QUANTIFICATION OF ANTHROPOGENIC DISTURBANCES IN FOREST AS A FUNCTION OF DISTANCE TO HUMAN HABITATION- A CASE STUDY FROM PEECHI - VAZHANI WILDLIFE SANCTUARY

By,

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Quantification of anthropogenic disturbances in forest as a function of distance to human habitation: a case study from Peechi - Vazhani wildlife sanctuary.**" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"Quantification of anthropogenic disturbances in forest as a function of distance to human habitation: a case study from Peechi - Vazhani wildlife sanctuary"** is a record of research work done independently by **Mr. Paul, C. Roby (2010-17-106)** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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DEDICATED TO

My loving Parents &Achu.

INTRODUCTION

1.INTRODUCTION

Tropical forests occupy about 7% of the earth's land surface, harbouring approximately two-third of all biological populations. These forests are characterised by species richness, high standing biomass and greater productivity. Being situated closer to highly populated areas, people depend on theseforests for their livelihood. This dependency, when unsustainable, lead to deforestation and degradation. The net decrease in forest area during the period 2000–2010 was 5.2 million hectares per year and the loss was mostly in the tropical regions (FAO, 2010).

Forest disturbances cause alterations or changes to the natural state of forest ecosystem, which can be of biotic and abiotic origin. Anthropogenic influence comprises the majority of biotic disturbances. India also shares the problem of forest disturbances especially in the case of moist deciduous forests (MDF). Anthropogenic disturbances in moist deciduous forests (MDFs), covers upto 86 % of India's forest area, are caused mainly by people. People depend on MDFs for timber, non timber forest products and firewood.Kerala has 43.6 percent of the State's total forest area under MDFs. Due to high population density, and small sized protected areas, MDFs in Kerala are prone to high degree of human disturbances and associated problems.

Forest disturbance studies fall into two main categories, those based primarily on ground measurements of vegetation across a human-use gradient and others that rely on temporal and spatial remote sensed data. A combination of both these approaches is essential for measuring disturbances with much accuracy as both have their inherent shortcomings. The remote sense based approach typically does not account for hunting, livestock-grazing, habitat degradation and other human pressures that operate at micro level and directly contribute to species loss, whereas the ground based studies are time consuming. Lack of criterion and indicators for original landscapes and virgin forests, prevents us from finding how much undisturbed is a forest or how far has it deviated from the undisturbed state.

Disturbances in forest ecosystems cannot be easily measured for want of well accepted set of indicators. The degree of disturbance can be understood from the changes the forest ecosystem has undergone from the undisturbed state. Connell (1978) suggested the Intermediate Disturbance Hypothesis (IDH), which states that with the absence of human interference there is in every natural region a clear relationship between the main ecological factors of climate and soil and the forest formations, for ecosystem disturbance studies. Different types and patterns of human interference will lead to different forest degradation processes and distinctive biodiversity loss, leading to distinctive change in natural state. For measuring human disturbances in forest, there is a need for a set of indicators and criteria. An index, a value worked out of different indicators, can best suit the purpose of measuring the naturalness of a forest/ how disturbed it is. These indicators can either be qualitative or quantitative or a combination of both, and may vary with forest type, climate or edaphic characters. Large variations in many local factors limit the identification and use of a common set of indicators based on vegetation or soil factors worldwide or a large geographic area. Until now no such common indicators have been identified based on vegetation and soil parameters in India. Researchers resorted to visual signs of human disturbance in forest like presences of stumps, cut notches and branches, fire signs, cattle and human trails etc. To assess forest disturbances quantitatively, there is a need for a critical set of indicators of forest ecosystem health or ecosystem quality which can be used across different ranges of forest types and disturbance intensities.

Disturbance is a relatively discrete event that can interrupt forest structure, species composition, the physical environment and the change in availability of resources. . Rates of change/ disturbance, however, may vary considerably, depending upon what forest attributes is being measured and the intensity, duration and frequency of the disturbance. Characterizing disturbance needs a clear understanding of forest dynamics, which requires understanding of synergistic interactions between bio-physical and anthropogenic drivers of change in tropical forests, which can be so complicated to the extent that the post disturbance state can have no clear distinction between successional and mature-phase vegetation. Every component of forest ecosystem is needed to be taken into account to assess the health or the present status of the forest, as each component contribute in its own way reflecting a complex interplay of disturbance events, and are often interpreted in terms of how forests have responded to and recover from recent and historic disturbance regimes.

This study aims to understand the impacts of human habitation on forest vegetation and soil using the indicators of forest disturbances/health. Disturbance indexes based on these indicators were developed so that the human disturbances in forest or the state of forest can be measured qualitatively/ quantitatively. These indexes can be used for comparing different forests and can be used as a tool for decision making in conservation and protection of forests. This study also developed a disturbance map using these disturbance indexes, in the moist deciduous forestsof Peechi- Vazhani wildlife sanctuary (P-V WLS).

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1. OVERVIEW

Deforestation and forest degradation are progressive and associated processes, and is a result of anthropogenic stress on the forest, combined with climate change, conversion of the forest area into forest fragments, pasture, and degradation of habitat (Jose et al., 2011). Marrakesh Accord of UNFCCC defined deforestation as ‘the direct human-induced conversion of forested land to non-forested land’ (Ravindranath et al., 2012). The Food and Agriculture Organization defines deforestation as ‘the conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10% threshold’ (Puyravaud et al., 2010). Lanley (2003) defined forest degradation as a quality decrease in forest conditions, without necessarily involving a reduction in forest area. Degradation can be related to one or more forest ecosystem components like vegetation, fauna, soil etc; affecting the interactions between these components and more generally its functioning. Forest deforestation can be assessed by the change in area of forest over a spatio- temporal scale. Whereas, forest degradation is a complex process and its drivers may be completely different from those for deforestation, thus presenting greater challenges in assessment or monitoring as compared to deforestation. Studies have been done to understand the process and extent of deforestation, but a very few works deals with the process of forest degradation, its extent/ intensity and the drivers it depends.

2.2. GLOBAL SCENARIO OF DEFORESTATION AND DISTURBANCES

2.2.1. Global

Tropical forests are subject to a wide range of disturbances, both natural and anthropogenic, of variable duration, intensity, and frequency; and are caused by a range of factors that vary at global and local contexts (Geist and Lambin, 2002). Globally the annual deforestation rates of tropical moist deciduous and tropical dry forests was about 2.2 and 0.7 million ha respectively (Mayaux et al., 2005) and rate of destruction was alarming for Asian tropical forests (Laurance, 2007). Vast areas of forests presently considered to be primary or virgin are, in fact, late secondary forest (Budowski, 1970; Bush and Colinvaux, 1994). According to Forest Resource assessment report (FAO, 2010), about 36% of world forest are categorized as primary forest, i.e. forest of native species where there are no clearly visible indications of human activities and the ecological processes have not been significantly disturbed, the rest is constituted by other categories of forest like naturally regenerated areas and planted forest. Primary forests in the tropical moist forests type are the most species-rich and diverse terrestrial ecosystems. The report further states that the decrease of primary forest area was about 0.4 percent annually over a ten-year period, whereas this decrease in area was after the reclassification of primary forest areas to 'other naturally regenerated forest' which was affected by selective logging and other human interventions. Tropical forests are decreasing in area and are also being degraded, both processes which result in the loss of biodiversity (Amelung and Diehl, 1992; Whitmore and Sayer, 1992). Human disturbance in tropical forests dates back to early human occupation in tropical regions and is not a phenomenon of the colonial and modern eras (Sanford et al., 1985; Gómez-Pompa and Kaus 1990; Fairhead and Leach 1998). Human impacts appear to be particularly acute in tropical rainforests; mainly because of the fact that the rainforests are biologically characterized by a uniquely complex architecture with humid, dark and stable microclimate (Pohlman, et al., 2009) and also sustains many species, that are specialized for forest-interior and understory conditions; including some species that strongly avoid forest edges (Laurance, et al., 2002; Laurance et al., 2004) and those even un capable of traversing narrow forest clearings (Develey and Stouffer, 2001; Laurance, et al., 2004; and Laurance and Gomez, 2005).

2.2.2. India

The forests have been meeting various demands and livelihood of people for centuries and have been used by communities over millennia for a variety of uses and practices (Lele and Hegde, 1997; Shankar *et al*., 1998). With increase in population, the stress on these forests were so high that the harvesting and removal of forest resources are no longer sustainable in many areas, which ultimately lead to habitat destruction, over exploitation, pollution and species introduction (UNEP, 2001). In India forest make up 21.02% of the total geographical area of the country and includes three biodiversity hotspot along with Western Ghats and the area under forests in India, has increased consistently from 63.34 m ha in 1997 to 69.20 m ha in 2009 (FSI, 2011). The net annual forest loss or deforestation is estimated to be 65,300 ha during 2003–05, 46,850 ha during 2005–07 and 43,300 ha during 2007–09, even though the national total area estimates show a net gain. This led many to believe that deforestation is not taking place in India. Tropical forests constitute as much as 86% of the forested area in India, of which 53% is dry deciduous, 37% moist-deciduous and the rest is wet-evergreen or semi-evergreen (Singh and Singh, 1991). India shares the problems of forest disturbance and degradation with the rest of the world, with a large and rapidly increasing population whose needs for forest goods and services must be met from a fixed land base (Parikh, 1977). These forests are strongly impacted by anthropogenic activities, particularly, excessive grazing, trampling and firewood removals (Champion and Seth, 1968; Singh and Singh, 1991), and in many parts are being converted into dry deciduous scrub and savanna. The disturbance intensity is not uniform across the forest (Chaturvedi et al., 2011).

Protected areas (PAs) cover about 5% of the total land area in India and support about 4.5 million people (Kothari et al., 1995). Over five million people have been estimated to reside within a countrywide network of 593 wildlife reserves and national parks (Kothari *et al*., 1995; Madhusudan, 2000). Most of the Indian PAs are small sized (mean area < 300 km^2) having densely populated (>300 people/km^2) human settlements or households living within or adjoining them (Karanth, 2002; Davidar et al., 2008), those often depend on forest products as a source of sustenance or consumption (Banerjee, 1995; Saha, 2002; Kodandapani et al., 2004). Hence these PAs are vulnerable to human and domestic livestock activities (Rodgers et al., 2003). These anthropogenic pressures include unregulated and often illegal harvesting of forest biomass, livestock grazing, fuelwood, fodder extraction, and burning to promote grasses for fodder (Davidar et al., 2007; Karanth et al., 2006; Mammen, 2007). These activities represent substantial pressures on the forest resource base, which result in biodiversity loss, habitat fragmentation and land cover changes (Gadgil and Guha, 1992; Kothari et al., 1995; Murali et al., 1996; Somanathan and Borges, 2000; Rahmani, 2003). Over harvesting of forest products in a non-sustainable manner has had a drastic effect on the forest ecosystems in India (Anitha *et al.* 2003; Rai and Chakrabarti 2001).

2.2.3. Kerala including Western Ghats

The Western Ghats flora represents about 25 percentagefloraof India. Of the 4000 species of flowering plants in India, about 1500 are endemic to Western Ghats (Sasidharan, 2002).The rain forests of the Western Ghats mountain range support a variety of forest ecosystems and are unique. During the last few decades, these forests have been subjected to various human pressures generated by human activities in agriculture, construction of hydroelectric projects, raising monoculture plantations, logging and a host of other developmental projects, led to a steady depletion of forest areas (Somasekhar et al., 2003). The Western Ghats is a region that needs special attention, as it is with high human densities, smaller extent of area under strict protection, a large number of restricted range species (Cincotta et al., 2000; Gunawardene et al., 2007).

The forests of Kerala are decreasing at quite an alarming rate and are in various stages of biotic degradation (Nair, 2000), even though a total area of 2395 sq. km has been brought under Sanctuaries and National Parks (MoEF, 2008). The moist deciduous forests cover about 4,100 km^2that forms 43.6 percent of the Kerala's total forest area (FSI, 1989), but the problem of forest degradation in the Moist Deciduous Forests is more acute than that of the Evergreens due to high degree of anthropogenic influences. Moist Deciduous Forests are commercially much more important leading to greater human dependence on this forest type than that on the Evergreens (Swarupanandan and Sasidharan, 1992).

Pascal (1986) studied the forest formations in south India by classifying them into three broad categories - climax formations, the formations potentially related to climax and degraded stages. The climax dense evergreen forests and deciduous climax forests are the highest form of climatic climax and are considered to be undisturbed. Climax dense evergreen forests when disturbed, is replaced by evergreen and semi evergreen forest type, which are again grouped into disturbed and secondary subtypes. The further degradation of evergreen and semi evergreen type leads to deciduous secondary formations and more degraded stages. The anthropogenic degradation of deciduous climax forests leads to 2 major formations based on type of disturbance - open forest, savanna woodland and tree savanna when fire is the dominant factor; and the scrub woodland, dense thicket, low discontinuous thicket, scattered under-shrubs when over-grazing dominates and illicit felling is important.

2.2.3.1. Peechi- Vazhani Wildlife sanctuary (P-V WLS)

Prior to the formation of the Peechi- Vazhani Wildlife Sanctuary (P-V WLS) in 1958, the Reserve Forests were virtually a paradise for encroachers and settlers (Mohanan, 2000). After the declaration of the sanctuary, all the rights of people living in and around were ceased. Many villages adjoining the sanctuary were established only recently and the areas around the WLS have gradually increased in population density and the conversion of forest for agriculture continues. (Anitha and Muraleedharan, 2002). The construction of Peechi and Vazhani dams in the southern and northern portions of the Wild life Division, during the 1950s and 1960s, has directly accelerated the encroachment rate in these areas (Anitha and Muraleedharan, 2002). Most of the workers who participated in the construction later became encroachers, doubling the rate of deforestation in the second half of the century. Repeated plantation failures and subsequent encroachments are the major problems in this area. Many lands recorded as forest plantations were encroached (Narayanankutty, 1990). Adding to the concerns, the natural regeneration is heavily deficient in these forests especially that of commercially important tree species (Swarupanandan and Sasidharan, 1992).

2.3. METHODS OF STUDY OF DISTURBANCE

2.3.1. Understanding forest disturbances and its impact

Understanding the processes of forest degradation and disturbance is a prerequisite for the conservation and management of biodiversity. Discerning impacts of resident human populations is critical for park management and rural livelihoods (Liu et al., 2003). This involves determining how human dominated ecosystems functions and the ecological implications of human activities. Therefore, methods and tools that can quantify human - induced forest disturbance are especially important if we aim to develop buffer zones, manage human activities, while forest communities continue to live in and around PA's and derive livelihoods dependent on forest products, fuel wood and livestock grazing. Davidar et al., (2010) are of the view that the data from official sources seem inadequate to measure forest degradation in protected forests. Accurate estimation of forest condition through field assessments and remote sensing, and understanding the socio-economic variables associated with forest loss and degradation is needed for the sustainable management of Indian protected areas. The basic variables of disturbance are magnitude, frequency, size and dispersion. Severe disturbance or even a prolonged absence of disturbance generally has a depressing effect on biodiversity, but intermediate disturbance seems to enhance diversity in a system (White and Pickett, 1985). Disturbance is a driver of the landscape dynamics and acts at all spatio-temporal scales. However, human induced disturbances differ from natural disturbance especially in extent, severity and frequency.

Various theories were proposed to explain the effects of disturbances on natural forest ecosystems. Of these, the intermediate disturbance hypothesis (IDH) of Connell (1978) is the widely accepted. This hypothesis states that an empty habitat starts to become colonized and if this continues without disturbance, the vegetation follows a recognizable successional sequence. In the succession, diversity initially rises, but ultimately declines through competitive domination by a few species. IDH suggests that the highest diversity of tropical rain forest trees should occur either after a large disturbance or with smaller disturbances that are can be neither very frequent nor infrequent at an intermediate stage in succession. IDH can be used as a means to explain species coexistence, and to predict how local and broader scale diversity is related to disturbance history. Disturbances, depending on intensity cause regression to previous successional states. Disturbances lead to reduction in local diversity for systems in early successional stages and low intensity disturbances can lead to an increase in local diversity for those systems in late successional stages.

Anthropogenic activities (e.g. development, timber harvest) can disrupt the structural integrity of landscapes and are expected to impede, or in some cases facilitate ecological flows (e.g., movement of organisms) across the landscape (Gardner et al. 1987). Consequently, livestock grazing, fuelwood collection, fodder extraction and burning are recognized as 'chronic disturbances' (Singh, 1998) that can have substantial impacts on the entire forest ecosystem (Tilman and Lehman, 2001) including impacts on vegetation, soil and water resources, fauna and micro-climate.

2.3.2. Assessing forest disturbances

Forest disturbances influence species abundance which is an outcome of succession, and biodiversity in many communities; and that many studies suggested that the species abundance and diversity increases after disturbance events (Connell, 1978; White, 1979; Huston, 1994; Roberts and Gilliam, 1995). But in case of human - induced disturbances there are studies which show an increase in species abundance and biodiversity as the above but others observed it to be declining depending on the type and intensity of disturbance (Sagar et al., 2003). Hence, species composition and biodiversity can be used as a convenient measure of disturbance.Locally and regionally, disturbance modifies the spatial and temporal pattern of species composition, as well as the structure, dynamics and functioning of the ecosystems (White and Pickett, 1985; Sumina, 1994; Ramírez-Marcial et al., 2000) and tree diversity (Burslem and Whitmore, 1999; Hubbell et al., 1999). Not all species are equally affected by disturbances, since effects depend, on the type and intensity of the particular disturbance. Sheil (1999) opined that the disturbance of a suitable intensity will increase species richness in old-growth communities in consonance with intermediate disturbance hypothesis of Connell (1978), while the others believe that disturbance cannot increase diversity in genuine old-growth forest (Phillips et al., 1997). Few studies have attempted an integrated ecosystem functions approach to the impacts of forest disturbance, one that elucidates the linkages and feedbacks between, for example, changes in vegetation structure and composition, soil impacts, nutrient cycling and hydrology (Hector and Bagchi, 2007).

The common approaches for studying the process of forest disturbance are ground based measurements and remote sensing. These two approaches can be used to assess the influence of human settlements on forest; both have inherent shortcomings and are constrained by use of a priori classification of human use into disturbed and undisturbed sites (Vaidyanathan et al., 2010). Studies based solely on ground based measurements at one time did not fully address issues of spatial coverage. On the other hand, the use of remote sensing data has to deal with issues of geo-rectification, classification accuracy and more importantly, influence of bio-physical variables (e.g. rainfall). Moreover, the latter approach does not account for hunting, livestock-grazing, NTFP collection, habitat degradation and other human pressures that operate under the canopy at very small patch sizes that directly contribute to species loss and hence, underestimates the loss in conservation values over time (Hansen and DeFries, 2007). It is also essential that ground measurements of anthropogenic impacts be periodically undertaken. A forest may look flourishing from above the canopy, but may be severely degraded underneath.

Remote sensing and GIS have been successfully employed to monitor the disturbance regimes of forest ecosystems and are powerful tools to address the impact due to forest degradation (Jha et al., 2000; Vaidyanathan et al., 2010; Jose et al., 2011). This technology is so powerful that it can be used to understand the changes in forest cover and the extent of degradation in an ecosystem over a time period.

2.3.3. Forest disturbance indicators and indices

2.3.3.1. Species composition and vegetation structure

During the past decade, substantial effort has been aimed at identifying a group of easily measured, widely applicable plant traits that could serve as a metric to track and predict temporal change in plant communities. However, quantitative studies on the impacts of forest disturbance in India were relatively few until recently (Shahabuddin and Prasad, 2004). A majority of these studies has separately focussed on impacts on either vegetation (Shankar *et al*., 1998; Madhusudan, 2000; Sagar *et al*., 2003; Kumar and Shahabuddin, 2005), soils (Sahani and Behera, 2001) or wildlife (Madhusudan, 2004).

Every natural ecosystem has a clear relationship between the main ecological factors of climate and soil and the forest formations. Different patterns of human interference/ disturbances lead to forest degradation processes and distinctive biodiversity loss (Blasco et al. 2000). The changes in ecosystem can be identified using certain indicators and these indicators can be used to measure disturbances in forest ecosystem by measuring their changesfrom an undisturbed state to the present ones. Many management-sensitive forest species and structures have been listed as distinctive indicators of a forest's near-natural state (Smith and Theberge, 1987; Trass et al., 1999; Kuuluvainen, 2002). Sheil and Burslem (2003) states that there is no simple indicator of rainforest disturbance. Those structural characteristics, used as indicators, are often specific to particular forest types, and their threshold values depend on soil moisture and productivity, species composition and natural disturbance regimes (Linder et al., 1997; Jonsson and Jonsell, 1999; Meier et al., 2005). Sheil (1999) suggested that the changes in the quantity and quality of light can be used as a direct measured indicator, while some others noted other resources and microclimate through space and time is unrealistic (White and Jentsch, 2001). Field studies require indirect measures of disturbance. Hubbell et al. (1999) used canopy height, but the biological meaning of this measurement is uncertain. Molino and Sabatier (2001) used the percentage of heliophilic stems (and basal area), a biological measure that has a definite successional interpretation, as required for the IDH. There is a need for a critical set of indicators of forest ecosystem health or ecosystem quality which has been subjected to rigorous testing across a range of stand management and disturbance intensities (Smith and Theberge, 1987; Dale and Beyeler, 2001; Kohv and Liira, 2005).

Mathematical values of richness or diversity of plants, suggested for the evaluation of forest stands affected by disturbance, are not very useful for practical purposes without compositional data (Roberts and Zhu, 2002); and attributing all observed vegetation changes to either human influence or bio-physical processes leads to a simplistic view of complex patterns and dynamics in landscapes that change over time (Vaidyanathan et al., 2010). These indicators of disturbances or that of naturalness of forest ecosystems can be incorporated into one, called the index. These indices may contain vegetation, soil, abiotic or human indicators; or all of it. An index has utility, when it helps the forest manager or policymaker to make a decision with the indicator (Hagan and Whitman, 2006).

These indices do so have certain limitations especially while interpreting it; this is mainly due to the lack of knowledge of the nature's reference values for original landscapes and virgin forests. Without which the challenge of preserving or restoring habitats is only partially feasible. The missing reference information has resulted from an historical failure to conserve natural areas and generally hinders quality assessments of management practices that attempt to mimic natural forest processes (Winter et al., 2010). Many workers have tried to overcome this drawback by assuming a natural or near naturalforest nearby the study location having the same species composition or forest types as undisturbed.

The species respond differently to site conditions such as climate, physiography, soil and light conditions (Daubenmire, 1968; Barnes and Van Lear, 1998). Various natural or anthropogenic disturbances can alter these species responses, depending on the degree of disturbance; the species composition seems to change (Jose et al., 1996). A proper knowledge on ecological processes and biotic pressure can help in understanding the persistence of long-lived plant communities (Sundriyal and Sharma, 1996) and it is essential to know which aspects of which disturbance are important to which species (Simberloff, 2001). Lewis et al., (2009) states that some species may benefit from either natural or anthropogenic disturbances, while others are detrimentally impacted. Thus, species composition and biodiversity can be used as indicators of disturbance regime and/or management practices in forests (Ferris-Kaan et al., 1998; Zumeta and Ellefson, 2000; Larsson and Danell, 2001; Gaonaa et al., 2010). Hence, structural diversity, measured as variation along a vertical or horizontal profile, appears a good indicator of forest management effects (Roberts and Gilliam, 1995; Lindgren and Sullivan, 2001). Stand characteristics (i.e., stand maturation and canopy thinning) are known to be the most important factors influencing the composition of species assemblages (Aubert et al., 2003). Venkateswaran and Parthasarathy (2003) observed more evergreen species and higher density in the less disturbed forest than in disturbed dry evergreen forest on the Coromandal coast of Tamil Nadu.

a) Density of trees

Trees are dominant life form in forest ecosystems, that are taxonomically easily identifiable, easy to locate and count precisely (Condit et al., 1996). Hartmann and Messier (2011) states that trees can influence competitive interactions among individuals; as tree growth vary through time as a response to changes in environment (eg. climate), competition and also as a result of human or natural disturbances which, (e.g., timber harvests or insect outbreaks), can selectively remove or kill other trees from the competitive environment of remaining (i.e., unharvested, surviving) trees. The anthropogenic disturbances have adverse impact on the woody vegetation. Significant changes that was brought in forest vegetation structure and composition following long term extractive use by humans was the lower species diversity, densities and regeneration of trees in heavily impacted forests (Murali and Hegde, 1996; Murali *et al*., 1996; Sekar, 1999; Shanker *et al.,* 1998). This ultimately results in the degradation and loss of the forest cover and biodiversity (Garrigues, 1999; Pouchepadass and Puyravaud, 2002; Silori and Mishra, 2001). Yadav and Gupta

(2006) also reported the decrease in density and basal area of most of the woody species with increase in human disturbance, with the exception of certain species showing the vice verse. Studies note that forest tree canopy density can be used as an indicator of forest status, particularly from the perspective of forest biomass stocks and degradation.

Information on forest structure, composition and association, biotic pressure and type of species surviving, and the extent of biomass removal in the forest can help to rejuvenate depleting forest through silvicultural practices and community involvement (Ramakrishnan and Toky, 1981; Singh and Singh, 1991). Moreover, the future forest structure and composition could be indicated by the regeneration status of the tree species. Hence, a sustained regeneration and growth of all species of older plants/ trees is also required for better growth of any plant community (Ramakrishnan et al., 1981).

b) Canopy gap

Disturbances such as land use change, timber harvesting and surface fires causes tree fall / canopy gaps, that results in changes of the physical environment and the availability of resources like light (Horn, 1974; White and Pickett, 1985). Canopy gaps due to tree falls, based on intermediate disturbance hypothesis (IDH), are localized disturbances that promote the coexistence of species that have different resource use strategies, dispersal and competitive abilities (Hubbell et al., 1999; Molino and Sabatier, 2001). Disturbance regimes may further depress those old-growth tree populations existing prior to the disturbance, thereby facilitates the proliferation of light-demanding disturbance adapted plant species (Barlow et al., 2003; Barlow and Peres, 2004) and even new or alien species. These light demanding trees are called pioneers/ secondary successional pioneers. Forest recovery from burning, strongly depends on initial colonization of the site pioneer trees (Whitmore, 1983) whereas establishment of late-successional trees depends on the presence of remnant forests in the area (Hawthorne, 1990). Nykvist (1996) studied the impact of fire and observed pioneer species like *Macaranga* dominating the site after eight years, apart from a few primary tree species that was established due to seed dispersal from undamaged areas.

Differences in biogeography, past expose to natural and human disturbance regimes affect the abundance and diversity of pioneer/light-demanding species, as well as the sensitivity of the native floras to edge effects (Gardner et al., 2009; Rodríguez et al., 2007).

c) Leaf area index (LAI)

Leaf area has been shown to be highly correlated with productivity in a variety of ecosystems including forests (Gholz, 1982; Waring, 1983; Webb et al., 1983) and can be used as an indicator of stress in forests (Waring, 1985). Leaf area index (LAI) is important in understanding canopy gap dynamics and disturbance (Brokaw, 1985; Denslow, 1987; Clark, 1990; Lawton, 1990). LAI is commonly used to compare canopy development or structure over time, under different environmental conditions, or among species (Martens et al., 1993). The study conducted by Jose et al., (1996) showed that any disturbance that significantly exposes the forest floor, thereby lowering soil moisture and altering soil nutrient status, can adversely affect the regeneration of many species in the shola forest. Ravindranath et al., (2012) observed that any patch of forest moving from higher crown class to lower crown class, could potentially be considered to be subject to forest degradation.

d) Invasive species

Disturbance may also lead to the proliferation and vigorous growth of certain plants species that may be present earlier in less proportion or even establishment of non native/alien plants. These invasive species are known to change disturbance frequency or intensity thereby alters ecosystem function (Smith, 1994; Mullett and Simmons, 1995), trophic structure (Cross, 1982; Hobbs and Mooney, 1986; Braithwaite et al., 1989) and resource availability (Vivrette and Muller, 1977; Vitousek and Walker, 1989; Boswell and Espie, 1998). Among these factors, disturbance may favour invasions by disrupting strong competitive-species interactions (Fox and Fox, 1986; Crawley, 1987) and locally increasing different limiting resources (Hobbs, 1989). Stapaniana and Cassell (1999) observed the higher proportion of introduced plant species inGeorgia and Alabama after disturbance. Tree fall gaps formed by disturbances may also facilitate colonization and establishment of non-native invasive plants that are mostly strong light demanders and capable of multiplying vigorously in limited resource availability (Brown and Gurevitch, 2004). Sharma and Raghubanshi (2009) and Raghubanshi and Tripathi (2009) studied the effect of invasive species following disturbances.

e) Under storey vegetation

Understory vegetation is the key element representing ecological changes that may occur over a few years to decades, and vegetation structure can indicate differences in disturbance regimes (Dale and Beyeler, 2001; Dale et al., 2002). This group of plants can be used as indicators of change or disturbance in particular forest ecosystems. But previous studies stress on a certain species, this is due to the presence of huge number of species of herbs and shrubs that are likely to be found on the sample plots and the diversity they represent.

f) Dead trees

A standing dead tree may be the result of natural senescence, and as such dead trees will always be present in natural forests. However, the number of standing dead trees may increase as a result of biotic factors (pathogens and insect attack), and crowns being broken by abiotic factors (lightning, storm or fire) (Gale and Hall, 2001), these which disintegrate gradually with occasional branches falling to the forest floor and the trunk remaining upright. Variation in the way tree die and disintegrate affects the availability of light and nutrients and the sequential replacement and growth of the remaining vegetation (Gale and Hall, 2001). Gaonaa et al. (2010) considered standing dead trees as indicator of natural or human disturbance.

2.3.3.2. Anthropogenic activities

The main human/anthropogenic activities on forest are grazing, collection of NTFP, fodder, timber and fuel wood. So the visual indicators of these human disturbances like cut signs, notches on branches, stumps, partial timber, lopping signs, cattle dung and trails, roads, signs of fire etc. can serve as a good indicator of disturbance.

Grazing of livestock is one of the typical human occupations that causes disturbance in forest adjoining human habitation.Grazing and browsing animals impact the forest in a manner that the first one removes under storey vegetation including regeneration while the latter damage trees and their sapling.Grazing of domestic livestock can decrease food sources for wild herbivores resulting in local extinctions or emigration of animals dependent on specific vegetation cover (Madhusudan and Mishra, 2003), increased transmission of diseases and parasites to wild herbivores (Rahmani, 2003), shifted nutrient dynamics due to increased soil erosion and compaction and changed overall plant composition (Sekhar, 1998; Middleton, 2003). Anthropogenic disturbances like grazing by cattle and removal of dead branches and dry leaves from the ground can alter the nutrient dynamics (Sekhar, 1998), constant movement of cattle and humans erodes the top soil layer (Belsky and Blumenthal, 2002) and browsing by goats and sheep can affect re-growth, reduce perennial cover and increase exotic annual cover (Yates et al., 2001).

The next main dependency of humans on forest is for NTFP and firewood collection. Fuel wood and NTFP collection of assorted plant parts has directly affected food availability for several wild species dependent on these resources and indirectly affected plant survival, regeneration and recruitment patterns (Murali et al., 1996; Somanathan and Borges, 2000). Rural areas in India account for about 85% of the total fuel wood consumption (Natarajan, 1997) of which 62% is from forest sources (Leach, 1987). This pressure on forest is aggravated due to the unsustainable harvest of forest produce (Arjunan et al., 2006), which has again increased by the rapid and extensive market expansion and also the change in access. These human activities have had concomitant effects on ecological interactions and ecosystem functioning (Robinson, 1993).This dependency showed an inverse relationship with income level, social status and education in India (Wunder, 2001, Davidar et al., 2008). Repeated resource extraction reduces tree productivity and regeneration capacity, finally affecting tree density and in the long-run causing local extinction.

Roads, cattle/human trails and other linear infrastructure such as power lines, gas lines, railroads and canals are the important features of human activity in forest, and they are known to have important environmental impacts on natural habitats and ecosystems worldwide (Trombulak and Frissel, 2000; Forman et al., 2002). Forest edge plants may also be stressed by anthropogenic influence, particularly through resource harvest, fire burns, livestock grazing, invasion of exotic species, and vegetation clearing (Olupot and Chapman, 2006). Moreover, the number of human trails traversing the plots also indicates the intensity of use by people for grazing as both people and livestock tend to use regular paths through the forest (Shahabuddin and Kumar, 2007).

Fire is one of the major causes of forest destruction and degradation. They generally known to be associated with NTFP collection, poaching and cattle grazing, and is a collateral activity (Saha, 2002). The canopy cover, the floristic composition of tree species, and past disturbances in the landscape, influence fuel continuity and determine how ease and intensity at which the vegetation may be ignited (Kodandapani et al, 2004). Forest fires are rare in undisturbed moist deciduous forests, however past disturbance histories such as logging have now rendered the disturbed moist deciduous susceptible to fires (Woods, 1989). Once disturbed, the understorey of these forests are invaded by grass species, rendering the forests vulnerable to forest fires (Suresh et al., 1996; Freifelder et al., 1998)

2.3.3.3. Soil characteristics

Soil is an integral part of forest ecosystem, especially in the tropics. Soil and vegetation exhibit an integral relationship, where soil supports vegetation by providing moisture, nutrients and anchorage, and on the other hand vegetation provides protective cover for soil, by suppressing soil erosion, and maintaining soil nutrient through litter accumulation and nutrient cycling. Soil properties have a particularly large influence on the composition and structure of terrestrial flora (Tilman, 1982;

Marx et al., 1999; Iturbe, 2000). Vegetation strongly affects soil characteristics, including soil volume, chemistry, and texture, which feed-back to affect various vegetation characteristics, including productivity, structure, and floristic composition (Brant et al., 2006). The disturbance, compaction, and degradation of soils impact the soil structure and reduce its ability to provide these functions. Disturbances like timber logging and burning of slash are the major pathways of soil nutrient loss from forest ecosystems (Critchley and Bruijnzeel, 1996). The entry of heavy machinery into forest stands during partial harvest may cause a combination of soil compaction and root damage to trees near skid trails (Kozlowski, 1999; Ronnberg, 2000; Nadezhdina et al., 2006). This disturbance may reduce water availability and uptake (Startsev and McNabb, 2001; Komatsu et al., 2007), and consequently, reduce the competitiveness of trees close to skid trails. Soil nutrient levels and regimes may also be altered near edges (Forman, 1986).

Undisturbed forest soil has good structural properties and this not only helps infiltration, but also increases the water holding capacity of the soil. In disturbed forest where timber has been harvested or litter and undergrowth has been removed has a different condition, and erosion rates can be very high. Often, infiltration-excess overland flow makes up less than one per cent of the incoming rainfall in undisturbed tropical forest but on agricultural fields with little or no conservation practices this figure may increase to as much as 30 per cent (Critchley and Bruijnzeel, 1996).

Some studies highlighted different adaptation strategies of plants in different soil types (Goldblatt, 1979; Richards et al., 1997), as different species have requirement for particular soil resources, and are therefore restricted to such environments, while others reported a positive relationship between plant richness and soil fertility (Grubb, 1987; Wright, 1992). Austin (2002) suggested that soil exerts two main effects on plants, namely direct and resource. Direct effects relate to, for example, pH, while resource effects relate to nutrients and water availability. Some studies have shown positive relationships between plant richness and rainfall (Knight et al., 1982; O'Brien, 1993), while others have shown weak or no correlations (Barbour and Diaz, 1973;

Currie and Paquin, 1987). Vegetation is not only reflected by edaphic characteristics such as soil texture (Moss, 1991), but also mineralogy, organic matter, electrical conductivity (EC) and exchangeable sodium percentage (ESP) (McBride, 1994).Soil conditions are the sole environment variable responsible for regeneration establishment, due to close relationship with forest succession and can reflect successional stages and the support for species with various soil requirements (Viereck, 1966, 1970; Lloyd and Pigott, 1967). Each soil constituent (N, pH, and P) also has a particular role in regeneration (Adedeji, 1984; Vitousek et al., 1989; Huda et al., 2009; Yang et al., 2010).

a) Chemical characteristics

i. pH

Soil pH characterizes soil acidity and is strongly correlated with base saturation, organic carbon, total nitrogen and cation exchange capacity (CEC), that are important parameters to characterize soil fertility for plant production (Landon, 1984).). Soil salinity and pH are also potentially useful factors to consider in a study on plant growth and richness. This is because extreme saline conditions may result in nutrient toxicity related to excess sodium and chloride ions (Larcher, 1980; Marschner, 1986), as well as restricted soil water availability due to an elevated osmotic potential (Ayers and Westcot, 1985). pH extremes can constrain plants distribution, not only through direct effects, but also by influencing the availability of nutrients. Grime (1973) and Gould and Walker (1999) found a unimodal relationship between plant richness and pH; where, plant richness declined toward both acidic and alkaline soils, which may have been due to a decline in the availability of certain nutrients. Arunachalam and Arunachalam (1999) states low soil pH in the undisturbed forest as compared to the disturbed sites could be the result of lower rate of leaching leading to greater accumulation of reaction products in the soil.

Alexander and Balagopalan (1980) in a case study on the reserved and vested forest of Attappady reported that most of the surface horizons were slightly acidic to neutral in reaction. The pH increased with depth. The soils in evergreen forest were most acidic followed by slightly acidic semi evergreen, followed by near neutral soils of moist deciduous forest and the dry deciduous forest. The pH for Kerala forest soils ranged from evergreen forest having acidic reaction (4.00) and that for dry deciduous forest that were near neutral (6.95) (Elsy, 1989). Thomas et al., (2000) observed an increase in soil pH in the moist deciduous forest of Kerala following fire.

ii. Organic carbon

Schlesinger (1977) states soil organic C as the largest C reservoir in many terrestrial ecosystems including grasslands, savannas, boreal forests, tundra, some temperate forests, and cultivated systems, comprising as much as 98% of ecosystem C stocks in some systems. Globally, the amount of C stored in soil is equal to the amount stored in vegetation and in the atmosphere combined (Schimel, 1995). A substantial portion of C fixed by vegetation is transferred to the soil annually (Raich and Nadelhoffer, 1989), a portion of which is refractory material with long turnover times (Falloon and Smith, 2000); the rest decomposes relatively rapidly and is returned to the atmosphere as CO_2. Thus soil C is a large, relatively dynamic component of terrestrial C stocks. Organic matter is responsible for most desirable soil structure, increases soil porosity, impervious water and air, reduces soil erosion by wind and water and it is the reservoir of nitrogen. The nature of soil organic matter in a range of forest soils has been affected by tree species and soil physico-chemical condition (Howard *et al*., 1997). Soil organic matter is an important determinant of the cation exchange capacity of soils, particularly in coarse texture soils.

Alexander and Balagopalan (1980) studied the soils in the reserved and vested forests of Attapady area of Kerala and reported that the carbon content decreased with depth in the profiles. They further noted that most of the surface soil samples were rich in organic carbon with the maximum in evergreen, followed by semi evergreen and moist deciduous forests. Thomas et al. (1987) found a close correlation between organic carbon and the bases in the soils of natural forest of Trichur forest division. Balagopalan (1987) observed that the organic carbon was relatively low in man made plantations compared with that of natural forest in the Trivandrum forest division. Elsy

(1989) studied the forest soils of Kerala and reported that the organic carbon was 0.58 % for semi evergreen forest soils and for moist deciduous forest it was the maximum at 5.36 %. The C: N ratio for these forest soils ranged from 11.67 for dry deciduous forest to the lowest of 5.29 for hill top evergreen. Soil organic matter increases the absorption of Zn, Cu and Mn in soil (Borah *et al*., 1992). Sagar et al. (2008) found an inverse relationship between soil carbon and disturbance level, and a positive relationship between soil carbon and nitrogen in the dry tropical forest and argued that disturbance controls the soil quality due mainly to biomass removal limiting the organic matter input into the soil. Evidently, the degree of soil fertility of the sites was reflected in the above-ground carbon density.

iii.Total nitrogen

The soils stores more than 90% of the Nitrogen in the terrestrial biosphere (Schlesinger, 1986). Nitrogen and Phosphorous are considered the most important limiting factors for vegetation growth and carbon accumulation (Vitousek and Howarth, 1991) and almost all natural ecosystems are affected by the amount of plant available forms of these elements(Seneviratne, 2000). Venkateswaranand Parthasarathy (2003) compared the nutrient status at different soil depths of the natural forests and manmade plantations of Nilgiris in Tamil Nadu and observed that the total Nitrogen status was very high in 0-15 cm soil layer. Elsy (1989) observed that the total nitrogen content was observed to be highest for moist deciduous forest (0.56 %) and the least for hill top evergreen forest (0.09 %). Jose et al. (1996) studied the vegetation responses along edge-to-interior gradients in the Shola forest in the Eravikulam National Park and reported that the total nitrogen increased from forest edge to the interiors and it also had a higher correlation with soil moisture. This study also observed nitrogen mineralisation to be highly correlated with soil water availability. Neff et al., (2005) observed that forest soils affected by fire/ burning have lower soil nitrogen content that unburned soils.

iv. Available phosphorus

Phosphorus occurs in a sedimentary cycle;the vast majority of P is tied up in organic matter and inorganic sediments and is also rendered unavailable to plants and microorganisms through precipitation of insoluble phosphate and the adsorption of phosphate onto clay particles, peat, and Iron (Fe) and Aluminum (Al) hydroxides. Jose et al. (1996) studied the Shola forest in the Eravikulam National Park and observed significant correlation between available phosphorus and organic carbon supports the view that organic matter is a principal source of phosphorus cycling in forest ecosystems. Phosphorus exhibited a negative correlation with soil pH, which indicates a higher solubility of phosphorus compounds under lower PH, and a higher positive correlation with organic carbon.

v. Available potassium

About 25- 80 % of potassium from the forest trees, litter and soil is lost due to disturbances like forest fire or slash burning, along with other nutrients like Calcium, Phosphorus etc (Critchley and Bruijnzeel, 1996). Janssens et al. (1998) studied the relationship between plant biodiversity and different soil chemical factors in numerous sites located in grassland ecosystems of temperate regions and observed higher soil potassium content in sites with higher species diversity values. Thomas et al. (2000) observed an increase in soil potassium content in moist deciduous forest of Kerala affected by forest fires, but Neff et al. (2005) observed that the content was unchanged in burned and unburned soil.

vi. Cation exchange capacity (CEC)

Alexander and Balagopalan (1980) observed high CEC for moist deciduous forest soils and that CEC decreased with depth in all the forest types. The CEC for moist deciduous forest soils were in a range of 14-26 meq/ 100gm soil and that for semi evergreen forest soils was 18-25 meq/ 100gm soil. Balagopalan (1987) studied the soil properties of natural forest and plantations of Trivandrum forest division and reported that in natural forest sequence exchangeable bases, exchangeable acidity, CEC and base saturation were higher in Moist Decidous Forest. The CEC of forest soils of Kerala varied from 1.1 to 17.5 cmol(+) (Thomas and Brito-Mutunayagam, 1965;

Yadav et al., 1970). Elsy (1989) studied soil CEC of different forest types in Kerala and observed that the MDF was having the maximum value of 36.43 meq / 100 gm soil, for semi evergreen forest it was 28.12 meq / 100 gm soil and for evergreen it was low at 21.62 meq / 100 gm soil. The concentration of exchangeable cations varied significantly in the forest types, with Ca^{2+} forming the major portion and was in a range of 1.12-7.00 meq/100 gm soil in MDF and 1.12 – 1.4 meq/ 100 gm soil in semi evergreens, it is followed by Mg^{2+}(.08-1.00 in MDF and 0.08-0.17 in semi evergreen), K^{+} (0.08-0.21 in MDF and 0.03-0.13 in semi evergreen) and Na^{+}(0.04-0.12 in MDF and 0.04-0.07 in semi evergreen).

b) Physical characteristics

i. Soil texture

Soil texture is the most fundamental attribute of soil fertility. Soil fertility increases with clay content, but high clay-soil are prone to drought in dry areas and to flooding in wet areas. Clay soils lowered the production of plant than sandy soil in arid areas; the plant production is higher in wet areas due to the interacting effect of clay on soil water and nutrient status. Clay content has a controlling influence on the soil water retention (Scholes, 1990). Moreover, it is negatively related to the mineralization of nitrogen (Cote *et al.* 2000). The structure of soil influences organic matter turnover and fertility of soil and plays an important key role in the ability of soil to store organic matter (Balabane, 1996). Sala et al. (1997) reported that species richness is more influenced by soil texture than by rainfall, because it determines the location where water is stored. Fine textured soils store more water near the surface layers than coarse-textured soils and as a result are thought to favour grassy vegetation with shallow root systems, as opposed to woody vegetation with longer roots.

Elsy (1989) observed the soils in the moist deciduous forest to have the coarse fragments in a range of 15.4- 87.3% and the gravel content to be greater than 20%. The MDFs showed a loamy texture, with a silt content of 24.01%, whereas sandy textures were exhibited by tropical evergreen and semi evergreen forests. The coarse sand to fine sand ratio was observed to be highest in grasslands (5.18) and lowest in evergreen forest soil (1). Kumar et al. (2012) studied the natural forest of Konni Forest division (Kerala) and observed that the moist deciduous habitat has soil gravel content ranging between 7 – 20 %. Generally the soil is sandy loam and moderately acidic. The sand content varies between 60– 85 %. High organic carbon content was present. In evergreen forest soil gravel content ranges between 10 – 17 %. The soil was sandy loam and strongly acidic. Very high organic carbon content was present. Sand content varied between 70 – 85 %.

ii. Soil moisture content

Soil moisture is an important parameter that determines the health of the soil, by determining its capability to support vegetation, making available and supplying the critical soil nutrients. Elsy (1989) studied the soil moisture retained in different forest types in Kerala and observed it to be around 28.08 to 37.02% (at 0.3 bars or field capacity) and 12.42-18.4% (at 15 bars or wilting point). Elsy (1989) noted that the apparent density of soils in Kerala forest, which was maximum for evergreen forest (1.24 g cm^{-3}) and the least for moist deciduous forest (0.9 g cm^{-3}).Total species richness was potentially maximal at low infiltrability (Cody, 1989; Mills et al., 2009; Medinski et al., 2010).

2.4. Part studies

2.4.1. Studies based on species composition and vegetation structure

Slik et al. (2003) employed the indicator value (IV) method of Dufrene and Legendre (1997) to test their hypotheses that the species of *Macaranga*and *Mallotus*can be used forest disturbance indicators. They also correlate between the forest structural variables and the occurrence of both the species using canonical correspondence analysis (Jongman et al., 1987). They categorised the area into primary forest, selectively logged forest, forest burned once, and repeatedly burned forest. All *Macaranga* and *Mallotus* individuals taller than 30 cm were counted, identified, and their position recorded. Indicator Value (IV) was calculated. To assess the relationship between the severity of forest disturbance and the occurrence of *Macaranga* and *Mallotus* species, nine forest structural variables were measured and calculated for all the plots. These variables were selected to reflect forest disturbance and covered a wide spectrum of the forest structure.

Somashekar et al. (2003) studied the impact of human settlements on forest structure and composition in Kudremukh National Park (India). Phytosociological analysis of tree species and determination of stand quality, using Ramakrishnan index of stand quality (RISQ), was done in both tribal and non tribal areas and undisturbed forest. The result of the study was that there is a large difference between disturbed and undisturbed areas with respect to regeneration, tree species, basal area, etc.

Onaindia et al. (2004) assessed the effects of different human-induced traditional management disturbance levels on plant species cover and diversity, and the horizontal and vertical structure of temperate forest. Site disturbances categories for each site location was based on actual data, field vegetation mapping and historical records, representing different classes and intensities of human- induced disturbance regimes.

A study to determine whether a given area in the forest patch is disturbed or undisturbed was conducted by Chandrashekara (2005) in the Mannavan shola forest (Kerala). This study used qualitative indicators of anthropogenic disturbance such as the presence of stumps of cut trees, debris including branches and leaves of cut trees, remnants of lopping, occurrence of paths, cattle or their excreta, hoof mark, trampled soil or compacted soil, large and abnormal canopy gaps, understorey plants which are not characteristic to relatively undisturbed forest patch, and exposed soil. The phyto-sociological studies revealed that there is significant difference with respect to dominant species and vegetation composition between disturbed and undisturbed sites. It also showed that the density of trees in sapling and different girth classes at the mature phase was less in the disturbed plot.

Davidar et al. (2008) conducted socio economic survey and attempted to study the pattern quantity and nature of harvest and extraction of forest produce by villagers from Kalakad–Mundanthurai Tiger Reserve (Tamil Nadu). They reported that the forest resource interest in the villagers decline with increasing distance from the forest boundary, but was based upon the product that was harvested, and the distance to the market (Gunatilake, 1998; Gunatilake and Chakravorty, 2002). This study also observed that the households with lower annual income, social status and education would be likely to show greater resource interest in the forest.

Anitha et al. (2010) studied the tree species diversity and community composition of an anthropogenic disturbed moist deciduous forest of Western Ghats in Anaikatty Reserve Forest (TN). This study came to a conclusion that tree population assemblages were determined by both altitude and disturbance gradients, while species assemblages of the regenerating populations were primarily influenced by disturbance. They could identify only two groups in the regenerating tree populations, the first one mixture of semievergreen and early successional species, and the second, a mixture of deciduous and scrub species.

Jose et al. (2011) assessed the forest disturbance in the Shendurney wildlife sanctuary using remote sensing and GIS, and showed that drastic forest cover changes occurred between 1971 and 2009. This study indicated that the sanctuary underwent severe disturbances so that a large amount of evergreen forest has changed to semi evergreen and moist deciduous forests. Of the different types of disturbances that affect the sanctuary, the major ones being that due to anthropogenic activities, which includes periodic occurrence of forest fire and land cover change.

Anbarashan and Parthasarathy (2013) studied the diversity and ecology of lianas in tropical dry evergreen forests on the Coromandel Coast of India under various disturbance regimes.

2.4.2. Studies based onhuman/anthropogenic disturbance indices in forest

Studies that focus on human activities that caused disturbances in forest mainly focussed two themes. The first, assessed the impacts that causes vegetation changes mainly based on stand characteristics like structure and composition, mean diameter, height, basal area etc and was compared with other stands under study; then conclusions were drawn into that stands having near natural or ideal state as undisturbed or virgin and grouping others as disturbed with the degree of disturbance based on the distance or how far are they from the natural state. According to Loidi (1994), ‘‘naturalness can be widely expressed in terms of distance from the climax or potential natural vegetation; the highest naturalness would correspond to potential natural vegetation in an undisturbed situation’’.

The latter workers assigned indices based on indicators that based on what there should be for a natural or undisturbed state of a forest. They take into account the signs of human activities and indicators of vegetation or soil or both together. These were summarised to index values, this was for the ease of representation and comparison between forest having similar vegetation, climate and edaphic characteristics or to compare across a fairly wider spatial scales.

Jalas (1955) to measure disturbance and unnaturalness of vegetation, assessed from a four-point scale based largely on the degree of disturbance to the soil, it has been extended to five (Kim et al., 2002), seven (Steinhardt et al., 1999) or to ten-point scale (Hill et al., 2002). This sort of ‘‘reverse’’ index of naturalness is used mainly to categorise plant species and plant communities.

Edarra (1997) proposes to estimate the naturalness of plant communities from 0 to 10, according to the grade of anthropogenic influence. Value 0 corresponds to areas intensively urbanised, fully occupied by buildings, roads, etc, almost without plants; and 10 is the value for mature forests that are not exploited, vegetation on rocks, cracks and gravel beds, peat land, marsh lands, coastal salt marshes, non-intervened dunes, etc. But he gives no further criteria to separate the intermediate categories.

Bovet and Ribas (1992) developed a landscape classification according to the dominance of structural elements (abiotic, biotic and anthropogenic) using symbols (square, circle and triangle which are combined graphically, one within the other, following their order of dominance or, eventually, inexistence. Fifteen combinations are possible. They start by selecting the working scale and delimiting the landscape area under study. Thereafter, they define the group of dominant elements (visual) and, finally, they consider the present functioning of the landscape.

Sundriyal and Sharma (1996) assessed the anthropogenic pressure on temperate forests of Mamlay watershed in Sikkim. The study included the effect of human disturbance on regeneration and its implication on the forest structure along with the biomass extraction by the villagers. This forest has been meeting and satisfying the material needs of the majority of the population, but the study revealed there is decline in species number and composition and this was attributed to the local anthropogenic subsistence needs including indiscriminate cutting, selective felling by the Forest Department, invasive exotic species and lack of strict enforcement of protection/conservation laws.

Chandrashekara (1998) introduced an index, Ramakrishnan index of stand quality (RISQ), which can be used to access the quality or the disturbance in a forest. This index is based on assigning values, for each species in a forest called pioneer indexes, from 1 -3. The pioneer index values were assigned for the tree species based on available literature. Pioneer index is 1 for the species whose seedlings establish in closed canopy area but need small canopy gaps to grow up, Pioneer index is 2 for the species whose seedlings establish in small gaps but need small to medium size gaps to grow up, and Pioneer index is 3 for the species whose seedlings need larger canopy gaps for both establishment and growth. The Ramakrishnan index of stand quality (RISQ) of a given site can vary from 1.0 (all stems, group 1 species; forest stand is undisturbed) to 3.0 (all stems strong light-demanding species and all group 3species, forest stand is highly disturbed). RISQ values were also worked out for assessing the disturbance of three sacred groves of Kerala, under different types of ownerships and management (Chandrashekara and Sankar, 1998), in comparing the disturbance levels of a relatively undisturbed forest patch and a 10-year old selectively logged area in a wet evergreen forest at Nelliampathy, Kerala (Chandrashekara and Ramakrishnan, 1994).

Machado (2003) suggested an index of naturalness. Here he considered the term natural as “to anything that is not been made or influenced by humans, particularly by technology” (Hunter, 1996; Angermeier, 2000). Its zero to ten pointed scale developed for the Iberian Peninsula, which ends with mature non-exploited forests.

Sagar and Singh (2004) analysed the impact of different degree of disturbance on species composition and on dispersal pattern of selected species in the dry tropical deciduous forest of the Vindhyan hill ranges of India. The sites were ranked according to the degree of disturbance they experience. The criteria used to delineate the disturbance levels where that the soil erosion and rockyness belong to natural disturbances category, and while other factors of disturbance are considered biotic/ anthropogenic. Impact factors for other sites were assigned, which was calculated as ratios of the distance of this site (distance of the site to road) to the distance of the other sites.

Venkateswaran and Parthasarathy (2003) studied the structure, composition and the impact of human disturbance in the tropical dry evergreen forests on the coromandel coast of India. Disturbances were qualitatively classified (as in Veblen *et al*. 1992, with modifications). All the sub-classes in various types of disturbance were ranked into relatively none (score 0), relatively low (1), medium (2) and high (3) levels of disturbance. The disturbance variables taken into consideration were: Site encroachment (construction of road and temple), impact temple visitors on area used for cooking or parking etc, degree of cattle and goat browsing and resource removal (NTFP, firewood, medicinal). The sum of all scores for each site provides an overall ranking of anthropogenic disturbance in the forests. High ranks signify high levels of anthropogenic disturbance and low ranks low levels of disturbance.

Arjunan et al. (2005) tried to quantify the human disturbances in forest of the Kalakad-Mundanthurai Tiger Reserve (Tamil Nadu). The vegetation analysis was done along with the mean monthly extraction pressure on the forest by nearby villagers. Monthly extraction pressure, an indicator of disturbances, was calculated by the number of cut stems and branches on all standing stems ≥3.18 cm dbh was recorded every 3 months in each plot. Extraction pressure was given as the [(total number of cuts*100/total number of plants in the plot)/ 3] to give monthly percentages for each village. The number of trees, regeneration, shrubs and lianas was lower in the disturbed sites compared to that in undisturbed sites. The species that are not used by the villagers was occurring at high densities and regenerated well, thus concludes that unregulated resource extraction has an adverse impact on the forest structure, diversity and regeneration.

Karanth et al. (2006) studied the forest disturbances in Bhadra Wildlife Sanctuary (BWS) in relation to village size and resource use by villagers with varying household sizes. This study was done by analysing the socioeconomic survey and field survey data for ecological indicators of forest use and disturbance. The various habitat disturbance variables measured include visible and easily documented signs of human induced disturbance activity in the forest like cut stems, cut bamboo, lopped trees, tree notches, fire intensity, exotic weeds etc. The data were ranked in classes as absent, low, medium and high and subsequently represented on a numerical scale between 0 and 3. The study noted that three major factors influence forest disturbance around each village in BWS; village size (households), distance from village and proximity to other villages. Yadav and Gupta (2006) studied the impact of human disturbance on the woody vegetation in the Sariska Tiger Reserve. This study has taken into consideration the vegetation and edaphic attributes of the study area.

Shahabuddin and Kumar (2007) quantified the effects of anthropogenic disturbance caused specifically by altered vegetation structure and composition, on bird species assemblages located in Sariska Tiger Reserve. Vegetation structure of the tree layer in terms of canopy cover, basal area, tree density, average tree height, tree height diversity and tree species richness and quantitative descriptors/ indicators of anthropogenic disturbance due to biomass extraction, including proportion of trees showing signs of lopping, average scale of lopping of trees, number of human trails and number of piles of livestock dung, were measured. Lopping score for each tree was additionally measured on a scale of 0–4. Canopy cover, tree basal area and the average height of trees, were found to decline significantly with disturbance in Sariska. Even though tree density, tree species richness and tree height diversity showed similar trends, these differences were not statistically significant.

Liira et al. (2007) studied the forest structure and ecosystem quality in conditions of anthropogenic disturbance along productivity gradient in the boreo-nemoral forest site-types of Estonia. The forest structural and species composition features, were assessed using a set of 39 characteristics, including the average stand height, stand age, tree species, basal area, total tree canopy closure, the vertical profile of foliage cover (both were visually assessed), quantity of standing dead wood and large snags (DBH >8 cm and height >1.3 m), trees with DBH <40 cm and DBH >40 cm, basal area of lying dead trees, presence or absence of various stand indicators such as wind-thrown or wind-broken trees, unusually shaped or damaged trees, and the number of cut stumps, etc were recorded. Under storey shrub and tree sapling layer composition, presence of well-known and easily recognizable forest biodiversity or historical indicators such as epiphytic lichens, epiphytic moss, ground lichen, macro fungi on live and dead wood, large insect holes and any signs of woodpecker activitieswere estimated. This study also introduced an index called “Management intensity index”, which was based on the presence or absence of anthropogenic disturbance indicators within two distance classes. The visible signs of anthropogenic activities (e.g., cut stumps, forest tracks, trampling, ditches trash, etc.) were recorded. Each indicator has a score (1 or 2) that describes the proportional effect. The management intensity index (MI) is the sum of scores of indicators of anthropogenic disturbances, weighted by the distance class. The observation of any sign within a radius of 0–30 m doubled the effect scores compared to the effect score within a radius of 30–60 m around the sampling point. The management intensity index is equal to zero, if none of the anthropogenic activity indications were present within a radius of 60 m; and the maximum value for forestland fraction can reach upto 30 in a case of clear-cut area.

Tucker et al. (2008) quantified the human influence in forest by using an index of disturbance called forest conditions index, that focuses on mature forests and uses data for trees with dbh >10 cm, from the forest under study and a reference forest. The idea of reference forest refers to a forest with no history of disturbance in recent past. The overall index of disturbance value was derived from four equally weighted ratios; based on study forest to reference undisturbed forest, for total basal area, mean dbh, tree density to total density and the total species present in the forest. By the application of a quantitative approach for comparing forests across differing vegetative, edaphic, and climatic conditions, this study suggests a way to distinguish human impacts from the underlying biophysical characteristics and has the potential to allow more specific assessments of the outcomes of forest management strategies by distinguishing biological and human components of human-environment systems.

Mehta et al., (2008) assessed the ecosystem impacts of disturbance in the dry tropical forest of Bandipur National Park in India. The vegetation data recorded include shrub and tree vegetation (> 1 foot height), species counts and heights, DBH, average plot tree height, canopy cover etc. Observations on indicator variables of the field disturbance in the plot were recorded and combined into a field disturbance index (FDI). FDI comprised of presence/absence observations of five indicator variables: T-Trails (cattle or jeep); C-cut and/or broken stems; D-livestock dung; P-People; and F-Fire. For each plot, FDI was calculated as FDI =T +C+D+P+F. Indicator P were assigned a value of 1 if people were sighted while sampling.

Gaonaa et al. (2010) developed a multi-criterion ecological index for the evaluation of local tropical forest conditions in Mexico, which was based on qualitative and semi-quantitative data. Variables of anthropogenic origin like extraction activities, such as firewood extraction and wood harvesting, animal grazing/ trampling, and the use of fire, all that affect the seedlings and juveniles of the forests. The observations were grouped into three classes as a function of the intensity or frequency of each disturbance: absent or low, medium, and high, based on a scale from 0 (worst condition) to 1 (best condition); the number of intermediate value classes depended on the number of categories defined in the field data sheet.

The human disturbances in Tadoba-Andhari Tiger Reserve (Maharashtra) were assessed by Vaidyanathan et al. (2010) using the field survey method, for vegetation analysis and signs of disturbance, and the remote sensing data. A Combined Impact Index (CII) was calculated to identify zones of human impacts, by summing the individual disturbance estimates. The study also computed a ‘Human Influence Index’ for each point at a distance of 10 km to settlement, where a direct impact to flora or fauna was observed. CII was calculated as the distance from the human settlement divided by the corresponding population of the settlement. The vegetation changes for the area were obtained using remote sensing data at two time scales NDVI and Calibrated Vegetation Index (CVI) datasets. The anthropogenic disturbances were classified into six categories, wood extraction, grazing, fire, poaching, NTFP collection and human-wildlife conflicts. Human-wildlife conflicts included loss of livestock and human life to wild predators, as well as retaliatory killing of wildlife by humans. This study recommends the use of a time-series CVI or NDVI data, which are continuous and hence can detect dynamics of landscape change over comparisons of two or three-dates of classified land-cover maps which cannot capture these complex dynamics.

Rudisser et al. (2012) proposed a degree of naturalness (Nd), distance to natural habitat (Dn) and the composite index distance to nature (D2N) as a highly comprehensible environmental indicator set that can be used as surrogate for land use related anthropogenic influence on biodiversity. Degree of naturalness (Nd) is status quo-oriented and calculated on the basis of spatial land use and land coverage information. Land use types were classified along a seven staged naturalness scale. The index ‘distance to nature’ (D2N) is calculated combining the raster maps. Values are scaled along a range from zero to one. Zero indicates natural/no distance, while one represents completely artificial/far from natural habitat for the indicators Nd and Dn respectively.

Anbarashan and Parthasarathy (2013) assessed the diversity and ecology of lianas in the tropical dry forest of Coromondal coast of India along the human disturbance gradient. In this study, sites were classified into four disturbance categories, using a semi-qualitative assessment of various anthropogenic activities that was ranked as rare (1), occasional (2) or frequent (3). The human activities considered as disturbance include signs of temple visitors' impact, live stock grazing, tree felling, fuel wood and fodder leaf collection, soil removal for construction, the number and width of trails inside the forest, road construction, litter and edible fruit collection, medicinal plant removal, human occupation, extent of bio-invasion and cultural attachment of the local people as sacred groves. The site disturbance score for a site was the sum of all the scores that had high ranks (31–40) was designated as heavily disturbed sites, 21–30 as much disturbed sites, 11–20 as moderately disturbed sites and 1–10 as relatively undisturbed sites.

2.4.3. Studies based on soil

Burger and Kelting (1999) proposed a Soil Quality Index and a soil quality model that can be used to indicate forest stand health. Soil quality is a function of several attributes, but, for a particular site, attributes or their indicators are chosen because they have been shown to be correlated with forest productivity, and because they are sensitive to impacts that are imposed by management practices. According to them the soil attributes or indicators of attributes that are neither resistant nor resilient to management-induced change. When an impact on the soil occurs, the indicator responds and the change in the indicator remains as long as the impact remains. A pie-chart model was used by them to illustrate the concept of a soil-quality model and the features of indicators that are needed to measure sustainability. Soil quality is indexed as a fraction of one (area of the circle in this spatial model).

Barbhuiya et al. (2004) studied the dynamics of soil microbial biomass along with forest disturbance. This study observed that disturbance resulted in considerable increase in air temperature and light intensity in the forest and decline in the soil nutrients concentration. Felling results in opening up of forest canopy and alterations in the forest-floor microenvironment that deteriorates the soil nutrient level. Tree cutting resulted in considerable changes in the microclimate and soil physico-chemical and microbiological properties of the forest. Thinning of the canopy in the disturbed stands was responsible for reduced litter depth and greater light intensities, and greater soil and air temperatures on the forest floor. Greater water holding capacity of the soil in the undisturbed forest was attributed to high clay and organic matter contents. Low soil organic matter in the disturbed stands may be attributed to less litter production and faster decomposition rate (Vitousek et al., 1986).

Sharma and Raghubanshi (2009) studied the influence of invasive species (*Lantana camara*) on soil physico-chemical properties in the dry deciduous forests of India. The soil properties in sites under forest canopy and lantana cover were of similar in type, texture and pH suggesting that the variation in decomposition is not caused by physiochemical differences in the soils. But the decomposition rates were different, this may be due to the dense canopy of shrubby lantana could have increased the soil moisture content beneath its canopy (Sharma and Raghubanshi, 2006).

Challenges faced in similar studies

A challenge in the study of human impacts is to understand what social, economic, and institutional factors can lead to particular environmental outcomes (Tucker, 2008). The various anthropogenic disturbance assessment studies in India have taken into account the various parameters like vegetation, soil and visible sighs of human influence in forest alone or together. Also, there was no clear cut criterion for the measures of indicators, as it varied among the studies. The indices made for one region or a forest types cannot be used across the world, as the parameters like species composition, structure, canopy density or forest mensuration values for a particular forest may represent a mature and healthy forest in one location but a highly degraded forest in another (Tucker, 2008), due to wide variations in forest formation and geographical and climatic variations. Moreover, the soil indices parameter values are not uniform across the world. Thus, Indicator value should be allotted for different forests, geology, altitude, soil etc. Also, naturalness of a forest cannot be teleological link to a climax situation because natural disturbances may revert ecosystems to more juvenile or intermediate stages, which are as natural as the mature ones.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1. Study site

3.1.1. Location

The Peechi-Vazhani Wildlife Sanctuary (P-V WLS) established in 1958 (Fig 1), the second oldest sanctuary in Kerala. This sanctuary lies within the geographical extremes of latitudes $10^0$26' N and 10^0 40' N longitudes 76^0 15' E and 76^0 28' E longitude in the taluks of Thrissur and Thalappilly, covering a total area of 125 km^2. P-V WLS is bordered by Chimmoni Wildlife Sanctury in the east and the forest of Palakkad Division in the north. The sanctuary is in the administrative jurisdiction of Peechi Wild life Division of the Northern Wild life Circle. The corridor between Peechi on the south and Vazhani forest tract on the north is breached by National Highway 47, resulting in the isolation of Vazhani half from the Peechi forests which is contiguous with the forests of southern Kerala (Maria Florence and Yesodharan, 2000).

3.1.2. Vegetation

Menon and Balasubramanyan (1985) reported that the major type of forest in the area is of the moist deciduous forest (MDF) type which is more continuous than the following the patchy distributed semi-evergreen type. Evergreen forest represents climax vegetation with small patches occurring on the higher slopes of some hills intermingled with the other forest types especially, where suitable microclimate prevails. Semi-evergreen forests are usually found at relatively lower elevations and occur as atransition zone between moist deciduous and evergreen forests.During the dry season (January to March), the upper canopy of moist deciduous forest is leafless, making these areas prone to annual fire.

3.1.3. Climate

The climate of the area is generally of a warm humid type. The relative humidity is usually higher than 55% and reaches up to 100% in monsoon season.The temperature

MAP OF PEECHI- VAZHANI WILDLIFE SANCTUARY

Fig. 1. Map of the study area.

of the region varies from 15°C to 20°C (November to January), but the temperature rises to about 38°C (March to April). The rainy season prevails from June to August. The sanctuary receives an annual rainfall of 2000 – 4000 mm per annum.

3.1.4. Physiography

The terrain is highly rugged and hilly, undulating with the altitude ranging from 30 m to 928 m. The highest peak in the division is Ponmudi. The area is well drained with three major rivers Kurumali puzha, Manali puzha and the Wadakkanchery puzha. There are two irrigation projects within the sanctuary, viz. Peechi and Vazhani, with water spread area of 12.95 sq. km and 1.843 sq. km respectively (Narayanankutty and Nair, 1990).

3.1.5. Geology, Rock and Soil

The main geological formation is the metamorphic gneiss series. On the lower, it tends to become lateritic. There are considerable extents of rocky blanks consisting of sheet rocks in the region. The ground is often very bouldery, chiefly in the deciduous areas. Oxisol or red ferrallitic soil, originated from weathering of crystalline rocks like granite, gneisses and charnockites. Surface soil is generally sandy loam in texture while the sub surface soil is loamy. Initial stages of laterization are observed where the soils are devoid of vegetal cover and erosion is active.

3.1.6. Human Habitation

There are human settlements, which are dependent on forest, in and around the sanctuary. They are the pioneer rice cultivating settlers, migrant farmers, the scheduled caste (Kavaras, Vettuvas, Parayas, Pulayas) and the major forest-dependent tribal community (Malayan and Kadars) and other backward castes. There are 20 tribal settlements residing in and along the periphery of the sanctuary, 17 in Peechi and three in Vazhani forest tracts.

3.2.Methodology

3.2.1. Floristic analysis

3.2.1.1. Sampling

The study is conducted in the moist deciduous forests of P-V WLS. Data was collected after stratifying the forests into three strata based on distance from habitation (0-2000 m, 2000-6000 m and beyond 6000 m). Three such locations adjoining habitations were randomly selected for study, they include Vaniyampara section (10^0 34' 72" N, 76^0 24'37" E), Ollakkara colony of Ollakkara section (10^0 31' 10" N, 76^0 26' 36"E) and Jandamukku of Manamangalam section (10^0 31' 01" N, 76^0 21' 79" E). The samples were taken along a transect, originating from the habitation and moving to the uninhabited area interior of forest. Four samples of 2500 m^2 were drawn randomly from the three strata's along a transect. These samples were surveyed for trees, saplings and regeneration. From each of these selected samples, four sub samples of 100 m^2 were enumerated for herbs and shrubs.

3.2.1.2. Phytosociology

The vegetation was quantitatively analyzed for their abundance, frequency, density and their relative values and important value index (Curtis and McIntosh, 1950). Quantitative sampling of vegetation was carried out separately among the categories of trees, saplings and seedlings adopting Point-centred quarter method (Cottam and Curtis, 1956). All individuals with GBH equal to or above 10 cm and height greater than 1 m were classified as "tree" and were enumerated by measuring their height and GBH using Ravi altimeter and a tape respectively. All individuals having a GBH below 10 cm but height above 1 m is classified as "Saplings". And those with both GBH and height less than 10 cm and 1 m respectively were grouped as "regeneration". In order to determine the quantitative relationship between the species, the following parameters were determined.

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

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

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

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

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

6. Basal Area (BA) $= \frac{GBH^2}{4\Pi}$

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

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

3.2.1.3. Floristic diversity

Species diversity is applied to represent the species richness, relative abundance or the variability in a community. Shannon- Weiner index and Simpson index were used as species diversity measurements (Magurann, 1988). The following indices were worked out:

i ***a. Simpson Index***, $D = 1- \sum (n_i /N)^2$ (Simpson, 1949)

Where,

n_i – Number of individuals of the species.

N- Total number of individuals in the plot

D- Diversity

b. Concentration of dominance, $Cd = \sum (n_i /N)^2$

ii ***a. Shannon-Weiner's index***, ***H' = 3.3219(Log N-1/N ∑ n_i Log n_i)*** (Shannon and Weiner, 1962)

Where, Ni – Number of individuals of the species

N – Total number of individuals

b. ***H max= 3.3219 log $_{10}$ S***

Where, H max - the maximum dispersion taking in to account the number of species present in the plot

S – Total number of species

c. ***Equitability (E) = H'/H max***

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.

iii ***Ramakrishnan Index of Stand Quality (RISQ)*** (Chandrashekara, 1998)

RISQ can be used to access the forest quality or the disturbance in a forest. This index is based on assigning values, for each species in a forest called pioneer indexes, ranging from 1 -3. The pioneer index values were assigned for the tree species based on available literature. Pioneer index is 1 for the species whose seedlings establish in closed canopy area but need small canopy gaps to grow up, Pioneer index is 2 for the species whose seedlings establish in small gaps but need small to medium size gaps to grow up, and Pioneer index is 3 for the species whose seedlings need larger canopy gaps for both establishment and growth (all stems strong light-demanding species). The Ramakrishnan index of stand quality (RISQ) of a given site can vary from 1.0 (all stems, group 1 species; forest stand is undisturbed) to 3.0 (all trees group 3; forest stand is highly disturbed).

RISQ = ∑ {(*ni* / *N*) × species pioneer index};

Where, *ni* and *N* are the same as that in the Shannon index of general diversity.

3.2.1.4. Canopy gap analysis

Brokaw (1982) defined canopy gap as a vertically projected hole in the canopy that was estimated to have extended down to an average height of 2 m above the forest floor at the time the gap was created. The gap area was estimated from a scale drawing based on six measured radii and freehand drawing of irregular gap margins. Only gaps estimated in the sample plots to be 20 m^2 or greater were sampled.

Leaf area index (LAI, leaf area per unit ground area) is an important canopy parameter needed for many physiological and ecosystem studies (Nemani and Running, 1989). In this study, the canopy openness was measured in the centre of each sample plot usingLICOR LAI-2000 Plant Canopy Analyzer. LICOR LAI-2000 Plant Canopy Analyzer calculates LAI by comparing differential light measurements above and below canopy.The readings were taken in the open using the instrument at above head level to avoid personal interferences. The canopy gap area was measured using a graph paper by plotting the ends of the canopies using 6 prominent points.

3.2.1.5. Profile characterisation

Profile diagram is a physical, size to scale, pictorial transactional representation of a representative segment of the forest land (Richard, 1952). A strip of 50 X 20 m stand was selected from each strata and a linear representation of this strip was made in a size to scale graph ignoring the width of the strip. Positions of the tree were marked on the line. Total height and height to the first branch forming crown were recorded using an altimeter. Crown diameter was measured by tracing it on the ground with the help of two long rods. The vertical projection of the crown shape of each tree was drawn by hand in the field. From these pictorial and quantitative data obtained, the profile diagram was made, keeping the measurements to scale.

3.2.2. Soil Studies

From each study samples, surface soil was collected to a depth of 20 cm. The collected samples were packed in air tight containers and brought to the laboratory. The samples were air dried and passed through a two mm sieve. The sieved samples are then stored in a polythene bag for further physico-chemical analysis.

3.2.2.1 Physical properties

3.2.2.1.1. Soil texture

Texture of soils was determined by international pipette method (Piper, 1942). 20 g of air dried soil samples were taken in 500 ml beaker. 60 ml, 6% H_2O_2 was added and kept in water bath to remove the organic matter in the soil. 8 ml, 1N NaOH was added and stirred well for better dispersion of soil particles. Contents were transferred to a spout less cylinder of 1000 ml and from which 20 ml of suspension pipette out to find out 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 also obtained.

3.2.2.1.2. Bulk density

The bulk density of the soil was determined using core sampler method. The soil collected was transferred in to an air tight container and the weight of the soil was found out.

Bulk density = Mass of soil/ Core volume

3.2.2.1.3. Infiltration rate

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimeters per hour. The rate decreases as the soil becomes saturated.

A Double Ring infiltrometer of 10 cm diameter and 15 cm diameter, both having a length of 40 cm, was used to measure the infiltration rate (Appendices 1). This instrument was hammered into the soil to a depth of 20 cm and was filled with water. The instantaneous readings corresponding to subsequent times, in minutes, were recorded.

3.2.2.2. Chemical properties

3.2.2.2.1. Soil pH

The pH of soils was measured in a 1: 2.5 soil water suspension potentiometrically using a pH meter (Jackson, 1958).

3.2.2.2.2. Soil electrical conductivity

The electrical conductivity of soils was measured in a 1: 2.5 soil-water suspension potentiometrically using an electrical conductivity meter.

3.2.2.2.3. Soil moisture content

Soil moisture content was determined by weight loss after drying 10 g fresh soil at 60°C for 24 h.

3.2.2.2.4. Organic carbon

Organic carbon content of the soil was determined by wet digestion method using 0.2 g soil (Walkley and Black, 1934). Soil organic matter was determined by multiplying the value of organic carbon by 1.724 (Van Bemmelen factor).

3.2.2.2.5. Available phosphorus

Available phosphorus in the soil samples were extracted using Bray No.1 reagent (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate Ascorbic acid blue colour method (Watanabe and Olsen, 1965) using a spectrophotometer.

3.2.2.2.6. Available potassium

Available potassium in the soil samples were extracted using neutral 1N ammonium acetate and estimated using flame photometry (Jackson, 1958).

3.2.2.2.7. Exchangeable cations and cation exchange capacity (CEC)

Exchangeable cations were estimated by the method of Hendershot and Duquette (1986). The exchangeable cations in the soil sample were extracted using 0.1 M

Barium Chloride solution. Exchangeable Ca, Mg, Fe, Mn, Cu and Zn were estimated using Atomic Absorption Spectrophotometer. Na and K estimated using flame photometer. Exchangeable Al was estimated colorimetrically using Aluminon (Jayman and Sivasubramanian, 1974). The CEC was then calculated and expressed in $cmol(p^{+})kg^{-1}$.

3.2.2.3. Soil Quality Index

The soil quality index used in the study was a modification of that developed by Amacher et al. (2007) for United States Department of Agriculture (USDA). Certain indicator value of the above index was modified using indicator values assigned by Kerala state planning board for farm and agroforestry system. Those indicator values that were modified to suit Kerala forest conditions were pH, electrical conductivity, organic carbon, available phosphorus, available potassium, bulk density, sand fraction and infiltration rate (Table 1). The total SQI for each site was calculated by summing the individual index values.

Total SQI = Σ individual soil property index values

The total SQI is then expressed as a percentage of the maximum possible value of the total SQI for the soil properties that are measured:

SQI, % = (total SQI / maximum possible total SQI for properties measured) x 100

3.2.3. Anthropogenic disturbances

Different anthropogenic disturbances variables were measured like - number of roads, distance from the road, intensity of grazing, forest fires, stumps left, cut stems and bamboos, lopping intensities etc was assessed visually, and ranked. Data for the habitat variables were ranked in classes as absent or present, and was represented as 0 and 1. These combined / total scores of human disturbance variables were used to represent each sample sites.

Table 1 Parameters for Soil Quality Index (SQI)

Soil Quality Index (SQI)					
Sl. No	**Parameter**	**Level**	**Interpretation**	**Index**	**Remarks**
1	Bulk density (g/cm^3)	> 1.5	Possible adverse effects	1	USDA/ KFRI
		≤ 1.5	Adverse effects unlikely	0	
2	Coarse fragments (percent)	> 50	Possible adverse effects	1	USDA/ KFRI
		≤ 50	Adverse effects unlikely	0	
3	Soil pH	4.5 - 5.5	Strongly acidic	2	Kerala planning board
		5.6 - 6.0	Moderately acidic	1	
		6.1 - 6.5	Slightly acidic	0	
		6.6 - 7.3	Neutral	1	
4	EC (µS cm^{-1})	< 100	Low	1	Kerala state planning board
		100 - 300	Medium	0	
		>300	High	1	
5	Organic Carbon (%)	< 0.76	Low	2	Kerala state planning board
		0.76 - 1.50	Medium	1	
		> 1.50	High	0	
6	Total Nitrogen (%)	> 0.5	High	0	USDA/ KFRI
		0.1 - 0.5	Moderately acidic	1	
		< 0.1	Low	2	
7	Available Phosphorus (kg / ha)	< 10	Low	2	Kerala state planning board
		1 0 - 24	Medium	1	
		> 24	High	0	
8	Available Potassium (kg / ha)	< 115	Low	2	Kerala state planning board
		115 - 275	Medium	1	
		> 275	High	0	
9	Infiltration rate (mm)	< 15	Low	2	FAO
		15 - 50	Medium	1	
		> 50	High	0	

3.2.3.1. Human disturbance indicator (HDI)

The disturbances in forest were assessed by developing an index called human disturbance indicator, which was a modified form of site disturbance impact factor-SDI (Sagar et al., 2003)., which was based on scores assigned to visual signs of disturbance indicators. The signs of disturbance include cuts or notches on trees (C), lopped branches (L), cattle/ human trails T), livestock dung's (LD), fire damaged trees – fire scorched trees (ST) and completely burned trees (BT), stumps (S), Standing dead trees (DT) and fallen dead trees (FT) . The presence and absence of an indicator was scored one or zero respectively. The scores for C, T, LD, ST, BT, and S were added; and DT and FT were subtracted from the index.

$$\text{Human disturbance indicator, HDI} = C + T + L + LD + ST + BT + S - DT - FT$$

The index was represented as percentage which was done based on the ratio between human disturbance indicator (HDI) for the site to the sum of the maximum disturbance scores (or maximum HDI) for the study area. This index is then converted to percentage, making this index applicable to any forest.

$$\text{HDI \%} = (\text{HDI}/\ \text{maximum HDI}) \times 100$$

RESULTS

4. RESULTS

4.1. Vegetation studies

4.1.1. Species composition and vegetation structure of the trees in study area

The species composition found in the three study locations of Peechi- Vazhani wildlife sanctuary (P-VWLS) comprised a total of 62 tree species, four liana species, 46 species of herbs and shrubs including three invasive species(Table 2).A total of 1764 trees were identified and enumerated in 36 sample plots (2500 m^2 each) in three different locations of P-V WLS.

A total of 1764 trees were encountered in the study. The number of trees in P-V WLS varied with location and strata. The Manamangalam forests with 945 trees represented 53.6 % of the total trees in P-V WLS, whereas Vaniyampara sites and Ollakkara sites contributes 28.2 % and 18.2 % of the total trees in the sanctuary (Fig 2a). The analysis of variancefor the three locations based on strata's showed significant difference in the number of trees. Of the total 1764 trees enumerated in the study, 839 trees were present in strata 1, 489 trees in strata 2 and 436 trees in strata 3 (Fig 2b). This means that the trees in strata 1, 2 and 3 represented 47.56 %, 27.72 % and 24.72 % of the total trees, respectively.

The Abundance (A), Relative density (RD), Relative Basal area (RBA) and Important value index (IVI) of all tree species (>10 cm GBH and > 100cm height) in P-VWLS is given in Table 3 and 4.*Xylia xylocarpa* recorded the highest abundance of 33.44. The other five tree species that recorded abundance greater than 10 were *Terminalia paniculata* (21.78), *Tectona grandis* (21.11), *Cleistanthus collinus* (17.33), *Macaranga peltata* (15.29), *Wrightia tinctoria* (14.22) and *Holarrhena pubescens* (11.6)(Fig. 3). Of the 1764 trees in the study area, about 63 % of the total relative density of all tree species in P-V WLS was contributed by seven species together which include *Xylia xylocarpa* (17.05 %), *Terminalia paniculata* (11.1 %), *Tectona grandis* (10.76 %), *Wrightia tinctoria* (7.25 %), *Macaranga peltata* (6.1 %) and *Holarrhena pubescens* (5.9%)(Fig.4).

Table 2. Species composition of P-V WLS.

Sl.No	Species	Habit
1	*Albizia amara*	Tree
2	*Albizia lebbeck*	"
3	*Albizia odoratissima*	"
4	*Albizia procera*	"
5	*Alstonia scholaris*	"
6	*Anogeissus latifolia*	"
7	*Bauhinia racemosa*	"
8	*Bixa orolina*	"
9	*Bombax ceiba*	"
10	*Briedelia retusa*	"
11	*Callicarpa tomentosa*	"
12	*Careya arborea*	"
13	*Cassia fistula*	"
14	*Cleistanthus collinus*	"
15	*Dalbergia lanceolaria*	"
16	*Dalbergia latifolia*	"
17	*Dillenia pentagyna*	"
18	*Dipterocarpus indicus*	"
19	*Erythrina stricta*	"
20	*Ficus exasperata*	"
21	*Garuga pinnata*	"
22	*Gmelina arborea*	"
23	*Grewia tiliifolia*	"
24	*Haldina cordifolia*	"
25	*Holarrhena pubescens*	"
26	*Hydnocarpus pentandra*	"
27	*Hymenodictyon orixense*	"
28	*Lagerstroemia lanceolata*	"
29	*Lannea coromandelica*	"
30	*Macaranga peltata*	"
31	*Mallotus philippensis*	"
32	*Melia dubia*	"
33	*Mitragyna parvifolia*	"
34	*Morinda pubescens*	"
35	*Olea dioica*	"
36	*Oroxylum indicum*	"
37	*Phyllanthus emblica*	"
38	*Polyalthia fragrans*	"
39	*Pterocarpus marsupium*	"
40	*Pterospermum reticulatum*	"

Sl.No	Species	Habit
41	*Schleichera oleosa*	"
42	*Spondias pinnata*	"
43	*Sterculia guttata*	"
44	*Sterculia urens*	"
45	*Stereospermum chelonoides*	"
46	*Stereospermum colais*	"
47	*Strychnos nux-vomica*	"
48	*Syzygium cuminii*	"
49	*Tabernaemontana heyneana*	"
50	*Tectona grandis*	"
51	*Terminalia bellirica*	"
52	*Terminalia elliptica*	"
53	*Terminalia paniculata*	"
54	*Tetrameles nudiflora*	"
55	*Trewia nudiflora*	"
56	*Vitex altissima*	"
57	*Wrightia tinctoria*	"
58	*Xanthophyllum arnottianum*	"
59	*Xylia xylocarpa*	"
60	*Zanthoxylum rhetsa*	"
61	*Zizyphus xylopyrus*	"
62	*Saracca indica*	"
63	*Helicteres isora*	
64	*Acacia insia*	Liana
65	*Butea parviflora*	"
66	*Calycopteris floribunda*	"
67	*Entada rheedei*	"
68	*Chromolaena odorata*	Invasive species
69	*Lantana camara*	"
70	*Mikania micrantha*	"
71	*Asparagus racemosa*	Undergrowth
72	*Abrus precatorius*	"
73	*Ageratum conyzoides*	"
74	*Biophytum sensitivum*	"
75	*Caesalpinia mimosoides*	"
76	*Clerodendrum infortunatum*	"
77	*Commelina paludosa*	"
78	*Costus speciosa*	"
79	*Curculigo orchioides*	"
80	*Cyclea peltata*	"
81	*Desmodium triflorum*	"
82	*Dioscorea bulbifera*	"

Sl.No	Species	Habit
83	*Eranthemum capense*	"
84	*Gloriosa superba*	"
85	*Glycosmis pentaphylla*	"
86	*Hemidesmus indicus*	"
87	*Hyptis suaveolens*	"
88	*Ichnocarpus frutescens*	"
89	*Impatiens spp*	"
90	*Leea indica*	"
91	*Leucas aspera*	"
92	*Maranta arundinacea*	"
93	*Mimosa pudica*	"
94	*Mussaenda glabrata*	"
95	*Naregamia alata*	"
96	*Naringi crenulata*	"
97	*Peperomia reflexa*	"
98	*Phaulopsis imbricata*	"
99	*Piper longum*	"
100	*Rauvolfia serpentina*	"
101	*Rauvolfia tetraphylla*	"
102	*Rhodomyrtus tomentosa*	"
103	*Sida rhombifolia*	"
104	*Synedrella nodiflora*	"
105	*Teramnus labialis*	"
106	*Thespesia lampas*	"
107	*Thylophora indica*	"
108	*Tridax procumbens*	"
109	*Urena lobata*	"
110	*Vitex negundo*	"
111	*Ziziphus oenoplia*	"
112	*Ziziphus trinerva*	"

Table 3. Relative density (RD), Abundance (A), Relative basal area (RBA) and Important value index (IVI) of trees (>10 cm GBH and > 100 cm height) in P-V WLS.

Sl. No	Species	RD (%)	A	RBA (%)	IVI
1	*Albizia amara*	0.11	2	0.15	0.60
2	*Albizia lebbeck*	0.23	2	0.18	1.07
3	*Albizia odoratissima*	0.51	1.8	0.33	2.55
4	*Albizia procera*	0.40	3.5	0.18	1.06
5	*Alstonia scholaris*	0.28	5	0.52	0.97
6	*Anogeissus latifolia*	0.62	5.5	0.86	1.75
7	*Bauhinia racemosa*	0.11	2	0.03	0.47
8	*Bixa orolina*	0.06	1	0.00	0.45
9	*Bombax ceiba*	3.97	8.75	5.57	9.14
10	*Briedelia retusa*	0.85	2.14	0.89	4.00
11	*Callicarpa tomentosa*	0.23	2	0.13	1.01
12	*Careya arborea*	1.25	3.67	0.62	3.29
13	*Cassia fistula*	0.85	2.5	0.13	2.79
14	*Cleistanthus collinus*	2.95	17.33	0.83	2.18
15	*Dalbergia lanceolaria*	0.06	1	0.01	0.46
16	*Dalbergia latifolia*	1.59	3.5	1.93	5.48
17	*Dillenia pentagyna*	4.93	9.67	7.59	11.62
18	*Dipterocarpus indicus*	0.23	4	0.05	0.50
19	*Erythrina stricta*	0.06	1	0.00	0.45
20	*Ficus exasperata*	0.23	2	0.06	0.95
21	*Garuga pinnata*	0.06	1	0.00	0.44
22	*Gmelina arborea*	0.23	2	0.10	0.99
23	*Grewia tiliifolia*	2.95	7.43	4.82	7.95
24	*Haldina cordifolia*	0.57	2	1.16	3.37
25	*Holarrhena pubescens*	5.89	11.56	0.76	4.80
26	*Hydnocarpus pentandra*	0.11	2	0.01	0.45
27	*Hymenodictyon orixense*	0.06	1	0.00	0.45
28	*Lagerstroemia lanceolata*	3.51	7.75	8.19	11.77
29	*Lannea coromandelica*	2.38	7	2.83	5.51
30	*Macaranga peltata*	6.06	15.29	1.77	4.93
31	*Mallotus philippensis*	0.62	2.2	0.27	2.49
32	*Melia dubia*	0.17	1.5	0.67	1.56
33	*Mitragyna parvifolia*	0.06	1	0.04	0.49
34	*Morinda pubescens*	0.06	1	0.00	0.45
35	*Olea dioica*	0.62	5.5	0.05	0.94
36	*Oroxylum indicum*	0.11	1	0.01	0.90
37	*Phyllanthus emblica*	0.11	1	0.13	1.02
38	*Polyalthia fragrans*	0.11	2	0.08	0.52
39	*Pterocarpus marsupium*	0.51	3	0.69	2.02

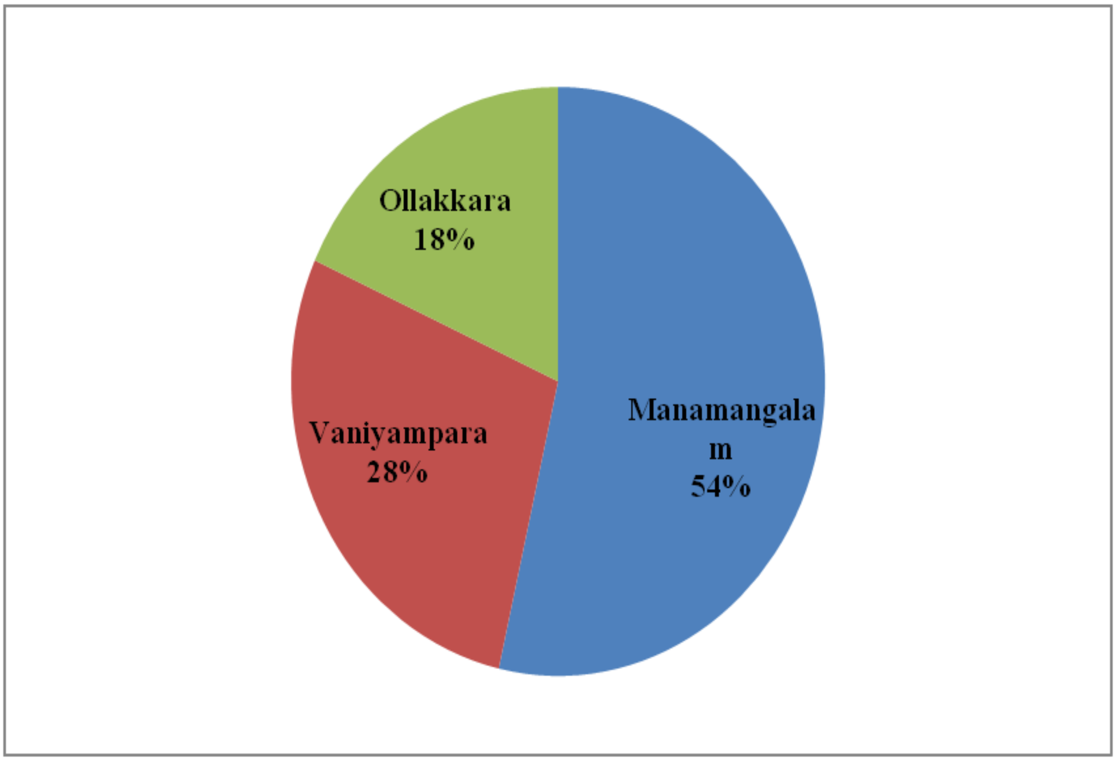
Sl. No	Species	RD	A	RBA	IVI
40	*Pterospermum reticulatum*	0.28	2.5	0.10	0.98
41	*Saracca indica*	0.06	1	0.00	0.45
42	*Schleichera oleosa*	1.19	5.25	1.99	3.77
43	*Spondias pinnata*	0.23	1.33	0.09	1.42
44	*Sterculia guttata*	0.57	2.5	0.23	2.01
45	*Sterculia urens*	0.06	1	0.01	0.45
46	*Stereospermum chelonoides*	0.17	3	0.01	0.45
47	*Stereospermum colais*	0.45	4	0.75	1.64
48	*Strychnos nux-vomica*	1.30	4.6	0.17	2.39
49	*Syzygium cuminii*	0.06	1	0.05	0.49
50	*Tabernaemontana heyneana*	0.57	2	0.03	2.25
51	*Tectona grandis*	10.76	21.11	11.99	16.08
52	*Terminalia bellirica*	2.44	5.38	5.17	8.73
53	*Terminalia elliptica*	1.47	3.25	2.11	5.66
54	*Terminalia paniculata*	11.10	21.78	15.22	19.31
55	*Tetrameles nudiflora*	0.51	3	1.53	2.86
56	*Trewia nudiflora*	0.23	2	0.28	1.17
57	*Vitex altissima*	0.11	1	0.03	0.91
58	*Wrightia tinctoria*	7.25	14.22	1.29	5.35
59	*Xanthophyllum arnottianum*	0.23	4	0.05	0.50
60	*Xylia xylocarpa*	17.05	33.44	17.25	21.40
61	*Zanthoxylum rhetsa*	0.17	3	0.02	0.46
62	*Zizyphus xylopyrus*	0.06	1	0.00	0.44

Table 4. Relative density (RD), Abundance (A), Relative basal area (RBA) and Important value index (IVI) of forest (trees = >10 cm GBH and > 100 cm height) at the three study locations (Manamangalam – M, Vaniyampara – V and Ollakkara – O).

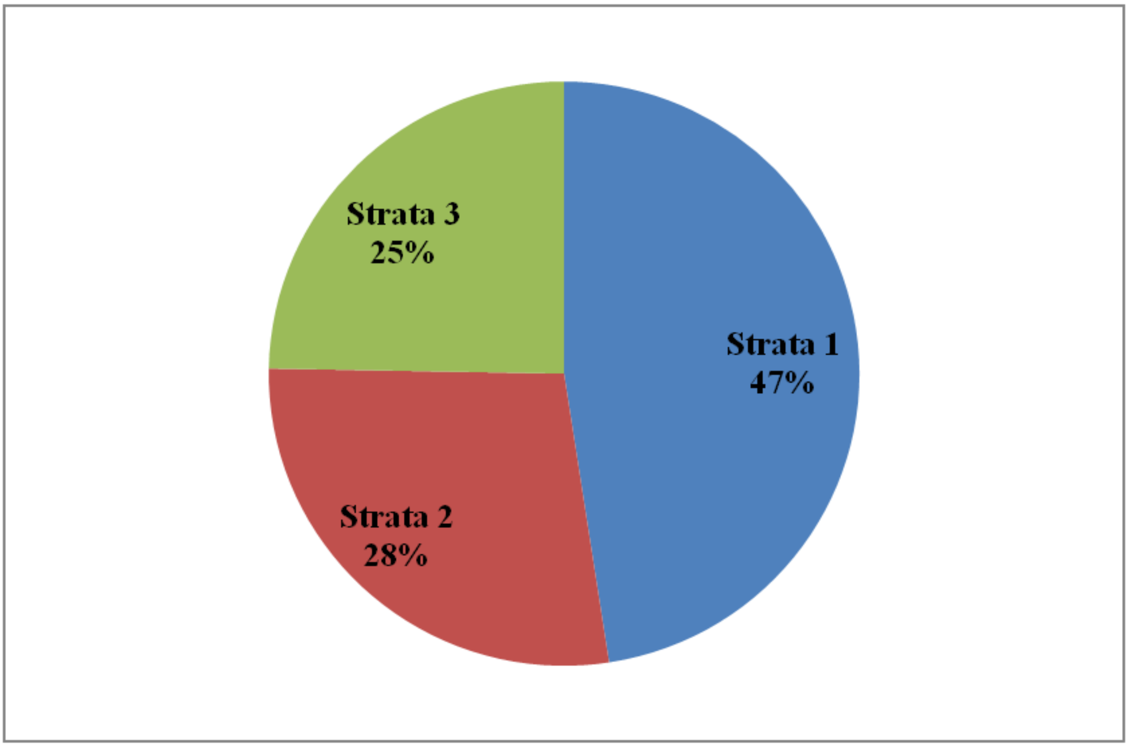
Sl. No.	Species	Relative Density (%)			Abundance			Relative Basal area (%)			Important Value Index		
		M	V	O	M	V	O	M	V	O	M	V	O
1	*Albizia amara*	0.21			1.00			0.41			1.44		
2	*Albizia lebbeck*	0.32		0.31	3.00		1.00	0.02		0.58	0.54		1.46
3	*Albizia odoratissima*	0.53	0.80		1.00	2.00		0.31	0.69		1.35	1.77	
4	*Albizia procera*	0.74			3.50			0.47			1.51		
5	*Alstonia scholaris*		1.01			5.00			1.65			2.73	
6	*Anogeissus latifolia*	0.32	1.61		3.00	8.00		0.02	2.70		0.54	3.79	
7	*Bauhinia racemosa*			0.62			2.00			0.10			1.86
8	*Bixa orolina*	0.11			1.00			0.01			0.52		
9	*Bombax ceiba*	5.19	1.41	4.35	8.17	2.33	7.00	8.20	1.54	6.07	11.35	4.76	11.38
10	*Briedelia retusa*	1.06	0.80	0.31	1.43	1.33	1.00	2.18	0.15	0.09	5.80	2.30	0.97
11	*Callicarpa tomentosa*	0.42			2.00			0.34			1.37		
12	*Careya arborea*	1.48	1.01	0.93	2.33	2.50	3.00	1.47	0.08	0.16	4.58	2.23	1.92
13	*Cassia fistula*	1.16	0.20	0.93	1.57	1.00	1.50	0.18	0.03	0.17	3.80	0.57	2.81
14	*Cleistanthus collinus*	5.50			5.78			2.21			6.91		
15	*Dalbergia lanceolaria*	0.11			0.50			1.25			2.28		
16	*Dalbergia latifolia*	1.69	1.01	2.17	3.20	1.67	2.33	1.58	1.24	1.59	4.17	3.39	6.00
17	*Dillenia pentagyna*	1.48	6.04	13.35	1.56	1	14.33	3.93	8.69	11.56	8.58	14.63	21.34
18	*Dipterocarpus indicus*		0.80			4.00			0.16			1.24	
19	*Erythrina stricta*	0.11			1.00			0.01			0.53		
20	*Ficus exasperata*	0.11	0.60		1.00	3.00		0.07	0.12		0.58	1.19	
21	*Garuga pinnata*	0.11			1.00						0.52		
22	*Gmelina arborea*			1.24			2.00			0.34			2.10
23	*Grewia tiliifolia*	3.07	0.80	5.90	3.22	4.00	6.33	5.29	0.80	7.84	9.96	1.88	14.04
24	*Haldina cordifolia*	0.11	1.41	0.62	0.50	2.33	2.00	0.58	3.38	0.24	1.61	5.53	1.12
25	*Holarrhena pubescens*	8.15	3.02	3.73	7.70	5.00	4.00	0.92	0.15	1.21	6.15	2.85	7.39
Sl.	**Species**	**Relative Density (%)**			**Abundance**			**Relative Basal area (%)**			**Important Value Index**		

No.		M	V	O	M	V	O	M	V	O	M	V	O
26	*Hydnocarpus pentandra*		0.40			2.00			0.02			0.56	
27	*Hymenodictyon orixense*	0.11			1.00			0.01			0.53		
28	*Lagerstroemia lanceolata*	2.43	3.42	6.83	3.29	5.67	7.33	5.49	7.79	12.05	9.13	11.57	19.14
29	*Lannea coromandelica*	2.33	4.02		3.14	6.67		3.34	5.03		6.97	8.28	
30	*Macaranga peltata*	6.46	6.64	4.04	8.71	11.00	6.50	2.46	1.40	1.35	6.13	7.35	4.90
31	*Mallotus philippensis*	0.21	1.81		1.00	3.00		0.03	0.74		1.07	3.44	
32	*Melia dubia*		0.60			1.50			2.12			3.73	
33	*Mitragyna parvifolia*	0.11			1.00			0.11			0.63		
34	*Morinda pubescens*		0.20			1.00			0.01			0.55	
35	*Olea dioica*		2.21			5.50			0.16			2.86	
36	*Oroxylum indicum*	0.21			1.00			0.03			1.06		
37	*Phyllanthus emblica*	0.11		0.31	1.00		1.00	0.10		0.30	0.62		1.19
38	*Polyalthia fragrans*		0.40			2.00			0.25			0.79	
39	*Pterocarpus marsupium*		0.80	1.55		4.00	2.50		0.26	1.99		1.88	4.64
40	*Pterospermum reticulatum*		1.01			2.50			0.30			1.91	
41	*Schleichera oleosa*	1.27	1.81		3.00	4.50		1.38	4.68		3.45	6.84	
42	*Spondias pinnata*	0.11	0.60		1.00	1.50		0.09	0.18		0.61	1.79	
43	*Sterculia guttata*	0.53	1.01		1.67	2.50		0.19	0.51		1.74	2.12	
44	*Sterculia urens*		0.20			1.00			0.02			0.56	
45	*Stereospermum chelonoides*		0.60			3.00			0.03			1.11	
46	*Stereospermum colais*	0.85			2.00			0.20			2.27		
47	*Strychnos nux-vomica*	2.01	0.80		2.11	2.00		0.66	0.10		5.32	1.18	
48	*Syzygium cuminii*		0.20			1.00			0.15			0.69	
49	*Tabernaemontana heyneana*	0.42	1.21		2.00	2.00		0.23	0.06		1.26	3.28	
50	*Tectona grandis*	15.45	5.43	5.28	18.25	9.00	5.67	20.04	6.60	7.91	24.31	10.94	15.86
51	*Terminalia bellirica*	0.95	4.83	3.11	1.80	8.00	3.33	1.91	9.57	4.86	4.50	14.43	11.03
52	*Terminalia elliptica*	1.38	1.81	1.24	2.60	3.00	2.00	3.72	1.17	1.13	6.31	4.40	3.78
Sl. No.	**Species**	**Relative Density (%)**			**Abundance**			**Relative Basal area (%)**			**Important Value Index**		
		M	**V**	**O**	**M**	**V**	**O**	**M**	**V**	**O**	**M**	**V**	**O**

53	*Terminalia paniculata*	12.38	8.85	10.87	9.75	14.67	11.67	18.90	11.28	14.74	25.21	17.25	23.62
54	*Tetrameles nudiflora*		1.81			3.00			4.85			8.08	
55	*Trewia nudiflora*		0.80			2.00			0.90			2.51	
56	*Vitex altissima*	0.11	0.20		1.00	1.00		0.02	0.06		0.54	0.60	
57	*Wrightia tinctoria*	8.47	4.43	8.07	6.67	7.33	8.67	1.34	0.26	2.33	7.61	4.58	10.30
58	*Xanthophyllum arnottianum*		0.80			4.00			0.17			1.78	
59	*Xylia xylocarpa*	11.96	22.13	24.22	9.42	36.67	26.00	10.29	19.85	23.38	16.60	26.49	34.15
60	*Zanthoxylum rhetsa*		0.60			3.00			0.06			0.60	
61	*Zizyphus xylopyrus*	0.11			1.00						0.52		
62	*Saracca indica*	0.11			1.00			0.01			0.52		



(a)



(b)

Fig. 2. Number of trees in P-V WLS based on (a) location and (b) stratum.

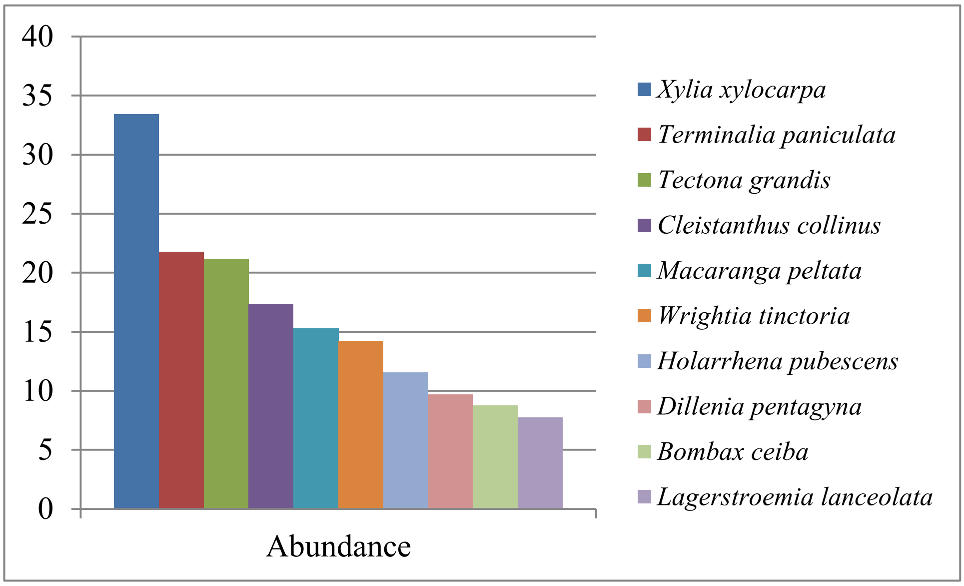


Fig. 3. The Abundance (A) of 10 tree species in P-V WLS**.**

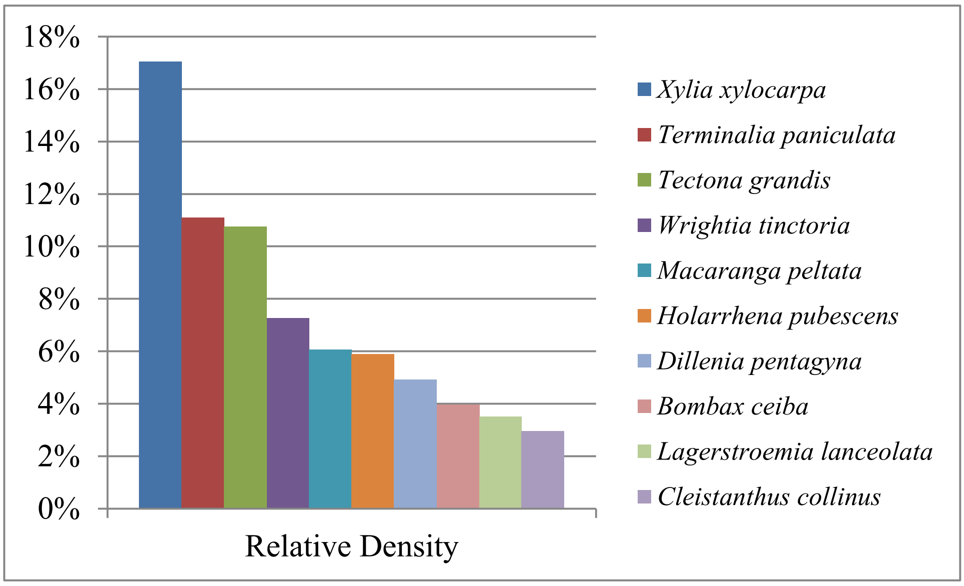


Fig. 4. The Relative density (RD) of 10 tree species in P-V WLS

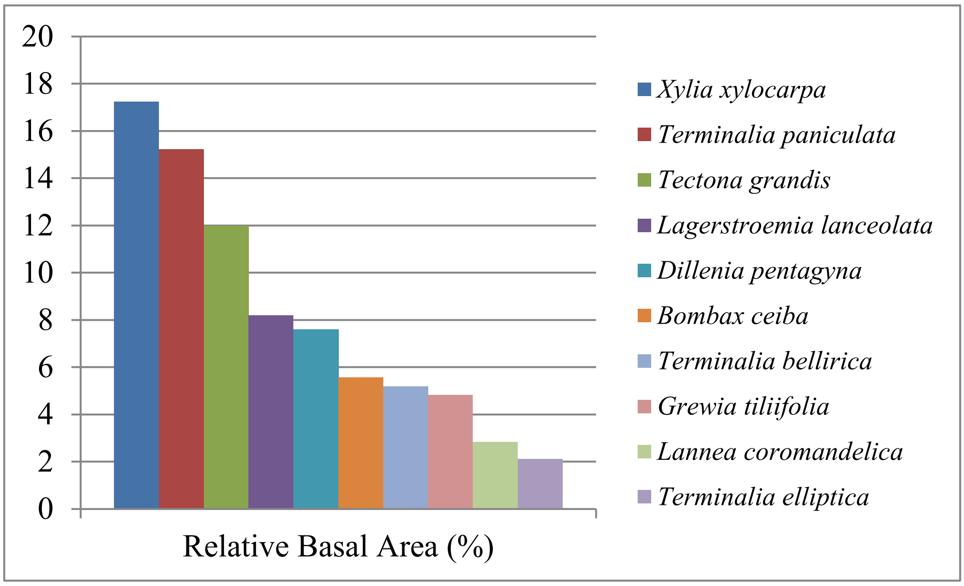


Fig. 5. Relative basal area (RBA) of 10 tree species in the study area.

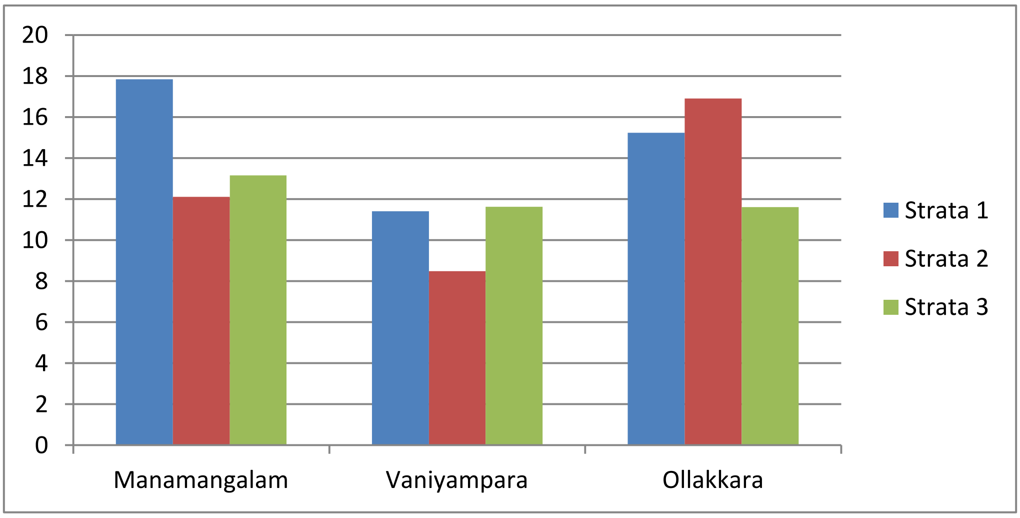


Fig. 6. Location and strata wise total basal area (m^2) of trees in the study area

The 1764 trees of the 62 tree species in P-V WLS, together account for 118.95 m^2 basal area (Fig 5 and 6).Of which six species accounted for 65 % of total basal area. These species include *Xylia xylocarpa* (17.24 %), *Terminalia paniculata* (15.22 %), *Tectona grandis* (11.99%), *Lagerstroemia lanceolata* (8.19 %), *Dillenia pentagyna* (7.59 %)and *Bombax ceiba* (5.59 %). About 10 % of total relative basal area for P-V WLS is contributed by 46 tree species, and each individually accounts for less than 1 % of the total. The 10 tree species with the largest RBAs in the study area are given in Fig 5.*Xylia xylocarpa* recorded the highest IVI with 21.4,which is followed by four species having IVI values greater than 10 including *Terminalia paniculata* (19.31), *Tectona grandis* (16.07), *Lagerstroemia lanceolata* (11.76) and *Dillenia pentagyna* (11.62). About 49 tree species each, individually recorded IVI values less than one. The 10 tree species with the largest IVI's in the study area are given in Fig 7.

In this study, the mean height and the number of trees in the four height classes – 1-10 m, 11 – 20 m, 21 – 30 m and 31 – 40 m were analysed. It was observed that the tree height varied with location.Of all the enumerated trees in P-V WLS, the largest number of trees belonged to the 11 – 20 m height class with a total of 728 trees, followed by 699 trees in 10 – 20 m class and 316 trees in 21- 30 m class and the height class that represented the least number of trees was the 31 – 40 m height class (Fig 8 a). There was significant difference between trees of different strata's too (Fig 8 b). The mean height of the trees in each stratum showed significant difference between strata 1and 2 with strata 3, with the lowest for strata 1 with 12.42 ± 1.38 m, followed by strata 2 with 12.75 ± 2 m and the highest for strata 3 with 16.36 ± 1.9 m.

The tree height classes were analysed in location basis. The trees in Manamangalam location had 43.2 % of its trees in the height class of 1 – 10 m, 40. 9 % in 11 – 20 m class, 14.6 % of trees in 21 – 30 m class and 1.3 % of trees under 31- 40 m class respectively. In Vaniyampara, the classes 1 – 10 m, 11- 20 m, 21 – 30 m and 31 – 40 m classes were represented by 36.8 %, 39.2 %, 22.3 % and 1.6 % of the trees, respectively. In Ollakkkara, the classes 1 – 10 m, 11- 20 m, 21 – 30 m and 31 – 40 m classes were represented respectively by 28.6 %, 44.4 %, 25.2 % and 1.9 % of the trees in the location.

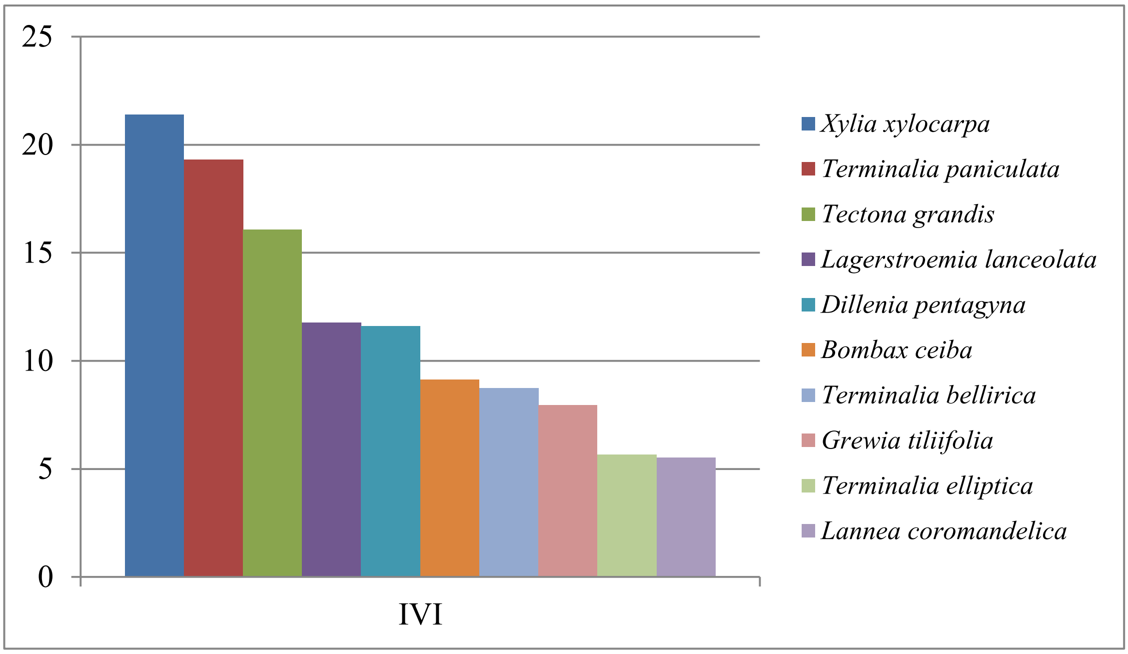
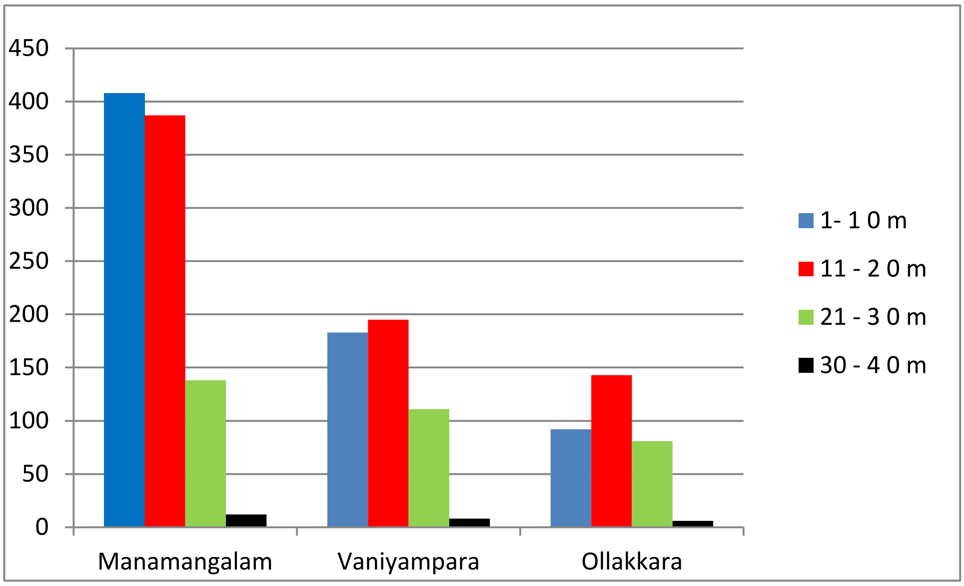
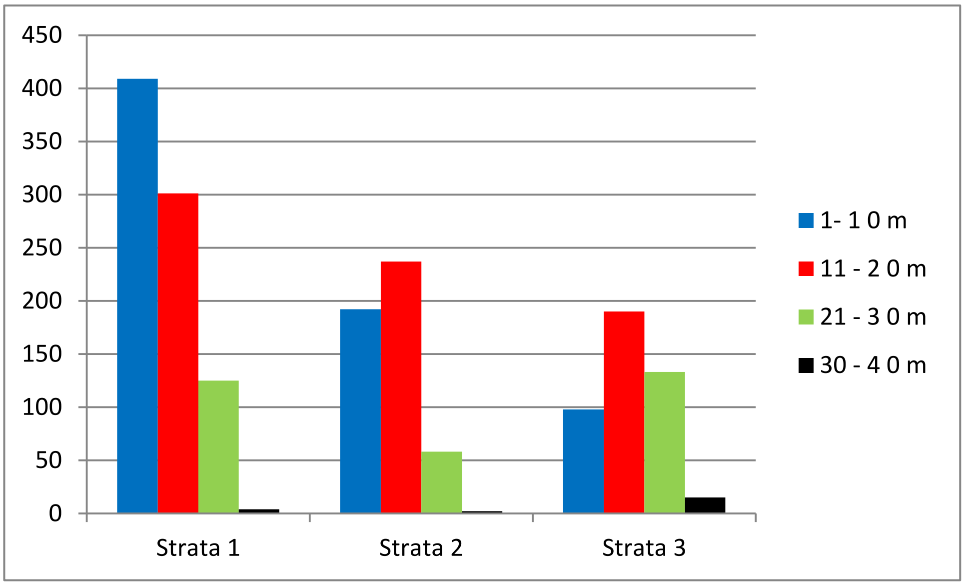


Fig. 7. Important value index (IVI) of 10 tree species in the study area.



(a)



(b)

Fig. 8. Tree height classes at P-V WLS based on (a) location and (b) stratum.

The study noted a decrease in number of trees in lower height class and also a larger number of trees in higher height class when moving from strata 1 to strata 3. In strata 1, 48.7% of the trees in this stratum fall under the 1-10 m class, whereas this class was represented by only 39.3 % and 22.5 % of the total trees in strata 2 and strata 3 respectively. In 11- 20 m class, the strata 1 had 35.9 % of its trees whereas there was an increase in percentage representation of trees in strata 2, with 48.5 % of trees under this class, followed by a decrease in percentage of trees in strata 3 (43.6 %) compared to strata 2. In 21- 30 m and 31-40 m class, strata 1 had 14.9 % and 0.47 % of its trees where as strata 2 had 11.9 % and 0.41 % of trees. In strata 3, it represented 30.5 % and 3.44 % of the total trees.

The trees were grouped into seven GBH classes and the mean GBH and the number of trees in each GBH classes (31 – 60 cm, 61 – 90 cm, 91 – 120 cm, 121 – 150 cm, 151 – 180 cm, 211 -240 cm and 271 – 300 cm) based on strata and location was taken into account. Of all the trees in P-V WLS, 425 trees felled into the 10 – 30 cm GBH class, 362 trees in 31 -60 cm GBH class, 340 trees in 61 -90 cm GBH class and the least represented GBH classes were that of 241 -270 cm and 270 – 300 cm. Based on location, Manamangalam had higher percentage of trees in GBH class of 10 – 30 cm with 28.7 %, whereas Vaniyampara and Ollakkara had 22.9 % and 13.4 % of their trees in the GBH class respectively. Manamangalam and Vaniyampara locations showed similarities in case of their trees under the GBH classes of 31 – 60 cm, 61 – 90 cm, 91 – 120 cm and 121 – 150 cm; with 22.3 % and 22.3 % for 31 – 60 cm class, 19.9 % and 18.9 % for 61 – 90 cmclass, 11.2 % and 12.7 % for 91 – 120 cmclass, 10.1 % and 9.7 % for 121 -150 cm class, respectively. In Ollakkara location, the GBH classes from 10 – 30 cm, 31 – 60 cm, 61 – 90 cm, 91 – 120 cm, 121 – 150 cm and 151 – 180 cm varied little with each other, with highest of 17.4 % for 91 -120 cm GBH class, followed by 17.1 % for 61 – 90 cm class. In case of GBH class of 151 – 180 cm the highest was at Vaniyampara with 7. 2 % and in 181 – 210 GBH class the highest was by the trees of Ollakkara with 6.8 %. In 211 -240 cm and 271 – 300 cm GBH classes, highest percentage was represented by trees of Ollakkara with 2.8 % and 0.9 % of its trees (Fig 9 a).

In strata wise analysis, the mean GBH for each strata and number of trees in each GBH classes were studied. The mean GBH in strata 1 (0.75 ± 0.22 m) and strata 2 (0.80 ± 0.22 m) was significantly different from that in strata 3 (0.98 ± 13 m).

While moving from strata 1 to 3, the GBH class of 10 -30 cm showed a steady decreasing trend in number of trees, whereas GBH class of 31-60 cm and 61 – 90 cm showed a slow decrease. The GBH class of 91 -120 cm showed a near constant value in the strata's while other classes tend to increase. GBH class of 0 – 30 cm, 31 -60 cm and 61 – 90 cm represented 33.9 %, 10.5 % and 9 % in strata 1, whereas it represented 18.8 %, 6.1 % and 5.7 %; and 13.1 %, 3.2 % and 4.6 % of strata 2 and strata 3 respectively. The GBH class of 91 – 120 cm and 121 – 150 cm showed a slight decreasing trend, whereas the higher height classes showed an increasing trend (Fig 9 b).

4.1.1.1. Species composition and vegetation structure of forest at Manamangalam (trees >10 cm GBH and > 100 cm height).

A total of 945 trees belonging to 44 species were recorded in Manamangalam forest in all the three strata's(Table 5). Of which *Tectona grandis* recorded the highest abundance of 18.25. This was followed by *Terminalia paniculata* (9.75)*, Xylia xylocarpa* (9.42)*, Macaranga peltata* (8.71)and *Bombax ceiba* (8.17). An abundance value of one or less than one in Manamangalam forest was recorded for 17 tree species.

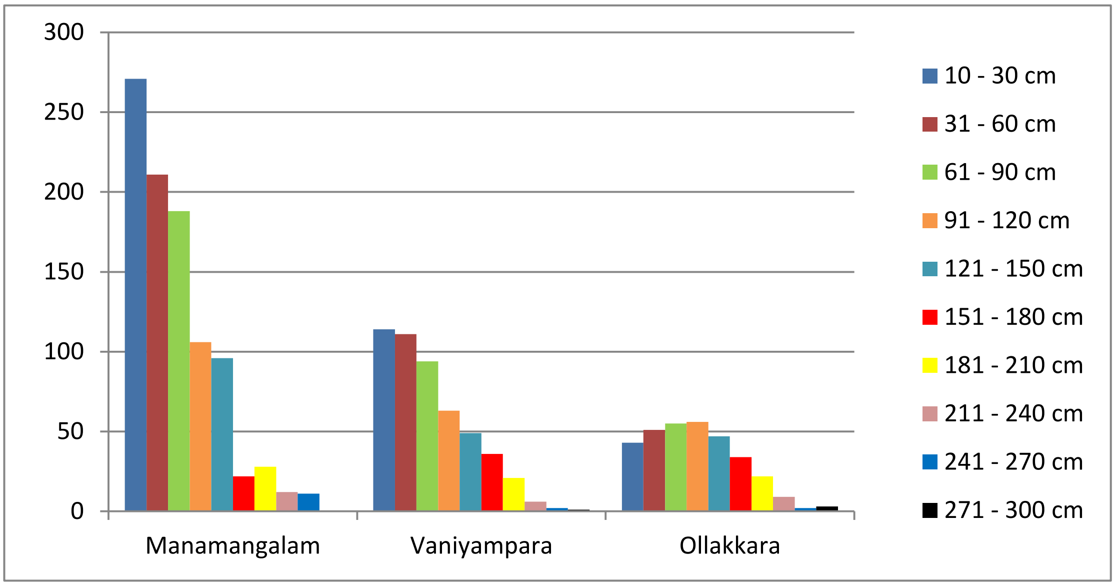
In Manamangalam forest,526 trees of 36 tree species was recorded in strata 1, whereas strata 2 and strata 3 are represented by 217 trees (25 species) and 202 trees (26 species) respectively.*Tectona grandis* recorded the highest abundance value of 32 in the strata 1 of Manamangalam. This was followed by *Holarrhena pubescens* and *Terminalia paniculata* with an abundance value of 14.25. Three more species had abundance value greater than 10; they include *Cleistanthus collinus*, *Bombax ceiba* and *Wrightia tinctoria*.In strata 2, the highest abundance was that of *Xylia xylocarpa* (12.5), which was followed by *Terminalia paniculata* (6.25), *Grewia tiliifolia* (5.67) etc.No tree species was observed to have an abundance value greater than 10 in the strata 3 of

Manamangalam. *Terminalia paniculata*had the highest abundance (8.75) in strata 3 of Manamangalam, followed by *Lannea coromandelica* (7.5) and*Xylia xylocarpa* (7).

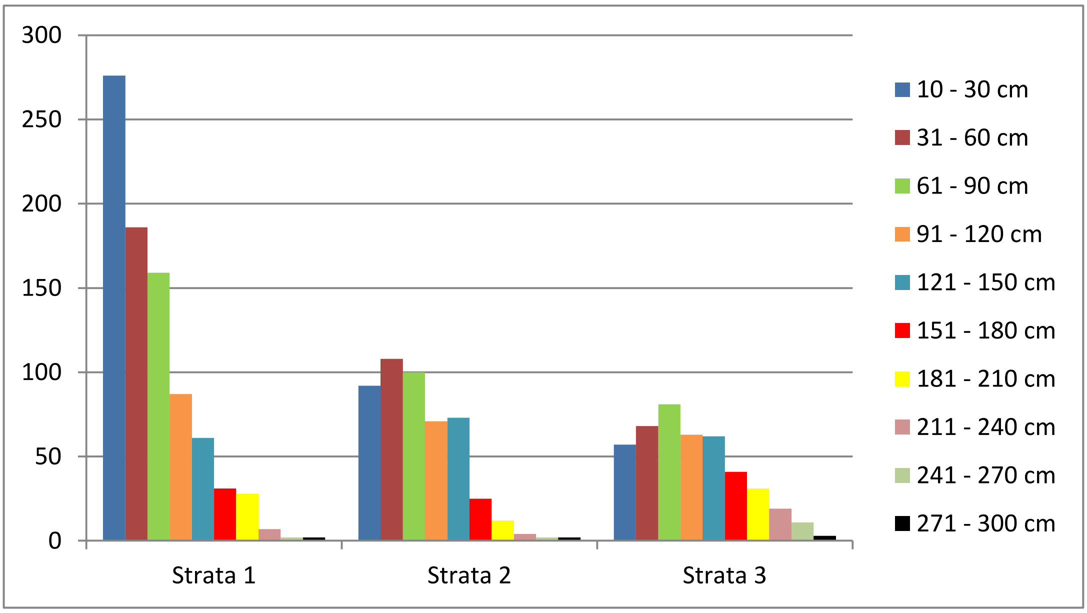
Tectona grandis recorded the highest relative density of 24.5% in strata 1 of Manamangalam. *Tectona grandis*was followed by *Holarrhena pubescens*, *Terminalia paniculata* (10.9 % each) and*Macaranga peltata* (10%). Of the 36 species present in the strata 1 of Manamangalam, 24 species represent less than 1 % of relative density and together contribute to 8.6 % of the total relative density. In strata 2, *Xylia xylocarpa* has the highest relative density with 23 %. It is followed by *Terminalia paniculata* (11.5 %), *Grewia tiliifolia* and *Wrightia tinctoria* (7.8 % each). Rest 50 % of the total density in strata 2 is comprised by 21 species.

Only three tree species had a relative density of 10 % or more in strata 3. They are*Terminalia paniculata* (17.24 %)with the highest, followed by *Xylia xylocarpa* (13.8 %) and *Wrightia tinctoria* (10.3 %). About 7 % of the relative density is represented by 12 species, each with less than 1 %.

A total of 44.46 m^2ha^{-1} basal area was observed for all the 945 trees in Manamangalam. Of which, strata 1 had a total basal area of 17.83 m^2, strata 2 had 11.40 m^2 and strata 3 had 15.23 m^2 (Fig. 5). *Tectona grandis* has the highest relative basal area in strata 1 with 40.4 % of its total basal area. This is followed by *Bombax ceiba* (16.3 %), *Terminalia paniculata* (15.6 %) and *Macaranga peltata* (5.4 %). These species along with *Dalbergia lanceolaria*, *Dalbergia latifolia*, *Terminalia bellirica*, *Xylia xylocarpa* and *Wrightia tinctoria* formed 90 % of the total basal area in this stratum. In strata 2 of Manamangalam 13 of the 25 species, in the order of decreasing basal area, constitute 91 % of the total basal area; with the highest for *Xylia xylocarpa* (24 %), followed by *Terminalia paniculata* (15.6 %), *Grewia tiliifolia* (13 %) etc.About 25 % of the basal area of strata 3 is represented by *Terminalia paniculata,* and then by *Lagerstroemia lanceolata* (11.9 %), *Xylia xylocarpa* and *Dillenia pentagyna* (9.3 %), etc. In this stratum, 14 species individually represent only less 1 % to the total basal area and together they comprise less than 5 % of total basal area of the strata.



(a)



(b)

Fig. 9. Tree GBH classes at P-V WLS based on (a) location and (b) stratum.

Table 5.Species composition of forest at Manamangalam (trees =>10 cm GBH and > 100 cm height).

Sl.No	Species	Relative Density (%)			Abundance			Relative Basal area (%)			IVI		
		Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3
1	*Albizia amara*	0.38			1			1.02			3.77		
2	*Albizia lebbeck*	0.57			3			0.05			1.43		
3	*Albizia odoratissima*		0.46	0.49	0	1	1		0.43	0.59		1.97	2.38
4	*Albizia procera*	1.15	0.46		6	1		1.08	0.15		2.46	1.69	
5	*Anogeissus latifolia*	0.57			3			0.05			1.43		
6	*Bixa orolina*			0.49			1			0.02			1.81
7	*Bombax ceiba*	8.81	0.92	0.49	11.5	2	1	16.29	3.63	2.15	21.86	5.18	3.94
8	*Briedelia retusa*	0.19	1.38	2.96	1	1	2	0.03	2.03	4.81	1.40	6.66	10.20
9	*Callicarpa tomentosa*	0.38		0.99	2		2	0.58		0.31	1.95		2.10
10	*Careya arborea*	0.19	5.07	0.99	1	3.67	1	0.17	4.53	0.71	1.54	9.20	4.29
11	*Cassia fistula*	1.34	1.38	0.49	2.33	1	1	0.25	0.28	0.01	4.37	4.91	1.80
12	*Cleistanthus collinus*	4.60	6.91	6.40	12	3.75	4.33	0.94	5.36	1.35	3.72	11.58	6.77
13	*Dalbergia lanceolaria*	0.19			0.5			3.12			5.86		
14	*Dalbergia latifolia*	2.30		1.97	4		2	2.69		1.47	6.82		5.06
15	*Dillenia pentagyna*	0.38	1.84	3.94	2	1	2	0.25	2.54	9.28	1.62	8.72	16.46
16	*Erythrina stricta*	0.19			1			0.02			1.39		
17	*Ficus exasperata*	0.19			1			0.17			1.54		
18	*Garuga pinnata*	0.19			1			0.01			1.38		
19	*Grewia tiliifolia*	0.57	7.83	4.43	1	5.67	3	0.33	12.89	5.42	4.45	17.58	10.82
20	*Haldina cordifolia*	0.19			1			0.13		1.53	1.50		3.31
21	*Holarrhena pubescens*	10.92	5.99	3.45	14.25	3.25	3.5	1.81	0.43	0.23	7.40	6.65	3.84
22	*Hymenodictyon orixense*	0.19			1			0.03			1.40		
23	*Lagerstroemia lanceolata*		3.69	7.39		2	5		5.54	11.89		11.73	17.32
24	*Lannea coromandelica*	0.57	1.84	7.39	1.5	1.33	7.5	0.77	2.63	6.88	3.51	7.27	10.52

Sl.No	Species	Relative Density (%)			Abundance			Relative Basal area (%)			IVI		
		Strata	**Strata**	**Strata 3**	**Strata 1**	**Strata**	**Strata 3**	**Strata**	**Strata**	**Strata**	**Strata**	**Strata**	**Strata**
25	*Macaranga peltata*	9.96	4.15		13	3		5.43	1.09		11.01	5.75	
26	*Mallotus philippensis*	0.19	0.46		1	1		0.08	0.02		1.45	1.56	
27	*Mitragyna parvifolia*	0.19			1			0.29			1.66		
28	*Oroxylum indicum*	0.19		0.49	1		1	0.03		0.06	1.40		1.85
29	*Phyllanthus emblica*			0.49						0.29			2.08
30	*Schleichera oleosa*		4.15	1.48		3	3		4.12	0.94		8.78	2.74
31	*Spondias pinnata*		0.46			1			0.36			1.91	
32	*Sterculia guttata*	0.19		1.97	1		2	0.11		0.42	1.48		4.01
33	*Stereospermum colais*	0.77	1.84		1.33	4		0.15	0.55		4.27	2.11	
34	*Strychnos nux-vomica*	2.11	2.76	0.99	2.75	1.5	2	0.45	1.84	0.03	5.95	8.02	1.82
35	*Tabernaemontana*	0.57	0.46		3	1		0.06	0.80		1.43	2.34	
36	*Tectona grandis*	24.52	1.84	6.90	32	4	4.67	40.43	3.09	8.84	46.15	4.65	14.27
37	*Terminalia bellirica*	0.96	1.84		2.5	1.33		2.46	3.60		5.21	8.23	
38	*Terminalia elliptica*	0.38	1.84	3.45	2	4	2.33	0.55	3.36	7.70	1.92	4.92	13.09
39	*Terminalia paniculata*	10.92	11.52	17.24	14.25	6.25	8.75	15.63	15.67	25.13	21.22	21.94	32.44
40	*Vitex altissima*	0.19			1			0.05			1.42		
41	*Wrightia tinctoria*	8.05	7.83	10.34	10.5	4.25	5.25	2.25	0.91	0.58	7.81	7.14	7.83
42	*Xylia xylocarpa*	6.70	23.04	13.79	8.75	12.5	7	2.27	24.14	9.33	7.82	30.52	16.61
43	*Zizyphus xylopyrus*			0.49			1			0.01			1.80
44	*Saracca indica*			0.49			1			0.02			1.81

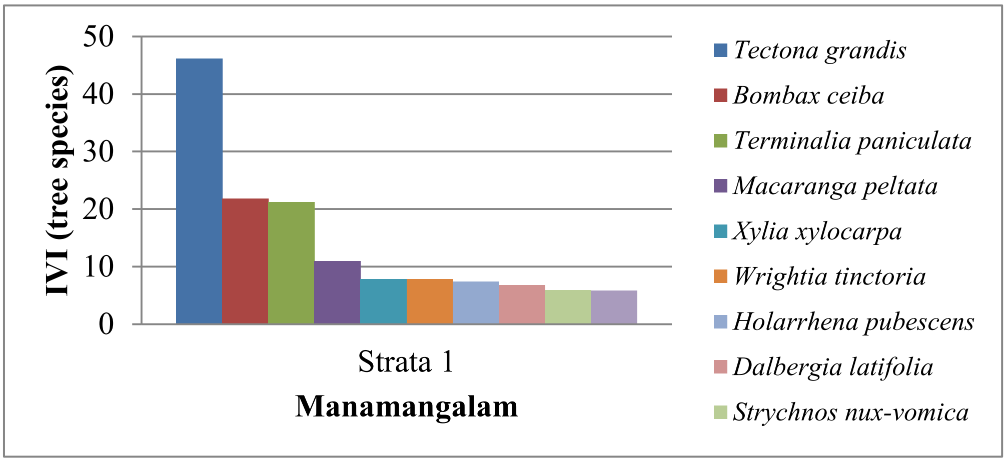


Fig.10 a

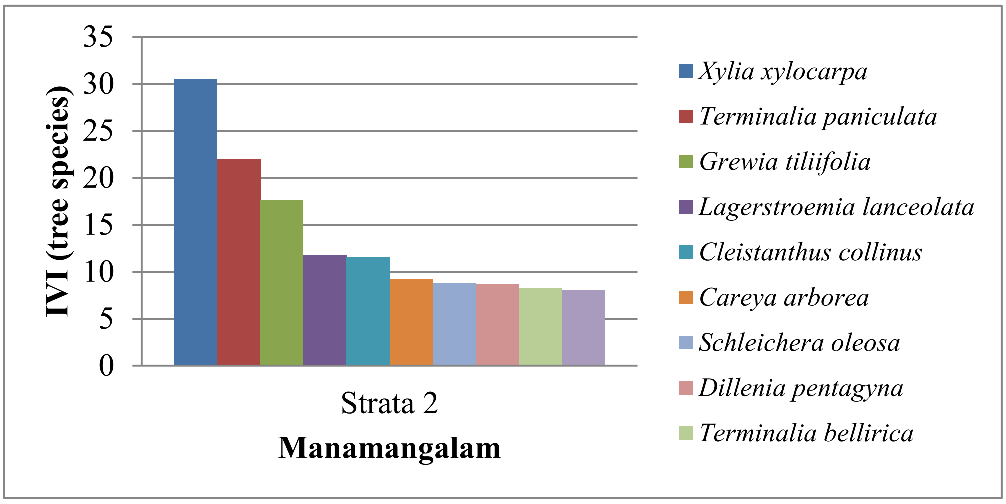


Fig. 10 b

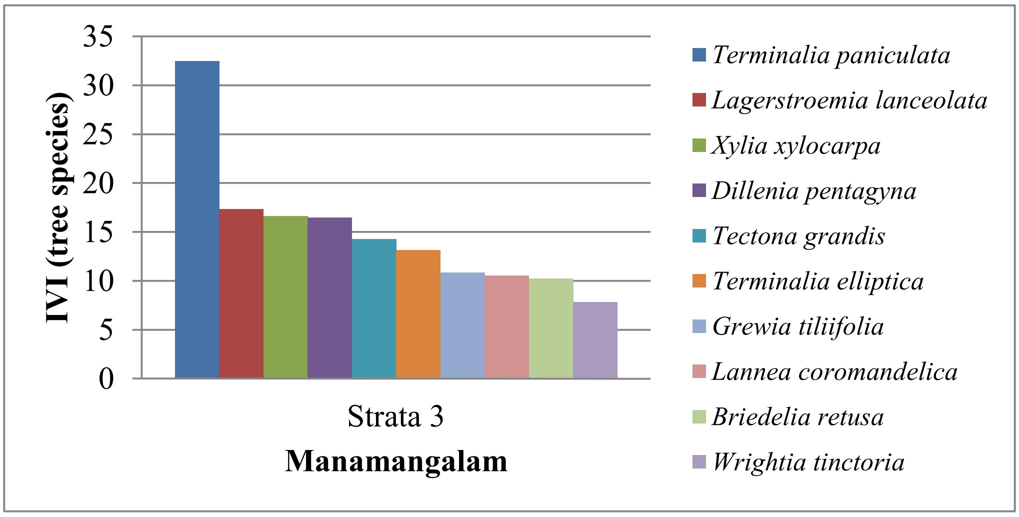


Fig. 10 c

Fig.10. Important value index (IVI) of tree species at Manamangalam (a) Strata 1, (b) Strata 2 and (c) Strata 3.

Table 6. Species composition of forest at Vaniyampara (trees =>10 cm GBH and > 100 cm height).

Sl. No	Species	Relative Density			Abundance			Relative Basal area			IVI		
		Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3
1	*Albizia odoratissima*	0.51		2.22	1.00		3.00	1.58		0.40	3.15		2.18
2	*Alstonia scholaris*	2.56			2.50			5.11			8.26		
3	*Anogeissus latifolia*	4.10			4.00			8.37			11.54		
4	*Bombax ceiba*	1.54	1.19	1.48	1.50	1.00	1.00	0.83	0.77	2.43	3.97	3.81	5.95
5	*Briedelia retusa*	1.03	0.60	0.74	1.00	1.00	1.00	0.18	0.16	0.13	3.32	1.68	1.89
6	*Careya arborea*	1.54	1.19		1.50	1.00		0.07	0.25		3.21	3.30	
7	*Cassia fistula*			0.74			1.00			0.07			1.83
8	*Dalbergia latifolia*	0.51	0.60	2.22	1.00	1.00	1.50	0.06	0.10	2.66	1.63	1.62	6.20
9	*Dillenia pentagyna*	6.67	6.55	4.44	3.25	2.75	2.00	16.21	9.58	2.85	22.53	15.70	8.16
10	*Dipterocarpus indicus*		2.38			2.00			0.73			3.78	
11	*Ficus exasperata*	1.54			1.50			0.36			3.50		
12	*Grewia tiliifolia*			2.96			2.00			1.78			5.32
13	*Haldina cordifolia*	1.03	0.60	2.96	2.00	1.00	2.00	0.58	1.76	6.19	2.16	3.28	9.73
14	*Holarrhena pubescens*	1.54	3.57	4.44	3.00	3.00	3.00	0.12	0.18	0.15	1.70	3.25	3.70
15	*Hydnocarpus pentandra*	1.03			2.00			0.08			1.65		
16	*Lagerstroemia lanceolata*	3.59	2.38	4.44	3.50	1.33	3.00	8.49	5.09	8.64	11.66	9.66	12.19
17	*Lannea coromandelica*	6.15	3.57	1.48	6.00	2.00	2.00	9.48	6.47	1.11	12.66	11.05	2.88
18	*Macaranga peltata*	6.67	7.14	5.93	4.33	3.00	2.00	1.79	1.80	0.92	6.55	7.93	8.00
19	*Mallotus philippensis*	0.51	2.38	2.96	1.00	2.00	2.00	0.04	1.16	1.03	1.61	4.21	4.57
20	*Melia dubia*		1.19	0.74		1.00	1.00		5.51	1.94		8.55	3.71
21	*Morinda pubescens*		0.60			1.00			0.05			1.58	
22	*Olea dioica*	2.56	3.57		5.00	1.50		0.20	0.44		1.79	6.53	
23	*Polyalthia fragrans*			1.48			2.00			0.56			2.33

Sl. No	Species	Relative Density			Abundance			Relative Basal area			IVI		
		Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3	Strata 1	Strata 2	Strata 3
24	*Pterocarpus marsupium*	2.05			1.33			0.82			5.53		
25	*Pterospermum reticulatum*	1.03	1.79		2.00	1.50		0.15	1.11		1.72	4.16	
26	*Schleichera oleosa*		1.79	4.44		3.00	2.00		0.87	9.95		2.40	15.26
27	*Spondias pinnata*		1.19	0.74		1.00	1.00		0.18	0.30		3.22	2.06
28	*Sterculia guttata*	1.54	1.19		3.00	1.00		0.98	0.86		2.55	3.90	
29	*Sterculia urens*			0.74			1.00			0.05			1.81
30	*Stereospermum chelonoides*	1.54			1.50			0.10			3.24		
31	*Strychnos nux-vomica*	1.03	1.19		2.00	2.00		0.17	0.20		1.74	1.73	
32	*Syzygium cuminii*	0.51			1.00			0.48			2.04		
33	*Tabernaemontana heyneana*	1.03	1.79	0.74	1.00	1.00	1.00	0.04	0.19	0.02	3.18	4.75	1.78
34	*Tectona grandis*	0.51	5.36	12.59	1.00	3.00	4.25	0.01	3.78	12.74	1.58	8.38	19.89
35	*Terminalia bellirica*	4.10	3.57	7.41	2.67	3.00	2.50	9.56	4.29	12.23	14.29	7.36	19.32
36	*Terminalia elliptica*	3.08	1.19	0.74	1.50	2.00	1.00	1.85	0.64	0.95	8.13	2.17	2.71
37	*Terminalia paniculata*	7.18	11.90	7.41	4.67	5.00	2.50	8.95	19.02	9.06	13.71	25.20	16.15
38	*Tetrameles nudiflora*	1.54	1.79	2.22	1.50	3.00	1.00	3.68	4.72	5.76	6.82	6.26	11.04
39	*Trewia nudiflora*		1.19	1.48		1.00	2.00		0.77	1.60		3.81	3.37
40	*Vitex altissima*	0.51			1.00			0.18			1.75		
41	*Wrightia tinctoria*	0.51	7.74	5.93	1.00	3.25	2.67	0.01	0.74	0.19	1.58	6.87	5.52
42	*Xanthophyllum arnottianum*	2.05			1.33			0.53			5.23		
43	*Xylia xylocarpa*	27.18	20.83	16.30	13.25	8.75	5.50	18.74	28.58	16.26	25.27	34.85	23.44
44	*Zanthoxylum rhetsa*	1.54			3.00			0.18			1.76		

Tectona grandis had the highest IVI value in strata 1 with 46.15. *Tectona grandis* is followed by *Bombax ceiba* (21.9), *Terminalia paniculata* (21.2), *Macaranga peltata* (11), *Xylia xylocarpa* (7.8), *Wrightia tinctoria* (7.8) etc (Fig 10 a).In strata 2, the IVI values for tree species had in the order such that the high*Xylia xylocarpa* (24.1), *Terminalia paniculata* (15.7),*Grewia tiliifolia* (12.9), *Lagerstroemia lanceolata* (5.5), and *Cleistanthus collinus* (5.4 (Fig 10 b).*Terminalia paniculata* had the highest IVI value in the strata 3 of Manamangalam with 32.4, which was followed by *Lagerstroemia lanceolata* (17.3), *Xylia xylocarpa* (16.6), *Dillenia pentagyna* (16.5) and*Tectona grandis* (14.3) (Fig 10 c).

4.1.1.2. Species composition and vegetation structure of forest at Vaniyampara (trees- >10 cm GBH and > 100 cm height).

A total of 497 trees belonging to 44 species were recorded in Vaniyamparafrom all the three strata's, the results were furnished in Table 6.*Xylia xylocarpa*recorded the highest abundance of 36.7. This was followed by *Terminalia paniculata, Macaranga peltata, Dillenia pentagyna*and *Bombax ceiba*. About Thirty three species recorded an abundance value of 5 or less in Vaniyampara forest.

A total of 195 trees of 34 tree species represented the vegetation in strata 1, whereas strata 2 and strata 3 are represented by 167 trees (29 species) and 135 trees (27 species) respectively.

Xylia xylocarpa is the most abundant in the strata 1 with an abundance value of 13.25. It is followed by *Lannea coromandelica* (6), *Olea dioica* (5), *Terminalia paniculata* (4.6) and*Macaranga peltata* (4.3). In strata 2, *Xylia xylocarpa* recorded the highest abundance with 8.75, which is followed by *Terminalia paniculata* (5) and*Wrightia tinctoria* (3.25). A total of 11 tree species individually represented an abundance of one in this stratum. In strata 3, *Xylia xylocarpa* (5.5) represented the highest abundance, followed by *Tectona grandis* (4.25), *Holarrhena pubescens* (3) and*Lagerstroemia lanceolata* (3).

Of the 195 trees belonging to 34 species in strata1, the first five species with greatest relative density represented 50 % of the total trees in strata 1, where *Xylia xylocarpa* represented the highest relative density of 27.2 %, which was followed by *Terminalia paniculata* (7.2 %), *Macaranga peltata* (6.7 %), *Dillenia pentagyna* (6.7 %) and *Lannea coromandelica* (6.2 %). Strata 2 was similar to strata 1 with five species with greatest relative density together contributed to nearly 50 % of the total density, which includes *Xylia xylocarpa* (21 %), *Terminalia paniculata* (12 %), *Wrightia tinctoria* (7.7 %), *Macaranga peltata* (7.1 %) and *Dillenia pentagyna* (6.7 %). Of the 135 trees of 27 tree species in strata 3, about 50 % of the tree density is again represented by 5 species, which includes *Xylia xylocarpa* (16.3 %), *Tectona grandis* (12.6 %), *Terminalia bellirica* (7.4 %), *Terminalia paniculata* (7.4 %) and *Wrightia tinctoria* (5.9 %).

All the 497 trees in Vaniyampara account for a total basal area of 37.48 m^2. The strata 1 of Vaniyampara recorded 195 trees (34 species) which account for 12.1 m^2 basal area. More than 50 % of the total basal area in this stratum was represented by four tree species with *Xylia xylocarpa* (18.7 %) the highest, followed by *Dillenia pentagyna* (16.2 %), *Terminalia bellirica* (9.6 %) and *Lannea coromandelica* (9 %). In strata 2, 167 trees contributed a total basal area of 8.48 m^2, of which three tree species accounted for 57 % of the total basal area; this included*Xylia xylocarpa* (28.7 %), *Terminalia paniculata* (19 %) and *Dillenia pentagyna* (9.6 %). In strata 3, 135 trees account a total basal area of 16.9 m^2, where four species represented more than 50 % of the total tree basal area which includes *Xylia xylocarpa* (16.3 %), *Tectona grandis* (12.7 %), *Terminalia bellirica* (12.2 %) and *Schleichera oleosa* (10 %).

Xylia xylocarpa (25.3) had the highest IVI in strata 1 of Vaniyampara, which is followed by *Dillenia pentagyna* (22.5), *Terminalia bellirica* (14.3), *Terminalia paniculata* (13.7) and *Lannea coromandelica* (12.7) (Fig 11 a). In strata 2, *Xylia xylocarpa* represented the highest IVI with 34.85, followed by *Terminalia paniculata* (25.2), *Dillenia pentagyna* (15.7) and*Lannea coromandelica* (11.05) (Fig 11 b). In strata 3, seven tree species represents an IVI value greater than 10. These include *Xylia xylocarpa* (23.4), *Tectona grandis* (19.9), *Terminalia bellirica* (19.3), *Terminalia*

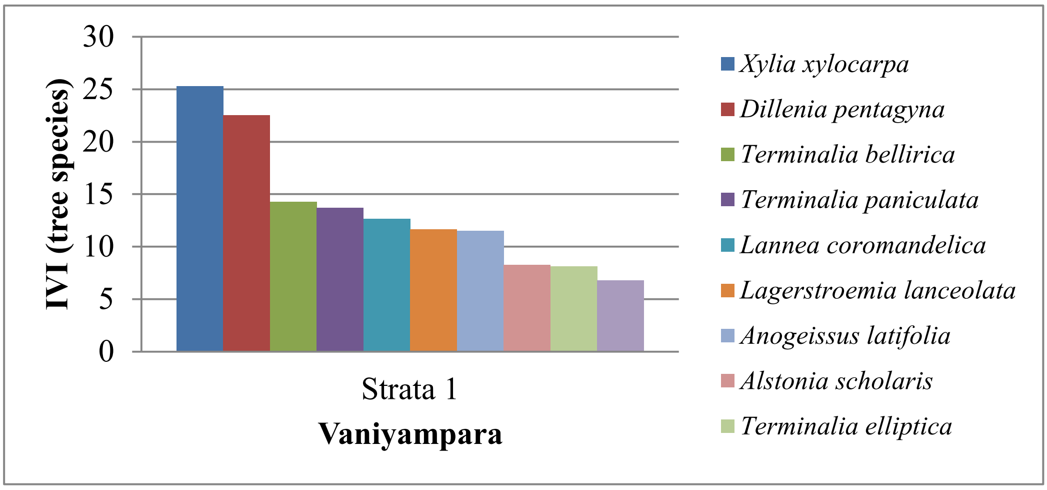


Fig. 11 a

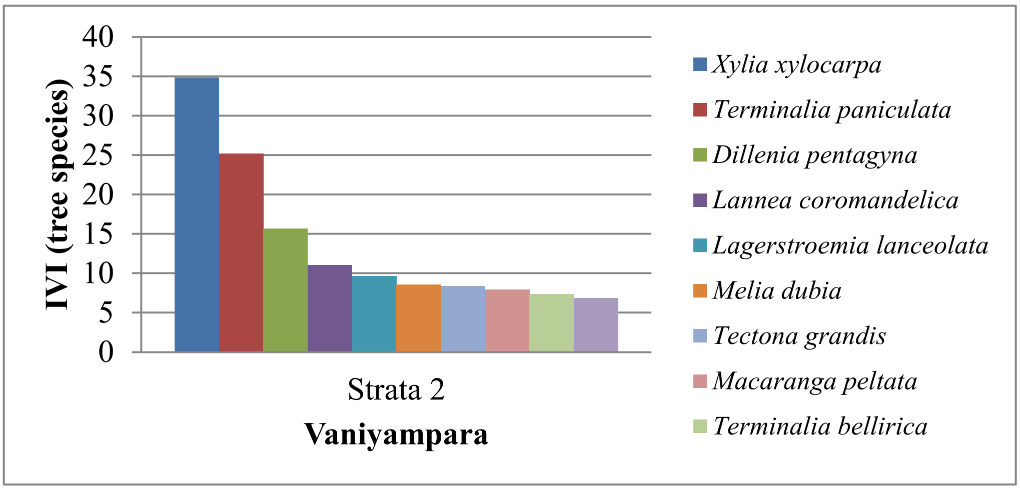


Fig 11 b

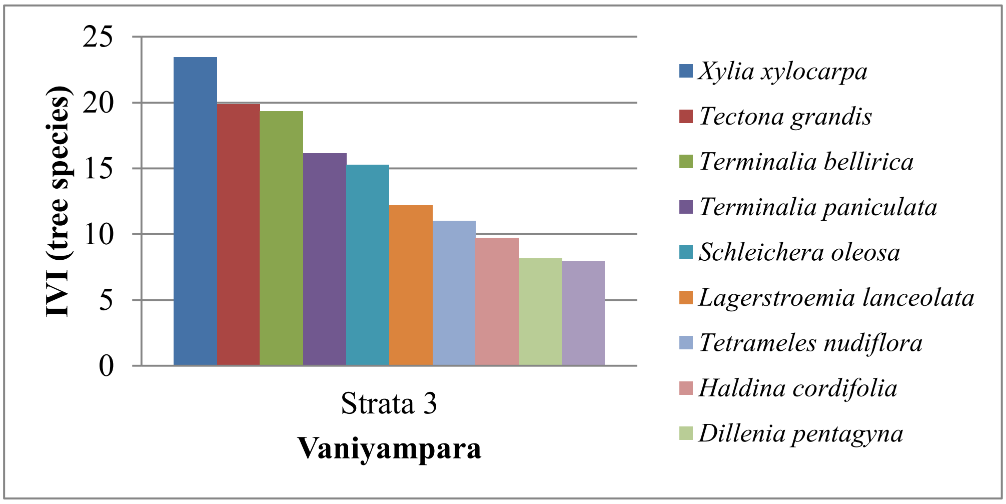


Fig 11 c

Fig. 11 Important value index (IVI) of trees of Vaniyampara (a) Strata 1, (b) Strata 2 and (c) Strata 3.

paniculata (16.2), *Schleichera oleosa* (15.3), *Lagerstroemia lanceolata* (12.2) and *Tetrameles nudiflora* (11) (Fig 11 c).

4.1.1.3. Species composition of forest at Ollakkara (trees- >10 cm GBH and > 100 cm height).

A total of 322 trees belonging to just 22 species were recorded in Ollakkara (Table 7). Of which *Xylia xylocarpa*recorded the highest abundance of 26. This was followed by *Dillenia pentagyna* (14.3), *Terminalia paniculata* (11.7) and *Wrightia tinctoria*(8.7).Thirteen species recorded an abundance value of 5 or less than five in Ollakkara forest.A total of 118 trees of 15 tree species represented the vegetation in strata 1, whereas strata 2 and strata 3 are represented by 105 trees (15 species) and 99 trees (18 species) respectively.

Xylia xylocarpa (8.25) had the highest abundance in strata 1 of Ollakkara, which is followed by *Dillenia pentagyna* (6), *Terminalia paniculata* (4.7), *Wrightia tinctoria* (4) and *Grewia tiliifolia* (3.7). In strata 2, highest abundance was for*Xylia xylocarpa* (7.25), followed by *Lagerstroemia lanceolata* (3.75), *Terminalia paniculata* (3.5), *Dillenia pentagyna* (3.25) and*Wrightia tinctoria* (3.25). In strata 3, again the highest abundance is for *Xylia xylocarpa* (4), *Dillenia pentagyna* (3), *Macaranga peltata* (3), *Dalbergia latifolia* (3), *Gmelina arborea* (3) and*Tectona grandis* (2.5).

Of the 118 trees found in strata 1, *Xylia xylocarpa* (28 %) had the highest relative densitywhich is followed by *Dillenia pentagyna* (15.3 %), *Terminalia paniculata* (19.9 %), *Grewia tiliifolia* (9.3 %) and*Wrightia tinctoria* (5.9 %). In strata 2 among the 105 trees, highest relative density was againfor*Xylia xylocarpa* (27.6 %), followed by *Lagerstroemia lanceolata* (14.3 %), *Terminalia paniculata* (13.3 %), *Dillenia pentagyna* (12.4 %) and*Wrightia tinctoria* (12.4 %). Out of the 99 trees in strata 3, the highest density was recorded for *Xylia xylocarpa* (16.6 %), followed by *Dillenia pentagyna* (12.1 %), *Tectona grandis* (10 %), *Bombax ceiba* (9 %) and*Grewia tiliifolia* (7 %).

The 322 trees in the three strata's of Ollakkara together represented a total basal area of 36.38 m^2 out of which 118 trees in strata 1 account for 13.15 m^2, with the highest

Table 7 Species composition of forest at Ollakkara (trees = >10 cm GBH and > 100 cm height).

SL. No	Species	Relative Density (%)			Abundance			Relative Basal area (%)			IVI		
		Strata 1	**Strata 2**	**Strata 3**	**Strata 1**	**Strata 2**	**Strata 3**	**Strata 1**	**Strata 2**	**Strata 3**	**Strata 1**	**Strata 2**	**Strata 3**
1	*Albizia lebbeck*			1.01			1.00			1.82			4.16
2	*Bauhinia racemosa*		1.90			1.00			0.32			5.74	
3	*Bombax ceiba*	4.24		9.09	2.50		2.25	1.48		17.36	7.41		26.75
4	*Briedelia retusa*	0.85			1.00			0.26			3.21		
5	*Careya arborea*		2.86			1.50			0.50			5.93	
6	*Cassia fistula*		1.90	1.01		1.00	1.00		0.53	0.01		5.96	2.34
7	*Dalbergia latifolia*	1.69	1.90	3.03	1.00	1.00	3.00	1.25	1.85	1.73	7.14	7.28	4.09
8	*Dillenia pentagyna*	15.25	12.38	12.12	6.00	3.25	3.00	10.02	11.18	13.68	19.00	22.12	23.10
9	*Gmelina arborea*		0.95	3.03		1.00	3.00		0.48	0.57		3.20	2.92
10	*Grewia tiliifolia*	9.32	0.95	7.07	3.67	1.00	2.33	12.32	0.25	10.37	21.23	2.96	17.42
11	*Haldina cordifolia*			2.02			2.00			0.75			3.10
12	*Holarrhena pubescens*	4.24	0.95	6.06	1.67	1.00	2.00	2.13	0.15	1.23	10.99	2.86	8.27
13	*Lagerstroemia lanceolata*	1.69	14.29	5.05	2.00	3.75	1.67	3.38	25.41	8.50	6.34	36.36	15.52
14	*Macaranga peltata*	5.93		6.06	3.50		3.00	2.70		1.16	8.65		5.87
15	*Phyllanthus emblica*	0.85			1.00			0.84			3.79		
16	*Pterocarpus marsupium*	3.39		1.01	2.00		1.00	5.17		0.38	11.08		2.71
17	*Tectona grandis*	3.39	2.86	10.10	1.33	1.50	2.50	8.96	8.25	6.38	17.82	13.68	15.78
18	*Terminalia bellirica*	2.54	2.86	4.04	1.50	1.50	1.33	7.04	0.51	6.74	12.95	5.95	13.76
19	*Terminalia elliptica*		2.86	1.01		1.50	1.00		2.56	0.99		8.00	3.32
20	*Terminalia paniculata*	11.86	13.33	7.07	4.67	3.50	2.33	21.39	15.33	6.60	30.33	26.27	13.65
21	*Wrightia tinctoria*	6.78	12.38	5.05	4.00	3.25	1.67	4.24	1.93	0.56	10.19	12.86	7.59
22	*Xylia xylocarpa*	27.97	27.62	16.16	8.25	7.25	4.00	18.82	30.74	21.18	30.87	41.83	30.64

RBA recorded for *Terminalia paniculata* (21.4 %) in the strata, which was followed by *Xylia xylocarpa* (18.8 %), *Grewia tiliifolia* (12.3 %), *Dillenia pentagyna* (10 %) and *Tectona grandis* (9 %). In strata 2, the 105 trees account for a total basal area of 11.63 m^2, with the highest RBArecorded for*Xylia xylocarpa* (30.7 %), followed by *Lagerstroemia lanceolata* (25.4 %), *Terminalia paniculata* (15.3 %), *Dillenia pentagyna* (11.2 %) and*Tectona grandis* (8.3 %). In strata 3, 99 trees had a total basal area of 11.6 m^2. Of the 11.6 m^2 in this stratum, *Xylia xylocarpa* (21.2 %) recorded the highest RBA followed by *Bombax ceiba* (17.4 %), *Dillenia pentagyna* (13.7 %), *Grewia tiliifolia* (10.4 %), *Lagerstroemia lanceolata* (8.5 %) and *Terminalia bellirica* (6.7 %).

In strata 1, highest IVI was for *Xylia xylocarpa* (30.9), followed by for *Terminalia paniculata* (30.3), *Grewia tiliifolia* (21.2), *Dillenia pentagyna* (19) and*Tectona grandis* (17.8) (Fig 12 a). In strata 2, highest IVI was again to *Xylia xylocarpa* (41.8), followed by *Lagerstroemia lanceolata* (36.4), *Terminalia paniculata* (26.3), *Dillenia pentagyna* (22.1), *Tectona grandis* (13.7) and *Wrightia tinctoria* (12.9) (Fig 12 b). In strata 3, *Xylia xylocarpa* (30.6) recorded the highest IVI followed by *Bombax ceiba* (26.8), *Dillenia pentagyna* (23), *Grewia tiliifolia* (17.4), *Tectona grandis* (15.8) and*Lagerstroemia lanceolata* (15.5) (Fig 12 c).

The profile diagram for the strata's of each location shows distinctive changes in tree species and height. This also gives the density of the stand, the canopy height and the vertical layers of canopy (Fig 13).

4.1.2. Species composition of tree saplings (<10 cm GBH and > 100 cm height) in the study area.

Of the 62 tree species found in P-V WLS, only 32 species was represented in saplings population. A total of 395 saplings were recorded in whole of P-V WLS. The most abundant saplings were that of *Xylia xylocarpa* (3.2), which was followed by *Anogeissus latifolia* (3), *Wrightia tinctoria* (2.9), *Macaranga peltata* (2.6), *Holarrhena*

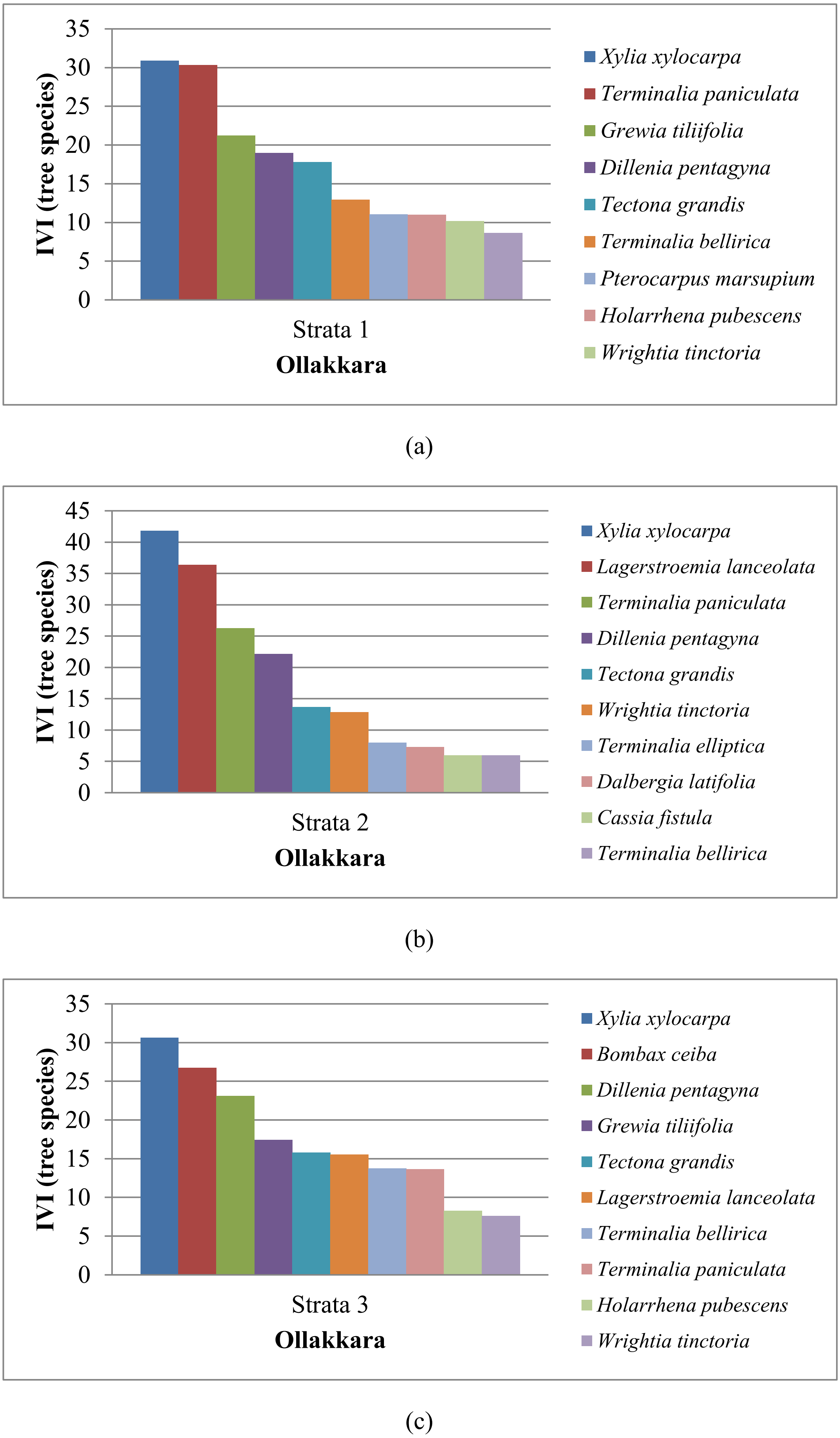
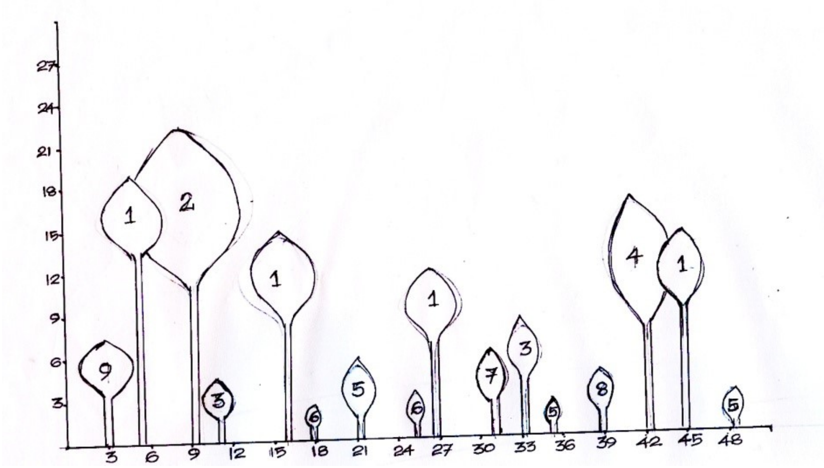
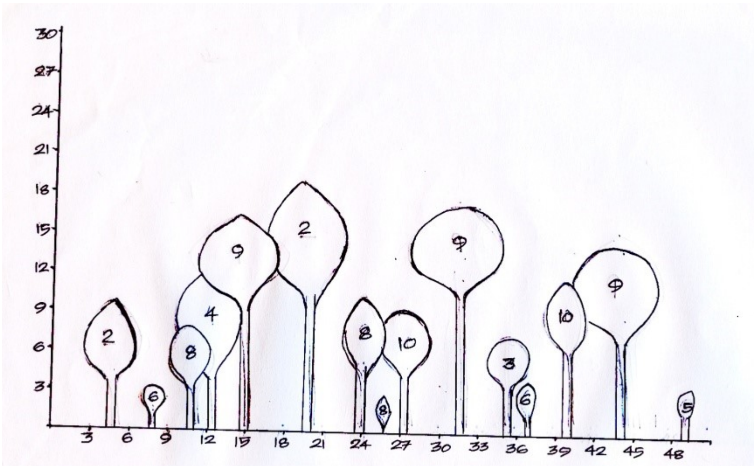


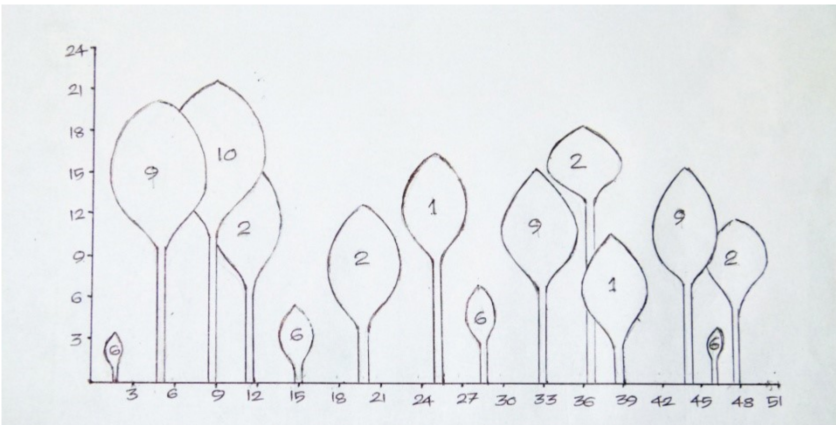
Fig. 12 Important value index (IVI) of tree species at Ollakkara (a) Strata 1, (b) Strata 2 and (c) Strata 3.



(a)



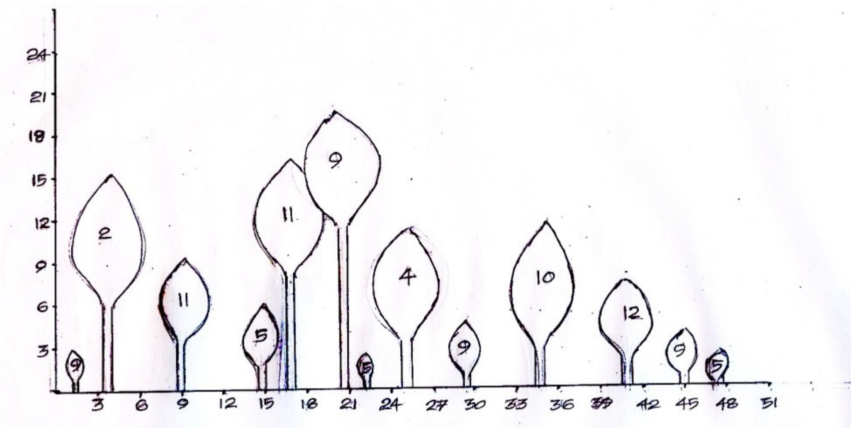
(b)



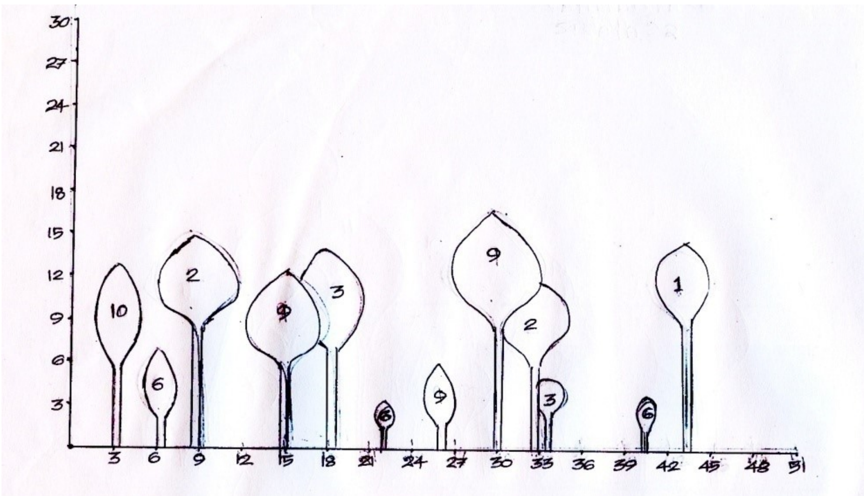
(c)

Fig. 13 Profile diagram for strata 3 of Manamangalam (a) strata 1, (b) strata 2 and (c) strata 3.

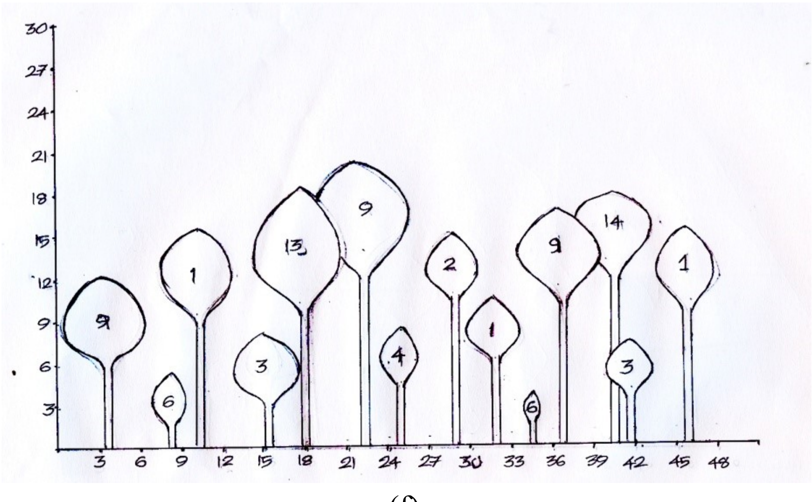
1 - *Tectona grandis,* 2 - *Terminalia paniculata,* 3 - *Macaranga peltata,* 4 –*Bombax ceiba,* 5 – *Holarrhena pubescens,* 6 – *Wrightia tinctoria,* 7 – *Strychnos nux-vomica,* 8 - *Cleistanthus collinus,* 9 - *Xylia xylocarpa,* 10 - *Dillenia pentagyna,* 11 - *Lannea coromandelica,*12 - *Alstonia scholaris,* 13 - *Terminalia bellirica,* 14 - *Lagerstroemia lanceolata,* 15 - *Careya arborea,* 16 - *Dalbergia latifolia,* 17 - *Grewia tiliifolia*



(d)



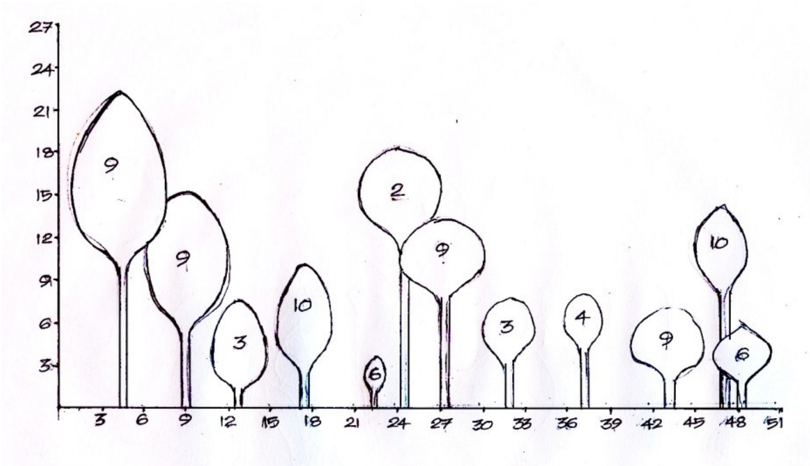
(e)



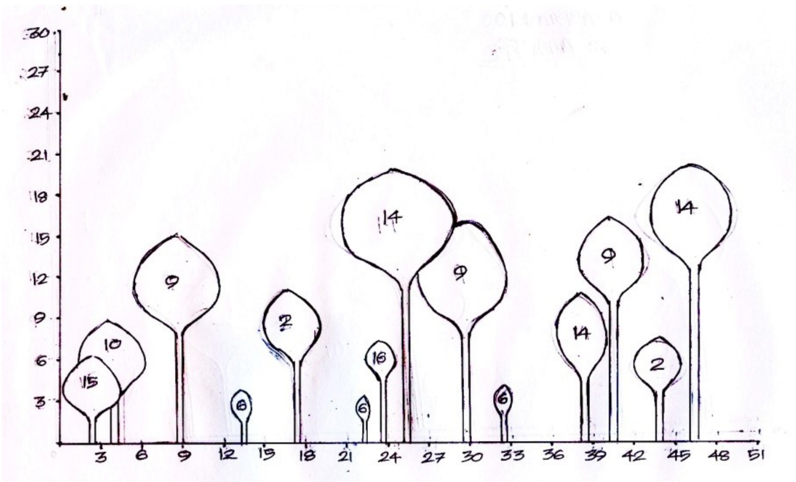
(f)

Fig.13. Profile diagram for strata 3 of Vaniyampara (d) strata 1, (e) strata 2 and (f) strata 3.

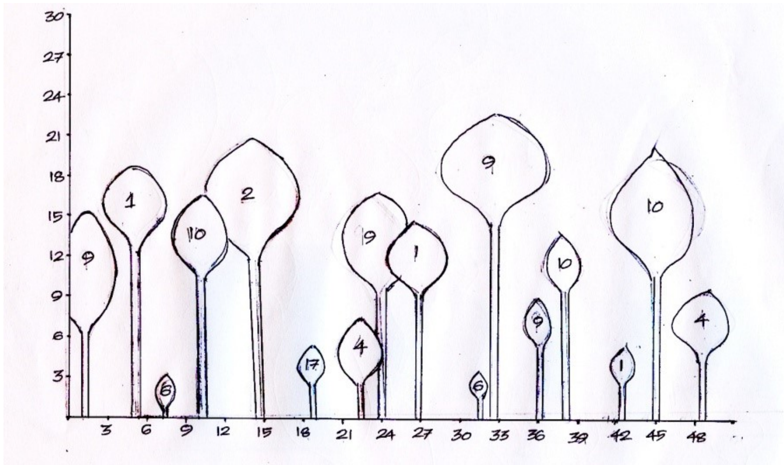
1 - *Tectona grandis,* 2 - *Terminalia paniculata,* 3 - *Macaranga peltata,* 4 –*Bombax ceiba,* 5 – *Holarrhena pubescens,* 6 – *Wrightia tinctoria,* 7 – *Strychnos nux-vomica,* 8 - *Cleistanthus collinus,* 9 - *Xylia xylocarpa,* 10 - *Dillenia pentagyna,* 11 - *Lannea coromandelica,*12 - *Alstonia scholaris,* 13 - *Terminalia bellirica,* 14 - *Lagerstroemia lanceolata,* 15 - *Careya arborea,* 16 - *Dalbergia latifolia,* 17 - *Grewia tiliifolia*



(g)



(h)



(i)

Fig.13. Profile diagram for strata 3 of Ollakkara (g) strata 1, (h) strata 2 and (i) strata 3.

1 - *Tectona grandis,* 2 - *Terminalia paniculata,* 3 - *Macaranga peltata,* 4 –*Bombax ceiba,* 5 – *Holarrhena pubescens,* 6 – *Wrightia tinctoria,* 7 – *Strychnos nux-vomica,* 8 - *Cleistanthus collinus,* 9 - *Xylia xylocarpa,* 10 - *Dillenia pentagyna,* 11 - *Lannea coromandelica,*12 - *Alstonia scholaris,* 13 - *Terminalia bellirica,* 14 - *Lagerstroemia lanceolata,* 15 - *Careya arborea,* 16 - *Dalbergia latifolia,* 17 - *Grewia tiliifolia*

pubescens (2.43) and *Tectona grandis* (2.4). Thirteen species had an abundance value of one (Table 8).

Seven out of the 62 species represented 75 % of saplings in P-V WLS. The highest relative density is recorded by the saplings of *Xylia xylocarpa* (23 %), it was followed by *Wrightia tinctoria* (17.7 %), *Macaranga peltata* (13.2 %), *Holarrhena pubescens* (8.6 %), *Tectona grandis* (6.1 %) and *Schleichera oleosa* (3.3 %).

4.1.2.1. Species composition of tree saplings at Manamangalam.

In strata 1 a total of 57 saplings belonging to 15 species were recorded. The highest abundance was recorded for *Tectona grandis* (5), which was followed by *Wrightia tinctoria* (4), *Holarrhena pubescens* (3.5) and *Macaranga peltata* (3.5). The highest relative density was for *Holarrhena pubescens* and *Macaranga peltata* (24.6 %), followed by *Wrightia tinctoria* (14 %), *Tectona grandis* (8.8 %) and *Bombax ceiba* (7 %). More than 75 % saplings were of these 5 tree species in this stratum.

In strata 2, a total of 77 saplings belonging to 13 species were recorded, with *Xylia xylocarpa* (5.5) as the most abundant followed by *Schleichera oleosa* (5), *Macaranga peltata* (4.7) and *Wrightia tinctoria* (4.7). More than 75 % of the saplings in this stratum was made up of four tree species, with the highest being *Xylia xylocarpa* (28.6 %); followed by *Macaranga peltata* (18.2 %), *Wrightia tinctoria* (18.2 %) and *Schleichera oleosa* (13 %).

In strata 3, 53 saplings belonging to 11 species was recorded. The highest abundance in this stratum for saplings was that of *Cleistanthus collinus* (3) and *Xylia xylocarpa* (3). It was followed by *Holarrhena pubescens* (2.7) and *Zizyphus xylopyrus* (2.3). About 80 % of the saplings present belong to 5 species, with the highest density for *Xylia xylocarpa* (22.6 %), followed by *Wrightia tinctoria* (17 %), *Holarrhena pubescens* (15 %), *Zizyphus xylopyrus* (13.2 %) and *Tectona grandis* (11.3 %).

Table 8 Relative density (RD%) and abundance (A) for saplings of tree saplings (<10 cm GBH and > 100cm height) in P-V WLS.

Sl. No	Species	Manamangalam						Vaniyampara						Ollakkara					
		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3	
		RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A
1	*Albizia lebbeck*													6.06	2.00				
2	*Anogeissus latifolia*															1	3.00		
3	*Bombax ceiba*	7.02	1.33					5.26	0.50										
4	*Briedelia retusa*			1.30	1.00	3.77	2.00			2.17	1.00								
5	*Careya arborea*	1.75	1.00	2.60	2.00													4.17	1.00
6	*Cassia fistula*	1.75	1.00			1.89	1.00					3.57	1.00			3.33	1.00		
7	*Cleistanthus collinus*	3.51	2.00	1.30	1.00	5.66	3.00												
8	*Dalbergia latifolia*	1.75	1.00	2.60	2.00							1.79	1.00	3.03	1.00				
9	*Dillenia pentagyna*			1.30	1.00	3.77	2.00	5.26	1.00	2.17	1.00	1.79	1.00	3.03	1.00			4.17	1.00
10	*Grewia tiliifolia*											5.36	1.00	3.03				4.17	1.00
11	*Holarrhena pubescens*	24.56	3.50	7.79	2.00	15.09	2.67	5.26	1.00	2.17	1.00			12.12	2.00				
12	*Lagerstroemia lanceolata*											3.57	1.00						
13	*Lannea coromandelica*					3.77	2.00					1.79	1.00						
14	*Macaranga peltata*	24.56	3.50	18.18	4.67			26.32	1.67	15.22	2.33	12.50	1.75	12.12	2.00	3.33	1.00		
15	*Mallotus philippensis*									2.17	1.00	3.57	1.00					12.50	1.50
16	*Melia dubia*									2.17	1.00								
17	*Morinda pubescens*									2.17	1.00								
18	*Olea dioica*									19.57	2.25					3.33	1.00		
19	*Polyalthia fragrans*																	4.17	1.00
20	*Pterospermum reticulatum*							5.26	1.00	2.17	1.00								

Sl. No	Species	Manamangalam						Vaniyampara						Ollakkara					
		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3	
		RD	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**
21	*Schleichera oleosa*			12.99	5.00							3.57	0.67					4.17	1.00
22	*Spondias pinnata*			2.60	1.00														
23	*Stereospermum chelonoides*			1.30	1.00														
24	*Strychnos nux-vomica*	1.75	1.00	1.30	1.00											6.67	1.00	4.17	1.00
25	*Tabernaemontana heyneana*							15.79	1.00	4.35	1.00							4.17	1.00
26	*Tectona grandis*	8.77	5.00			11.32	2.00			4.35	2.00	16.07	2.25	6.06	2.00				
27	*Terminalia bellirica*	1.75	1.00									8.93	1.25						
28	*Terminalia elliptica*	1.75	1.00																
29	*Terminalia paniculata*	3.51	2.00			1.89	1.00					5.36	1.50					8.33	1.00
30	*Wrightia tinctoria*	14.04	4.00	18.18	4.67	16.98	2.25			15.22	1.75	17.86		15.15	1.67	5	3.75	8.33	2.00
31	*Xylia xylocarpa*	1.75	1.00	28.57	5.50	22.64	3.00	36.84	2.33	26.09	3.00	14.29	2.67	39.39	3.25	23.33	3.50	41.67	2.50
32	*Zizyphus xylopyrus*	1.75	1.00			13.21	2.33												

4.1.2.2. Species composition of tree saplings in Vaniyampara (tree saplings- <10 cm GBH and > 100 cm height).

In strata 1, a total of 19 saplings belonging to seven species were recorded. The highest abundance was recorded for *Xylia xylocarpa* (2.33), which was followed by *Macaranga peltata*(1.7), *Dillenia pentagyna* (1), *Holarrhena pubescens* (1) etc. The highest relative density was recorded for *Xylia xylocarpa* (36.8 %), followed by *Macaranga peltata* (26.3 %), *Tabernaemontana heyneana* (15.8 %), *Bombax ceiba* (5.3 %) etc. More than 75 % saplings density was accounted by just three species.

In strata 2, a total of 46 saplings belonging to 13 species were recorded with, the most abundant was *Xylia xylocarpa* (3), followed by *Macaranga peltata* (2.3), *Olea dioica* (2.3) and *Tectona grandis* (2). More than 75 % of the saplings density were made of four tree species, *Xylia xylocarpa* (26.1 %); *Olea dioica* (19.6 %), *Macaranga peltata* (15.2 %) and *Wrightia tinctoria* (15.2 %).

In strata 3, a total of 56 saplings belonging to 14 species were present. The highest abundance in this stratum for saplings was that of *Xylia xylocarpa*(2.7), followed by *Tectona grandis*(2.3), *Macaranga peltata* (1.8), *Terminalia paniculata* (1.5) and *Terminalia bellirica* (1.3). Seventy five percent of the saplings present belong to six species, with the highest density for *Wrightia tinctoria* (17.9 %), followed by *Tectona grandis*(16 %), *Xylia xylocarpa*(14.3 %), *Macaranga peltata* (12 %), *Terminalia bellirica* (8.9 %) and *Grewia tiliifolia* (5.4 %).

4.1.2.3. Species composition of tree saplings in Ollakkara (tree saplings- <10 cm GBH and > 100 cm height).

In strata 1, 33 saplings belonging to eight species were present. The highest abundance was recorded for *Xylia xylocarpa* (3.25), which was followed by *Albizia lebbeck* (2), *Holarrhena pubescens* (2) and *Macaranga peltata* (2). Among the eight species in this strata the highest relative density was for *Xylia xylocarpa* (39.4 %), followed by *Wrightia tinctoria* (15.2 %), *Holarrhena pubescens* (12 %) and *Macaranga peltata* (12 %). More than 75 % saplings present were of these four species.

In strata 2, 30 saplings represented six species; with the most abundant being *Wrightia tinctoria* (3.75), followed by *Xylia xylocarpa* (3.5), *Anogeissus latifolia* (3) and *Cassia fistula* (1). More than 80 % of the saplings were by three tree species, with the highest by *Wrightia tinctoria* (50 %); followed by *Xylia xylocarpa* (23.3 %) and *Anogeissus latifolia* (10 %).

In strata 3, 24 saplings were recorded which belonged to 11 species. The highest abundance in this strata was for *Xylia xylocarpa*(2.5), followed by *Wrightia tinctoria* (2), *Mallotus philippensis* (1.5), *Careya arborea* (1), *Dillenia pentagyna* (1) etc. About 75 % of the saplings present belong to five species, with the highest density for *Xylia xylocarpa* (41.7 %), followed by *Mallotus philippensis* (12.5 %), *Terminalia paniculata* (8.3 %), *Wrightia tinctoria* (8.3 %) and *Careya arborea* (4.2 %).

4.1.3. Species composition of regeneration (<10 cm GBH and < 100 cm height) in the study area.

Regeneration in all three locations of P-V WLS together was represented by 885 regenerations belonging to 34 species (Table 9). The most abundant of it was *Xylia xylocarpa*(7.4), *Wrightia tinctoria* (6.8), *Holarrhena pubescens* (6.5), *Macaranga peltata* (5.9), *Dalbergia latifolia* (4.8), *Grewia tiliifolia* (4.6) and *Cleistanthus collinus* (4). The density of seven species together comprised 75 % of that of all the regenerations present.

4.1.3.1. Species composition of tree regeneration in Manamangalam (tree regeneration = <10 cm GBH and < 100 cm height).

In strata 1, regenerations were accounted to 14 species and were represented by 199 seedlings. Of which the most abundant regeneration is that of *Macaranga peltata* (13), followed by *Grewia tiliifolia* (12.5), *Holarrhena pubescens* (9.25), *Wrightia tinctoria* (8.5) and *Careya arborea* (6.5). About 75 % of the total regeneration present was accounted to four tree species. The highest relative density is for *Macaranga peltata* (26 %), followed by *Holarrhena pubescens* (19 %), *Wrightia tinctoria* (17 %) and *Grewia tiliifolia* (13 %).

Table 9 Relative density (RD %) and abundance (A) for regenerations of tree species (<10 cm GBH and <100 cm height) at P-V WLS.

Sl. No	Species	Manamangalam						Vaniyampara						Ollakkara					
		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3	
		RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A
1	*Albizia odoratissima*											0.96	1.0						
2	*Bixa orolina*			0.39	1.0					2.78	1.0								
3	*Bombax ceiba*	3.52	2.3											7.32	1.5	3.57	1.0		
4	*Briedelia retusa*					3.81	2.0					0.96	1.0						
5	*Callicarpa tomentosa*	1.01	1.0	0.39	1.0														
6	*Careya arborea*	6.53	6.5			4.76	5.0					0.96	1.0			3.57	1.0	4.76	1.0
7	*Cassia fistula*			0.39	1.0					1.39	1.0	2.88	3.0			3.57	1.0	7.14	1.5
8	*Cleistanthus collinus*	3.52	3.5	2.33	6.0	2.86	3.0												
9	*Dalbergia latifolia*	2.51	5.0	5.04	6.5	1.9	2.0					3.85	4.0						
10	*Dillenia pentagyna*					1.9	2.0			2.78	1.0			7.32	3.0			2.38	1.0
11	*Grewia tiliifolia*	12.56	12.5									3.85	2.0	2.44	1.0	3.57	1.0	2.38	1.0
12	*Holarrhena pubescens*	18.59	9.25	4.65	12.0	13.3	4.67	8.3	3.0	6.94	2.5								
13	*Lagerstroemia lanceolata*			1.16	3.0											3.57	1.0	2.38	1.0
14	*Lannea coromandelica*					4.76	5.0			1.39	1.0								
15	*Macaranga peltata*	26.13	13.0	12.79	8.25			44.4	4.0	25.0	4.5	6.73	2.33	12.20	1.67			9.52	4.0
16	*Mallotus philippensis*									4.17	1.5	4.81	2.5			3.57		4.76	1.0
17	*Olea dioica*									4.17	3.0	11.54	3.0					2.38	1.0
18	*Phyllanthus emblica*															3.57	1.0		
19	*Polyalthia fragrans*											0.96	1.0						
20	*Pterospermum reticulatum*											2.88	3.0						
21	*Schleichera oleosa*			6.20	8.0							7.69	4.0			21.43	1.0	2.38	1.0
22	*Spondias pinnata*			0.39	1.0														

Sl. No	Species	Manamangalam						Vaniyampara						Ollakkara					
		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3	
		RD	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**	**RD**	**A**
23	*Stereospermum*			1.16	3.0														
24	*Stereospermum colais*															10.71	1.0		
25	*Syzygium cuminii*	0.5	1.0	1.16	1.5														
26	*Tabernaemontana*							19.4	2.33	6.94	2.5	2.88	3.0					19.1	2.67
27	*Tectona grandis*	1.51	3.0			11.4	4.0			2.78	2.0	11.54	6.0	26.83	5.5	17.86	1.67	2.38	1.0
28	*Terminalia bellirica*	1.01	2.0	0.78	2.0					2.78	1.0	3.85	2.0						
29	*Terminalia paniculata*	1.51	3.0			7.6	4.0			4.17	1.5	6.73	2.33			3.57	1.0	4.76	1.0
30	*Tetrameles nudiflora*									1.39	1.0	0.96	1.0						
31	*Trewia nudiflora*											0.96	1.0						
32	*Wrightia tinctoria*	17.09	8.5	29.84	25.7	10.5	3.67	8.3	1.5	16.67	3.0	8.65	2.25			17.86	5.0	11.9	2.5
33	*Xylia xylocarpa*	4.02	4.0	33.33	21.5	30.5	8.0	19.4	2.33	16.67	4.0	16.35	5.67	43.90	6.0	3.57	1.0	23.8	3.33
34	*Zizyphus xylopyrus*					6.67	3.5												

In strata 2 a total of 258 regenerations were observed, belonging to 15 species, of which the highest abundance was for *Wrightia tinctoria* (25.7), *Xylia xylocarpa*(21.5), *Holarrhena pubescens* (12), *Macaranga peltata* (8.25), *Schleichera oleosa* (8) and *Dalbergia latifolia* (6.5). The most of the regeneration (75 %) account to three species which include *Xylia xylocarpa*(33 %), *Wrightia tinctoria* (30 %) and *Macaranga peltata* (13 %).

In strata 3, a total of 105 regenerations were observed for 12 species. The highest abundance was for *Xylia xylocarpa*(8), followed by *Careya arborea* (5), *Lannea coromandelica* (5), *Holarrhena pubescens* (4.7) and *Tectona grandis* (4). About 73 % of the total regeneration belonged to five tree species, with the highest relative density for *Xylia xylocarpa*(30 %), followed by *Holarrhena pubescens* (13 %), *Tectona grandis* (11 %), *Wrightia tinctoria* (10 %) and *Terminalia paniculata* (8 %).

4.1.3.2. Species composition of tree regeneration in Vaniyampara (tree regeneration = <10 cm GBH and < 100 cm height).

In strata 1, a total of 36 regenerations belonging to just five species were observed, of which the most abundant regeneration is that of *Macaranga peltata* (4), followed by *Holarrhena pubescens* (3), *Tabernaemontana heyneana* (2.3), *Wrightia tinctoria* (2.3) and *Xylia xylocarpa*(1.5). The highest relative density is for *Macaranga peltata* (44 %), followed by *Tabernaemontana heyneana* (19 %), *Xylia xylocarpa*(19 %), *Holarrhena pubescens* (8 %) and *Wrightia tinctoria* (8 %).

In strata 2, 15 species representing 72 individuals were observed of which the highest abundance was for *Macaranga peltata* (4.5),*Xylia xylocarpa*(4), *Olea dioica* (3), *Wrightia tinctoria* (3), *Holarrhena pubescens* (2.5), *Tabernaemontana heyneana* (2.5) etc. The most regeneration in this stratum (76 %) was accounted for six species which include *Macaranga peltata* (25 %), *Wrightia tinctoria* (17 %), *Xylia xylocarpa*(17 %), *Holarrhena pubescens* (7 %), *Tabernaemontana heyneana* (7 %) and *Mallotus philippensis* (4 %).

In strata 3, 104 regenerations belonging to 20 species were observed. The highest abundance was for *Tectona grandis* (6), followed by *Xylia xylocarpa*(5.7), *Dalbergia* *latifolia* (4), *Schleichera oleosa* (4), *Cassia fistula* (3) and *Olea dioica* (2). In this stratum *Xylia xylocarpa*(16 %) accounted for the highest relative density followed by *Olea dioica* (12 %), *Tectona grandis* (12 %), *Wrightia tinctoria* (9 %), *Schleichera oleosa* (8 %) and *Macaranga peltata* (7 %).

4.1.3.3. Species composition of tree regeneration in Ollakkara (tree regeneration = <10 cm GBH and < 100 cm height).

In strata 1, regenerations were recorded for six species, with 41 individuals, of which the most abundant was *Xylia xylocarpa*(13), followed by *Tectona grandis* (12.5), *Dillenia pentagyna* (9.25), *Macaranga peltata* (8.5), *Bombax ceiba* (6.5) and *Grewia tiliifolia* (1). Of the six tree species present, the highest relative density was for *Xylia xylocarpa* (44 %), followed by *Tectona grandis*(27 %), *Macaranga peltata*(12 %), *Bombax ceiba* (7 %), *Dillenia pentagyna* (7 %) and *Grewia tiliifolia* (2 %).

In strata 2, of the 28 regeneration belonging to ten species recorded, the highest abundance was for *Wrightia tinctoria* (5), followed by *Tectona grandis* (1.7), *Bombax ceiba* (1), *Careya arborea* (1) and *Cassia fistula* (1). The most regeneration (about 70 %) was accounted for five species which include *Schleichera oleosa* (21 %), *Tectona grandis* (18 %), *Wrightia tinctoria* (18 %), *Stereospermum colais* (11 %) and *Bombax ceiba* (13 %).

In strata 3, 42 regenerations belonging to 14 tree species were observed. The highest abundance was for *Macaranga peltata*(4) followed by *Xylia xylocarpa*(3.3), *Tabernaemontana heyneana* (2.7), *Wrightia tinctoria* (2.5), *Cassia fistula*(1.5) and *Careya arborea* (1). About 70 % of the total regeneration belonged to five tree species, with the highest relative density for *Xylia xylocarpa*(24 %), followed by *Tabernaemontana heyneana* (19 %), *Wrightia tinctoria* (12 %), *Macaranga peltata*(10 %) and *Cassia fistula* (7 %).

4.1.4. Species composition of Undergrowth (Herbs and Shrubs) in P-V WLS.

From about an area of 14,400 m^2 (400 m^2 × 36 sample plots) under the sub plots, a total of 2022 herbs and shrubs belonging to 41 species were observed in the course of study from P-V WLS (Table 10). The herbs and shrubs varied with distance from habitation.

4. 1.4.1. Species composition of undergrowth (herbs and shrubs) of Manamangalam.

A total of 33 species in strata 1, 32 species in strata 2, and 24 species in strata 3 of herbs and shrubs were found in Manamangalam. *Costus speciosa* had the highest relative density in strata 1 and strata 2 of Manamangalam with 12 % and 11 % respectively of all the herbs and shrubs. In strata 3, the highest densitywas for *Caesalpinia mimosoides* (13 %). In strata 1, other species with higher densities include *Caesalpinia mimosoides* (11 %), *Mussaenda glabrata* (9 %) and *Leucas aspera* (6 %). In strata 2, other species with higher density included *Leucas aspera* (11 %) and *Caesalpinia mimosoides* (8 %). In strata 3, *Caesalpinia mimosoides* and *Gloriosa superba* (13 %) is followed by *Phaulopsis imbricate* (10 %), *Naregamia alata* and *Costus speciosa* (8 %).

In strata 1, the highest abundance was for *Leucas aspera* (6), which was followed by *Caesalpinia mimosoides* (5.2), *Tridax procumbens* (5) and *Costus speciosa*(4.9). In strata 2, *Phaulopsis imbricate* (5.3) was the most abundant undergrowth followed by *Costus speciosa*(5) and *Leucas aspera* (5). In strata 3, *Costus speciosa*(4.9) was the most abundant undergrowth followed by *Gloriosa superba* (5) and *Naregamia alata* (4).

4.1.4.2. Species composition of undergrowth (herbs and shrubs) of Vaniyampara.

The herbs and shrubs in strata 1 was represented by 27 species, strata 2 and strata 3 by 29 species of herbs and shrubs. In strata 1, the highest density was for *Caesalpinia mimosoides* (24 %), followed by *Mussaenda glabrata* (7 %) and *Costus speciosa*(7 %). In strata 2, also *Caesalpinia mimosoides* (18 %) had the highest density, which was followed by *Rhodomyrtus tomentosa* (8 %) and *Glycosmis pentaphylla* (8 %). In strata 3, highest density was for *Gloriosa superba* (16 %), which was followed by *Caesalpinia mimosoides* (14 %), *Glycosmis pentaphylla* (10 %) and *Dioscorea bulbifera*(7%).

Table. 10. Relative density (RD %) and abundance (A) of all under growth (herbs and shrubs) in P-V WLS.

Sl. No	Species	Manamangalam						Vaniyampara						Ollakkara					
		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3	
		RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A
1	*Asparagus racemosa*	1.02	3.00	1.10	1.00									0.37	1.00				
2	*Abrus precatorius*	0.34	1.00	1.83	2.50	2.02	2.00							0.37	1.00	1.63	1.50		
3	*Ageratum conyzoides*							0.52	1.00	1.18	2.00	0.86	2.00						
4	*Biophytum sensitivum*									0.59	1.00	2.58	2.00	0.37	1.00	1.09	1.00	2.91	2.00
5	*Caesalpinia mimosoides*	10.58	5.17	8.42	3.83	12.63	3.13	23.71	5.75	18.24	3.88	14.16	4.13	8.49	2.56	5.98	2.75	5.83	1.71
6	*Clerodendrum infortunatum*	0.68	2.00	0.73	1.00	4.04	1.60	0.52	1.00	1.76	1.50	2.15	1.67	1.11	1.00	4.35	1.60	3.88	2.00
7	*Commelina paludosa*	0.68	1.00	2.93	4.00	3.03	2.00	0.52	1.00	2.94	1.67	1.72	4.00	12.92	5.00	1.63	1.50	2.43	1.67
8	*Costus speciosa*	11.60	4.86	10.99	5.00	7.58	5.00	6.70	3.25	6.47	3.67			11.07	6.00	10.87	3.33	16.50	6.80
9	*Curculigo orchioides*							0.52	1.00			6.87	2.67						
10	*Cyclea peltata*	1.71	1.67	3.30	3.00			6.19	3.00	4.71	2.67	6.01	4.67	3.69	2.50	1.63	1.50	3.88	2.67
11	*Desmodium triflorum*									0.59	1.00			0.74	2.00	2.72	2.50		
12	*Dioscorea bulbifera*	1.02	3.00	0.73	2.00			1.55	1.50	5.88	2.50	7.30	2.13	0.74	2.00	7.07	4.33	1.94	4.00
13	*Eranthemum capense*	1.02	1.50			1.01	2.00	2.06	1.33	2.35	2.00	0.43	1.00	1.48	1.33	2.17	1.33	1.94	2.00
14	*Gloriosa superba*	1.71	2.50	5.13	2.80	12.63	5.00	5.67	2.75	4.71	1.60	16.31	5.43			10.87	2.86	10.68	4.40
15	*Glycosmis pentaphylla*	3.75	2.75	5.49	3.75	6.06	2.40	6.19	2.00	7.65	2.17	10.30	3.43	2.95	2.67	6.52	4.00	6.31	3.25
16	*Hemidesmus indicus*	3.41	2.00	1.83	1.67			4.64	1.80	3.53	2.00			0.74	1.00	1.63	1.50		
17	*Hyptis suaveolens*									1.76	1.50	0.86	1.00						
18	*Ichnocarpus frutescens*	1.02	1.50			2.02	2.00												
19	*Impatiens spp*	2.39	1.00	1.83	1.67	3.54	1.75	5.15	2.50	2.35	4.00	1.72	1.33	1.11	1.50			2.91	2.00
20	*Leea indica*	1.02	1.50					4.64	4.50			2.58	3.00	2.95	2.67				

Sl. No	Species	Manamangalam						Vaniyampara						Ollakkara					
		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3		Strata 1		Strata 2		Strata 3	
		RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A	RD	A
21	*Leucas aspera*	6.14	6.00	10.99	5.00													11.17	5.75
22	*Maranta arundinacea*	5.80	3.40	1.10	3.00	4.55	3.00	1.55	3.00	1.18	2.00	1.29	3.00	4.06	3.67	1.09	2.00	1.46	3.00
23	*Mimosa pudica*	0.68	1.00	0.37	1.00			0.52	1.00										
24	*Mussaenda glabrata*	9.22	2.70	4.76	3.25	4.04	2.00	7.22	1.75	4.71	2.00	3.43	2.67	6.27	1.89	2.72	1.25	4.37	3.00
25	*Naregamia alata*	2.39	2.33	5.49	3.00	8.08	4.00	0.52	1.00	2.35	4.00	0.43	1.00	2.58	2.33	5.43	2.50	7.77	2.29
26	*Naringi crenulata*	2.39	3.50	0.73	2.00	0.51	1.00							0.74	1.00	0.54	1.00		
27	*Peperomia reflexa*	1.71	1.67	1.10	1.00			2.06	1.33	1.76	1.50	0.43	1.00	2.95	1.60	2.72	1.67	0.49	1.00
28	*Phaulopsis imbricata*	5.12	2.50	5.86	5.33	9.60	3.17	3.09	2.00	1.76	1.00	1.72	2.00	4.06	2.75	2.72	1.67	4.37	1.80
29	*Piper longum*	0.68	1.00	0.37	1.00	2.53	2.50			2.94	1.67	2.58	2.00	0.74	2.00			1.46	1.50
30	*Rauvolfia serpentina*	0.68	2.00	3.30	2.25	4.55	1.80			4.12	3.50	2.58	2.00	2.21	3.00	2.17	2.00	0.97	2.00
31	*Rauvolfia tetraphylla*			1.10	1.50	2.02	2.00									0.54	1.00	0.97	1.00
32	*Rhodomyrtus tomentosa*	2.39	2.33	4.76	4.33	4.04	4.00	1.55	1.50	8.24	3.50	0.43	1.00	4.06	3.67	3.80	3.50	1.46	3.00
33	*Sida rhombifolia*	4.44	3.25	4.76	2.60	0.51	1.00	4.64	3.00	1.76	1.50	1.29	1.50	7.75	3.00	4.35	1.33	0.97	2.00
34	*Synedrella nodiflora*	3.41	1.43	1.47	2.00			2.06	1.33			0.43	1.00	3.69	2.00	3.80	1.75		
35	*Teramnus labialis*	1.02	1.00	2.20	1.50	0.51	1.00	1.03	2.00	1.18	2.00	1.72	1.33	1.11	1.50				
36	*Thylophora indica*													0.70	2.00				
37	*Tridax procumbens*	3.41	5.00	1.47	4.00					2.35	4.00	1.72	4.00	1.48	4.00				
38	*Urena lobata*	2.73	2.00	0.37	1.00			0.52	1.00			1.72	2.00	1.85	1.67	2.72	2.50		
39	*Vitex negundo*			0.73	2.00	1.52	3.00			0.59	1.00					2.17	1.33		
40	*Ziziphus oenoplia*	5.46	2.29	3.66	2.50	1.52	1.50	5.15	2.00	0.59	1.00	4.72	3.67	5.54	3.00	4.89	2.25	2.91	2.00
41	*Ziziphus trinerva*	0.34	1.00	1.10	1.50	1.52	1.50	1.55	1.00	1.76	1.00	1.72	1.00	1.85	1.25	2.17	1.33	2.43	1.00

The highest abundance in strata 1 was for *Caesalpinia mimosoides* (5.8), *Leea indica* (4.5), *Costus speciosa* (3.3), *Cyclea peltata* (3) etc. In strata 2, the abundance of herbs and shrubs in decreasing order was *Impatiens spp.* (4), *Naregamia alata*(4), *Tridax procumbens* (4),*Caesalpinia mimosoides* (3.9) and *Costus speciosa* (3.6). In strata 3, *Gloriosa superba* (5.4) recorded the highest abundance, followed by *Cyclea peltata* (4.7), *Caesalpinia mimosoides* (4.1) and *Commelina paludosa*(4).

4.1.4.3. Species composition of undergrowth (herbs and shrubs) of Ollakkara.

In strata 1, the relative density of species in decreasing order was as follows with the highest for *Commelina paludosa*(13 %), *Costus speciosa* (11 %), *Caesalpinia mimosoides* (8 %), *Sida rhombifolia* (8 %) and *Mussaenda glabrata* (6 %). In strata 2, the highest relative density was recorded for *Costus speciosa* and *Gloriosa superba* (11 %), which was followed by *Dioscorea bulbifera* (7 %), *Glycosmis pentaphylla* (7 %) and *Caesalpinia mimosoides* (7 %). In strata 3, the highest relative density was for *Costus speciosa* (17 %), followed by *Leucas aspera* (11 %), *Gloriosa superba* (11 %) and *Naregamia alata* (8 %).

In strata 1, the highest abundancewas recorded for *Costus speciosa* (6) which was followed by *Commelina paludosa*(5), *Tridax procumbens* (4) and*Maranta arundinacea* (3.7). In strata 2, *Dioscorea bulbifera* (4.3) had the highest abundance, which was followed by *Glycosmis pentaphylla* (4), *Rhodomyrtus tomentosa* (3.5), *Costus speciosa* (3.3) etc. In strata 3, species with higher abundance were *Costus speciosa* (6.8), *Leucas aspera* (5.8), *Gloriosa superba* (4.4), *Dioscorea bulbifera* (4) and *Glycosmis pentaphylla* (3.3).

4. 1.5. Other species that was recorded from the study area

4.1.5.1. Helicteres isora

A total of 171 individuals of *Helicteres isora* was recorded from Manamangalam; of which 73 was from strata 1, 58 from strata 2 and 40 from strata 3. At Vaniyampara, a total of 187 individuals of *Helicteres isora* was recorded; with 58 individuals from strata 1, 63 from strata 2 and 68 from strata 3. In Ollakkara, a total of 140 individuals of *Helicteres isora* was observed; with 45, 54 and 41 individuals representing strata 1, 2 and 3 respectively.

4.1.5.2. Liana's

A total of 151 lianas belonging to four liana species were recorded from P-V WLS in this study. These include *Acacia insia*, *Butea parviflora*, *Calycopteris floribunda* and *Entada rheedei*. In Manamangalam, 62 lianas, belonging to all the four species, were recorded in which the highest relative density and abundance corresponds to *Acacia insia* (74 % and 5.11 respectively). *Butea parviflora* comes second in relative density and abundance with 17.7 % and 1.83 respectively. In Vaniyampara, a total of 53 lianas also belonging to four species were recorded. The highest density and abundance was for *Acacia insia* with 80.5 % and 4.14 respectively. *Calycopteris floribunda* recorded the second highest RD and abundance with 27.8 % and 2.5 respectively. In Ollakkara, a total of 36 liana's belonging to 3 species were recorded with highest relative density and abundance for *Acacia insia* with 77.4 % and 4.6 respectively.

In all the strata's, *Acacia insia*constituted the highest relative density. *Butea parviflora* was second in relative densityin strata 1 and 3 of Manamangalam, strata 3 of Vaniyampara and Ollakkara. *Calycopteris floribunda*occupied the second position in strata 2 of Manamangalam, strata1 of Vaniyampara and, strata 2 and 3 of Ollakkara.

4.1.5.3. Invasive species

A total of 3 invasive/ exotic species were observed in the sanctuary. The invasive species include *Chromolaena odorata*, *Lantana camara* and *Mikania micrantha*. *Chromolaena odorata* was recorded from all the strata's and with highest relative density and abundance. *Lantana camara* was absent in the strata 3 of Manamangalam, strata 3 of Vaniyampara and the three strata's of Ollakkara. *Mikania micrantha* was absent in the strata 2 and 3 of all the study sites.

4.1.6 Canopy gap area of the study area

The canopy gap area in the forests varied with location and strata (Table 11). Statistically, the canopy gap area for the locations of Manamangalam and Ollakkara, with 142.25 ±75.5 m^2 and 160.7 ± 45.3 m^2, was significantly different from that at Vaniyampara (202 ± 95.1 m^2).

When comparing the strata's in all the three locations, the three strata's were statistically different with each other with strata 1 with 229.8 ± 67.9 m^2, strata 2 with 180.4 ± 55.8 m^2 and strata 3 with 94.8 ± 30.8 m^2. In Manamangalam, there was a decrease in canopy gap area with 209.56 ± 69.74 $m^2$for strata 1, 154.69 ± 24.14 $m^2$for strata 2 and 62.5 ± 27 $m^2$for strata 3with a mean of 142.25 ± 75.5 m^2. In Vaniyampara the canopy gap area for strata 1, 2 and 3 were 291.31 ± 44.9m^2,211.56 ± 83.87$m^2$and 103.13 ± 18.44m^2respectively with a mean of 202 ± 95.13 m^2. In Ollakkara, the canopy gap area for strata 1, 2 and 3 were 188.44 ± 46.45m^2, 175 ± 39.86m^2 and 118.75 ± 11.46m^2 with a mean of 160.73 ± 45.29 m^2. The analysis of variance showed that the canopy gap area decreased significantly with stratum, strata 1 (229.77 ± 67.91 m^2) was different from strata 2 (180.42 ± 55.81 m^2) which were again different from strata 3 (94.79 ± 30.67 m^2).

4.1.7. Leaf area index (LAI)

The LAI in the entire P-V WLS varied with location and strata (Table 11). The LAI for the locations of Vaniyampara (0.88 ± 0.33) and Ollakkara (1.03 ± 0.36) is statistically different from that of Manamangalam with 1.28 ± 0.39.

When comparing the three strata's at all the locations, strata 1 (0.86 ± 0.25) and strata 2 (0.91 ± 0.32) were statistically similar, but is different from that of strata 3 (1.43 ± 0.32). The canopy gap area increased significantly when moving towards the interior forest strata's and the highest LAI was observed in the strata 3 of all the locations.

Table 11 Location and strata wise canopy gap area (m^2) and Leaf area index (LAI) of the study area

Location	Strata	Canopy gap area (m^2)	LAI
Manamangalam	**Strata 1**	209.56 (69.74)	0.99 (0.24)
	Strata 2	154.69 (24.14)	1.14 (0.26)
	Strata 3	62.5 (27)	1.72 (0.13)
	Total	142.25 (75.5) ^{a}	1.28 (0.39) ^{b}
Vaniyampara	**Strata 1**	291.31 (44.9)	0.80 (0.21)
	Strata 2	211.56 (83.87)	0.61 (0.14)
	Strata 3	103.13 (18.44)	1.23 (0.27)
	Total	202 (95.13) ^{b}	0.88 (0.33) ^{a}
Ollakkara	**Strata 1**	188.44 (46.45)	0.80 (0.3)
	Strata 2	175 (39.86)	0.97 (0.3)
	Strata 3	118.75 (11.46)	1.33 (0.32)
	Total	160.73 (45.29) ^{a}	1.032 (0.36) ^{a}
Overall	**Strata 1**	229.77 (67.91) ^{c}	0.86 (0.25) ^{a}
	Strata 2	180.42 (55.81) ^{b}	0.91 (0.32) ^{a}
	Strata 3	94.79 (30.67) ^{a}	1.43 (0.32) ^{b}
	Total	168.33 (76.96)	1.07 (0.39)

4.1.8. Ramakrishnan index of stand quality (RISQ)

The RISQ value for trees at each location and strata were calculated. The RISQ (trees) for all the study site of Manamangalam was 2.35, which for Vaniyampara and

Ollakkara were 2.27 and 2.40 respectively (Table 12). Based on strata, strata 1, 2 and 3 of Manamangalam had RISQ (trees) values of 2.5, 2.13 and 2.2; that for Vaniyampara were 2.25, 2.25 and 2.3; and for Ollakkara were 2.42, 2.24 and 2.57 respectively (Table 13).

The RISQ values for tree saplings in P-V WLS were also analysed. Considering all the study sites in a location the RISQ for tree saplings, were 2.17 for Manamangalam forest, 2.3 for Vaniyampara and for Ollakkara it was 2.16 (Table 12). Based on strata, the highest RISQ value was for strata 3 of Vaniyampara (2.45). In Manamangalam and Ollakkara, the strata 1 had the highest RISQ for saplings with 2.42 and 2.3 respectively (Table 13).

The RISQ values for tree regenerations were also calculated based on location and strata. Based on location, Ollakkara had the highest RISQ (regeneration) values with 2.27, followed by Manamangalam and Ollakkara with 2.25 and 2.27 respectively. Based on strata, the highest RISQ (regeneration) values were for strata 1 of Ollakkara (2.56) and Manamangalam (2.52). In Vaniyampara, the strata 2 had the highest RISQ for regeneration with 2.31.

Table 12. Ramakrishnan index of stand quality (RISQ) for the three locations of P-V WLS based on trees, saplings and regeneration.

Location	RISQ (Tree)	RISQ (Saplings)	RISQ (Regeneration)
Manamangalam	2.35	2.17	2.25
Vaniyampara	2.27	2.3	2.24
Ollakkara	2.4	2.16	2.27
Total	**2.32 ± 0.14**	**2.2 (0.17)**	**2.25 (0.18)**

Table 13. Ramakrishnan index of stand quality (RISQ) for the strata's of the three locations of P-V WLS based on trees, saplings and regeneration.

Location	Strata	RISQ (Tree)	RISQ (Saplings)	RISQ (Regeneration)
Manamangalam	Strata 1	2.5	2.42	2.52
	Strata 2	2.13	2.07	2.08
	Strata 3	2.2	2.04	2.18
Vaniyampara	Strata 1	2.25	2.21	2.25
	Strata 2	2.25	2.15	2.31
	Strata 3	2.33	2.45	2.18
Ollakkara	Strata 1	2.42	2.3	2.56
	Strata 2	2.24	2.17	2.14
	Strata 3	2.57	1.96	2.07
Overall	**Strata 1**	**2.39 (0.12)**	**2.31 (0.11)**	**2.44 (0.17)** b
	Strata 2	**2.2 (0.07)**	**2.13 (0.06)**	**2.18 (0.12)** a
	Strata 3	**2.37 (0.18)**	**2.15 (0.26)**	**2.15 (0.06)** a

*values with similar subscript do not differ from each other

4.2 Floristic diversity of vegetation of P-V WLS

4.2.1. Floristic diversity of trees (Trees - >10 cm GBH and >100cm height)

The floristic diversity for all the trees in P-V WLS were calculated (Table 14). The Simpson's index and concentration of dominance (Cd) for the trees of Manamangalam and Vaniyampara locations was 0.92 and 0.08. Those for Ollakkara were 0.89 and 0.11. The Shannon- Wiener index, H max and Equitability for Manamangalam was 2.83, 5.46 and 0.52; for Vaniyampara it was 3.11, 5.46 and 0.57 and for Ollakkara it was 2.52, 4.39 and 0.57 respectively. The floristic diversity for trees in each stratum was analysed (Table 15).

Strata 1 of Manamangalam had a Simpson's index of 0.89 and Cd 0.11, for Vaniyampara it was 0.90 and 0.10 and in Ollakkara it was 0.86 and 0.14. The Shannon

Wiener index,H max and Equitability for strata 1 in Manamangalam was 2.58, 5.21 and 0.50; for Vaniyampara it was 2.9, 5.09 and 0.57 and for Ollakkara it was 2.28, 3.91 and 0.58, respectively. Simpson's index and Cd in Manamangalam location were 0.90 and 0.10; for Vaniyampara it was 0.92 and 0.08, and for Ollakkara location it was recorded as 0.85 and 0.15. The Shannon Wiener index, H max and Equitability for strata 2 in Manamangalam is 2.7, 4.64 and 0.58; for Vaniyampara it is 2.89, 4.86 and 0.59, and for Ollakkara they are 2.18, 3.91 and 0.56, respectively. Simpson's index and Cd in Manamangalam location was 0.91 and 0.09; for Vaniyampara it was 0.93 and 0.07, and for Ollakkara location it was recorded as 0.91 and 0.09. The Shannon Wiener index, H max and Equitability for strata 2 in Manamangalam is 2.7, 4.64 and 0.58; for Vaniyampara it is 2.9, 4.75 and 0.61, and for Ollakkara the values are 2.62, 4.17 and 0.63, respectively.

Table 14. Location wise floristic diversity index of trees (>10 cm GBH and >100 cm height.

Location	**Simpsons Index**	**Cd**	**Shannon Wiener index**	**H max**	**Equitability (E)**
Manamangalam	0.92	0.08	2.83	5.46	0.52
Vaniyampara	0.92	0.08	3.11	5.46	0.57
Ollakkara	0.89	0.11	2.52	4.39	0.57

Table 15. Strata wise floristic diversity index of trees (>10 cm GBH and >100 cm height)

Location	Strata	Simpsons Index	Cd	Shannon Wiener index	H max	Equitability (E)
Manamangalam	Strata 1	0.89	0.11	2.58	5.21	0.5
	Strata 2	0.9	0.1	2.7	4.64	0.58
	Strata 3	0.91	0.09	2.7	4.64	0.58
Vaniyampara	Strata 1	0.9	0.1	2.9	5.09	0.57
	Strata 2	0.92	0.08	2.89	4.86	0.59
	Strata 3	0.93	0.07	2.9	4.75	0.61
Ollakkara	Strata 1	0.86	0.14	2.28	3.91	0.58
	Strata 2	0.85	0.15	2.18	3.91	0.56
	Strata 3	0.91	0.09	2.62	4.17	0.63

4.2.2 Floristic diversity of regenerations and saplings of P-V WLS

The floristic diversity for regeneration and saplings of tree species were assessed both location wise (Table 16) and strata wise (Table 17).

The Simpson's index and Cd for saplings and regeneration in strata 1 of Manamangalam were same with 0.84 and 0.16, respectively.The Shannon wiener index, h max and Equitability for saplings and regeneration in this stratum were 2.17, 3.91 and 0.55 and; 2.11, 3.81 and 0.55, respectively. The Simpson's index and Cd for saplings in strata1 of Vaniyampara was 0.76 and 0.24 and that for regeneration it was 0.84 and 0.16, respectively. The Shannon Wiener index, H max and Equitability for saplings were 0.82, 2.81 and 0.29, and that for regeneration was 1.41, 2.32 and 0.61. In Ollakkara, the Simpson's index and Cd for saplings and regeneration were 0.78 and 0.22; and 0.87 and 0.13, respectively. And the Shannon Wiener index, H max and Equitability for saplings and regeneration were 1.72, 3.71 and 0.54; and 1.44, 2.58 and 0.56, respectively. The Simpson's index and Cd for saplings and regeneration in the study location of Manamangalam were 0.83 and 0.17, and 0.77 and 0.23 respectively.

Table 16. Location wise floristic diversity of regeneration and saplings in P-V WLS.

Table 12 - Location wise floristic diversity of regeneration and saplings in P-V WLS.										
Location	**Saplings**					**Regeneration**				
	Simpsons Index	**Cd**	**Shannon Wiener index**			**Simpsons Index**	**Cd**	**Shannon Wiener index**		
			H'	**H max**	**Equitability (E)**			**H'**	**H max**	**Equitability (E)**
Manamangalam	0.88	0.12	2.44	5.29	0.46	0.86	0.14	2.34	5.36	0.44
Vaniyampara	0.88	0.12	2.52	5.09	0.5	0.9	0.1	2.6	5.326	0.49
Ollakkara	0.8	0.2	2.16	4.75	0.45	0.88	0.12	2.43	5.04	0.48

Table 17. Strata wise floristic diversity of regeneration and saplings in P-V WLS.

Table 13 - Strata wise floristic diversity of regeneration and saplings in P-V WLS.											
Location	**Strata**	**Saplings**					**Regeneration**				
		Simpsons Index	**Cd**	**Shannon Wiener index**			**Simpsons Index**	**Cd**	**Shannon Wiener index**		
				H'	**H max**	**Equitability (E)**			**H'**	**H max**	**Equitability (E)**
Manamangalam	**Strata 1**	0.84	0.16	2.17	3.91	0.55	0.84	0.16	2.11	3.81	0.55
	Strata 2	0.83	0.17	2.18	3.7	0.59	0.77	0.23	1.82	3.91	0.47
	Strata 3	0.86	0.14	1.53	3.46	0.44	0.85	0.15	2.16	3.58	0.6
Vaniyampara	**Strata 1**	0.76	0.24	0.82	2.81	0.29	0.71	0.29	1.41	2.32	0.61
	Strata 2	0.84	0.16	0.74	3.7	0.2	0.86	0.14	2.29	3.91	0.59
	Strata 3	0.89	0.11	1.47	3.81	0.39	0.91	0.09	2.66	4.32	0.62
Ollakkara	**Strata 1**	0.78	0.22	1.72	3.17	0.54	0.71	0.29	1.44	2.58	0.56
	Strata 2	0.68	0.32	1.23	2.81	0.44	0.87	0.13	2.26	3.7	0.61
	Strata 3	0.78	0.22	0.78	3.46	0.23	0.87	0.13	2.29	3.81	0.6

The Shannon wiener index, H max and Equitability for saplings and regeneration in this stratum were 2.18, 3.7 and 0.59 and; 1.82, 3.91 and 0.47, respectively.

The Simpson's index and Cd for saplings in strata 2 of Vaniyampara was 0.84 and 0.16 and that for regeneration it was 0.84 and 0.16, respectively. The Shannon Wiener index, H max and Equitability for saplings were 0.74, 3.7 and 0.2, and that for regeneration was 2.29, 3.91 and 0.59. In Ollakkara, the Simpson's index and Cd for saplings and regeneration were 0.68 and 0.32; and 0.87 and 0.13, respectively. And the Shannon Wiener index, H max and Equitability for saplings and regeneration in this strata at Ollakkara were 1.23, 2.81 and 0.44; and 2.26, 3.7 and 0.61, respectively.

The Simpson's index and Cd for saplings and regeneration in the strata 3 of Manamangalam were 0.86 and 0.14, and 0.85 and 0.15 respectively.The Shannon wiener index, H max and Equitability for saplings and regeneration in this stratum were 1.53, 3.46 and 0.44 and; 2.16, 3.58 and 0.6, respectively. The Simpson's index and Cd for saplings in this stratum of Vaniyampara was 0.89 and 0.11 and that for regeneration it was 0.91 and 0.09, respectively. The Shannon Wiener index, H max and Equitability for saplings were 1.47, 3.81 and 0.39, and that for regeneration was 2.66, 4.32 and 0.62. In Ollakkara, the Simpson's index and Cd for saplings and regeneration were 0.78 and 0.22; and 0.87 and 0.13, respectively. And the Shannon Wiener index, H max and Equitability for saplings and regeneration in this strata at Ollakkara were 0.78, 3.46 and 0.23; and 2.29, 3.81 and 0.60, respectively.

4.2.3 Floristic diversity of herbs and shrubs of P-V WLS

The floristic diversity index for herbs and shrubs were calculated for the sanctuary, locations and for strata's (Table 18 and Table 19). The Simpson's index and concentration of dominance (Cd) of herbs and shrubs in the strata 1 of Manamangalam, Vaniyampara and Ollakkara were 0.94 and 0.06, 0.91 and 0.09 and 0.94 and 0.06 respectively. For strata 2 the Simpson's index and Cd were 0.94 and 0.06 in Manamangalam, 0.93 and 0.07 in Vaniyampara, and 0.94 and 0.06 in

Table 18. Location wise floristic diversity indices of herbs and shrubs

Location	Simpsons Index	Cd	Shannon Wiener index		Equitability (E)
			H'	H max	
Manamangalam	0.95	0.05	3.2	5.13	0.62
Vaniyampara	0.93	0.07	3.07	5.09	0.6
Ollakkara	0.95	0.05	3.22	5.13	0.63

Table 19. Strata wise floristic diversity indices of herbs and shrubs

Location	Strata	Simpsons Index	Cd	Shannon Wiener index		
				H'	H max	Equitability (E)
Manamangalam	**Strata 1**	0.94	0.06	3.12	5.04	0.62
	Strata 2	0.94	0.06	3.1	5	0.62
	Strata 3	0.93	0.07	2.86	4.58	0.62
Vaniyampara	**Strata 1**	0.91	0.09	2.79	4.75	0.59
	Strata 2	0.93	0.07	3	4.86	0.62
	Strata 3	0.92	0.08	2.87	4.86	0.59
Ollakkara	**Strata 1**	0.94	0.06	3.04	4.95	0.61
	Strata 2	0.94	0.06	3.09	4.81	0.64
	Strata 3	0.92	0.08	2.83	4.59	0.62

Ollakkara. In Strata 3, these values were 0.93 and 0.07 for Manamangalam, 0.92 and 0.08 for Vaniyampara and, 0.92 and 0.08 for Ollakkara.

The Shannon Wiener index, H max and Equitability of the herbs and shrubs in strata1 of Manamangalam were 3.12, 5.04 and 0.62, for Vaniyampara it was 2.79, 4.75 and 0.59 and for Ollakkara it was 3.04, 4.95 and 0.61 respectively. For strata 2 at Manamangalam it was 3.1, 5 and 0.62, for Vaniyampara it was 3, 4.86 and 0.62, and for Ollakkara it was 3.09, 4.81 and 0.64 respectively. For strata 3, at Manamangalam these values were 2.86, 4.58 and 0.62, at Vaniyampara it was 2.87, 4.86 and 0.59; and at Ollakkara these index values were 2.83, 4.59 and 0.62 respectively.

4.3. Soil studies

Soil samples collected were analysed for various physical and chemical properties.

4.3.1 Physical properties of soil

The physical properties of soils studied include soil textural analysis, bulk density, Moisture content and infiltration rate.

4.3.1.1. Soil texture

Textural analysis revealed that soil texture is sandy loam for all the locations and strata's in P-V WLS (Table 20).

There was no statistically significant difference between the sand percentage of soil depending on strata or on location. The highest sand percentage was observed in the location of Vaniyampara with a mean value of 68.03 ±1.87 % and the other two locations had the similar sand percentage, with 66.97 ± 1.81 % for Manamangalam and Ollakkara with 66.95 ± 3.03 %. Based on strata, the highest sand percent was observed for strata 1 with 68.1 ± 2.3 %, which was followed by strata 2 with 67.1 ±1.99 % and the lowest for strata 3 with 66.74 ± 2.55 %.

Table 20. Textural analysis of soils.

Location	Distance	%		
		Sand	Clay	Silt
Manamangalam	**Strata 1**	66.97 (2.01)	15.73 (0.63)	14.68 (0.66)
	Strata 2	67.32 (1.47)	17.18 (1.22)	14.59 (0.59)
	Strata 3	66.64 (2.37)	17.14 (0.94)	14.73 (1.13)
	Total	66.98 (1.82)	16.68 (1.12) [b]	14.67 (0.75)
Vaniyampara	**Strata 1**	68.34 (2.12)	15.29 (0.85)	15.59 (1.60)
	Strata 2	67.05 (2.43)	14.57 (1.29)	14.32 (0.74)
	Strata 3	68.69 (0.65)	16.58 (0.96)	14.43 (0.41)
	Total	68.03 (1.87)	15.48 (1.29) [a]	14.78 (1.12)
Ollakkara	**Strata 1**	69.12 (2.87)	15.7 (1)	14.16 (0.94)
	Strata 2	66.88 (2.55)	16.51 (1.08)	13.86 (1.18)
	Strata 3	64.87 (2.84)	17.27 (1.21)	14.13 (0.73)
	Total	66.96 (3.08)	16.49 (1.19) [b]	14.05 (0.89)
Overall	**Strata 1**	68.14 (2.33)	15.58 (0.79) [a]	14.81 (1.20)
	Strata 2	67.08 (1.99)	16.09 (1.58) [a]	14.26 (0.85)
	Strata 3	66.74 (2.55)	16.99 (0.99) [b]	14.43 (0.78)
	Total	67.32 (2.32)	16.22 (1.28)	14.50 (0.96)

*values with similar subscript do not differ from each other

Table 21. Bulk density of soils (g cm^{-3}).

Distance	Manamangalam	Vaniyampara	Ollakkara	Overall
Strata 1	1.02 (0.11)	1.03 (0.07)	0.87 (0.05)	0.97 (0.11) [ab]
Strata 2	0.99 (0.13)	0.99 (0.04)	0.76 (0.03)	0.91 (0.14) [a]
Strata 3	1.01 (0.06)	1.12 (0.1)	0.93 (0.08)	1.02 (0.11) [b]
Total	1.01 (0.1) [b]	1.05 (0.09) [b]	0.85 (0.09) [a]	0.97 (0.12)

*values with similar subscript do not differ from each other

The silt fraction was statistically similar with respect to strata as well as location. The location with highest silt fraction was Vaniyampara (14.78 ± 1.12 %), which was followed by Manamangalam (14.67 ± 7.49 %) and the lowest was for Ollakkara (14.05 ± 8.87 %).

In case of strata's, the highest silt fraction was represented in strata 1 (14.80 ± 1.2 %), followed by strata 3 (14.43 ± 7.76 %) and the lowest for strata 2 (14.26 ± 8.5 %).

The clay fraction of the soils differed with location as well as with strata. The highest clay fraction was for Manamangalam location (16.68 ± 1.12 %) followed by Ollakkara (16.50 ± 1.20 %) and Vaniyampara (15.48 ± 1.28 %). The locations Manamangalam and Ollakkara had statistically significant clay fraction, which both was different from that at Vaniyampara.

When comparing strata's, the clay fraction was highest in the third strata with 16.99 ± 9.94 % which was followed by strata 2 with 16.08 ± 1.58 % and the lowest clay fraction was found in soils of strata 1 with 15.57 ±7.87 %. When comparing the clay fraction between strata's, strata 1 and strata 2 were statistically similar with each other, but were significantly different from strata 3.

4.3.1.2 Bulk density

The soil bulk density varied with location as well as with strata (Table 21). The highest soil bulk density of Manamangalam was at strata 1 (1.02 ± 0.11gm cm^{-3}) and the lowest was at strata 2 (0.99 ± 0.13gm cm^{-3}). In Vaniyampara and Ollakkara, the highest was at strata 3 with 1.12 ± 0.1gm cm^{-3} and 0.93 ± 0.08gm cm^{-3}respectively. The mean bulk densities for the locations Manamangalam and Vaniyampara were similar with 1.01 ± 0.1 and 1.05 ± 0.9 gm cm^{-3} respectively, but were significantly different from that at Ollakkara (0.85 ± 0.09 gm cm^{-3}).

Based on strata wise analysis, the soil bulk density showed statistically significant difference between strata 2 (0.91 ± 0.14 gm cm^{-3}) and strata 3 (0.85 ± 0.09 gm cm^{-3}), but both these strata were similar to that of strata 1 (0.97 ± 0.11 gm cm^{-3}).

Table 22. Moisture content of the soils (%).

Distance	Manamangalam	Vaniyampara	Ollakkara	Overall
Strata 1	9.98 (1.24)	7.09 (3.25)	14.38 (2.67)	**10.49 (3.88)** [a]
Strata 2	12.48 (4.99)	10.59 (1.86)	13.04 (1)	**12.04 (3.04)** [a]
Strata 3	17.54 (2.27)	11.99 (1.93)	17.05 (1.52)	**15.53 (3.15)** [b]
Total	**13.33 (4.41)** [b]	**9.89 (3.08)** [a]	**14.82 (2.42)** [b]	**12.68 (3.91)**

*values with similar subscript do not differ from each other

Table 23. Infiltration rates for 30 minutes of the soils (mm)

Distance	Manamangalam	Vaniyampara	Ollakkara	Overall
Strata 1	162 (6.63)	164 (9.05)	149.25 (11.95)	**158.42 (10.95)** [a]
Strata 2	164.5 (9.57)	175.5 (7.55)	143.75 (9.39)	**161.25 (15.93)** [ab]
Strata 3	175.75 (14.03)	188.75 (3.86)	139.5 (8.81)	**168 (23.51)** [b]
Total	**167.42 (11.39)** [b]	**176.08 (12.39)** [b]	**144.17 (10.08)** [a]	**162.56 (17.54)**

*values with similar subscript do not differ from each other

4.3.1.3 Moisture content

Soil moisture percent / content varied with location and also with strata (Table 22). The locations Manamangalam and Ollakkara had statistically similar moisture content with 13.33 ± 4.41 % and 14.82 ± 2.42 % respectively. The moisture content at Ollakkara (9.89 ± 3.08 %) was significantly lower from the other two locations.

Based on strata wise analysis, in Manamangalam the moisture content of the soils varied from 12.48 ± 4.99 % (strata 2) to 17.54 ± 2.27 % (strata 3). In Vaniyampara, the soil moisture content varied from 7.09 ± 3.25 % (strata 1) to 11.99 ± 1.93 % (strata 3). In Ollakkara it ranged from 13.04 ± 1 % (strata 2) to 17.05 ± 1.52 % (strata 3).

When comparing strata's at the three locations, strata 1 and 2 were statistically similar but was significantly different from strata 3 with the mean values 10.49 ± 3.88 %, 12.04 ± 3.04 % and 15.53 ± 4.41 % respectively. The highest moisture content was observed in strata 3 or as we move to the interior of the forest.

4.3.1.4 Infiltration

The infiltration rates of the sites were assessed using double ring infiltrometer. The rate of infiltration was measured for 30 minutes and was expressed in mm. The highest infiltration rate was for the location of Vaniyampara (176.08 ± 12.39 mm) which was followed by that at Manamangalam (167.42 ± 11.39 mm) and the lowest infiltration was observed at Ollakkara (144.17 ± 10.08 mm)(Table 23). The infiltration rates at the locations Manamangalam and Vaniyampara were statistically similar but both were significantly different from that of Ollakkara.

When analysing the infiltration rates based on strata, the strata 3 had the highest infiltration (168 ± 23.51 mm) with 175.75 ± 14.03 mm, 188.75 ± 3.86 mm and 139.5 ± 8.81 mm for Manamangalam, Vaniyampara and Ollakkara respectively. Strata 1 was followed by strata 2 (161.25 ±15.93 mm), with 164.5 ± 9.57 mm, 175.5 ± 7.55 mm and 143.75 ± 9.39 mm for Manamangalam, Vaniyampara and Ollakkara respectively. The lowest infiltration was mm for strata 1 (158.42 ± 10.95 mm),with 162 ± 6.63 mm, 164 ± 9.05 mm and 149.25 ± 11.95 mm for Manamangalam, Vaniyampara and Ollakkara respectively. The analysis of variance showed that strata 1 and strata 3 were significantly different with each other but both are interrelated to strata 2.

4.3.2. Chemical properties of the soil's of P-V WLS.

The chemical properties of soils of P-V WLS were analysed for pH, electrical conductivity (EC), organic carbon, total Nitrogen, available Phosphorous, available Potassium, cation exchange capacity (CEC) and exchangeable cations (Table 24).

4.3.2.1 Soil pH

The analysis of variance showed that the soil pH varied which location and also with strata. The soil pH was observed to be highest in the location of Ollakkara (6.09 ±0.26), which was followed by that at Vaniyampara (5.89 ± 0.22) and the lowest pH was for Manamangalam (5.53 ± 0.28). The pH values at all the locations were significantly different from each other.

When comparing soil pH based on strata's, the strata 1 of Manamangalam, Vaniyampara and Ollakkara had a soil pH of 5.49 ± 0.22, 5.70 ± 0.24 and 6.10 ± 0.23 respectively. The strata 2 of Manamangalam, Vaniyampara and Ollakkara had a soil pH of 5.28 ± 0.2, 6.05 ± 0.13 and 5.89 ± 0.09. And in strata 3, Manamangalam, Vaniyampara and Ollakkara had a soil pH of 5.83 ± 0.05, 5.92 ± 0.13 and 6.30 ± 0.27. The analysis of variance also showed that the pH for strata 3 (6.01 ± 0.27) was significantly different from that at strata 1 (5.76 ± 0.34) and strata 2 (5.74 ± 0.37).

4.3.2.2 Electrical conductivity

The analysis of variance for comparing EC along the locations and strata's showed that the EC to be similar between Manamangalam (243.78 ± 71.41µS cm^{-1}) and Vaniyampara (272.2 ± 66.99µS cm^{-1}) but was highly different from that at Ollakkara (398.96 ± 175.18µS cm^{-1}). When studying EC along strata, strata 1 had the highest EC which decreased steeply in the other two strata's. While comparing the variance of EC along the strata's, strata 1 of Manamangalam, Vaniyampara and Ollakkara had an EC of 289.83 ± 47.3 µS cm^{-1}, 275.2 ± 65.05 µS $cm^{-1}$and 506.43 ± 256.4 µS cm^{-1}respectively. The strata 2 of Manamangalam, Vaniyampara and Ollakkara had an EC

Table 24. Chemical properties of soil

Location	Distance	pH	Electrical Conductivity(μ S cm^{-1})	Total C %	Total N %	Avaliable P (kg ha^{-1} soil)	Avaliable K (kg ha^{-1} soil)	C/N ratio	CEC (Cmol(p+)kg^{-1}
Manamangalam	Strata 1	5.49 (0.22)	289.83 (47.3)	3.71 (0.81)	0.43 (0.25)	21.42 (8.3)	281.88 (94.35)	10.85 (5.54)	34.31 (2.31)
	Strata 2	5.28 (0.2)	218.7 (76.04)	3.45 (1.18)	0.52 (0.2)	29.44 (20.57)	247.5 (41.4)	14.26 (3.7)	28.93 (4.73)
	Strata 3	5.83 (0.05)	222.8 (80.15)	4.03 (0.13)	0.45 (0.14)	61.27 (56.24)	398.75 (55.46)	9.51 (2.3)	37.73 (1.43)
	Total	5.53 (0.28)^{a}	243.78 (71.41)^{a}	3.73 (0.79)	0.46 (0.19)	37.38 (36.33)^{ab}	309.38 (91.14)^{a}	11.54 (4.23)	33.65 (4.74) ^{a}
Vaniyampara	Strata 1	5.70 (0.24)	275.2 (65.05)	4.12 (1.34)	0.30 (0.09)	35.18 (15.11)	264 (92.14)	7.70 (3.99)	30.38 (5.66)
	Strata 2	6.05 (0.13)	280.1 (43.09)	2.95 (0.85)	0.34 (0.11)	55.29 (43.35)	262.63 (72.6)	9.54 (3.92)	32.96 (1.78)
	Strata 3	5.92 (0.13)	261.3 (100.57)	2.67 (0.31)	0.30 (0.03)	85.08 (46.25)	290.13 (35.18)	10.28 (2.75)	34.42 (1.74)
	Total	5.89 (0.22)^{b}	272.2 (66.99)^{a}	3.25 (1.07)	0.31 (0.08)	58.52 (40.21) ^{b}	272.25 (65.31)^{a}	9.17 (3.45)	32.59 (3.67) ^{a}
Ollakkara	Strata 1	6.10 (0.23)	506.43 (256.4)	3.52 (0.49)	0.39 (0.12)	17.95 (5.19)	576.13 (345.65)	9.55 (2.46)	36.57(10.47)
	Strata 2	5.89 (0.09)	389.93 (105.14)	4.33 (1.47)	0.43 (0.11)	17.35 (8.68)	558.25 (132.04)	9.19 (2.07)	39.39 (1.5)
	Strata 3	6.30 (0.27)	300.53 (85.48)	3.97 (0.75)	0.50 (0.37)	19.03 (10.93)	500.5 (186.89)	9.94 (4.45)	38.00 (2.15)
	Total	6.09 (0.26)^{c}	398.96 (175.18)^{b}	3.94 (0.97)	0.44 (0.21)	18.12 (7.81)^{a}	544.96 (219.09)^{b}	9.56 (2.88)	37.99 (5.76)^{b}
Overall	**Strata 1**	5.76 (0.34)^{m}	357.15 (178.57)	3.78 (0.89)	0.37 (0.16)	24.85 (12.2)^{m}	374.00 (244.27)	9.37 (4.02)	33.75 (6.87)
	Strata 2	5.74 (0.37)^{m}	296.24 (102.81)	3.58 (1.23)	0.43 (0.15)	34.03 (30.36)^{mn}	356.13 (170.25)	10.99 (3.87)	33.76 (5.28)
	Strata 3	6.01 (0.27)^{n}	261.54 (87.19)	3.55 (0.79)	0.42 (0.22)	55.13 (47.88)^{n}	396.46 (136.94)	9.91 (3)	36.72 (2.35)
	Total	5.84 (0.34)	304.98 (131.68)	3.64 (0.97)	0.40 (0.18)	38.00 (34.96)	375.53 (184.5)	10.09 (3.62)	34.74 (5.23)

*values with similar subscript do not differ from each other

of 218.7 ± 76.04µS cm^{-1}, 280.1 ± 43.09µS cm^{-1} and 389.93 ± 105.14µS cm^{-1} and that for strata 3 were 222.8 ± 80.15µS cm^{-1}, 261.3 ± 100.57µS cm^{-1} and 300.53 ± 85.48µS cm^{-1} respectively. The analysis of variance also showed that there were no significant differences between the strata's.

4.3.2.3 Organic carbon

The analysis of variance for comparing organic carbon along locations and strata's showed no significant difference of organic carbon among them. The highest carbon content was observed in the location of Ollakkara (3.94 ± 0.97 %) and the lowest was for Vaniyampara (3.25 ± 1.07 %).

In Manamangalam, the strata 1, 2 and 3 had an organic carbon percentage of 3.71 ± 0.81 %, 3.45 ± 1.18 % and 4.03 ± 0.13 % respectively. In Ollakkara, the organic carbon percentage varied from 2.67 ± 0.31 % in strata 3 to 4.12 ± 1.34 % in strata 1. And in Ollakkara, it varied from 3.52 ± 0.49 % in strata 1 to 4.33 ± 1.47 % in strata 2. When comparing strata's alone, the mean value of organic carbon showed a decreasing order, with the highest at strata 1 (3.78 ± 0.89 %) and the lowest at strata 3 (3.55 ± 0.79 %).

4.3.2.4 Available phosphorus

The analysis of variance for available phosphorous among locations showed that the available phosphorous in Ollakkara (18.12 ± 7.81kg ha^{-1} soil) and Vaniyampara (58.52 ± 40.21 kg ha^{-1} soil) were significantly different to each other but both were similar to that at Manamangalam (37.38 ± 36.33kg ha^{-1} soil).

In Manamangalam, strata 1, 2 and 3 had an available soil phosphorus content of 21.42 ± 8.3kg ha^{-1}, 29.44 ± 20.57kg ha^{-1} and 61.27 ± 56.24 kg ha^{-1}; that for Vaniyampara was 35.18 ± 15.11kg ha^{-1}, 55.29 ± 43.35kg ha^{-1} and 85.08 ± 46.25kg ha^{-1} and for Ollakkara, it was 17.95 ± 5.19kg ha^{-1}, 17.35 ± 8.68kg ha^{-1} and 19.03 ± 10.93kg ha^{-1} respectively.

The analysis of variance of available phosphorous along strata's also showed that there were significant differences among strata's. The available phosphorous showed a decreasing trend toward interior forest. The stratum 1 (24.85 ± 12.2 kg ha^{-1} soil) was significantly different from that at strata 3 (55.13 ± 47.88kg ha^{-1} soil), but both these strata's were similar to strata 2 (34.03 ± 30.36 kg ha^{-1} soil).

4.3.2.5 Available potassium

The analysis of variance for available potassium showed that it differed with location but there were no significant differences among strata's. Ollakkara was significantly different from the other two locations. The highest mean available potassium was observed in the location of Ollakkara (544.96 ± 219.09 kg ha^{-1} soil), followed by Manamangalam (309.38 ± 91.14 kg ha^{-1} soil) and Vaniyampara (272.25 ± 65.31 kg ha^{-1} soil). Based on strata, the strata 1, 2 and 3 of Manamangalam had soil available potassium of 281.88 ± 94.35kg ha^{-1} soil, 247.5 ± 41.4kg ha^{-1} soil and 398.75 ± 55.46 kg ha^{-1} soil respectively; that for strata 1, 2 and 3 of Vaniyampara were 264 ± 92.14 kg ha^{-1} soil, 262.63 ± 72.6 kg ha^{-1} soil and 290.13 ± 35.18 kg ha^{-1} soil respectively. The soil available potassium for strata 1, 2 and 3 of Ollakkara were 576.13 ± 345.65 kg ha^{-1} soil, 558.25 ± 132.04 kg ha^{-1} soil and 500.5 ± 186.89 kg ha^{-1} soil respectively.

The strata wise analysis of variance for soil available potassium showed no significant difference between the strata's.

4.3.2.6. Cation exchange capacity (CEC)

The analysis of variance for CEC along the three locations and strata's showed significant differences within locations but not with strata's. Ollakkara was significantly different from the other two locations that were similar to each other. CEC was highest in Ollakkara (37.99 ± 5.76Cmol(p^+)kg^{-1}), which was followed by Manamangalam (33.65 ± 4.74Cmol(p^+)kg^{-1}) and Vaniyampara (32.59 ± 3.67Cmol(p^+)kg^{-1}).

In Manamangalam, the strata 1, 2 and 3 had a CEC of 34.31 ± 2.31Cmol(p^+)kg^{-1}, 28.93 ± 4.73Cmol(p^+)$kg^{-1}$and 37.73 ± 1.43Cmol(p^+)kg^{-1}respectively. In Vaniyampara it was 30.38 ± 5.66Cmol(p^+)kg^{-1}, 32.96 ± 1.78Cmol(p^+)$kg^{-1}$and 34.42 ± 1.74

Cmol(p^+)kg^{-1}respectively and in Ollakkara, it was 36.57 ± 10.47Cmol(p^+)kg^{-1}, 39.39 ± 1.5 Cmol(p^+)$kg^{-1}$and 38.00 ± 2.15 Cmol(p^+)kg^{-1}respectively.

The strata wise analysis of variance for CEC showed no significant differences between strata's.

4.3.3. Soil Quality index (SQI)

SQI was calculated using the selected parameters of soil health and assigning index values to them (Table 1). In this study, the SQI for each study plot were indexed (Table 25). The SQI for study plots varied from one to five and the SQI % varied from 6.7 % to 33.3 %. In Manamangalam and Vaniyampara, the strata 1, 2 and 3 had a SQI % of 23.33 %, 23.33 % and 16.67 % respectively; and in Ollakkara, that were 21.67 %, 23.33 % and 18.33 % respectively.

4.4. Anthropogenic / Human disturbance

4.4.1 Correlation of anthropogenic forest disturbances with other vegetation and soil parameters

The correlation between signs of human disturbance and other vegetation and soil parameters were assessed (Table 26). The cut signs or notches on trees showed a positive relationship with canopy gap area and an inverse relationship with LAI, soil moisture content and number of saplings species. The number of lopped branches showed an inverse relation between LAI and a positive relation with canopy gap area, cut signs and fire damage. Fire damage showed an inverse relationship with LAI, soil moisture, total soil nitrogen and number of regenerations. Cattle and human trails had a positive relationship between lopped branches and a negative relationship with LAI and soil moisture content.

4.4.2. Human disturbance indicator (HDI) for P-V WLS

The HDI values for P-V WLS were calculated based on both locations and strata's (Table 27). The highest HII was for Vaniyampara with 68.33 %, which was followed

Table 25. Soil quality index (SQI)

(BD-Bulk density, EC-Electrical conductivity, To.C-Total Carbon %, To.N-Total Nitrogen, Ava.P- Available Phosphorus, Ava. K- Available Potassium, CS%- coarse sand %, IR- Infiltration rate)

Location	Strata	Plot	BD	pH	EC	To. C	To. N	Ava. P	Ava. K	C S%	IR	SQI	SQI %	SQI % for strata
Manamangalam	1	1	0	2	0	0	1	1	0	0	0	4	26.67	23.33
		2	0	1	1	0	1	0	0	0	0	3	20	
		3	0	2	0	0	1	1	1	0	0	5	33.33	
		4	0	1	0	0	0	0	1	0	0	2	13.33	
	2	1	0	1	0	0	0	1	1	0	0	3	20	23.33
		2	0	2	0	0	1	1	1	0	0	5	33.33	
		3	0	2	0	0	1	0	1	0	0	4	26.67	
		4	0	2	0	0	0	0	0	0	0	2	13.33	
	3	1	0	1	0	0	1	1	0	0	0	3	20	16.67
		2	0	1	1	0	1	1	0	0	0	4	26.67	
		3	0	1	0	0	1	0	0	0	0	2	13.33	
		4	0	1	0	0	0	0	0	0	0	1	6.67	
Vaniyampara	1	1	0	1	0	0	1	1	1	0	0	4	26.67	23.33
		2	0	2	0	0	1	0	1	0	0	4	26.67	
		3	0	1	1	0	1	0	0	0	0	3	20	
		4	0	1	1	0	1	0	0	0	0	3	20	
	2	1	0	1	1	0	1	1	1	0	0	5	33.33	23.33
		2	0	0	0	0	1	0	1	0	0	2	13.33	
		3	0	1	0	0	1	0	2	0	0	4	26.67	
		4	0	1	0	0	1	1	0	0	0	3	20	
	3	1	0	0	1	0	1	0	1	0	0	3	20	16.67
		2	0	1	0	0	1	0	1	0	0	3	20	
		3	0	1	0	0	1	0	0	0	0	2	13.33	
		4	0	1	0	0	1	0	0	0	0	2	13.33	

Location	Strata	Plot	BD	pH	EC	To. C	To. N	Ava. P	Ava. K	C S%	IR	SQI	SQI %	SQI % for strata
Ollakkara	**1**	1	0	0	1	0	1	1	0	0	0	3	20	**21.67**
		2	0	1	0	0	1	1	1	0	0	4	26.67	
		3	0	1	1	0	0	1	0	0	0	3	20	
		4	0	0	1	0	1	1	0	0	0	3	20	
	2	1	0	1	1	0	0	1	0	0	0	3	20	**23.33**
		2	0	1	1	0	1	1	0	0	0	4	26.67	
		3	0	1	1	0	1	1	0	0	0	4	26.6	
		4	0	1	1	0	1	0	0	0	0	3	20	
	3	1	0	1	0	0	1	1	0	0	0	3	20	**18.33**
		2	0	0	0	0	1	0	0	0	0	1	6.67	
		3	0	1	1	0	1	1	0	0	0	4	26.67	
		4	0	0	1	0	1	1	0	0	0	3	20	

Table 26. Correlation coefficient for parameters that shows significant interrelationship with signs of human disturbance.

	Canopy gap area	LAI	Soil moisture content %	pH	Total soil nitrogen (%)	Fine sand %	Clay %	Infiltration rate	Total sapling species	Total saplings number	Total regeneration species	Regeneration - Total No.
Cut/ notches	.697**	-.376*	-.497**	-.099	-.285	.360*	-.381*	-.066	-.360*	-.380*	-.466**	-.223
Lopped tree branches	.367*	-.338*	-.479**	-.045	-.008	.210	-.249	.052	-.069	-.143	-.146	-.102
Fire damaged trees	.492**	-.401*	-.537**	.082	-.412*	.443**	-.485**	.373*	-.106	-.314	-.105	-.352*
Cattle/ Human trails	.153	-.480**	-.371*	.008	-.007	.147	-.178	-.058	-.056	.034	.094	.069

** Significant at 0.01 levels; * Significant at 0.05 levels; others are non-significant

Table 27. Human disturbance indicator (HDI) for the locations and strata's of P-V WLS (%).

Strata	Manamangalam	Vaniyampara	Ollakkara	Overall (Strata)
1	45	80	65	**63.33** [a]
2	5	65	25	**31.67** [b]
3	15	60	10	**28.33** [b]
Overall (location)	**21.67** [c]	**68.33**[a]	**33.33** [b]	**41.11**

*values with similar subscript do not differ from each other

by Ollakkara with 33.33 % and the least was for Manamangalam, with 21.67 %. Based on strata the HII for strata 1, 2and 3 of Manamangalam were 45 %, 5 % and 15 % respectively. Those for strata 1, 2 and 3 of Vaniyampara were 80 %, 65 % and 60 % and for Ollakkara it was 65 %, 25 % and 10 % respectively. The strata wise analysis showed that the three strata's were significantly different from each other.

4.5. Cluster analysis of the strata's of P-V WLS

The cluster analysis for strata's was done using RISQ value for trees, sapling and regeneration; Soil quality index (SQI) and Human disturbance indicator (HDI) (Fig 14). The result shows two major groups of clusters at a rescaled distance of 25. The first cluster included strata 1 of Ollakkara, all the strata's of Vaniyampara and strata 1 of Manamangalam. The second cluster includes strata 2 and 3 of Ollakkara andManamangalam.

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      Rescaled Distance Cluster Combine

                               0         5        10        15        20        25
Num  +---------+---------+---------+---------+---------+

  Vaniyampara strata 2     5   -+
  Ollakkara strata 1       7   -+---+
  Vaniyampara strata 3     6   -+   +-----+
  Vaniyampara strata 1     4   -----+     +--------------------------------------+
  Manamangalam strata 1    1   -----------+                                      |
  Manamangalam strata 3    3   -+                                                |
  Ollakkara strata 3       9   -+---+                                            |
  Manamangalam strata 2    2   -+   +--------------------------------------------+
  Ollakkara strata 2       8   -----+
```

Fig. 14. Dendrogram of cluster analysis using average linkage (Between groups)

DISCUSSION

5. DISCUSSION

The study was done to identify and quantify the impacts of human disturbance in the forest and was conducted in the locations of Peechi-Vazhani wild life sanctuary. The results of the study are discussed in this chapter.

5.1 Vegetation studies

The study delineated the forest formations in P-V WLS to be the secondary deciduous forest, which clearly shows the state of forest degradation and the nature of disturbances in the sanctuary. The secondary deciduous forests are degraded evergreen or semi evergreen forests occupying large areas within the zone of the wet evergreen formations. They are degraded mainly due to anthropogenic disturbance resulting in opening of the canopy, leading to major changes in soil conditions and in humidity. Floristically and structurally these formations are close to the moist deciduous climax forests but they mainly differ in the composition of the under storey. The protection at the level of the secondary deciduous forest results in gradual closing of the canopy. This evolution leads to enrichment in evergreen species and the forest progresses towards the semi evergreen stage. The structure of deciduous climax forest gets altered into two different types based on the important cause of degradation- the open forest/ savanna-woodland/tree savanna, when fire is the dominant factor; and the scrub woodland/ dense thicket/ low discontinuous thicket/ scattered under-shrubs, when over-grazing and illicit felling dominates (Table 28). The opening of the stand and presence heavy anthropogenic pressure leads to progressive degradation of the exposed soil and favours laterization leading to an enrichment of more resistant species such as *Xylia xylocarpa* (Pascal, 1986).

The forests in the entire sanctuary resemble a *Xylia xylocarpa* dominated secondary moist deciduous forest but the detailed analysis of the study area shows the presence of different sub formations in the strata's. *Xylia xylocarpa* is a representative species of deciduous secondary forest formations. The location wise analysis of the study area was done based on the IVI's for trees, *Xylia xylocarpa* was the most abundant in

Table 28 – Forest map of south India's classification (Pascal, 1986)

Forest map of south India's classification (Pascal, 1986)					**Classification of Champion and Seth (1968)**
Group 1. Evergreen and semi evergreen climax forest and degradation	**A.** Evergreen and semi evergreen climax forest				
	Evergreen and semi evergreen forests	Disturbed			
		Secondary			
	B. Secondary or degraded stages	Secondary moist deciduous forests			3B/C2 : Southern moist deciduous forest
					3B/2S1 : Southern secondary moist deciduous forest
					3B/C1a : Very moist teak forest
					2B E3 : Moist Bamboo brakes
					2B E4 : Lateritic semi evergreen forest (*Xylia* mixed forest)
		Other degraded	Tree savanna to grass savanna		
			Thicket to scattered shrubs		
Group 2. Deciduous climax forests and degradation		Forests	*Lagerstroemia – Tectona – Dillenia* type		3B/C1b : Moist Teak forest
					2B/E3 : Moist Bamboo brakes
			Dry deciduous	*Anogeissus – Tectona – Terminalia* type	5A/C1b : Dry Teak forest
					3b/C1c : Slightly moist teak forest
				Anogeissus – Chloroxylon – Albizia type	5A/C3 : Southern dry mixed deciduous
					5A/ E4 : Hardwickia forest
		Degraded stages		Woodland to tree savanna	5/ 2S1 : Secondary dry deciduous forest
					5/DS2 : Dry savanna forest
				Scrub woodland to low scattered shrubs	5/DS1 : Dry deciduous scrub
					6A/ C1 : Southern thorn forest
					5/ DS3 : Euphorbia scrub

Vaniyampara and Ollakkara, and one of the most abundant in Manamangalam. In Manamangalam, *Tectona grandis* was the most dominating species due to the presence of uniform sized *Tectona grandis* trees in abandon teak plantations (Fig 10a). There was no major difference in case of species abundance between locations.

The study used Ramakrishnan index of stand quality (RISQ) to assess the forest disturbance. This index quantifies the ecological state of the forest using values ranging from one to three. The index was calculated by assigning pioneer index values, from 1 -3, for each species in a forest. Pioneer index is 1 for the species whose seedlings establish in closed canopy area, but need small canopy gaps to grow up, Pioneer index is 2 for the species whose seedlings establish in small gaps but need small to medium size gaps to grow up, and Pioneer index is 3 for the species whose seedlings need larger canopy gaps for both establishment and growth. If the Ramakrishnan index of stand quality (RISQ) for a given site is 1.0, then all stems in the forest are group 1 species and the forest stand is undisturbed; if it is 3.0, then all the stems are strong light-demanding species and hence the forest stand is highly disturbed. The RISQ for the trees of entire P-V WLS was found to be 2.32 ± 0.14; this shows the dominance of light demanders in the Peechi Vazhani forests and thus its degradation.

When comparing the three strata's of P-V WLS the RISQ values for trees, saplings and regeneration showed a maximum in the strata 1(Table 13). This again shows that the most disturbed stratum in the sanctuary is that closest to the human habitation. This result was in accordance with the present human disturbances that were found in the study area as evidenced by the indicators (Table 27). The RISQ value for trees was lowest for strata 2 (2.2 ± 0.07). The increase in RISQ values for trees in strata 3 was due to the high RISQ values at Ollakkara (2.57). The RISQ values for regeneration and saplings were lower than that for trees in strata 2 and strata 3. In strata 1, the RISQ values for regeneration were higher than that for trees, which means higher representation of light demanders in regenerations of strata 1.

When assessing the IVI's of trees in three strata's of P-V WLS, *Xylia xylocarpa* had the highest IVI in the strata 1 of Vaniyampara and Ollakkara but *Tectona grandis* had the highest IVI in strata 1 of Manamangalam, *Xylia xylocarpa* was followed by *Bombax ceiba*, *Terminalia paniculata*, *Macaranga peltata, Terminalia elliptica, T. paniculata, Lagerstroemia lanceolata, Tectona grandis, Dillenia pentagyna, Dalbergia latifolia, Albizia odoratissima* and *Careya arborea*. The stratum 1 of Manamangalam clearly shows the ecological transition of Teak plantation to secondary moist deciduous forests. The abundance of *Xylia xylocarpa* and pioneers like *Wrightia tinctoria*, *Holarrhena pubescens* and *Macaranga peltata* in this stratum of Manamangalam not only adds to the forest recovery process but also shows its past disturbance.The under storey is often overgrown by *Clerodendrum infortunatum and Helicteres isora*, *Lantana camara* and *Chromolaena odorata.* The presence of evergreen species like *Olea dioica*, *Pterospermum reticulatum*, *Hydnocarpus pentandra* etc makes this strata at Vaniyampara resemble the description for a degraded secondary deciduous forest formations defined by Pascal (1986). The presence of *Anogeissus latifolia* in Vaniyampara can be ascertained to the rockiness or the low soil depth in this stratum. The forest at strata 1 of Ollakkara had a similar tree composition as that of Vaniyampara, except to the absence of evergreen species and lower representation of pioneer light demanders. The regenerations and saplings in strata 1 include that of *Xylia xylocarpa*, *Macaranga peltata*, *Tabernaemontana heyneana*, *Bombax ceiba* and *Dillenia pentagyna*, which shows a higher representation of light demanding pioneers in the stratum. This can be due to opening up of canopy, which is evident from the presence of large canopy gap area and also the low leaf area index (LAI) observed in this stratum (Table 11). LAI in this study showed an inverse relationship between human disturbances like cuts/notches, lopping, fire damage and trails. Hence this substantiates the continuing occurrence of disturbance in strata 1 of P-V WLS. The tree mean height and mean GBH was found to be lowest in this stratum, with the highest proportion of trees in the lowest height class and GBH classes (Fig 8b and 9b). The regeneration and saplings in this stratum was low obviously due to the lighter disturbances. This forest was highly impacted by human activities which were evident from the signs of lopping and cuts/notches in trees; and had the highest human disturbance indicator (HDI) values in their locations (Table 27).

Xylia xylocarpa had the highest IVI in strata 2 of all the locations, which was followed by *Terminalia paniculata*, *Dillenia pentagyna*, *Lannea coromandelica* and *Lagerstroemia lanceolata*. The forest formation in this stratum was also secondary moist deciduous forest. The tree composition of this stratum was similar to that at strata 1; except in Vaniyampara, which have a higher representation of like *Olea dioica*, *Tetrameles nudiflora*, *Mallotus philippensis* and *Dipterocarpus indicus*. The presence of *Cleistanthus collinus* in Manamangalam and *Strychnos nux-vomica* in Vaniyampara forest can be attributed to local effects. The understorey was mainly dominated by *Helicteres isora* andinvasive species like *Chromolaena odorata*. The forest at Vaniyampara is ecologically degraded and the presence of human disturbances like cut/notches, lopped branches and cattle/human trails observed in this stratum adds to this degradation in this stratum, but was not severe as that at strata 1 (Table 27). When analysing the regenerations and saplings, higher representation was by *Xylia xylocarpa*, followed by *Wrightia tinctoria*, *Holarrhena pubescens*, *Dalbergia latifolia*, *Schleichera oleosa*, *Callicarpa tomentosa* etc. The presence of light demanders in regeneration and saplings shows the opening in canopy and the presence of deciduous species like *Schleichera oleosa*, *Callicarpa tomentosa* etc shows the continuation of this stage. The majority of regeneration and saplings in this stratum represented the non pioneer species; which can be due to gradual closing of canopy and the reduction in canopy gap area and increase in LAI. This shows the process of continuation of the existing forest formations. The presence of *Macaranga peltata* and *Holarrhena pubescens* shows the still existing opening in the canopy.

Strata 3 are the interior forests which are at maximum distance from human habitation/sources of human influence. The highest IVI at this stratum was for *Terminalia paniculata* at Manamangalam and was for *Xylia xylocarpa* in Vaniyampara and Ollakkara. They were followed by *Lagerstroemia lanceolata*, *Dillenia pentagyna*, *Tectona grandis* and *Terminalia elliptica*. The species composition of this stratum at all the locations was the same and the forest formation wassecondary moist deciduous forests as they lacked the evergreen species of evergreen and semi evergreen climax. The higher IVI for *Terminalia paniculata* and *Lagerstroemia lanceolata* than *Xylia xylocarpa* at Manamangalam (Fig 10) and the IVI's of the above species on par with *Xylia xylocarpa*, at Vaniyampara (Fig 11) and Ollakkara (Fig 12), shows a more undisturbed condition prevalent in this stratum (Table. 24). The number of lianas and invasive species were low compared to other strata's in this study location. The regenerations and saplings showed a higher representation of *Xylia xylocarpa*, *Wrightia tinctoria*, *Holarrhena pubescens*, *Tectona grandis* and *Terminalia paniculata*. The presence of light demanders in the regeneration and saplings of strata 3 shows the opening's in the canopy; however, the lowest canopy gap area and the highest LAI were observed here (Table 11). This stratum observed the highest mean height and mean GBH for trees and also the highest representation of trees by higher height and GBH classes; this can be indicating an undisturbed forest (Arjunan et al., 2005).

The study of the vegetation showed the existence of a disturbed/ degraded forest in P-V WLS. The disturbances on vegetation were observed to be decreasing towards interior forest. The disturbance in P-V WLS is more of a location specific nature. The variations found along the strata were also seen among the locations, with varying intensity. The Vaniyampara forest were the most affected by human disturbances whereas the Manamangalam forests were the least affected (Fig. 16). The location wise variation in human disturbances contributes to the strata wise differences.

5.2 Soil studies

5.2.1 Physical properties of soil

The textural analysis revealed that the soil texture is sandy loam for all the strata's, with a granular and crumby structure. The sand and silt percent of the soils was not significantly different between the strata's.But the clay percent of strata 1 and strata 2 was significantly different from that of strata 3, thus there was a significant increase in clay percent while moving to the interior of forests (Table 20). The higher clay content shows low rates of erosion which relates to healthy soilsin the forest interiors. The bulk density of soils showed a significant difference between strata, with the highest at strata 3 and the lowest at strata 2. The infiltration rate also showed a significant increase to the interior of forest in this study (Table 23). The soil moisture content showed a significant increase when moving to interior forests, with the maximum at strata 3; a similar trend was observed by Jose et al., (1996). This increase in soil moisture to the interior of forest can be due to the closing of canopy, the higher LAI and smaller canopy gap areas (Table 11); and the interaction of higher clay content of strata 3 with organic carbon, along with higher infiltration rates, contribute to higher moisture content in soils.

5.2.2 Chemical properties of soil

This study observed a significant increase in soil pH of the interior forests, in spite the low levels of disturbance in interior forest. This increase in pH can be due to the interaction of the higher clay content with organic carbon.This study observed no significant difference in EC between strata's. Elsy (1989) reported that the moist deciduous forest soils had a maximum carbon and nitrogen content of 5.29 % and 0.52 % respectively; whereas it was observed to be 3.78 % and 0.43 % in this study. This study found no significant difference between the strata's for soil carbon and nitrogen.The available phosphorus increased significantly to the interior of forests, with a maximum at strata 3 with 55.13 ± 47.88 kg ha $^{-1}$. The available potassium showed no significant difference between strata's. The CEC of the study area was 34.74 ± 5.23 Cmol(p^{+})kg^{-1}, which was in accordance with the study of Elsy (1989), butin this study no significant strata wise difference for CEC was observed.

The analysis of chemical and physical properties of soils showed that changes exist as we move to the interior forest. The physical properties like clay content, moisture content and pH are indicators of healthy soils, these properties increased to the interior forest. The significant increase in clay content will moving to the interior forest is an indication of low erosion. Similarly the moisture content along with infiltration rate increases to the interior forests. Thus obviously this study concludes that human disturbance have impacts on soil, the negative impacts on soils reduces with distance from habitation. The SQI was used to develop a soil quality map for P-V WLS, these shows that the human disturbance in the study area was not severe enough to affect the soil quality. The SQI also decreased toward the interior forests (Fig. 15).

5.3 Anthropogenic disturbances in forest

This study concludes that anthropogenic disturbances on forest ecosystems can be measured and these disturbances show an inverse relationship with distance from human habitation. The interior of forest had least signs of disturbance than that near to human habitation. The vegetation studies shows that the forests of P-V WLS are in degraded stage, these forests need to be protected and conserved. The major anthropogenic disturbances observed in these forests include cutting of trees (presence of stumps), lopping of branches and the existence of fire and the continuing stress of human disturbance will cause further degradation of the existing forests. The Human disturbance indicator (HDI) was used to develop the forest disturbance map of P-V WLS (Fig.16).

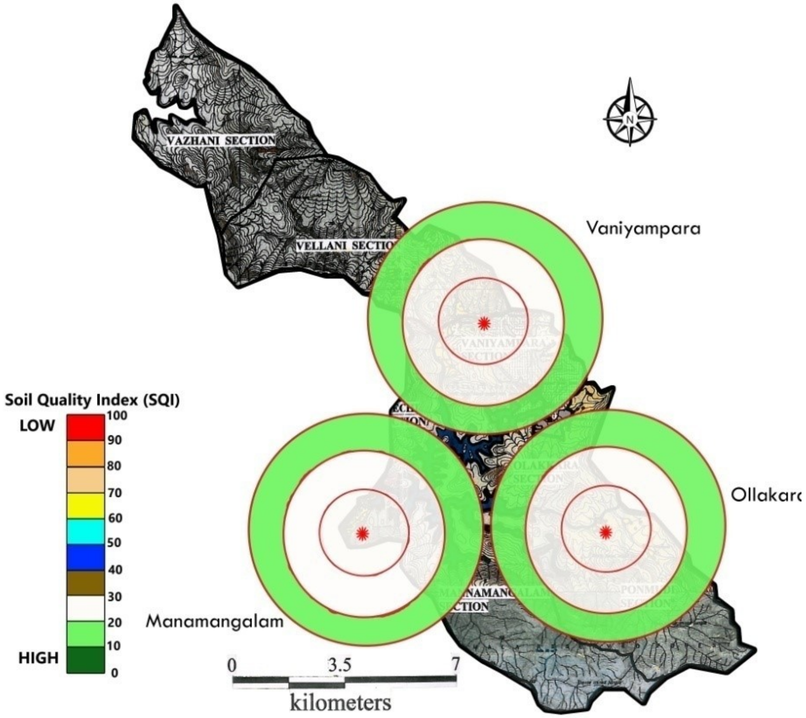

Fig. 15. Soil quality map for P-V WLS using SQI

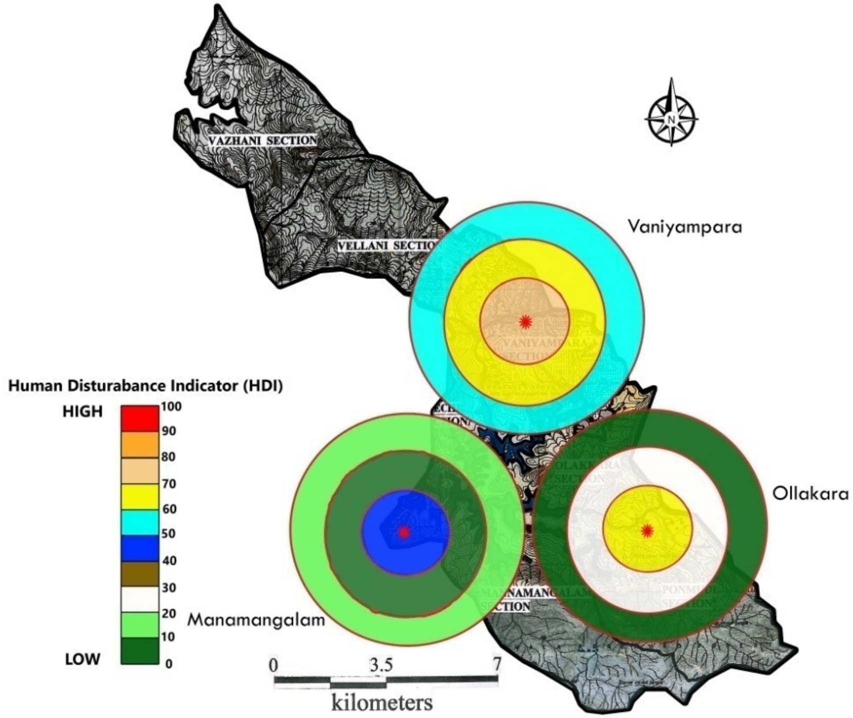

Fig. 16. Human disturbance map for P-V WLS using HDI

CONCLUSION

The study of vegetation, soil and signs of human disturbances showed the disturbed/ degraded stages of forests of P-VWLS. The vegetation represents the ecological state of the forest and its degradation, which was revealed by RISQ, IVI, canopy gap, LAI, mean tree height, mean tree GBH and IVI. These degradations were found to be decreasingtoward interior forest. The soil properties like clay content, moisture content and pH were also affected by disturbances. The human disturbances were observed to be decreasing towards interior forest and were significantly related to the above vegetation and soil properties. These degraded forests of P-V WLS require strict protection from anthropogenic disturbances to revert back to healthy and undisturbed climax formations. These protection and conservation strategies should be location specific.

SUMMARY

SUMMARY

The objective of this study was to identify the nature of human disturbances in the forests of P-V WLS and quantify its impacts. This study took into consideration the vegetation components, soil properties and signs of human activities in the sanctuary and to prepare a disturbance map for P-V WLS.

1. The forests of this sanctuary are secondary moist deciduous climax forest. This shows that the human activities in these forests to be intense in the past.

2. The secondary deciduous forests are degraded forms of evergreen and semievergreen climax forest.

3. The Ramakrishnan Index of Stand Quality (RISQ) for trees, saplings and regeneration shows that the forest is dominated by light demanders, which again shows the degradation in this forest. This ascertains the continuation of the disturbances in forest.

4. The RISQ value for regeneration was the lowest at the strata 3, which indicate the increase of shade tolerant species in the regeneration toward interior forest.

5. *Xylia xylocarpa* is an indicator of laterization, which is due to the progressive degradation of the exposed soil. *Xylia xylocarpa* had the highest IVI in the forests of P-V WLS, this shows that the forests are edaphically degraded.

6. The highest mean height and GBH of trees were observed to the interior forest.

7. The canopy gap area decreased towards interior forest.

8. LAI increased towards the interior forests, which indicates the closeness of canopy.

9. LAI in this study showed an inverse relationship between human disturbances like cuts/notches, lopping, fire damage and trails.

10. The clay content of soils increased towards the strata 3, this shows less soil erosion in the interior forest.

11. The soil pH, moisture content and infiltration rates increased towards strata 3, this shows healthy soils towards the interior of forests.

12. The signs of human disturbance decreased towards inner strata's, which shows that the human disturbances in forest had an inverse relationship with distance from habitation.

13. The vegetation, soil and human disturbance components of this study show that the human influence on forest was highly location specific. The Vaniyampara forest was highly disturbed and the Manamangalam forests were the least disturbed.

14. The human disturbance indicator (HDI) and soil quality index (SQI) showed the highest values in strata 1and the lowest in strata 3. This obviously ascertains that the disturbed state of strata 1 and also shows that disturbance decreased towards interior forest.

15. The HDI and SQI showed remarkable difference between locations.

15. The disturbance map of P-V WLS was made using HDI and SQI.

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QUANTIFICATION OF ANTHROPOGENIC DISTURBANCES IN FOREST AS A FUNCTION OF DISTANCE TO HUMAN HABITATION- A CASE STUDY FROM PEECHI - VAZHANI WILDLIFE SANCTUARY

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ABSTRACT OF THE THESIS

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ABSTRACT

A study was conducted inthe moist deciduous forest of Peechi- Vazhani Wildlife sanctuary to understand and quantify the impacts of human induced disturbances on forest, based on vegetation, soil and anthropogenic disturbance indicators. Three siteswere randomly selected from the sanctuary. Based on distance from these human habitations, the forests at these locations were divided into three strata (0-2 km, 2 -6 km and beyond 6 km). Four samples (each 2500 m^2) were selected randomly from each of the strata's and surveyed for trees, saplings, regeneration, soil and disturbance. Four sub samples of (100 m^2 each) in each of the selected samples were enumerated for herbs and shrubs.Various forest health indicators of vegetation, soil and disturbance were studied.Based on these indicators, the study developed Human Disturbance Indicator (HDI) and Soil Quality Index (SQI) to assess/ quantify the impact of human disturbance on forest. The ecological stages of these forests were assessed using Ramakrishnan index of stand quality (RISQ), vegetation composition and structure. This study observed the forests of P-V WLS to be secondary moist deciduous forests. Significant differences were observed between forests near human habitations and those away from it in terms of vegetation structure but not in diversity. Significant differences were observed between strata in terms of number of trees, mean GBH, mean height, canopy gap and LAI. However, differences were observed among the strata in species of diversity of saplings and seedlings. Significant differences were seen between strata in terms of clay fraction, moisture content, bulk density, pH, infiltration rate, available P and SQI. Differences were seen among strata in terms of HDI.However, all these differences were found to be influenced by location effects too. The study concluded that the degradation was influenced by location as well as distance from habitations. The disturbance map and soil quality map was developed using the indexes.

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APPENDICES

Appendices 1.(a) Double Ring infiltrometer

(b) Measuring infiltration rate using Double Ring infiltrometer

Appendices 2 – ANOVA table for vegetation parameters

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected model	Number of trees	24488.278[a]	4	6122.069	13.64	0
	Number of tree species	330.944[b]	4	82.736	10.855	0
	Mean height (m) of trees	169.577[c]	4	42.394	26.309	0
	Mean GBH (m) of trees	1.153[d]	4	0.288	18.91	0
	Tree basal area (m^2)	.047[e]	4	0.012	1.381	0.263
	Number of saplings species	72.944[f]	4	18.236	7.245	0
	Number of saplings	599.333[g]	4	149.833	8.773	0
	Number of regeneration species	60.611[h]	4	15.153	6.914	0
	Number of regeneration	10585.167[i]	4	2646.292	13.454	0
	Canopy gap area (m^2)	134406.694[j]	4	33601.67	14.293	0
	LAI	3.396[k]	4	0.849	13.81	0
	Number of trees	85751.36	1	85751.36	191.06	.000
	Number of tree species	6778.78	1	6778.78	889.39	.000
	Mean height (m) of trees	6895.48	1	6895.48	4279.15	.000
	Mean GBH (m) of trees	25.53	1	25.53	1675.16	.000
	Tree basal area (m^2)	0.34	1	0.34	39.91	.000
	Number of saplings species	1078.03	1	1078.03	428.29	.000
	Number of saplings	4830.25	1	4830.25	282.84	.000
	Number of regeneration species	1469.44	1	1469.44	670.44	.000
	Number of regeneration	26082.25	1	26082.25	132.60	.000
	Canopy gap area (m^2)	1020015.84	1	1020015.84	433.87	.000
	LAI	40.83	1	40.83	664.21	.000

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Location	Number of trees	16720.06	2	8360.03	18.63	.000
	Number of tree species	321.56	2	160.78	21.09	.000
	Mean height (m) of trees	54.90	2	27.45	17.03	.000
	Mean GBH (m) of trees	0.79	2	0.40	26.07	.000
	Tree basal area (m^2)	0.03	2	0.02	2.03	.148
	Number of saplings species	39.39	2	19.69	7.82	.002
	Number of saplings	453.17	2	226.58	13.27	.000
	Number of regeneration species	24.39	2	12.19	5.56	.009
	Number of regeneration	9360.67	2	4680.33	23.79	.000
	Canopy gap area (m^2)	22459.30	2	11229.65	4.78	.016
	LAI	1.00	2	0.50	8.10	.001
Distance	Number of trees	7768.22	2	3884.11	8.65	.001
	Number of tree species	9.39	2	4.69	0.62	.547
	Mean height (m) of trees	114.68	2	57.34	35.58	.000
	Mean GBH (m) of trees	0.36	2	0.18	11.75	.000
	Tree basal area (m^2)	0.01	2	0.01	0.73	.489
	Number of saplings species	33.56	2	16.78	6.67	.004
	Number of saplings	146.17	2	73.08	4.28	.023
	Number of regeneration species	36.22	2	18.11	8.26	.001
	Number of regeneration	1224.50	2	612.25	3.11	.059
	Canopy gap area (m^2)	111947.40	2	55973.70	23.81	.000
	LAI	2.40	2	1.20	19.52	.000
Error	Number of trees	13913.36	31	448.82		
	Number of tree species	236.28	31	7.62		
	Mean height (m) of trees	49.95	31	1.61		
	Mean GBH (m) of trees	0.47	31	0.02		
	Tree basal area (m^2)	0.26	31	0.01		

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Error	Number of saplings species	78.03	31	2.52		
	Number of saplings	529.42	31	17.08		
	Number of regeneration species	67.94	31	2.19		
	Number of regeneration	6097.58	31	196.70		
	Canopy gap area (m^2)	72879.78	31	2350.96		
	LAI	1.91	31	0.06		
Total	Number of trees	124153.00	36			
	Number of tree species	7346.00	36			
	Mean height (m) of trees	7115.01	36			
	Mean GBH (m) of trees	27.16	36			
	Tree basal area (m^2)	0.65	36			
	Number of saplings species	1229.00	36			
	Number of saplings	5959.00	36			
	Number of regeneration species	1598.00	36			
	Number of regeneration	42765.00	36			
	Canopy gap area (m^2)	1227302.31	36			
	LAI	46.13	36			
Corrected total	Number of trees	38401.64	35			
	Number of tree species	567.22	35			
	Mean height (m) of trees	219.53	35			
	Mean GBH (m) of trees	1.63	35			
	Tree basal area (m^2)	0.31	35			
	Number of saplings species	150.97	35			
	Number of saplings	1128.75	35			
	Number of regeneration species	128.56	35			
	Number of regeneration	16682.75	35			
	Canopy gap area (m^2)	207286.48	35			

	LAI	5.30	35				

a. R Squared = .638 (Adjusted R Squared = .591)

b. R Squared = .583 (Adjusted R Squared = .530)

c. R Squared = .772 (Adjusted R Squared = .743)

d. R Squared = .709 (Adjusted R Squared = .672)

e. R Squared = .151 (Adjusted R Squared = .042)

fj. R Squared = .483 (Adjusted R Squared = .416)

g. R Squared = .531 (Adjusted R Squared = .470)

h. R Squared = .471 (Adjusted R Squared = .403)

i. R Squared = .634 (Adjusted R Squared = .587)

j. R Squared = .648 (Adjusted R Squared = .603)

k. R Squared = .641 (Adjusted R Squared = .594)

Appendices 3. ANOVA table for soil parameters

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Soil moisture content	313.601[l]	4	78.4	10.93	0
	Bulk Density	.326[m]	4	0.081	12.115	0
	pH	2.509[n]	4	0.627	12.296	0
	EC	220049.564[o]	4	55012.39	4.409	0.006
	Soil carbon	3.399[p]	4	0.85	0.901	0.476
	Total Nitrogen	.188[q]	4	0.047	1.546	0.213
	Available P	3220.759[r]	4	805.19	4.443	0.006
	Available K	110494.444[s]	4	27623.61	6.313	0.001
	CEC	266.271[t]	4	66.568	2.99	0.034
	Clay	22.394[u]	4	5.598	4.909	0.003
	Silt	5.653[v]	4	1.413	1.642	0.189
	Sand	21.883[w]	4	5.471	1.019	0.413
	Infiltration rate	7119.111[x]	4	1779.778	15.109	0
	SQI	273.760[y]	4	68.44	1.656	0.185
	Soil moisture content	5791.21	1	5791.21	807.406	0
	Bulk Density	33.68	1	33.68	5010.32	0
	pH	1226.517	1	1226.517	24039.7	0
	EC	3348412.018	1	3348412	268.344	0
	Soil carbon	476.258	1	476.258	504.813	0
	Total Nitrogen	5.846	1	5.846	192.013	0
	Available P	10741.425	1	10741.43	59.275	0
	Available K	1048917.361	1	1048917	239.729	0
	CEC	43455.518	1	43455.52	1951.93	0

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
	Clay	9470.987	1	9470.987	8304.23	0
	Silt	7566.389	1	7566.389	8790.49	0
	Sand	163149.651	1	163149.7	30373.9	0
	Infiltration rate	951275.111	1	951275.1	8075.39	0
	SQI	16041.911	1	16041.91	388.131	0
Location	Soil moisture content	153.602	2	76.801	10.708	0
	Bulk Density	0.256	2	0.128	19.017	0
	pH	1.947	2	0.974	19.081	0
	EC	163830.091	2	81915.05	6.565	0.004
	Soil carbon	3.016	2	1.508	1.598	0.218
	Total Nitrogen	0.167	2	0.083	2.737	0.08
	Available P	2025.625	2	1012.813	5.589	0.008
	Available K	108469.097	2	54234.55	12.395	0
	CEC	196.253	2	98.126	4.408	0.021
	Clay	9.939	2	4.969	4.357	0.021
	Silt	3.735	2	1.868	2.17	0.131
	Sand	9.004	2	4.502	0.838	0.442
	Infiltration rate	6537.389	2	3268.694	27.748	0
	SQI	0	2	6.94E-05	0	1
Distance	Soil moisture content	159.999	2	79.999	11.153	0
	Bulk Density	0.07	2	0.035	5.214	0.011
	pH	0.562	2	0.281	5.51	0.009
	EC	56219.474	2	28109.74	2.253	0.122
	Soil carbon	0.383	2	0.192	0.203	0.817
	Total Nitrogen	0.022	2	0.011	0.356	0.704
	Available P	1195.133	2	597.567	3.298	0.05
	Available K	2025.347	2	1012.674	0.231	0.795
	CEC	70.018	2	35.009	1.573	0.224
	Clay	12.455	2	6.227	5.46	0.009
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.

Distance	Silt	1.918	2	0.959	1.114	0.341
	Sand	12.879	2	6.44	1.199	0.315
	Infiltration rate	581.722	2	290.861	2.469	0.101
	SQI	273.76	2	136.88	3.312	0.05
Error	Soil moisture content	222.351	31	7.173		
	Bulk Density	0.208	31	0.007		
	pH	1.582	31	0.051		
	EC	386820.258	31	12478.07		
	Soil carbon	29.246	31	0.943		
	Total Nitrogen	0.944	31	0.03		
	Available P	5617.6	31	181.213		
	Available K	135638.194	31	4375.426		
	CEC	690.149	31	22.263		
	Clay	35.356	31	1.141		
	Silt	26.683	31	0.861		
	Sand	166.512	31	5.371		
	Infiltration rate	3651.778	31	117.799		
	SQI	1281.267	31	41.331		
Total	Soil moisture content	6327.162	36			
	Bulk Density	34.214	36			
	pH	1230.608	36			
	EC	3955281.84	36			
	Soil carbon	508.903	36			
	Total Nitrogen	6.979	36			
	Available P	19579.784	36			
	Available K	1295050	36			
	CEC	44411.938	36			
	Clay	9528.736	36			
	Silt	7598.725	36			

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Total	Sand	163338.046	36			
	Infiltration rate	962046	36			
	SQI	17596.938	36			
Corrected Total	Soil moisture content	535.952	35			
	Bulk Density	0.534	35			
	pH	4.091	35			
	EC	606869.822	35			
	Soil carbon	32.646	35			
	Total Nitrogen	1.132	35			
	Available P	8838.358	35			
	Available K	246132.639	35			
	CEC	956.42	35			
	Clay	57.749	35			
	Silt	32.336	35			
	Sand	188.396	35			
	Infiltration rate	10770.889	35			
	SQI	1555.027	35			

l. R Squared = .585 (Adjusted R Squared = .532)

m. R Squared = .610 (Adjusted R Squared = .560)

n. R Squared = .613 (Adjusted R Squared = .563)

o. R Squared = .363 (Adjusted R Squared = .280)

p. R Squared = .104 (Adjusted R Squared = -.011)

q. R Squared = .166 (Adjusted R Squared = .059)

x. R Squared = .661 (Adjusted R Squared = .617)

y. R Squared = .176 (Adjusted R Squared = .070)

r. R Squared = .364 (Adjusted R Squared = .282)

s. R Squared = .449 (Adjusted R Squared = .378)

t. R Squared = .278 (Adjusted R Squared = .185)

u. R Squared = .388 (Adjusted R Squared = .309)

v. R Squared = .175 (Adjusted R Squared = .068)

w. R Squared = .116 (Adjusted R Squared = .002)

Appendices 4. ANOVA table for signs of anthropogenic disturbance

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Dead and fallen trees	36.500[z]	4	9.125	1.325	0.283
	Cut and notches on trees	74.111[aa]	4	18.528	23.103	0
	Lopped branches	10.278[ab]	4	2.569	4.893	0.004
	Fire damage trees	732.444[ac]	4	183.111	23.151	0
	Cattle or Human trails	1.278[ad]	4	0.319	2.68	0.05
	Dead and fallen trees	1600	1	1600	232.319	0
	Cut and notches on trees	78.028	1	78.028	97.295	0
	Lopped branches	13.444	1	13.444	25.604	0
	Fire damage trees	521.361	1	521.361	65.916	0
	Cattle or Human trails	34.028	1	34.028	285.526	0
Location	Dead and fallen trees	8	2	4	0.581	0.565
	Cut and notches on trees	5.389	2	2.694	3.36	0.048
	Lopped branches	2.889	2	1.444	2.751	0.079
	Fire damage trees	655.056	2	327.528	41.409	0
	Cattle or Human trails	0.389	2	0.194	1.632	0.212
Distance	Dead and fallen trees	28.5	2	14.25	2.069	0.143
	Cut and notches on trees	68.722	2	34.361	42.846	0
	Lopped branches	7.389	2	3.694	7.036	0.003
	Fire damage trees	77.389	2	38.694	4.892	0.014
	Cattle or Human trails	0.889	2	0.444	3.729	0.035
Error	Dead and fallen trees	213.5	31	6.887		
	Cut and notches on trees	24.861	31	0.802		
	Lopped branches	16.278	31	0.525		
	Fire damage trees	245.194	31	7.909		
	Cattle or Human trails	3.694	31	0.119		

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Total	Dead and fallen trees	1850	36			
	Cut and notches on trees	177	36			
	Lopped branches	40	36			
	Fire damage trees	1499	36			
	Cattle or Human trails	39	36			
Corrected Total	Dead and fallen trees	250	35			
	Cut and notches on trees	98.972	35			
	Lopped branches	26.556	35			
	Fire damage trees	977.639	35			
	Cattle or Human trails	4.972	35			

z. R Squared = .146 (Adjusted R Squared = .036)

aa. R Squared = .749 (Adjusted R Squared = .716)

ab. R Squared = .387 (Adjusted R Squared = .308)

ac. R Squared = .749 (Adjusted R Squared = .717)

ad. R Squared = .257 (Adjusted R Squared = .161)

Appendices 5. Human disturbance indicator (HDI) for P-V WLS

Location	Strata	Plots	L	T	C	ST	BT	LD	S	DT	FT	Score	HDI
Manamangalam	**1**	1	1	1	1	0	0	0	1	0	1	3	60
		2	1	1	1	0	0	0	1	0	1	3	60
		3	0	1	1	0	0	0	1	1	1	1	20
		4	1	1	1	0	0	0	1	1	1	2	40
	2	1	0	1	1	0	0	0	1	1	1	1	20
		2	0	1	0	0	0	0	1	1	1	0	0
		3	0	1	0	0	0	0	1	1	1	0	0
		4	0	1	0	0	0	0	1	1	1	0	0
	3	1	0	1	1	1	1	0	1	1	1	3	60
		2	0	0	0	0	0	0	1	1	1	-1	0
		3	0	0	0	0	0	0	1	1	1	-1	0
		4	0	0	0	0	0	0	1	1	1	-1	0
Vaniyampara	**1**	1	1	1	1	1	1	0	1	1	1	4	80
		2	1	1	1	1	1	0	1	1	1	4	80
		3	1	1	1	1	1	0	1	1	1	4	80
		4	1	1	1	1	1	0	1	1	1	4	80
	2	1	1	1	1	1	1	0	1	1	1	4	80
		2	0	1	0	1	1	0	1	1	1	2	40
		3	0	1	1	1	1	0	1	1	1	3	60
		4	1	1	1	1	1	0	1	1	1	4	80
	3	1	1	1	1	1	1	0	1	1	1	4	80
		2	0	1	0	1	1	0	1	1	1	2	40
		3	1	1	1	1	1	0	1	1	1	4	80
		4	0	1	0	1	1	0	1	1	1	2	40
Ollakkara	**1**	1	0	1	1	1	1	1	1	1	1	4	80
		2	1	1	1	1	1	0	1	1	1	4	80
		3	1	1	1	1	0	0	1	1	1	3	60
		4	0	1	1	1	0	0	1	1	1	2	40
	2	1	1	1	1	0	0	0	1	1	1	2	40
		2	0	1	0	0	0	0	1	1	0	1	20
		3	0	1	0	0	0	0	1	1	0	1	20
		4	0	1	1	0	0	0	1	1	1	1	20
	3	1	1	1	0	0	0	0	1	1	1	1	20
		2	0	1	0	0	0	0	1	1	1	0	0
		3	0	1	1	0	0	0	1	1	1	1	20
		4	0	1	0	0	0	0	1	1	1	0	0