FUNCTIONAL DIVERSITY OF AN EVERGREEN FOREST ECOSYSTEM OF VAZHACHAL FOREST DIVISION, KERALA

By

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(2014-17-116)

THESIS

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DEPARTMENT OF FOREST MANAGEMENT AND UTILISATION
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DECLARATION

I hereby declare that the thesis entitled **"FUNCTIONAL DIVERSITY OF AN EVERGREEN FOREST ECOSYSTEM OF VAZHACHAL 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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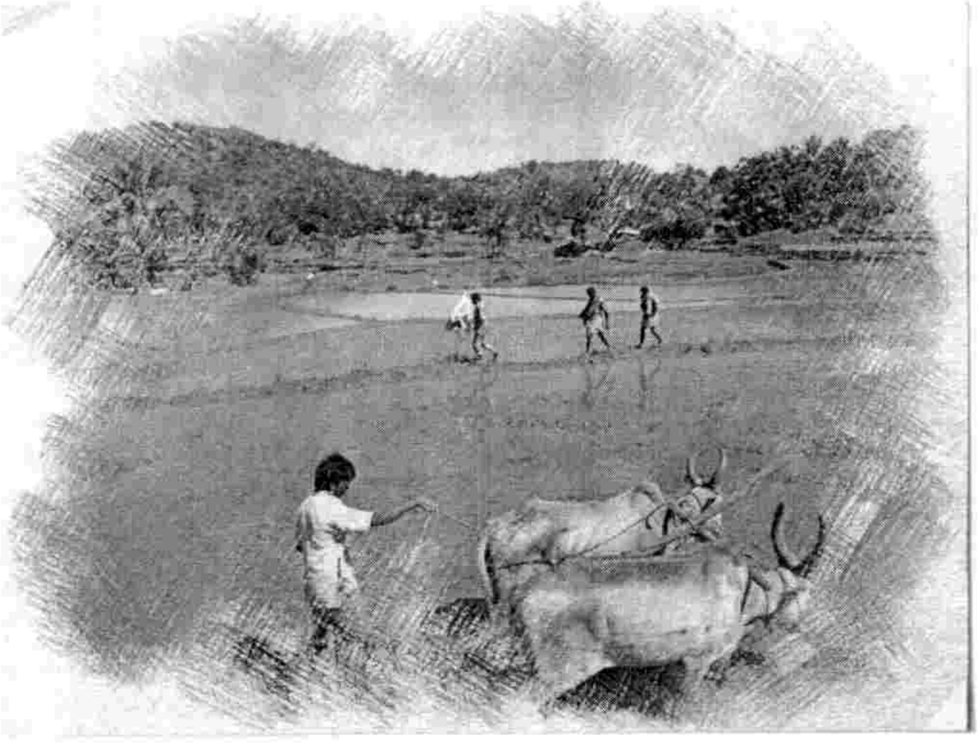
Dedicated to

Farming Communities of the Nation



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Introduction

INTRODUCTION

Among all the forest types, the tropical rain forests are one of most threatened ecosystem. Our nation has around 70.17 M ha (21.34 percent) of forests (FSI, 2015) and also one of the 12 mega-biodiversity countries in the world. It is also one of the top ten species rich nations. However, our pristine forests regularly suffer fragmentation and loss of habitat quality from anthropogenic pressures like new developmental projects, deforestation and also commercial monoculture plantations like tea, coffee, oil palms, pines and eucalypts (Raman *et al.*, 2009; Anitha *et al.*, 2010). Decreased genetic variation and increased edge effects are also not uncommon in Indian forests (Laurance *et al.*, 2007). In addition to this, our forest ecosystems are also facing the negative impacts of a human-induced climate change (IPCC, 2014).

The rapid changes in our forest ecosystems *per se* calls for an urgent need to understand the spatial and temporal "change matrix" that is happening therein. A deeper understanding about the functioning of ecosystems is now an important research priority. Indian forestry is now not only focusing on sustainably managing our forests for productive functions. We are also aiming to shore up our forest's capability to provide environmental and socio-economic functions in a sustainable manner. The latest National Working Plan Code (NWPC) 2014 is tailored to achieve these goals. The Code also stresses the need to continuously assess the sustainability of various forest functions using a set of related quantitative, qualitative or descriptive attributes so as to periodically measure or assess the direction of change of forest ecosystems (MOEF, 2014). The NWPC also speaks about monitoring Functional Diversity (FD). The MOEF (2014) has emphasized the necessity to generate more reliable information on the determining factors which are influencing the long-term stability and recovering ability of our forest ecosystems from major disturbances. In this context, FD analyses of forest ecosystems are more relevant as the data they provide will be useful in formulating strategies for conservation, management and enhancement of overall biodiversity through sustainable management and use practices.

Traditionally all ecosystem monitoring and assessments studies are largely limited to species richness and plant diversity assessments. The "functional roles" that organisms play in the ecosystems (Mason *et al.,* 2005) are often overlooked or left unrecognized in ecosystem assessments. However there is an increasing realization that ecosystem dynamics is not just a function of the resident species diversity (Coleman and Whitman, 2005) but also a function of the individual roles that each organism plays in that ecosystem. These roles are realized to be crucial in the ecosystem processes. Plant diversity and density, two key ecosystem characteristics, play catalytic roles in controlling the dynamics of soil carbon accretion. Likewise, individual species could mediate primary productivity, nutrient cycling, regulation of water supply and regulation of pest and diseases etc. But individual species contributions is highly variable and contextual and has to be understood properly (Mason *et al.,* 2013). Globally, there is now a corpus of knowledge to support the "functional roles" played by organisms in the ecosystem functioning and processes. But such information is lacking in the case of tropical evergreen forests.

The diversity of species functions in communities is the Functional Diversity of that community. FD could also be the diversity of the "functional traits" of the particular species in a community (Mason and Bello, 2013). Functional diversity generally involves understanding communities and ecosystems based on what organisms do. Meanwhile, functional traits (FT) or characters of organisms are the effects of environmental factors or responses of ecosystem functioning (Lavorel and Garnier, 2002; Carmona *et al.,* 2016). Number of traits exist within species and also between species (Perez-Harguindeguy, *et al.,* 2013) and hence there exist an amazing array of trait diversity. So FD could also be interpreted as "the extent of functional trait variation (or differences) among the species in a community". This could also be a measure of species trait diversity. Hence, functional diversity can be a predictor tool of the functional consequences of anthropogenic biotic changes (Chapin *et al.,* 2000;

Loreau *et al.,* 2002). Invariably FD measures are now excellent predictor of changes in ecosystem processes.

The Western Ghats is an acclaimed biodiversity hotspots in the world (Myers, 2000). The forests in the Vazhachal Forest Division is the part of Anaimalai hills in the southern-Western Ghats and is celebrated for its high degree of endemism (Bachan, 2003; Raman *et al.,* 2009; Anitha *et al.,* 2010). Like elsewhere, here too, there are evidences of tremendous changes in the forest structure and dynamics over time. Thus, a well-planned temporal investigation of the Functional Diversity of this area will provide valuable benchmark data about ecosystem drivers, effects, and responses over time. Such data will help us to understand the "change matrix" and take informed actions in the effective conservation and sustainable management and utilization of these tropical evergreen forests. Since the concept of FD analysis is an emerging line of investigation, there is also a need to standardize an appropriate and replicable protocol for measuring and assessing species and functional diversity which the Kerala Forest Department can later employ to meet the objectives of the new National Working Plan Code 2014.

With these backgrounds, the present study was conceptualized with the following objectives;

a) To enumerate the species and functional diversity of selected aboveground and belowground biological components of a tropical evergreen forest ecosystem.
b) To understand the links between diversity, soil aspects and functioning of the tropical evergreen forest ecosystem.

Review of literature

REVIEW OF LITERATURE

Forest is an important natural resource for the human beings. Tropical forests are home to world's most threatened biodiversity hotspots (Blaser *et al.,* 2011; Sathish *et al.*, 2013). These forests also supports more or less half of the human population which induces extreme pressure on them (FAO, 2012; Sabogal *et al.*, 2013). In addition, climate change is also currently causing rapid negative impacts in structure and functioning of ecosystems (IPCC, 2014). Hence, there is an urgent need to periodically monitor the functioning of ecosystems (Perez-Harguindeguy *et al.*, 2013; MOEF, 2014). Most often ecosystem monitoring is related with the species richness. The quantitative values are assigned equal weightage ignoring the ecosystem functions that different species deliver in the ecosystems (Mason *et al.*, 2005). On other hand, functional diversity (FD) will throw light on the individual roles that species play in ecosystem functioning in changing environments (Petchey and Gaston, 2006).

Functional traits (FT) or characters of an organism are the effect of environmental factors or response of ecosystem functioning (Heemsbergen *et al.*, 2004). Numerous traits exist within species and also between species (Cornelissen *et al.,* 2003; Perez-Harguindeguy *et al.,* 2013). Functional diversity indices like functional richness, functional evenness, functional dispersion, functional redundancy and functional divergence (Mason *et al.,* 2005; Petchey and Gaston, 2006) will help to develop a deeper understanding of the ecosystem functioning (MEA, 2005). Understanding of behaviors of the communities is useful in evolving proper management strategies and predicting the interactions of plants and animals in changing environments (Bhat and Murali, 2001).

2.1. Phytosociological studies in India

Tropical regions always have luxuriant biodiversity in the world due to the abundant overhead sunlight coupled with rainfall (Magesh, 2014; Blaser *et al.*, 2011).

The diversity of tree is a key component of total biodiversity in many ecosystems as they provide wide range of resources and habitats for all organisms found in forest (Jayakumar and Nair, 2013). So, the tree forms one of the major structural and functional base in the tropical forest ecosystems and also serve as indicator of changes in the landscape level (Magesh, 2014). Most often diversity of trees varies with environmental factors, edaphic factors, level of disturbance and biotic factors (Parthasarathy *et al.*, 2008). Small sized inventory plots has several advantages over large plots. Small sized plots can be easily repeated and much variation of the habitats can be represented in many small plots scattered throughout the area than in one large plot equal in area (Magesh, 2014).

Ganesh *et al.* (1996) explored the undisturbed mid elevation evergreen forest of Kalakad Mundanthurai Tiger Reserve in Southern western Ghats. He reported the total of 173 tree species from 35 families from 3.82 ha area of Agasthyamalai. Forest has L shaped curve DBH classes indicates good regeneration in the climax forest. Highest species diversity index is 4.87 recorded in Thekakachi of Kalakad. *Cullenia exarillata*, *Aglaia elaeagnoidea* and *Palaquium ellipticum* are the predominant species whereas *Lauraceae*, *Rubiaceae* and *Euphorbiaceae* are the predominant families in the Agasthyamalai.

Pascal and Pelissier (1996) reported a mean density is 635 trees per ha and basal area 123.8 m^2 in tropical wet evergreen forest in Uppangala, Karnataka. He recorded ninety one tree species in which 47 species were endemic to the Western Ghats. *Vateria indica, Myristica dactyloides*, *Humboltia brunonis* and *Dipterocarpus indicus* were dominant in this forest. A total of 31 families represented by *Euphorbiaceae*, *Anacardiaceae*, *Lauraceae* and *Meliaceae* were the dominant families in Uppangala in central Western Ghats. On the lower sloping areas, the stratification was continuous and saturated with *Vateria indica* and *Myristica dactyloides*. This justifies the argument that the tropical evergreen forest is dominated by different species in different canopy strata.

Parthasarathy (1999) studied the distribution of undisturbed and human-impacted sites of tropical wet evergreen forest in Kalakad National Park, Western Ghats, India. Greatest species richness (85 species ha^{-1}) and tree density (855 stems ha^{-1}) was found in the undisturbed evergreen forest than other studied landscapes. *Cryptocarya bourdillonii, Cullenia exarillata, Harpullia arborea* and *Myristica dactyloides* are the predominant trees in undisturbed evergreen forest. *Elaeocarpus venustus*, *Litsea wightiana*, *Viburnum punctatum* and *Vitex altissima* are dominant in the frequently disturbed cardamom plantations which are not found in undisturbed evergreen forest and selectively felled secondary forest. *Euphorbiaceae*, *Moraceae* and *Myrtaceae* were the predominant families in the evergreen forests.

Kadavul and Parthasarathy (1999) studied the tropical semi-evergreen forest in the Shervarayan hills of Eastern Ghats, India. *Chionanthus paniculata, Syzygium cumini, Canthium dicoccum* and *Ligustrum perrottetii* are the predominant species whereas *Euphorbiaceae*, *Rubiaceae, Oleaceae* and *Rhamnaceae* are the dominated families in the all types of land use system in the Sanyasimalai reserve forest of the Shervarayan hills. Species richness (50 species belong to 30 families) was greatest in the undisturbed forest plot, where the soil is deeper. The author observed that while tree girth increased there is a decrease in species richness and stand density.

Ayyappan and Parthasathy (1999) inventoried the tree community spectrum of 30 ha permanent plots of the Varagalaiar in Anamalai Tiger Reserve in Tamil Nadu. They reported a total of 153 tree species in 50 families with 447 trees per ha. In this area *Poeciloneuron indicum* and *Dipterocarpus indicus* occupies the upper storey. *Reinewardtiodendron anamalayanum* and *Fahrenheitia zeylanica* was observed in the midstorey while *Drypetes longifolia* was found in the lower storey.

Parthasarathy (2001) studied the three disturbances level of evergreen forest in Sengaltheri and adjoining areas of the KMTR of the southern Western Ghats. He recorded a total of 125 species from 42 families and 91 genera in which undisturbed forest recorded highest richness of 82 species and 965 stems ha^{-1}.

Annaselvam and Parthasarathy (2001) studied the diversity and distribution of herbaceous vascular epiphytes in a tropical evergreen forest at Varagalaiar, Western Ghats, India. A total of 26 epiphytic species from 19 genera distributed in 16 families in angiosperms was reported from this place. *Orchidaceae*, *Piperaceae* and *Araceae* were the dominant families. *Drynaria quercifolia* of *Polypodiaceae* is the most dominant ferns among 10 species found in the study area.

Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh of Eastern Himalayas reveals that mildly disturbed stand (20% disturbance) has the highest species richness with 54 species of 51 genera than other sampled stands (Bhuyan *et al.*, 2003). All the stands were dominated with *Shorea assamica*, *Dipterocarpus macrocarpus*, *Mesua ferrea*, *Castanopsis indica*, *Terminalia chebula* and *Vatica lanceaefolia*. Highest tree species diversity index (2.02) and the highest forest stand density (5452 stems ha^{-1}) was recorded in the undisturbed stand (0% disturbance index). *Dipterocarpaceae*, *Clusiaceae*, *Theaceae* and *Combretaceae* contributed more than 90% to the total stand. Highest shrub density was observed in the undisturbed stand and maximum species richness was observed in the mildly disturbed stand. *Blastus cochinchinensis* and *Litsea salicifolia* are the dominant shrubs. Similarly the highest herb and vine density was onserved in the undisturbed stand. *Cyperus rotundus*, *Forestia glabrata* and *Pteris quadrissmita* were common to all the stands.

Effect of gap size on the species composition in humid tropical forests of Uttara Kannada district by Bhat and Ravindranath (2007). They encountered slightly more number of species in large gaps due to the availability of sunlight which triggers the establishment, survival and abundance of species. Large gaps in tropical evergreen forests favours the transportation of the seeds of different species. At the same time, light demanding species establishes very well whereas small gaps favoured by the shade demanding species.

Parthasarathy *et al.* (2008) studied the 75 sites of tropical dry evergreen forest along the Coromandel Coast of peninsular India. They enumerated 149 woody species distributed in the 49 families belonging to 122 genera with species richness range from 10-69 species. Among the life forms, trees dominated the region and the species encountered were *Memecylon umbellatum, Tricalysia sphaerocarpa* and *Pterospermum canescens*.

Ramachandra *et al.* (2012a) extensively studied the Kan forest (tropical wet evergreen forest) of central Western Ghats. He documented around 185 species, 109 species of trees, 39 species of shrubs, 12 species of herbs and 25 species of climbers from sampled area of 1.8 ha. *Dipterocarpus indicus, Palaquium ellipticum, Mesua ferrea* and *Syzygium spp.* are the predominant species which there. A total of 51 families of which *Euphorbiaceae*, *Rubiaceae* and *Lauraceae* are dominant families. In shrubs, species like *Dichapetalum gelonioides, Psychotria flavida, Memecylon terminale* and *Glycosmis pentaphylla* are predominant in the Kan forests. Dense evergreen forests always have low amount of herbs. However Kan forest of Karnataka displayed a similar trend with 12 species belonging to 7 families and 10 genera. *Alpinia malaccensis, Boesenbergia pulcherrima, Cyrtococ cumoxyphyllum, Dracaena terniflora, Justicia simplex, Lagenandra ovata, Ophiorrhiza hirsutula* and *Rungia pectinata* are some of dominant herbs which occurred in the Kan forests.

The vegetation structure and ecological characteristics of forest of North Andaman Islands was studied by Prasad *et al.* (2009). The tropical evergreen forest there reported 93 species, 67 genera and 36 families. *Myristica andamanica. Pterygota alata, Dipterocarpus grandiflorus, Celtis wightii* and *Pterospermum acerifolium* dominated in the evergreen forests. While the evergreen forest reported high species richness and basal area, the semi-evergreen forest displayed high tree diversity, but the moist deciduous species had high tree density. *Anacardiaceae* and *Sterculiaceae* are the dominant families across all the forest types and were distributed throughout the North Andaman Islands. Distribution of tree girth class showed decreasing number of trees with increasing girth class, indicating the occurrence of good natural regeneration in these forests.

Sathish *et al.* (2013) compared the floristic diversity in tropical wet evergreen forest between northern and southern parts of Western Ghats of Karnataka. *Lagerstroemia lanceolata, Elaeocarpus tuberculatus, Dimocarpus longan, Canarium strictum and Hopea glabra* are dominant in the southern part whereas *Knema attenuata, Oleadioica, Spondias pinnata, Hopea ponga* and *Syzygium gardneri* in the northern part. This may be due to disturbances which resulted in changes in the forest structure and composition. *Hopea glabra* and *Knema attenuate* are high ranking endemics in southern and northern regions respectively. This study shows that the richness and diversity of southern part was comparatively higher than northern part of Western Ghats, whereas the richness of threatened tree species was comparatively higher in northern part of Western Ghats.

A total of 133 species including 81 tree species from 34 families and 52 liana species distributed from 28 families were inventoried from the ten sites of tropical dry evergreen forest on the Coromandel Coast of India (Vivek and Parthasarathy, 2015). *Memecylon umbellatum, Glycosmis mauritiana* and *Albizia amara* were the predominant tree species. Among lianas, *Strychnos lenticellata, Combretum albidum* and *Reissantia indica* were the most abundant liana species in tropical dry evergreen forest of the Coromandel Coast.

2.1.2. Floristic diversity studies in Kerala

Basha (1987) conducted exhaustive study at Silent Valley National Park. They identified 383 individuals of 33 species in a 50 x 50 m plot. The index of Simpson's diversity was 3-3.9 in the tropical wet evergreen forests at Silent Valley National Park. Meanwhile, Sankar (1990) found 335 individuals (> 10 cm GBH) of 33 trees species belonging to 18 families in 50 x 50 m quadrats in the undisturbed evergreen forests at Pothurnala of Nenmara forest division in Kerala. The Simpson's index was estimated to be 0.87 which indicates high species diversity in west coast evergreen forests. *Palaquium ellipticum* and *Cullenia exarillata* are the dominant species which occupies the top storey. The second storey was dominated by the *Agrostistachys meiboldii* and *Drypetes alata.*

Hussain (1991) compared the three different landuse systems in Nelliyampathy area of Kerala and observed the physiognomy, phytosociology, phenology, microclimate and soil attributes in tropical wet evergreen forest. Undisturbed evergreen forests registered a maximum of 17 different species belonging to 13 families with 177 individuals (>30 cm GBH) in 50 x 50m quadrats than the other studied land use systems. The highest value of diversity index and Simpson index was recorded from evergreen forest compared to the other landuse systems. The first storey was dominated by species such as *Palaquium ellipticum, Cullenia exarillata* and the second storey was dominated by *Drypetes wightii.*

Chandrashekara and Ramakrishnan (1994) studied the vegetation and gap dynamics of a tropical wet evergreen forests in Nelliyampathy area. A total of 69 species are recorded from the Nelliyampathy area. Canopy gaps are common in this type of forest due to tree fall during monsoon season (Krishnan, 2001). *Palaquium ellipticum, Cullenia exarillata* and *Mesua nagassarium* are well represented in seedlings, saplings and mature trees whereas trees like A*glaia exstipulata* and *Mastixia arborea* are not observed in seedling stages. The size distribution of seedlings, saplings and mature trees showed negative exponential distribution which clearly indicates the prevalence of small girth class stems. A study was carried out by Rajesh and their co-workers (1996) to characterize development of vegetation as the time function after selection felling in tropical wet evergreen forests of Sholayar. Four quadrats (40 m x 40m) were established in selected patches of 7, 16, 21 and 28 year before 1992 representing the early and late seral characteristics. All trees and shrubs above (10 cm) were enumerated, while to study the regeneration four 5x5m sub quadrats established in the main quadrats. Even though the relative proportion of the early and late successional species was dependent of gap age, about 62-85% of the tree species were common across logging coupes. As the gap age increased, abundance of late successional species such as *Palaquium ellipticum*, *Mesua nagassarium* and *Vateria indica* were also increased. Floristic diversity declined as time after gap formation increased. Moreover. Floristic diversity indices were generally lower than those of many formations in the Western Ghats. Vegetation structure of tropical wet evergreen forests along the Western Ghats which varied location to location depends on the prevailing conditions (Pascal and Ramesh, 1987; Pascal *et al.*, 2004).

Varghese and Kumar (1997) studied the floristic and edaphic attributes of three fresh water swamps in southern Western Ghats by establishing 50 x50 m quadrats in each swamps. The swamp vegetation exhibited lower floristic diversity and smaller floristic variation than other surrounded tropical wet evergreen forests. Utkarsh *et al.* (1998) extensively studied the entire Western Ghats using 108 transect lines (average of 383 m x 20m) across seven forest types. A total of 20785 individuals belongs to 398 species. Chandrashekara *et al.* (1998) reported that *Palaquium ellipticum, Cullenia exarillata, Mesua ferrea* and *Drypetes wightii* are the dominant species in the mature tree phase in the permanent plot established in the wet evergreen forest at Pothumala. In this *Ardisia pauciflora, Syzygium laetum, Meigogyne pannosa* and *Aglaia tomentosa* are the dominant shrub species.

Varghese and Balasubramanyan (1999) was conducted studied floristic diversity of the wet evergreen forest in Agasthyamalai region of the southern Western Ghats, Four 0.1 ha plots were laid using stratified random sampling. He recorded a total of 435 individuals belonging to 79 species and spreading over 37 families. The stand density shows gradual increase from lower altitude to high altitude in the tropical west coast evergreen forest. This forest type were dominated by the *Mesua-Cullenia- Dimocarpus* type with Clusiaceae, Myrtaceae and Lauraceae as the important families. Varghese and Menon (1999) recorded 151 tree species over 51 families with 62 endemics from Peppara wildlife sanctuary in Kerala. Maximum diversity index (3.25) in tropical evergreen forest. It has Euphorbiaceae, Anacardiaceae and Clusiaceae as dominant families. *Dimocarpus longan, Cullenia exarillata* and *Vateria indica* are dominant trees in the Peppara wildlife sanctuary.

Sharma *et al.* (2002) studied extensively the floristic, insect and bird diversity in new Amarambalam reserves of Nilgiri Biosphere Reserves all seven forest types. Out these forest types tropical evergreen forest recorded highest species richness with 155 species comprising 132 tree, 18 liana and four shrubs were recorded from 92 plots extending to 8200 ha, than other studied forest types.

The extensive study conducted at across Vazhachal forest division reveals that a total of 166 species which belongs to 144 genera and 66 families (Bachan, 2003). *Vateria, Hopea, Hydnocarpus* and *Xanthophyllum* are predominant near riverside of west coast wet evergreen forests. Fabaceae, Euphorbiaceae and Orchidaceae are predominant families existed along the riversides of evergreen forest. The wet evergreen forests recorded tree diversity ranges about 419 trees/ ha.

Damodharan (2004) conducted study at tropical evergreen forest in Sholayar reveals that 101 species (>10 cm GBH) with 907 individuals per ha. *Cullenia exarillata* is registered highest density followed by the *Palaquium ellipticum* and *schleichera oleosa.* The index of species diversity was 0.98 which quite high in tropical wet evergreen forest in Sholayar. He has observed that maximum five strata in typical tropical wet evergreen forest. Magesh (2014) aims to understand the floristic and structural status over tropical wet evergreen forest of Parambikulam Tiger Reserve in Kerala. He recorded that a total of 161 species of flowering plants belonging to 103 families 564 individuals/ha (>30 cm GBH) were recorded from all over Parambikulam Tiger Reserve. Tropical wet evergreen forest was dominated with *Palaquium ellipticum, Aglaia barberi, Drypetes oblongifolia* and *Cullenia exarillata* with Euphorbiaceae Lauraceae and Meliaceae as dominant families. High value of tree diversity 4.07 Simpson's dominance value (0.02) and Margalef's

Species richness values are high in trees forms (19.44) when compared to other life forms West coast tropical evergreen forests. Girth class distribution for the evergreen forest represents a negative exponential or 'inverse J' curve which showing the good population of regeneration (Richards, 1996).

Nair and Jayakumar (2005) examined the floristic diversity of shola-grassland vegetation in new Amarambalam reserve forest of Kerala. In relation to variation of altitude fifty six quadrats of 30 m x 30 m were laid randomly. Floristically, the shola forest comprised of 65 species of angiosperms, composed of 41 trees. 9 shrubs, 3 liana and 2 herbaceous species in 25 sample plots. The adjoining grasslands harbored 50 species of angiosperms from 31 sample plots. Plant diversity analysis indicated that Shannon index of shola vegetation is higher than that of grasslands, because this may be due to forest fire and other anthropogenic influences which degrades the condition of the grasslands.

A field study was conducted at south Wayanad district of Kerala to compare the various floristic and edaphic attributes of three land use patterns viz. ecologically fragile land, section 5 land and vested forest (Aneesh, 2011). Five 20x20 m size were established in each land use system and all individuals are enumerated as 10 cm above DBH and below 10 DBH. Maximum of 40 species registered in the ecologically fragile land than others. Vested forest had the maximum density, basal area followed by ecologically fragile land and section 5 land.

Sakthivel and Sreekumar (2011) studied the biodiversity significance, landuse pattern and conservation of Malayattoor forests in the Western Ghats of Kerala. It has greater floristic diversity which shows 385 species of angiosperms from the all over Malayattoor forests division of Kerala. 171 species of flowering plants of which about 35% are endemic to Peninsular India. Some of the Western Ghats endemics are *Baccaurea courtallensis*, *Calophyllum elatum*, *Bhesa indica*, *Chilocarpusmalabaricus*, *Palaquium ellipticum*, *Ormosia travancorica*, *Syzygium mundagam*, *Microtropis latifolia*, *Aglaia barberi*, *Dysoxylum malabaricum*, *Gomphostemma keralensis*, *Psychotria anamallayana* and *Miliusa tomentosa*. The main rare threatened plants in the forest are *Vateria indica, Dipterocarpus indicus*, *Hopea glabra*, *Hopea parviflora, Nothopegia beddomei*, *Myristica malabarica*, *Litsea bourdillonii* and *Diospyros ovalifolia*. Manju *et al.* (2011) recorded 40 species of bryophytes including 24 mosses and 16 liverworts of Kakkavayal reserve forest in the Western Ghats.

Kumar *et al.* (2012) explored the floral diversity of Konni Forest Division and its distribution in relation to various edaphic factors. The forest division covers two major forest types are southern moist mixed deciduous forest and west coast evergreen forests. *Vateria indica, Palaquium ellipticum, Cullenia exarillata* and *Mesua ferrea* predominates in the evergreen patch. The Shannon – Weiner diversity index of west coast evergreen forests ranges from 3.2 – 3.8 also showed fairly moderate species diversity. West coast evergreen forests of Konni is evenly distribution of plant species and the Pielou's evenness index is between 0.91 – 0.98. The Simpson's dominant index was between 0.4 – 0.6 indicating no over dominance of species in the west coast evergreen forests.

Jayakumar and Nair (2013) assessed the species diversity and tree regeneration patterns of different types of vegetation in new Amarambalam part of Western Ghats, India by using the stratified random sampling. The tropical evergreen forest was second highest number of 122 species (>30 cm GBH) with Euphorbiaceae and Rubiaceae as dominated families in 30 m × 30 m plots. The tropical evergreen forest was highest density and second highest Shannon Weiner index of 3.34. 98 species were matured, 81 species were sapling and 78 species were seedling stage. *Palaquium ellipticum, Agrostistachys borneensis, Myristica beddomei, Reinwardtiodendron anamalaiense* and *Calophyllum polyanthum* as the dominant species.

Chandrashekara (2013) studied the tree population dynamics in a low elevation evergreen forest in Sivapuram in the Western Ghats of Kerala, India where

Knema attenuata, Myristica malabarica, Holigarna arnottiana, Polyalthia fragrans and *Hopea parviflora* were dominant tree species. There is no significant change in species richness, density and basal area over the last decades.

2.2. Morphological Functional traits of trees

2.2.1. Plant type

Tropical plants are adopting different strategies to withstand the adverse conditions prevailing their habitat in which one of the most prevalent is senescence of leaves (Singh and Kushwaha, 2005). Plant types are influenced by the abiotic factors, which in turn affect intra- and inter annual pattern of water, carbon and energy balance (Chaturvedi and Raghubanshi, 2013; Singh and Kushwaha, 2005). Plant type is primarily influences the range of important eco-physiological processes, including photosynthesis, transpiration, stomatal conductance, chlorophyll content, thermoregulation and vary with a number of environmental factors (Yates *et al.*, 2010). Deciduous plants are shed their leaves during the drought or frost seasons of the year which prevents the damages from the plants parts and conserve the energy which increases the survival of plant species of that locations (Singh *et al.*, 2016). Mass or bulk leaves deposition in the forest floor conserve the soil moisture by means of mulching, provides suitable shelters of other organisms and nutrient dynamics of the forests. Singh *et al.* (2016) reported the plants types of tropical dry deciduous forests of Gurgaon district in northern India. Parthasarathy *et al.* (2008) studied the 75 tropical dry evergreen forest in peninsular India recorded a total of 149 species in which 75 are evergreen (50%), deciduous (45 species, 30%) and brevi-deciduous species. Chaturvedi (2010) studied the plant leaf traits in the vindhyan regions of the India.

2.2.2. Leaf type

Leaf traits are most important to determine the herbivory damage (Anil and Parthasarathy, 2016a). Generally plants are has two types leaves like simple and compound. The compound leaves helps the plants to increase leaf cooling and controlling water loss (Yates *et al.,* 2010). Also helps to avoid high light intensity, high temperature and excessive evaporation by folding of their leaflets at noon. Singh *et al.* (2016) studied the leaf type the tropical dry deciduous forest region of Gurgaon district in northern India.

2.2.3. Leaf toughness

Leaf toughness or texture is the coarseness of the leaf of the plant (Kitajima and Poorter, 2010). Tropical plants were adopting the different leaf toughness like glabrous and pubescent. Different leaf texture of the tropical evolved due to various factors such as environments, defensive chemical compounds, disturbances etc. (Wakio, 2010; Shanij *et al*., 2016). High toughness of leaves were reduces the palatability or decomposing or fracturing by the organisms like invertebrates and microbes, simultaneously plants gets ability of balancing water loss, resistance to herbivores and pathogen infections (Cornelissen *et al*., 1999; Gessner, 2005; Goncalves *et al.,* 2007; Wakio, 2010; Shanij *et al*., 2016). High toughness of leaves slowly decompose in the forest floor which provides ideal shelter to invertebrates and ideal microclimate to the other organisms (Graca and Zimmer, 2005; Rahman *et al*., 2013).

2.2.4. Leaf size

Leaf size is the amount of leaf area. It is potentially influences many aspects of functioning of tree such as of transpiration rates, photosynthesis rate and chlorophyll content often varies in a predictable way in response to environmental gradients (Westoby *et al*., 2002). There is distinctive variation among genera, species and individuals within a species, even between the same individuals at different stages of development or on different parts of the same tree (Malhado *et al*., 2009). These variations are influenced due to the factors like environmental, edaphic, chemical compositions and disturbances (Wakio, 2010; Shanij *et al*., 2016). More leaf area facilitates the more amount of photosynthesis which is influenced in the faster growth of trees (Niinemets, 1998). Singh *et al.* (2016) studied the functional traits of leaves in tree and shrub species from three protected forests in the tropical dry deciduous forest region of Gurgaon district in northern India.

2.2.5. Bark thickness

Bark thickness is the amount of extraneous tissues from the vascular cambium (including secondary phloem, periderm and nonconductive tissues outsides to the periderm) present in the plant (Paine *et al.*, 2010). Bark thickness is plays an important role in determining the plant resistance to the biotic and abiotic disturbances, wood degradation, structural support, water balance, affinity of epiphytes, microbes, invertebrates and animals (Wilson and Witkowski, 2003; Rajput and Rao, 2007; Nelson and Hudler, 2007; Paine *et al.*, 2010;Poorter *et al.*, 2014; Anil and Parthasarathy, 2016b). More amount bark thickness will helps to reduce the above said disturbance and vice versa. Bark thickness varies with plant species, stem diameter and location of the plant (Hegde *et al.*, 1998). Wood boring organisms has ability to weak, or kill standing trees via boring the hole, thereby reducing the timber quality and also playing important functional role by provides the habitats to the other organisms like food for ants, nests for birds, refuge or shelter for millipedes, host sites for the parasites etc. (Thomas *et al.*, 2009). Thicker barked plants also become a habitat for tree nesters and wood borers. Yunus *et al.* (1990) reported that mean bark thickness of 1.80 cm from the 103 inland trees of India. Hegde *et al.* (1998) studied the bark thickness of 77 woody species in evergreen forests in Uttara Kannada in Karnataka. Pinard and Huffman (1997) reported that mean bark thickness of Bolivian forest is 1.44 cm. Poorter *et al.* (2014) recorded the bark thickness of 50 woody species from each dry and moist forest of Bolivia. Anil and Parthasarathy (2016b) assessed the bark thickness of 105 woody plant species from Indian tropical dry evergreen forest ranged from 0.01 to 2.23 ± 0.22 cm which was positively related to stem diameter for all species.

2.2.6. Bark texture

Bark texture or coarseness is playing crucial role in determining the resistance to biotic and abiotic disturbance factors to the plant (Rajput and Rao, 2007; Paine *et al.*, 2010). Density, diversity and locomotion of both sessile as well as mobile organisms on tree bark (Cramer, 1975; Stephenson, 1989). Smooth texture bark on tree was have to be anatomical defences against insect attack (Ferrenberg and Mitton, 2014). Fissure barked plants become a habitat for tree nesters and wood borers. Yunus *et al.* (1990) examined the bark texture of the 103 inland trees of India. Thomas *et al.* (2009) reported the bark texture of 32 tall-tree species from 20 families in Nilgiri Biosphere Reserve in Western Ghats. Indian tropical dry evergreen forest, the most common bark texture was rough (51.42%) with deep fissures followed by smooth texture (Anil and Parthasarathy, 2016b).

2.2.7. Fruit type

The fruit is the one of most important reproductive material in the form of seeds to the future plant generations (Bawa and Hadley, 1991; Bhat and Murali, 2001). Plants in the tropics are evolved by adopting the different types of fruiting (Like drupe, berry, samara, legumes, nuts, follicles capsules, dehiscent etc. for their survival (Bawa *et al.*, 1989). Fruit types are evolved by numerous biotic and abiotic factors. Fleshy fruit pulp is the one of the major food resource for many frugivores like invertebrates, mammals, birds and also reptiles (Watve *et al.*, 2003). These frugivores is also act as seed dispersers which is a fundamental process where the zoochorous assisted natural regeneration (Howe and Smallwood, 1982; Gabriella and Howe, 2007; Albrecht *et al.*, 2012). Fallen fruits were offer the delicious food resources for organisms like microbes invertebrates and other animals, at the sametime these organisms helps to improve the survivability of the plant species (Chukwuka *et al.*, 2010; Ruxton and Schaefer, 2012; Hanumantha *et al.*, 2014). Parthasarathy (1999) reported that evergreen forest of Kalakad- Mundanthurai Tiger Reserve of Tamil Nadu which has 76% bear fleshy fruits (48% berries and 28%

drupes), 24% dry fruits (including 5% of species with arillate seeds) and the remaining without any rewards. 92% of epiphytes in the wet evergreen forest in the Western Ghats are produce capsule and dust diaspores whereas remaining 8% produce berries and nutlets (Annaselvam and Parthasarathy, 2001). Sethi and Howe (2012) observed the different fruit types in a semi-evergreen forest of the Indian Eastern Himalaya. Parthasarathy *et al.* (2008) recorded that drupe and berry were the common fruit types and were found in tropical dry evergreen forest of peninsular India. Capsule, follicle and pods are predominant fruit type in tropical dry evergreen forest of Coromandel Coast of peninsular India (Anil and Parthasarathy, 2015).

2.2.8. Dispersal mode

Dispersing of reproductive material is crucial role in survival and distribution of plant species (Howe, 1977; Bawa *et al.*, 1989). So the establishment and extinction of plant species of a forest area widely influenced by the diversity and abundance of dispersal agents (Watve *et al.*, 2003; Anil and Parthasarathy, 2015). Most of the species are adopting the dispersing of seeds by means of animals, explosive, passive and wind at the sametime (Bawa *et al.*, 1989; Murali and Sukumar, 1994; Davidar *et al.*, 2015), dispersing seeds are crucial role in the life history of organisms like microbes and invertebrates (Ganesh and Davidar, 1999). Sethi and Howe (2012) studied the seed dispersers in a semi-evergreen forest of the Eastern Himalaya. The majority of species are autochorous (wind dispersal) and a few with berries and nutlets are dispersed by small vertebrates (Anil and Parthasarathy, 2015).

2.3. Litter dwelling invertebrates

Pedogenesis or soil formation is significantly influenced by the set of physical, chemical and biotic processes (Mani *et al.*, 2008). Primarily after the physical weathering of rocks, which colonize the substrate by the pioneer species such as lichen, mosses and other organisms (Culliney, 2013). Then further breaks down into soil particles with the addition of organic matter by the colonization of the higher plants and soil invertebrates (Mani *et al.*, 2008; Biswas and Mukherjee, 2013). Thus, forest soils are formed by an amalgamation of clastic materials and biological origin. The direct or indirect actions of soil invertebrates in the decomposition of litters and adhering microflora convert into other forms of energy.

Invertebrates are the dominant group of animal kingdom throughout the world (Edgar, 1992; Ewers *et al.*, 2014). Most of the terrestrial invertebrates are at least some stages of their life as soil dwellers (Giller, 1996). However, an enormous number of invertebrates are living in the soil which consists of *Turbellarians, Oligochaetes, Crustaceans, Insecta, Diplopods, Chilopods, Arachnids* and *Gastropods* (Coleman *et al.*, 2004).

Invertebrates found in the soil are playing the most important functional role in engineering the forest soil ecology and maintenance of health (Jones *et al.*, 1994; Pimentel *et al.*, 1997; Barrios 2007; Jouquet *et al.*, 2014). Because, these are playing an important role in regulation of soil climate, decomposition of litters, soil detoxification, nutrient mobilization, pollination, trophic regulation, seed dispersal, microhabitat for other fauna and also act as biological control in the edaphic environment (Edgar, 1992; Nicholsa *et al.*, 2008; Johnson *et al.*, 2015; Shanij *et al.*, 2016). Most of invertebrates are adopted different type feeding habits such as detritivores, microbivores, coprovores and saprovores (Rahman *et al.*, 2012). It also regulated by physiochemical characters of the soil such as aggregation and porosity, hydraulic properties, acidity, nutrient content and soil organic matter (SOM) thereby improves the soil structure which increases the microorganisms population (Gardi and Jeffery, 2009). These regulations directly influence the richness and abundance of vegetation (Barrios, 2007). So, there is the positive relationship between abundance of soil invertebrates and soil fertility of ecosystem (Agoua *et al.*, 1998; Lenka *et al.*, 2010). Due to its extraordinary opportunities for studying on population and community ecology offered by the soil invertebrates, it is often used as a monitoring tool for ecosystem management (Jouquet *et al.*, 2014). Being good indicators of climatic conditions as well as seasonal and ecological changes, they can effective in formulating strategies for biodiversity conservation prioritization programme (Giller, 1996; Fernandez, 2012; Jouquet *et al*., 2014).

Highly sensitive to the environmental factors such as litter depth, vegetation, temperature, humidity, light, rainfall and slope of the terrain are directly effects the abundance of soil invertebrates (Rossi and Blanchart, 2005; Sabu *et al*., 2008; Nicholsa *et al*., 2008; Rahman *et al*., 2012). These leads to spatial and temporal heterogeneity of soil invertebrates in many of forest ecosystems (Giller, 1996; Rossi and Blanchart, 2005). *Isoptera* is most dominant order among invertebrates in the tropical forests which has a greater assimilation rate allows converting a major portion of litter directly into biomass than other soil invertebrates (Maa *et al*., 2015). On other hands *Collembola*, *Oribatida*, *Myriapoda* and *Isopoda* are greater contribute indirectly to nutrient cycling is via as secondary decomposers by pulverizing and passage through their gut (Sarkar *et al*., 2015; Maa *et al*., 2015). Pedoturbation of *Hymenoptera, Blattodea, Haplotaxida* and other soil invertebrates brings subsoil to the surface, thereby increasing the mineral content of the topsoil, providing passage for air and water infiltration (Vinod and Sabu, 2007). Local litter invertebrates occur abundantly, with a wide range of mobility. It requires enormous sampling efforts in relation to microclimate/environmental factors (Anu and Sabu, 2006). Millipedes plays an important role in soil formation processes as primary destructors of plant debris (Alagesan and Ramanathan, 2013).

Gadagkar *et al.* (1993) reported the 140 ant species belonging to 32 genera and 6 sub families from different locations of Uttara Kannada district in Western Ghats. Rossi and Blanchart (2005) recorded that the termites, earthworms and ants were the dominant groups in primary forests than other land use systems in central part of Western Ghats. Anu and Sabu (2006) assessed the diversity of litter ant assemblages in evergreen, deciduous and shola vegetation types of the Wayanad region of the Western Ghats by employing conventional and taxonomic diversity indices. They recorded about 22 species of ants and *Tapinoma* species was the dominant species in evergreen forests. Lenka *et al.* (2010) studied different land use system in and around the Similipal National Park of Orissa and found that *Isoptera* was the most dominant order of invertebrates in forest ecosystem due to the minimum amount of disturbance. *Hymenoptera* and *Araneae* were numerically dominant taxa in Sadayagiri hills of Western Ghats (Fernandez, 2012). Rahman *et al.* (2012) observed that taxonomic richness and abundance of soil invertebrates in the evergreen forest when compared to other landuse patterns. This was due to less anthropogenic pressure, habitat heterogeneity and wide range of food resources in the forest ecosystem. In the tropical deciduous forest ecosystem. Selvarani and Amutha (2013) investigated the diversity and composition of litter ants in Megamalai, Western Ghats and found that the evergreen forest had more number of individuals compared to other sampled forest types. Five millipede species under 4 orders were reported from Alagar hill reserve forest in Tamil Nadu (Alagesan and Ramanathan, 2013). Sivadasan *et al.* (2013) studied the ant diversity of Periyar Tiger Reserve in Southern Western Ghats and found that 31 ant species under 14 genus and 4 subfamilies were collected from different habitats. Lena *et al.* (2012) encountered 721 individuals belong to 50 different species and species diversity was about 2.87. Sarkar *et al.* (2015) found that the order *oribatid* was the most abundant group of invertebrates followed by *collembolans* in different types of land use patterns in West Bengal. *Gastropoda* and *Isoptera* were the dominant order in the evergreen forests of Kalakad - Mundanthurai Tiger Reserve (Mohanraj *et al.*, 2014). Bhavana *et al.* (2015) recorded 10 termite species under 4 subfamilies within a family in different landuse systems in Wayanad district. Plantations had more wood feeding termites like *Odontotermes obesus*, *Odontotermes anamallensis* and *Odontotermes yadevi*.

2.4. Soil microflora

More than 90% of the ecosystem`s net terrestrial primary production will enter to the food webs of detritivorous and get recycled (Giller, 1996; Ritz and

Young, 2004). Below-ground contributions were 1.75 times higher than above ground litter inputs and roots might provide 2.3 times more nitrogen to the soil pool (Culliney, 2013). These litters were further decomposed by microbes and invertebrates found in the soil, after it was physically weathered. Soil fungi were pioneers in the colonization of the substrates and makes them solubilized by producing enzymes (Hyde *et al.*, 2001; Sudhakaran *et al.*, 2014). The increase in bacterial population will lead to further degradation and get mixed ups with soil. Microbes efficiently convert the plant litter into much narrow carbon-nutrient ratios (Giller, 1996; Pathma and Sakthivel, 2012).

Most of the nutrients in the litter/soil system are temporarily stored or immobilized in microbial biomass and subsequently released by arthropods, as feces and death. Hence soil microbes are playing remarkable role in improvement of soil nutrient cycling, soil structure and also nurturing life of other organisms in that area (Ritz and Young, 2004; Satish *et al.*, 2007; Das *et al.*, 2013; Sudhakaran *et al.*, 2014). More amount of soil biomass constituted by fungi rather than bacteria (Saravanakumar and Kaviyarasan, 2010). Decomposition and recycling of energy by adopting the different feeding strategies such as detritivorous, microbivorous, coprovorous and saprovorous which will helps to easy decompose (Banaker *et al.*, 2012). These soil microflora are affected either directly or indirectly affected by the factors such as soil temperature, acidity, moisture content, organic matter and other soil parameters and also vice versa (Ritz and Young, 2004; Saravanakumar and Kaviyarasan, 2010; Das *et al.*, 2013). There is a huge variation of microbial population due to difference in prevailing micro and macro climatic, vegetative and also edaphic factors of that particular area (Sankaran and Balasundaran, 2000; Paulus *et al.*, 2006). Most often higher microbial population seen in surface of soil may be due to the more amounts of organic carbon, higher aeration, favorable moisture content and favorable temperature (Barbhuiya *et al.*, 2004; Wang *et al.*, 2010; Bhattacharyya and Jha, 2011). These microbes are able to sustain a relatively high biodiversity, however only a fraction of all the species have been described and very little is known about their community structure and dynamics (MEA, 2005). There are severe taxonomic and scale problems which affect our ability to work with soil communities (Armsworth *et al.*, 2007).

2.4.1. Population of soil microflora

Tropical evergreen forests are home to greatest biodiversity (including microbes) in the world, though diversity of microorganisms and their temporal interaction with physical and biological elements are not much explored due to various reasons (Sankaran and Balasundaran, 2000; Paulus *et al.*, 2006; Alagawadi *et al.*, 2012; Lakshmipathy *et al.*, 2012). Fungi are the largest and more diversified group of soil microbes in shola forests in Kerala (Sankaran and Balasundaran, 2000). Arunachalam and Arunachalam (2000) observed that gradual increase of bacterial population with increase in gap size, while no definite trend was observed for population of fungal. Barbhuiya *et al.* (2004) quantified that variations of microbial biomass and its role in soil organic matter and nutrient flux. Greater amount of bacteria and fungi populations in undisturbed evergreen forest than disturbed forest. Also variations of microbial populations across sites and also soil depth. Satish *et al.* (2007) reported that the diversity of soil fungi in Mudumalai National Park. Saravanakumar and Kaviyarasan (2010) enumerated fungal population in different locations in Tamil Nadu part of Western Ghats. More diversity and richness of soil microbes are registered in the evergreen forest than the other land use patterns sampled in Central Western Ghats (Alagawadi *et al.*, 2012). This may be due to high richness and evenness of above ground vegetation. Ramachandra *et al.* (2012b) found that high C: N ratio in evergreen forest of Western Ghats leads to faster rate decomposition because of it is moisture and high temperature combines to enhance population of soil microbes. Banaker *et al.* (2012) studied the underlying relationships of fungal and various properties of soils in central Western Ghats. Relation of soil bacterial and fungal populations to micro environment and soil characters in Dibru- Saikhowa Biosphere Reserve in Assam (Das *et al.*, 2013). Varghese *et al.* (2014) record that the population of actinomycetes in evergreen forests of Shendurney Wildlife Sanctuary. Sudhakaran *et al.* (2014) reported that the highest bacterial population at tropical dry evergreen forest, Coromandel Coast of India. Bhattacharyya and Jha (2015) studied the influence of soil properties in bacterial population in varying degree of disturbances.

2.5. Edaphic characteristics

Soil is one of the most diverse habitats and also complex ecosystems in earth. Forest vegetation is greatly influenced by underlying soil edaphic factors in addition to the climatic factors (Basha *et al.*, 1987; Kadavul and Parthasarathy, 1999; Asok and Shoba, 2014). Also there is considerable variation in the soil properties across similar land use pattern due to diversified flora and fauna (Sujatha and Thomas, 1997; Thangasamy *et al.,* 2005). Forest soil characters varies with climate, topography, weathering processes microbial activities and vegetation cover (Hussain, 1991; Bhattacharyya *et al.*, 2000; Reddy *et al.*, 2012). Several workers have made attempt to study the soil character and forest vegetation (Rajesh *et al.*, 1996; Kadavul and Parthasarathy, 1999; Kumar *et al.*, 2012; Asok and Shoba, 2014). Soil differences related to vegetation were more noticeable in surface layer (0- 15 cm) and later on effects of vegetation diminished with depth of soil. Either soil characters may significantly affect the populations of soil invertebrates (Barrios, 2007; Gardi and Jeffery, 2009; Rahman, 2010) and soil microbes nor organisms also influence the characteristics of the soil (Ritz and Young, 2004).

2.5.1. Soil physical properties

2.5.1.1. Soil Texture

Soil texture is the degree of coarseness of soil particles which is determined by the sand silt and clay proportions (Mani *et al.*, 2008). It is originated from the underlying parent material through various pedogenic process. It is most important factors to determine the biogeochemical cycles and air–water relationships which is essential for productivity and fertility of soil (Silver *et al.*, 2000; Osmon, 2011; Ramachandra *et al.*, 2012b). It is greatly widely varies across the locality. Lower bulk density results due to loamy nature of soil. A higher proportion of sand in loam produces sandy loam, which is the most predominant in tropical evergreen forest soil of Western Ghats (Suma *et al.*, 2011; Kumar *et al.*, 2012). More amount of sand and loam recorded in the evergreen forest of western Ghats due to less disturbance combined with wide range of soil biota results high pore space in soil (Ramachandra *et al.*, 2012b). In evergreen forest soil gravel content ranges between 10 – 17% (Kumar *et al.*, 2012). Arunachalam and Arunachalam (2000) observed that sandy loam of soil across wet hill forests.

2.5.1.2. Soil Bulk Density

Soil bulk density is the mass of dry soil per unit bulk volume which is an indicator of the amount of pore space available within soil horizons. It is generally depends on soil structure, pore space and composition of soil particles (Thangasamy *et al.*, 2005). It increases with depth of soil because low amount of finer particles of soil (Osmon, 2011). Bulk density influences the soil water relationship which tremendous impacts on vegetation and soil biota of that locality (Ramachandra *et al.*, 2012b).

Asok and Shoba (2014) find that the significant variation of soil bulk densities with respect to different depth and vegetation classes in Shendurney Wildlife Sanctuary of Kerala, India. Rahman *et al.* (2012) found that less bulk density values (1.6) when compared to other land use system in Malapuram district of Kerala. This is due to low anthropogenic disturbance and high amount of flora and fauna. Ramachandra *et al.* (2012b) recorded that forest soils are lower bulk density than other land use pattern may be due to loamy texture of forest soil.

2.5.1.3. Soil Moisture

Soil moisture is one of the predominant factors to determine the patterns of the forest types in a particular locality (Longman and Janik, 1987). Soil moisture content varies widely mainly depends upon seasonal rainfall of the location (Osmon, 2011; Ramachandra *et al.*, 2012b). Higher level of Soil moisture conditions results in more production of biomass residues, which is potential food source for soil organisms (Bot and Benites, 2005). Optimum moisture (field capacity) supports more soil biota activity. More moisture leads to poor aeration ultimately results suffocation causes reduction of metabolic activity of soil organisms and then leads to death. It is also affected by the soil texture, temperature, rainfall, vegetation etc.

Hussain (1991) observed that more soil moisture content (24-52 mm) in undisturbed evergreen forest of Nelliyampathy due to closed canopy of evergreen forest and also variation of phenological activity of vegetation. Rajesh *et al.* (1996) find that the moisture content of soil is higher in relatively low heighted trees. Arunachalam and Arunachalam (2000) observed that more or less same soil moisture across gap and understory forests. Barbhuiya *et al.* (2004) measured that more soil moisture content in undisturbed forest. Ramachandra *et al.* (2012b) observed that highest moisture content in evergreen forest in Western Ghats due to lower bulk density of soil leads to more space between soil particles results more moisture content.

2.5.1.4. Soil temperature

Soil temperature is the important physical properties which determines most of the physical, chemical and biological properties of the soils also influence physiological activity of soil organisms as well as forest plants (Mani *et al.*, 2008). It has tremendous ecological impacts through evaporation, transpiration, CO_2 emission due to soil respiration (Roby, 2013). In forest ecosystems, it is a prime most factor to decide the decomposition rate, humus formation, root activity, root growth, populations of microbial and soil invertebrate (Bot and Benites, 2005). Forest soil temperature is varies place to place because it is effected by numerous factors such as soil moisture, organic matter, site topography, texture, climate conditions (solar radiation, air temperature), surface area of litter and canopies of plants (Arunachalam and Arunachalam, 2000; Bot and Benites, 2005). Arunachalam and Arunachalam (2000) observed that the average soil temperature is 19 – 20°C in wet tropical forests of India. Barbhuiya *et al.* (2004) quantified that variations of soil temperature in two land use pattern in north east India. He reported that more clay content in undisturbed evergreen forest than disturbed area. Hussain (1991) recorded that low soil temperature (17 – 21˚C) in undisturbed evergreen forest when compared to two other land use patterns in Nelliyampathy area of Kerala because of closed canopy.

2.5.2. Soil chemical properties

2.5.2.1. Soil acidity

Acidity of the forest soil is one of the most crucial factor to determine type and quality of vegetation found in that particular area. Changes in soil acidity is significantly regulates the soil nutrients, this indirectly affects the biomass production and other associated biological components in soil (Bot and Benites, 2005). Increase in acidity (decrease pH value) leads to decrease the decomposition process by reducing population of bacteria and vice versa. In neutral pH with high temperature and humidity leads to faster rate of decomposition, thus supports increased number of species in the soil organisms. Extreme saline pH may influences the availability of the nutrients. Low pH caused by more rainfall whereas high pH due to water stagnation.

Sankar (1990) observed strong acidic nature of soil in unworked evergreen forest at Pothurnala of Nenmara Forest Division. Rajesh *et al.* (1996) reported that soil acidity increases with increase in age group of selection felling forest of Vazhachal due to high amount litter fall results in increases of organic acids in soil. Arunachalam and Arunachalam (2000) observed that moderate level of soil acidity in shilling, northeast India. Barbhuiya *et al.* (2004) reported that there is not much variation of soil acidity in undisturbed evergreen forest and disturbed forest. Aneesh (2011) found that undisturbed evergreen forests recorded low pH values when compared to other land used systems. Strong or moderate acidic soils are found in evergreen forests due to high rainfall leads to leaches of bases towards steeper layers (Ramachandra *et al.*, 2012b). Kumar *et al.* (2012) observed that strong acidic nature of evergreen soil in Konni forest division of Kerala. Rahman *et al.* (2012) found that moderate acidic level when compared to other landuse pattern in Malapuram district of Kerala due to soil contains aluminum ions.

2.5.2.2. Soil Electrical conductivity

Electrical conductivity of the soil is a measure of soluble nutrients which a determining factor in soil salinity. Electrical conductivity of soils widely varies across forests which regulates type and composition of vegetation (Mishra *et al.*, 2013). It is also one of the important indicator for determine physical, chemical and biological properties of soil (Paillet *et al.*, 2010; Chaudhari *et al.*, 2014). It is often plays essential role in nutrient availability of the soil to the vegetation. Vijayakumar and Vasudeva (2011) found that significant difference between electrical conductivity the soils in fresh water swamps and adjacent evergreen forests due to land slope, permeability and rainfall are responsible for leach out alkali and alkaline bases from soil. Mishra *et al.* (2013) observed that high electrical conductivity in rehabilitated forest when compared to evergreen and degraded forest in upper gangetic plains.

2.5.2.3. Soil Organic Carbon

Soil can able to stores two or three times more carbon than that of atmosphere as CO_2 (Davidson *et al.*, 2000) and 2.5 to 3.0 times as much as that stored in plants in the terrestrial ecosystem (Chhabra *et al.*, 2002; Ramachandran *et al.*, 2007). Soil organic carbon is an important determinant of site fertility by maintaining physical and chemical properties of soil (Rajesh *et al.*, 1996; Ramachandra *et al.*, 2012b). Soil fauna are convert the organic matter from the above vegetation decomposes and stores as soil organic carbon at different depths. Soil organic matter act as carbon source for various groups of microorganisms living in the soil (Ramachandra *et al.*, 2012b). Increase of soil organic carbon leads to the decrease in runoff thereby increase of water infiltration thereby reduces the soil erosion (Fernandez, 2012). Also increases the absorption of Zn, Cu and Mn like micronutrients. Soil organic carbon significantly influences the soil texture cation exchange capacity, soil water balance, microbial population and it also acts a source of plant nutrients (Ramachandra *et al*., 2012b).

Dense canopy, thick under cover, high species composition, deeper root biomass, fine soil texture cool temperature and more precipitation tends to more organic carbon (Divya *et al*., 2016). Soil organic carbon (SOC) was decreases with increasing soil depths. Sankar (1990) observed the moderate organic carbon content of soil in unworked evergreen forest at Pothurnala of Nenmara Forest Division. Rajesh *et al.* (1996) studied the soils of Vazhachal forest division which shows that higher amount of organic content in relatively more height tree area. Barbhuiya *et al.* (2004) reported that more organic carbon content of soil resulted in more water holding capacity of the soil. Suma *et al.* (2011) recorded higher organic carbon content in evergreen forests of kallada river basin. Evergreen forests in Konni forest division recorded high organic content (3.43) than moist deciduous forest in that locality (Kumar *et al*., 2012). Ramachandra *et al.* (2012b) recorded that high amount of carbon content in evergreen forest than other land use pattern. It is due to undisturbed litter layer found in the soil leads to reduce the runoff, erosion and leaching of nitrogen from the soil leads to enhance the soil biota and faster decomposition rate. Divya *et al.* (2016) find that Soil organic carbon are low in dry deciduous forest (0.13%) and high in shola forest (13.89%) of surface layer in Idukki district of Kerala.

Materials and methods

MATERIALS AND METHODS

The present study was carried out during 2014-16 to enumerate the species and functional diversity of selected aboveground and belowground biological components of the tropical west coast wet evergreen forest (IA/C4) ecosystem of Vazhachal Forest Division. The details of the study area and methodology followed in the investigations are described below.

3.1. STUDY AREA

3.1.1. Name, Location and Extent

Vazhachal Forest Division falls under Mukundapuram taluk of Thrissur district and Aluva taluk of Ernakulam district. It lies within the geographical range of 10° 05' to 10° 23' N latitudes and 76°09' to 76°52' E longitudes. This division was established on August 1, 1981 and stretches of about 41394.39 ha (KFD, 2012). It is enveloped by a portion of the Parambikulam Tiger Reserve on the north; Aliyar reserve in the northeast; Valparai reserve in the east; areas of Malayattoor Forest Division on the south and Chalakudy forest division on the west. This division comprises of five forest ranges namely Athirappalli, Charpa, Vazhachal, Kollathirumedu and Sholayar (KFD, 2012).

3.1.2. Terrain

The altitude of Vazhachal forest division varies from 200 m to 1300 m above MSL with highly rugged and hilly topography. The maximum height of 1300 m is recorded at Karimala Komban in Sholayar Range. The eastern side is more undulating than the western side of the division.

3.1.3. Climate

3.1.3.1. Rainfall

The division enjoys most of the showers from southwest monsoon and rest from northeast monsoon. The division enjoys most of the showers from southwest

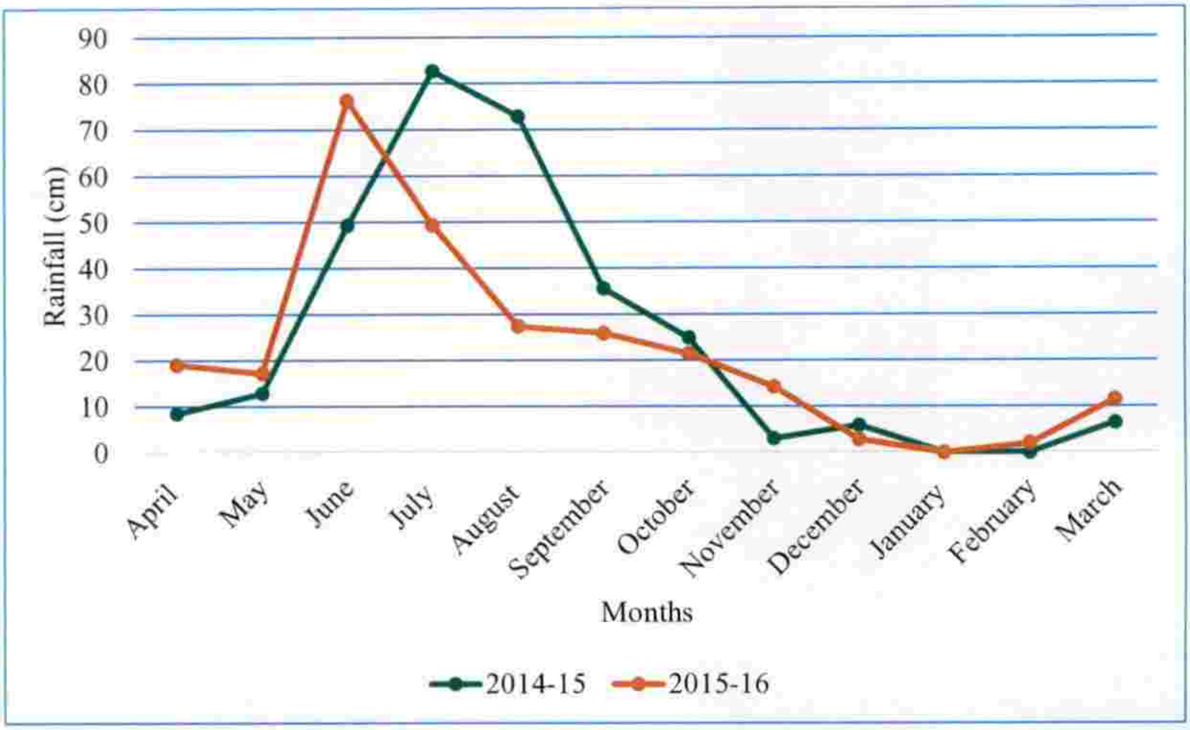

Fig. 1. Precipitation regime of Vazhachal evergreen forest ecosystem

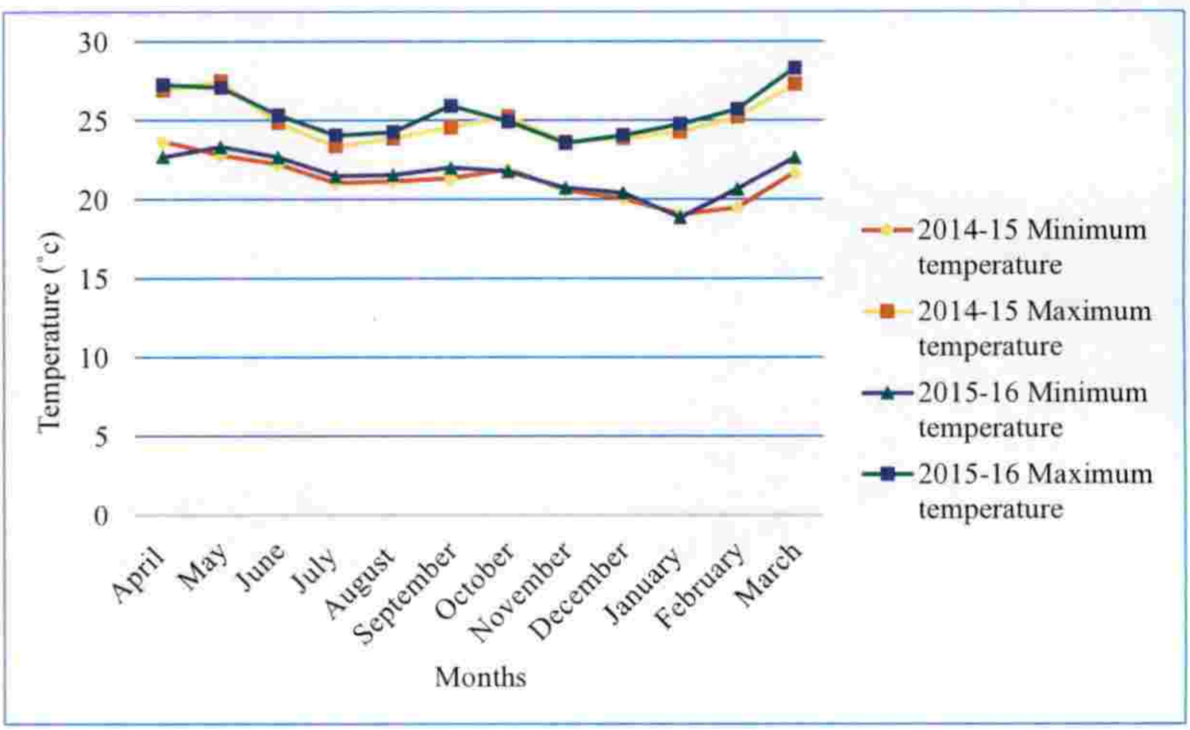

Fig. 2. Temperature regime of Vazhachal evergreen forest ecosystem

monsoon and rest from northeast monsoon. This region experiences cold season during November to February followed by summer during February to May. The area also enjoys pre-monsoon showers during the month of May. Southwest monsoon is heavy and regular during June to September. Northeast monsoon is light and irregular in the month of October to November. The average precipitation is around 3000 mm. The rainfall recorded from April 2014 to March 2016 in this ecosystem is given in Fig. 1.

3.1.3.2. Relative Humidity

The mean relative humidity varies from 50 percent to 90 percent and reaches maximum relative humidity during the rainy season.

3.1.3.3. Temperature

Vazhachal forest division enjoys salubrious climate with cooler days during November to January and hotter days from February to May. The hilltops enjoy a cooler climate than plains due to altitude and rainfall variations. The mean annual temperature ranges from 14 °C to 36 °C. The temperature regimes of the study area during April 2014 to March 2016 is given in Fig. 2.

3.1.3.4. Wind

Normally, wind does not cause much damage in this division. Violent thunders associated with pre-monsoon showers causes uprooting of trees and also spreads the seeds of weeds which results in the spread of weed growth.

3.1.4. Hydrology

The study area has abundant rivers, notably Chalakudiyar, Sholayar, Idamalayar, Karapparayar and Periyar. There are a number of small rivers and waterfalls which drain into the major rivers and finally drains into the Arabian Sea. Sholayar, Peringalkuthu and Idamalayar are the three major reservoirs in this area.

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3.1.5. Geology, Rock and Soil

The division consists of crystalline rocks of Archaean age of either igneous or metamorphic genesis series. Charnockites, granites, magnetite quartz and granitic gneisses with narrow bands of pyroxene granulate are widely occurs in the division. These are weathered into Oxisols or red ferrallitic (KFD, 2012). Lateritic soils are found in the lower tracts of the division. In the slopes, boulders are very often observed. The soil of division varies from very shallow gravelly soil on the upper slopes to deep fine textured soil on the lower slopes and in the valleys due to geological erosion and the resultant alluvial deposition along the stream and riverbanks. The surface soils are generally sandy loam in texture although the subsurface soil is loamy nature.

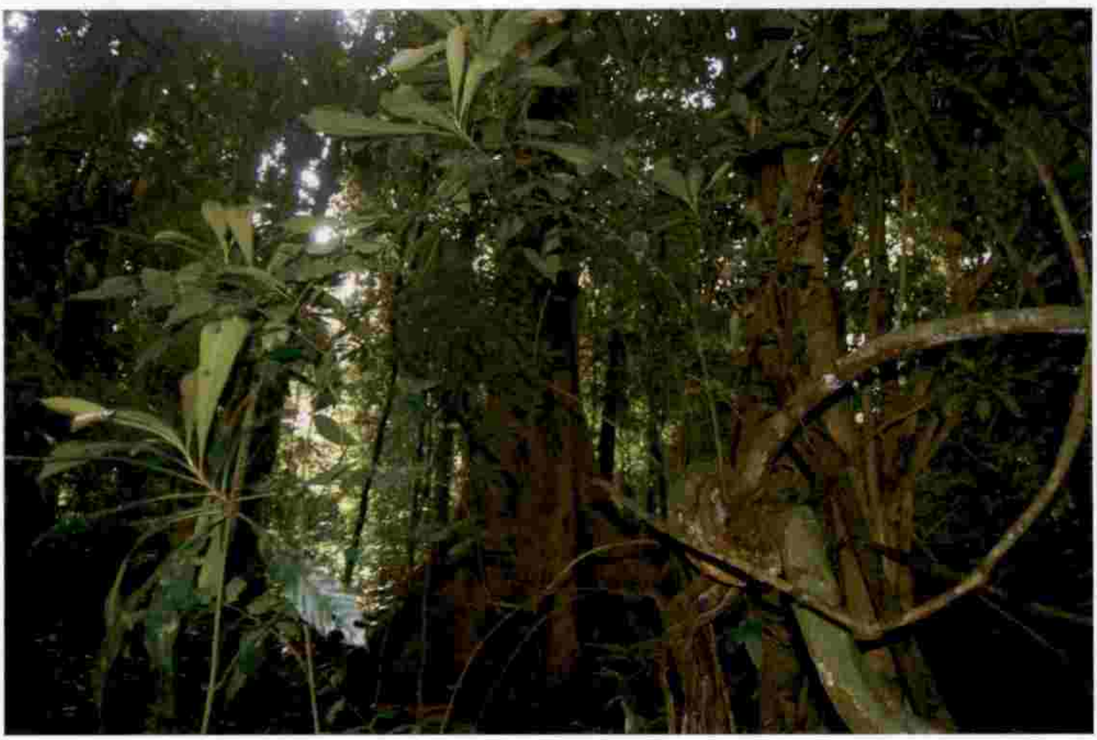
3.1.6. Vegetation

Most of the area in the division is under natural forest i.e. 34114.14 ha (58%). The division has major forest-based plantations such as Teak (3891.37 ha), Elavu (1777.99 ha) and also has miscellaneous plantations like Eucalypts, *Grevillea*, *Albizia*, *Bombax*, *Acacia* and *Erythrina* which are maintained by the forest department (KFD, 2012). Plantations of cash crops like Oil palm, Rubber, Cashew, Coconut, Coffee and Tea were dominating the periphery of the study area. The forests types, as per Champion and Seth (1968) are Southern Tropical West coast Evergreen forests (IA/C4), Southern Tropical West coast tropical semi-evergreen forests (2A/C2) and Southern tropical moist mixed deciduous forests (3B/C2). Apart from this, reed and bamboo brakes and riparian forest ecosystem are also found along the river.

3.1.6.1. Southern Tropical West Coast Evergreen Forests (IA/C4)

The southern tropical wet evergreen forest occurs in the areas of Malakkapara, Thavalkkuzhippara, Ambalappara, Sholayar, Karimalagopuram, Anakayam, Karanthodu, Repra, Shiekalmudi etc. this covers an area of about 5117.12 ha (15%)

Canopy of evergreen forests



Undergrowth in evergreen forests

Plate 1. An overview of tropical west coast wet evergreen forests in Vazhachal forest division

of natural forests in this division. Heavy rainfall due to, the higher altitude and slopes favors the growth of luxuriant vegetation which allows only few amount of sunlight because the closed canopy cover the upper region of the forest. These are "climatic climax" type of vegetation with trees of more than 45 m in height. Epiphytes, pteridophytes, orchids, mosses, aroids etc. are most commonly seen in the lower canopy. Common species found in the top canopy are *Lophopetalum wightianaum*, *Dysoxylum malabaricum*, *Palaquium ellipticum*, *Cullenia exarillata*, *Artocarpus heterophyllus*, *Calophyllum polyanthum*, *Vateria indica*, *Mesua ferrea* etc. Middle canopy is occupied by *Meliosma simplicifolia*, *Vepris bilocularis*, *Canarium strictum*, *Euodia lunu-ankenda*, *Semecarpus travancorica*, *Myristica dactyloides*, *Hydnocarpus macrocarpa*, *Bhesa indica* etc. Species like *Ardisia pauciflora*, *Litsea floribunda*, *Clausena indica*, *Atalantia monophylla*, *Litsea bourdillonii* etc. are common in the lower canopy. The undergrowth is occupied by species like *Laportea crenulata*, *Croton zeylanicus*, *Sarcococca coriacea* etc. *Sabia malabarica*, *Embelia ribes*, *Strobilanthus* sp., etc. are the commonly found climbers. In higher altitude i.e. 1200 m above MSL species like *Heritiera papilio*, *Calophyllum austroindicum* etc. forms the upper canopy. Middle canopy is dominated by the *Cinnamomum sulphuratum* etc. Strobilanthus is mainly found in the undergrowth.

3.1.6.2. Southern Tropical Semi Evergreen Forests (2A/C2)

Tropical Semi-Evergreen forests occur at Mukkumpuzha, Poringal, Ooiassery, Watchmaram, Manimaruthithodu, Muduvarachal etc. It covers an area of 13645.65 ha (40%) of natural forests in the division. These are found due to retrogression succession and has less dense canopy than evergreen forests. Upper canopy is dominated by *Calophyllum polyanthum*, *Dysoxylum malabaricum*, *Myristica dactyloides*, *Vateria indica*, *Mangifera indica*, *Kingiodendron pinnatum*, *Pterygota alata*, *Gymnacranthera canarica*, etc. The middle canopy is dominated by species like *Toona ciliata*, *Polyalthia fragrans*, *Elaeocarpus serratus*, *Garcinia morella*, *Vepris bilocularis*, *Neolitsea scrobiculata*, etc. Species like *Alangium salvifolium*, *Xanthophyllum flavescens*, *Ixora arborea*, *Callicarpa tomentosa*, etc. are there in the lower canopy. Undergrowth like *Laportea crenulata*, *Glycosmis arborea*, *Pellionia heyneana* etc. is present. Climbers like *Caesalpinia cucullata*, *Bauhinia phoenicea*, *Entada* sp., etc. are also found.

3.1.6.3. Southern Tropical Moist Mixed Deciduous Forests (3B/C2)

Southern tropical moist mixed deciduous forests are the predominant forest type in this division with an extent of 22631.62 ha (45%). It occurs in areas of lower slope and ridges of division. These vegetation which become leafless during the dry season, however, starts flushing at the onset of monsoon. Top canopy constitutes species like *Alstonia scholaris, Bombax ceiba, Grewia tilifolia, Tectona grandis, Terminalia crenulata, Xylia xylocarpa,* etc. Species like *Bridelia retusa*, *Caryota urens*, *Gmelina arborea*, *Cassia* etc. are present in the lower canopy. *Acacia intsia*, *Butea suberba* etc. are common climbers found in this division. Now-a-days weeds like *Mikania macrantha*, *Lantana camara* etc. are also common.

3.2. METHODS

3.2.1. Experimental Site

The entire Vazhachal Forest Division (413 km^2) was divided into 100 permanent grid plots, with each grid having a size of 2 km^2 as per the National Working Plan Code 2014 (MOEF, 2014) guidelines on Forest Resource Assessment (FRA). Within the 100 grid plots, 22 plots falling under the evergreen forest ecosystem were identified for further sampling. From this 22, one evergreen forest grid was selected (Grid No. 60) on the basis of composition of vegetation (Fig. 3.) for detailed investigations (Thottathura, Chandanthodu, Nellikunnu, Sorrikal- 46 and Anamadankuthu). Within this grid, five randomly laid plots 0.1 ha (31.62 m x 31.62 m) were established as per the FRA guidelines of National Working Plan Code 2014 (MOEF, 2014). The layout of the sample plots is given in Fig. 4.

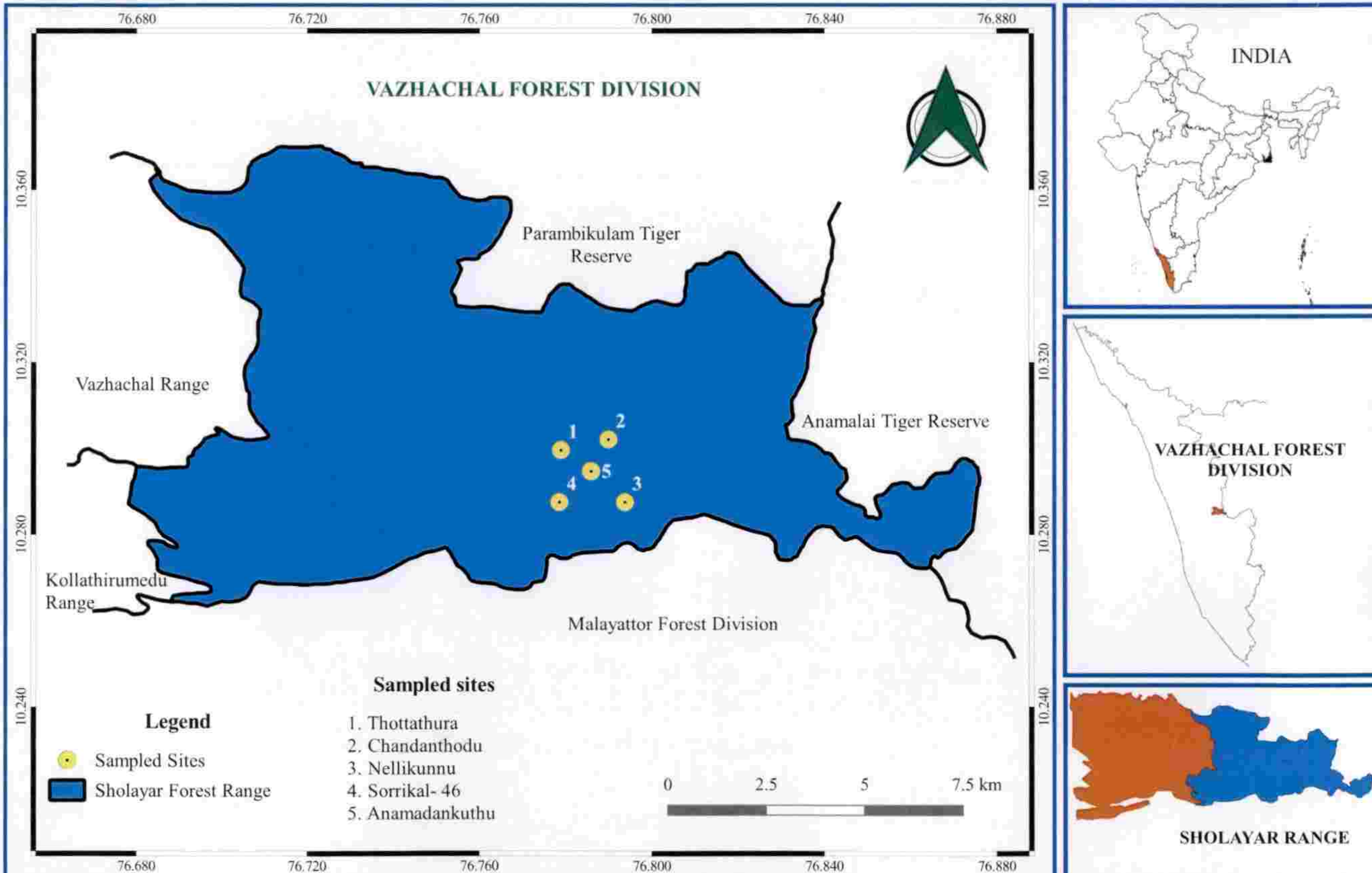


Fig. 3. Geographic location of the study area

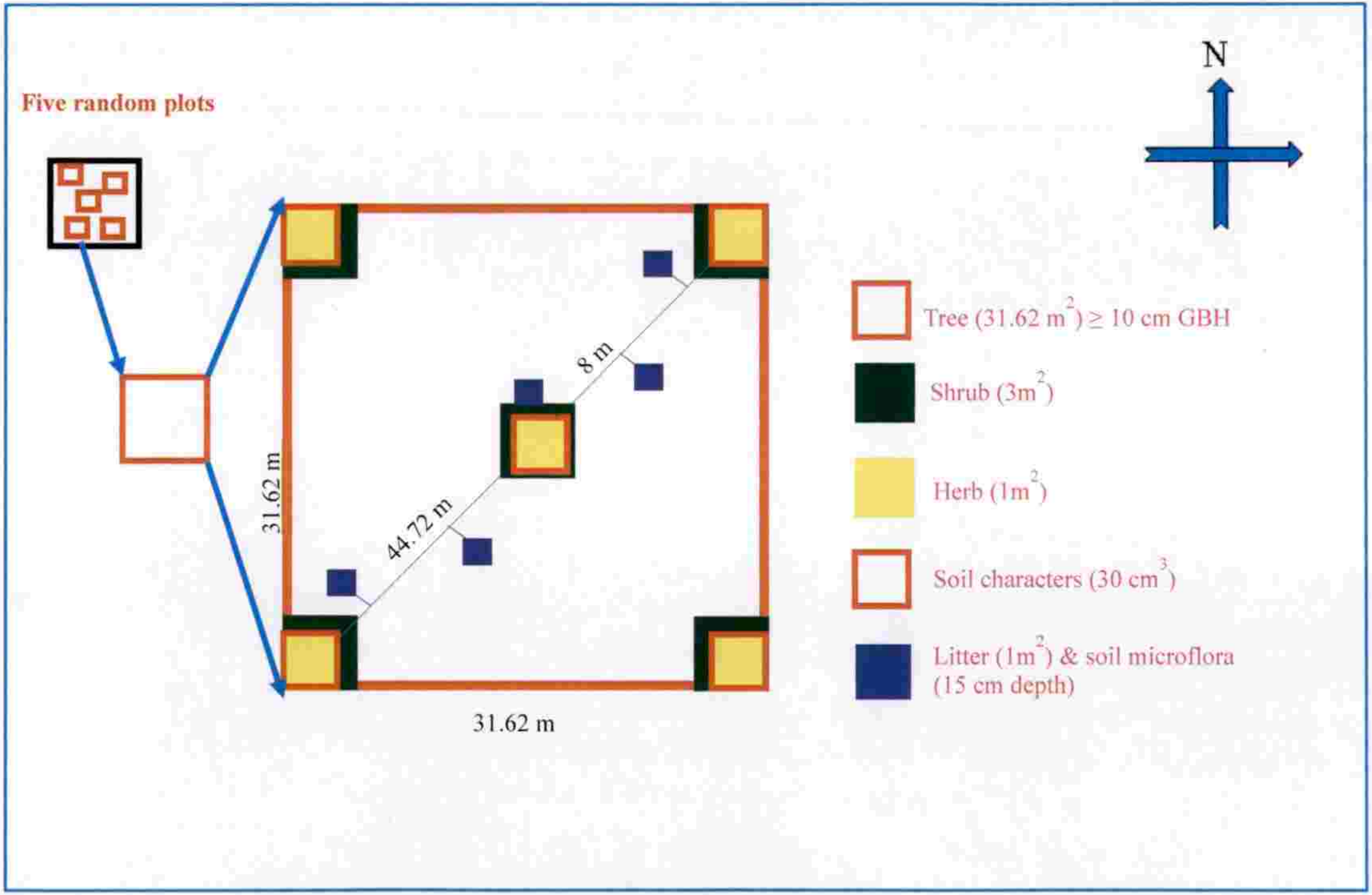


Fig. 4. Lay out of the sample plots

Aligning the sample plots

Measuring girth of tree

Measuring soil temperature

Collecting soil samples

Collecting leaf litter samples

Plate 2. Field lay out and collecting samples from the study area

3.2.2. Phytosociological investigations

3.2.2.1. Tree Height and Girth

In the sample plots, all the trees (above 10 cm GBH) in the 0.1 ha plot was enumerated (MOEF, 2014). All the species standing in the plot were identified by referring to published sources such as Gamble and Fisher (1915-1935), Mathew (1983), Sasidharan and Sivaraman (1996), Pascal and Ramesh (1987), KFRI's Flowering plants of Kerala Ver 2.0 (Sasidharan, 2012), Western Ghats Trees ID (Ramesh *et al*., 2010) and also by contacting plant taxonomists and dendrologists. The height of all trees was measured by using a Haga altimeter and expressed in meter. All trees were measured at a height of 1.37 m for girth measurements from ground level (Girth at Breast Height) by using tailor's tape and expressed in centimeters (Chaturvedi and Khanna, 1982).

3.2.2.2. Shrubs

In all the four corners and also at the central point of the 0.1 ha plot, a total of five 3 m x 3 m quadrats were laid out and all the shrubs (total count) inside it were counted and identified.

3.2.2.3. Herbs

As like the shrubs, 1 m x 1 m nested quadrats were laid within the 3 m X 3 m quadrats. All the herbs (total count) were enumerated and species are recorded and identified.

3.2.2.4. Phytosociological analysis

Vegetation community was quantitatively analyzed for their density, abundance, frequency and their relative values (Curtis and McIntosh, 1951). The Important Value Index for the species was determined as the sum of the relative frequency, relative density and relative dominance (Curtis, 1959).

Alpinia malaccensis

Arisaema leschenaultii

Colocasia esculenta

Curcuma neilgherrensis

Drosera burmannii

Laportea bulbifera

Oplismenus compositus

Pellionia heyneana

Plate 3. Herbs recorded in Vazhachal evergreen forest ecosystem

Dendrocnide sinuata

Psychotria nudiflora

Saprosma glomeratum

Solanum violaceum

Strobilanthes barbatus

Strobilanthes ciliatus

Plate 4. Shrubs recorded in Vazhachal evergreen forest ecosystem

Argyreia hirsuta

Calamus brandisii

Calamus rotang

Coscinium fenestratum

Leea indica

Pandanus tectorius

Piper trioicum

Smilax zeylanica

Plate 5. Climbers recorded in Vazhachal evergreen forest ecosystem

Adiantum aethiopicum

Adiantum caudatum

Anisocampium cummingianum

Arachniodes aristata

Christella arida

Cyathea nilgirensis

Diplazium australe

Microsorum linguiforme

Plate 6. Pteridophytes recorded in Vazhachal evergreen forest ecosystem

Daedalea dochmia

Ganoderma lucidum

Microporus xanthopus

Oxyporus cervinogilus

Panus conchatus

Phellinus adamantinus

Phellinus rhytiphloeus

Schizopora paradoxa

Plate 7. Polyphores recorded in Vazhachal evergreen forest ecosystem

Agrostistachys borneensis

Arenga wightii

Artocarpus heterophyllus

Baccaurea courtallensis

Cullenia exarillata

Vateria indica

Plate 8. Trees recorded in Vazhachal evergreen forest ecosystem

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1. Density (D) = No. of individuals/hectare

2. Relative Density (RD) $= \frac{\text{No. of individuals of the species}}{\text{No. of individuals of all the species}} \times 100$

3. Abundance (A) $= \frac{\text{Total no. of individuals of the species}}{\text{No. of quadrats of occurrence}}$

4. Frequency (F) $= \frac{\text{No. of quadrats of occurrence}}{\text{Total No. of quadrats studied}} \times 100$

5. Relative Frequency (RF) $= \frac{\text{Frequency of individual species}}{\text{Sum of frequency of all species}} \times 100$

6. Basal Area (BA) $= GBH^2/4\pi$

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

8. Important Value Index (IVI) = RD + RF + RBA

9. Relative Importance Value Index (RIVI) = Important Value Index /3

3.2.2.5. Floristic diversity

In addition to the quantitative analysis, diversity of species was calculated using Shannon – Weiner index and Simpson index (Magurann, 1988). The following formulae was used for determining the diversity of vegetation.

a) Species richness

Species richness is depicted the distinct relationship between the locations and its number of species is recognizable. The species richness was calculated using Margalef's Index (Margalef, 1958).

Margalef's Richness Index (R) = S-1/ In N

Where, S = Total number of species, N = Basal area of species

b) α -Diversity analysis

α - diversity estimates the diversity of vegetation which is often used as the indications of the well-being of any ecosystem, the following indices were worked out to assess, compare the range and distribution of plant species in the study area.

The diversity of species was calculated using Shannon- Wiener Index (Shannon and Weaver, 1963).

Shannon-Weiner's index, H' = 3.3219(Log N-1/N ∑ ni Log ni)

Where, ni = Number of individuals of the species, N = Total number of individuals

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

Simpson index D = 1 - ∑ (ni/N) 2

Where, ni = Number of individuals of the species, N = Total number of individuals in the plot, D = Diversity

Equitability gives an idea of the real distribution as compared to the maximum dispersion taking into account the number of species present in the plot. Equitability (E) was calculated following (Pielou, 1966)

Pielou`s evenness index (E) = H'/H max

Where, H max = 3.3219 log 10 S, S = Total no of species, H'= Shannon-Weiner's index

3.2.3. Assessment of Functional Traits

3.2.3.1. Morphological Traits of Trees

Plant functional traits of the tree species in the sample plots were recorded in the field and also by referring to the standard plant manuals like Gamble and Fisher (1915–1935), Mathew (1983) and Vajravelu *et al.* (1987). Plant functional traits were also sourced from published sources such as Gamble and Fisher (1915-1935), Mathew (1983), Sasidharan and Sivaraman (1996), Pascal and Ramesh (1987), Hegde *et al.* (1998), Padaki and Parthasarathy (2000), Ganesh and Davidar (2001), Kushwaha and Singh (2005), Western Ghats Trees ID (Ramesh *et al.*, 2010), Parthasarathy *et al.* (2008), Sringeswara *et al.* (2010), Muthumperumal and Parthasarathy (2010), KFRI's Flora of Kerala Ver 2.0 (Sasidharan, 2012), Vivek and Parthasarathy (2015), Singh *et al.* (2016), Anil and Parthasarathy (2016a) and Anil and Parthasarathy (2016b).

a) Plant type

Classification of plant type as Evergreen (no leafless period), brevi-deciduous (Few days to few weeks) and deciduous (more than months) as per the longevity of the leaves was done as per Singh and Kushwaha (2005) and Parthasarathy *et al.* (2008).

b) Leaf size

Leaf size classification was done based on Raunkiaer (1934). He classified the leaf size into six classes – Leptophyll (up to 0.25 cm^2), Nanophyll (0.25 – 2.25 cm^2), Microphyll (2.25 – 20.25 cm^2), Notophyll (20.25-45.00 cm^2), Mesophyll (45-182.25 cm^2), Macrophyll (182.25 – 1640.25 cm^2) and Megaphyll (> 1640.25 cm^2).

c) Leaf texture

The texture of the leaves were classified as glabrous and pubescent following Anil and Parthasarathy (2016a).

d) Leaf type

Simple and compound leaves were classified following Sringeswara *et al.* (2010).

e) Bark thickness

Following Anil and Parthasarathy (2016b), on the basis of barks thickness were classified as Thin (<0.5 cm), Medium (0.5 -1.00 cm) and Thick (>1.00cm).

f) Bark texture

Anil and Parthasarathy (2016b) classified the bark texture based on the morphology as smooth, slightly rough and rough.

g) Fruit type

Berry, drupe, follicle, capsule, samara, syconium, pods and aggregate fruits were categorized following Annaselvam and Parthasarathy (2001).

h) Dispersal mode

Three categories of fruit dispersals were identified viz., autochory, anemochory and zoochory following Ganesh and Davidar (2001) and Anil and Parthasarathy (2015).

3.2.3.4. Functional diversity

a) Functional richness (FRic)

The amount of niche space filled by species in the community was calculated following (Mason *et al.*, 2005).

b) Functional evenness (FEve)

The evenness of traits abundance distribution in filled niche space (Mason *et al.*, 2005).

$$FEve = \frac{\sum_{b=1}^{S-1} \min\left(PWE_b, \frac{1}{S-1}\right) - \frac{1}{S-1}}{1 - \frac{1}{S-1}}$$

Where, PEWb – Partial Weighted Evenness, S - Number of species

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$$PEW_b = \frac{EW_b}{\sum_{b=1}^{S-1} EW_b}$$

Where EWb - Weighted Evenness

$$EW_b = \frac{d_{ij}}{W_i + W_j}$$

c) Functional divergence (FDiv)

It describes spreads of traits across the trait space (Pla *et al.*, 2012). Functional divergence also express the degree of functional dissimilarity in trait values within the community (Mason *et al.*, 2005).

$$FDiv = \frac{\Delta d + \overline{dG}}{\Delta|d| + \overline{dG}}$$

Where Δ |d| = absolute abundance-weighted deviances, $\Delta|d| = \sum_{i=1}^{S} W_i\, x\left|dG_i - \overline{dG}\right|$, Δd = abundance-weighted deviances $\Delta d = \sum_{i=1}^{S} W_i \,x\, (dG_i - \overline{dG})$wi - The relative abundance of species 'i', dGi - Euclidean distance of each species.

$$\text{Euclidean distance of each species } dG_i = \sqrt{\sum_{t=1}^{T} (x_{ti} - g_t)^2}$$

$$\text{Mean distance dG of the S species to the gravity center } \overline{dG} = \frac{1}{S}\sum_{i=1}^{S} dG_i$$

Gravity center of V species that forms the vertices of the convex hull Gv= {g_1, g_2, ...g_t}

$$g_t = \frac{1}{V}\sum_{i \in Sv}^{V} x_{ti}$$

Where Sv is the subset of all the V species forming the vertices of the convex hull, xti is the coordinate (trait value) of species 'i' on the't' trait, T is the total number of traits and gt is the coordinate of the gravity center for trait't'.

d) Functional dispersion (FDis)

FDis is the average distance of individual species to the centroid of all species in the community trait space taken into account the relative abundances of species by computing the weighted centroid. It is calculated from the 'species x trait' matrix as

$$C = \{C1, C2, \ldots\ldots, Ct\}$$

Vector C has the coordinates of the weighted centroid in the T-dimensional space and Ct for t =1, ...T, is estimated for each dimension (trait) as

$$C_t = \sum_{i=1}^{S} W_i X_{ti}$$

Wi the relative abundance of species 'i' and Xti the value of the't' attribute of species 'i'.

FDis, the weighted average distance Z from each species to the weighted centroid c, is then computed as

$$\text{FDis} = \sum_{i=1}^{S} W_i Z_i$$

3.2.5. Diversity of Litter Dwelling Invertebrates

Line transect method (at equal distances of 8 m along the diagonal in a northeast direction) was employed to collect litter from five 1 m x1 m quadrats located on either side of transect. Litter samples are collected by scraping up all litter and loose humus from within the plot area into large polythene bags. To prevent the escape of invertebrates, samples were collected as quickly as possible. Collected samples were taken to the laboratory to study the soil invertebrates by using Berlese

Oven drying the soil samples

Estimating the soil organic carbon

Extracting invertebrates by Berlese Funnel Method

Soil invertebrates

Estimating soil microbial population

Different media for inoculation

Plate 9. Processing the collected samples

Funnel Method (Berlese, 1905). In the bottom of the Berlese Funnel apparatus, water was kept to prevent the escape of the organisms.

3.2.6. Diversity of Soil Microflora

Along a northeast direction inside the 0.1 ha plot, a line transect was made along the diagonal to undertake the soil microbial studies. At every 8 m along this transect, five 1 m x 1 m quadrats located on either side of transect were taken. From the center of each 1 m x 1 m plot, soil samples were collected from a depth of 15 cm (6 inches). The collected soil was analyzed for the total population of bacteria (10^4 dilution), fungi (10^2 dilution), actinomycetes (10^4 dilution), nitrogen fixers (10^4 dilution), phosphate solubilizers (10^4 dilution) and fluorescent pseudomonads (10^4 dilution) using serial dilution by pour plate count method. Plates were observed up to 14 days for colonies.

No. of microflora per gram of soil = Number of colonies / Amount plated × dilution factor

3.2.7. Edaphic Attributes

In the center of each of the 3 m x 3 m plots used for enumerating the shrubs, 30 cm x 30 cm x 30 cm soil pits were dug to collect soil. The collected soil samples were later analyzed in the laboratory for the different soil edaphic attributes.

3.2.7.1. Soil Physical properties

a) Soil Texture

The soil texture was measured by wetting the soil and using international pipette method (Piper, 1942). 20 g of the air-dried soil samples were taken in 500 ml beaker. 60 ml of 6% H_2O_2 was added to the beaker to destruct the organic matter of the soil. Then 8 ml of 1N NaoH was added and stirred simultaneously for the dispersion of soil particles. The contents were transferred into 1000 ml spout less cylinder. 20 ml suspension pipetted out from the cylinder was used to find out the

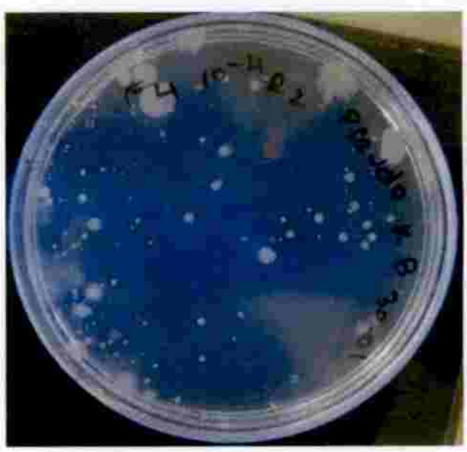
Fungi

Bacteria

Actinomycetes

Phosphate solubilizers

Nitrogen fixers



Fluorescent pseudomonads

Plate 10. Soil micro-organisms recorded in Vazhachal evergreen forest ecosystem

clay and silt particles based on their sedimentation time. By repeated washing of the sediments and after oven drying, the weight of sand particles was measured using weighing balance.

b) Bulk density

The soil bulk density was determined by using steel cylinder (Jackson, 1958). Core samples of the undisturbed soil were collected and transferred to an airtight container. It was oven dried and the weight was recorded. The volume of soil was calculated by measuring cylinder volume ($\pi r^2 h$). The bulk density was calculated by dividing the oven dry weight of soil samples (g) by volume of the core sample.

c) Soil moisture

Soil moisture was determined by the gravimetric method. It was determined by calculating the weight loss after drying the fresh soil at 100-110°C for 24 hours.

Soil moisture content (%) = Wet soil (g) – Dry soil (g)/ Dry soil (g) x 100

d) Soil temperature

The temperature of soil was measured at a depth of 15 cm. Using a wood auger a 15 cm deep hole was made and a soil thermometer was placed in the hole. After 15 minutes, observations were recorded.

3.2.7.2. Soil chemical properties

a) Soil pH

The pH of soil samples was determined by using aqueous suspension method (Jackson, 1958). Soil pH was measured by using pH meter with Soil- Water suspension ratio of 1:2.5.

b) Soil electrical conductivity

The electrical conductivity of the soil (EC) was measured by using electrical conductivity meter in the ratio of soil water suspension 1:2.5. (Jackson, 1958).

c) Estimation of soil organic carbon (SOC)

The soil organic carbon was determined by wet digestion method (Walkley and Black, 1934). The soil samples were dried and fine-grained using mortar and pestle and then passed through 2 mm sieve. 0.5 g sieved soil samples was transferred into a 500 ml conical flask to which 10 ml of 1 N $K_2 Cr_2 O_7$ and mixed thoroughly. 20 ml of Conc. $H_2 So_4$ was added to the conical flask and then was kept for 30 minutes for oxidation. Then 100 ml distilled water was added with two drops of phenanthroline indicator. It was titrated against 0.5 N $FeSo_4$ solution until dull green color to chocolate dull red color. A blank was also run simultaneously and readings were noted.

$$\text{Soil organic carbon (\%)} = \frac{\text{Amount of 1 N } K_2 Cr_2 O_7 \text{used x 0.003 x 100x 100}}{\text{77 x weight of sample g}}$$

Soil organic matter was calculated by multiplying the value of organic carbon by 1.334 (Van Bemmelen factor).

3.2.8. Statistical Analysis

The experimental data was subjected to statistically analysis using the one way analysis of variance (one way ANOVA) by using SPSS V.21.0. Species accumulation curve and rank abundance assessments were done using BiodiversityR Ver. 2.6-1 (Kindt and Coe, 2005). To relate the vegetation, soil microflora, soil invertebrates and edaphic attributes, multivariate analysis was done. Functional traits were linked with ecosystem properties using FDiversity Ver 1.0 (Casanoves *et al.*, 2011).

Results

RESULTS

The present study was carried during 2014-16 to understand the species and functional diversity of an evergreen forest ecosystem of Vazhachal Forest Division in Kerala. The results obtained from the study of the sampled plots are outlined below.

4.1. Species Composition and Vegetation Structure (<10 cm GBH) in all Plots

All individual species having a GBH of below 10 cm were recorded from all the plots (Table 1 and Fig. 5).

4.1.1. Thottathura

A total of 79 species including 18 tree recruits, 14 shrubs, 18 herbs, 12 climbers, 5 pteridophytes, 4 orchids, 2 epiphytes, 2 bryophytes and 4 polypores were recorded from Thottathura.

4.1.2. Chandanthodu

In Chandanthodu, a total of 66 species were recorded, of which 24 tree recruits, 13 shrubs, 11 herbs, 6 climbers, 6 pteridophytes, 2 epiphytes and 4 polypores.

4.1.3. Nellikunnu

From Table 1 and Fig. 5, it can be seen that Nellikunnu, there were 17 recruits, 10 shrubs, 9 herbs, 5 climbers, 5 pteridophytes, 2 orchids, 6 epiphytes and 3 polypores. A total of 57 species were recorded from Nellikunnu.

4.1.4. Sorrikal- 46

Sorrikal- 46 had the highest number Sorrikal- 46 had the highest number of species (80). Of these 27 were recruits, 10 shrubs, 17 herbs, 6 climbers, 5 pteridophytes, 4 epiphytes, 4 bryophytes and 6 polypores.

4.1.5. Anamadankuthu

Sixty nine species including 24 recruits, 12 shrubs, 11 herbs, 6 climbers, 6 pteridophytes, 4 epiphytes and 6 polypores were recorded from Anamadankuthu.

Table 1. Plot wise species composition (<10 GBH) at Vazhachal evergreen forest ecosystem

Sl. No.	Species	Family	Habit	Thottathura	Chandanthodu	Nellikunnu	Sorrikal- 46	Anamadankuthu
1.	*Actinodaphne malabarica*	Lauraceae	Trees	✓	✓	✓	✓	✓
2.	*Aglaia barberi*	Meliaceae	,,	✓		✓	✓	✓
3.	*Agrostistachys borneensis*	Euphorbiaceae	,,	✓		✓	✓	
4.	*Alangium salvifolium*	Alangiaceae	,,	✓				
5.	*Antiaris toxicaria*	Moraceae	,,			✓		✓
6.	*Antidesma montanum*	Euphorbiaceae	,,				✓	
7.	*Aphanamixis polystachya*	Meliaceae	,,	✓			✓	
8.	*Artocarpus heterophyllus*	Moraceae	,,	✓	✓			
9.	*Bischofia javanica*	Euphorbiaceae	,,			✓		✓
10.	*Calophyllum polyanthum*	Clusiaceae	,,			✓	✓	✓
11.	*Canarium strictum*	Burseraceae	,,		✓	✓	✓	
12.	*Carallia brachiata*	Rhizophoraceae	,,		✓			
13.	*Chionanthus mala-elengi*	Oleaceae	,,	✓				
14.	*Chrysophyllum roxburghii*	Sapotaceae	,,				✓	✓
15.	*Chukrasia tabularis*	Meliaceae	,,					
16.	*Cinnamomum malabatrum*	Lauraceae	,,		✓			
17.	*Cullenia exarillata*	Bombacaceae	,,	✓	✓			
18.	*Dalbergia lanceolaria*	Fabaceae	,,		✓			
19.	*Debregeasia longifolia*	Urticaceae	,,				✓	
20.	*Dimocarpus longan*	Sapindaceae	,,	✓	✓		✓	
21.	*Diospyros bourdillonii*	Ebanaceae	,,				✓	
22.	*Dipterocarpus indicus*	Dipterocarpaceae	,,	✓		✓	✓	✓
23.	*Drypetes wightii*	Euphorbiaceae	,,				✓	✓
24.	*Dysoxylum beddomei*	Meliaceae	,,					✓
25.	*Dysoxylum malabaricum*	Meliaceae	,,	✓	✓			
26.	*Elaeocarpus variabilis*	Elaeocarpaceae	,,					✓
27.	*Flacourtia montana*	Flacourtiaceae	,,		✓			

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28.	*Garcinia wightii*	Clusiaceae	,,		✓			
29.	*Hopea parviflora*	Dipterocarpaceae	,,		✓		✓	
30.	*Kingiodendron pinnatum*	Fabaceae	,,				✓	
31.	*Knema attenuata*	Myristicaceae	,,			✓	✓	
32.	*Lophopetalum wightianaum*	Celastraceae	,,					✓
33.	*Macaranga peltata*	Euphorbiaceae	,,	✓				
34.	*Mallotus philippensis*	Euphorbiaceae	,,			✓		✓
35.	*Mangifera indica*	Anacardiaceae	,,		✓			
36.	*Mastixia arborea*	Cornaceae	,,				✓	
37.	*Meigogyne pannosa*	Annonaceae	,,				✓	
38.	*Melicope lunu-ankenda*	Rutaceae	,,		✓			✓
39.	*Mesua ferrea*	Clusiaceae	,,	✓			✓	
40.	*Myristica beddomei*	Myristicaceae	,,		✓	✓	✓	✓
41.	*Palaquium ellipticum*	Sapotaceae	,,	✓	✓		✓	
42.	*Persea macrantha*	Lauraceae	,,					✓
43.	*Phoebe wightii*	Lauraceae	,,		✓			
44.	*Poeciloneuron indicum*	Clusiaceae	,,		✓			✓
45.	*Polyalthia fragrans*	Annonaceae	,,		✓			
46.	*Reinwardtiodendron anamalaiense*	Meliaceae	,,		✓		✓	
47.	*Schefflera wallichiana*	Araliaceae	,,				✓	
48.	*Strychnos nux-vomica*	Loganiaceae	,,	✓	✓	✓		✓
49.	*Syzigium laetum*	Myrtaceae	,,	✓				
50.	*Tetrameles nudiflora*	Datiscaceae	,,	✓	✓	✓		✓
51.	*Toona ciliata*	Meliaceae	,,		✓	✓		
52.	*Trichilia connaroides*	Meliaceae	,,					✓
53.	*Turpinia malabarica*	Staphyleaceae	,,			✓		✓
54.	*Vateria indica*	Dipterocarpaceae	,,	✓	✓		✓	✓
55.	*Vernonia arborea*	Astraceae	,,			✓	✓	✓
56.	*Xanthophyllum arnottianum*	Polygalaceae	,,				✓	✓
57.	*Xylia xylocarpa*	Fabaceae	,,			✓		✓

58.	*Aeschynanthus perrottetii*	Gesneriaceae	Shrubs	✓				
59.	*Ageratina adenophora*	Astraceae	,,				✓	
60.	*Allophylus serratus*	Sapindaceae	,,	✓		✓		✓
61.	*Antidesma acidum*	Euphorbiaceae	,,	✓				
62.	*Barleria courtallica*	Acanthaceae	,,	✓				
63.	*Costus speciosus*	Costaceae	,,	✓	✓			
64.	*Debregeasia longifolia*	Urticaceae	,,				✓	
65.	*Dendrocnide sinuata*	Urticaceae	,,	✓	✓	✓	✓	✓
66.	*Dendrophthoe falcata*	Loranthaceae	,,					✓
67.	*Ecbolium viride*	Acanthaceae	,,	✓	✓		✓	
68.	*Grewia serrulata*	Tiliaceae	,,			✓	✓	✓
69.	*Isonandra lanceolata*	Sapotaceae	,,				✓	
70.	*Justicia beddomei*	Acanthaceae	,,	✓				
71.	*Justicia santapaui*	Acanthaceae	,,			✓		
72.	*Lepianthes umbellata*	Piperaceae	,,	✓	✓			✓
73.	*Nothapodytes nimmoniana*	Icacinaceae	,,	✓			✓	✓
74.	*Persicaria chinensis*	Polygonaceae	,,		✓			
75.	*Piper hapnium*	Piperaceae	,,		✓			
76.	*Rungia wightiana*	Acanthaceae	,,	✓	✓			✓
77.	*Sida mysorensis*	Malvaceae	,,			✓	✓	
78.	*Strobilanthes ciliatus*	Acanthaceae	,,	✓	✓	✓	✓	✓
79.	*Strobilanthes decurrens*	Acanthaceae	,,		✓		✓	
80.	*Strobilanthes dupenii*	Acanthaceae	,,	✓				✓
81.	*Strobilanthes neoasper*	Acanthaceae	,,			✓		✓
82.	*Symplocos macrophylla*	Symplocaceae	,,		✓	✓		
83.	*Tabernaemontana gamblei*	Apocynaceae	,,	✓				
84.	*Tarenna monosperma*	Rubiaceae	,,		✓	✓		✓
85.	*Taxillus tomentosus*	Loranthaceae	,,		✓			
86.	*Thottea siliquosa*	Aristolochiaceae	,,		✓	✓		✓
87.	*Alpinia malaccensis*	Zingiberaceae	Herbs	✓	✓	✓		✓

88.	*Amorphophallus commutatus*	Araceae	,,	✓	✓	✓		✓
89.	*Arisaema leschenaultii*	Araceae	,,	✓				✓
90.	*Belosynapsis vivipara*	Commenliaceae	,,	✓				✓
91.	*Bulbophyllum kaitiense*	Orchidaceae	,,				✓	
92.	*Clerodendrum infortunatum*	Lamiaceae	,,				✓	
93.	*Colocasia esculenta*	Araceae	,,	✓			✓	
94.	*Commelina paludosa*	Commelinaceae	,,	✓	✓			✓
95.	*Costus speciosus*	Costaceae	,,				✓	
96.	*Crassocephalum crepidioides*	Asteraceae	,,	✓	✓		✓	
97.	*Curcuma aeruginosa*	Zingiberaceae	,,	✓	✓			
98.	*Curcuma orchioides*	Zingiberaceae	,,		✓	✓	✓	
99.	*Cyrtococcum longipes*	Poaceae	,,	✓	✓		✓	
100.	*Dicliptera foetida*	Acanthaceae	,,	✓			✓	
101.	*Girardinia diversifolia*	Urticaceae	,,	✓				✓
102.	*Glycosmis pentaphylla*	Rutaceae	,,				✓	
103.	*Impatiens gardneriana*	Balsaminaceae	,,	✓			✓	
104.	*Laportea bulbifera*	Urticaceae	,,			✓	✓	
105.	*Leea indica*	Leeaceae	,,			✓	✓	
106.	*Micrococca mercurialis*	Euphorbiaceae	,,	✓	✓	✓	✓	
107.	*Oplismenus compositus*	Poaceae	,,	✓		✓	✓	✓
108.	*Peperomia pellucida*	Piperaceae	,,	✓				✓
109.	*Robiquetia josephiana*	Orchidaceae	,,				✓	
110.	*Scleria corymbosa*	Cyperaceae	,,	✓	✓		✓	
111.	*Sonerila rheedii*	Melastomataceae	,,	✓				✓
112.	*Strobilanthes ciliatus wall.*	Acanthaceae	,,			✓		
113.	*Tabernaemontana gamblei*	Apocynaceae	,,			✓	✓	
114.	*Zingiber neesanum*	Zingiberaceae	,,	✓	✓			✓
115.	*Asparagus racemosus*	Liliaceae	Climbers	✓		✓	✓	
116.	*Caesalpinia bonduc*	Fabaceae	,,		✓			
117.	*Calamus brandisii*	Palmae	,,	✓	✓	✓		✓

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118.	*Calamus hookerianus*	Palmae	,,	✓				✓
119.	*Calamus thwaitesii*	Palmae	,,	✓	✓			✓
120.	*Calamus travancoricus*	Palmae	,,				✓	
121.	*Calamus vattayila*	Palmae	,,				✓	
122.	*Coscinium fenestratum*	Menispermaceae	,,		✓			
123.	*Derris brevipes*	Fabaceae	,,			✓		
124.	*Diploclisia glaucescens*	Menispermaceae	,,		✓			
125.	*Gnetum edule*	Gnetaceae	,,			✓		
126.	*Millettia rubiginosa*	Fabaceae	,,				✓	
127.	*Paramignya beddomei*	Rutaceae	,,	✓				
128.	*Pandanus tectorius*	Pandanaceae	,,	✓	✓		✓	
129.	*Piper mullesua*	Piperaceae	,,	✓			✓	✓
130.	*Smilax zeylanica*	Smilacaceae	,,	✓				✓
131.	*Strychnos colubrina*	Loganiaceae	,,	✓				
132.	*Toddalia asiatica*	Rutaceae	,,	✓				✓
133.	*Ventilago maderaspatana*	Rhamnaceae	,,	✓				
134.	*Vigna pilosa*	Fabaceae	,,	✓		✓		
135.	*Acrostichum aureum*	Pteridaceae	Pteridophytes	✓				
136.	*Adiantum aethiopicum*	Pteridaceae	,,				✓	
137.	*Adiantum caudatum*	Pteridaceae	,,				✓	
138.	*Anisocampium cummingianum*	Athyriaceae	,,		✓		✓	✓
139.	*Arachniodes aristata*	Dryopteridaceae	,,		✓	✓	✓	✓
140.	*Blechnum colensoi*	Blechnaceae	,,		✓	✓		✓
141.	*Bolbitis semicordata*	Lomariopsidaceae	,,		✓	✓		✓
142.	*Botrychium lanuginosum*	Botrychiaceae	,,	✓				
143.	*Christella arida*	Thelypteridaceae	,,	✓				
144.	*Christella parasitica*	Thelypteridaceae	,,		✓	✓		
145.	*Cyathea nilgirensis*	Cyatheaceae	,,		✓		✓	✓
146.	*Diplazium australe*	Athyriaceae	,,	✓			✓	
147.	*Pteridium aquilina*	Pteridaceae	,,	✓				

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148.	*Bulbophyllum kaitiense*	Orchidaceae	Orchids	✓				
149.	*Christisonia tubulosa*	Orobanchaceae	,,	✓		✓		
150.	*Peliosanthes teta*	Haemodoraceae	,,	✓				
151.	*Robiquetia josephiana*	Orchidaceae	,,	✓		✓		
152.	*Funaria hygrometrica*	Funariaceae	Epiphytes					
153.	*Heterodermia japonica*	Physiciaceae	,,	✓	✓	✓	✓	✓
154.	*Hypotrachyna crenata*	Parmeliaceae	,,			✓		
155.	*Leptogium brebissonii*	Collemataceae	,,					
156.	*Lycopodium cernuum*	Collemataceae	,,	✓	✓	✓	✓	✓
157.	*Macromitrium sulcatum*	Othotrichaceae	,,					✓
158.	*Usnea undulata*	Parmeliaceae	,,			✓	✓	
159.	*Floribundaria floribunda*	Meteriaceae	Bryophytes	✓			✓	
160.	*Funaria hygrometrica*	Funariaceae	,,				✓	✓
161.	*Macromitrium sulcatum*	Othotrichaceae	,,				✓	
162.	*Meteriopsis reclinata*	Meteriaceae	,,	✓				
163.	*Daedalea dochmia*	Fomitopsidaceae	Polyphores	✓	✓			
164.	*Fomes pseudosenex*	Polyporaceae	,,	✓	✓			
165.	*Funalia caperata*	Polyporaceae	,,	✓	✓			
166.	*Leucophellinus hobsonii*	Schizoporaceae	,,				✓	
167.	*Microporellus obovatus*	Polyporaceae	,,					✓
168.	*Microporus xanthopus*	Polyporaceae	,,	✓	✓			✓
169.	*Oxyporus cervinogilus*	Schizioporaceae	,,					✓
170.	*Panus conchatus*	Polyporaceae	,,				✓	
171.	*Phellinus adamantinus*	Hymenochaetaceae	,,		✓			
172.	*Phellinus fastuosus*	Hymenochaetaceae	,,				✓	
173.	*Phellinus rhytiphloeus*	Hymenochaetaceae	,,				✓	
174.	*Schizopora paradoxa*	Schizoporaceae	,,		✓			✓
175.	*Trametes menziesii*	Polyporaceae	,,				✓	

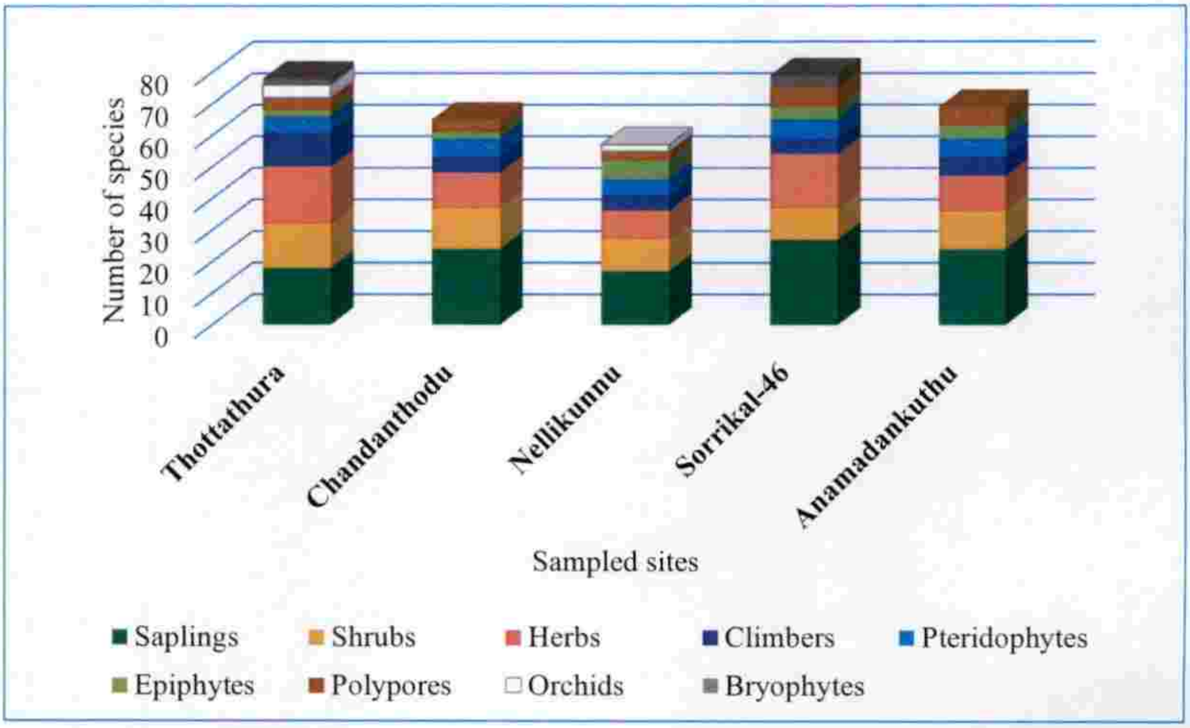

Fig. 5. Plant species composition (<10 cm GBH) at Vazhachal evergreen forest ecosystem

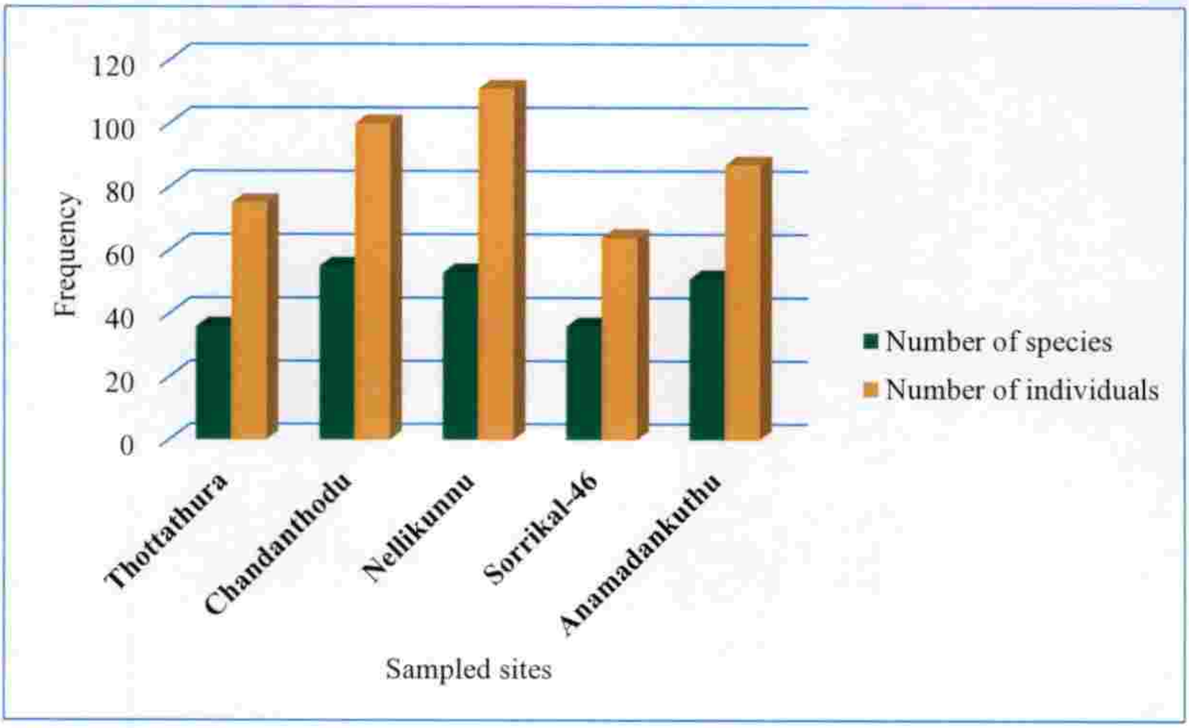

Fig. 6. Tree species composition (>10 cm GBH) at Vazhachal evergreen forest ecosystem

4.1.6. Overall

From all the sample plots of Vazhachal forest division, 176 plant species including 57 recruits, 29 shrub species, 28 herbs, 20 climbers, 14 pteridophytes, 13 polypores, 7 epiphytes, 4 orchids and 4 bryophytes could be recorded.

4.2. Species Composition and Vegetation Structure (>10 cm GBH)

4.2.1. Overall Abundance (A), Density (D), Relative Density (RD) Basal Area (BA) and Relative Basal Area (RBA)

Overall, *Aglaia barberi* recorded the highest abundance followed by *Palaquium ellipticum, Cullenia exarillata, Mesua ferrea* and *Dipterocarpus indicus* in that order. The total density of all the plots is 1093 individuals per ha. *Aglaia barberi* had the highest density of 47.5 individuals per ha (Table 2). Out of the 84 species seen, only two species had a relative density of more than four percent (Fig. 6). The overall total basal area was 85.43 m^2 with *Palaquium ellipticum* recording the highest basal area (3.87 m^2) followed by Cullenia *exarillata* (3.37 m^2), *Mesua ferrea* and *Dipterocarpus indicus* (2.77 m^2).

4.2.2. Overall Percentage Frequency (PF), Relative Frequency (RF), Importance Value Index (IVI) and Relative Importance Value Index (RIVI)

Out of 84 species, 14 species recorded highest frequency. The relative frequencies of these 14 species were more than 2% (Table 2). *Palaquium ellipticum* dominates the vegetation with an IVI value of 10.79 followed by *Cullenia exarillata* (9.79), *Dipterocarpus indicus* (9.27) and *Aglaia barberi* (8.83) in that order. Other than these three species, all the other species had less than 3% relative importance value index.

Table 2. Species-wise population characteristics (> 10 cm GBH) at Vazhachal evergreen forest ecosystem

Sl. No.	Species	Abundance	Density (Individuals per ha)	Relative Density (%)	Basal Area (m^2)	Relative Basal Area (%)	Frequency (%)	Relative Frequency (%)	Importance Value Index	Relative Importance Value Index
1.	*Actinodaphne malabarica*	3.00	37.5	3.43	1.58	1.85	100	2.14	7.42	2.47
2.	*Aglaia barberi*	3.80	47.5	4.35	2.01	2.35	100	2.14	8.83	2.94
3.	*Agrostistachys borneensis*	2.80	35	3.20	1.04	1.21	100	2.14	6.55	2.18
4.	*Alstonia scholaris*	1.00	5	0.46	0.60	0.71	40	0.85	2.02	0.67
5.	*Antiaris toxicaria*	1.00	10	0.91	1.28	1.50	80	1.71	4.12	1.37
6.	*Antidesma montanum*	1.67	12.5	1.14	0.83	0.97	60	1.28	3.40	1.13
7.	*Aphanamixis polystachya*	1.75	17.5	1.60	0.33	0.39	80	1.71	3.70	1.23
8.	*Aporusa bourdillonii*	1.50	7.5	0.69	0.24	0.28	40	0.85	1.82	0.61
9.	*Arenga wightii*	1.00	2.5	0.23	0.05	0.05	20	0.43	0.71	0.24
10.	*Artocarpus heterophyllus*	1.50	15	1.37	2.17	2.53	80	1.71	5.62	1.87
11.	*Baccaurea courtallensis*	1.00	2.5	0.23	0.25	0.29	20	0.43	0.95	0.32
12.	*Bischofia javanica*	1.00	10	0.91	1.17	1.37	80	1.71	3.99	1.33
13.	*Bombax ceiba*	1.00	2.5	0.23	2.26	2.65	20	0.43	3.30	1.10
14.	*Calophyllum polyanthum*	1.20	15	1.37	0.85	1.00	100	2.14	4.51	1.50
15.	*Canarium strictum*	2.67	20	1.83	0.85	0.99	60	1.28	4.10	1.37
16.	*Carallia brachiata*	1.00	2.5	0.23	1.22	1.43	20	0.43	2.09	0.70
17.	*Chionanthus mala-elengi*	1.67	12.5	1.14	0.12	0.14	60	1.28	2.57	0.86
18.	*Chrysophyllum roxburghii*	2.00	5	0.46	1.83	2.14	20	0.43	3.02	1.01
19.	*Chukrasia tabularis*	1.67	12.5	1.14	0.52	0.61	60	1.28	3.03	1.01
20.	*Cinnamomum malabatrum*	1.33	10	0.91	0.35	0.41	60	1.28	2.61	0.87

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21.	*Cryptocarya wightiana*	1.00	2.5	0.23	1.20	1.41	20	0.43	2.07	0.69
22.	*Cullenia exarillata*	3.40	42.5	3.89	3.37	3.95	100	2.14	9.97	3.32
23.	*Dalbergia lanceolaria*	1.50	7.5	0.69	0.44	0.51	40	0.85	2.05	0.68
24.	*Debregeasia longifolia*	1.50	7.5	0.69	0.11	0.13	40	0.85	1.67	0.56
25.	*Dimocarpus longan*	2.40	30	2.74	1.03	1.21	100	2.14	6.09	2.03
26.	*Dimorphocalyx glabellus*	2.00	15	1.37	1.73	2.03	60	1.28	4.68	1.56
27.	*Diospyros bourdillonii*	1.67	12.5	1.14	1.38	1.62	60	1.28	4.04	1.35
28.	*Dipterocarpus indicus*	3.40	42.5	3.89	2.77	3.24	100	2.14	9.27	3.09
29.	*Drypetes wightii*	3.25	32.5	2.97	1.65	1.93	80	1.71	6.62	2.21
30.	*Dysoxylum beddomei*	1.00	5	0.46	0.49	0.57	40	0.85	1.88	0.63
31.	*Dysoxylum malabaricum*	1.50	7.5	0.69	1.54	1.80	40	0.85	3.34	1.11
32.	*Elaeocarpus variabilis*	2.00	10	0.91	0.81	0.95	40	0.85	2.72	0.91
33.	*Ficus microcarpa*	1.00	2.5	0.23	1.05	1.23	20	0.43	1.89	0.63
34.	*Filicium decipiens*	1.00	2.5	0.23	0.32	0.37	20	0.43	1.03	0.34
35.	*Flacourtia montana*	1.00	2.5	0.23	0.04	0.04	20	0.43	0.70	0.23
36.	*Garcinia morella*	2.00	10	0.91	0.16	0.19	40	0.85	1.96	0.65
37.	*Garcinia wightii*	1.25	12.5	1.14	0.55	0.64	80	1.71	3.50	1.17
38.	*Gomphandra coriacea*	2.50	25	2.29	0.52	0.60	80	1.71	4.60	1.53
39.	*Gordonia obtusa*	1.00	2.5	0.23	0.70	0.81	20	0.43	1.47	0.49
40.	*Hertiera papillo*	2.00	5	0.46	0.91	1.07	20	0.43	1.95	0.65
41.	*Holigarna grahamii*	1.00	10	0.91	1.10	1.29	80	1.71	3.91	1.30
42.	*Hopea parviflora*	3.25	32.5	2.97	1.18	1.38	80	1.71	6.07	2.02
43.	*Humboltia brunonis*	1.00	2.5	0.23	2.00	2.34	20	0.43	3.00	1.00

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44.	*Hydnocarpus pentandra*	1.00	5	0.46	1.63	1.91	40	0.85	3.22	1.07
45.	*Ixora brachiata*	1.00	7.5	0.69	0.34	0.40	60	1.28	2.37	0.79
46.	*Kingiodendron pinnatum*	1.00	7.5	0.69	1.25	1.47	60	1.28	3.44	1.15
47.	*Knema attenuata*	1.00	12.5	1.14	0.42	0.50	100	2.14	3.78	1.26
48.	*Litsea floribunda*	1.00	2.5	0.23	1.45	1.70	20	0.43	2.35	0.78
49.	*Lophopetalum wightianaum*	2.50	12.5	1.14	0.56	0.66	40	0.85	2.66	0.89
50.	*Macaranga peltata*	2.50	12.5	1.14	0.66	0.78	40	0.85	2.77	0.92
51.	*Madhuca bourdillonii*	1.00	2.5	0.23	2.27	2.66	20	0.43	3.32	1.11
52.	*Mallotus philippensis*	1.00	5	0.46	0.36	0.42	40	0.85	1.73	0.58
53.	*Mangifera indica*	1.00	5	0.46	0.86	1.01	40	0.85	2.32	0.77
54.	*Mastixia arborea*	1.00	5	0.46	1.07	1.26	40	0.85	2.57	0.86
55.	*Meigogyne pannosa*	2.00	25	2.29	0.39	0.46	100	2.14	4.88	1.63
56.	*Melicope lunu-ankenda*	1.75	17.5	1.60	0.93	1.08	80	1.71	4.39	1.46
57.	*Mesua ferrea*	3.40	42.5	3.89	2.14	2.50	100	2.14	8.53	2.84
58.	*Myristica beddomei*	2.00	25	2.29	0.48	0.56	100	2.14	4.99	1.66
59.	*Neolitsea cassia*	1.00	2.5	0.23	2.04	2.39	20	0.43	3.04	1.01
60.	*Nothopegia colebrookeana*	1.00	2.5	0.23	0.83	0.97	20	0.43	1.63	0.54
61.	*Palaquium ellipticum*	3.60	45	4.12	3.88	4.54	100	2.14	10.79	3.60
62.	*Persea macrantha*	1.00	2.5	0.23	1.35	1.57	20	0.43	2.23	0.74
63.	*Phoebe wightii*	1.50	7.5	0.69	0.82	0.96	40	0.85	2.50	0.83
64.	*Poeciloneuron indicum*	2.00	20	1.83	0.43	0.51	80	1.71	4.05	1.35
65.	*Polyalthia fragrans*	1.00	2.5	0.23	1.39	1.62	20	0.43	2.28	0.76
66.	*Prunus ceylanica*	1.00	5	0.46	1.22	1.43	40	0.85	2.75	0.92

67.	*Pterospermum reticulatum*	1.50	7.5	0.69	1.13	1.33	40	0.85	2.87	0.96
68.	*Reinwardtiodendron anamalaiense*	1.50	15	1.37	0.39	0.46	80	1.71	3.54	1.18
69.	*Saraca asoca*	1.00	2.5	0.23	0.07	0.08	20	0.43	0.74	0.25
70.	*Schefflera wallichiana*	1.33	10	0.91	0.45	0.53	60	1.28	2.72	0.91
71.	*Spondias pinnata*	1.67	12.5	1.14	0.21	0.25	60	1.28	2.68	0.89
72.	*Sterculia guttata*	1.00	5	0.46	1.21	1.42	40	0.85	2.73	0.91
73.	*Strychnos nux-vomica*	1.75	17.5	1.60	0.21	0.24	80	1.71	3.56	1.19
74.	*Symplocos macrophylla*	2.00	5	0.46	0.43	0.50	20	0.43	1.39	0.46
75.	*Syzygium laetum*	1.00	2.5	0.23	0.04	0.05	20	0.43	0.71	0.24
76.	*Tetrameles nudiflora*	2.60	32.5	2.97	1.60	1.87	100	2.14	6.98	2.33
77.	*Toona ciliata*	1.33	10	0.91	0.78	0.91	60	1.28	3.11	1.04
78.	*Trichilia connaroides*	1.00	5	0.46	0.44	0.52	40	0.85	1.83	0.61
79.	*Turpinia malabarica*	0.50	2.5	0.23	2.31	2.71	40	0.85	3.79	1.26
80.	*Vateria indica*	2.75	27.5	2.52	1.44	1.68	80	1.71	5.91	1.97
81.	*Vatica chinensis*	1.00	7.5	0.69	1.29	1.51	60	1.28	3.48	1.16
82.	*Vernonia arborea*	1.25	12.5	1.14	0.35	0.41	80	1.71	3.26	1.09
83.	*Xanthophyllum arnottianum*	1.40	17.5	1.60	0.62	0.73	100	2.14	4.46	1.49
84.	*Xylia xylocarpa*	2.00	20	1.83	1.06	1.24	80	1.71	4.78	1.59
Total		**137.00**	**1093**	**99.95**	**85.44**	**100.00**	**4680**	**100.00**	**299.95**	**100.00**

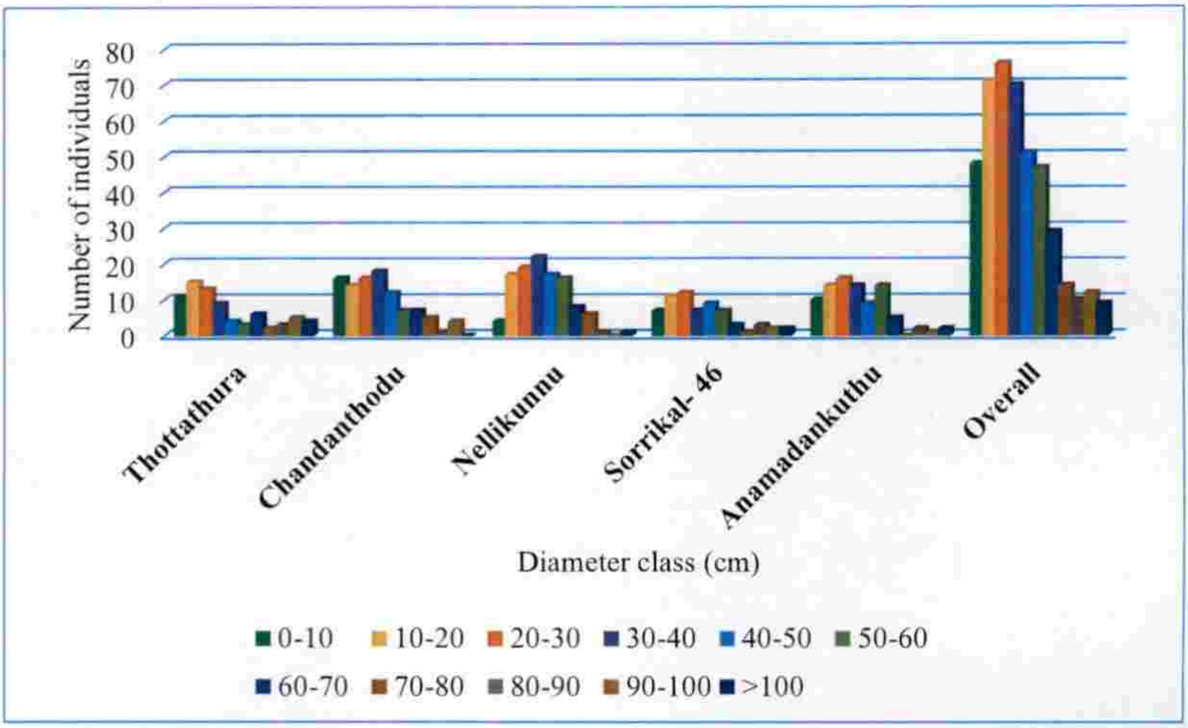

Fig. 7. Diameter - Frequency distribution at Vazhachal evergreen forest ecosystem

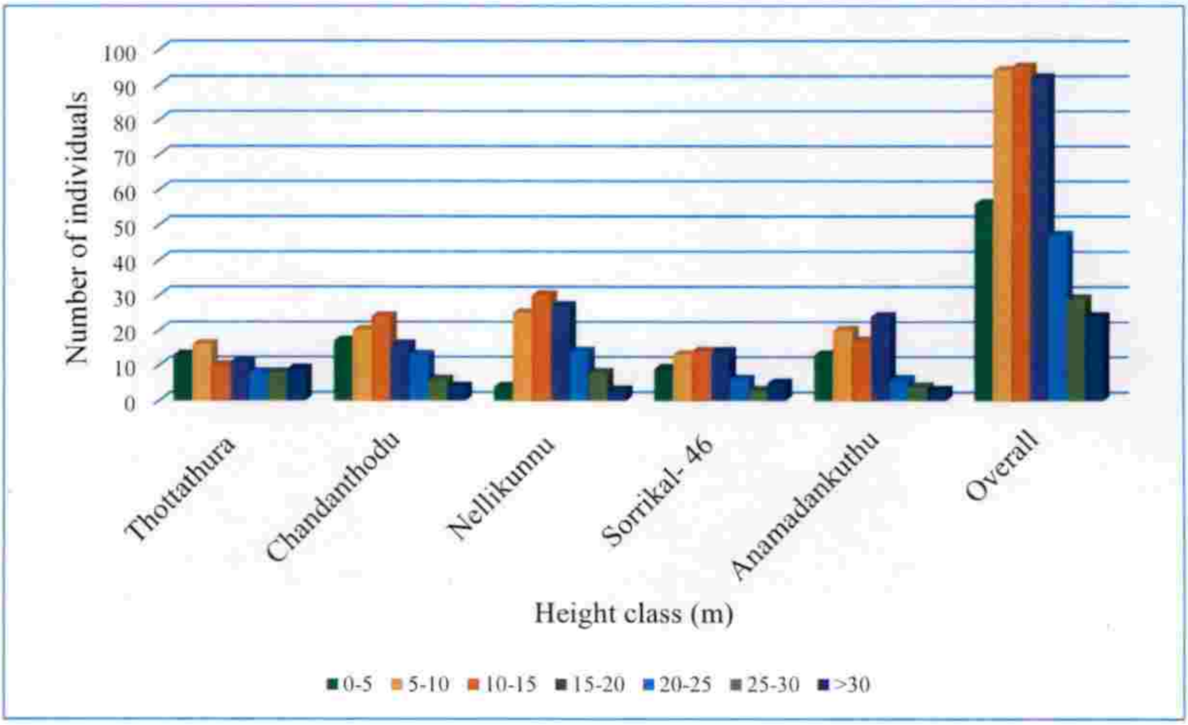

Fig. 8. Height - Frequency distribution at Vazhachal evergreen forest ecosystem

4.3. Diameter –frequency distribution

The distribution of diameter-frequencies is depicted in Fig. 7.

4.3.1. Thottathura

The diameter-frequency distribution (Fig. 7) showed that the maximum number of individuals were seen in the lower diameter classes i.e., 0-10, 10-20, 20-30 and 30-40 cm. The reversed J shaped curved after 10-20 cm diameter class onwards.

4.3.2. Chandanthodu

Here, accumulation of individuals was maximum in the lower diameter classes. Except for the 0-10, 10-20 and 20-30 cm class, the remaining diameter classes resembled the reversed J shaped pattern (Fig. 7).

4.3.3. Nellikunnu

Fig. 7 showed that majority of the individuals of this stand were in the middle diameter class i.e., 10-20, 20-30, 30-40 and 50-60 cm classes.

4.3.4. Sorrikal- 46

The diameter-frequency had a peak at 20-30 cm diameter class and then represented the reverse J shaped curve (Fig. 7).

4.3.5. Anamadankuthu

From Fig. 7, it can be observed that more diameter-frequencies were observed upto 50-60 cm classes.

4.4. Height –frequency distribution

The distribution of height –frequencies is depicted in the Fig. 8.

4.4.1. Thottathura

The height - frequency distribution for Thottathura (Fig. 8) showed that the maximum number of individuals were seen in the lower height classes i.e., 0-5 and 5-

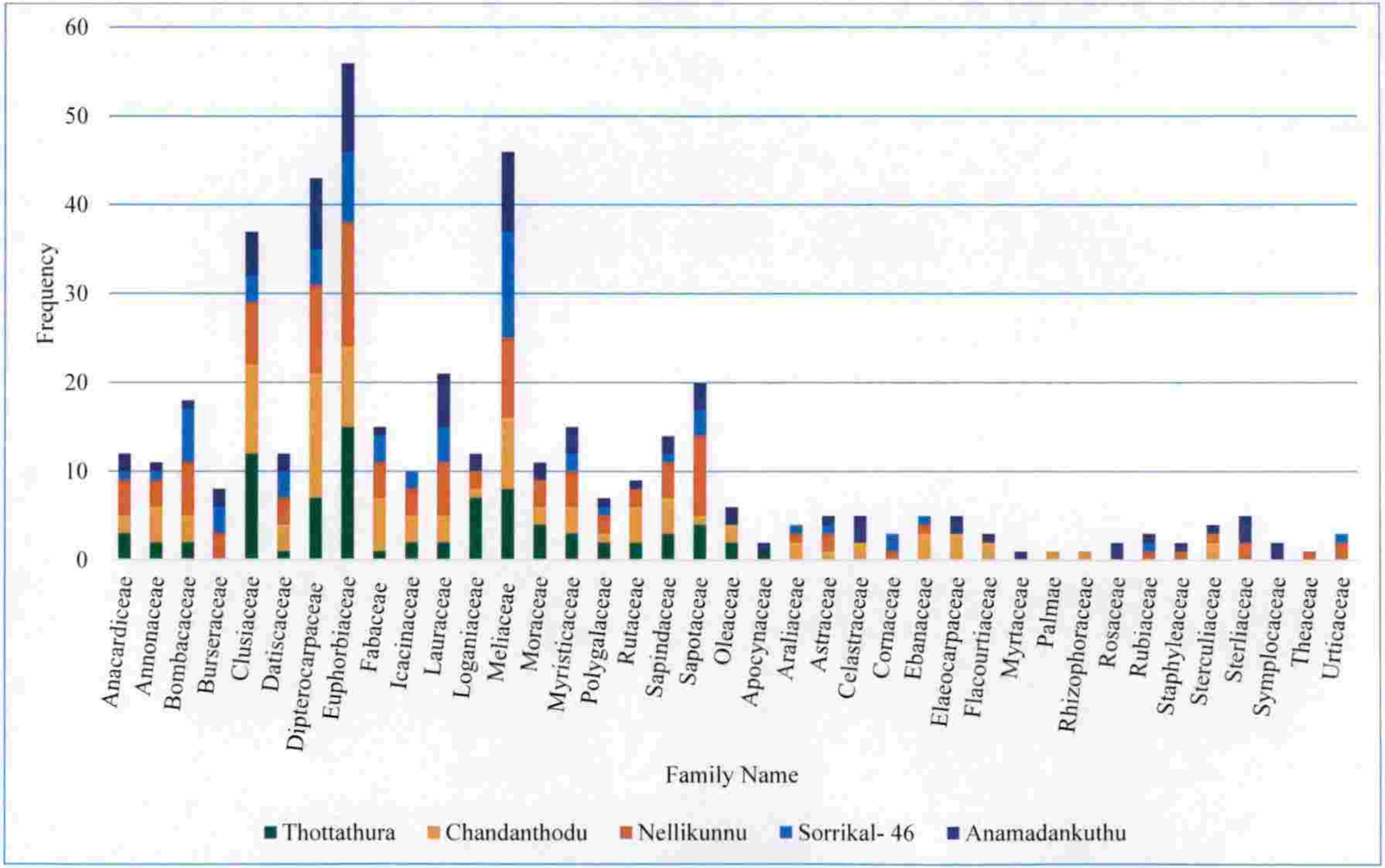

Fig. 9. Family wise distribution of tree individuals at Vazhachal evergreen forest ecosystem

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10 m. More height class was observed in the dominant species like *Aglaia barberi, Agrostistachys borneensis, Dimorphocalyx glabellus, Dipterocarpus indicus* and *Palaquium ellipticum.*

4.4.2. Chandanthodu

The height-frequency had a peak at 10-15 cm height class (Fig. 8). Agrostistachys *borneensis, Drypetes wightii* and *Mesua ferrea* represented the higher height classes.

4.4.3. Nellikunnu

From Fig. 8, it can be observed that more height - frequencies are observed upto the 15-20 cm classes. *Debregeasia longifolia, Tetrameles nudiflora* and *Xylia xylocarpa* are represented in the highest height classes.

4.4.4. Sorrikal- 46

Accumulation of individuals was maximum in the middle height classes (Fig. 8). More height classes were observed in the species like *Actinodaphne malabarica, Cullenia exarillata* and *Palaquium ellipticum.*

4.4.5. Anamadankuthu

Aglaia barberi, Drypetes wightii and *Mesua ferrea* were observed in the higher canopy (Fig. 8). More number of trees were observed in the middle height class, namely 15-20 m height.

4.5. Dominant tree families

From table 3 and fig. 9, it can be seen that out of a total of 39 families recorded, *Euphorbiaceae* (106 individuals per ha) is the dominant family followed by *Meliaceae* (96 individuals per ha) and Dipterocarpaceae (88 individuals per ha). A total of fourteen families registered maximum frequency of 100%, followed by five families with 80% frequency. The highest basal area is recorded in *Bombacaceae* followed by *Sapotaceae* and *Staphyleaceae*. The maximum Importance Value Index (IVI) was observed in *Dipterocarpaceae* (18.52) followed by *Euphorbiaceae* (18.18) and *Meliaceae* (16.86) respectively.

4.6. Floristic diversity (>10 cm GBH)

The details of floristic diversity indices were detailed in the Table 4.

4.6.1. Margalef`s index of Richness (R)

The highest value of Margalef`s index was observed in Chandanthodu (19.53) followed by Nellikunnu (18.47) and Anamadankuthu (17.67) in that order. Overall the Margalef`s index (R) is 28.31.

4.6.2. Shannon Weiner Index (H`)

Shannon Weiner index (H`) was observed to be highest in Chandanthodu (3.77) followed by Sorrikal- 46 (3.78) and Nellikunnu (3.77) in that order. The highest diversity (H max) was observed in Chandanthodu (5.60) followed Nellikunnu (5.55) and in Anamadankuthu (5.50). The overall Shannon Weiner index (H`) and highest diversity (H max) was 4.08 and 6.19 respectively.

4.6.3. Simpson`s Index of Diversity (D)

The highest value of Simpson's index of diversity (D) was recorded in Sorrikal- 46 (9.848) followed by Chandanthodu (0.9846). Whereas the lowest value of concentration of dominance (Cd) was observed in Sorrikal- 46 and Chandanthodu respectively. Overall the Simpson's index of diversity and concentration of dominance is 0.9808 and 0.192 respectively.

4.6.4. Pielou's Evenness Index (E)

The highest value of Pielou`s index of evenness was recorded in the Anamadankuthu (0.6880) followed by Plot (0.6860). Overall Pielou's evenness index (E) of a tropical west coast evergreen forest is 0.6587.

Table 3. Family-wise population characteristics at Vazhachal evergreen forest ecosystem

Sl. No.	Family	Abundance	Density (Individuals per ha)	Relative Density (%)	Frequency (%)	Relative Frequency (%)	Basal Area (m^2)	Relative Basal Area (%)	Importance Value Index	Relative IVI
1.	Anacardiaceae	2.40	24	2.73	100	3.85	7.01	2.02	8.60	2.87
2.	Annonaceae	2.20	22	2.50	100	3.85	8.14	2.35	8.69	2.90
3.	Apocynaceae	1.00	4	0.45	40	1.54	6.03	1.74	3.73	1.24
4.	Araliaceae	1.33	8	0.91	60	2.31	4.50	1.30	4.51	1.50
5.	Astraceae	1.25	10	1.14	80	3.08	3.47	1.00	5.21	1.74
6.	Bombacaceae	3.60	36	4.09	100	3.85	27.90	8.05	15.98	5.33
7.	Burseraceae	2.67	16	1.82	60	2.31	8.46	2.44	6.57	2.19
8.	Celastraceae	2.50	10	1.14	40	1.54	5.62	1.62	4.30	1.43
9.	Clusiaceae	8.00	80	9.09	100	3.85	7.01	2.02	14.96	4.99
10.	Cornaceae	1.00	4	0.45	40	1.54	10.74	3.10	5.09	1.70
11.	Datiscaceae	2.60	26	2.95	100	3.85	16.00	4.62	11.42	3.81
12.	Dipterocarpaceae	8.80	88	10.00	100	3.85	16.19	4.67	18.52	6.17
13.	Ebanaceae	1.67	10	1.14	60	2.31	13.80	3.98	7.43	2.48
14.	Elaeocarpaceae	2.00	8	0.91	40	1.54	8.15	2.35	4.80	1.60
15.	Euphorbiaceae	10.60	106	12.05	100	3.85	7.93	2.29	18.18	6.06
16.	Fabaceae	3.00	30	3.41	100	3.85	5.92	1.71	8.96	2.99
17.	Flacourtiaceae	1.50	6	0.68	40	1.54	5.37	1.55	3.77	1.26
18.	Icacinaceae	2.50	20	2.27	80	3.08	5.15	1.49	6.84	2.28
19.	Lauraceae	5.20	52	5.91	100	3.85	11.93	3.44	13.20	4.40
20.	Loganiaceae	1.75	14	1.59	80	3.08	2.09	0.60	5.27	1.76
21.	Meliaceae	9.60	96	10.91	100	3.85	7.29	2.10	16.86	5.62
22.	Moraceae	2.75	22	2.50	80	3.08	14.64	4.22	9.80	3.27
23.	Myristicaceae	3.00	30	3.41	100	3.85	4.52	1.30	8.56	2.85
24.	Myrtaceae	1.00	2	0.23	20	0.77	0.42	0.12	1.12	0.37
25.	Oleaceae	1.67	10	1.14	60	2.31	1.20	0.35	3.79	1.26

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26.	Palmae	1.00	2	0.23	20	0.77	0.46	0.13	1.13	0.38
27.	Polygalaceae	1.40	14	1.59	100	3.85	6.20	1.79	7.23	2.41
28.	Rhizophoraceae	1.00	2	0.23	20	0.77	12.24	3.53	4.53	1.51
29.	Rosaceae	2.00	4	0.45	20	0.77	12.24	3.53	4.76	1.59
30.	Rubiaceae	1.00	6	0.68	60	2.31	3.40	0.98	3.97	1.32
31.	Rutaceae	1.75	14	1.59	80	3.08	9.25	2.67	7.34	2.45
32.	Sapindaceae	2.60	26	2.95	100	3.85	6.22	1.79	8.59	2.86
33.	Sapotaceae	4.60	46	5.23	100	3.85	25.91	7.47	16.55	5.52
34.	Staphyleaceae	0.50	2	0.23	40	1.54	23.15	6.68	8.44	2.81
35.	Sterliaceae	1.00	6	0.68	60	2.31	14.03	4.05	7.04	2.35
36.	Sterculiaceae	2.50	10	1.14	40	1.54	11.73	3.38	6.06	2.02
37.	Symplocaceae	2.00	4	0.45	20	0.77	4.30	1.24	2.46	0.82
38.	Theaceae	1.00	2	0.23	20	0.77	6.96	2.01	3.00	1.00
39.	Urticaceae	2.00	8	0.91	40	1.54	1.08	0.31	2.76	0.92
Total		**107.93**	**880**	**100.00**	**2600**	**100.00**	**346.65**	**100.00**	**300.00**	**100.00**

Table 4. Plot-wise floristic diversity indices at Vazhachal evergreen forest ecosystem

Plot	Area (Ha)	Number of Species (S)	Basal Area (A)	Number of Individuals (N)	Margalef`S Richness Index (R)	Shannon- Wieners Index		Simpson Index		Pielou's Index (E)
						H`	H max	D	Cd	
Thottathura	0.1	36	453.12	75	13.18	3.43	5.01	0.9755	0.0245	0.6845
Chandanthodu	0.1	55	582.69	100	19.53	3.84	5.60	0.9846	0.0154	0.6860
Nellikunnu	0.1	53	652.61	111	18.47	3.77	5.55	0.9807	0.0193	0.6795
Sorrikal-46	0.1	36	399.03	64	13.46	3.40	5.01	0.9752	0.0248	0.6787
Anamadankuthu	0.1	51	676.01	87	17.67	3.78	5.50	0.9848	0.0152	0.6880
Overall	0.5	84	854.37	437	18.31	4.08	6.19	0.9808	0.0192	0.6587

4.7. Plant Functional Traits of tree species

Table 5 and Fig. 10-17 depicts the plant functional traits of trees in the sampled sites.

4.7.1.1. Thottathura

An analysis of plant functional traits of the 36 tree species, revealed that 23 species (63.8%) are belonging to the evergreen plant type. In leaf type category, 66% (24 species) were having with simple leaves. Twenty seven species (75%) exhibited glabrous textured leaves, while 24 species (66%) were with mesophyll leaves. Eighteen species (50%) had a smooth textured bark while 16 species (44%) were in the category of medium bark thickness. The dominant fruit type was capsule with 17 species (47.2%) under this. The dominant dispersal type is anemochory with 18 species (50%).

4.7.1.2. Chandanthodu

Evergreen plant types were dominant, 67.2% (37 species), Forty one species having simple leaves out of 55 species (74.5%) was recorded in Chandanthodu. Glabrous textured leaves is dominant with 43 species (78.18%). Thirty six species (65.4%) exhibited mesophyll leaves. Twenty seven species (49.09%) were having smooth bark texture while 26 species (47.2%) were having medium bark thickness. Capsule fruit type is the dominant fruit type trait with 18 species (32.7%) representing this category. The dominant fruit dispersal trait type is Zoochory with 29 species recording this trait (0.52%).

4.7.1.3. Nellikunnu

An analysis of different plant functional traits of the 53 tree species, revealed that 40 species (75.4%) displayed evergreen plant type. Over 62% (33 species) traits fell under the simple leaf category. A total of 40 species (75.47%) displayed glabrous leaves and 35 species (66%) exhibited mesophyll leaves. A total of 29 species (54.7) had a smooth bark texture and 31 species (58.49%) exhibited medium bark thickness. The dominant dispersal type is Zoochory with 30 species (56.60%). Capsule fruit type dominant fruit trait with 17 species (32.07).

4.7.1.4. Sorrikal- 46

Out of 36 tree species, 27 species were evergreen plant type (75%) and 24 species (72%) were under the simple leaf trait type. A total of 23 species (63.8%) exhibited smooth bark texture trait. Twenty one species (80.7%) exhibited medium bark thickness. Glabrous leaves are dominant trait with 27 species (58.33%) and mesophyll leaves were the dominant ones in this trait category with 25 species (69.4%). The dominant dispersal type is Zoochory with 20 species (55.5%). The dominant fruit trait was capsule fruit type with 19 species (52.77%).

4.7.1.5. Anamadankuthu

Out of 51 species, 38 tree species (74.5%) were of evergreen plant type and simple leaves dominated with 39 species (76.47%).Thirty eight species (74.5%) exhibited glabrous textured leaves and 33 species (64.7%) exhibited mesophyll leaves. Twenty seven species (52.9%) had a smooth bark texture and 29 species (56.8%) were having medium bark thickness. Capsule fruit type dominated with 19 species (37.2%). The dominant dispersal type is Zoochory with 29 species (56.8%).

4.7.1.6. Overall plant functional traits of tree species

An analysis of plant functional traits of all the 84 tree species revealed that evergreen plant type dominates with 59 species (70.2%). In leaf trait category, 61 species (72.6%) were with simple leaves. Sixty six species (78.57%) had glabrous textured leaves while 54 species (64.2%) displayed mesophyll leaves. Forty species (47.2%) were with smooth bark texture and 45 species (53.5%) were having medium bark thickness. Capsule fruit type was the dominant trait with 27 species (32.1%) coming under this category. The dominant dispersal type is Zoochory with 47 species (55.95%).

Table 5. Plant functional traits at Vazhachal evergreen forest ecosystem

Sl. No.	Species	Plant Type	Leaf Type	Leaf Texture	Leaf Size	Bark Thickness	Bark Texture	Fruit Type	Dispersal Mode
1.	*Actinodaphne malabarica*	E	S	G	Ms	Tn	S	Br	Z
2.	*Aglaia barberi*	E	C	G	N	Tn	S	Br	Z
3.	*Agrostistachys borneensis*	E	S	G	Ms	Mm	S	C	Z
4.	*Alstonia scholaris*	D	S	G	Ms	Tk	R	P	At
5.	*Antiaris toxicaria*	E	S	G	N	Tk	SR	D	Z
6.	*Antidesma montanum*	E	S	G	Mc	Tn	S	D	Z
7.	*Aphanamixis polystachya*	E	C	P	Ms	Mm	SR	C	Ae
8.	*Aporosa bourdillonii*	E	S	G	Ms	Mm	S	C	Ae
9.	*Arenga wightii*	E	C	G	Ma	Tk	R	D	Z
10.	*Artocarpus heterophyllus*	E	S	G	Ms	Tk	SR	Ag	Z
11.	*Baccaurea courtallensis*	D	S	G	Ms	Mm	R	C	Ae
12.	*Bischofia javanica*	E	C	G	Ms	Mm	S	Br	Z
13.	*Bombax ceiba*	D	C	G	Ms	Tk	R	C	Ae
14.	*Calophyllum polyanthum*	E	S	G	Ms	Tk	R	D	Z
15.	*Canarium strictum*	E	C	G	Ms	Mm	S	D	Z
16.	*Carallia brachiata*	B	S	G	N	Tk	SR	D	Z
17.	*Chionanthus mala-elengi*	B	S	G	N	Tn	SR	D	Z
18.	*Chrysophyllum roxburghii*	E	S	G	N	Tk	R	Br	Z
19.	*Chukrasia tabularis*	B	C	G	Ms	Tk	R	C	Ae
20.	*Cinnamomum malabatrum*	E	S	G	Ms	Mm	R	Br	Z
21.	*Cryptocarya wightiana*	E	S	G	Ms	Tk	SR	D	Z
22.	*Cullenia exarillata*	E	S	P	Ms	Tk	S	C	Ae
23.	*Dalbergia lanceolaria*	D	C	G	Mc	Tk	R	P	At
24.	*Debregeasia longifolia*	E	S	G	Ms	Mm	S	Br	Z
25.	*Dimocarpus longan*	E	C	G	Ms	Mm	S	D	Z
26.	*Dimorphocalyx glabellus*	E	S	G	Ms	Mm	SR	C	Ae
27.	*Diospyros bourdillonii*	E	S	P	Ms	Mm	R	Br	Z
28.	*Dipterocarpus indicus*	E	S	G	Ms	Mm	S	S	Ae

29.	*Drypetes wightii*	E	S	G	Mc	Mm	S	C	Ae
30.	*Dysoxylum beddomei*	E	C	P	N	Mm	SR	C	Ae
31.	*Dysoxylum malabaricum*	E	C	P	Ms	Mm	R	C	Ae
32.	*Elaeocarpus variabilis*	E	S	P	N	Mm	S	D	Z
33.	*Ficus microcarpa*	E	S	G	N	Mm	S	S	Z
34.	*Filicium decipiens*	E	C	G	Mc	Mm	R	D	Z
35.	*Flacourtia montana*	B	S	G	Ms	Mm	S	Br	Z
36.	*Garcinia morella*	E	S	G	Ms	Tk	S	Br	Z
37.	*Garcinia wightii*	E	S	G	Mc	Tk	S	Br	Z
38.	*Gomphandra coriacea*	E	S	G	N	Mm	S	D	Z
39.	*Gordonia obtusa*	E	S	G	N	Mm	S	C	Ae
40.	*Hertiera papillo*	D	S	G	Ms	Tn	R	S	Ae
41.	*Holigarna grahamii*	E	S	P	Ma	Tk	SR	D	Z
42.	*Hopea parviflora*	E	S	G	N	Mm	R	S	Ae
43.	*Humboltia brunonis*	E	C	G	Ms	Tn	SR	P	At
44.	*Hydnocarpus pentandra*	B	S	G	Ms	Tn	S	Br	Z
45.	*Ixora brachiata*	B	S	G	Ms	Mm	S	Br	Z
46.	*Kingiodendron pinnatum*	E	C	G	N	Mm	R	P	At
47.	*Knema attenuata*	B	S	G	Ms	Mm	S	C	Ae
48.	*Litsea floribunda*	E	S	P	Ms	Mm	R	Br	Z
49.	*Lophopetalum wightianaum*	E	S	G	Ms	Tn	S	C	Ae
50.	*Macaranga peltata*	D	S	G	Ma	Mm	SR	C	Ae
51.	*Madhuca bourdillonii*	B	S	P	Ma	Mm	R	Br	Z
52.	*Mallotus philippensis*	D	S	P	Ms	Mm	S	C	Ae
53.	*Mangifera indica*	E	S	G	Ms	Tn	R	D	Z
54.	*Mastixia arborea*	E	S	G	Ms	Tn	R	D	Z
55.	*Meigogyne pannosa*	E	S	P	Mc	Mm	S	F	Ae
56.	*Melicope lunu-ankenda*	B	C	G	Ms	Mm	R	C	Ae
57.	*Mesua ferrea*	E	S	G	N	Tk	R	C	Ae
58.	*Myristica beddomei*	E	S	G	Ms	Tk	S	C	Ae

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59.	*Neolitsea cassia*	E	S	G	L	Mm	R	D	Z
60.	*Nothopegia colebrookeana*	E	S	G	N	Mm	S	D	Z
61.	*Palaquium ellipticum*	E	S	G	N	Mm	S	Br	Z
62.	*Persea macrantha*	E	S	G	Ms	Tk	R	Br	Z
63.	*Phoebe wightii*	E	S	P	Ms	Mm	S	D	Z
64.	*Poeciloneuron indicum*	E	S	P	Ms	Mm	R	C	Ae
65.	*Polyalthia fragrans*	E	S	G	Ms	Tk	S	Br	Z
66.	*Prunus ceylanica*	E	S	G	Ms	Mm	R	D	Z
67.	*Pterospermum reticulatum*	E	S	P	Ms	Tk	S	C	Ae
68.	*Reinwardtiodendron anamalaiense*	B	S	P	N	Tn	S	Br	Z
69.	*Saraca asoca*	E	C	G	Ms	Tn	SR	P	At
70.	*Schefflera wallichiana*	E	C	G	Ms	Mm	R	Br	Z
71.	*Spondias pinnata*	D	C	G	Ms	Tk	S	D	Z
72.	*Sterculia guttata*	D	S	G	Ma	Tk	S	C	Ae
73.	*Strychnos nux-vomica*	B	S	G	Ms	Tk	S	Br	Z
74.	*Symplocos macrophylla*	E	S	G	Ms	Mm	R	D	Z
75.	*Syzygium laetum*	E	S	G	N	Mm	S	Br	Z
76.	*Tetrameles nudiflora*	D	S	P	Ms	Mm	S	C	Ae
77.	*Toona ciliata*	B	C	G	Ms	Tk	R	C	Ae
78.	*Trichilia connaroides*	E	C	G	Ms	Tk	SR	C	Ae
79.	*Turpinia malabarica*	E	C	G	N	Mm	S	Br	Z
80.	*Vateria indica*	B	C	P	Ms	Tk	SR	C	Ae
81.	*Vatica chinensis*	E	S	G	Ms	Mm	S	C	Ae
82.	*Vernonia arborea*	E	S	P	Ms	Mm	R	F	Ae
83.	*Xanthophyllum arnottianum*	B	S	G	Ms	Mm	S	D	Z
84.	*Xylia xylocarpa*	D	C	G	Ms	Tk	R	P	At

Plant type: E- Evergreen, D- Deciduous, B- Brevi-deciduous; **Leaf type**: S- Simple, C-Compound; **Leaf Texture**: G- glabrous, P- Pubescent; **Leaf size**: Ms- Mesophyll, N- Notophyll, Ma- Macrophyll, Mc- Microphyll L- Leptophyll; **Bark thickness**- Tn- Thin, Tk- Thick, Mm- Medium; **Bark texture**- S- Smooth, SR- Slightly Rough, R- Rough; **Fruit type**- Br- Berry, D- Drupe, F- Follicle, C- Capsule, S-Samara, S-Syconium, P-Pods, Ag- Aggregate; **Dispersal mode**- Z- Zoochory, Ae- Anemochory, At- Autochory

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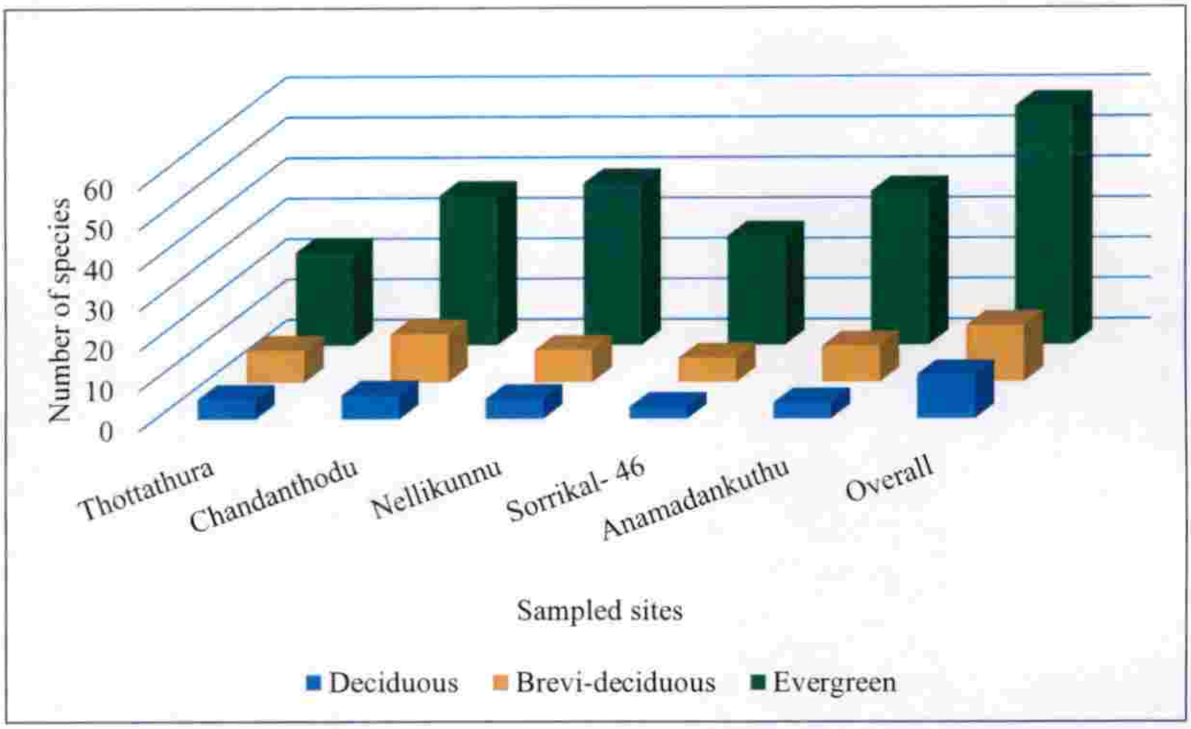

Fig. 10. "Plant type" distribution at Vazhachal evergreen forest ecosystem

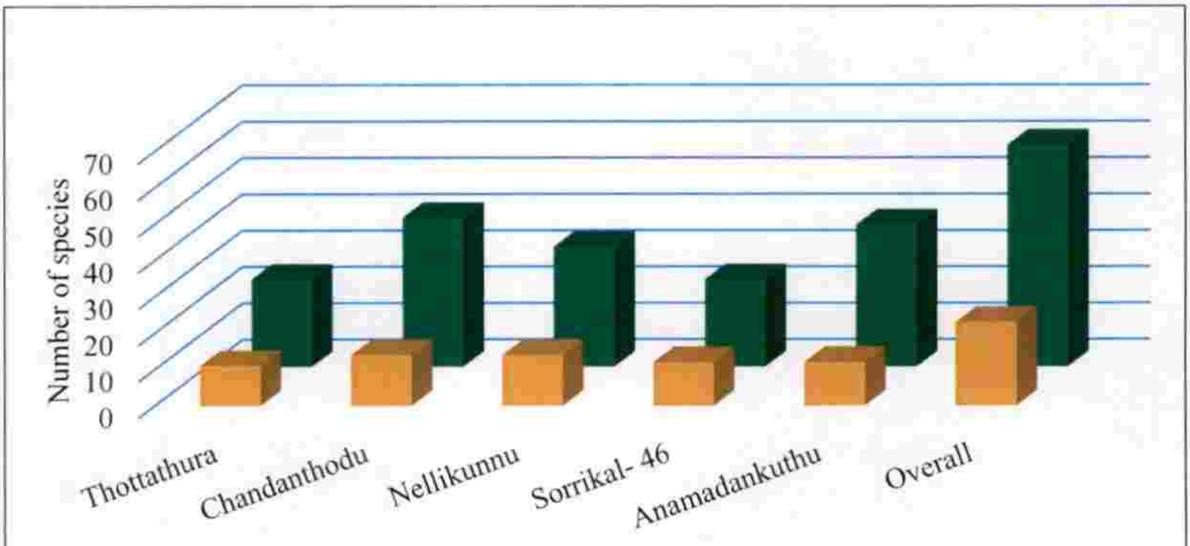

Fig. 11. "Leaf type" distribution at Vazhachal evergreen forest ecosystem

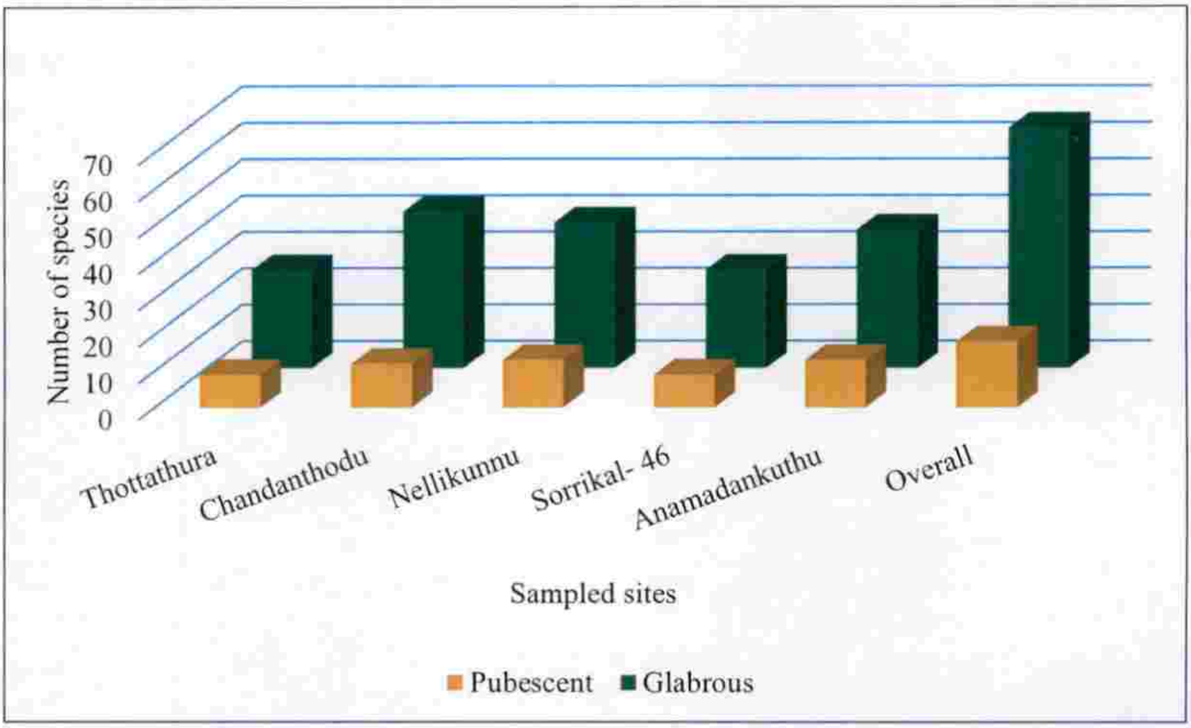

Fig. 12. "Leaf texture" distribution at Vazhachal evergreen forest ecosystem

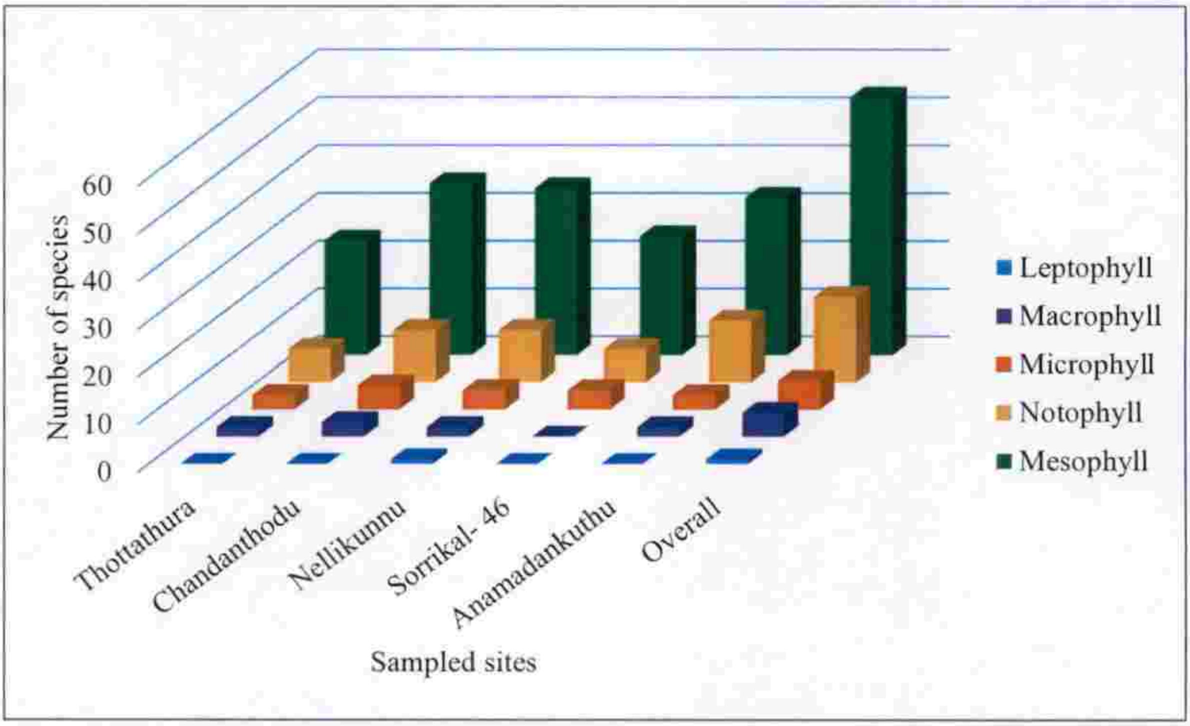

Fig. 13. "Leaf size" distribution at Vazhachal evergreen forest ecosystem

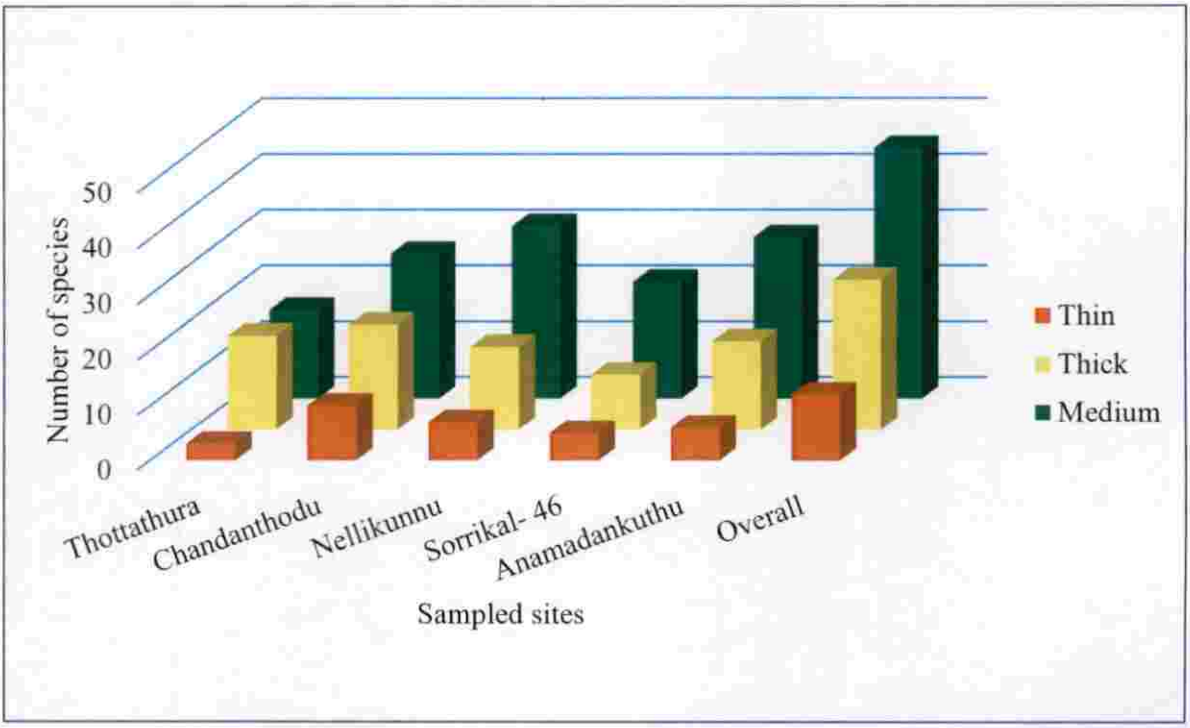

Fig. 14. "Bark thickness" distribution at Vazhachal evergreen forest ecosystem

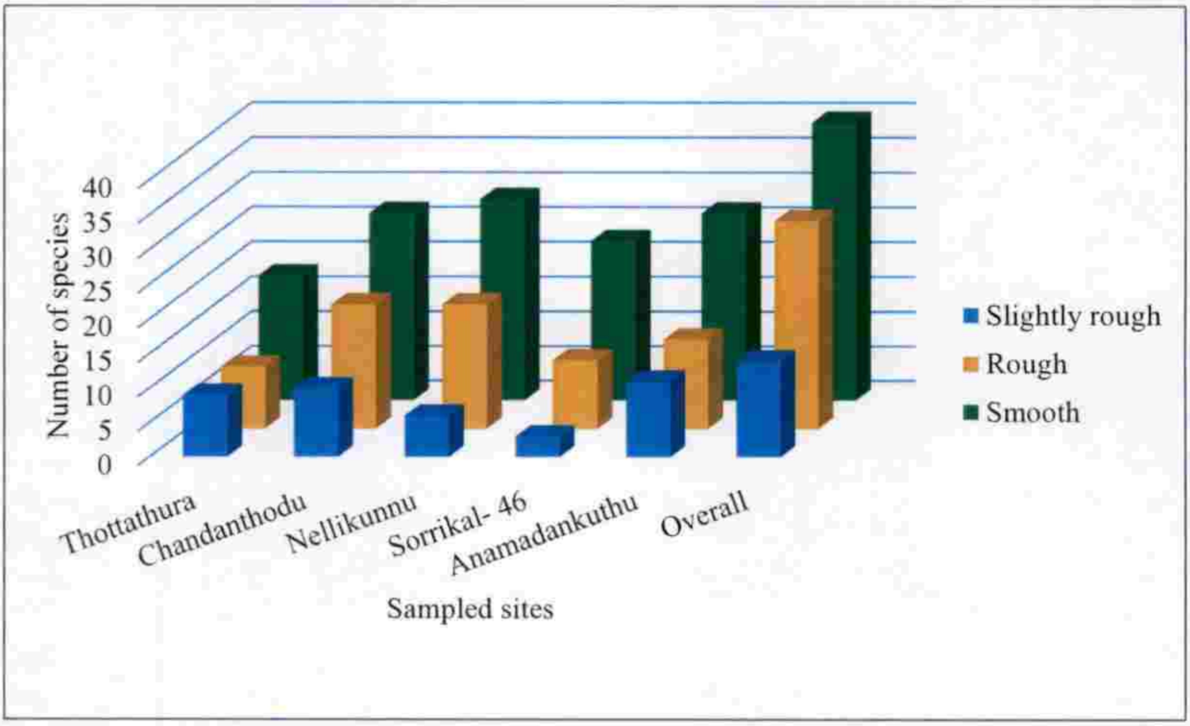

Fig. 15. "Bark texture" distribution at Vazhachal evergreen forest ecosystem

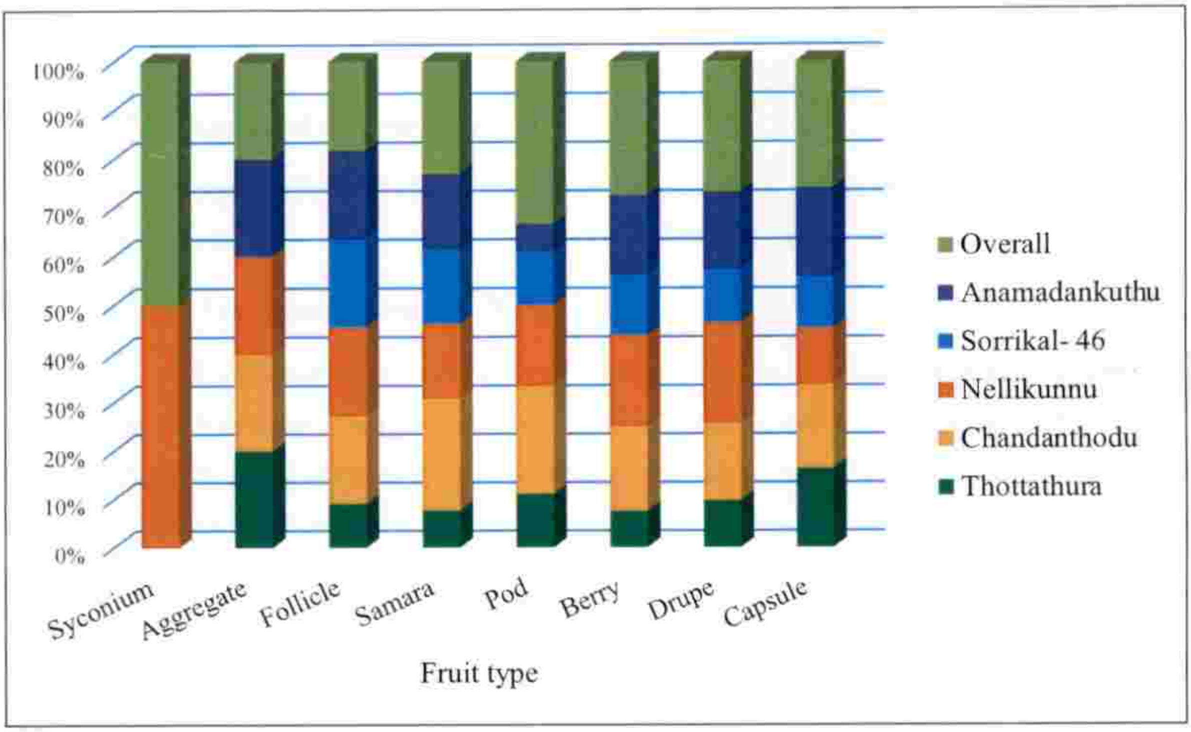

Fig. 16. "Fruit type" distribution at Vazhachal evergreen forest ecosystem

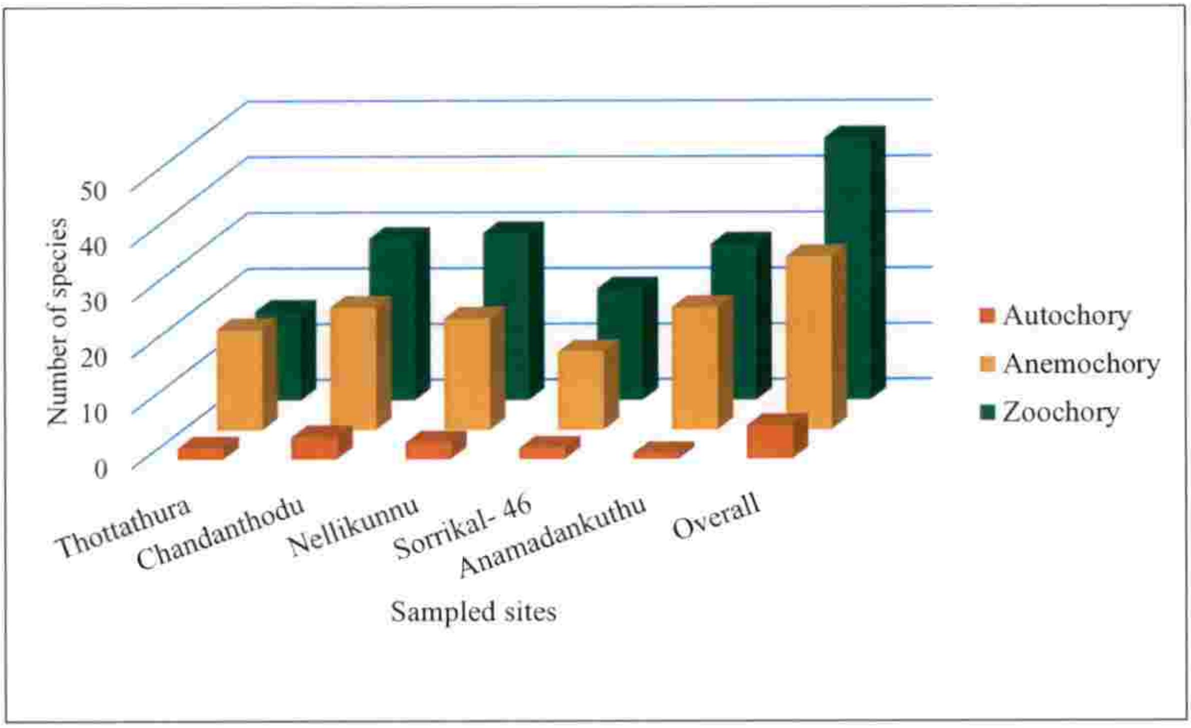

Fig. 17. "Seed dispersal" distribution at Vazhachal evergreen forest ecosystem

4.7.2. Functional diversity analysis

The details of the functional diversity analysis in the sampled sites is depicted in Table 6.

4.7.2.1. Functional richness (FRic)

Functional richness shows the diversity of the functional traits in the ecosystem. The highest value of functional richness (FRic) was recorded in Chandanthodu (12.89) followed by Nellikunnu (12.39). Overall the functional richness (FRic) of this evergreen forest is 17.11.

4.7.2.2. Functional evenness (FEve)

The maximum value of functional evenness (FEve) was observed in Thottathura (0.83) followed by Sorrikal- 46 (0.71), Chandanthodu (0.72) and Anamadankuthu (0.71) in that order. Overall, the functional evenness (FEve) of this evergreen forest is 0.74.

4.7.2.3. Functional divergence (FDiv)

The highest value of functional divergence (FDiv) was observed in Thottathura (0.83), followed by Sorrikal- 46 (0.77), Nellikunnu (0.72) and Nellikunnu (0.73) in that order. Overall, the functional divergence (FDiv) of all the sampled plots is 0.84.

4.7.2.4. Functional dispersion (FDis)

The Functional Dispersion (FDis) shows the spreading of the functional traits in the particular ecosystem. Chandanthodu (2.14) recorded the highest value followed by Nellikunnu (2.13). Overall, the functional divergence (FDiv) of this evergreen forest is 2.27.

4.8. Soil invertebrates

4.8.1. Abundance (A), Density (D), Relative Density (RD) of soil invertebrates

The details of the Abundance (A), Density (D) and Relative Density (RD) of soil invertebrates is depicted in the Table 7. A total of 860 individuals belonging to 28 different orders of soil invertebrates were recorded from the evergreen forest ecosystem. *Isoptera* (30%) recorded highest relative density followed by *Hymenoptera* (12.67%) and *Coleoptera* (12.33%). The percentage frequencies of 10 soil invertebrate orders were more than 5%.

4.8.2. Diversity indices of the soil invertebrates

The details of the functional diversity analysis in the sampled sites is depicted in Table 8. Among all the sampled plots, the maximum number of individuals was recorded in Nellikunnu with 194 individuals belonging to 21 different invertebrate orders.

4.8.2.1. Shannon-Weiner index

The highest Shannon Weiner index (H`) value was obtained for Anamadankuthu (2.39). The highest value of H max was observed in Anamadankuthu and Nellikunnu with 4.25 each. Overall the Shannon Weiner index (H`) of the evergreen forest was 2.40.

4.8.2.2. Simpson`s index

The highest value of Simpson`s index of diversity (D) was observed in Sorrikal-46 (0.189). The highest concentration of dominance (cd) were observed in 0.882 respectively. Overall Simpson`s index of diversity (D) of the evergreen forest with regards to the soil invertebrates is 0.141.

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Table 6. Functional diversity analysis of Vazhachal evergreen forest ecosystem

Plot	Functional Evenness (FEve)	Functional Divergence (FDiv)	Functional Dispersion (FDis)	Functional Richness (FRic)
Thottathura	0.83	0.83	2.05	1.7
Chandanthodu	0.72	0.72	2.14	12.89
Nellikunnu	0.7	0.7	2.12	12.39
Sorrikal-46	0.73	0.73	1.93	2.9
Anamadankuthu	0.71	0.77	1.94	7.01
Overall	0.76	0.84	2.27	17.11

Table 7. Population charecteristics of soil invertebrates at Vazhachal evergreen forest ecosystem

Sl. No.	Order	Abundance	Density (Individuals per ha)	Relative density (%)	Frequency (%)	Relative frequency (%)
1.	*Arachnida*	29	464	3.37	80	4.12
2.	*Blattaria*	11	176	1.28	80	4.12
3.	*Chilopoda*	52	832	6.05	100	5.15
4.	*Coleoptera*	106	1696	12.33	100	5.15
5.	*Collembola*	7	112	0.81	80	4.12
6.	*Dermaptera*	4	64	0.47	60	3.09
7.	*Diptera*	18	288	2.09	100	5.15
8.	*Ephemeroptera*	4	64	0.47	60	3.09
9.	*Gastropoda*	40	640	4.65	100	5.15
10.	*Gnathobdellida*	78	1248	9.07	100	5.15
11.	*Hemiptera*	2	32	0.23	40	2.06
12.	*Hymenoptera*	109	1744	12.67	100	5.15
13.	*Isopoda*	3	48	0.35	60	3.09
14.	*Isoptera*	258	4128	30.00	100	5.15
15.	*Lepidoptera*	29	464	3.37	100	5.15
16.	*Mantodea*	5	80	0.58	60	3.09
17.	*Mecoptera*	1	16	0.12	20	1.03
18.	*Diplopods*	30	480	3.49	100	5.15
19.	*Neuroptera*	4	64	0.47	40	2.06
20.	*Oligochaeta*	42	672	4.88	100	5.15
21.	*Orthoptera*	4	64	0.47	40	2.06
22.	*Phasmida*	5	80	0.58	60	3.09
23.	*Plecoptera*	3	48	0.35	20	1.03

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24.	*Psocoptera*	4	64	0.47	60	3.09
25.	*Scorpiones*	2	32	0.23	40	2.06
26.	*Thysanoptera*	3	48	0.35	60	3.09
27.	*Thysanura*	6	96	0.70	60	3.09
28.	*Trichoptera*	1	16	0.12	20	1.03
Total		**860**	**13760**	**100.00**	**1940**	**100.00**

Table 8. Diversity indices of soil invertebrates at Vazhachal evergreen forest ecosystem

Plot	Number of Order (O)	Number of Individuals (N)	Shannon-Wiener Index		Simpson Index		Pielou's Index (E)
			H`	H max	D	Cd	
Thottathura	19	160	2.2602	4.116	0.164	0.836	0.549
Chandanthodu	20	177	2.3185	4.188	0.137	0.863	0.554
Nellikunnu	21	194	2.3853	4.256	0.134	0.866	0.560
Sorrikal-46	16	159	2.0797	3.876	0.189	0.811	0.537
Anamadankuthu	21	170	2.3960	4.256	0.118	0.882	0.563
Overall	28	860	2.4026	4.658	0.141	0.859	0.516

Table 9. Population of soil microorganisms at Vazhachal evergreen forest ecosystem

Microbial Population (cfu per gram of soil)*					
Sample Plots	**Thottathura**	**Chandanthodu**	**Nellikunnu**	**Sorrikal-46**	**Anamadankuthu**
Bacteria ($x10^6$)	43	50	46.5	37	45.5
Fungi ($x10^3$)	22.5	31.5	25	25.5	27
Fluorescent pseudomonads ($x10^4$)	16	19	17.5	19.5	19.5
N_2 fixers ($x10^4$)	17.5	14	16	12	12.5
Actinomycetes ($x10^4$)	15	17.8	18	14.5	17.5
Phosphate solubilizers ($x10^3$)	16	20.5	19	21	23.5

*Mean of replication

4.8.2.3. Pielou's Evenness Index

Pielou's Evenness index (E) was highest in Anamadankuthu (0.563). Sorrikal-46 is significantly different with Anamadankuthu and Nellikunnu. Overall Pielou's evenness index (E) of the tropical west coast wet evergreen was 0.516.

4.9. Populations of soil microorganisms

The details of soil microflora studies is depicted in Table 9.

4.9.1. Bacteria

The largest bacterial population was observed in Chandanthodu (50 x 10^6cfu per gram of soil) followed by Nellikunnu (46.5 x 10^6cfu per gram of soil). Sorrikal-46 recorded the smallest bacterial colonies (37 x 10^6cfu per gram of soil) followed by Thottathura (43 x 10^6cfu per gram of soil).

4.9.2. Fungi

The lowest number of fungal colonies were observed in Thottathura (22.5 x 10^3cfu per gram of soil) by Nellikunnu with 25x10^3cfu per gram of soil. Chandanthodu recorded the largest soil fungal colonies (31.5 x 10^3cfu per gram of soil) followed by Anamadankuthu (27 x 10^3cfu per gram of soil).

4.9.3. Fluorescent pseudomonads

The highest populations of soil fluorescent pseudomonads was observed in Sorrikal- 46 (19.5x10^4cfu per gram of soil) and Anamadankuthu (19.5 x10^4cfu per gram of soil) followed by Chandanthodu (19x10^4cfu per gram of soil). Thottathura recorded the lowest amount of soil fluorescent pseudomonads colonies (16 x 10^4cfu per gram of soil) behind by Nellikunnu (17.5 x 10^4cfu per gram of soil).

4.9.4. Nitrogen fixers

Thottathura recorded the largest colonies of Nitrogen fixers 17.5 x 10^4cfu per gram of soil followed by Nellikunnu (16 x 10^4cfu per gram of soil).

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4.9.5. Actinomycetes

The largest populations of soil actinomycetes was observed in Thottathura with 18 x 10^4cfu per gram of soil followed by Anamadankuthu (17.5 x 10^4cfu per gram of soil) and Nellikunnu (17 x 10^4cfu per gram of soil).

4.9.6. Phosphate solubilizers

The least amount of soil phosphate solubilizers were observed in Thottathura with 16x 10^3 cfu per gram of soil. The largest population of phosphate solubilizers was observed in Sorrikal- 46 (21 x 10^3cfu per gram of soil) and Anamadankuthu (23.5 x 10^3cfu per gram of soil) respectively.

4.10. Edaphic factors

The observations regarding the various edaphic factors from the sampled sites is given in Table 10.

4.10.1. Soil temperature

Soil temperature was significantly different from each other among sampled sites. The soil temperature was highest in Thottathura (22.36°C) followed by Anamadankuthu (20°C). Of all the plots, the lowest temperature was observed in Nellikunnu (18.22°C).

4.10.2. Soil bulk density

The bulk density of soil obtained from the sample sites ranged from 1.18-1.30 $gcm^{-3.}$ The bulk density also showed significant statistical difference between the sampled sites.

4.10.3. Soil moisture content

Soil moisture content between the sampled sites was not significantly different from each other. The moisture content of the soil varied from 28.33-29.97%.

4.10.4. Soil organic carbon

Across the different sampled sites, organic carbon content of soil showed no significant difference between the sampled sites and ranged from 3.97-4.33%.

4.10.5. Soil acidity

Soil acidity (pH) ranged from 4.55 to 6.48. Thottathura had a nearly neutral pH of 6.48 followed by Sorrikal- 46 (5.13). The lowest pH was registered in Anamadankuthu (4.55).

4.10.6. Electrical conductivity of the soil

Across the sampled sites, the electrical conductivity of soil differed significantly between each other. The highest value was observed in Anamadankuthu (0.096dS) followed by Thottathura (0.090dS).

4.10.7. Soil texture

The tropical evergreen forests of Vazhachal recorded the sandy loam type of texture.

4.10.7.1. Sand

The higher amount of sand fraction was recorded in Thottathura (79.50%) followed by Anamadankuthu (78.55%).

4.10.7.2. Silt

The silt fraction of the sampled sites significantly differed from each other. The lowest value of silt fraction was observed in Anamadankuthu (15.1%).

4.10.7.3. Clay

The highest clay content value (7.13%) was observed in Chandanthodu followed by Anamadankuthu (6.35%).

Table 10. Plot-wise soil characteristics of Vazhachal evergreen forest ecosystem

Plot	Soil temperature (°C)	Bulk density (g cm^{-3})	Moisture content (%)	Organic carbon (%)	Soil acidity pH	Soil electrical conductivity EC (dSm^{-1})	Sand (%)	Silt (%)	Clay (%)
Thottathura	22.36±0.29^{a}	1.29±03	29.00±1.34	4.33±0.09	6.48±0.02^{a}	0.090±0.003^{a}	79.50±0.73^{a}	15.05±0.80^{b}	5.45±0.36^{bc}
Chandanthodu	19.54±0.42^{bc}	1.30±05	28.33±0.95	4.27±0.15	5.33±0.11^{b}	0.054±0.007^{b}	77.19±0.56^{b}	15.68±0.41^{ab}	7.13±0.47^{a}
Nellikunnu	18.22±1.28^{c}	1.18±02	29.97±1.08	4.35±0.10	4.77±0.04^{cd}	0.060±0.010^{b}	77.10±0.76^{b}	17.38±0.48^{a}	5.54±0.72^{bc}
Sorrikal-46	19.00±0.94^{bc}	1.39±53	29.40±1.15	3.97±0.07	5.13±0.06^{bc}	0.057±0.004^{b}	78.40±0.65^{ab}	17.01±0.63^{a}	4.65±0.16^{c}
Anamadankuthu	20.00±0.57^{b}	1.28±0.03	28.59±1.35	4.00±0.06	4.55±0.24^{c}	0.09±0.00^{a}	78.45±0.65^{ab}	15.10±0.57^{b}	6.35±0.33^{ab}
Overall	19.82	1.28	29.06	4.19	5.25	0.07	78.15	16.04	5.82
F-Value	11.003*	2.947^{ns}	0.301^{ns}	3.408^{ns}	34.747*	7.800*	2.181*	3.276*	4.351*
CD value	1.38	0.13	3.51	0.30	0.38	0.02	2.01	1.76	1.34

Means with same letter as superscripts indicates homogeneous groups *Indicates significant at 5% level; ns indicates non-significant at 5% level

Discussion

DISCUSSION

The present study was carried out during 2014- 16 for understanding the species and functional diversity of a tropical west coast wet evergreen forest ecosystem (1A/C2) located in the Vazhachal forest division in Kerala. The results of the findings are discussed below.

5.1. Vegetation Diversity

This study could count 57 young tree recruits, 29 shrubs, 28 herbs, 19 climbers, 14 pteridophytes, 13 polypores, 7 epiphytes, 4 orchids and 4 bryophytes from the 0.5 ha (0.1 ha x 5 sample plots =0.5 ha) (Table 1). The tree statistics include eighty four tree species with 1093 individuals per hectare and a basal area of 85.43m^2 (Table 2). Damodharan (2004) had recorded 101 species from 2000m^2 in Sholayar forests which is located very close to the present study area. Because, greatest species diversity is one of the remarkable features of tropical humid forests in presence of more soil nutrients and higher rainfall year around (Parsons and Cameron, 1974). The study area was dominated by *Aglaia barberi, Cullenia exarillata, Mesua ferrea* and *Palaquium ellipticum* which formed the top canopy. The total number of trees as well as tree species observed in this ecosystem is very typical of tropical west coast wet evergreen forest ecosystems and has been recorded by several workers on earlier occasions also (Varghese and Balasubramanyan, 1999; Damodharan, 2004; Bhat and Ravindranath, 2007; Jayakumar and Nair, 2013; Magesh, 2014). The sample plots taken up for studies in the tropical west coast wet evergreen forest ecosystem (1A/C2) of the Vazhachal forest division was no difference in terms of variations in aspect and exposure. *Euphorbiaceae*, *Dipterocarpaceae* and *Meliaceae* were observed as the dominant tree families (Table 3), which is also not a surprising observation in an evergreen ecosystem. At a micro-scale, these forest ecosystems are mosaics of variations in altitude, hydrology, geology and environmental fluctuations which subsequently determine the above ground vegetation composition (Whitmore, 1984; Pascal *et al.*, 2004).

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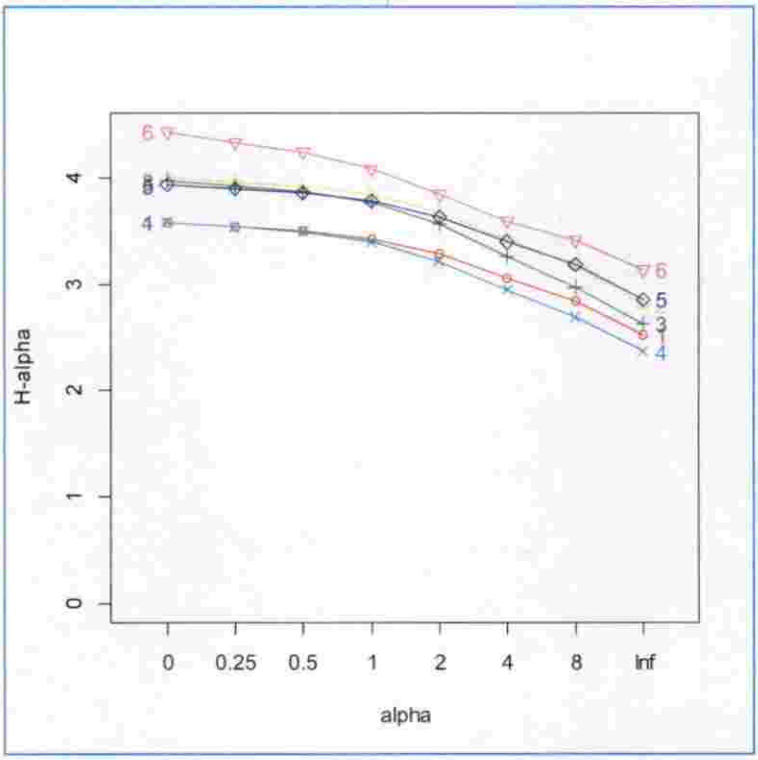
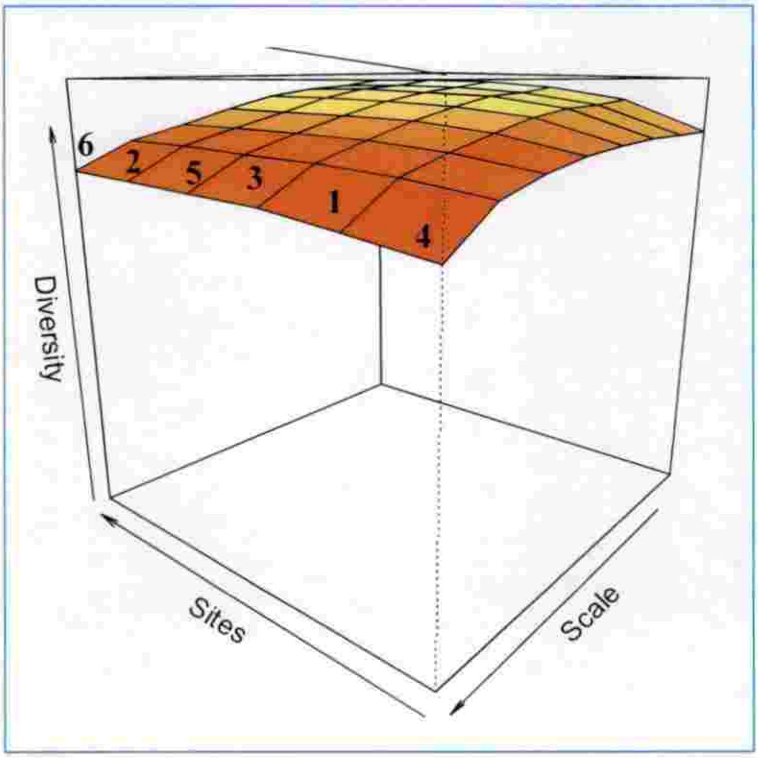
Rényi's diversity profiling highlights the plot-wise difference in evenness and species richness based on aggregated data. Though species richness was higher at a few plots, there was hardly any overall difference. Many profiles lines were intersecting (Fig. 18a and Fig. 18b) and hence no differentiation on ranking based on diversity can be made out. This confirms the argument that there is little plot-wise difference in species diversity in the studied ecosystem. This is because the area had a continuity of "evergreen traits", even though the sampled plots were located around 800-1000 m apart. The same trend was also observed for the plot-wise species richness. Principal component analysis employing species abundance, however returned some plot-wise differences (Fig. 19). Diversity of Species at a particular place and time is a function of several factors like edaphic, climatic and topographic factors including perturbations. At Vazhachal too, the creation of canopy gaps is a recurring event which alters species richness and evenness. Also due to the variations in the microclimates, slight differences in the composition of vegetation at all levels (trees, shrubs and hers) were observed. However these variations in the species composition were not that marked. This is confirmed by the fact that Rényi's diversity profiling and Principal Component Analysis returned only minor variation vis-à-vis vegetation characteristics across the five sites.

Usually the evergreen ecosystems have high species diversity indices due to high species richness and evenness. The plant species diversity indices like Margalef Richness Index [28.31], Shannon-Wiener Index [4.08], Simpson Index [0.98] and Pielou's Index [0.65] for the evergreen ecosystem was observed (Table 4) to be on a par with the earlier richness and evenness values reported on this area and other similar evergreen ecosystems (Rajesh *et al.,* 1996; Damodharan, 2004). Individual plot wise too, the species had high species diversity indices. This is not a unique observation when considering the fact that the sampled plots are "true representatives" of the larger evergreen ecosystem. The minor changes recorded vis-à-vis species diversity (Table of plot wise diversity indices) in the plots under this study can be attributed to several locality factors and also natural and anthropogenic disturbances. Natural biotic pressure includes the location far away from the water bodies, roads, settlements, high tensioned power lines and thus less



1-Thottathura, 2-Chandanthodu, 3-Nellikunnu, 4-Sorrikal- 46, 5-Anamadankuthu, 6-Overall

Fig. 18a. Plot-wise species richness and evenness at Vazhachal evergreen forest ecosystem



1-Thottathura, 2-Chandanthodu, 3-Nellikunnu, 4-Sorrikal- 46, 5-Anamadankuthu, 6-Overall

Fig. 18b. Plot-wise tree species accumulation at Vazhachal evergreen forest ecosystem

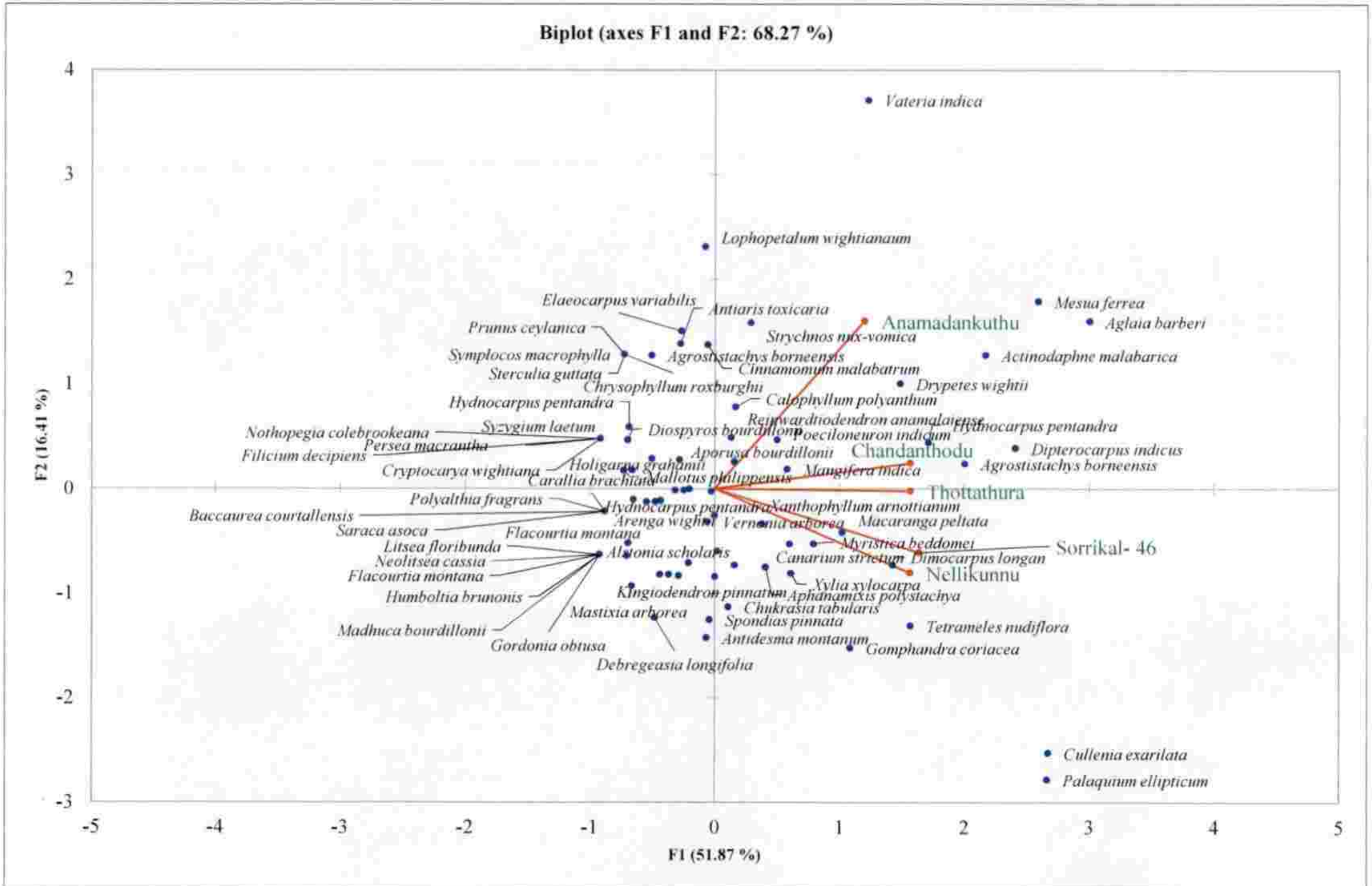


Fig. 19. Principle component analysis of tree species at Vazhachal evergreen forest ecosystem

pressure from wild animals. (Parthasarathy *et al.*, 2008; Anitha *et al.*, 2010). Absence of recent canopy gaps will enable the development of a healthy population of trees (Chandrashekara and Ramakrishnan, 1994; Bhat and Ravindranath, 2007) which in this case too, would have influenced the vegetation structure and composition. Interestingly some deciduous trees like *Tetrameles nudiflora*, *Macaranga peltata* etc. could also be recorded from the area, which previous workers too had also reported (Rajesh *et al.*, 1996; Damodharan, 2004; Magesh, 2014). This could be due to the fact that this ecosystem had been previously subjected to selection felling operations (KFD, 2012) and the present forest is secondary in nature. However the continuous presence of non-evergreen species in this ecosystem will affect the "eco-spaces" that should be occupied otherwise by the evergreen species and in the long run may ultimately affect the present species diversity and composition. Population wise (Fig. 8 and Fig. 9), the studied ecosystem has a healthy plant population structure as evidenced by the inverse J shaped curves obtained for the diameter frequency as well as height frequency distributions.

5.2. Functional Diversity

Functional diversity is an expression of the range of species traits in ecosystems. These traits can be morphological, biochemical, physiological, structural, phenological or behavioral characteristics that are expressed in phenotypes of individual organisms and are considered relevant to the response of such organisms to the environment and/or their effects on ecosystem properties (Violle *et al.*, 2007). Traits are usually a co-expression of underlying biophysical or biochemical properties and processes of an organism. Morphological traits also represent the adaptations to different diets or habitats, physiological traits, reproductive traits or behavioural traits. Analysis of the plant type trait (Fig. 10), revealed that the dominating plant type trait was evergreen trait (70.20%). Species wise, the sampled sites are dominated by evergreen species and the higher proportion of evergreen type plant trait observed is a result of this domination. Evergreen species are reported to exhibit a more conservative leaf strategy with higher leaf mass per area, greater construction costs and longer leaf life span (Bai *et al.*, 2015). The existing locality factors also favours the continuance of an "evergreen niche". At the same time, the secondary nature of the forests is evident by the occasional presence of semi-evergreen and moist deciduous species which is a plausible reason why the other plant traits like brevi-deciduous is also getting expressed in the study area (Anil and Parthasarathy, 2016a).

Trees like *Aglaia barberi, Bischofia javanica, Canarium strictum, Chukrasia tabularis, Dimocarpus longan, Dysoxylum malabaricum, Melicope lunu-ankenda* and *Toona ciliate* which were observed in the studied ecosystem have compound leaves (Table 5). However, investigations conducted on the leaf trait revealed that the dominating (Fig. 11) leaf trait was the simple leaf trait (72.60%). Sringeswara *et al.* (2010) had also observed that simple leaf trait dominate in an evergreen ecosystem of Kudremukh National Park. According to Boeger *et al.*, (2004), simple leaves usually has thick cuticle which helps in the fast draining of the falling rainwater, retarding the growth of epiphylls and reduces the loss of soluble nutrients by leaching. Evergreen species generally tend to have thicker leaves, thicker spongy and palisade mesophyll, more palisade mesophyll layers and a thicker sub-epidermis. Meanwhile, Lohbeck *et al.* (2015) argues that compound-leaved species often have photonastic leaves, which can avoid high insolation and therefore high temperature and excessive evaporation by folding their leaflets at noon or during the dry season (e.g., some Fabaceae species). Compoundness also increases leaf cooling and control of water loss (Yates *et al.*, 2010). It is also an efficient way of increasing leaf area for light capture (Niinemets, 1998). At Vazhachal, there does not exist conditions that favour the domination of "leaf compoundness". However the exact reason for the competitive advantage of having simple leaves in "evergreen niches" like that here in Vazhachal has to be scientifically explored and substantiated.

As already explained thicker leaves has more palisade mesophyll layers and thicker sub-epidermis are typical "evergreen" traits. In this case too, the dominant leaf texture trait at Vazhachal was glabrous (78.57%) followed by the pubescent traits (Fig. 12). According to Anil and Parthasarathy (2016a), glabrous leaves provide extra leaf toughness which will reduce the chance of "herbivory" and "predation" by invertebrates and microbes. Additionally, the thick cuticular layer facilitates faster draining of falling rain water and also resistance from pathogen infections (Cornelissen *et al*., 1999; Gessner, 2005; Goncalves *et al.,* 2007; Shanij *et al*., 2016). Glabrous leaf litters decompose slowly in the forest floor which provides ideal shelter for the soil invertebrates and other soil resident organisms (Graca and Zimmer, 2005; Rahman *et al*., 2012), a fact that was also confirmed through our concurrent observations on soil residents organisms, which will be described later.

It was also observed that 64.2 percent of the studied vegetation (Fig. 13) exhibited mesophyllous leaf traits followed by notophyll trait (33.33%). Vivek and Parthasarathy *et al.* (2008) and Sringeswara *et al*. (2010), have reported such trends in similar environments. Mesophyllous leaves have the ability to influence the rapid growth of trees through increased transpiration rates, photosynthesis rate and chlorophyll content (Westoby *et al*., 2002). The predominance of mesophyll leaves in evergreen forests is positively correlated to their habitat preferences, wetness and heat combination, which is a characteristic feature of the rain forest climate (Richards, 1952). In this particular ecosystem too, all the dominant trees like *Agrostistachys borneensis, Cullenia exarillata, Dipterocarpus indicus,* etc. were exhibiting mesophyllous traits. Basically pioneers like *Macaranga peltata* and *Symplocos macrophylla* who were observed to occupy the canopy gaps were on the other hand, had macrophyllous traits (Table 5).

Different bark thickness or texture in tropical forests evolved due to various factors such as environments, defensive chemical compounds, disturbances etc. in the particular locations (Wakio, 2010; Dorji *et al.*, 2015; Shanij *et al*., 2016). Bark traits play an important functional role by providing habitats to other organisms like food for ants, nests for birds, refuges or shelter for millipedes, host sites for the parasites etc. (Thomas *et al*., 2009). Usually, trees in fire or drought prone areas have medium thick barks (Paine *et al*., 2010). An evergreen forest is not a flammable landscape and hence experience only moderate level of disturbances when compared to such trees in stressed environments. The investigation at Vazhachal (Fig. 14) showed that the dominating bark thickness trait was medium bark thickness (5.0- 10.00 mm; 53.5%) followed by the thick bark (>10.00 mm; 32%). These observations are on a par with the reports of earlier studies in tropical evergreen forests (Hegde *et al*., 1998; Sagar and Singh, 2005; Anil and Parthasarathy, 2016b).

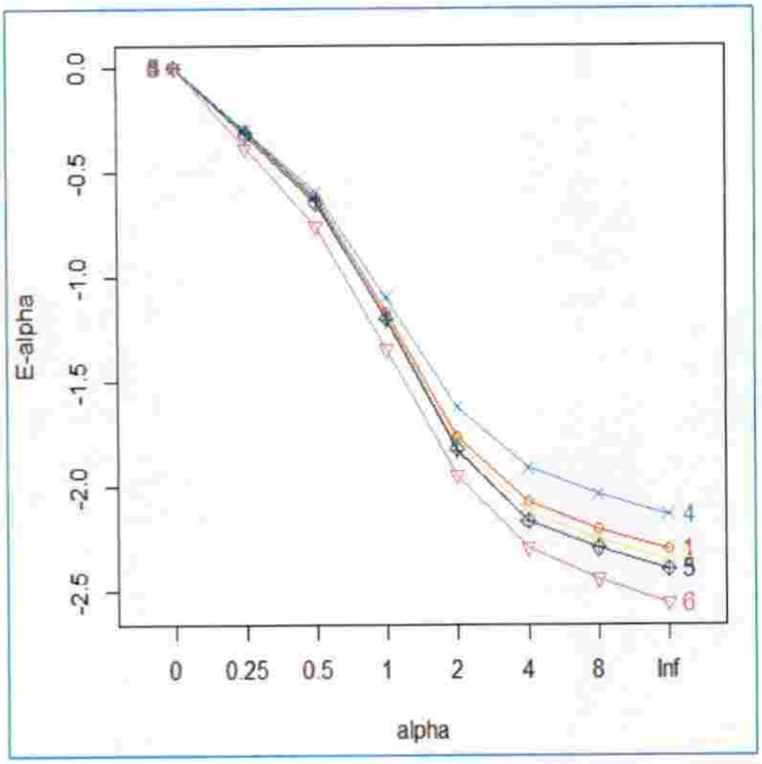
This ecosystem also returned higher trait values (Fig. 15) for smooth textured bark nature (47.2%), followed by rough (47%) and slightly rough (16.6%) nature. The bark texture or coarseness observed at Vazhachal follows relatively the same trend as reported from other tropical evergreen forests of the Western Ghats (Hussain, 1991; Padaki and Parthasarathy, 2000; Anil and Parthasarathy, 2016b). Bachan (2003), who had studied the Vazhachal forest ecosystems reports that this ecosystem is most preferred nesting sites for critically endangered birds like hornbills which usually prefers the smooth barked trees such as *Palaquium ellipticum, Cullenia exarillata, Agrostistachys borneensis* and *Aglaia barberi* since they are easily prone to natural holes (Table 5). Smooth bark traits also favour the colonization by various epiphytes like lichens, pteridophytes, bryophytes, orchids etc. Our study also encountered substantial amount of epiphytic life forms from the study area (Table 5).

Fallen fruits offer delicious food resources for organisms like microbes, invertebrates and other animals, at the same time these organisms helps to improve the survivability of the plant species (Chukwuka *et al*., 2010; Ruxton and Schaefer, 2012; Hanumantha *et al*., 2014). Capsule type of fruits (32%) were the dominant fruit trait (Fig. 16) at Vazhachal followed by drupe (26%) and berry (26%). Though similar observations were made by Parthasarathy *et al*. (2008), Sethi and Howe (2012), Anil and Parthasarathy (2015) and Mohandass *et al*. (2016), this domination is somewhat surprising considering the fact that capsule type of fruits are typical of drier ecosystems. The secondary nature of the studied ecosystem perhaps is a satisfactory reason for this trait aberration. *Agrostistachys borneensis*, *Cullenia* *exarillata*, *Dysoxylum beddomei*, *Macaranga peltata*, *Mesua ferrea* and *Tetrameles nudiflora* have capsule type of fruits (Table 5). At the same time, typical evergreen fruit traits like drupe and berry were also observed to be closely dominating this ecosystem. Fleshy fruit pulp is also one of the major food resource for many frugivores like invertebrates, mammals and also birds. These frugivores also act as seed dispersers which is a fundamental process through which the zoochorous assisted natural regeneration happens (Howe and Smallwood, 1982; Gabriella and Howe, 2007; Albrecht *et al*., 2012). Interestingly it was observed that zoochory (55.95%) followed by anemochory (37%) and autochory are the dominant dispersal traits (Fig. 17). Several earlier observations by Ganesh and Davidar (1999), Ganesh and Davidar (2001) and Mohandass *et al*. (2016) in the evergreen forests of Western Ghats also corroborate the present observation. Berries and drupes are usually dispersed by small vertebrates mostly by feeding (Umashankar *et al*., 1990; Anil and Parthasarathy, 2015). *Cullenia exarillata*, which was observed in the studied ecosystem has capsule type of fruits which is an important food source for threatened animals like Lion Tailed Macaques, Nilgiri langurs which are inhabiting this region (Kumar, 1995; Kumara and Santhosh, 2013). In case of *Aglaia barberi*, widely present in the sampled sites has seeds embedded in berry and exhibits zoochory (Gamble and Fisher, 1915). So it is clear that predominance of berry type of fruits and the abundance of frugivorous fauna in this locality are possible determinants of zoochory type of fruit dispersal.

As already pointed out, functional diversity refers to trait diversity and is increasingly seen as an alternate measure of species diversity. The indices recommended for expressing functional diversity usually describe its two broad aspects (i) how much of the functional niche space is filled by the existing species (functional richness) and (ii) how this space is filled (functional evenness, functional divergence/variance). Functional diversity of a community, therefore can be expressed as the diversity of measured traits with the help of three indices: functional richness (FRic), functional evenness (FEve) and functional divergence (FDiv). FR indices generally measure how much niche space is filled, FEve and FDiv indices tell how this space is filled. At Vazhachal, the study could observe high (Table 6) functional richness (FRic). Functional richness is the number of functions performed by the particular species (Mason *et al.*, 2005). The study could generate high species diversity indices which confirms the high species richness and evenness in that area. From Table 6, it is also evident that functional richness values showed variation across the sample plots which can be attributed to the plot-wise differences in species richness. The functional evenness (FEve) value (0.76) obtained for the studied ecosystem indicates that 76 percent of the resident tree species has identical pairs of functional traits. The trait values obtained at Vazhachal, namely evergreen plant type (70.2%), simple leaf type (72.6%), glabrous textured leaf type (78.57%) etc. indicates the spread of other functional niches too (eg. compound leaf trait, other leaf type traits etc) which justifies the relatively high FEve value. It shows the consociation or association traits in a community where the uniform distribution of species. Functional divergence (FDiv) which measures the variation or deviation of the species functions, on the other hand was 0.84 for Vazhachal (Ville´ger *et al.*, 2008). This is due to the existence of a multitude of traits like fruit type (Aggregate, pods, syconium, etc.) leaf size (Leptophyll, Microphyll, notophyll etc.) to name a few traits, in the same ecosystem.

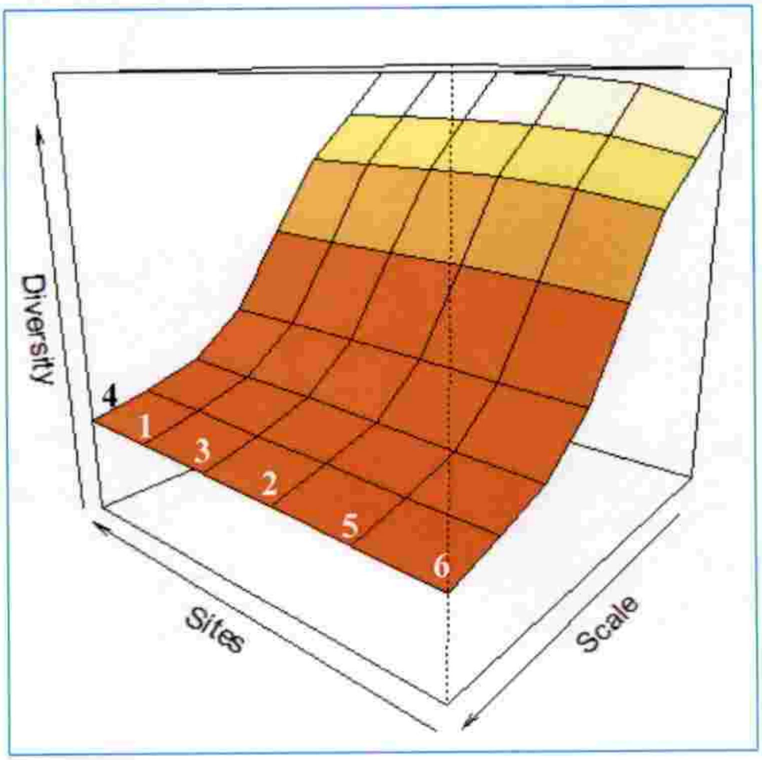
5.3. Soil invertebrates

The tropical evergreen forest ecosystem has many micro-food webs which work at the soil level. In these complex food webs, there operates several "litter transformers", "ecosystem engineers" and "bio-turbaters" which are known to us as the soil invertebrates. At Vazhachal, the study could record 16-21 orders of soil invertebrates and 159-194 individuals from the sampled sites (Table 7). These observations on soil invertebrate richness are in line with earlier studies in the Western Ghats (Mathew *et al.*, 1998; Anu and Sabu, 2006; Rahman *et al.*, 2010; Mohanraj *et al.*, 2014). Several factors directly and indirectly influence the soil invertebrate`s distribution and diversity. The list will include the composition of the standing vegetation, litter quality, litter depth, climatic factors and also slope of the terrain (Rossi and Blanchart, 2005; Sabu *et al.*, 2008). It is an established fact



1-Thottathura, 2-Chandanthodu, 3-Nellikunnu, 4-Sorrikal- 46, 5-Anamadankuthu, 6-Overall

Fig. 20a. Plot-wise soil invertebrates richness and evenness at Vazhachal evergreen forest ecosystem



1-Thottathura, 2-Chandanthodu, 3-Nellikunnu, 4-Sorrikal- 46, 5-Anamadankuthu, 6-Overall

Fig. 20b. Plot-wise soil invertebrates accumulation at Vazhachal evergreen forest ecosystem

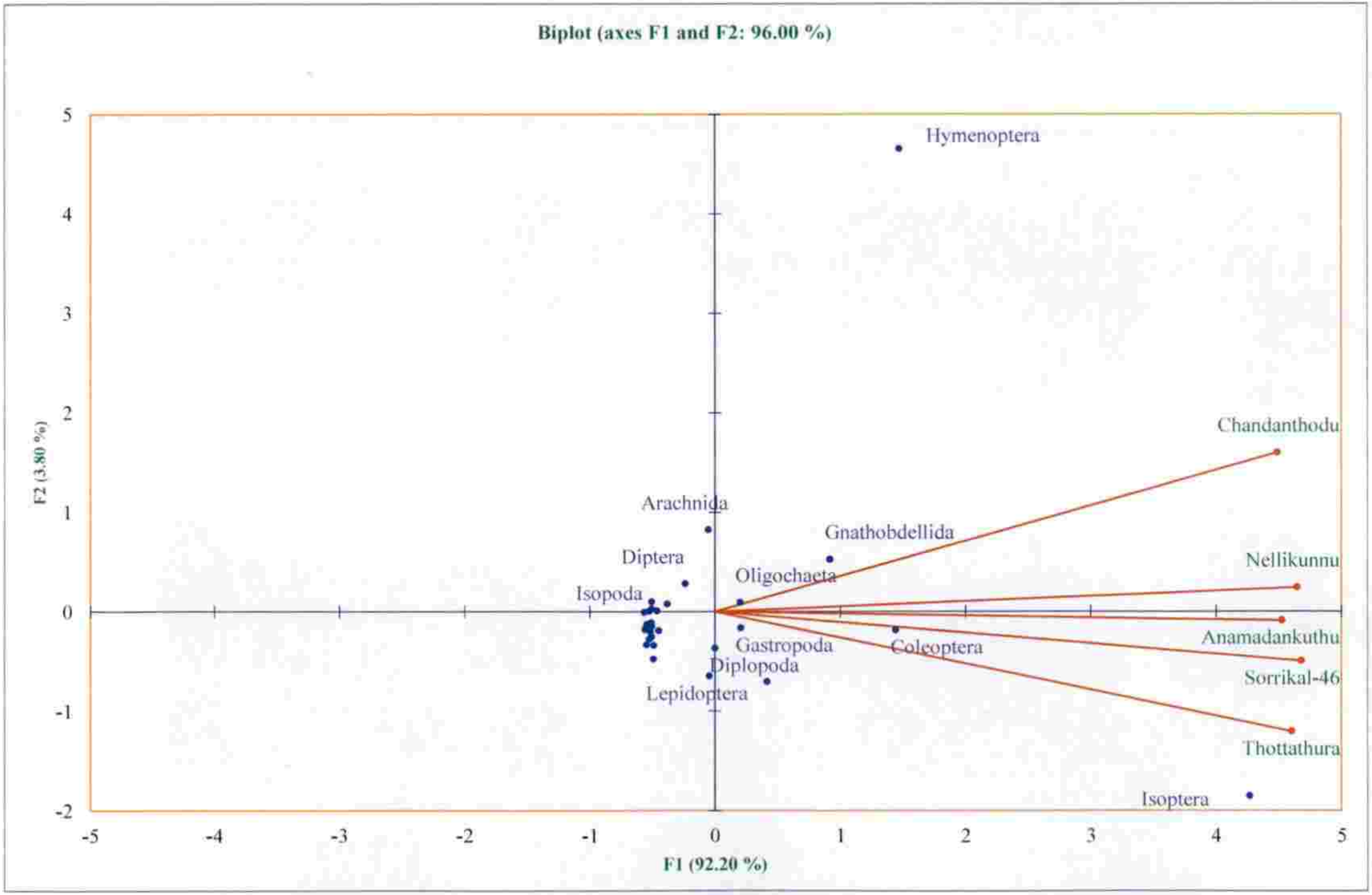


Fig. 21. Principle component analysis of soil invertebrates at Vazhachal evergreen forest ecosystem

that higher plant species richness provides a wide range of food and shelter options for the soil invertebrates (Mathew *et al.*, 1998; Rahman *et al.*, 2012).

The diversity of the soil invertebrates (28 orders) observed at Vazhachal of course, is a function of the observed high plant species and richness diversity. The Simpson`s index of diversity (D) and Shannon- wiener index of invertebrates at Vazhachal ranged from 0.81- 0.86 and 2.07- 2.39 respectively (Table 8). This is on a par with the reports published by Mathew *et al.* (1998) for the same region. The Vazhachal ecosystem was dominated by *Isoptera* (30%), followed by *Hymenoptera* (12.67%) and *Coleoptera* (12.33%). This observation is also in agreement with Rahman (2010), Fernandez (2012) and Mohanraj *et al.* (2014). Large arthropods basically are also litter transformers. Organisms like earthworms, termites and to a lesser extent, ants are "ecosystem engineers" that create diverse organo-mineral structures. The role of termites in ecosystems is to loosen soil (reduction of bulk density) and both vertical and horizontal transport through bioturbation. The plot wise minor variations in the distribution of soil invertebrates are because of the plot-centric variations in the resident locality factors and plant species compositions (Fig. 20a and Fig. 20b). For example the Chandanthodu plot has abundant leeches (Gnathobdellida) and earthworms (Oligochaeta) which probably could be an influence of a more closed canopy of that plot (Fig. 21), which ensures higher quantities of leaf litter and naturally also more soil moisture.

5.4. Soil microorganisms

Soil microorganism viz., bacteria, fungi, actinomycetes, nitrogen fixing bacteria, phosphate solubilizing microorganisms (PSM) and fluorescent pseudomonads was identified from the Vazhachal forest ecosystem soil during the course of this study (Table 9). The composition of the various microbial communities differed under the different sample plots. Plot-wise variations in soil temperature, acidity, moisture content, organic matter and other soil parameters could be the primary reason for this (Satish *et al.*, 2007; Saravanakumar and Kaviyarasan, 2010; Varghese *et al.*, 2014). The plot wise variations in plant species composition and structure also might have played an influential role. The population of bacteria at Vazhachal ranged from 43 to 50 x 10^6cfu g^{-1} which is in line with Isaac and Nair (2004), Saravanan *et al.* (2012), Nampoothiri *et al.* (2013) and Bhattacharyya and Jha (2015). A diverse litter type contributed by an equally diverse plant community will hike up the microbial population (Curl and Truelove, 1989). In addition to this, higher plant diversities also offer a range of root exudates and nutrients to soil bacteria aiding the rhizosphere microbial population (Thoms and Gleixner, 2013). High organic content and high soil moisture (both these parameters were high at Vazhachal) will also enhance the soil invertebrates and microbial population (Shilpkar *et al.*, 2010). Soil fungi are pioneers in the colonization of the substrates and they degrade substrates by producing enzymes (Hyde *et al.*, 2001; Sudhakaran *et al.*, 2014). Increase in bacterial population leads to further degradation and get mixed up with soil (Saravanakumar and Kaviyarasan, 2010). The soil fungal colonies ranged from 22.5- 31.5 x 10^3cfu g^{-1}. These observations in line with reports of Rane and Gandhe, (2006), Satish *et al.* (2007), Banaker *et al.* (2012) and Bagyaraj *et al.* (2015). More soil moisture and prevalence of a constant soil temperature ensure better colonies of soil fungi. At Vazhachal, these conditions abound, which will be ensuring a constant soil moisture content and soil temperature further favouring the growth of fungal colonies.

The soil fluorescent pseudomonads populations ranged from 17.5- 19.5 x 10^4 cfu g^{-1} which is in agreement with the observations by Sonawane *et al.* (2014) and Suneesh *et al.* (2015) at Western Ghats. As in the above case, a higher plant species richness together with a diverse amount of litter and exudates of different kinds are crucial determinants of the population structure of fluorescent pseudomonads (Saravanan *et al.*, 2012; Thoms and Gleixner, 2013). Concurrently, the Vazhachal forests also had high soil organic carbon and high moisture content which would have additionally favoured the growth of fluorescent pseudomonads (Shilpkar *et al.*, 2010). Meanwhile, the population of nitrogen fixers ranged from 12.5- 18 x10^4cfu g^{-1} and is in agreement with Bagyaraj *et al.*, (2015) at Western Ghats forests of Karnataka. The soil population of nitrogen fixers too is a function of the diversity of resident plant species diversity (Wang *et al.*, 2010). The soil actinomycetes populations of Vazhachal ranged from 15- 18x 10^3cfu g^{-1} and

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corroborates the earlier views by Nithya and Ponmurgugan (2012), Varghese *et al.* (2014) and Bagyaraj *et al.* (2015).The population of actinomycetes are influenced by soil physicochemical properties and the soil microclimate (Stackebrandt *et al.*, 1991; Shilpkar *et al.*, 2010; Varghese *et al.*, 2014). Higher plant species richness and also higher tree density (Table 2) at Vazhachal naturally would have proved conducive for the soil actinomycetes. Phosphate solubilizer's population at Vazhachal, at the same time, ranged between 16- 23.5 x 10^3cfu g^{-1}. These values are in line with Korikanthimath *et al.* (2000), Bagyaraj *et al.*, (2015) and Baliah *et al.* (2016) in other parts of the Western Ghats. The population of phosphate solubilizers depends on different soil properties like P content, organic content and climatic factors of the sites (Kim *et al.*, 1998). Continuous disturbance and lower OM content in the soil can reduce the population of phosphate solubilizers (Arunachalam and Arunachalam, 2000). Naturally due to higher plant species richness and other resultant soil conditions, the observed phosphate solubilizer's population at Vazhachal is not surprising.

5.5. Edaphic characteristics

Recorded soil temperatures (at 15 cm depth) at Vazhachal ranged from 18.22- 22.36°C (Table 10). In a forested environment, soil temperature is highly location specific and depends to large extent on the locality factors, canopy cover, vegetation density and distance from the water bodies, roads, settlements and other disturbances. At around 30 km north to the present study area in the undisturbed evergreen forests of Neliampathy hills, Hussain *et al.* (1991) recorded a mean annual soil temperature of 19.1°C. In tropical humid forests, a closed canopy will create obstacles for the free penetration of sunlight to the forest floor. Reduced sunlight and more rainfall ensures the prevalence of lower soil temperatures in the evergreen forests (Balasubramanyan, 1987; Jose *et al.*, 1996; Roby, 2013). The studied evergreen forest patch of Vazhachal has a closed canopy as evidenced by the higher tree densities observed there. Additionally, the resident trees were providing refugia for the spongy epiphytes in their trunks and twigs. These in turn traps rain water and releases it slowly to the ground. In addition to these, the abundance of thick undergrowth like *Strobilanthus* spp. and thick litter layer on the ground here act as a mulch and retain moisture. All the factors would have contributed and ensured a continuous availability of moisture and also cut the evaporation of water from the forest floor which kept down the soil temperature. The observations for soil moisture are no less different. The soil moisture content at Vazhachal ranged from 28.33 to 29.97% which is in line with other reports published from the other parts of evergreen forests of Western Ghats (Balasubramanyan, 1987; Rajesh *et al*., 1996; Ramachandra *et al.,* 2012b; Devagiri *et al*., 2016). As described, higher vegetation densities which ensures a closed canopy and (Table 2) retains higher soil moisture levels. Increased litter turnover and a thick undergrowth also kept up the soil moisture.

Soil bulk density at Vazhachal ranged from 1.18 to 1.30 gcm^{-3} which is in agreement with the values obtained by earlier workers in the other evergreen forest ecosystems in the Western Ghats (Ramachandra *et al*., 2012b; Asok and Shoba, 2014; Rahman *et al*., 2012). Higher floral diversity influences the soil bulk density through the continuous addition of leaf litter in surface layer. The tropical climate in turn favours faster leaf litter decomposition (Kumar *et al.,* 2012). The litter layer also provides adequate food sources and shelter opportunities for the soil based decomposers to act faster and thereby reduce the soil bulk density. Yet another plausible reason for the high soil bulk density values observed in the ecosystem can be attributed to the low biotic disturbances the area suffers. All these favourable conditions persist at Vazhachal.

The organic carbon content of soil ranged from 3.97- 4.33% which follows the expected pattern at other parts of Western Ghats (Rajesh *et al*., 1996; Barbhuiya *et al*., 2004; Devagiri *et al*., 2016). Generally the undisturbed west coast wet evergreen forests of Western Ghats has more soil organic carbon content naturally due to year around litter fall in combination with higher rainfall. This litter layer is a refugia for the numerous soil organisms. In addition to this the organic content created out of decomposition of wind-thrown large trees also boost the soil organic matter. It is an accepted fact that higher organic content in the soil will increase the soil moisture content and reduce the soil bulk density (Roby, 2013). Dense canopy, thick under cover, high species richness, deeper root biomass, fine soil texture, cool temperature and more precipitation tends to favours the production of more organic carbon (Divya *et al*., 2016). All these favourable conditions existed in the studied forest ecosystem at Vazhachal.

The recorded ranges of soil acidity (pH) was from 4.55 to 6.48 was also in agreement with other studies conducted at similar areas of Western Ghats (Barbhuiya *et al*., 2004; Kumar *et al*., 2012; Divya *et al*., 2016). The plot-wise variations could be due to specific situations in those plots. The prevalence of neutral pH in the soil could be due to the high organic carbon in addition to the high clay content of the soil in that location (Table 10). The low pH value obtained could be due to the relatively higher elevations, wherein due to the higher rainfall washing down the soil organic and clay content to the lower soil layers or lower elevations (Roby, 2013). Simultaneously, degradation of leaf litter will increase the production of organic acids which also is a reason for the reduced soil acidity (Aneesh, 2011). Across the sampled sites, the electrical conductivity of soil ranged from $0.054 dSm^{-1}$ to $0.096 dSm^{-1}$. These observations were in line with other studies conducted at the similar forests present in the Western Ghats (Saravanakumar and Kaviyarasan, 2010; Vijayakumar and Vasudeva, 2011; Reddy *et al*., 2012). Low values in some plots was probably due to altitudinal variations wherein the run off rain water is more likely to wash away the alkali and alkaline bases of soil to lower elevation. This could result in more sand content and low electrical conductivity (Vijayakumar and Vasudeva, 2011).

The observed soil texture at Vazhachal is sandy loam which is in line with the trend seen in forest soils (Pascal *et al*., 2004; Kumar *et al*., 2012; Aneesh, 2011) elsewhere. Higher proportion of sand in forest surface was observed in the present study and this could be due to the effect of continuous rainfall which may be washing down the finer particles from surface layer to lower layer (Mani *et al*., 2008).

5.6. Ecosystem functioning

Vazhachal is blessed with abundant rainfall (Fig.1) and nutrients rich soil (Table 10). The occurrence of more sunlight combined with soil moisture naturally triggers more photosynthesis activity. The higher levels of photosynthesis and transpiration in turn produce more food which results in faster growth rates. It is also evident from our study (Table 2) that Vazhachal has a higher basal area and higher species diversity. Analysis also reveals that the tree population is positively related with soil moisture content, organic carbon, silt and clay content (Table 10) whereas it is negatively correlated with soil temperature, bulk density, soil acidity, soil electrical conductivity and sand fraction (Table 11). These trends are in line with the reports of Kumar *et al*. (2012), Aneesh (2011) and Asok and Shoba (2014) in similar ecosystems. In most of the sample plots (Table 2) the study could note larger number of individuals and also sometimes the presence of the bigger trees which invariably contributed to the closed nature of the canopy. A closed canopy has several ecological and physiological implications. One of the biggest impacts of this situation is reflected in the micro-climate. A closed canopy also reduces the penetration of direct sunlight to the ground. This triggers an increase in the soil moisture content and cuts down the soil temperature. An increased soil moisture content causes a washout of the silt and clay fraction. This will reduce the acidity and electrical conductivity of the soil. Our observations in the sampled plots are also in these directions. Due to dissolving or washing out of the clay and silt content, only sand remain, which partially explains the presence of sandy loam soil in the study area. The occurrence of more number of individuals and bigger sized trees provides opportunities for the copious dumping of leaf litter and other organic matter in higher proportions to the forest floor. More and varied leaf litter and high soil moisture content create scenarios for faster decomposition by offering a variety of food options and refugia for the myriad soil resident organisms. This activity will naturally result in the significant increase of soil organic carbon thereby decreasing the soil bulk density and increase in the silt and clay fraction in the soil. The present analysis could find positive relation between number of species and soil moisture content, bulk density, silt, clay content whereas it is negatively related with soil temperature, organic carbon, soil acidity, soil electrical conductivity and sand fraction (Table 11).

In this study, the number of species also positively correlated with all microbial populations other than the nitrogen fixers (Table 12). These may be due to the fact that nitrogen fixers are mostly host specific species, especially legumes. It is reported that the presence of free living nitrogen fixing organisms will stimulate the plant roots to exudate (Das *et al.*, 2013). These will increase the nitrogen content of soil which will ultimately modify the acidity and organic matter of soil by the stimulating growth of other microorganisms (Thoms and Glexiner, 2013). It is recently reported that the immense diversity of microorganisms and animals that live belowground contributes significantly to shaping the aboveground biodiversity and the functioning of terrestrial ecosystems. So it is possible that the nitrogen fixers at Vazhachal also would have played their role in the shaping of individuals in forest ecosystem. The number of individuals also positively correlated with all other microbes other than fungi, actinomycetes and fluorescent pseudomonads (Table 12). Increased vegetation density will decrease the soil pH. Increased densities will also create an abundance of leaf litter which facilitates the retention of more moisture content. Increased moisture content will enable the leaching out of organic acids which will attract the aerial mycelia formation of actinomycetes and fungal population (Priyadharsini and Dhanasekaran, 2015).

There are many micro-food webs involving micro fauna in tropical evergreen forest soils. Large arthropods basically are also litter transformers. Organisms like earthworms, termites and, to a lesser extent, ants, are "ecosystem engineers" that create diverse organo-mineral structures. The role of termites in

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Table 11. Correlation coefficient for the interrelation between soil edaphic factors with number of individuals and number of tree species

		Number of individual	Number of species
Soil Temperature		-0.456	-0.509
Bulk density		-0.152	0.068
Moisture content		0.107	-0.218
Organic carbon		0.596	0.244
Soil acidity (pH)		-0.398	-0.61
Soil electrical conductivity (Ec)		-0.261	-0.207
Soil texture	Sand	-0.785	-0.789
	Silt	0.208	0.04
	Clay	0.585	0.782

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

Table 12. Correlation coefficient for the interrelation between soil microorganisms, number of individual and number of tree species

	Number of individual	Number of species
Bacteria	0.851	0.87
Fungi	0.401	0.696
Fluorescent pseudomonads	-0.088	0.308
Nitrogen fixers	0.292	-0.101
Actinomycetes	-0.011	0.07
Phosphate solubilizers	0.036	0.433

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

Table 13. Correlation coefficient for the interrelation between soil microflora and soil edaphic factors

	Bacteria	Fungi	Fluorescent pseudomonads	Nitrogen fixers	Actinomycetes	Phosphate solubilizers
Soil temperature	-0.073	-0.396	-0.579	0.484	0.810	-0.514
Bulk density	-0.367	0.393	0.836	-0.843	-0.776	0.662
Moisture content	-0.406	0.917*	-0.316	0.270	0.731	-0.325
Organic carbon	0.562	-0.115	-0.788	0.901*	0.224	-0.769
Soil acidity	-0.149	-0.403	-0.737	0.662	0.459	-0.841
Soil electrical conductivity	-0.036	-0.443	-0.276	0.184	0.722	0.051
Sand	-0.557	-0.646	-0.351	0.163	0.481	-0.285
Silt	-0.286	-0.089	0.149	-0.131	-0.967	0.010
Clay	0.901*	0.985	0.212	-0.036	0.576	0.297

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

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ecosystems is to loosen soil (reduction of bulk density) and both vertical and horizontal transport through bioturbation. In an evergreen forest ecosystem like Vazhachal, all these organisms operate at nested scales of time and space and have myriad effects on soil function in the order of micro-levels. The number of individual and diversity of species positively correlated with several invertebrates orders (Table 14). Similar results were also obtained for several other authors (Mathew *et al.,* 1998; Fernandez, 2012; Rahman *et al.,* 2013). As has been emphasized, Vazhachal has greater abundance of vegetation which manifests in the form of higher organic matter production. In our study sites also, higher rainfall coupled with high organic matter content in soils triggers the population of various types of invertebrates by providing sources of nutrient and shelter (Table 14 and Fig.1).

Generally the soil surface temperature of a forest ecosystem will increase due to an open canopy or due to the proximity to settlements or roads. Higher soil temperature leads to decrease in the population of invertebrates and microorganisms by the affecting their survival, physiology and reproduction. In the study sites, the invertebrate population was observed to be directly related with soil temperature (Table 14). These are in line with the observations by Mathew *et al.* (1998), Anu and Sabu (2006) and Rahman *et al.* (2012). Higher moisture content and leaf litter will attract more organisms. These organisms survive by feeding or by fragmenting the leaf litter like organic matter to a finer fraction. These finer fractions are mixed by the soil dwelling organisms like *Oligochaeta* (Earthworms), *Diplopoda* (millipedes), *Hymenoptera* (ants) which will decrease the bulk density of the soil. Soils with low bulk density and higher moisture content attract more microbes for further degradation. Our observations are also in the same line, viz., low bulk density (Table 7), more invertebrates (Table 8) and more microbes (Table 10). Higher population of soil invertebrates and microorganisms leads to an increase in the production of organic acids (Pathma and Sakthivel, 2012). It will result in the decrease in acidity, electrical conductivity and also increases the organic content of the soil. Higher organic content of the soil increases the silt and clay content. So higher invertebrate and

Table 14. Correlation coefficient for the interrelation between soil invertebrates, number of individual and number of tree species

	Number of individual	Number of species
Araneae	0.737	0.441
Blattaria	0.543	0.229
Chilopoda	0.829	0.575
Coleoptera	0.601	0.478
Collembola	0.13	0.033
Dermaptera	0.546	0.26
Diptera	0.845	0.755
Ephemeroptera	0.022	0.387
Gastropoda	0.137	0.188
Gnathobdellida	0.948**	0.47
Hemiptera	0.868	0.089
Hymenoptera	0.662	0.763
Isopoda	0.868	0.189
Isoptera	0.901*	0.813
Lepidoptera	0.414	0.029
Mantodea	0.784	0.849
Mecoptera	0.012	0.285
Diplopoda	0.260	0.062
Neuroptera	0.717	0.513
Oligochaeta	0.132	0.136
Orthoptera	0.563	0.562
Phasmida	0.638	0.803
Plecoptera	0.012	0.285
Psocoptera	0.243	0.863
Scorpiones	0.005	0.068
Thysanoptera	0.262	0.068
Thysanura	0.597	0.749
Trichoptera	0.374	0.522

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

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Table 15. Correlation coefficient for the interrelation between soil invertebrates and soil edaphic factors

	Soil temperature	Bulk density	Moisture content	Organic carbon	Acidity (pH)	Electrical conductivity (EC)	Soil texture		
							Sand	Silt	Clay
Arachnida	-0.389	0.113	0.413	0.812	-0.048	-0.641	-0.712	0.016	0.164
Blattaria	-0.414	0.023	0.525	0.719	-0.116	-0.755	-0.645	0.65	-0.056
Chilopoda	-0.591	0.035	0.521	0.677	-0.226	-0.632	0.223	-0.028	-0.155
Coleoptera	-0.087	0.411	0.28	0.284	-0.373	-0.48	0.116	0.644	0.161
Collembola	0.086	0.91*	0.399	0.704	-0.776	-0.376	0.325	0.669	0.401
Dermaptera	-0.095	0.441	0.595	0.477	-0.174	-0.306	-0.101	0.202	-0.131
Diptera	-0.597	0.023	0.395	0.273	-0.677	-0.068	-0.639	0.376	0.243
Ephemeroptera	-0.232	0.481	0.725	0.366	-0.266	-0.369	-0.374	-0.194	0.62
Gastropoda	-0.384	0.203	0.723	0.455	-0.191	-0.752	0.386	-0.096	0.488
Gnathobdellida	-0.175	0.328	0.634	0.645	-0.631	-0.28	-0.101	-0.391	0.551
Hemiptera	-0.499	0.061	0.199	0.168	0.072	0.096	0.026	-0.012	-0.247
Hymenoptera	-0.589	0.355	0.237	0.24	-0.369	-0.717	0.397	0.262	0.652
Isopoda	-0.499	0.061	0.199	0.168	-0.672	-0.096	-0.726	0.012	0.747
Isoptera	-0.017	0.1	0.755	0.148	0.101	-0.329	-0.21	0.591	0.88*
Lepidoptera	-0.022	0.499	0.719	0.78	0.28	0.044	0.096	0.363	-0.317
Mantodea	-0.502	0.034	0.061	0.068	0.763	0.113	0.558	-0.097	-0.473
Mecoptera	-0.063	0	0.401	0.558	-0.523	-0.689	0.223	-0.485	0.311
Diplopods	-0.756	0.553	0.743	-0.076	0.266	-0.855	0.937*	0.970*	0.918*
Neuroptera	-0.568	0	0.667	0.327	-0.549	-0.092	-0.521	0.54	-0.066
Oligochaeta	-0.761	-0.868	0.555	0.341	-0.4	-0.78	-0.44	0.886*	0.924*
Orthoptera	-0.417	0	-0.011	-0.045	-0.72	-0.302	-0.292	0.165	0.117
Phasmida	-0.291	-0.067	0.567	0.041	0.576	-0.038	0.535	0.294	-0.89
Plecoptera	-0.063	0	0.401	0.558	-0.523	-0.689	0.223	-0.085	0.311
Psocoptera	-0.633	0.04	0.288	0.379	-0.632	-0.234	-0.786	0.375	0.399
Scorpiones	0.100	-0.613	-0.55	0.574	0.794	-0.027	0.178	-0.57	0.45
Thysanoptera	-0.323	0.674	0.27	0.317	0.027	0.028	0.319	0.253	-0.064
Thysanura	-0.363	0.026	0.091	0.139	-0.764	-0.323	-0.351	0.092	0.469
Trichoptera	-0.101	0.075	0.624	0.261	0.058	-0.488	-0.531	-0.187	0.772

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

Table 16. Correlation coefficient for the interrelation between soil invertebrates and soil microorganisms

	Bacteria	Fungi	Fluorescent Pseudomonads	Nitrogen fixers	Actinomycetes	Phosphate solubilizers
Arachnida	0.503	0.155	-0.385	0.538	-0.307	-0.466
Blattaria	0.265	0.061	-0.365	0.478	-0.476	-0.519
Chilopoda	-0.507	-0.185	0.222	-0.384	0.429	0.251
Coleoptera	0.419	-0.266	-0.277	0.338	0.189	0.052
Collembola	0.462	-0.105	-0.733	0.772	0.803	-0.675
Dermaptera	0.241	-0.512	-0.529	0.564	-0.019	-0.271
Diptera	0.528	0.104	0.033	0.101	-0.227	0.244
Ephemeroptera	0.303	0.925*	0.745	-0.654	0.077	0.595
Gastropoda	0.214	0.220	0.331	-0.347	0.697	0.549
Gnathobdellida	0.257	0.601	0.784	-0.741	0.26	0.911*
Hemiptera	-0.83	-0.631	-0.329	0.137	-0.088	-0.496
Hymenoptera	0.664	0.876	0.402	-0.204	-0.2	0.279
Isopoda	0.083	0.631	0.329	-0.137	0.088	0.496
Isoptera	-0.701	-0.674	-0.432	0.311	-0.579	-0.609
Lepidoptera	0.109	-0.596	-0.82	0.844	-0.148	-0.745
Mantodea	-0.62	-0.300	-0.246	0.107	0	-0.498
Mecoptera	0.127	0.118	0.44	-0.456	0.395	0.709
Diplopods	0.182	0	-0.064	0.021	0.913*	0.124
Neuroptera	0.293	-0.184	-0.151	0.239	-0.382	0.035
Oligochaeta	-0.496	0.08	0.455	-0.478	-0.965**	0.226
Orthoptera	0.302	-0.082	0.12	-0.059	-0.088	0.413
Phasmida	-0.801	-0.789	-0.492	0.322	-0.321	-0.634
Plecoptera	0.127	0.118	0.44	-0.456	0.395	0.709
Psocoptera	0.673	0.296	0.059	0.115	-0.211	0.216
Scorpiones	0.396	0.192	-0.479	0.529	0.645	-0.579
Thysanoptera	0.17	-0.603	-0.569	0.549	0.381	-0.248
Thysanura	0.519	0.271	0.34	-0.239	0.135	0.625
Trichoptera	0.647	0.873	0.257	-0.096	0.215	0.101

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

microorganism populations will increase the organic content, silt, clay and also decrease the electrical conductivity and acidity of the soil. At Vazhachal, an increased amount of soil moisture and abundant leaf litter has possibly influenced the presence of soil dwelling invertebrates like *Oligochaeta* (earthworms), *Gnathobdellida* (Leeches), *Isoptera* (termites) and *Coleoptera* (beetles) (Table 15). Their fragmenting activites in turn might have further attracted and favoured the fungal and bacterial population. Our studies also report the possible connection between more soil organic carbon (Table 7), more invertebrates (Table 8) and more microbes (Table 16). Our observations led further credence to the increasing realization that the patterns of below-ground community organization are impacting the aboveground community dynamics and ecosystem functioning in this tropical evergreen forest (Rahman *et al.,* 2012). However we need to improve our understanding of the underpinning mechanisms that shape these complex biological communities at different spatio-temporal scales by undertaking specialized investigations in these lines.

Functional traits are plastic and vary spatially and temporally. The future line of work must therefore involve making ecosystem-wise quantitative assessments of the various morpho-physiological and other traits of all resident above ground and belowground biological components and comprehensively understand the functional roles played out by these organisms. This dataset must be read with the resident soil and environmental variables and the resulting information must be integrated in prospective forest management strategies pertaining to that ecosystem.

Summary

SUMMARY

The present study was carried during 2014-16 to understand the species and functional diversity of the tropical west coast wet evergreen forest (IA/C4) ecosystem of Vazhachal Forest Division of Thrissur district in Kerala. The study also tried to understand the links between diversity, soil aspects and functioning of this evergreen forest ecosystem. The results obtained from the summarized are explained below.

1. At the tropical wet west coast evergreen forest of Vazhachal forest division, this study could record 175 life forms. This list includes which 57 tree recruits, 29 shrubs, 28 herbs, 19 climbers, 14 pteridophytes, 13 polypores, 7 epiphytes, 4 orchids and 4 bryophytes.
2. A total of 84 tree species (> 10 cm GBH) was recorded from the entire 0.5 ha area.
3. *Aglaia barberi, Cullenia exarillata, Mesua ferrea, Palaquium ellipticum* and *Dipterocarpus indicus* are the dominant tree species in Vazhachal forest division.
4. The density of tropical west coast wet evergreen was 1093 individuals per hectare with a basal area of $85.43m^2$.
5. The diameter frequency as well as height frequency distribution of evergreen forests showed the reverse J shaped curve which reflects a good regeneration status.
6. *Euphorbiaceae*, *Dipterocarpaceae* and *Meliaceae* are the tree dominant families.
7. Chandanthodu reported highest Margalef richness index and Shannon-Wieners index. Anamadankuthu plot has the highest Simpson index and Pielou`s index. Species richness is not distinguishable between Chandanthodu, Nellikunnu and Anamadankuthu. However it was observed to be riles richer in Thottathura and Sorrikal- 46.
8. Among plant functional traits of the tree species, evergreen plant type dominated (70.2%).

9. Simple type of leaves was the most dominant leaf type (72.6%). Glabrous textured leaves dominated (78.57%) the ecosystem. Mesophyll type of leaves was exhibited by 64.2% of the 84 trees.
10. Trees with smooth bark texture accounted for 47.2% while 53.5% had medium bark thickness.
11. Capsule fruit type was the dominant (32.1%) fruit type with zoochory (55.95%) was the dominant dispersal type.
12. The highest functional richness (FRic) and Functional dispersion (FDis) was observed in Chandanthodu followed by Nellikunnu. The maximum value of functional evenness (FEve) and functional divergence (FDiv) was observed in Thottathura followed by Sorrikal- 46.
13. No significant difference with regards to bulk density (1.18-1.30 gcm^{-3}), moisture content (28.33-29.97%) and organic carbon (3.97-4.33%) was observed between the sample plots.
14. The soil temperature (at 15 cm depth) ranges from 18.22- 22.36°C. The soil acidity (pH) of evergreen forests ranges from 4.55 - 6.48 and highest pH in Thottathura. The soil electrical conductivity (Ec) of evergreen forests ranges from 0.054 $mSm^{-1}$to 0.096 mSm^{-1}.
15. The soil in the tropical evergreen forests of Vazhachal was sandy loam in texture. The highest fraction of Sand was observed in Thottathura (79.50%), Silt in Anamadankuthu (15.1%) and clay in Chandanthodu (7.13%).
16. A total of 28 different order of soil invertebrates was recorded with 860 individuals. *Isoptera* (30%) dominated followed by *Hymenoptera* and *Coleoptera*.
17. Shannon Wiener Index and Pielou`s Evenness of soil invertebrates was highest in Anamadankuthu. Simpson`s diversity of soil invertebrates was highest in Sorrikal- 46.
18. Bacteria colonies were the most populous soil microorganisms. The population range observed at Vazhachal is as follows: Bacteria (37-50 x 10^6cfu per gram of soil), Fungi (22.5-31.5 x 10^3 cfu per gram of soil), Fluorescent pseudomonads (16- 19.5 x10^4cfu per gram of soil), N_2 fixers (12-

17.5 x 10^4cfu per gram of soil), Actinomycetes (14.5 -18 x 10^4cfu per gram of soil) and Phosphate solubilizers (16-23.5 x 10^3 cfu per gram of soil).

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Appendices

APPENDICES

Appendix 1. Composition of nutrient media used for soil microbial analysis

a) Nutrient Agar medium (Bacteria)

	$g\ lit^{-1}$
Agar	20.0
Beef extract	3.0
Distilled water	1000 ml
Nacl	5.0
Peptone	5.0
pH	6.8 - 7.2

b) Martin's Rose Bengal Agar medium (Fungi)

	$g\ lit^{-1}$
Agar	20.0
Dextrose	10.0
Distilled water	1000 ml
KH_2PO_4	1.0
$MgSO_4$	0.5
Peptone	5.0
Rose Bengal	0.003
Streptomycin sulphate	0.03 (3 ml of 1 % stock solution)

c) Ken Knight medium (Actinomycetes)

	$g\ lit^{-1}$
Agar	20
Dextrose	1
Distilled water	1000 ml
Kcl	0.1
KH_2PO_4	0.1

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$MgSO_4$	0.1
NH_4SO_4	0.1
pH	7.0

d) Pikovskaya`s agar media (Phosphate solubilizers)

	g lit^{-1}
$(NH_4)_2SO_4$	0.5
Agar	20
$Ca_3(PO_4)$	5
Distilled water	1000 ml
$FeSO_4.7H_2O$	0.002
Glucose	10
Kcl	0.2
$MgSO_4.7H_2O$	0.1
$MnSO_4.7H_2O$	0.002
Nacl	0.2
Yeast extract	0.5

e) Jenson`s agar media (Nitrogen Fixers)

	g lit^{-1}
Agar	15
Distilled water	1000 ml
K_2HPO_4	1
$MgSo_4.7H_2O$	0.5
Nacl	0.5
$FeSO_4$	0.01
Sucrose	20
$CaCo_3$	2
pH	7

f) Kings B media (Fluorescent Pseudomonas)

	$g\ lit^{-1}$
Agar	15
Distilled water	1000 ml
Glycerol	10 ml
K_2HPO_4	1.5
$MgSo_4.7H_2O$	1.5
Peptone	20
pH	7.2 - 7.4

Appendix 2. Result of ANOVA for soil edaphic factors

a) Result of ANOVA for comparing bulk density

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	.109	.027	2.947	.046
Within Plots	20	.185	.009		
Total	24	.295			

b) Result of ANOVA for comparing moisture content

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	8.542	2.135	.301	.874
Within Plots	20	141.724	7.086		
Total	24	150.265			

c) Result of ANOVA for comparing moisture content

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	.689	.172	3.408	.028
Within Plots	20	1.011	.051		
Total	24	1.700			

e) Result of ANOVA for comparing Soil acidity (pH)

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	11.243	2.811	34.747	.000
Within Plots	20	1.618	.081		
Total	24	12.861			

f) Result of ANOVA for comparing Soil electrical conductivity

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	.008	.002	7.800	.001
Within Plots	20	.005	.000		
Total	24	.013			

g) Result of ANOVA for comparing sand fraction

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	20.245	5.061	2.181	.108
Within Plots	20	46.420	2.321		
Total	24	66.665			

h) Result of ANOVA for comparing Silt fraction

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	23.432	5.858	3.276	.032
Within Plots	20	35.763	1.788		
Total	24	59.195			

i) Result of ANOVA for comparing clay fraction

Source	df	Sum of Squares	Mean Square	F	Sig.
Between Plots	4	17.906	4.476	4.351	.011
Within Plots	20	20.576	1.029		
Total	24	38.482			

j) Result of ANOVA for comparing clay fraction

Source	df	Sum of Squares	Mean Square	F	Sig.
Between plots	4	48.977	12.244	11.003	.000
Within plots	20	22.256	1.113		
Total	24	71.233			

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FUNCTIONAL DIVERSITY OF AN EVERGREEN FOREST ECOSYSTEM OF VAZHACHAL FOREST DIVISION, KERALA

By

DEEPAKKUMAR R.
(2014-17-116)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

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Faculty of Forestry

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COLLEGE OF FORESTRY
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KERALA, INDIA

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ABSTRACT OF THE THESIS

The study was undertaken in a wet evergreen forest ecosystem in the Sholayar forest range of Vazhachal forest division, Thrissur, Kerala with the principal objective to enumerate the species and functional diversity of selected aboveground and belowground biological components. The study also aimed at understanding the links between diversity, soil aspects and functioning of this forest ecosystem. As per the FRA guidelines of NWPC 2014, five sample plots an area of 0.1 ha (31.62 m x 31.62 m) were randomly laid out in selected grid (Grid No. 60) of Vazhachal forests. A total of 175 life forms were recorded from 0.5 ha (0.1 x 5 nos.) area. It includes 57 tree recruits, 29 shrubs, 28 herbs, 19 climbers, 14 pteridophytes, 13 polypores, 7 epiphytes, 4 orchids and 4 bryophytes. The observed overall plant species diversity indices Margalef Richness Index (28.31), Shannon-Wiener Index (4.08), Simpson Index (0.98) and Pielou's Index (0.65) are on a par with the richness and evenness values reported earlier from this and other similar evergreen ecosystems. Eighty four tree species were recorded from the 0.5 ha area with basal area of 85.43m^2. *Aglaia barberi, Cullenia exarillata, Mesua ferrea* and *Palaquium ellipticum* are dominant trees in the top canopy. *Euphorbiaceae*, *Dipterocarpaceae* and *Meliaceae* were the dominant tree families. The diameter frequency as well as height frequency distribution showed an inverse J shaped curve which reflects a healthy plant population structure. Rényi's diversity profiling and Principal Component Analysis returned only minor variation vis-à-vis vegetation characteristics across the five

sampled sites. The dominating plant functional traits like evergreen plant (70.2%), simple leaf (72.6%), glabrous textured leaf (78.57%), smooth textured bark (47.2%), medium thick bark (53.5%), capsule fruit (32.1%) and zoochorous dispersal (55.95%) are the typical plant functional traits expected in a tropical evergreen forest ecosystem. The functional diversity indices are FRic (17.11), FEve (0.76), FDiv (0.84) and FDis (2.27). There were 28 different orders of soil invertebrates in the 0.5 ha area. *Isoptera*, *Hymenoptera* and *Coleoptera* are the dominant orders. The species diversity index of the soil invertebrates were Shannon-Wiener Index (2.40), Simpson Index of diversity (0.14) and Pielou's evenness Index (0.51). The resident soil microbial population includes Bacteria (44.4 x 10^6 cfu g^{-1}), Fungi (26.3 x 10^3 cfu g^{-1}), Fluorescent pseudomonads (18.3 x10^4 cfu g^{-1}), Nitrogen fixers (14.4 x 10^4 cfu g^{-1}), Actinomycetes (16.4 x 10^4 cfu g^{-1}) and Phosphate solubilizers (20 x 10^3 cfu g^{-1}). The various edaphic properties observed were also typical of an evergreen forest [Soil temperature (19.82°C), Bulk density (1.28g cm^{-3}), moisture content (29.06%), organic carbon (4.19%), soil acidity (5.25), Soil electrical conductivity (0.07dSm^{-1}) and Sandy loam soil (Sand- 78.15%, Silt- 16.04%, and Clay- 5.82%)]. The study could also observe several linkages between functional traits and ecosystem functioning.