	*Cullenia exarillata*	0	0	0	2	2	0	0	0	0	0	4
13	*Dillenia pentagyna*	0	0	0	0	0	1	0	0	0	0	1
14.	*Dimocarpus longan*	0	0	0	0	0	0	0	0	0	1	1
15	*Dysoxylum malabaricum*	0	0	0	0	0	0	0	0	0	1	1
16	*Elaeocarpus tuberculatus*	0	0	0	0	0	0	2	0	0	1	3
17	*Elaeocarpus serratus*	0	0	0	0	0	0	0	2	0	0	2
18	*Ficus hispida*	0	0	0	1	0	0	0	0	0	0	1
19	*Gordonia obtusa*	0	1	1	2	0	3	0	0	0	0	7
20	*Holigarna beddomei*	0	0	0	0	1	0	0	0	0	0	1

Table 7 continued…

21.	*Holigarna grahamii*	0	0	0	0	1	0	0	0	0	0	1
22	*Hopea parviflora*	0	0	0	2	0	0	0	0	0	0	2
23	*Hydnocarpus macrocarpa*	0	0	0	1	0	1	0	0	0	0	2
24	*Knema attenuata*	0	0	1	0	1	0	0	0	0	0	2
25	*Litsea bourdillonii*	0	0	0	0	0	0	0	0	0	1	1
26	*Litsea coriacea*	0	0	0	0	1	0	0	0	0	0	1
27.	*Litsea floribunda*	0	0	0	2	1	1	0	0	0	0	4
28.	*Litsea keralana*	0	0	0	1	1	0	0	0	0	0	2
29.	*Litsea laevigata*	0	0	0	0	0	1	0	0	0	0	1
30.	*Litsea wightiana*	0	0	1	0	0	1	0	0	0	0	2
31	*Macaranga peltata*	0	0	0	0	0	0	0	0	0	1	1
32	*Madhuca longifolia*	0	0	0	0	0	1	1	0	0	0	2
33	*Maesa indica*	0	0	0	0	0	0	0	1	0	1	2
34	*Meliosma pinnata*	0	0	0	0	0	1	0	0	0	0	1

Table 7 continued…

35	*Meliosma simplicifolia*	0	0	0	0	0	0	1	1	1	1	4
36	*Mesua ferrea*	0	0	0	0	0	0	1	0	1	0	2
37	*Nothapodytes nimmonia*	0	0	2	0	2	0	0	0	0	0	4
38	*Palaquium ellipticum*	0	0	0	0	0	0	0	0	0	1	1
39.	*Persea macarantha*	0	0	0	1	1	0	0	0	0	0	2
40.	*Photinia integrifolia*	0	0	0	0	0	1	1	0	0	0	2
41.	*Prunus ceylanica*	0	0	0	0	1	0	0	0	0	0	1
42.	*Psychotria nigra*	0	0	0	0	0	0	1	0	0	0	1
43.	*Psydrax dicoccos*	0	0	0	0	0	1	1	0	0	0	2
44	*Schleichera oleosa*	0	0	0	0	0	2	1	2	0	0	5
45	*Solenocarpus indicus*	0	0	0	0	0	1	0	0	0	0	1
46	*Sterculia guttata*	0	0	0	0	1	2	1	0	0	0	4
47	*Syzigium mundagam*	0	0	0	0	0	0	1	0	0	0	1
48	*Trichilia connaroides*	0	0	0	0	0	1	0	0	0	1	2

Table 7 continued

49	*Turpinia cochinchinensis*	0	0	0	2	0	0	1	0	0	0	3
50	*Vateria indica*	0	0	0	0	0	0	0	1	1	2	4

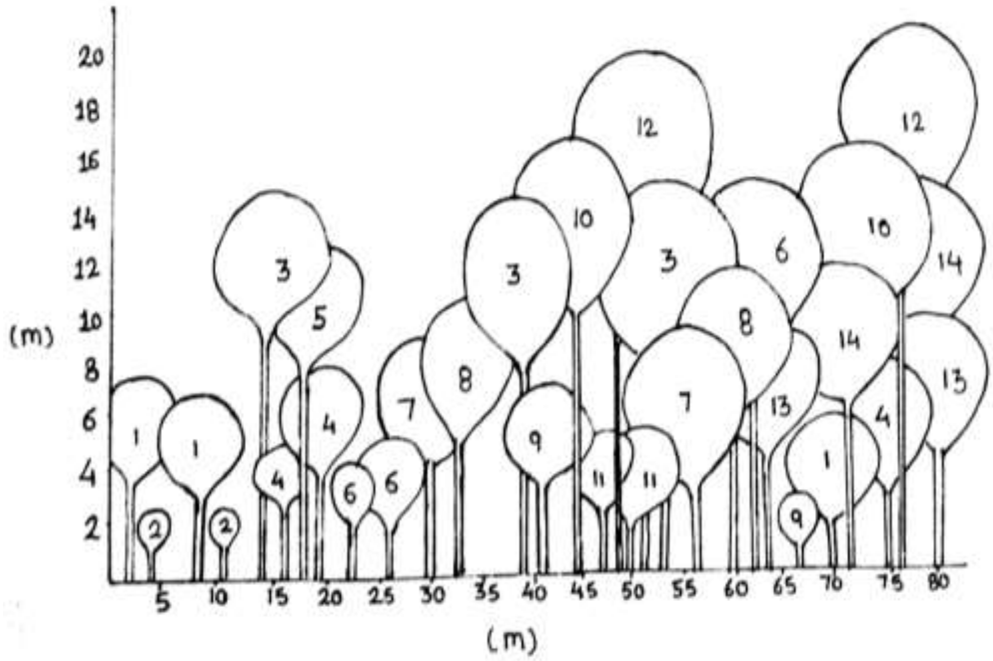


Fig. 5 Profile diagram of Zone I (350-900 m above MSL)

1. *Aporosa cardiosperma* 2. *Meliosma simplicifolia* 3.*Litsea bourdillonii*

4.*Ficus hispida* 5. *Knema attenuata* 6.*Actinodaphne malabarica* 7.*Clausena anisata*

8. *Elaeocarpus tuberculatus* 9.*Alstonia scholaris* 10. *Dysoxylum malabaricum*

11.*Madhuca neriifolia* 12.*Hopea parviflora* 13.*Alseodaphne semecarpifolia*

14.*Litsea wightiana*

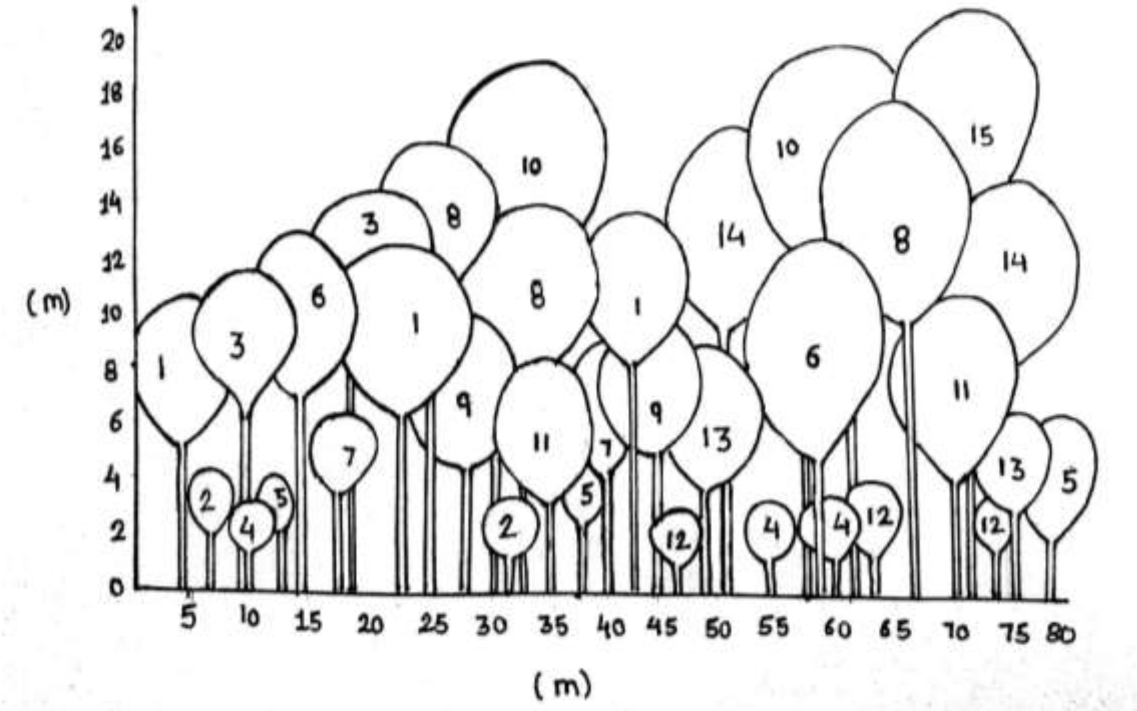


Fig. 6 Profile diagram of Zone II (900-1450 m above MSL)

1. *Mesua ferrea 2.Psychotria nigra 3.Vateria indica 4. Actinodaphne bourdillonii*

5. Litsea keralana 6.Hopea parviflora 7.Gordonia obtusa 8.Calophyllum polyanthum

9. Elaeocarpus tuberculatus 10.Canarium strictum 11.Meliosma simplicifolia

12.Clerodendendron viscosum 13. Turpinia cochinchinensis 14. Madhuca longifolia

15. Palaquium ellipticum

4.1.4. Profile diagram

Profile diagrams of representative 10 m× 80 m strips of the two altitudinal zones are shown in Fig. 5-6.

4.1.5.1. Zone I (350-900 m above MSL)

The profile diagram of lower zone was shown in Fig. 5.Three different strata were recorded. First stratum consists of species like *Meliosma simplicifolia, Aporosa cardiosperma, Actinodaphne malabarica, Ficus hispida, Alstonia scholaris and Madhuca neriifolia*. Majority of the species occupied the second stratum with dominant ones were *Litsea bourdillonii, Elaeocarpues tuberculatus* and *Alseodaphne semecarpifolia.Hopea parviflora* and *Dysoxylum malabaricum* were the prominent species in third stratum.

4.1.5.2. Zone II (900-1450 m above MSL)

Fig. 6 represents the profile diagram of higher zone. A comparatively denser crown was observed and the canopy was also closed. Three different strata were observed .*Psychotria nigra, Litsea keralana, Clerodendron viscosum* and *Actinodaphne bourdilonii* were the main dominant trees in lower storey. *Gordonia obtusa, Elaeocarpus tuberculatus and Turpinia cochinchinensis* were the main prominent species of middle strata. Third stratum consists of tree species like *Canarium strictum* and *Palaquium ellipticum*.

4.1.5. Phytosociological analysis

Abundance, density, and relative density of tree species (>10cm GBH) in the two altitudinal zones i.e. Zone I and Zone II were calculated (Table 8).

4.1.6.1. Zone I (350-900 above MSL)

Myristica dactyloides recorded the highest abundance of 2.33 individuals per quadrat and was observed in most of the quadrats. A total of 38 species having a density of 613 individual's ha^{-1} was reported from the sampled area (Table 8). *Myristica dactyloides* and *Dysoxylum malabaricum* recorded the highest density of 47 individuals per hectare, followed by *Macaranga peltata* with 40 individual's ha^{-1}. Relative densities were also recorded highest of *Myristica dactyloides* and *Dysoxylum malabaricum* followed by *Macaranga peltata* with 7.61% and 6.896% respectively.

Dysoxylum malabaricum and *Macaranga peltata* recorded the highest frequency of 0.33. The percentage frequencies of 22 tree species out of total 38 tree species enumerated were found to be more than 13. In terms of relative frequencies *Dysoxylum malabaricum* and *Macaranga peltata* were recorded highest with values 7.143 percent.

The total basal area of tree species in lower zone is around 20.31 m^2 of which 33.94% and 18.02% were accounted for two tree species *viz.*, *Dysoxylum malabaricum* and *Michelia nilagirica* (Table 8). Out of total 37 tree species around 6 tree species have a relative basal area more than 6 percent.

In zone I, *Dysoxylum malabaricum* was observed to be the dominant species with IVI of 34.85 followed by *Macaranga peltata* (16.65). The majority of the tree species had IVI below 10. Table 8 shows that 84.21 % of the tree species in the enumerated area of lower zone had IVI less than 10.

4.1.6.2 Zone II (900-1450 above MSL)

The abundance and density of all species from the Zone 2 were 67.09 and 713.33 individual's ha^{-1} respectively. Among the 50 species present *Gordonia* *obtusa* and *Schleichera oleosa* recorded the highest densities with 46 and 33 individuals per hectare respectively**.** These two species *Gordonia obtusa* and *Schleichera oleosa* accounted for 6.54 and 4.672 percent of relative densities while all other had valued less than 4.

Gordonia obtusa and *Schleichera oleosa* were observed with the highest frequency as 0.266 in Zone 2. The percentage frequencies of around 23 tree species out of 51 tree species were found to be more than 13. The relative frequencies of *Gordonia obtusa* and *Schleichera oleosa* were recorded highest with values 4.878 percent.

In comparison to lower zone there was a significant decline in the total basal area in higher zone.The total basal area of higher zone was recorded to be 12.31 m^2. The highest relative basal area was observed in *Vateria indica* as 16.69% followed by *Meliosma simplicifolia* as 8.85% (Table 9).

Vateria indica dominates the vegetation with an IVI of 24.09 followed by *Gordonia obtusa* (19.39) and *Meliosma simplicifolia* (16.25). Table 10 shows that 82.35 % of the tree species in the enumerated area of higher zone had IVI less than 10.

Table 8. Phytosociological analysis of tree species (>10 cm GBH) in Zone I (350- 900m above MSL)

SI No.	Species	Abundance (A)	D (individuals/ha)	RD (%)	F (%)	PF	RF (%)	BA (m^2)	RBA (%)	IVI	RIVI
1.	*Actinodaphne malabarica*	1.5	20	3.26	0.13	13.33	2.85	0.11	0.54	6.65	2.22
2.	*Aglaia simplicifolia*	1	13.33	2.17	0.13	13.33	2.85	0.04	0.22	5.25	1.75
3.	*Alseodaphne semecarpifolia*	1	13.33	2.17	0.13	13.33	2.85	0.03	0.15	5.18	1.73
4.	*Alstonia scholaris*	1	20	3.26	0.2	20	4.28	0.03	0.17	7.72	2.57
5.	*Aporosa cardiosperma*	2	13.33	2.17	0.06	6.66	1.42	0.05	0.25	3.85	1.28
6.	*Artocarpus hirsutus*	1	20	3.26	0.13	13.33	2.85	0.15	0.71	6.83	2.28
7.	*Bhesa indica*	1	13.33	2.17	0.13	13.33	2.85	0.62	3.07	8.10	2.70
8.	*Bombax ceiba*	1	6.67	1.08	0.06	6.66	1.42	2.11	10.40	12.91	4.30
9.	*Cinnamomum camphora*	1	6.67	1.08	0.06	6.66	1.42	0.03	0.16	2.68	0.89

Abundance (A), Density (D), and Relative Density (RD), Frequency (F),Percent frequency (PF), Relative frequency (RF), Basal Area (BA), Relative Basal Area (RBA)

Table 8 continued…

10.	*Cinnamomum malabatrum*	1	6.67	1.08	0.06	6.66	1.428	0.01	0.06	2.58	0.86
11.	*Clausena anisata*	1	6.67	1.08	0.06	6.66	1.42	0.01	0.04	2.56	0.85
12.	*Dysoxylum malabaricum*	1.4	46.67	7.61	0.33	33.33	7.14	4.08	20.10	34.85	11.62
13.	*Elaeocarpus tuberculatus*	1.5	20	3.26	0.13	13.33	2.85	0.34	1.70	7.881	2.60
14.	*Ficus hispida*	1	13.33	2.17	0.13	13.33	2.85	0.06	0.28	5.31	1.77
15	*Ficus tsjahela*	11	6.67	1.08	0.06	6.66	1.42	0.04	0.22	2.74	0.91
16.	*Garcinia rubro- echinata*	1	6.67	1.08	0.06	6.66	1.42	0.03	0.17	2.68	0.89
17.	*Harpullia arborea*	1	6.67	1.08	0.06	6.66	1.42	0.02	0.10	2.62	0.87
18.	*Hopea parviflora*	1.5	20	3.26	0.13	13.33	2.85	0.11	0.52	6.64	2.21
19.	*Isonandra perrottetiana*	1	6.67	1.08	0.06	6.66	1.42	0.17	0.84	3.35	1.12
20.	*Knema attenuata*	1.5	20	3.26	0.13	13.33	2.85	0.22	1.07	7.19	2.40
21.	*Litsea bourdillonii*	2	13.33	2.17	0.06	6.66	1.42	1.27	6.27	9.87	3.29
22.	*Litsea floribunda*	1	6.67	1.08	0.06	6.66	1.42	0.01	0.06	2.58	0.86
23.	*Litsea wightiana*	1	13.33	2.17	0.13	13.33	2.85	0.11	0.53	5.56	1.85

Table 8 continued…

24.	*Macaranga peltata*	1.2	40	6.52	0.33	33.33	7.14	0.61	2.99	16.65	5.55
25.	*Madhuca neriifolia*	3	20	3.26	0.06	6.66	1.42	0.75	3.69	8.38	2.79
26.	*Magnolia nilagirica*	1.34	26.67	4.34	0.2	20	4.28	2.33	11.47	20.11	6.70
27.	*Mallotus philippensis*	1.34	26.67	4.34	0.2	20	4.28	1.39	6.85	15.48	5.16
28.	*Melicope lunu-ankenda*	2	13.33	2.17	0.06	6.66	1.42	0.26	1.28	4.89	1.63
29.	*Meliosma simplicifolia*	1	13.33	2.17	0.13	13.33	2.85	0.02	0.08	5.11	1.70
30.	*Memecylon talbotianum*	1	6.67	1.08	0.06	6.66	1.42	1.36	6.69	9.20	3.07
31.	*Mesua ferrea*	1	6.67	1.08	0.06	6.66	0.14	0.01	0.06	2.58	0.86
32.	*Myristica dactyloides*	2.33	46.67	7.61	0.2	20	4.28	0.60	2.94	14.84	4.95
33.	*Pallaqum ellipticum*	2	13.33	2.17	0.06	6.66	0.14	0.89	4.40	8	2.67
34.	*Poeciloneuron indicum*	1	13.33	2.17	0.13	13.33	2.85	0.71	3.48	8.51	2.84
35.	*Schleichera oleosa*	1	13.33	2.17	0.13	13.33	2.85	0.22	1.07	6.10	2.03
36.	*Spathodea companulata*	1.5	20	3.26	0.13	13.33	2.85	0.55	2.73	8.85	2.95
37.	*Turpenia cochinchinensis*	1	20	3.26	0.133	13.33	2.857	0.16	0.78	6.90	2.30

Table 8 continued…

38.	*Vateria indica*	1	13.33	2.17	0.133	13.33	2.857	0.79	3.87	8.90	2.97
	Total	**49.11**	**613.33**	**100**		**466.66**	**99.99**	**20.3**	**100**	**300**	**100**

Table 9. Phytosociological analysis of tree species (>10 cm GBH) in zone II (900-1450m above MSL)

SI No	**Species**	**Abundance**	**Density (Individuals per ha)**	**RD (%)**	**F (%)**	**PF**	**RF (%)**	**BA (m^2)**	**RBA (%)**	**IVI**	**RIVI**
1.	*Acronychia pedunculata*	1	6.67	0.93	0.06	6.66	1.219	0.1	0.84	2.99	1.00
2.	*Actinodaphne bourdillonii*	1.5	20	2.80	0.13	13.33	2.439	0.11	0.87	6.11	2.04
3.	*Actinodaphne hookeri*	1.5	20	2.80	0.13	13.33	2.439	0.10	0.83	6.07	2.02

Abundance (A), Density (D), and Relative Density (RD), Frequency (F),Percent frequency (PF), Relative frequency (RF), Basal Area (BA), Relative Basal Area (RBA)

Table 9 continued…

4.	*Alseodaphne semecarpifolia*	1	6.67	0.93	0.06	6.66	1.219	0.03	0.23	2.38	0.79
5.	*Antidesma montanum*	2	13.33	1.86	0.066	6.66	1.219	0.06	0.46	3.55	1.18
7.	*Apollonias arnotii*	1	6.67	0.934	0.066	6.66	1.219	0.04	0.36	2.52	0.84
8.	*Calophyllum polyanthum*	1	6.67	0.93	0.06	6.66	1.219	0.02	0.20	2.35	0.78
9.	*Canarium strictum*	1.34	26.66	3.73	0.2	20	3.658	0.42	3.45	10.85	3.62
10.	*Cinnamomum malabatrum*	1	13.33	1.86	0.13	13.333	2.439	0.07	0.55	4.86	1.62
11.	*Clerodendron viscosum*	1.5	20	2.80	0.13	13.333	2.439	0.07	0.57	5.81	1.94
12.	*Cullenia exarillata*	2	26.66	3.73	0.13	13.333	2.439	0.32	2.59	8.76	2.92

Table 9 continued…

13.	*Dillenia pentagyna*	1	6.66	0.93	0.06	6.666	1.219	0.03	0.24	2.39	0.80
14.	*Dimocarpus longan*	1	6.66	0.93	0.06	6.666	1.219	0.11	0.93	3.09	1.03
15.	*Dysoxylum purpureum*	1	6.66	0.93	0.06	6.66	1.219	0.35	2.85	5.01	1.67
16.	*Elaeocarpus tuberculatus*	1.25	20	2.80	0.26	26.66	4.878	0.52	4.24	11.92	3.97
17.	*Elaeocarpus serratus*	1	13.33	1.86	0.13	13.33	2.439	0.22	1.80	6.11	2.04
18.	*Ficus hispida*	1	6.67	0.93	0.06	6.66	1.219	0.02	0.13	2.29	0.76
19.	*Gordonia obtusa*	1.75	46.66	6.54	0.26	26.66	4.878	0.98	7.97	19.39	6.46
20.	*Holigarna beddomei*	1	6.67	0.93	0.06	6.66	1.219	0.02	0.19	2.34	0.78

Table 9 continued…

21.	*Holigarna grahamii*	1	6.67	0.93	0.06	6.66	1.219	0.02	0.17	2.33	0.78
22.	*Hopea parviflora*	1	13.33	1.86	0.13	13.33	2.439	0.02	0.16	4.46	1.49
23.	*Hydnocarpus pentandrus*	2	13.33	1.86	0.06	6.66	1.219	0.09	0.70	3.79	1.26
24.	*Knema attenuata*	2	13.33	1.86	0.13	13.33	2.857	0.07	0.55	3.64	1.21
25.	*Litsea bourdillonii*	1	6.67	0.93	0.06	6.66	1.219	0.29	2.38	4.54	1.51
26	*Litsea coriacea*	1	6.67	0.93	0.06	6.66	1.219	0.03	0.21	2.37	0.79
27.	*Litsea floribunda*	2	26.66	3.73	0.13	13.33	2.439	0.32	2.59	8.76	2.92
28.	*Litsea keralana*	1	13.33	1.86	0.13	13.33	2.439	0.07	0.61	4.92	1.64

Table 9 continued…

29.	*Litsea laevigata*	1	6.67	0.93	0.06	6.66	1.21 9	0.03	0.24	2.39	0.8
30.	*Litsea wightiana*	2	13.33	1.86	0.06	6.66	1.21	0.09	0.74	3.83	1.28
31.	*Macaranga peltata*	1	6.67	0.93	0.06	6.66	1.21	0.20	1.66	3.81	1.27
32.	*Madhuca longifolia*	2	13.33	1.86	0.06	6.66	1.21	0.15	1.23	4.32	1.44
33.	*Maesa indica*	2	13.33	1.86	0.06	6.66	1.21	0.58	4.68	7.77	2.59
34.	*Meliosma pinnata*	1	6.67	0.93	0.06	6.66	1.21	0.03	0.26	2.41	0.80
35.	*Meliosma simplicifolia*	1.33	26.66	3.73	0.2	20	3.65	1.09	8.85	16.25	5.42
36.	*Mesua ferrea*	1	13.33	1.86	0.13	13.33	2.43	0.19	1.55	5.86	1.95
37.	*Nothapodytes nimmonia*	2	26.66	3.73	0.13	13.33	2.43	0.07	0.58	6.76	2.25
38.	*Palaquium ellipticum*	1	6.67	0.93	0.06	6.66	1.21	0.54	4.37	6.53	2.18
39.	*Persea macarantha*	1	13.33	1.86	0.13	13.333	2.43	0.08	0.66	4.97	1.66
40.	*Photinia integrifolia*	2	13.33	1.86	0.06	6.666	1.21	0.15	1.18	4.27	1.42
41.	*Prunus ceylanica*	1	6.67	0.93	0.06	6.66	1.21	0.02	0.20	2.40	2.35

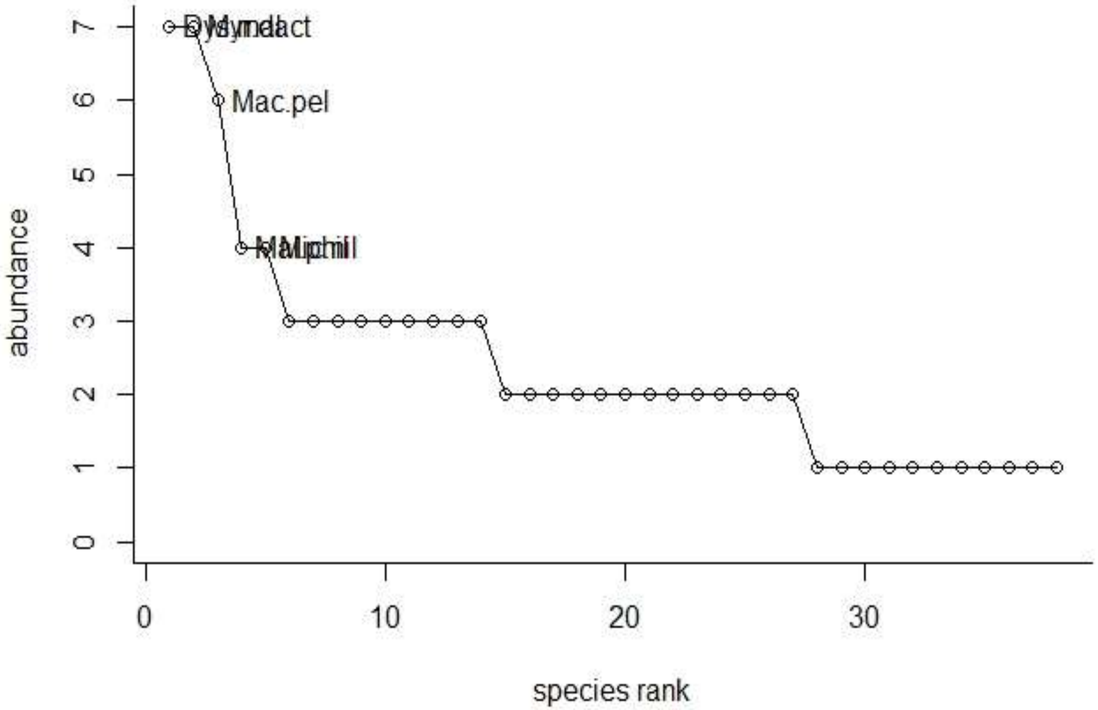
Table 9 continued…

42.	*Psychotria nigra*	1	6.67	0.93	0.06	6.66	1.21	0.03	0.25	2.40	0.80
43.	*Psydrax dicoccos*	2	13.33	1.86	0.13	13.33	2.43 9	0.15	1.23	5.54	1.85
44.	*Schleichera oleosa*	1.25	33.33	4.67	0.26	26.66	4.87	0.64	5.22	14.77	4.92
45.	*Solenocarpus indicus*	1	6.67	0.93	0.06	6.666	1.21	0.03	0.28	2.44	0.81
46.	*Sterculia guttata*	1.33	26.66	3.73	0.2	20	3.65	0.5	4.07	11.47	3.82
47.	*Syzigium mundagam*	1	6.67	0.93	0.06	6.66	1.21	0.05	0.39	2.55	0.85
48.	*Trichilia connaroides*	2	13.33	1.86	0.13	13.33	2.43	0.82	6.62	10.93	3.64
49.	*Turpinia cochinchinensis*	3	20	2.80	0.06	6.66	1.21	0.22	1.8	5.83	1.94
50.	*Vateria indica*	1.33	26.66	3.73	0.2	20	3.65	2.05	16.69	24.09	8.03
	Total	**67.09**	**713.33**	**100**		**546.6**	**99.9 9**	**12.3 1**	**99.99**	**299.9**	**100**

4.1.6. Rank-abundance curve

Rank abundance curve was calculated for around 38 tree species recorded in the zone I (350-900 above MSL). *Dysoxylum malabaricum* secured rank 1 as this species had the largest abundance (7).*Cinnamomum camphora* was ranked 38 as the species had the lowest total abundance. Figure 7 shows the rank-abundance curve for all of the 38 tree species identified in zone I.

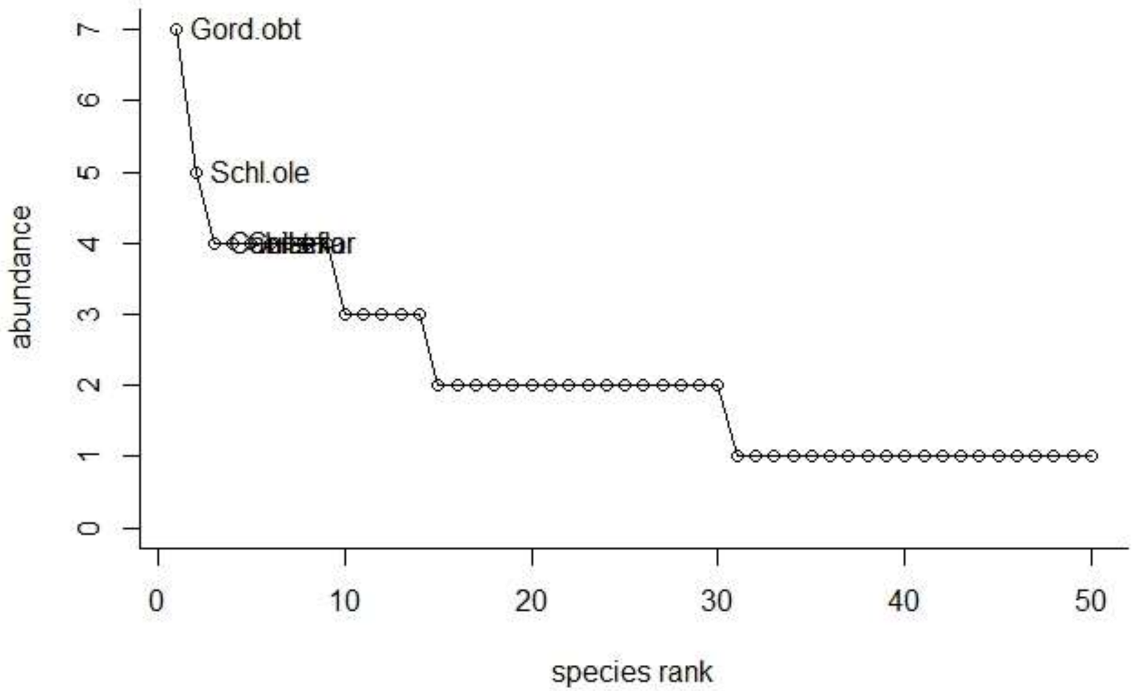
Figure 8 shows the rank-abundance curve for all of the 50 tree species identified in zone II (900 -1450m above MSL).*Gordonia obtusa* secured rank 1 as this species had the largest abundance (7).*Psychotria nigra* was ranked as 50 since this species had the lowest total abundance



1. Dys. mal. *Dysoxylum malabaricum*
2. Myr dac. *Myristica dactyloides*
3. Mac. pel. *Macaranga peltata*
4. Mal. phil. Mallotus philippensis
5. Mic. nil. *Michelia nilagirica*

38. *Cinnamomum camphora*

Fig. 7 Rank-abundance curve for the Zone I (350-900 above MSL)



1. Gord. obt. *Gordonia obtusa*
2. *Sch.oleo* *Schleichera oleosa*
3. *Can. Str.* *Canarium strictum*
4. *Cul. Exa. Cullenia exarillata*

50. Psy. nig. Psychotria nigra

Fig. 8 Rank abundance curve for the Zone II (900-1450 above MSL)

4.1.7. Floristic diversity (>10cm GBH)

Floristic diversity indices for the two altitudinal zones are given in Table 10.A total of 92 individuals (>10cm GBH) of 38 tree species was recorded in lower zone whereas, around 107 individuals (>10cm GBH) of 50 tree species were observed in higher zone. The Concentration of dominance C_d (Simpson index) values were lowest (0.96) in lower zone and was comparatively higher in higher zone (0.97) (Table 10, Fig. 9) .The Shannon-Wiener index value in the study area ranged from 3.47 in the lower elevation to 3.74 in upper elevation (Table 10, Fig. 9).The Pielou's index of Evenness value was observed to be lowest (0.953) in the lower altitude compared to the upper elevation (0.957) (Table 10, Fig. 9).

Table10. Floristic diversity indices for the tree vegetation of two altitudinal zones

Altitudinal Zone	Area (Ha)	No. of Tree Species	No. of individuals (N)	Simpson index	Shannon-Wieners index	Pielou's index of evenness
Zone I	0.15	38	92	0.96	3.47	0.953
Zone II	0.15	50	107	0.97	3.74	0.957

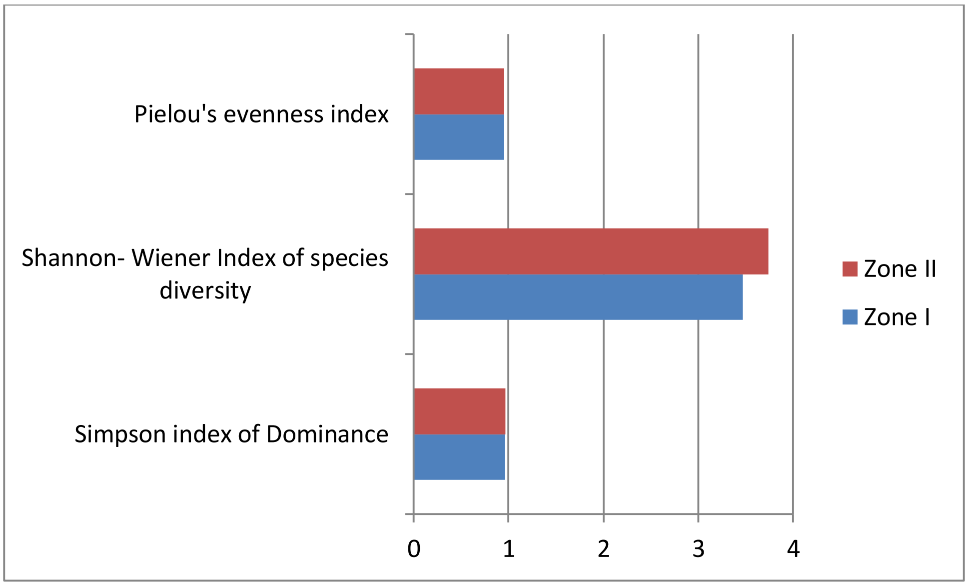


Fig. 9 Floristic diversity indices of tree vegetation in two altitudinal zone

4.2 Soil studies

4.2.1. Physico- chemical properties of soil

4.2.1.1. Soil Bulk density

The soil bulk density (BD) of zone I was observed to be highest in (20-40 cm) soil layer of site S10 as 1.33g cm^{-3} and lowest in surface layer (0-20 cm) of site S 14 as 0.77 g cm^{-3} (Table 11).In zone II (900-1450 above MSL) highest value was recorded in (20-40cm) soil layer of site S8 as 1.34 g cm^{-3} and lowest in top layer (0-20 cm) site S6 as 0.71 g cm^{-3} (Table 11).The analysis by independent sample t-test of bulk density revealed that the mean values of bulk density between two depths in each elevation did not differ significantly. Similarly, the variation in mean values between two elevations in each depth was also observed to be non-significant. The depth-wise and elevation wise variations of bulk density (dry weight) are represented in Table 11.

Table11. Bulk density (dry weight) (g cm^{-3}) at two depths and in two different elevation zones

Two depth in each elevation				
	Bulk Density (g cm^{-3}) (Mean± SE)		t- value	p-value
Zone	0-20	20-40		
Zone I	0.97 ± 0.03	1.05±0.04	-1.942	0.147*
Zone II	0.92 ± 0.03	0.98±0.04	-1.152	0.259*
Two elevation in each depth				
	Bulk Density (g cm^{-3}) (Mean± SE)		t-value	p-value
Soil depth	Zone I	Zone II		
0-20	0.97±0.03	0.92±0.03	1.138	0.265*
20-40	1.05±0.04	0.98±0.04	1.166	0.254*
SE- Standard error *indicate non-significant at 5% level **indicate significant at 5% level				

4.2.1.2. Soil pH

The soil pH in both altitudinal zones was observed as acidic soil. In zone I (350-900m asl) the ultra acidic (<3.5) soil was observed in lower layer (20-40 cm) in site S9 as 3.46, Majority of the soil pH value range lies under range of extremely acid (<3.5-4.5) in lower zone .However, Very Strong Acid (4.5-5.0) was the main prominent pH range recorded in higher zone (Table 14). The analysis by independent sample t-test of soil pH revealed that the mean values of soil pH between two depths in each elevation was not significantly different with mean values ranged from 4.53- 4.78. Similarly, the mean value of soil pH in each soil depth was not found to vary significantly with change in elevation were also observed to be non-significant. The depth-wise and elevation wise variations of soil pH are represented in Table 12.

Table12. Soil pH at two depths and in two different elevation zones

Two depth in each elevation				
	Soil pH (Mean± SE)		t- value	p-value
Zone	0-20	20-40		
Zone I	4.53±0.138	4.6±0.183	-0.321*	0.751*
Zone II	4.78±0.147	4.63±0.107	0.795*	0.433*
Two elevation in each depth				
	Soil pH (Mean± SE)		t-value	p-value
Soil depth	Zone I	Zone II		
0-20	4.53±0.138	4.78±0.147	-1.235*	0.227*
20-40	4.61±0.183	4.63±0.107	-0.145*	0.886*
SE- Standard error *indicate non-significant at 5% level **indicate significant at 5% level				

4.2.1.3. Electrical Conductivity

The soil electrical conductivity (EC) (dS m^{-1}) in Zone I (350-900 above MSL) was observed to be highest in top layer (0-20 cm) in site S7 as 1.82 dS/m and lowest in deeper soil layer (20-40 cm) i.e. S9 as 0.30 dS/m. In Zone II (900-1450 above MSL) the highest was observed in upper layer (0-20 cm) in site S6 as 1.21 dS/m and lowest in deeper layer (20-40 cm) in lower layer S10 as 0.19 (Table 14).The analysis by independent sample t-test of soil electrical conductivity revealed that the mean values of electrical conductivity between two depths in each elevation did not vary signifantly and the value ranged from 0.53-

0.91. Similarly, the t-test between two elevations in each depth was also observed to be non-significant. The independent t-test depth-wise and elevation wise variations of soil electrical conductivity are represented in Table 13.

Table13. Soil Electrical Conductivity (d S m^{-1}) at two depths and in two different elevation zones

Two depth in each elevation				
	Soil EC (dS/m) (Mean± SE)		t- value	p-value
Zone	0-20	20-40		
Zone I	0.91±0.08	0.63±0.05	2.56**	0.016**
Zone II	0.68±0.06	0.53±0.05	1.85*	0.075*
Two elevation in each depth				
	Soil EC (dS/m) (Mean ± SE)		t-value	p-value
Soil depth	Zone I	Zone II		
0-20	0.91±0.08	0.68±0.06	-2.061*	0.049**
20-40	0.63±0.05	0.53±0.05	-1.29*	0.207*
SE- Standard error *indicate non-significant at 5% level **indicate significant at 5% level				

Table 14. Physico-chemical properties of soil in different elevation zone

Sites	Zone I						Zone II					
	BD		pH		EC		BD		pH		EC	
	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
S1	0.94	1.055	5.1	5.36	0.58	0.76	1.00	1.28	4.2	4.5	0.80	0.75
S2	1.02	1.05	4.87	4.9	1.15	0.67	0.80	0.76	4.9	4.98	0.45	0.47
S3	0.88	0.99	3.5	3.21	0.76	0.75	1.02	1.08	4.78	4.74	0.47	0.34
S4	1.11	1.17	4.37	4.18	0.68	0.54	0.88	0.97	4.81	4.52	0.32	0.27
S5	0.89	0.97	5.16	5.44	1.21	0.46	1.06	1.13	5.38	4.87	0.61	0.50
S6	0.96	1.01	4.58	4.39	0.85	0.41	0.71	0.76	4.16	4.3	1.21	0.288
S7	1.13	1.30	4.21	4.25	1.82	1.11	0.92	0.96	4.38	4.18	0.78	0.65
S8	1.17	1.29	4.34	4.35	0.91	0.76	1.06	1.34	5.76	4.98	0.56	0.54
S9	0.85	0.87	3.67	3.46	0.66	0.30	0.86	0.95	4.41	4.58	0.82	0.97
S10	1.21	1.33	4.33	4.72	0.81	0.35	0.97	0.99	5.41	5.59	0.57	0.19
S11	0.80	0.86	5.57	5.98	1.28	0.88	1.014	0.99	3.98	4.12	0.85	0.51

Table 14 continued…

S12	0.92	0.95	4.82	4.56	0.98	0.84	1.118	1.06	4.21	3.91	0.50	0.58
S13	0.84	0.86	4.43	4.87	0.68	0.54	0.84	0.87	4.55	4.78	0.42	0.45
S14	0.77	0.95	4.59	4.58	0.72	0.55	0.77	0.83	5.41	4.62	0.91	0.82
S15	1.07	1.15	4.43	4.84	0.43	0.49	0.71	0.73	5.38	4.87	0.87	0.55

4.2.1.4. Soil Organic Carbon

The Soil organic carbon (C) (%) in zone I (350-900m above MSL) ranged from 0.94% in site S10 (20-40 cm) soil layer to 6.47% in site S15 (0-20 cm) soil layer (Table17).In zone II (900-1450m above MSL) the soil organic carbon value range between 0.94% in site S4 (20-40 cm) soil layer to 8.76 % in site S15 in (0-20 cm) soil layer (Table 17).The soil organic carbon was recorded high (>1.5%) in both elevation zones. The analysis by independent sample t test of soil organic carbon revealed that variation in mean values of organic carbon between two depths in each elevation was observed to non significant .Similarly, the mean values of organic carbon between two elevations in each depth did not differ significantly with mean value ranged from 3.23-5.09. The independent t-test depth wise and elevation wise variations of Soil organic carbon are represented in Table 15.

Table15. Soil Organic Carbon (%) at two depths and in two different elevation zone

Two depth in each elevation				
	Soil Organic Carbon (%) (Mean± SE)		t- value	p-value
Zone	0-20	20-40		
Zone I	3.84±0.34	3.23±0.39	1.17*	0.25*
Zone II	5.09±0.63	4.18±0.62	1.03*	0.311*
Two elevation in each depth				
	Soil Organic Carbon (%) (Mean± SE)		t-value	p-value
Soil depth	Zone I	Zone II		
0-20	3.84±0.34	5.09±0.63	-1.75*	0.93*
20-40	3.23±0.39	4.18±0.62	-1.29*	0.21*

SE- Standard error

*indicate non-significant at 5% level **indicate significant at 5% level

4.2.1.5. Soil Total Nitrogen

The Soil total nitrogen (N) (%) registered in zone I (350-900 m above MSL) ranged between 0.012% in S4 (20-40 cm) soil layer to 0.33% in S14 (0-20 cm) soil layer (Table 17). In zone II (900-1450m above MSL) the value ranged between 0.07% in S10 (20-40 cm) to 0.39 %in site S15 (0-20 cm) soil layer (Table 17).The analysis independent sample t-test of soil total nitrogen revealed that the mean values of total nitrogen between two depths in each elevation did not differ significantly with value ranged from 0.11-0.22. Similarly, the mean values between two elevations in each depth were found to be non-significant.

The independent t-test depth-wise and elevation wise variations of Soil Total Nitrogen are represented in Table 16.

Table 16. Soil Total Nitrogen (%) at two depths and in two different elevation zones

Two depth in each elevation				
	Soil Total Nitrogen (%) (Mean± SE)		t- value	p-value
Zone	0-20	20-40		
Zone II	0.13±0.018	0.11±0.01	0.87*	0.38*
Zone II	0.22±0.02	0.18±0.02	1.41*	0.26*
Two elevation in each depth				
	Soil Total Nitrogen (%) (Mean± SE)		t-value	p-value
Soil Depth	Zone I	Zone II		
0-20	0.13±0.02	0.22±0.02	-3.07**	0.005**
20-40	0.11±0.01	0.18±0.02	-2.96**	0.006**
SE- Standard error *indicate non-significant at 5% **indicate significant at 5% level				

Table 17. Chemical properties of soil in different elevation zone

Sites	Zone I				Zone II			
	C		N		C		N	
	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
S1	3.07	2.6	0.09	0.08	2.21	1.82	0.16	0.15
S2	4.57	3.94	0.15	0.11	3.15	2.44	0.17	0.12
S3	5.84	5.28	0.15	0.06	2.52	2.05	0.14	0.13
S4	2.52	1.42	0.012	0.010	2.10	0.94	0.20	0.19
S5	3.78	2.68	0.11	0.105	7.57	6.63	0.13	0.13
S6	2.84	1.65	0.08	0.079	8.36	7.97	0.33	0.30
S7	3.47	3.07	0.09	0.075	6.94	4.5	0.35	0.16
S8	3.39	3	0.06	0.046	6.64	5.21	0.16	0.12
S9	4.73	4.02	0.15	0.13	2.84	2.68	0.16	0.15
S10	2.13	0.94	0.06	0.05	2.52	1.73	0.08	0.07
S11	2.28	1.57	0.15	0.11	5.21	4.57	0.19	0.17
S12	3.39	3.78	0.14	0.12	5.68	4.82	0.23	0.20
S13	3.55	3.315	0.147	0.13	4.34	2.36	0.25	0.23
S14	5.6	5.05	0.33	0.30	7.29	6.71	0.37	0.32
S15	6.47	6.15	0.18	0.17	8.76	8.36	0.39	0.34

4.2.2.6. Soil Available Phosphorus

The soil available Phosphorus (P) (kg ha^{-1}) registered in Zone I (350-900 m above MSL) ranged between 11.64kg ha^{-1} in site S4 (20-40 cm) soil layer to 314.24 kg ha^{-1} in S2 (0-20 cm) soil layer (Table 21). In Zone II (900-1450 m above MSL) the value ranged between 4.36 kg ha^{-1} in S2 (20-40 cm) to 1098.49 kg ha^{-1} in site S4 (0-20 cm) soil layer (Table 21).The soil available phosphorus value of both elevation zones was reported high (>24 kg ha^{-1}). The analysis by independent sample t-test of soil Available Phosphorus revealed that the mean values between two depths in each elevation was observed to non significant. Whereas, the mean values between two elevations in each depth was found to be significant with values ranged with mean value ranged from 65.31-320.43.The independent t-test depth wise and elevation wise variations of soil available phosphorus are represented in Table 18.

Table 18. Soil Available Phosphorus (kg ha^{-1}) at two depths and in two different elevation zones

Two depth in each elevation				
	Soil Available Phosphorus (kg ha^{-1}) (Mean± SE)		t- value	p-value
	0-20	20-40		
Zone I	97.93±23.17	65.31±19.38	1.08*	0.28*
Zone II	320.43±88.09	202.48±65.89	1.072*	0.293*
Two elevation in each depth				
	Soil Available Phosphorus (kg ha^{-1}) (Mean± SE)		t-value	p-value
	Zone I	Zone II		
0-20	97.93±23.17	320.43±88.09	-2.44**	0.027**
20-40	65.31±19.38	202.48±65.89	-1.99*	0.063*
SE- Standard error *indicate non-significant at 5% level **indicate significant at 5% level				

4.2.2.7. Soil Available Potassium

The Soil available potassium (K) (kg ha^{-1}) registered in Zone I (350-900m asl) ranged between 467.64 kg ha^{-1} in site S6 (20-40 cm) soil layer to 1057.20 kg ha^{-1} in S15 (0-20 cm) soil layer. In Zone II (900-1450m asl) the value ranged between 398.24 kg ha^{-1} in S5 (20-40 cm) to 1628.48 kg ha^{-1} in site S15 (0-20 cm) soil layer (Table 21). The soil available potassium of both elevation zones was recorded high (>275 kg ha^{-1}) (TNAU, 2016).The analysis by independent sample t-test of soil Available Potassium revealed that the mean values between two depths in each elevation was observed to non-significant.Whereas, the t-test between two elevations in each depth was found to be significant with mean value ranged from 778.84 - 990.48. The independent t-test depth wise and elevation wise variations of soil available potassium are represented in Table 19.

Table 19. Soil Available Potassium (kg ha^{-1}) at two depths and in two different elevation zones

Two depth in each elevation				
	Soil Available Potassium (Kg ha^{-1}) (Mean ± SE)		t- value	p-value
Zone	0-20	20-40		
Zone I	854.93±38.80	778.84±37.53	1.409*	0.17*
Zone II	990.48±84.15	799.71±81.22	1.631*	0.114*
Two elevation in each depth				
	Soil Available Potassium (Kg ha^{-1}) (Mean± SE)		t-value	p-value
Soil depth	Zone I	Zone II		
0-20	854.93±38.80	990.48±84.15	-1.46*	0.15*
20-40	778.84±37.53	799.71±81.22	-0.233*	0.818*
SE- Standard error *indicate non-significant at 5% level **indicate significant at 5% level				

4.2.2.8. Soil Available Calcium

The Soil available calcium (Ca) (mg Kg $^{-1}$) registered in zone I (350-900 m above MSL) ranged between 80 mg Kg $^{-1}$ in site S9 (20-40 cm) soil layer to 960 mg Kg $^{-1}$ in S15 (0-20 cm) soil layer. In zone II (900-1450m above MSL) the value ranged between 320 mg Kg $^{-1}$ in S5 (20-40 cm) to 1440 mg Kg $^{-1}$ in site S7 (0-20 cm) soil layer (Table 21). The soil available calcium content was recorded sufficient (>300 mg Kg^{-1}) in both elevation zones. The analysis by independent sample t test revealed that the mean values of soil available calcium (Ca) between two depths in each elevation resulted to be not significant with mean value ranged from700-325.3. Similarly the t-test between two elevation in each depth was also observed to be non significant. The depth wise and elevation wise variations of soil available calcium (Ca) are represented in Table 20.

Table 20. Soil available calcium (mg Kg^{-1}) at two depths and in two different elevation zones

Two depth in each elevation				
	Soil Available Calcium (mg Kg^{-1}) (Mean± SE)		t- value	p-value
Zone	0-20	20-40		
Zone I	424 ± 51.46	325.33 ± 45.45	1.437	0.162*
Zone II	700±84.04	520 ± 50.67	1.834	0.077*
Two elevation in each depth				
	Soil Available Calcium (mg Kg^{-1}) (Mean± SE)		t-value	p-value
Soil depth	Zone I	Zone II		
0-20	424 ± 51.46	700 ± 84.04	-2.801	0.009**
20-40	325.33 ± 45.45	520 ± 50.67	-2.86	0.008**
SE- Standard error *indicate non-significant at 5% level **indicate significant at 5% level				

Table 21. Chemical properties of soil in different elevation zone

Sites	Zone I						Zone II					
	P		K		Ca		P		K		Ca	
	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
S1	215.6	21.95	817.6	814.24	420	360	51.74	28.67	638.4	593.6	500	420
S2	314.24	272.24	975.5	808.64	300	120	54.99	4.36	764.96	683.2	680	480
S3	31.36	20.49	1005.7	853.4	400	360	1059.18	307.44	673.12	454.72	600	560
S4	12.656	11.64	694.4	660.8	240	180	1098.49	977.08	1142.4	697.76	520	360
S5	21.952	14.22	878.08	730.24	360	240	58.01	28.44	471.04	398.24	350	320
S6	25.872	17.24	640.6	467.04	320	200	77.16	57.23	862.4	623.84	540	460
S7	25.312	23.85	665.2	647.36	280	240	283.24	175.16	1062.8	856.8	1440	680
S8	20.94	18.81	860.16	786.24	440	360	619.24	511.16	694.4	584.64	580	360
S9	149.96	12.09	854.56	789.6	180	80	361.2	316.17	1131.2	1004.64	560	480

Table 21 continued

S10	74.36	63.39	595.84	572.32	380	240	248.41	38.30	1321.6	583.52	1280	960
S11	140.44	123.64	944.16	904.96	340	280	146.60	126.22	1057.28	851.2	500	440
S12	61.26	56.01	1043.84	976.64	420	360	236.43	163.07	920	853.25	490	380
S13	44.91	31.69	810.88	788.48	620	580	231.95	38.30	985.28	910.56	520	360
S14	163.40	146.49	980	883.68	700	600	151.87	139.21	1503.84	1393.28	780	640
S15	166.76	145.93	1057.28	999.04	960	680	128.01	126.33	1628.48	1506.4	1160	900

Intraset correlation between environment variables, and the first two ordination axes (Table. 22). In Zone I first CCA axis was significantly related to soil pH, soil electrical conductivity (EC), Bulk density (BD), soil organic carbon (C), soil total nitrogen (N), available phosphorus (P), available potassium (K), available calcium (Ca); total nitrogen (N),available potassium (K), and available calcium (Ca) had a positive relation and a negative correation with bulk density (BD) . The second CCA axis is significantly related to soil pH, soil electrical conductivity (EC), Bulk density (BD), soil organic carbon (C),soil total nitrogen (N), available potassium (K), available calcium (Ca); soil pH is strongly and positively related and BD, N and Ca are negatively correlated in Zone I (350-900m above MSL) (Appendix I Table 22 and Fig. 10.).

In Zone II (900-1450m above MSL) the first CCA axis is significantly related to soil pH, Bulk density (BD), soil organic carbon (C),soil total nitrogen (N),available phosphorus (P), available potassium (K), available calcium (Ca); soil organic carbon (C) and total nitrogen (N) are positively correlated and bulk density and available phosphorus are neagatively related.The second CCA axis is significantly related to soil pH, soil electrical conductivity (EC), Bulk density (BD), soil organic carbon (C),soil total nitrogen (N), available potassium (K), available calcium (Ca); soil pH is positively and strongly correlated and electrical conductivity, total nitrogen,available phosphorus are negatively correlated (Appendix II ,Table 23; Fig. 11).

In Zone I (350-900m above MSL) eight environment variables were significantly correlated with each other for example total nitrogen positively correlated with soil organic carbon and negatively with bulk density, available potassium positively correlated with soil organic carbon (Table 22).In Zone II (900-1450m above MSL) also eight environment variables were significantly correlated with each other for example total nitrogen is negatively related with bulk density, available potassium is positively correlated with total nitrogen (Table23).

Table 22. Interdataset Correlations coefficients of environmental variables and the first two CCA axes and Correlation coefficients between environmental variables of woody vegetation of tree species in zone I (350-900m above MSL)

Environment Variables	Axis 1	Axis 2	pH	EC	BD	C	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						
C	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	

pH- soil pH; EC- Electrical Conductivity; BD-Bulk density; C- Soil organic carbon; N- Soil total Nitrogen; P- Soil available phosphorus; K- Soil available potassium; Ca – Soil available calcium

**Significant at 0.01 levels (2-tailed), * Significant at 0.05 levels, others are non- significant (2-tailed).

Table 23.Interdataset Correlations coefficients of environmental variables and the first two CCA axes and Correlation coefficients between environmental variables of woody vegetation in zone II (900-1450 ma bove MSL)

Environment Variables	Axis 1	Axis 2	pH	EC	BD	C	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						
C	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*	

pH- soil pH; EC- Electrical Conductivity; BD-Bulk density; C- Soil organic carbon; N- Soil total Nitrogen; P- Soil available phosphorus; K- Soil available potassium; Ca – Soil available calcium

**Significant at 0.01 levels (2-tailed), * Significant at 0.05 levels, others are non- significant (2-tailed).

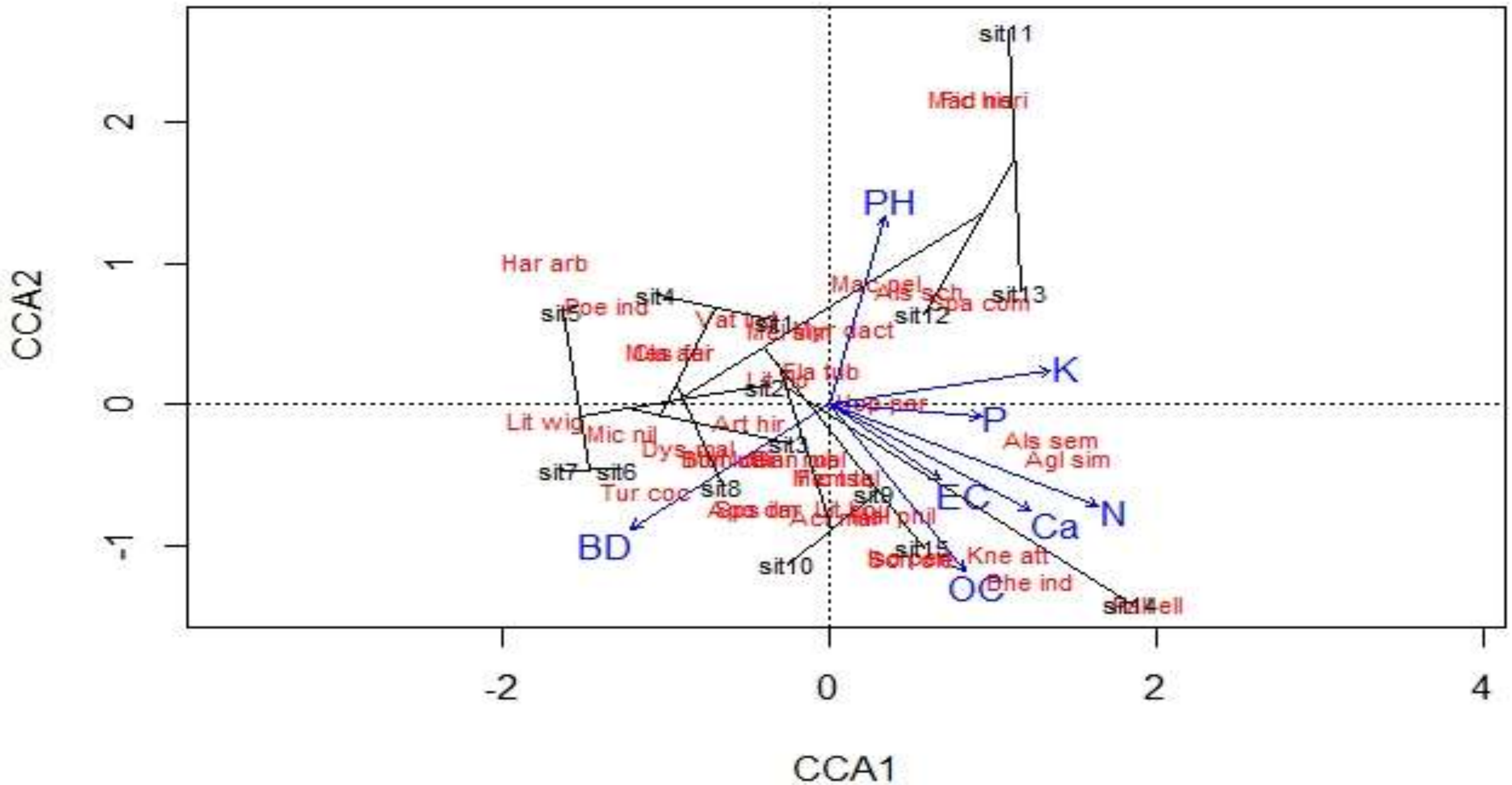


Fig. 10 CCA ordination graph for the first two axes for the dune meadow dataset using scaling method 1 and all the environmental variables as constraining variables in zone I (350-1450m above MSL)

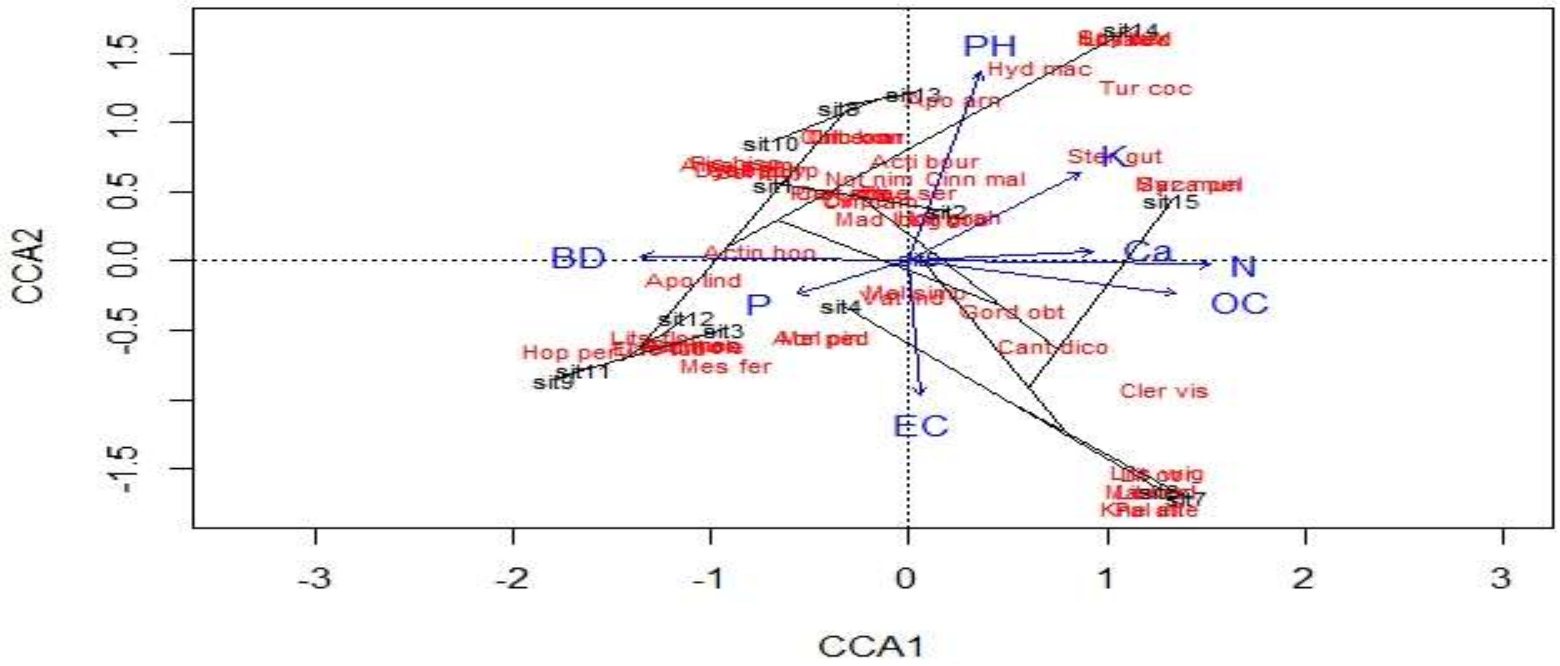


Fig. 11 CCA ordination graph for the first two axes for the dune meadow dataset using scaling method 1 and all the environmental variables as constraining variables in zone II (900-1450m above MSL)

DISCUSSION

The current study was conducted during 2019-2020 to understand the floristic composition, diversity and vegetation structure of a typical tropical forest along an altitudinal gradient (Zone I [350-900m above MSL] and zone II [900-1450m above MSL] in Mankulam Forest Division, Idukki, Kerala. This study also investigated the physico-chemical properties of soil along this gradient. The findings from the study are discussed here under.

5.1. Vegetation Diversity

Phytosociological analysis revealed that the tree species composition varied markedly between the two altitudinal zones. The forests of Mankulam is recorded as tropical west coast wet evergreen forest ecosystem (1A/C2) and the tree species composition in both of the altitudinal zones were recorded as evergreen (KFD, 2014).In Zone II, 50 trees with 107 individuals per hectare was recorded while in Zone I, only 38 trees with 98 individuals per hectare could be observed. *Palaquium ellipticum, Mesua ferrea* and *Poeciloneuron indicum* were the major trees in upper storey of Zone I, while *Macaranga peltata* and *Dysoxylum malabaricum* were dominant in second storey. The third storey comprised of *Litsea wightiana* and *Madhuca neriifolia*. Some semi- evergreen and mixed deciduous tree species like *Schleichera oleosa* and *Spathodea companulata* were also observed in lower zone. Researchers like Aneesh (2011), Magesh and Menon (2014) and Deepakkumar (2016) too had recorded the presence of these species in the lower altitudinal zones of similar evergreen forests in other forest divisions. In the lower zones of tropical forests, vegetation is in transitional stage between evergreen and deciduous vegetation and the presence of both evergreen and deciduous speciesis not surprising. Moreover, in this particular study area, the lower reaches of Zone I was lying close to human habitation, which also explains the presence of *Spathodea campanulata*. In Zone II, the major trees in upper storey were *Vateria indica* and *Canarium strictum*, whereas in the middle storey, *Litsea floribunda* and *Turpinia cochinchinensis* were dominant. In lower storey *Clerodendron viscosum, Meliosma simplicifolia* and *Litsea wightiana* were dominant. The tree species compositions were observed to be diverse in higher zone than lower zone as the site was understandably undisturbed and is having richer evergreen vegetation (KFD,2012).The dominant tree species reported in the two altitudinal zones of Mankulam matches with the species observations recorded by Aneesh (2011), Magesh and Menon (2014) and Ramachandran *et al.*(2019) in similar evergreen forests elsewhere in the Western Ghats region.

Species abundance is positively associated with species richness (Condit *et al.* 1998) and will come up with hands-on details of the biodiversity of an area. Rank abundance curve highlights the altitudinal zone difference in evenness and richness. In the present study also, rank abundance curve was observed to be quite wide and more horizontal (Fig. 8) in the Zone II (900-1450 above MSL) indicating its better tree species richness and evenness. In the Zone I, the rank abundance curve was narrower and less horizontal (Fig. 7).

Non-metric multidimensional scaling (NMS) based on Bray- Curtis distance also confirmed that Zone II had higher tree species abundance and lower tree abundance than Zone I (Fig. 12 and Fig. 13). Within the zones itself, a link between species abundance and increasing altitude could be observed. In zone I (Appendix I and Fig. 12) the abundance of *Litsea floribunda and Elaeocarpus tuberculatus* was higher in site 2. Insite 3 also, the abundance of *Garcinia rubro-echinata* and *Cinnamomum malabatrum* was higher. Similarly, within Zone II, with increase in altitude, the tree species abundance also increased in sites situated at higher elevations (Appendix II and Fig. 11). Abundance of *Elaeocarpus tuberculatus, Schleichera oleosa* and *Hopea parviflora* was high for Site 11.The abundance of *Antidesma montana, Litsea floribunda,* and *Persea macarantha* was higher in site 12 compared to other sites. Highest abundance of *Macaranga peltata Syzygium mundagam, Sterculia guttata* and *Cinnamomum malabatrum* was observed for site 15 (Fig.13). These observations indicate an increase in species abundance with altitude at Mankulam.

Increased abundances of species with growing altitude could be ascribed to several reasons. This could be due to geographic factors such as large undisturbed forest patches and presence of native indigenous evergreen trees, and biotic factors like accumulation of nutrient rich humus and a moderate climate (Brown *et al*. 1995; KFD, 2012) in higher zones. For woody vegetation the number of families increasing along the altitudinal gradient (Table 1 and Table 2).For example, woody families such as Lauraceae, is showing significant increase in species as well as increase in species abundance as elevation increases. *Lauracaeae* is among the most common families in low and middle elevation ranges of tropical evergreen forest (Li Hsi-wen *et al.* 1982). The increasing trend of species abundance could also be related to the fact that forest at higher elevations receive high light availability which may favour them (Cirimwani *et al* 2019).For example *Actinodaphne bourdillonii, Calophyllum polyanthum, Litsea keralana, Litsea coriacea, Persea macarantha* and *Photinia integrifolia* are the main characteristic species found in higher zone and are hardly observed at lower zone i.e. Zone I.

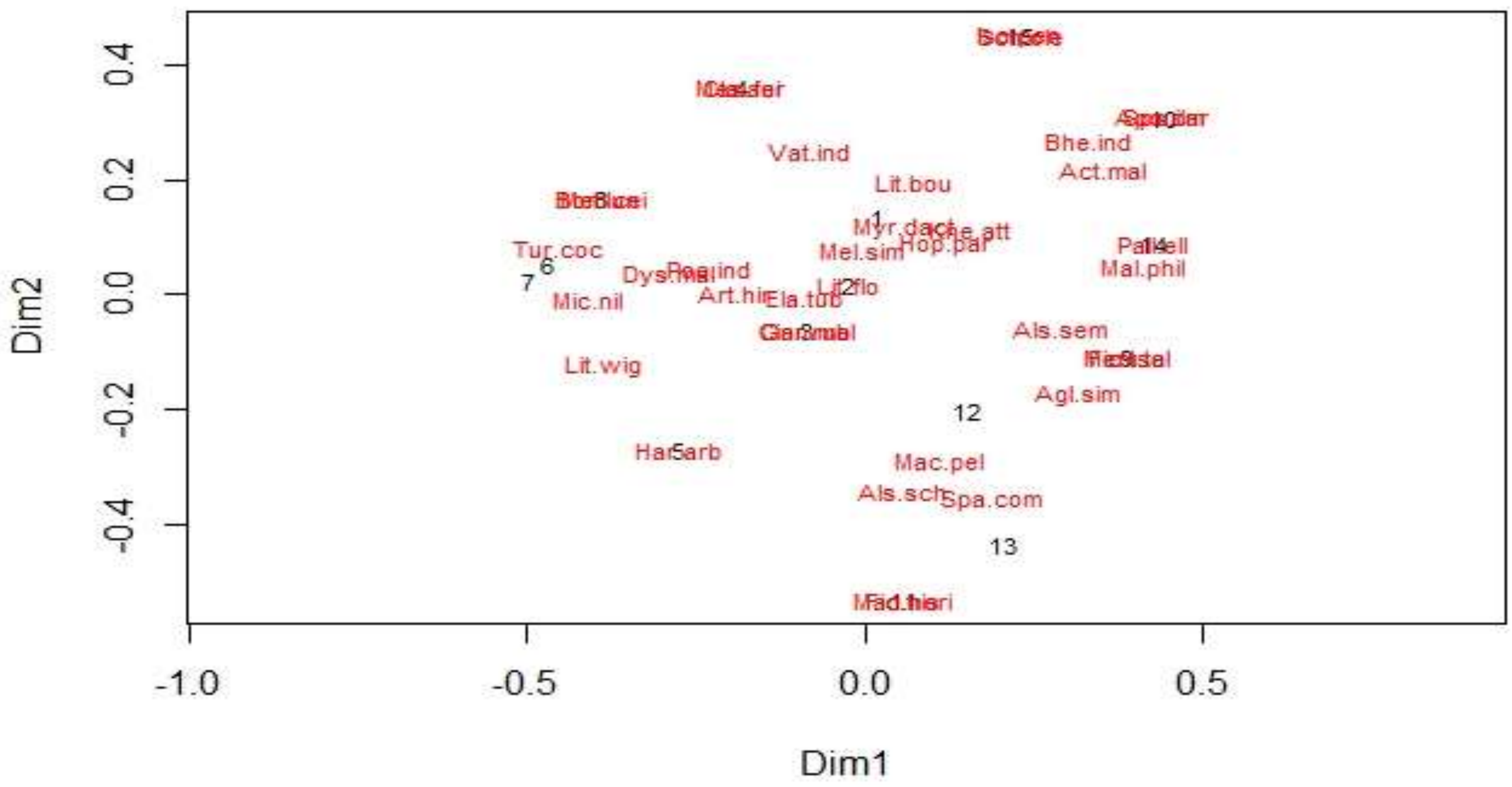


Fig. 12 Ordination graph for a two dimensional NMS based on Bray-Curtis distance for the zone I (350- 900m above MSL)

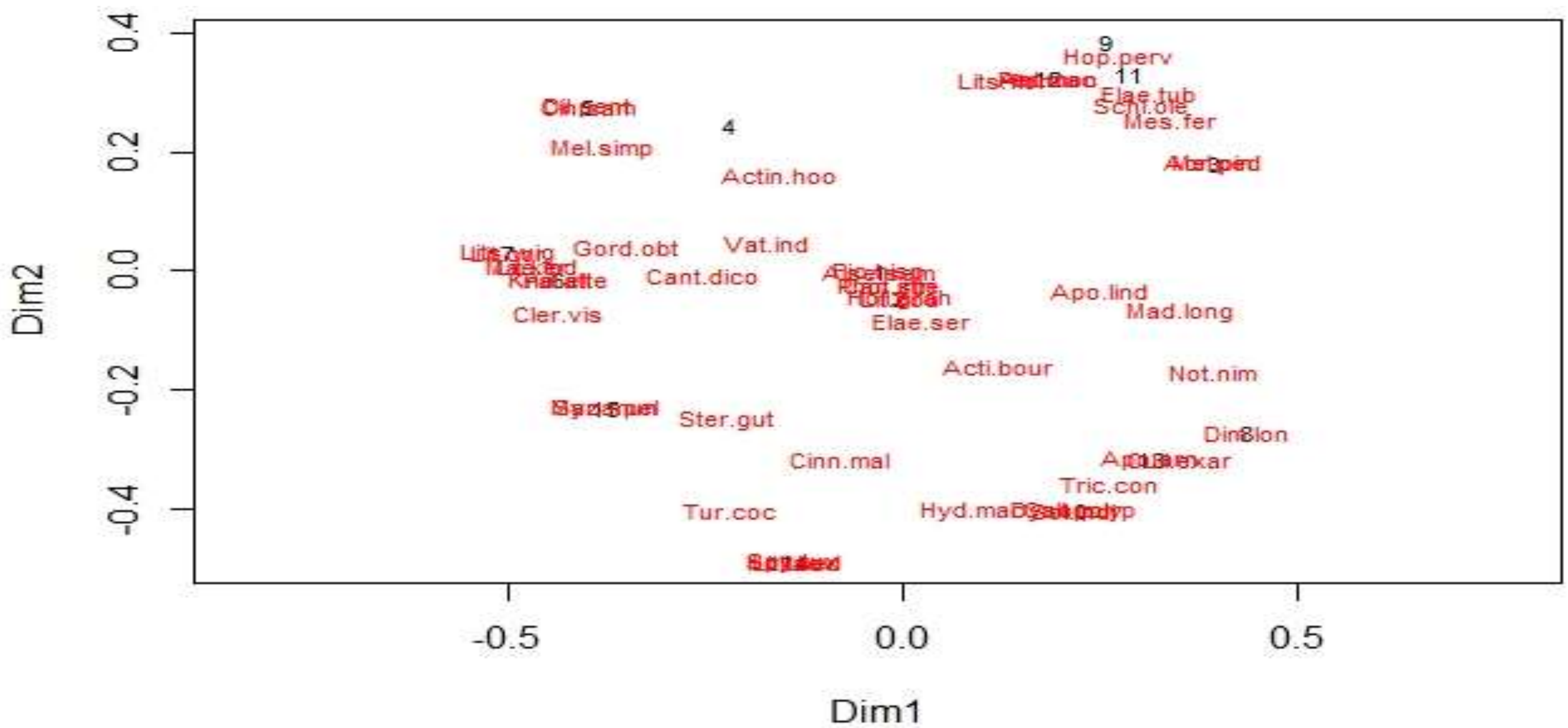


Fig. 13 Ordination graph for a two dimensional NMS based on Bray-Curtis distance for the zone II (900-1450m above MSL)

The total basal area was however higher in zone I than Zone II (Table 8 and Table 9), which could be due to the presence of species with higher girth classes like *Memecylon talbotianum*, *Palaquium ellipticum* and *Litsea bourdillonii*. Presence of higher tree density in Zone II leads to competition for light and other nutrients resulting lower basal area in higher zone (Tenzin and Hasenauer, 2017).

The diameter frequency distribution of higher zone showed a “bell shaped pattern” (Clatterbuck *et al*. 2010) with majority of individuals falling in the middle diameter classes. One reason for this could be past disturbances and the lower basal area of tree species individuals in higher zone (Table 9).In lower zone diameter frequency distribution had a “reverse J-shaped pattern” after 30-40 cm diameter class onwards, (Fig.3) which indicates a well established regeneration. On the other hand, the height frequency distribution of both altitudinal zones has a“bell shaped curve”. The reason is the more stocking in 10-15 m height class, which indicates a healthy forest in future (Fig. 4). Similar trend of diameter and height class frequency distribution was also observed by Deepakkumar, (2016) in Vazhachal forest division, a typical evergreen forest ecosystem in the Western Ghats.

Profile diagram is a pictorial transaction representation of representative segment of forest land and evergreen forests has a typical three layered forest structure as described by Aneesh, (2011) in Wayanad, Kerala. In Mankulam too, a similar three layered structure was observed in both zones. But, the percentage distribution of tree species in different storey’s in the canopy (<10 m, 10-20m, >20 m) showed a marked difference between zones (Table 5).Majority of the individuals in lower zone and higher zone were present in lower storey (< 10m). Poor stocking was observed in third storey of both the altitudinal zones. The typical three layered structure is a characteristic feature of a tropical forest. However, the percentage of trees in third storey is less in higher zone as compared to lower zone (Fig. 6 and Table 5) and could be due to large tree density and compact nature of the vegetation in higher zone.

As far as the floristic diversity indices are concerned, the concentration of dominance C_d (Simpson index) values were lowest (0.96) in Zone I compared to Zone II (0.97) (Table 10, Fig. 9).Similarly Shannon-Wiener index value in the study area ranged less from 3.47 (lower) to 3.74 (higher) (Table 10, Fig. 9).Although the differences are small, better values in the higher zone could be attributed to the presence of large undisturbed forest contributing to large amount of humus and litter fall formation resulting in higher carbon return (Gairola *et al.* 2012) which in turn, increases the SOC content (Table 17) and finally contribute in rich species diversity in Zone II.The Pielou's index of evenness value was also comparatively lower in zone I (Table 10, Fig. 9).Variation in the evenness pattern could be attributed to altitudinal pattern, variation in rainfall distribution and temperature (Reddy *et al.* 2011) in both altitudinal zone as all these could lead to higher evenness in Zone II. Zhang *et al.* (2013) too had observed similar trends of increase in dominance, diversity and evenness along an altitude in Baihua Mountain Reserve, Beijing, China. Altitude is the key factor affecting the floral diversity. Apart from that the community variation, environmental diversity and past anthropogenic disturbances also lead to change in species diversity pattern (Rahbek, 2005 ; Brinkmann *et al.* 2009).This study also observed higher species diversity and more dominance with increasing altitudinal gradient and gives support to the i.e. "humped distribution hypothesis" (Grime, 1973).

5.3. Soil trends along an altitude

Soil bulk density (BD) showed a declining trend with increase in altitude. However, bulk density value increased in lower depth (Table 11).The same trend of increase in bulk density with lower depth and decreasing value in higher elevation zones was reported in Mankulam and Eravikulam National Park of Western Ghats (Divya *et al.*2016). The mean values of bulk density, both depth and elevation wise was observed to be non-significant (Table 11).Canonical Correspondence Analysis (CCA) also revealed the increasing trend of species abundance along an altitude with higher species abundance in Zone II with respect to increasing ideal bulk density (<1.33 gm cm^{-3}).In Zone I abundance of species such as *Turpinia cochinchinensis, Dysoxylum malabaricum, Michelia nilagirica and Actinodaphne malabarica* was higher in soil with ideal bulk density (<1.33 gm cm^{-3}).However, lower species abundance was recorded in Zone I compared to Zone II (Fig. 10). In Zone II higher abundance of *Hopea perviflora, Litsea floribunda, Mesua ferrea, Meliosma pinnata ,Meliosma simplicifolia, Acronychia pedunculata, Meliosma pinnata, Actinodaphne hookeri, Aporosa lindleyana, Elaeocapus tuberculatus, Persea macarantha ,Vateria indica* and *Schleichera oleosa* was observed in the soil having ideal bulk density(<1.33 gm cm^{-3}) (Fig. 11). It could be concluded that the ideal bulk density values (<1.2 gm cm^{-3}) in Zone II (Table 14) is favouring ideal conditions for nutrient uptake and large root growth through root penetration resulting in higher species abundance (Bassett *et al.*2005).High floral diversity of evergreen tree species in higher zone facilitates continuous leaf litter addition throughout the year and the litter decomposition rates are faster in tropical climates (USDA, 1999;.Osman, 2012). Moreover, the diverse forest litter layer provides shelter and food to various soil microbes to act faster resulting in addition of humus which reduces the bulk density. Zone II also has comparatively lower biotic disturbances, while in zone I, most of the forest fringe areas experiences frequent disturbances which also changes the distribution of tree species (Kumar *et al.* 2012).

In Zone I, the soil pH was observed as extremely acid (3.5-4.5) and very strong acid (4.5- 5.5) in zone II (900-1450m above MSL) (Table 14). The lower pH values in both the altitudinal zones could be due to the generally higher rainfall in this area resulting in frequent leaching of exchangeable bases (Paul, 2013) to lower elevation from higher elevation. Heavy rainfall and higher temperature leading to leaching of bases and silica and formation of laterite soil could be another plausible reason for the extremely acidic soil in lower zonesof Mankulam. Another reason could be the open canopy nature in the lower zone which could be favouring laterisation (KFD, 2012) in the lower zone. Canonical Correspondence Analysis (CCA) clearly illustrated the increasing trend of species abundance along altitude.In Zone I abundance of *Myristica dactyloides, Macaranga peltata, Alstonia scholaris, Spathodea companulata, Ficus hispida and Madhuca nerifolia* is higher in soil with higher soil pH values (Fig. 10). In Zone II highest abundance of species like *Appollonias arnottii, Hydnocarpus macrophylla, Turpinia cochinchinensis, Psychotria nigra, Litsea laevigata* is present in soil having high soil pH (Fig. 11).Low count of sites having extremely acid soil in Zone II favouring higher evergreen tree species abundance (Goldberg,1982).Analysis indicate that most of the species observed in Zone I were semi evergreen and deciduous type (Table 1) which prefer mostly less acidic soil (Goldberg, 1982).As most sites of zone I possess extremely acidic soil and only few sites comprises less acidic soil therefore, less species abundance is reported in lower zone (Table 14).

Soil electrical conductivity (EC) was significantly higher in Zone I (Table 13) and is in conformity with the observations from several other studies conducted at similar forest in the Western Ghats (Reddy *et al.*2012; Deepakkumar, 2016).The frequent rainfall and the steep slopes causes leaching of the soluble salts from the surface layer in higher elevation zones could be the probable reasons for the significantly lower values in zone II.Compared to this scenario, in the lower zone, all the soluble salts which drained or leached from higher elevation zones get accumulated top soil layer resulting higher soil electrical conductivity (KFD, 2012). Canonical Correspondence Analysis (CCA) clearly illustrates the increasing trend of species abundance along an altitude with higher species abundance in Zone II with respect to soil electrical conductivity (0.75 -0.91dS/m).In Zone I higher abundance of tree species like *Knema attenuata, Mallotus philippensis, Schleichera oleosa and Isonandra pentandra* was seen in soil with EC range (1.25-1.82 dS m^{-1}) (Fig.10 and Table 14).This could be due to as excess salt in the root zone affect plant growth as it reduces water uptake from surrounding soil (Warrence *et al.* 2002;USDA, 2011) as most of the sites of Zone I possess high EC (1.25-2.25 dS/m) value resulting lower species abundance compared to zone II. In zone II higher abundance of tree species like *Meliosma simplicifolia*, *Vateria indica*, *Gordonia obtusa*, and *Canthium dicoccum* was recorded in soil having desirable range of electrical conductivity (0.75 -1.25 d S/m) (Table 14 and Fig.11).So in zone II, the presence of ideal range of soil EC could have favoured a better nutrient uptake mechanism in plants resulting in a better species abundance (USDA, 2011).

The soil organic carbon (C) content was observed to be comparatively higher (>1.5%) in higher zone surface horizon (0-20cm).Divya *et al.* (2016) reported increasing trends of SOC along an altitude gradient and decreasing trend with increasing depth in southern Western Ghats.The significant influence of altitude in each depth was observed in both elevational zones (Table 15). It is a known fact that presence of dense tree canopy and thick undercover vegetation result in high amount of carbon return through litter fall in tropical evergreen forests (Saenger and Snedaker, 1993; Divya *et al.* 2016). In this study also, in Zone II, a deeper root biomass, precipitation, cool temperature and slow decomposition (Chapin *et al.* 2002) and high tree species composition could have contributed to the accumulation of organic carbon in soils. But these reasons need to be investigated in depth to establish the exact relationships. As already mentioned, the vegetation diversity of zone II is higher. However, in the lower zone, mixture of evergreen with semi-evergreen and deciduous trees and less species composition forming canopy gaps leads to comparatively lesser litterfall on forest floor. Moreover, due to comparatively lower species richness, litter diversity will be also lower in zone I. All these too might have contributed to comparatively lower soil organic carbon values in zone I. The decreased soil organic C with soil depth in both altitude zones could be attributed to the better OM decomposition and humus formation in upper (0-20 cm) soil layers (Gairola *et al.*2012).Canonical Correspondence Analysis (CCA) revealed the increasing trend of species abundance along altitude with higher species abundance in zone II with respect to increasing trend of SOC along an altitude. In Zone Ihigher species abundance of *Knema attenuata, Bhesa indica, Schleichera oleosa* and *Isonandra pentandra* was recorded in soil having high C content (Fig. 10).As in

Zone I most of the sites were disturbed with previous anthropogenic activities resulting in less organic matter content hence species abundance is less with a mixture of semi-evergreen and moist deciduous (KFD, 2012).In Zone II, species like *Meliosma simplicifolia, Vateria indica, Gordonia obtusa, Canthium dicoccum* showed highest abundance in soils with richer organic carbon content (Fig. 11). Most of the sites of zone II had thicker litter layer forming higher organic carbon content favoring higher density of tropical evergreen trees (Table 7).

Soil total nitrogen (N) differs with elevation, vegetation type, and topographic position (Zhang *et al.* 2012).In the present study also; the total nitrogen content was less in zone I (Table 17). The total nitrogen content was higher in surface layer (0-20 cm) of Zone II compared to zone I. The values recorded showed an increasing trend along an altitude. This observation is in conformity with the earlier observations at similar elevation ranges of Western Ghats (Jose *et al.*1994; Divya *et al*. 2016) and in Eastern Ghats (Sahu *et al.* 2019). The presence of thick evergreen vegetation, high soil OM, higher litter fall on surface layer and steady rate of mineralization would have maintained a higher nitrogen budget in the soilupper layer (0-20cm) of zone II, despite higher nitrogen uptake by plants.Canonical Correspondence Analysis (CCA) also supported the linkage between soil total nitrogen and higher species abundance in Zone II.In zone I also, higher abundance of species as *Hopea parviflora, Alseodaphne semecarpifolia, Aglaia simplicifolia* was observed in soils that are rich in total nitrogen (Fig. 10). In zone II, higher abundance of species like *Meliosma simplicifolia, Vateria indica, Gordonia obtusa, Canthium dicoccum* was observed in soils having higher total nitrogen content (Fig. 11).Higher N content in litterfall of tropical evergreen trees in combination with mean annual precipitation increase the rate of N release in forest floor which in turn increase TN content (Campo *et al.*2013) hence, favouring high species abundance in zone II.

The available phosphorus (P) content was less in Zone I (Table 21). The increaseof available phosphorus along an altitude was also observed in Western Ghats by Divya *et al.*(2016) and in Eastern Ghats by Sahu *et al.*(2019).Among the two altitudinal zones, zone II recorded comparatively high (>24 Kg ha^{-1}) available phosphorus in top layer (0-20cm) (Table 21). A significant influence of altitude in each depth was also observed (Table 18). In tropical evergreen forest annual return of P in leaf litter is around 10.08 kg ha^{-1} (Stachell, 1974). Higher contribution of organic matter and a higher organic carbon nutrient recycling unit are the main factor which explains the higher values of available phosphorus in higher zone. The lower zone consists of a mixture of semi-evergreen and deciduous forest species and the peak litterfall occur in dry-wet transition period (Sanches *et al.* 2008). The decrease of soil available phosphorus with soil depth in both zones perhaps could be due to presence of root exudates and dead root used by soil microbes to produce enzymes, which leads to increase in soil available phosphorus on surface layer. The Canonical Correspondence Analysis (CCA) analysis further revealed an increasing trend of species abundance along an altitude with higher tree species abundance in Zone II with respect to increasing soil available phosphorus along an altitude.In Zone I higher abundance of *Hopea parviflora, Alseodaphne semecarpifolia, Aglaia simplicifolia* wasobserved in soils that are rich in available phosphorus (Fig. 10).The vegetation of Zone I comprises mixture of semi-evergreen and moist deciduous (Table 1) species whose leaves as well as litter fall contain less proportion of N:P compared to pure tropical evergreen species (Herrera *et al.* 1988; Hernandez,1999).In Zone II,higher abundance of *Hopea perviflora, Litsea floribunda, Mesua ferrea, Meliosma pinnata ,Meliosma simplicifolia, Acronychia pedunculata, Meliosma pinnata, Actinodaphne hookeri, Aporosa lindleyana, Elaeocapus tuberculatus, Persea macarantha ,Vateria indica* and *Schleichera oleosa* was highest in soils with high available phosphorus content (Fig.11).Available phosphorus content in top layer of soil is usually higher in tropical evergreen forest (Herrera *et al.* 1988, Hernandez,1999) as in Zone II in Mankulam forests comprises tropical evergreen vegetation whose green as well as senescent leaves and litter fall contain higher proportion of N:P compared to Zone I (Menendez *et al.*1988; Hernandez,1999). Therefore, available phosphorus content is reported higher in Zone II favouring high species abundance.

Available Potassium (K) content was recorded less in zone I (Table 21).The values of available potassium recorded in both altitudinal zones shows an increasing trend along an altitude at similar elevation ranges of Western Ghats by Jose *et al.*(1994), Divya *et al*. (2016).In temperate forest of Himalayas available K was observed to be significantly and positively correlated with altitude and shows an increasing trend along an altitude gradient by Gairola *et al.* (2012).Among the two altitudinal zones, zone II recorded significantly higher (>275 Kg ha^{-1}) available potassium in the top layer (0-20 cm) (Table 23) in form of exchangeable K, which further changed into soil solution (Dimri *et al.* 2006). The large species abundance in zone II contribute thick layer of organic matter on surface resulting improved K retention in soil and increasing K content on soil surface (Bourah and Nath, 2008).These entire factors explain the higher soil available K content in Zone II. Significant influence of altitude in each depth was also observed (Table 19). Canonical Correspondence Analysis (CCA) also corroborates the increasing trend of species abundance along an altitude with higher species abundance in zone II with respect to increase in soil available potassium along an altitude (Fig. 10 and Fig 11).In Zone I higher abundance of species *Hopea parviflora, Alseodaphne semecarpifolia, Aglaia simplicifolia* was observed in soils that are rich in available potassium (Fig. 10).In Zone II higher abundance of *Actinodaphne bourdillonii, Elaeocarpus serratus, Cinnamomum malabatrum, Madhuca longifolia* was seen inavailable potassium rich soils (Fig. 11). Superior vegetation structure, undisturbed forest patches and densely arranged evergreen tree species binds the soil tightly and helps in reduction of leaching and drainage might have favoured high available K content in zone II.Whereas, in zone I large disturbed patches and less abundance of tree species caused more leaching and drainage results in lower available potassium content (Basumatary and Bordoloi, 1992).

The available Calcium (Ca) content in Zone IIwas comparatively higher (Table21) and was highest in its top soil layer. Similar values of available Ca was observed along an altitude in the evergreen forest of Central Western Ghats by (Ramchandra *et al.* 2012).The available calcium values was reported sufficient (>300 mg Kg^{-1}) values (TNAU, 2016) in surface layer (0-20cm) of higher zone compared to deeper layer (20-40cm) of lower zone (Table 25). The higher rate of litter fall is due to the high species richness on the base cation availability which act as major source in higher Ca concentration in top layer (Brady and Weil,1999).Canonical Correspondence Analysis (CCA) clearly illustrates the increasing trend of species abundance along an altitude with higher abundance of tree species in Zone II.In Zone I higher abundance of tree species namely *Knema attenuata, Bhesa indica, Actinodaphne malabarica,Mallotus philippensis, Schleichera oleosa* and *Isonandra pentandra* was reported in sites having high Ca content (Fig. 10).In Zone II also higher abundance of tree species like *Meliosma simplicifolia, Vateria indica, Gordonia obtusa, Canthium dicoccum* was recorded in sites having higher soil available calcium in soil (Fig. 11). Higher abundance of evergreen trees results in higher organic matter mineralization and helps in increasing soil availability of base cations (McNabb *et al.* 1997) which could have enhanced the available Ca content in zone II of Mankulam forests.

The study done to understand the floristic composition, diversity and vegetation structure of a typical tropical forest along an altitudinal gradient Zone I [350-900m above MSL] and zone II [900-1450m above MSL] in Mankulam Forest Division, Idukki, Kerala revealed that the floristic composition, diversity, vegetation structure and physico-chemical properties of soil was clearly better in Zone II. As already explained, the reasons for this could be attributed to several factos, including the presence of a relatively undisturbed forest patch with richer and more even vegetation which is contributing to a higher soil organic matter content rich in humus and soil microbial activity. *Actinodapne bourdillonii, Apollonias arnottii, Calophyllum polyanthum, Litsea keralana, Litsea coriacea, Persea macarantha* and *Photinia integrifolia* were the main characteristic evergreen species observed in this zone (Fig.13). The existing microclimatic factors of zone II such as higher moisture regime, lower temperatures, better rainfall pattern and distribution and a different topography might also have significantly influenced the vegetation and soil properties in Zone II. These factors need to be individually studied to conclusively establish their influence. However, compared to Zone II forests, the forests in Zone I was more prone to frequent annual fires and had a history of past human disturbances which might have affected the species distribution and had accelerated soil deterioration. Moreover, presence of a mixture of evergreen and deciduous tree and lower organic matter content are significant factors that contributed to lower tree species diversity and soil properties in lower altitudinal zone. Hence, this studyon zonation of woody vegetation and soil along an altitude gradient supports the "humped" distribution hypothesis which highlights a peak in species diversity near the middle of the gradient (Austrheim, 2002; Zhang and Ru, 2010). However, a fuller understanding of whether or not the vegetation and soil factors will show a downward trend after peaking at the intermediate zone (in this study, Zone II) of an altitudinal gradient can be fully understood only after continuing the investigations at the next higher zone.

Future line of study

A more detailed study in the same location of Mankulam Forest Division coveringthe lower plant forms i.e. herbs and shrubs, regeneration status, tree crown diameter and canopy gap at different elevations has to be taken up to comprehensively understand the variations in vegetation diversity and soil properties along an altitudinal gradient. The top most elevation (zone III;1450-2100 m above MSL) of Mankulam forest division, though was proposed to be covered, but had to be dropped due to the Covid 19 restrictions, should be studied to fully understand and establish the existence of the "humped" distribution theory in tropical forest ecosystems. More comprehensive soil studies by including soil microbial and macro-faunal activities also has to be attempted to draw a complete picture of the functional dynamics of tropical evergreen forest along altitudinal gradients.

SUMMARY

The study titled "Zonation of woody vegetation and soil along an altitudinal gradient in Mankulam Forest Division" was carried out to evaluate the floristic composition, diversity and vegetation structure of typical tropical along an altitudinal gradient. The study also aimedto investigate the physico-chemical properties of soil along altitudinal gradient in two zones i.e. lower zone (350-900m above MSL) and higher zones (900-1450m above MSL). The results obtained from this study are summarized below:

1. The forest type in zone I was found to be West coast semi-evergreen forests (2A/C2) and West coast tropical evergreen forest (2A/C1) in zone II.

2. Zone II had the maximum density of 713.33 individual's ha^{-1} followed by lower zone 580 individual's ha^{-1}.

3. The stand basal area was highest in zone I (20.31 m^2) of which 4.08 m^2 was accounted for tree species *viz.*,*Dysoxylum malabaricum* and lowest in zone II (12.31 m^2).

4. *Dysoxylum malabaricum* was the dominant species in zone I whereas *Vateria indica* and *Gordonia obtusa* were the dominant species in zone II.

5. The diameter frequency curve showed reverse J- shaped pattern in higher zone and irregular shape in lower zone.

6. The floristic diversity was found to be maximum in higher zone with Simpson index of diversity (0.97), Shannon-wiener index (3.74) and Pielou's index of evenness (0.847) followed by lower zone as Simpson index of diversity (0.96), Shannon-wiener index (3.47) and Pielou's index of evenness (0.845).

7. The percentage distribution of individuals in different storey's showed that second and first storey is well represented in the vegetation of both altitudinal zones.

8. The value of bulk density (BD) (dry weight) was ranged between 0.77-1.33 gm cm^{-3} in zone II whereas in zone I it ranged from 0.71-1.34 gm cm^{-3}.

9. Soil pH was found prominently as extremely acid in zone I and it ranged from (3.21-5.44) and very strong acid in zone II ranged from (3.9- 5.5).

10. Electrical conductivity (EC) of soil is highest in zone I (0.30 – 1.82 dSm^{-1}) and highest in zone II value oscillate between (0.19-1.21 dSm^{-1}).

11. The soil organic carbon (C) content in Zone I ranged from (0.94-6.5 %) and in higher zone (0.94-8.76%). Significant influence of altitude in each depth was observed in both elevational zones.

12. The total Nitrogen (N) content was recorded highest in surface layer of both elevational zones ranged from (0.07% -0.39%) in zone II and lowest in zone I (0.01% -0.33%).

13. The comparison of available phosphorus (P) along both altitudinal zones revealed that in zone II high potassium content was recorded in surface layer (0-20 cm) as 11.64 – 314.24 Kg ha^{-1} followed by zone I in 4.36-1098.49 Kg ha^{-1}. Significant influence of altitude in each depth was observed in both elevational zones

14. The available potassium (K) content was recorded highest in zone II as 398- 1628 Kg ha^{-1} and in zone I value ranged between 467.64- 1057 Kg

ha^{-1}. Significant influence of altitude in each depth was observed in both elevational zones.

15. The available Calcium (Ca) content was observed highest in zone II (320-1440 mg Kg^{-1}) and in zone I (80-960 mg Kg^{-1}).

16. The Non-metric multidimensional scaling (NMS) illustrated that in zone II the abundance tree species abundance is higher towards various sites whereas, lower tree species abundance for various sites in zone I.

17. In zone I soil organic carbon positively correlated with total nitrogen and available potassium and soil organic carbon was negatively correlated with bulk density. In zone II total nitrogen is positively correlated with soil organic carbon and available potassium whereas, total nitrogen is negatively correlated with bulk density.

18. In Cannonical correspondence analysis it illustrates that in both elevational zones tree species as well as site abundance was observed to be higher in zone II (900-1450m above MSL) and lower in zone I (350m above MSL).

19. *Alseodaphne semecarpifolia, Alstonia scholaris, Clausena anisata, Mallotus philippensis* were the major prominent species observed specifically in zone I whereas, *Actinodapne bourdillonii, Apollonias arnottii, Calophyllum polyanthum, Litsea keralana* and *Photinia integrifolia* are the main characteristic evergreen species observed in zone II.

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ZONATION OF WOODY VEGETATION AND SOIL ALONG AN ALTITUDE GRADIENT IN MANKULAM FOREST DIVISION, KERALA

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ABSTRACT OF THE THESIS

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ABSTRACT

Altitudinal gradients are among the most powerful ‘natural experiments’ for testing ecological and evolutionary responses of biota and has strong influence on structure of vegetation.The present study was undertaken in a west coast tropical forest located along a gradient viz. Zone I (350-900m above msl) and Zone II (900-1450m above msl) in Mankulam Forest Division of Western Ghats region in Kerala, India. The aim of the study was to assess and compare the floristic composition, structure and diversity along this gradient. Additionally the changes in the physico-chemical properties of soil i.e.,Bulk density (BD) ,pH,Electrical conductivity (EC), total nitrogen (N), available phosphorus (P), available potassium (K), organic carbon (C) and available calcium (Ca) along this altitudinal gradient were also studied. Sampling of vegetation and soil was done using fifteen, 10 m x 10 m plots (covering 0.15ha in each altitudinal zone). Within each plot, all tree individuals (≥ 10cm GBH) were identified and their height was measured. In total, 200 individuals belonging to 88 tree species representing 34 families were recorded across the altitudinal gradient.In each sample plot, soil samples were analyzed at two depths viz. ‘upper’ (0–20 cm) and ‘lower’ (20–40 cm) along the altitudinal gradient.

The diameter frequency distribution showed a “bell shaped pattern” in both altitudinal zones. The vegetation profile diagram at both altitudes showed a typical three layered structure which is a characteristic feature of evergreen forest with majority of individuals in lower storey (<10 m) height classes in both zones. The maximum tree abundance (67.09) was recorded in Zone II. Tree density (713.33 trees ha^{-1}) was also higher in zone II compared to zone I (613.33 trees ha^{-1}).Similarly highest tree percent frequency (546.6%) was recorded in zone II. *Vateria indica* (IVI= 24.09) was found as dominating tree species in zone II, while in zone I dominating tree species was *Dysoxylum malabaricum* (IVI= 34.85). However, the tree basal area (20.31 m^2 ha^{-1}) was estimated higher in zone I compared to zone II with basal area (12.31 m^2 ha^{-1}).Rank abundance curve indicated highest abundance for *Gordonia obtusa* in zone II, while in zone I

Dysoxylum malabaricum recorded the highest abundance. Physico- chemical properties of soil viz. soil pH, C, N, P, K and Ca showed an increasing trend along the gradient. The highest values for soil pH (4.12-5.59), C (1.82-8.36%), TN (0.08-0.37 %), P (4.36- 1098.49 Kg ha^{-1}), K (398.24- 1628.48 Kg ha^{-1}) and Ca (320 - 1160 mg Kg^{-1}) was recorded in zone II. BD (0.77-1.33g cm^{-3}) and EC (0.30 – 1.82 dS m^{-1}) values were higher in 'upper' (0–20 cm) layer of zone I.

Canonical correspondence analysis (CCA) showed a complex interrelationship amongst species clustering, mountain ranges and soil properties. The study revealed that there is gradual increase in species abundance as the soil properties increases along the altitude, in both zones. Correlation analysis clearly indicated that in zone I AK is strongly and positively correlated with C because layer of organic matter significantly improves the retention of K in the soils. Whereas, N is negatively correlated with BD. Similarly, in zone II, TN was observed to be negatively correlated with BD while K was strongly and positively correlated with N.

The floral diversity indices *viz* Simpson index, Shannon index and Pielou index of evenness showed marginal variation along the gradient. However, there was variation in species composition along altitude. *Actinodaphne bourdillonii, Litsea keralana, Gordonia obtusa* and *Turpinia cochinchinensis* were the characteristic species in zone II. In zone I *Clausena anisata*, *Memecylon talbotianum* and *Madhuca neriifolia* were observed to be prominent.

Species abundance, diversity and vegetation structure and the physico-chemical properties of soil showed a ''humped'' pattern along this altitudinal gradient at Mankulam. In Zone II, species diversity was marginally better with higher species richness and better floristic structure and species composition. Soil properties were also observed to be better in zone II. The possible reason for this could be attributed to several reasons including the presence of luxuriant and comparatively undisturbed vegetation which could have contributed to a higher soil organic matter content rich in humus.

APPENDIX – I: Non-metric multidimensional scaling (NMS) for Lower zone

Site score

	[1]	[2]
1	0.017287191	0.136373171
2	-0.023330567	0.017053836
3	-0.085960589	-0.061726105
4	-0.180529486	0.362094193
5	-0.276082591	-0.268883722
6	-0.468497636	0.052914716
7	-0.497003205	0.022715117
8	-0.391847512	0.168131874
9	0.388863245	-0.106749058
10	0.443044100	0.309066774
11	0.056937521	-0.532470612
12	0.151932289	-0.202665423
13	0.206016201	-0.435636781
14	0.429863461	0.087220368
15	0.229307579	0.452561653

Stress

19.344473

Species score

		Dim1	**Dim2**
Act.mal	(*Actinodaphne malabarica*)	0.3537383083	0.2182931230
Agl.sim	(*Aglaia simplicifolia*)	0.3179398307	-0.1742082065
Als.sem	(*Alseodaphne semecarpifolia*)	0.2908978748	-0.0577225273
Als.sch	(*Alstonia scholaris*)	0.0589977109	-0.3432778327
Apo.car	(*Aporosa cardiosperma*)	0.4430441004	0.3090667739
Art.hir	(*Artocarpus hirsutus*)	-0.1925962641	0.0027474824

Bhe.ind	(*Bhesa indica*)	0.3295855200	0.2698910105
Bom.cei	(*Bombax ceiba*)	- 0.3918475121	0.1681318737
Cin.cam	(*Cinnamomum camphora*)	0.4430441004	0.3090667739
Cinn.mal	(*Cinnamomum malabatrum*)	-0.0859605889	-0.0617261049
Cla.ani	- (*Clausena anisata*)	-0.1805294862	0.3620941928
Dys.mal	- (*Dysoxylum malabaricum*)	-0.2890008068	0.0347086525
Ela.tub	- (*Elaeocarpus tuberculatus*)	-0.0877485968	-0.0058265710
Fic.his	(*Ficus hispida)*	0.0569375208	-0.5324706121
Fic.tse	(*Ficus tsjehala)*	0.3888632454	-0.1067490576
Gar.rub	(*Garcinia rubro-echinata)*	-0.0859605889	-0.0617261049
Har.arb	(*Harpullia arborea*)	- 0.2760825914	-0.2688837224
Hop.par	(*Hopea parviflora*)	0.1193031003	0.0889833554
Iso.pen	(*Isonandra perrottetiana)*	0.2293075791	0.4525616529
Kne.att	(*Knema attenuata)*	0.1559598032	0.1141908701
Lit.bou	(*Litsea burdillonii)*	0.0716734951	0.1954177740
Lit.flo	(*Litsea floribunda)*	-0.0233305671	0.0170538361
Lit.wig	*(Litsea wightiana*)	-0.3865428983	-0.1230843029
Mac.pel	(*Macaranga peltata*)	0.1132664922	-0.2915118365
Mad.neri	(*Madhuca neriifolia*)	0.0569375208	-0.5324706121
Mel.lun	(*Melicope lunu-ankenda*)	- 0.3918475121	0.1681318737
Mal.phil	(*Mallotus philippensis*)	0.4126585130	0.0456972567
Mel.sim	(*Melisma simplicifolia*)	-0.0030216879	0.0767135035
Mes.fer	(*Mesua ferrea*)	-0.1805294862	0.3620941928
Mem.tal	(*Memecylon talbotianum*)	0.3888632454	-0.1067490576
Mic.nil	(*Michelia nilagirica*)	-0.4083577363	-0.0062805040
Myr.dact	(*Myristica dactyloides*)	0.0577863206	0.1169206446
Pall.ell	(*Palaquium ellipticum*)	0.4298634609	0.0872203682
Poe.ind	(*Poeciloneuron indicum*)	-0.2283060388	0.0466052352
Sch.ole	(*Schleichera oleosa*)	0.2293075791	0.4525616529
Spa.com	(*Spathodea companulata*)	0.1879882300	-0.3579796618
Tur.coc	(*Turpinia cochinchinensis*)	-0.4524494512	0.0812539021

Vat.ind (*Vateria indica*)	-0.0816211475	0.2492336818

Appendix - II: Canonical Correspondance Analysis for zone I

Species Score

	CCA1	CCA2
Act mal (*Actindaphne malabarica*)	0.03533	-0.783156
Agl sim (*Aglaia simplicifolia*)	1.46678	-0.397446
Als sem (*Alseodaphne semecarpifolia)*	1.36420	-0.246742
Alssch (*Alstonia scholaris*)	0.57041	0.804352
Apo car (*Aporosa cardiosperma*)	-0.44550	-0.746181
Art hir (*Artocarpus hirsutus*)	-0.48619	-0.118470
Bhe ind (*Bhesa indica)*	1.22474	-1.247994
Bom cei (*Bombax ceiba*)	-0.62580	-0.370590
Cin.cam (*Cinnamomum camphora*)	-0.44550	-0.746181
Cinn mal (*Cinnamomum malabatrum*)	-0.19056	-0.372680
Cla ani (*Clausena anisata*)	-0.96391	0.384391
Dys mal (*Dysoxylum malabaricum*)	-0.86384	-0.318606
Ela tub (*Elaeocarpus tubercuatus)*	-0.05022	0.244001
Fic his (*Ficus hispida*)	0.91723	2.171776
Fic tse (*Ficus tsejehala*)	0.05098	-0.516151
Gar rub (*Garcinia rubro-echinata*)	-0.19056	-0.372680
Har arb (*Harpullia arborea*)	-1.73240	1.020836
Hop par (*Hopea parviflora*)	0.32521	0.005152
Iso pen (*Isonandra perrottetiana*)	0.50050	-1.087136
Kne att (*Knema attenuata*)	1.09073	-1.062764
Lit bou (*Litsea bourdillonii)*	0.15497	-0.729908
Lit flo (*Litsea floribunda*)	-0.30429	0.187226
Lit wig (*Litsea wightiana*)	-1.73365	-0.129603
Mac pel (*Macaranga peltata*)	0.29654	0.853526
Mad neri *(Madhuca neriifolia*)	0.91723	2.171776
Mel lun (*Melicope lunu-ankenda*)	-0.62580	-0.370590

Mal phil (*Mallotus philippensis*)	0.40136	-0.796834
Mel sim (*Meliosma simplicifolia*)	-0.22954	0.521217
Mesfer (*Mesua ferrea*)	-0.96391	0.384391
Mem tal (*Memecylon talbotianum*)	0.05098	-0.516151
Mic nil (*Michelia nilagirica*)	-1.26421	-0.199938
Myr dact (*Myristica dactyloides*)	0.09015	0.527660
Pall ell (*Palaquium ellipticum*)	1.94899	-1.408852
Poe ind (*Poeciloneuron indicum*)	-1.34815	0.702614
Sch ole (*Schleichera oleosa*)	0.50050	-1.087136
Spa com (*Spathodea companulata*)	0.91619	0.714429
Tur coc (*Turpinia cochinchinensis*)	-1.10815	-0.606863
Vat ind (*Vateria indica*)	-0.55935	0.619800

Site scores (weighted averages of species scores)

	CCA1	CCA2
sit1	-0.3239	0.5942
sit2	-0.3770	0.1286
sit3	-0.2357	-0.2737
sit4	-1.0531	0.7763
sit5	-1.6258	0.6662
sit6	-1.2896	-0.4632
sit7	-1.6404	-0.4665
sit8	-0.6446	-0.5796
sit9	0.2898	-0.6313
sit10	-0.2530	-1.1319
sit11	1.0953	2.6503
sit12	0.5850	0.6446
sit13	1.1715	0.7972
sit14	1.8517	-1.4140
sit15	0.5856	-1.0171

Biplot scores for constraining variables

	CCA1	CCA2
PH	0.1627	0.62968
EC	0.3228	-0.25309
BD	-0.5710	-0.41629
OC	0.3909	-0.55832
TN	0.7786	-0.34006
P	0.4377	-0.04208
K	0.6388	0.11400
Ca	0.5802	-0.35681

APPENDIX-III: Non-metric multidimensional scaling (NMS) for Zone II (900-1450M ASL)

Average weighted site score

	[,1]	[,2]
1	-0.0271342597	-0.0017110119
2	-0.0031728088	-0.0467386741
3	0.3949601257	0.1794156080
4	-0.2201760230	0.2456150667
5	-0.3994953132	0.2759437024
6	-0.4352648065	-0.0144132305
7	-0.4996313373	0.0323784636
8	0.4376765708	-0.2709961816
9	0.2589859138	0.3860979545
10	0.2169734438	-0.4022556274
11	0.2880972683	0.3300402718
12	0.1861903235	0.3235671941
13	0.3157115514	-0.3168645848
14	-0.1362227211	-0.4893249995

15 -0.3774979277 -0.2307539515

Stress Value

18.588405

Species Score

		Dim1	**Dim2**
Acr.ped	(*Acronychia pedunculata*)	0.3949601257	0.1794156080
Acti.bour	(*Actinodaphne bourdillonii*)	0.1218930513	-0.1608741301
Actin.hoo	(*Actinodaphne hookerii*)	-0.1558287686	0.1631730405
Alse.sem	(*Alseodaphne semecarpifolia*)	-0.0271342597	-0.0017110119
Ant.mon	(*Antidesma montanum*)	0.1861903235	0.3235671941
Apo.lind	(*Aporosa lindleyana*)	0.2525353560	-0.0361076778
Apo.arn	(*Apollonias arnottii*)	0.3157115514	-0.3168645848
Call.poly	(*Calophyllum polyanthum*)	0.2169734438	-0.4022556274
Can.stri	(*Canarium strictum*)	-0.0151535343	-0.0242248430
Cinn.mal	(*Cinnamom malabatrum*)	- 0.0802622420	-0.3165047895
Cler.vis	(*Clerodendron viscosum*)	- 0.4374646905	-0.0709295728
Cull.exar	(*Cullenia exarillata*)	0.3520095342	-0.3152781438
Dil.pent	(*Dillenia pentagyna*)	-0.3994953132	0.2759437024
Dim.lon	(*Dimocarpus longan)*	0.4376765708	-0.2709961816
Dyso.purp	(*Dysoxylum purpureum*)	0.2169734438	-0.4022556274
Elae.tub	(*Elaeocarpus tuberculatus*)	0.3140144360	0.2985179448
Elae.ser	(*Elarocarpus serratus*)	0.0249838012	-0.0828789027
Fic.hisp	(*Fics hispida*)	-0.0271342597	-0.0017110119
Gord.obt	(*Gordonia obtusa*)	- 0.3521961182	0.0395484960
Holi.bed	(*Holigarna beddomei*)	-0.1362227211	-0.4893249995
Holi.grah	(*Holigarna grahamii*)	-0.0031728088	-0.0467386741
Hop.parv	(*Hopea parviflora*)	0.2735415911	0.3580691132
Hyd.mac	(*Hydnocarpus macrocarpa*)	0.0897444151	-0.4030947921
Kne.atte	(*Knema attenuata*)	- 0.4352648065	-0.0144132305
Lit.bou	(*Litsea bourdillonii)*	- 0.0031728088	-0.0467386741
Lit.cor	(*Litsea coriacea)*	- 0.4996313373	0.0323784636

Lits.flor	(*Litsea floribunda*)	0.1282743707	0.3213301218
Lit.ker	*(Litsea keralana*)	- 0.4674480719	0.0089826166
Lit.laev	*(Litsea laevigata*)	- 0.1362227211	-0.4893249995
Lits.wig	(*Litsea wightiana*)	-0.4996313373	0.0323784636
Maca.pel	(*Macaranga peltata*)	- 0.3774979277	-0.2307539515
Mad.long	(*Madhuca longifolia*)	0.3553358386	-0.0687244884
Mae.ind	(*Maesa indica*)	-0.4674480719	0.0089826166
Mel.pin	(*Meliosama pinnata*)	0.3949601257	0.1794156080
Mel.simp	(*Meliosma simplicifolia*)	-0.3796994967	0.2074702338
Mes.fer	(*Mesua ferrea*)	0.3415286970	0.2547279399
Not.nim	(*Nothapodytes nimmonia*)	0.3965062047	-0.1698603350
Pal.ell	(*Palaquium ellipticum*)	-0.4352648065	-0.0144132305
Per.mac	(*Persea macarantha*)	0.1861903235	0.3235671941
Phot.inte	(*Photinia integrifolia*)	-0.0151535343	-0.0242248430
Pru. cey.	(*Prunus ceylanica)*	-0.3994953132	0.2759437024
Psy. nig.	(*Psychotria nigra*)	-0.1362227211	-0.4893249995
Psy .dico	(*Psydrax dicoccos*)	-0.2514020731	-0.0071801053
Schl.ole	(*Schleichera oleosa*)	0.3046387514	0.2797073273
Sol.indi	(*Solenocarpus indicus*)	0.2169734438	-0.4022556274
Ster.gut	(*Sterculia guttata*)	-0.2235978463	-0.2493928941
Syz.mun	(*Syzygium mundagum*)	-0.3774979277	-0.2307539515
Tric.con	*(Trichilia connaroides)*	0.2663424976	-0.3595601061
Tur.coc	(*Turpinia cochinchinensis*)	-0.2166477900	-0.4031346501
Vat.ind	(*Vateria indica*)	- 0.1714369745	0.0456880375

Appendix- IV: Cannonical correspondence Analysis for Higher zone

Species scores

	CCA1	CCA2
Acr ped (*Acronychia pedunculata*)	-0.433628	-0.55716
Actibour (*Actinodaphne bourdillonii*)	0.081824	0.72585

Actin hoo (*Actinodaphne hookeri*)	-0.745382	0.07426
Alse sem (*Alseodaphne semecarpifolia*)	-0.867499	0.70262
Ant mon (*Antidesma montanum)*	-1.090569	-0.59533
Apo lind (*Aporosa lindleyana*)	-1.074669	-0.14172
Apo arn (*Apollonias arnottii*)	0.239508	1.16238
Call poly (*Calophyllum polyanthum*)	-0.760826	0.65804
Can stri (*Canarium strictum*)	-0.330221	0.50914
Cinn mal (*Cinnamomum malabatrum*)	0.332137	0.60437
Cler vis (*Clerodendron viscosum*)	1.299680	-0.92232
Cull exar (*Cullenia exarillata*)	-0.280497	0.91072
Dil pent (*Dillenia pentagyna*)	-0.195703	0.43905
Dim lon (*Dimocarpus longan*)	-0.300336	0.91122
Dyso purp (*Dysoxylum purpureum*)	-0.760826	0.65804
Elae tub (*Elaeocarpus tuberculatus)*	-1.260686	-0.62585
Elae ser (*Elaeocarpus serratus*)	0.002982	0.50758
Fic hisp (*Ficus hispida*)	-0.867499	0.70262
Gordobt (*Gordonia obtusa*)	0.530504	-0.35801
Holi bed (*Holigarna beddomei*)	1.096532	1.61049
Holi grah (*Holigarna grahamii*)	0.207057	0.31565
Hop parv (*Hopea parviflora*)	-1.674215	-0.66020
Hyd mac (*Hydnocarpus macrocarpa)*	0.668020	1.38643
Kne atte (*Knema attenuata*)	1.213837	-1.78333
Lit bou (*Litsea bourdillonii*)	0.207057	0.31565
Lit cor (*Litsea coriacea*)	1.260101	-1.53434
Lits flor (*Litsea floribunda*)	-1.280831	-0.53891
Lit ker (*Litsea keralana*)	1.236969	-1.65883
Lit laev (*Litsea laevigata*)	1.096532	1.61049
Lits wig (*Litsea wightiana*)	1.260101	-1.53434
Maca pel (*Macaranga peltata*)	1.425101	0.55070
Mad long (*Madhuca longifolia*)	-0.097060	0.30261
Mae ind (*Maesa indica*)	1.236969	-1.65883

Mel pin (*Meliosma pinnata*)	-0.433628	-0.55716
Mel simp (*Meliosma simplicifolia)*	0.046093	-0.22404
Mes fer (*Mesua ferrea*)	-0.911070	-0.74932
Not nim (*Nothapodytes nimmonia*)	-0.198698	0.60692
Pal ell (*Pallaqum ellipticum*)	1.213837	-1.78333
Per mac (*Persea macarantha*)	-1.090569	-0.59533
Phot inte (*Photinia integrifolia*)	-0.330221	0.50914
Pru. Cey. (*Prunus ceylanica)*	-0.195703	0.43905
Psy. Nig. (*Psychotria nigra*)	1.096532	1.61049
Psy .dico (*Psydrax dicoccos*)	0.733579	-0.60934
Schl ole (*Schleichera oleosa*)	-1.061251	-0.60601
Sol indi (*Solenocarpus indicus*)	-0.760826	0.65804
Ster gut (*Stercullia guttata*)	1.038448	0.75688
Syz mun (*Syzygium mundagum*)	1.425101	0.55070
Triccon (*Trichilia connaroides*)	-0.260659	0.91021
Tur coc (*Turpinia cchinchinensis*)	1.206055	1.25723
Vat ind (*Vateria indica*)	-0.032732	-0.25124

Site scores (weighted averages of species scores)

	CCA1	CCA2
sit1	-0.67725	0.55535
sit2	0.19666	0.36237
sit3	-0.92299	-0.49233
sit4	-0.32806	-0.31875
sit5	0.06259	0.02032
sit6	1.26937	-1.65478
sit7	1.40947	-1.70631
sit8	-0.34062	1.11346
sit9	-1.78500	-0.85734
sit10	-0.68931	0.85804
sit11	-1.63780	-0.78106

sit12	-1.11957	-0.40431
sit13	0.02946	1.21020
sit14	1.12648	1.68071
sit15	1.32688	0.44491

Biplot scores for constraining variables

	CCA1	CCA2
PH	0.1809	0.68537
EC	0.0284	-0.48563
BD	-0.6794	0.01699
OC	0.6776	-0.11626
N	0.7635	-0.01365
P	-0.2850	-0.11804
K	0.4339	0.32004
Ca	0.4644	0.03244