FLORISTIC DIVERSITY AND REGENERATION STATUS OF MOIST DECIDUOUS FORESTS IN THRISSUR DISTRICT, KERALA: REASSESSMENT AFTER THREE DECADES

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled, **"Floristic diversity and regeneration status of moist deciduous forests in Thrissur District, Kerala: Reassessment after three decades"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"Floristic diversity and regeneration status of moist deciduous forests in Thrissur District, Kerala: Reassessment after three decades"** is a record of research work done independently by **Mr. Abhi Jamatia (2017-17-010)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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C E R T I F I C A T E

We, the undersigned members of the advisory Committee of **Abhi Jamatia, (2017-17-010)**, a candidate for the degree of **Master of Science in Forestry** with major in Silviculture and Agroforestry, agree that this thesis entitled **"Floristic diversity and regeneration status of moist deciduous forests in Thrissur District, Kerala: Reassessment after three decades"** may be submitted by him in partial fulfillment of the requirement for the degree.

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Place: Vellanikkara **Abhi Jamatia**

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Introduction

1. INTRODUCTION

Earth's biota constitutes a wide range of diversity of living beings. Taxonomists so far have catalogued as many as 30 million species of animals and plants inhabiting the earth in a variety of habitats and ecosystems (Wilson, 1992). In spite of such vast disparity, there is a biological relationship that exists between all the elements of the ecosystems. It is a fact that the living nature plays a significant role in the maintenance of ecological order of the ecosystems. This order is maintained by biodiversity, inter dependence among the different life forms, sustained productivity and food chain relationships, and maintenance of natural process of nutrient cycling, energy flow, homeostatic mechanism, evolutionary process and adopting potentiality of the living forms to the changing environment. The totality of the variations found in species, habitats and ecosystems is referred to as biological diversity or biodiversity.

The Botanical and Zoological Survey of the country have estimated that India's biodiversity constitutes 1,26,188 species (Khoshoo, 1996). These cover all the five kingdoms namely Monera, Protista, Fungi, Animalia and Plantae. According to the World Conservation Monitoring Centre (WCMC, 1992), 1,604,000 species have been detailed at the global level. India contributes 8 % of the world biodiversity in only 2-4 % land area globally. Out of 1-6 million species of life forms identified from different habitat types on earth. India possess 49,209 species of plants including 5,000 species of algae, 1600 lichens, 20,000 fungi, 2,700 bryophytes, 600 pteridophytes and 15,000 flowering plants against the world figure of 392, 700 which represents 12.53% of total plant species present on earth (Strauss and Agrawal, 1999). This immensely diverse living resources constitute the plant diversity of India and is treated as a genetic store house which is vital to shape the evolution of the life forms. Further all the life forms are inter related and balance the biodiversity. Any break in the fragile link between them disturbs the overall diversity of living forms.

It is well known that prosperity of the people depends the way they use their natural resources. Among the natural resources, forest occupies a unique position on account of its non-renewable nature. Tropical forest ecosystems in particular are endowed with rich biological diversity and habitat heterogeneity and play cardinal role in maintaining environmental stability and ecological balance. Tropical natural forests were evolved though millions of years of successional process in tune with the prevailing climate and edaphic conditions. In addition to the rich biological diversity, the forests also play significant role in dispensing multitude of ecological services that are essential for the survival of mankind. For instance, the agricultural prosperity of the state is primarily attributed to the vast stretches of natural forests sprawling in the Western Ghats and along the banks of the rivers in the plains of Kerala.

Moist Deciduous Forests (MDF) form the predominant natural forest vegetation in Kerala that once covered the lion share of the geographical area of the state. They enjoy a dominant space in the humid tropics by virtue of their species diversity and abundance and adaptability to changing environmental conditions as compared to evergreen forests that are fragile and sensitive to external perturbations. They played major role in maintaining the ecological balance and environmental stability of the Western Ghats and connected landscape for several centuries. On account of the vast expanse of forest cover, the MDF in the Western Ghats of Kerala contributed substantially to the agricultural prosperity especially in the midlands of Kerala primarily by regulating the hydrological regime that ensured round the year supply of water through perennial streams and rivers.

However, the last century has seen massive destruction of these valuable ecological assets on account of their economic advantages and intense human pressure on land for agricultural activity. Today the deterioration of the environment has been an inevitable outcome of developmental activities which was further aggravated the increasing strain on natural resources. The MDF are facing huge degradation due to intense development oriented man-made activities.

This has caused irreparable damages to the health of our pristine forests. Consequent to indiscriminate logging and demographic pressure the species diversity and structural attributes of these valuable forests have drastically reduced.

The health of natural forests is closely linked with the ecological services rendered by them. The serious reduction in the water yield in the rivers and streams emerging from the Western Ghats is a true reflection of the poor health of the natural forests which once regulated the hydrological balance of the state. Yet another benefit from natural forests is their enormous contribution to climate change mitigation as potential carbon sinks (Bernstein, L. *et. al.,* 2008). Natural forests especially MDF play cardinal role in meeting the INDC commitments of the country towards carbon neutrality.

In Kerala, these forests were under various management practices that ranged from the primitive slash and burn practices to selection felling. With the launching of the Forest Conservation Act, 1980 and subsequent awareness on the forest conservation, the exploitation of MDF has substantially reduced in Kerala which may have contributed to the eco- restoration of these forests. However, the recurring climatic extremes in Kerala contributed by global climate change may have their impacts on the ecological stability of these forests as well. Hence, comprehensive, long term studies on the present ecological status of the MDF in Kerala assume greater relevance. Unlike the prolific studies in the production forestry sector, such ecological studies on the natural forests are very much limited in India, particularly in Kerala.

One such attempt was made three decades back in selected locations in the MDF of Thrissur forest division (Narayanan, 1990). The study portrayed vast decline in forest regeneration status and species diversity and human activity was cited as the prominent driver of ecosystem degradation. Ever since this study, there has been considerable positive shift in the forest management strategies with stringent conservation measures. However, the climate aberrations in the past decades may have influenced the regeneration dynamics of these forest types. Hence, it would be interesting to revisit the previously studied MDF areas in the Thrissur district and reassess the regeneration status, species diversity and other vegetation parameters after a period of 30 years. This investigation may help to portray the changes in vegetation dynamics during the past three decades and to examine the possible drivers of their change.

The investigation was planned with the following objectives:

1. To assess the florisitc diversity, structure and regeneration status of moist deciduous forests in the selected locations in Thrissur forests, Kerala.
2. To investigate the vegetation changes and the drivers of change compared to a similar study carried out in the same locations three decades before.

Review of Literature

2. REVIEW OF LITERATURE

2.1 PHYTOSOCIOLOGY

The study of plant communities with regard to their components, structure and classification including species diversity, growth, trends of succession, etc. is phytosociology. The vegetation ecology, therefore is the study of both the structure of composition of species as well as the interrelationship of species in communities. Again it includes the study of community variations in the spatial or geographic sense, the study of community development, and change and stability over time (Muller-Dombois and Ellenberg, 1974). Plants typically occur together in repeating groups of associated plants called communities and are best described by the most typical species of a specific community (Tansley, 1935; Whittaker, 1970).

A mutual relationship can be seen between plants growing together with the environment. Plant composition in a community differs from habitat to habitat which play a vital role in determining the type of community. The ecosystem reaction to outer stimuli leads a certain pattern regardless to ecosystem type or stimuli (Lugo, 1978). Ecologists assume that the distribution of plant species in a community is not only controlled by the physical conditions prevailing in the habitat but the competitive interactions exists among the populations may also contribute to their distribution (Walter, 1979). The investigation of phytosociology permits for a wider insight into the structural makeup of the vegetation and it renders relatively correct results on the basis of a detailed analysis of sample plots distributed over the whole investigation area.

The relations of plant community with respect to their habitats were highlighted by many workers (Drude, 1897, Warming, 1909). The successional evolution of a community from its pioneer stage to the relatively stable climax stage was studied by Clement (1916, 1928). Clements had the view that the community similar to an organism is born, grows, reproduces and dies and all these various development stages or can be explained as an organic being. Each and every climax community can be formed again by repeating the successional stages in the same pattern. Further, the competition among the plants is known to play a vital role in forming their grouping patterns. However, the effect of competition can only be refined through experiments, whereby the relation of plants of the community are investigated under controlled conditions (Klapp, 1951). Knapp (1954) perform investigations on inter-specific competition for explaining relations in vegetation studies. It can lead to more accurate basis for studies in vegetation dynamics through experimental task with simplified plant communities. This topic received wide attention through Cowels (1899), Cooper (1913) and Clements (1916).

Clements (1916) had developed a system of classification based on successional patterns. He propounded a climatic climax community to which every other community was related in a sequence. This proposal was validated by many ecologists and used in similar or modified forms e.g., by Tansley (1936) in his description of the British Isles. Often floristic constitution has been considered as one of the important characters of the community (Danseeau, 1960). Each and every community species has its own ecological amplitude and also specific relationship to the environment. It has been observed that species with allelopathic properties decreases species diversity (Whittaker, 1970; McNaughton and Wolf, 1973). Often the plant distribution act as a means to the identification and categorization of the species in taxonomic ranking and species do not show uninterrupted distribution except few endemic species limited to a specific area.

2.1.1 *Phytosociology studies in Kerala*

Narayanan (1988) reported that the tropical moist deciduous forests of southwest India have three vertical levels of organization: upper, middle and lower tree strata. Highest species richness was in the middle stratum and least in the lower stratum. The upper and middle strata species (>20 cm dbh) contributed maximum basal area and tree density compared to lower stratum. Regeneration in teswarms of established seedlings was not proportional to that of unestablished. Generally saplings showed low survival probability and poor conversion rate to poles. Rajesh *et. al.*, (1996) in Sholayar Forest, Kerala reported that the density of typical early species declined as gap age in the forest increased. On the other hand, the concentration of late seral species (e.g. *Palaquium ellipticum*, *Knema attenuata* and *Mesua nagassarium*) increased in the older gaps.

Studies of Chandrasekara and Ramakrishnan (1994) in humid tropical forest of Kerala concluded that seedling regeneration and establishment occur in different patterns in gaps of different ages and sizes. The establishment and growth patterns of fundamental species like *Palaquium ellipticum* in selection felled forest may reach a stage like those in natural gaps only after about 10 years. Thus, the regeneration is affected in selection felled forest as well as repeated disturbance in these areas may remove these species and thus cause the change in forest structure.

Man-made disturbance causes interruption of forest structure and alteration in species composition which ultimately leads to decrease in tree species richness and abundance which are the major features of forests (Jayakumar and Nair, 2013). New recruits were detected in all vegetation types which indicates that the species are not heading towards extinction, alternately they may coexist with the resident species. However, the regeneration dynamics may alter in such disturbed forests. In a detailed vegetation study in Anakatty Hills of western ghats, it was seen that regeneration was influenced by different processes (Anitha *et. al.,* 2010). It is concluded that scarce, limited and old-growth 'specialists' may face 'local extinction' or replenished by disturbance-adapted generalists i.e., pioneer or secondary species. This condition may gradually lead to the conversion of five important vegetation types in the region into two major types and a few minor types in which the species composition would be a mixture of all five types i.e., a mosaic of various successional stages. Species with higher number of individuals in the recruiting class expected to be dominant in the near future. If it is not reserved, this structural disruption and species reduction may affect the functional qualities of the habitats (Anitha *et. al.*, 2010).

2.2 PLANT COMMUNITIES

Plant communities are studied using analytical characters which can be sub-divided into quantitative (frequency, density, abundance, basal cover, dominance etc.) and qualitative characters (physiognomy, phenology, life-form, etc.). Clements (1916) classified communities into plant formations, associations etc. Jaccard's formula was subsequently modified to explain quantitative aspects (Ellenberg, 1956) and qualitative aspects (Sorensen, 1948) of community change. Of these Sorensen's modification is widely accepted. Raunkiaer (1934) classified the plant communities into five major life forms viz. 1. Phanerophytes (P) 2. Chamaephytes (Ch), 3. Hemicryptophytes (H) 4. Cryptophytes (Cr) and Therophytes (Th) depending upon the general appearance and growth of the species. This classification is most widely understood and acclaimed.

There are two major concepts prevail in describing the classification of plant communities, individualistic and vegetation continuum concepts. According to the former, the communities are organised as basic units and may be classified, while the latter considers communities as an assemblage of species with similar environmental requirements and so cannot be classified as discrete units. The individualistic concept suggests that each species has a distribution within its total range of tolerance to environmental factors and tends to be distributed independently of others, occurring where it can disperse and survive (Gleason, 1926). This concept was criticised by some workers who stressed on interrelations between species of a community and considered that communities varied continuously in space with each point of the continuum being equally probable (Whittaker 1962; Curtis, 1959). Their view was that clear cut lines of separation between vegetation as well as environmental conditions will not occur under natural conditions and which lead to the concept of vegetational continuum

(Whittaker, 1962; Curtis and McIntosh, 1950). The continuum concept was further elaborated and communities expressed as landscape pattern and parallel to the environmental /vegetational gradient or ecocline (Whittaker, 1967). Further, it is not possible to draw a sharp line indicating the beginning of one community and the end of another. Instead, there is a zone of transition or an area where variety of species is higher than that in the neighbouring communities- a feature called "principle of edges". The plant communities fused into each other showing a explicit gradient which is connected with the environmental gradient (, 1968).

With regard to conservation it is important to record changes with time, biomass and productivity of communities with respect to environmental variables. The vegetation cover reflects numerous changes in its density, structure and composition with changes in environmental condition. The most important structural property of a community is an explicit quantitative relationship between scarce and prolific species. The phytosociological features and floristic constitution are beneficial for comparing one community with the other under certain environmental stress factors (Singh *et al.*, 1998). Often local and small catastrophic events decides the overall dynamics and floristic characteristics of forest communities (Ashton, 2003). Each of the species within the community has huge measures of its structural and functional individuality with different modality and ecological amplitude (Singh and Joshi, 1979).

2.3 SPECIES DIVERSITY

Floristic composition of vegetation and species diversity reflects the adaptation potential and gene pool of the community (Odum, 1971). Vegetation structure often regarded as index to general climate and soil conditions of a region. When taxonomic diversities are analysed with higher level taxonomic categories, such as genera or families may provide more information about the origin of diversity in the community (Ricklefs and Miller, 1999). But species play different roles within the community that are reflected in differences in habitat preference, activity period and other aspects of behaviour and ecology. And so, within the community there is not only taxonomic diversity, but ecological diversity as well (Ricklefs and Miller, 1999).

There are two views of species diversity prevailing in ecology. The local/ deterministic view holds that diversity is determined principally by biological interactions such as competition occurring at the local level. The regional/historical view emphasizes the importance of species differentiation and movement at the regional level and the interaction between local and regional processes. Contemporary ecology incorporates both of these views (Ricklefs and Miller, 1999). However, the diversity stability hypothesis explains that the traits differ in the species and ecosystems are likely to contain some species that can survive in a given environmental disturbance and thus compensate for competitors that are decreased by that disturbance (Lawton and Brown, 1993). This view thus predicts that biodiversity in terms of species diversity should promote resistance to disturbance (Tilman and Downing, 1994). In contrast, the species redundancy hypothesis states that the species are so similar that ecosystem functioning is independent of diversity (Lawton and Brown, 1993).

Biodiversity is very important for the survival of humans, economic built-up, ecosystem function and stability. It is not evenly distributed on the earth. The diversity increases from the poles to equator, and from low elevation to high elevation and greater on continents than on islands. Since the biodiversity is intricately linked with human being it is critically important for each and every nation's existence (Mittermeier et al. 1998). Biodiversity has allured the world attention because of the growing awareness of its importance on one hand and extensive decline on other hand. In the present situation, about 20% of all species are estimated to be vanished within a span of 30 years. The present rate of deforestation in tropical forests is 0.8% in a single year. It has been assumed that 2 to 5 species per hour are lost from tropical forests alone. Biodiversity is also being depleted because of legal and illegal trade in 8 economically and medicinally important plant species as levels of exploitation of these species are high (Singh and Kushwaha, 2008).

Tropical forests represent the most biologically diverse terrestrial ecosystem and harbor more than 50% of known plant species (Mayaux *et al*., 2005) in just 7% of the land area and vary in species richness from site to site and within plant communities (Okuda et al. 1997). Due to high species richness and concentration of endemic species, tropical forests are considered as an important terrestrial ecosystem on the earth (Mittermeier et al. 1998). It is very important that rich biological diversity of tropical rain forests has to be studied exhaustively to explore the complex interactions between biodiversity and ecosystem functioning (Giriraj et al. 2008). Despite the recent interest in tropical rainforests, studies on the biological diversity of dry forests has received less attention while it depleting at alarming pace. In recent years, quantitative floristic inventories have been applied to illustrate forest vegetation all over the world (Pappoe et al. 2010). Tree diversity is the basic aspect of biodiversity, as it provides habitat and resources for majority of the species in the forests and taxonomically better known among other species (Gentry 1992).

2.4 DIVERSITY INDICES

A number of quantitative diversity indices have been proposed to understand the phytosociology of the forest community (Sorensen, 1948, Simpson, 1949, Margaleff, 1958). Preston (1962), Margaleff (1958), Lloyd and Ghelardi (1964) have given particular attention to the distribution of number of individuals among the species of a community. Several other indices have also been devised to compare the community similarity indices (Whittaker, 1952; Bray and Curtis, 1957).

2.4.1 *Diversity in moist deciduous forests of India*

Limited studies are available on the MDF of India. In a study in the Nayagarh Forest Division, Odisha177 species of trees as been reported from a study area of 60 hectares that proved a medium level of diversity (Sahoo *et. al.,* 2016). The study revealed Shannon's Index varying from 2.07 to 3.79 across different sites which are within the reported range (0.83–4.1) for the forests of Indian sub-continent (Ayyappan and Parthasarathy 1999; Panda *et al.,* 2013).

In a phytosociological study in the Central Western Ghats, Kodagu, three different forest types viz. moist deciduous forests, dry deciduous forests and evergreen forests were enumerated (Hareesh and Nagarajaiah, 2019). The number of species found in these forests were 36, 41 and 121 respectively with a Shannon's index of 2.85, 2.99 and 4.55 respectively. A Simpson's Index value of 0.084 was reported in the moist deciduous forests. In yet another detailed study in Suruli falls, Southern Western Ghats, two distinctive tropical moist deciduous and dry deciduous forests were studied which yielded 39 and 34 species respectively. The Shannon's index and Simpson' index in moist deciduous forests was reported a value of 2.37 and 0.20 suggesting very low diversity. Also, much lower diversity indices (Shannon' index and Simpson's index was 2.65 and 0.11 respectively) were reported in dry deciduous forests (Naveenkumar and Sundarapandian, 2018).

In yet another study, Majumdar *et. al.,* (2012) recorded a total of 105 species of 79 genus and 39 families in four sites in lowland primary and secondary moist deciduous forests in Tripura. The mean Shannon– Wiener diversity index and mean Simpson's dominance index of all sites was recorded 3.02 and 0.10 respectively.

2.4.2 *Diversity in other tropical forests of India*

Great variability has been observed in diversity among tropical forest ecosystems in India. A study in dry deciduous forests in Southern Andhra Pradesh described total of 137 tree species within the 3 ha plots area, representing 98 genera in 44 families where Shannon-Wiener index (H) ranges from 4.11 to 4.89 (Reddy *et. al., 2008*). Whereas a study in a tropical dry deciduous forest of Bhadra Wildlife Sanctuary yielded a total of 1766 individuals that belonged to 46 species, 37 genera and 24 families. The Shannon-Wiener and Simpson's indices were 3.30 and 7.94, respectively for the whole 2 ha plot (Krishnamurthy *et. al.,* 2010).

Parthasarathy and Kadavul (1999) in Semi-Evergreen forests of Sherverayan Hills reported a total of 80 woody species that belonged to 71 genera and 44 plant families. Out of 4 sites studied, species richness was greatest in the less-disturbed plot where Shannon index ranged from 2.37 to 3.072 while the Simpson index ranged from 0.070 to 0.143. Yet another study in the tropical deciduous forests of the Eastern Ghats sampled over an area of 222 ha, revealed 882 plant species belonging to 532 genera and 129 families. The values of the two diversity indices varied greatly across the studied districts where Shannon's Index varied from 1.85-2.05, Simpson Index ranged between 0.013 and 0.018 (Panda *et. al.,* 2013). Phytosociological study in the Semi-evergreen forests of Manipur reported a total of 123 species (17 trees, 36 shrubs, 70 herbs) belonging to 48 families where the value of diversity index ranged from 0.109 to 2.49 (Devi and Yadava, 2006)

2.5 BASAL AREA IN TROPICAL FORESTS OF INDIA

Stand basal areas is often described as the index of the tree growth and productivity on forests. Distribution of basal area among the various social classes of a tree species in forests assumes greater relevance in appreciating the fitness of a particular tree species in a forest community. Sahoo *et al*., (2017) in MDF of Nayagarh, Odisha reported that the total basal area for the 60 ha area inventoried was 1014.65 m^2 which stands to be 16.91 m^2 ha^{-1}. In another phytosociology study of MDF of Simlipal, Odisha the mean basal area value was reported 71.11 m^2/ha ranging from 48.705 to 104.918 m^2/ha across eighteen different sites (Mishra and Mohanty, 2002). A similar study in moist deciduous forests in Tripura concluded that the mean basal area for all four forest groups inventoried was 18.01 m^2 ha^{-1} and was found maximum for Shorea community (26.21 m^2 ha^{-1}) and minimum for Hevea community which was 10.57 m^2 ha^{-1} (Majumdar *et. al.,* 2012).

In a study on the tropical forest types in Kodagu district, Karnataka, Hareesh and Nagarajaiah (2019) reported a basal area of 38.29 m^2 ha^{-1}, 38.58 m^2 ha^{-1} and 46.65 m^2 ha^{-1} for tropical dry deciduous, moist deciduous and evergreen forests respectively. In a similar study in the moist deciduous teak forests of

Karnataka the basal area ranged from 27.1 to 75.7 m^2 ha^{-1} yielding a mean basal area of 29.7 m^2 ha^{-1}. It is noteworthy that these reported values are fairly high as compared with many other tropical forest in India. For instance, investigations in the moist deciduous *Shorea robusta* forests in Uttar Pradesh and Uttarakhand reported that the basal area of 27 sites studied ranged from 20.2 to 67.6 m^2 ha^{-1} giving a mean basal area of 34.5 m^2 ha^{-1} (Rai, 2016). However, higher mean stand basal area also has been reported form Kakanad National Park in the Western Ghats that ranged from 61.7 to 94.6 m^2 ha^{-1}(Parthasarathy (1999). A similar study in Western Ghats inventoried in tropical deciduous forests of Kanyakumari, the basal area of adult trees in two sites were 34.7 m^2 ha^{-1} and 30.8 m^2 ha^{-1} (Sundarapandian and Kothandaraman, 2017).

However, report suggest that BA distribution in the tropical deciduous forests of Eastern Ghats were relatively lower to the tune of 10.47 m^2 ha^{-1} (Panda *et al.,* 2013). Conformity to these results yet another study investigated in tropical deciduous forests of Eastern Ghats revealed the BA ranged from 13.05 m^2 ha^{-1} to 28.42 m^2 ha^{-1} (Naidu *et. al.,* 2018). In an earlier study in the dry deciduous forest of Eastern Ghats, Andhra Pradesh, similar lower BA values has been reported to the extent of 11.43 m^2 ha^{-1} (Reddy *et. al.,* 2008).

Devi and Yadava (2006) in tropical semi-evergreen forest of Manipur reported the basal area to be 18.9 to 19.58 m^2 ha^{-1}. However, studies in the Semi-Evergreen Forests, Shervarayan Hills suggested higher BA that ranged from 21.6 to 44.3 m^2 ha^{-1} with a mean value of 34.9 m^2 ha^{-1} (Kadavul and Parthasarathy, 1999).

Tropical evergreen forests are reported to share higher BA compared with other forest types. For example, study in tropical wet evergreen forests of Namdapha National Park, Arunachal Pradesh recorded basal area ranges from 7.81 to 98.58 m^2 ha^{-1} (Nath *et al.,*2005) while the tropical rain forests of Southern and Northern Karnataka reported a basal area of 47.12 m^2 ha^{-1} and 41.54 m^2 ha^{-1} respectively (Sathish *et al.,* 2013). In a long term monitoring of six forest sites of

1 hectare each in moist tropical forests of Uttara Kannada district, Western Ghats, a significant increase in basal area after a span of twenty-four years has been reported. The death of trees opens the canopy, facilitates the availability of more light to lower strata, and reduces competition for moisture and nutrients owing to which it stimulates the growth of surviving neighbouring trees henceforth increasing the basal area (Bhat *et al*., 2011).

2.6 VEGETATION DENSITY

Vegetation density is yet another yardstick often described to distinguish the health and productivity of forest ecosystems. This is apparently variable with the type of the forest and prevailing biophysical conditions. In a study in Central Western Ghats, the number of stems per hectare was found to be 386, 391 and 491 respectively for tropical dry deciduous forests, moist deciduous and evergreen forests (Hareesh and Nagarajaiah, 2019). A similar study in the Southern Western Ghats reported a density of 275 stems/ha and 502 stems/ha in dry deciduous forests and moist deciduous forests respectively (Naveenkumar and Sundarapandian, 2018).

Variable density estimates are available from other Indian forests as well. For instance, a detailed study in the moist deciduous forest in Nayagarh Forest Division, Odisha which revealed a density ranging from 355.33 stems/ha to 740.53 stems/ha with a mean density of 526.23 stems/ha (Sahoo *et. al.,* 2017). Mishra and Mohanty (2002) in the moist deciduous forests of Simlipal biosphere reserve recorded a much higher density of 650 to 985 stems/ha with a mean density of 795 stems/ha studied across eighteen different sites. Whereas, in moist deciduous forests of Tripura, the density ranges were from 299.67 stems/ha to 464.77 stems/ha with a mean density of 391.32 stems/ha across four different sites (Majumdar *et. al.*,2012).

Interestingly the dry deciduous forests in India also recorded higher stand density. For example, about 883 stems per ha was reported from the tropical dry deciduous forests of Bhadra Wildlife Sanctuary, Karnataka (Krishnamurthy *et al*., 2010). A similar study in dry deciduous forests of North-Central Eastern Ghats recorded a mean tree density of 493 stems/ha ranging from 395 to 573 stems/ha enumerated across six plots (Naidu *et al.,* 2018). A detailed phyto-diversity study carried out in tropical deciduous forests in 10 districts of several states across Eastern Ghats with an inventory area of 222 hectare. The study depicted stand density between 309.45 stems/ha to 655.47 stems/ha resulting a mean density of 352.95 stems/ha at the landscape level (Panda *et. al.,* 2013)

2.7 REGENERATION OF TREE SPECIES

The term regeneration refers to processes including production, dispersal and germination of tree seeds and the subsequent establishment of seedlings. Regeneration behaviour of the forests largely depends on the production of seed and its germination, establishment of recruits and saplings in the forest (Rao, 1974). The presence of ample number of young poles in a given species population specifies successful regeneration while the absence of seedlings and saplings represents poor regeneration in a forest (Saxena and Singh, 1984).

The study of regeneration of forest trees has implications for the management of natural forests and is one of the thrust areas in forestry. The vegetative re-growth or sprouting following death of aboveground portions of mature trees can also be termed regeneration. Regeneration involves both the physiological development, which are inherited (genetic), as well as external ecological factors such as interactions with other plants and animals, climate and disturbances like fire or landslide (Price et al. 2010). Seed production of a tree is related to species, age, size, vigour and seed mast years of the parent tree, whereas long distance dispersal and germination of seeds are largely stochastic process (as opposed to deterministic processes) such as wind speed or animals' movements (Price et al. 2010).

The successful establishment of seedlings, the survival and growth processes that transform seedlings into saplings, can be even more complex, because plant ecology, environment factors and many random events that play significant or often deterministic roles. Regeneration processes contribute both to the maintenance of species composition in forests as well as allow the species to invade new regions it contributes to changes in species composition and leading to the migration of tree species across landscapes. Mortality in the regeneration phase of forests may be high where only a few individuals that germinate become seedlings and only a few seedlings grow into saplings (Botkin, 1992).

The success of natural regeneration depends generally on survival and dispersal of seeds and germinants. For the newly germinated seedlings successful establishment in sufficient number is the weakest link in the whole chain of the processes (Dwivedi, 1980). High mortality occurs during juvenile stage of seedlings due to several factors such as climatic, soil, biotic and genetic factors. Growth of seedlings and mortality are the most important factors in determining the survivor of immature trees in natural regeneration as numerous trees perish without reaching maturity (Messier et al. 1999). However, regeneration doesn't depend on plants alone because the process also involves physical factors such as light, temperature, moisture, nutrients and biotic factors such as herbivory, disease and competition with plants and animals (Barnes *et al*., 1980). Generally, regeneration of tree species is affected by man-made disturbance (Khan and Tripathi, 1990) and natural phenomena (Welden *et. al*., 1991).

In harvested or disturbed forest stands, natural regeneration occurs in four sequential stages, namely (1) a stand initiation and regeneration stage, (2) a thinning or stem exclusion stage, (3) a transition or under storey regeneration stage, and. (4) a steady state or old growth state (Oliver and Larson, 1996). Disturbance during any of these stages is going to induce physiological impairment of the trees and result in the failure of the overall stand regeneration (Kozlowski, 2002).

In contrast to stand replacing disturbances, which may eliminate all biological legacies and initiate primary succession, natural regeneration is usually a faster process when the disturbance magnitude is less strong and when biological legacies are left on the site. The previous vegetation would have altered the environmental conditions of the site, particularly the chemical and physical properties of the soil in a variety of ways. The intermediate disturbance hypothesis states that how frequency, magnitude and time may influence plant diversity and also presumes that coexisting species should be found at high numbers in intermediate magnitudes of these processes (Connell, 1978). Eight developmental stages have been identified in a natural forest series namely, "disturbance and legacy creation, cohort establishment, canopy closure, biomass accumulation or competitive exclusion, maturation, vertical diversification, horizontal diversification and pioneer cohort loss" by comparing different classification schemes addressing the stand development stages (Oliver and Larson, 1990; Spies *et al*., 1996; Carey and Curtis, 1996)

Several workers (such as Denslow 1987; Wright, 2002) mentioned that natural gap plays important role in forest regeneration. Gap regeneration is a composite process as the dynamics are affected by several factors associated with gap age and size, the neighbouring plant and animal communities, climate and human interference among others (Schupp *et al.,* 1989).

In the regeneration process, microsites also play important role since they affect the seedling establishment (Grubb, 1977; Sugita and Tani, 2001). The areas that differs in environmental characteristics on the spatial scale of an individual seed or seedling known as microsites (Titus and Moral, 1998). Micro-environmental factors differ with changes in season which influence the growth stages i.e. seedling, sapling and young trees of the plant communities that preserve the population structure of any forest. Therefore, it becomes an essential issue to understand the tree diversity, population structure and regeneration behaviour of forest communities for the maintenance of both natural forest and plantations.

2.7.1 *Regeneration in Indian tropical forests*

Many studies in the tropical forests of India provide diverse picture of the regeneration potential of forests. In such a study, Mishra *et. al.,* (2013) in Katerniaghat Wildlife Sanctuary reported good regeneration status in 64% (47 species) of the total species. However, 19 % economical species like *Madhuca longifolia, Terminalia elliptica, Buchanania cochinchinensis*, have been found in poor regeneration phase, whereas about 7% species found in no regeneration categories. In yet another study, Devi and Sarkar (2017) detailed that the total density of seedlings (6754 individual ha^{-1}) was found to be higher than the saplings (1002 individuals ha^{-1}) and adults (750 individuals ha^{-1}) in Semi-evergreen forests of Hollongapar Gibbon Wildlife Sanctuary, thus possessing overall 'good' regeneration condition of tree species at the community level. It was concluded that 24% tree species displayed "good" regeneration status, 36% exposed "fair" regeneration condition and 8% showed "poor" regeneration status and a total of 17% tree species had "no regeneration".

The distribution of various social classes was investigated by Jayakumar and Nair (2013) and observed that the dominant tree species in sapling and old stages were more or less similar in all vegetation types but dominant species in the seedling stage differed considerably. Out of 25 tree species prevalent across the different vegetation types, 16 species were found in the tree phase, 15 species in the sapling phase and 14 species were recorded in the seedling phase. Often physical barriers in the forest floor influence the regeneration process. For instance, it was reported that the density of seedlings was negatively correlated with litter cover (Facelli and Pickett, 2004 and Herault *et. al*., 1991). Also, the prevailing climatic conditions may also determine the soundness of forest regeneration. In such as study it was confirmed that the seedling and sapling densities of forests were approximately three times higher in high rainfall regions than low rainfall areas (Woo *et. al.,* 2018). Species assemblages of the regenerating populations were firstly influenced by disturbance while tree population collection were controlled by both disturbance and altitude gradients (Anitha *et al.,* 2010)

2.8 GAP DYNAMICS IN TROPICAL FORESTS

When one or few trees die in a forest due to natural disturbance, it creates a hollow place in the forest which is called a 'gap'. Gaps do not remain fixed but become confined sites of regeneration and growth where tree regeneration is usually a recruitment from buried or dispersed seed or advance regeneration. This phenomenon is called 'gap dynamics' (Van der Maarel, 1988; Brokaw and Busing, 2000). Very soon after the gap is created in a forest, different micro-environmental changes takes place. Light availability increases and root competition decreases in tropical evergreen forests. In the gaps, the availability of resources such as water and soil nutrients may temporarily increase (March and Skeen, 1976) due to which litter decomposition may be accelerated (Bormann and Likens, 1979). These changes would lead to a triggered regeneration and growth of primary species which have the capacity to germinate under a closed canopy and which remain suppressed until a gap is created (Bazzaz and Pickett, 1980).

In natural forests, biodiversity is reduced with canopy closure but increased after gap formation, because gaps resemble the natural forest in species composition over time due to plant succession. Numerous studies showed the importance of gaps in nurturing the regeneration and diversity of species inside old-growth forests in subtropical (Barik et al. 1992) and southern tropical regions of India (Chandrashekara and Ramakrishnan, 1993). The highest seedling density and volume are observed in large gaps. No significant difference in regeneration density were observed between middle gaps, small gaps and forest understory. Large gaps also had a higher closure rate than middle gaps and small gaps (Lu *et al.,* 2015). Canopy gaps created by death of few trees assume a dominant influence on forest composition by affecting the growth of forest trees (Stan and Daniels, 2014).

Materials and methods

3. MATERIALS AND METHODS

3.1 STUDY LOCATION:

The study was conducted in the moist deciduous forests located at Thrissur Forest Division, Kerala. These forests are uniquely located in the Western Ghats towards south of Palghat Gap in the form of a T shaped strip. It is bordered by settlements and revenue lands all along the western, eastern and northern boundaries and by the Chalakkudy and Nemmara Forest Division along the south and south-east respectively. The Division falls wholly within the limits of the Trichur Revenue District of the Kerala State and lies between the latitudes 10° 25’ and 10° 45’ N and longitudes 76°05 and 76° 30’ E. As reconstituted in 1980, it comprises an area of approximately 328 km^2 of forests divided into four administrative blocks, viz. Wadakanchery, Machad, Pattikkad and the Peechi Ranges.

The study area falls within the vast stretches of Moist Deciduous Forests (MDF) of Thrissur Forest Division. The forest patch is a complex association of different kinds of habitats like reservoirs, man-made forests and natural forests. Along the upper reaches of elevation, it forms part of the insulation belt around the wet evergreen forest formations of the Western Ghats. On the lower reaches, they are surrounded by settlements and agricultural lands. The division at present holds a total of 162 km^2 of natural moist deciduous forests covering 80 % of the whole natural forests. The area encompasses two reservoirs which is also surrounded by moist deciduous forests.

The present study forms an extension of investigations on the vegetation dynamics in the MDF of selected three locations in the Thrissur Forest Division thirty years before (Narayanan, 1988). The study locations included Karadippara and Kalluchal areas in Peechi Wildlife Sanctuary and Kuthiran region in the Pattikkad Forest Range, Thrissur Forest Division. All these three locations were revisited as part of the study and vegetation dynamics was re-assessed.

Karadippara: The forests in the Karadippara region are located in the inaccessible hilly areas presumably subject to less disturbance. It is about 2 km south east of Peechi Reservoir on the peak of Karadippara hillocks. The study area falls in the latitude 10^0 29' and longitude 76^0 23'. The area has occasionally bouldery rock formations close to the sample plots. The locality has a steep slope; fire is usual in the summer months. The dungs and footprints of elephants are frequently seen during the course of study. It is dominated by *Helectris isora* at the lower stratum.

Kalluchal: The locality is situated about 8 km south east from Kerala Forest Research Institute and 1.5 km east of Thamaravellachal region. It falls in the 10^0 30' latitude and 76^0 22' longitude. The slop is very gentle with rocky formations. The area is moderately disturbed with fallen tree logs at frequent intervals. It is also dominated by brushwood *Helectris isora* in the lower canopy.

Kuthiran: This area is located in the Pattikad Range of Thrissur Forest Division. It lies in the 30^0 $34^{'}$ latitude and 76^0 23' longitude. The forests is located about 1.5 km away from Thrissur-Pallakad NH 47 on the crest of Kuthiran hill. These forests are highly subjected to demographic pressure with scarce density of trees and is the most disturbed among the selected locations of study.

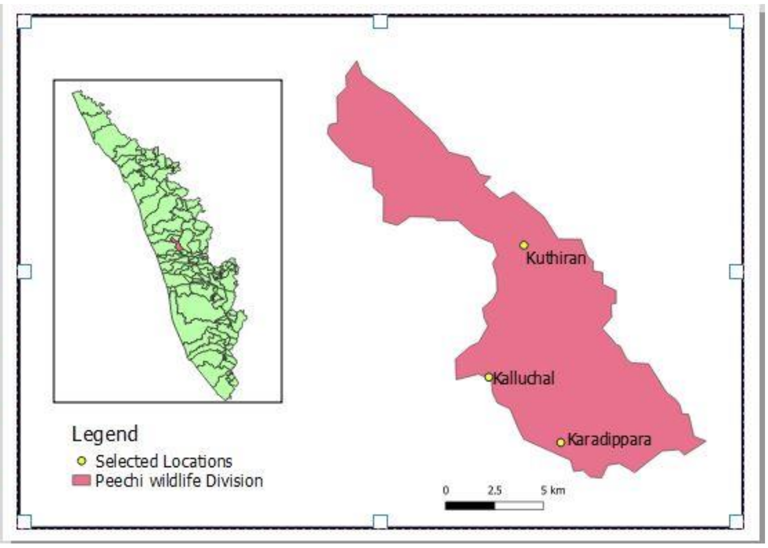

Fig 1. Map of study location

3.2 CLIMATE AND SOIL

Peechi has a humid type of climate. The maximum average temperature of the area in the summer season is 36^0 C while the minimum temperature recorded is 22^0C. The average annual rainfall is 2500 mm. The dry season is from December to May. The South-west monsoon generally sets in during the last week of May. On an average, there are 130 rainy days in a year. Kerala experienced 53% above normal rainfall during the monsoon season (till August 21^{st}) of 2018. The mean relative humidity ranged from 47% during February to 89% during June. Data on weather conditions such as temperature, rainfall and relative humidity obtained from the Department of Agricultural Meterology, College of Horticulture, Vellanikkara are given in Appendix I and graphically depicted in Figure 1.

The predominant parent material seen is of metamorphic rocks of the Gneiss series, weathering in large sheets, especially on the upper elevation. However, on the lower slopes the rocks tend to become lateritic. Occasionally, the exposed banks show the occurrence of lateritic parent materials. Owing to active weathering, the ground is very much bouldery. The soil is blackish or reddish and loamy.

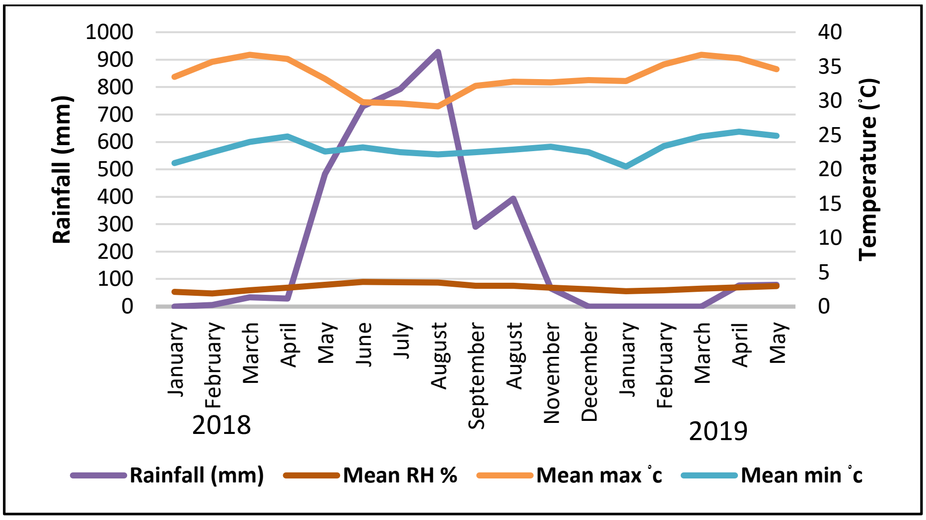

Fig 2. Mean monthly rainfall, temperature and relative humidity data from June 2017 to May 2019 at Peechi, Thrissur

3.3 METHODS

3.3.1 Sample Selection

In estimating the regeneration status conventional phytosociological methods were followed. Since the very objective of the study is to compare the vegetation in the same locations in relation to the study conducted 30 years before, similar methodology has been followed for obtaining reliable comparisons. The areas visited during this reconnaissance study were Kuthiran from Pattikkadu Range and Karadippara and Kalluchal from the Peechi Range.

3.3.2 Size of Releve

The experiment was conducted in permanent plots gridded at 10 m × 10 m. using the species-area guide line and the nested plot technique, Sharma *et. al*., (1983) had standardised the releve size for South Indian MDFs as 20 m^2. Here they took 3 m as the lower threshold for consideration as a tree. However, in the present study 30 cm GBH (10 cm DBH) was taken as the lower limit for consideration as a tree. The change in criterion was due to two reasons. Firstly, in most forested habitats regeneration is largely seed based. Most of the commercially important trees flower and fruit only after acquiring a certain age. Therefore, releve must be the sample size in which the fluctuation of number of species in terms of mother trees is minimum. Secondly, in recent years a general discontent in smaller sample sizes are obvious in forest ecological studies.

Species area relation were worked out using the 'expanding quadrat method' (Bharucha and de Leeuw, 1957). From the graph obtained the size of releve was determined to a limit, thereafter, a 10 percent increase in area scarcely leads to 10 percent increase in species. Thus the releve size was turned out to be 90^2 m^2 (8100 m^2) at Karadippara and at 60^2 m^2 (3600 m^2) each at Kalluchal and Kuthiran. The same releve size were followed for the study in the same location 30 years before (Narayanan, 1988).

Plate 1. Formation of quadrats in Karadippara forests, Thrissur

Plate 2. Formation of quadrats in Kuthiran forests, Thrissur

3.3.3 Sample Plots

Once the size of the releve was determined, sample plots were taken in same locations at Karadippara, Kalluchal and Kuthiran which were selected for the earlier study 30 years before. In each of the location 10 m × 10 m quadrats were taken in expanding quadrat method till the sample area cover corresponding releve size. For instance, the releve size of 90 × 90 m^2 for the Karadippara region was covered by taking 81 quadrats of size 10 m × 10 m in expanding quadrat method (Fig 1). Similarly, 36 sampling quadrats were taken each for the Kalluchal and Kuthiran regions such that they cover the releve size of 60 × 60 m^2. The quadrats were marked with wooden pegs on the ground and outlined by tying coloured nylon ropes to the pegs. Subsequent quadrats were laid out by extending the sides of the first quadrat using 10 m long nylon ropes.

3.3.4 Profile Diagram

A mimic of the physiognomy of the stands in the permanent plots at Karadippara, Kalluchal and Kuthiran were depicted in the form of a profile diagram. The profile diagram is a physical, size to scale pictorial transitional representation of a representative segment of the forest stand. A strip of 10 m x 80 m of forest area (eight plots of 10x10m size) was demarcated in a gridded plot. A linear representation of this strip is made in a size to scale graph ignoring the width of the strip. The position of each tree was marked on the line. Only those trees were measured whose GBH was above 30 cm. The total tree height was recorded using Haga altimeter. The vertical projection of crown shape of each tree was drawn by hand in the field. From these pictorial and quantitative data obtained, the profile diagram was synthesised, keeping the measurements to scale. The profile diagram was drawn for all the three experimental locations.

3.3.5 Gap estimation:

This experiment was conducted in the three study locations. The gap was studied in a strip of 10m × 80 m (eight quadrats of 10 m × 10 m size) in the same strip where the profile diagram was studied. A size to scale map of the plots was drafted on a graph paper. In each of the 10 m X 10 m quadrats, all the trees above 30 cm GBH were enumerated and numbered. The position of each of the trees in the quadrat was transcribed to binary numbers by measuring the distance from x and y co-ordinates of the quadrat to the tree. Later the binary numbers were translated to graphic points to mark the position of trees in the map.

In the map of the plot where the position of the trees were marked, the crown of the trees were also mapped. Perimeter of the tree crown were traced from the field itself. From the outline of the crown so obtained an approximately proportionate mapping was done on the graph sheet. The measurement is drawn to scale so that one metre on the ground is equal to one centimetre on the graph sheet. From this graph, each cell not covered by crown and partially covered by crown in the graph, were counted as one square centimetre. The cells which are covered by only half of the crown is counted as 0.5 square centimetre. All the values are added to get a total in square centimetres. The obtained value is further converted to square metres.

3.3.6 Tree enumeration

Tree enumeration and regeneration assessments were done in the permanent plots at Karadippara, Kalluchal and Kuthiran locations. Quadrats for regeneration enumeration were outlined by tying coloured nylon ropes on the pegs. All individuals belonging to all tree species were measured and recorded in data sheets. The size measurements were done under the following categories:

1. Height of all tree seedlings up to 1 m height

2. Girth of all individuals >= 1 cm GBH

3. The size class between > 1 m height and < 1 cm GBH were not measured but merely counted and recorded.

4. Above 30 cm GBH.

Plate 3. Measuring girth of a tree at breast height

Plate 4. Measuring collar diameter of a seedling

3.4 Phytosociological Analysis

The bulk of numerical data obtained from field were analysed for phytosociological parameters. Data were analysed to find out Density (D), Abundance (AB), Relative Density (RD), Percentage Frequency (% F), Relative Frequency (RF), Basal area (BA) and Relative Basal Area (RBA), for each species and for each location. Based on the results, Importance Value Index (IVI) and Relative Importance Value Index (RIVI) was calculated for individual localities.

The phytosociological parameters were discussed under and calculated using the following formulae:

Density

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total area of quadrats studied.

Density =No. of trees/area

Relative Density

Relative density is the study of numerical strength of a species in relation to the total number of individuals of all the species. It was calculated as:

$$\text{Relative density (RD)} = \frac{\text{Total no. of individuals of species 'A'}}{\text{Total no. of individuals of all species}} \times 100$$

Frequency (%)

Frequency refers to the degree of dispersion of individual species in an area and usually expressed in terms of percentage occurrence. It was studied by sampling the study area at several places and recorded the number of the species that occurred in each sampling units. It is calculated by the equation:

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

Relative frequency

The degree of dispersion of individual species in an area in relation to the number of all the species occurred.

$$\text{Relative frequency (RF)} = \frac{\text{Frequency value of species 'A'}}{\text{Sum of frequency value of all species}} \times 100$$

Basal Area

Basal area $= \pi D^2/4$ (Where, D = Diameter at breast height in metres; Basal area in square metres)

Relative Dominance

Dominance of a species is determined by the value of the basal cover usually represented by BA. Relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area.

$$\text{Relative Dominance (Rd)} = \frac{\text{Total basal area of species 'A'}}{\text{Total basal area of all species}} \times 100$$

Importance Value Index (IVI)

This index is used to determine the overall importance of each species (ecological fitness) in the community structure. For calculating this index, the percentage values of the relative density, relative frequency and relative dominance are summed up together and this value is designated as the Importance Value Index (IVI) of the species (Curtis 1959).

Importance value index = Relative density + Relative frequency + Relative dominance

Relative importance value index

Relative importance value index= Importance value index/3

3.5 DIVERSITY INDICES

A diversity index is a mathematical measure of species diversity in a community (Krebs, 1989; Hill, 1973). Popular diversity indices such as Simpson' Index, Shannon-Weiner Index and Margalef index were calculated using the web based online tool **'Biodiversity Calculator'**. The associated formulae and their significance are described below:

3.5.1 Species Richness (S) - The total number of different organisms present. It does not take into account the proportion and distribution of each species within a zone. Diversity measures the variation in species richness and abundance. Diversity Index combines the information on multiple species into a single number. These indices provide easily understandable measures of diversity.

3.5.2 Simpson's Diversity Indices

It is a measure of diversity which takes into account both richness and evenness. In ecology, it is often used to quantify the biodiversity of a habitat. It takes into account the number of species present, as well as the abundance of each species.

Simpson's Index (**D**) measures the probability that two individuals randomly selected from a sample will belong to the same species. Simpson's Index is calculated using the formula below :

$$D = \sum n (n-1) / N (N-1)$$

Where, D = Simpson Index

n = No. of individuals of each species

N = Total no. of individuals of all species

With this index, 0 represents infinite diversity and 1 represents no diversity. That is, the bigger the value of D, the lower the diversity. D is often subtracted from 1 to give Simpson's index of diversity. Web based ready reckoner online tool **'Biodiversity Calculator'** was used for calculating Simpson's index.

3.5.3 Simpson's Index of Diversity = 1 - D

The value of this index also ranges between 0 and 1, but now, the greater the value, the greater the sample diversity. This index represents the probability that two individuals randomly selected from a sample will belong to different species.

3.5.4 Shannon-Weiner Index (H')

The Shannon diversity index (*H*) is yet another index that is commonly used to characterize species diversity in a community. It sometimes referred to as the Shannon-Wiener Index is the information entropy of the distribution, treating species as symbols and their relative population sizes as the probability. The index values are between 0.0 – 5.0. Results are generally between 1.5 (low species richness and evenness) to 3.5 (high species evenness and richness), and it exceeds 4.5 very rarely. The values above 3.0 indicate that the structure of habitat is stable and balanced; the values under 1.0 indicate less stable habitat structure. It is calculated by the formula below:

$$H' = -\sum P_i \ln P_i$$

Where, Pi is the proportion of individuals found in species i. For a well-sampled community, we can estimate this proportion as pi = ni/N, where ni is the number of individuals in species i and N is the total number of individuals in the community.

3.5.5 Margalef Richness Index

Margalef Richness Index in Biodiversity = (S - 1) / Log (n)

Where, S = Total no. of species, n = Total no of individuals of all species

3.6 Statistical analysis

The data were subjected descriptive statistics using Microsoft Excel 2010 version to calculate various parameters. Parameter such as mean and standard deviation were calculated using web based agricultural statistics software package known as http://14.139.232.166/opstat/.

Results

4. RESULTS

4.1 Species diversity

A total of 51 species have been encountered in various study locations in the Moist Deciduous Forests of Thrissur Forest Division. The species diversity varied from 26 to 48 across the three locations under study. The number of species found in Karadippara and Kalluchal were 37 and 48 respectively (Table 1) while the Kuthiran the lowest with only 26 species.

Table 1. Releve size and total number of species in various study locations of MDF in Thrissur District.

Location	Relative Size	Total no. of species
Karadippara	8100 m^2	37
Kalluchal	3600 m^2	48
Kuthiran	3600 m^2	26

Richness of tree species of size ≥ 1 cm DBH corresponding to various vertical strata of the MDF under study in Thrissur forest division are given in Table 2. The data shows significant differences between individual strata. Diversity was least in the lower stratum (11.7 %), highest in the middle stratum (54.9 %), while that of the upper stratum was moderate (33.3 %).

The list of trees arranged according to their strata is given in Table 3. The species distribution across different strata were 17, 28 and 6 species respectively for upper, middle and lower stratum.

Table 2. Species richness in different vertical strata of the moist deciduous forests in all three locations in Thrissur district, Kerala.

I Stratum		II Stratum		III Stratum	
No. of species	Percentage	No. of species	Percentage	No. of species	Percentage
17	33.3	28	54.9	6	11.7

Table 3. Species wise information of forest vegetation in the various vertical strata of MDF in Thrissur forests, Kerala.

Plant species		
Upper stratum	Middle stratum	Lower stratum
1. *Alstonia scholaris*	1. *Ailanthus tryphysa*	1. *Glycosmis pentaphylla*
2. *Bombax ceiba*	2. *Annona squamosa*	2. *Holarrhena antidysentrica*
3. *Dalbergia sisoo*	3. *Aporusa lindeyana*	3. *Naringi crenulata*
4. *Dillenia pentagyna*	4. *Artocarpus hirsuta*	4. *Tabarnaemontana heyneana*
5. *Grewia tiliifolia*	5. *Bauhinia racemosa*	5. *Wrightia tinctoria*
6. *Haldina cordifolia*	6. *Bridelia squamosa*	6. *Helicteris isora*
7. *Lagerstroemia microcarpa*	7. *Bixa orellana*	
8. *Lannea coromandelica*	8. *Carralia brachiata*	
9. *Pterocarpus marsupium*	9. *Careya arborea*	
10. *Radermachera xylocarpa*	10. *Cassia fistula*	
11. *Stereospermum colias*	11. *Cleistanthus collinus*	
12. *Tectona grandis*	12. *Cordia wallichi*	
13. *Terminalia bellerica*	13. *Diospyros montana*	
14. *Terminalia crenulata*	14. *Garuga floribunda*	
15. *Terminalia paniculata*	15. *Hydnocarpu spentandra*	
16. *Tetrameles nudiflora*	16. *Mitragyna parvifolia*	
17. *Xylia xylocarpa*	17. *Macaranga peltata*	
	18. *Olea dioica*	
	19. *Sapindus laurifolia*	
	20. *Schleichera oleosa*	
	21. *Sterculia guttata*	
	22. *Sterculia urens*	
	23. *Strychnus nuxvomica*	
	24. *Syzygium cumini*	
	25. *Trema orientalis*	
	26. *Vitex altissima*	
	27. *Xeromphis spinosa*	
	28. *Zanthoxylum rhetsa*	

4.2 Plant density

Table 4 shows the tree density (number of stems per ha) in the various sampled areas in Thrissur forest division.

4.2.1 At location level: The number of stems per hectare ≥ 1 cm DBH, the moist deciduous forests has an average of 632 stems/ha. The highest number of stems was recorded in Kalluchal with 691 stems/ha and the lowest in Kuthiran with 516 stems/ha. Karadippara recorded slightly higher than Kalluchal with 688 stems ha^{-1} (Table 4).

However, the average per hectare growing stock of trees ≥ 20 cm DBH per hectare for all the MDF locations was 147 stems/ha. The highest number of stems in this category was recorded in Kuthiran with 163 stems/ha followed by Karadippara with 158 stems/ha and the lowest in Kalluchal with 119 stems/ha (Table 4).

4.2.2 At strata level: The number of stems ≥ 1 cm DBH for the different strata are given in Table 4. The average values for the upper, middle and lower strata are 284, 139 and 208 stems per ha respectively (Table 4). The maximum number of stems per hectare (≥ 1 cm DBH) is contributed by the species of the upper stratum with the exception in Kuthiran where the number of stems in the lower stratum was at par with the upper stratum (Table 4).

Table 4. Stems per hectare distribution of moist deciduous forests in Thrissur Forest Division, Kerala

Location	Stems per hectare				
	Size class				
	DBH ≥20 cm	DBH ≥1 cm			
	All trees	All trees	Upper Stratum	Mid stratum	Lower Stratum
Karadippara	158.02	688.89	319.75	154.32	214.81
Kalluchal	119.44	691.67	322.22	172.22	197.22
Kuthiran	163.89	516.67	211.11	91.67	213.89
Mean	147.11	632.41	284.36	139.40	208.64
SD	24.14	100.24	63.44	42.29	9.90

4.2.3 Plant density across species

The number of stems per hectare of all species in the MDF of all three study locations in Thrissur is given in Table 5. In Karadippara, *Xylia xylocarpa* contributed the maximum number of stems (111 stems/ha) followed by *Wrightia tinctoria* (146 stems/ha) and *Holarrhena antidysentrica* (67 stems/ha). The other dominant species in Karadippara are *Lagerstroemia lanceolata* (50 stems/ha), *Grewia tiliifolia* (44 stems/ha) and *Dillenia pentagyna* (27 stems/ha).

A similar pattern is also recorded in Kalluchal with highest contribution made by *Xylia xylocarpa* (188 stems/ha) followed by *Wrightia tinctoria* (127 stems) and *Holarrhena antidysentrica* (58 stems). In Kalluchal, the other species with higher share are *Cleistanthus collinus* (38 stems/ha), *Lagerstroemia lanceolata* (25 stems/ha) and *Terminalia paniculata* (22 stems/ha).

The location Kuthiran also showed the similar distribution of stems per hectare with maximum number of stems recorded for *Xylia xylocarpa* (91 stems/ha) followed by *Holarrhena antidysentrica* (75 stems) and *Wrightia tinctoria* (58 stems). But unlike in Karadippara and Kalluchal where the second highest contribution was given by *Wrightia tinctoria*, the second highest contribution in Kuthiran was given by *Holarrhena antidysentrica.* In Kuthiran, the other prominent species were *Naringi crenulata* (66 stems/ha), *Grewia tilifolia* (33 stems/ha), *Dillenia pentagyna* (25 stems/ha) and *Macaranga peltata* (22 stems/ha).

The understorey species *Helectris ixora* has made a significant contribution to all the three study locations. The number of stems per hectare of *Helectris isora* was 186, 133 and 91 stems/ha at Karadippara, Kalluchal and Kuthiran respectively. Conspicuously meagre presence of teak (*Tectona grandis*) in the Karadippara and Kalluchal regions is worth noticeable.

Table 5. Stems per hectare of all species of MDF of all three locations in Thrissur Forest Division, Kerala

	Stems per ha for various locations		
Species	Karadippara	Kalluchal	Kuthiran
Alstonia scholaris	-	2.78	-
Bombax ceiba	13.58	5.56	13.89
Dalbergia sisoo	22.22	8.33	5.56
Dillenia pentagyna	27.16	11.11	25.00
Grewia tiliifolia	44.44	16.67	33.33
Haldina cordifolia		2.78	
Lagerstroemia lanceolata	50.62	25.00	2.78
Lannea coromandelica	13.58	11.11	5.56
Pterocarpus marsupium	1.23	8.33	2.78
Radarmachera xylocarpa		2.78	
Stereospermum colias		2.78	
Terminalia bellerica	7.41	5.56	2.78
Terminalia crenulata	9.88	2.78	5.56
Terminalia paniculata	9.88	22.22	2.78
Tectona grandis	3.70	2.78	16.67
Trewia nudiflora	4.94	2.78	2.78
Xylia xylocarpa	111.1	188.8	91.67
Hollarhena antidysentrica	67.90	58.33	75.00
Wrightia tinctoria	146.9	127.7	58.33
Other Species			
Ailanthis tryphisa		16.67	8.33
Annona squamosa			5.56

Aporusa lindeyana		5.56	8.33
Artocarpus hirsutus	1.23	2.78	
Bauhinia racemosa		2.78	
Bixa orellana		5.56	
Bridelia squamosa		2.78	
Carralia brachiata		2.78	
Careya arborea		2.78	
Cassia fistula	1.23	5.56	19.44
Cleistanthus collinus	7.41	38.89	11.11
Cordia wallichi		2.78	
Diospyrus Montana	1.23	5.56	
Garuga floribunda	1.23	5.56	
Glycosmis pentaphylla		5.56	
Litsea	1.23	2.78	
Mitragyna parvifolia		2.78	
Macaranga peltata	22.22	16.67	22.22
Mallotus philippensis	2.78	2.78	
Naringi crenulata		5.56	66.67
Olea dioica	3.70	8.33	19.44
Sapindus laurifolia	9.88	2.78	
Schleichera oleosa		8.33	
Spondias pinnata		2.78	
Sterculia guttata	3.70	2.78	
Sterculia urens	2.47		
Strychnus nuxvomica	14.81	5.56	
Syzygium cumini		2.78	
Tabarnaemontana heyneana			2.78
Vitex altissima	2.47	5.56	
X. spinosa	1.23	8.33	

Zanthoxylum rhetsa	4.94		
Total no. of stems/ha	688.89	691.67	516.67
Helectris isora (HI)	186.11	133.33	91.66
Total (Including HI)	875.00	824.33	608.33

4.3 Relative density

The average relative density for the different strata are 44.62, 22.30 and 33.07 respectively for upper, middle and lower stratum. The average relative density is highest in case of upper stratum followed by lower stratum and lowest in middle stratum (Table 6).

Table 6. Relative density of plants (≥ 1 cm DBH) in the MDF at various locations in Thrissur Forest Division, Kerala.

Location	Relative density (RD) (%)		
	Upper stratum	Mid stratum	Lower stratum
Karadippara	46.42	22.40	31.18
Kalluchal	46.59	25.70	27.71
Kuthiran	40.86	18.82	40.32
Mean	44.62	22.30	33.07
SD	3.26	3.44	6.51

The relative density of all species of MDF of Thrissur Forest Division are given in Table 7. In Karadippara, the species having the highest relative density were *Wrightia tinctoria* (21.33) followed by *Xylia xylocarpa* (16.13) and *Holarrhena antidysentrica* (9.86). In Kalluchal, the species having the highest relative density was *Xylia xylocarpa* (27.31) followed by *Wrightia tinctoria* (18.47) and *Holarrhena antidysentrica* (8.43). A similar pattern is also recorded in Kuthiran wherein the species having the highest relative density was *Xylia xylocarpa* (17.74).

Table 7. Relative density of all species of MDF of Thrissur Forest Division, Kerala

Species	Karadippara	Kalluchal	Kuthiran
Alstonia scholaris		0.40	
Bombax ceiba	1.97	0.80	2.69
Dalbergia sisoo	3.23	1.20	1.08
Dillenia pentagyna	3.94	1.61	4.84
Grewia tiliifolia	6.45	2.41	6.45
Haldina cordifolia		0.40	
Lagerstroemia lanceolata	7.35	3.61	0.54
Lannea coromandelica	1.97	1.61	1.08
Pterocarpus marsupium	0.18	1.20	0.54
Radarmachera xylocarpa		0.40	
Stereospermum colias		0.40	
Terminalia bellerica	1.08	0.80	0.54
Terminalia crenulata	1.43	0.40	1.08
Terminalia paniculata	1.43	3.21	0.54
Tectona grandis	0.54	0.40	3.23
Trewia nudiflora	0.72	0.40	0.54
Xylia xylocarpa	16.13	27.31	17.74

Hollarhena antidysentrica	9.86	8.43	14.52
Wrightia tinctoria	21.33	18.47	11.29
Other species			
Ailanthus tryphysa		2.41	1.61
Ailanthus squamosa			1.08
Aporusa lindeyana	1.97	0.80	1.61
Artocarpus hirsutus	0.18	0.40	
Bauhinia racemosa	1.08	0.40	
Bixa orellana		0.80	
Bridelia squamosa		0.40	
Carallia brachiata		0.40	
Careya arborea		0.40	
Cassia fistula	0.18	0.80	3.76
Cleistanthus collinus	1.08	5.62	2.15
Cordia wallichi		0.40	
Diospyros montana	0.18	0.80	
Garuga floribunda	0.18	0.40	
Glycosmis pentaphylla			1.08

Hydnocarpus pentandra	1.25		
Litsea	0.18	0.40	
Mitragyna parvifolia		0.40	
Macaranga peltata	3.23	2.41	4.30
Mallotus philippensis	0.36	0.40	
Naringi crenulata	1.43	0.80	
Olea dioica	0.54	1.20	3.76
Sapindus laurifolia	1.43	0.40	
Schleichera oleosa	4.66	1.20	
Spondias pinnata		0.40	
Sterculia guttata	0.54	0.40	
Sterculia urens	0.36	0.80	
Strychnus nuxvomica	2.15	0.80	
Syzygium cumini	0.18	0.40	
Tabarnaemontana heyneana			0.54
Vitex altissima	0.36	0.80	0.54
Xeromphis spinosa	0.18	1.20	
Zanthoxylum rhetsa	0.72		
Total RD	100	100	100

4.3.1 Mean stems per hectare and mean relative density per hectare

The mean number of stems per hectare and mean relative density per hectare of selected species irrespective of locations is given in Table 8. The species having maximum average number of stems per hectare of all three study locations is *Xylia xylocarpa* (130 stems) which was followed by *Wrightia tinctoria* (110 stems), *Holarrhena antidysentrica* (67 stems), *Grewia tilifolia* (31 stems), *Lagerstroemia lanceolata* (26 stems) and *Dillenia pentagyna* (21 stems).

The species having the highest mean relative density per hectare are *Xylia xylocarpa* (20.39) followed by *Wrightia tinctoria* (17.03) and *Holarrhena antidysentrica* (10.94 stems).

Table 8. Mean stems per hectare and mean relative density per hectare of selected species of all three study locations in Thrissur Forest Division, Kerala

Species	Mean stems per hectare	Mean relative density per hectare (%)
Alstonia scholaris		0.13
Bombax ceiba	11.01	1.82
Dalbergia sisoo	12.04	1.84
Dillenia pentagyna	21.09	3.46
Grewia tilifolia	31.48	5.10
Haldina cordifolia		0.13
Lagerstroemia lanceolata	26.13	3.83
Lannea coromandelica	10.08	1.55
Pterocarpus marsupium	4.11	0.64
Radarmachera xylocarpa		0.13
Stereospermum colias		0.13
Terminalia bellerica	5.25	0.81
Terminalia crenulata	6.07	0.97
Terminalia paniculata	11.63	1.73

Tectona grandis	7.72	1.39
Trewia nudiflora	3.50	0.55
Xylia xylocarpa	130.5	20.39
Hollarhena antidysentrica	67.08	10.94
Wrightia tinctoria	110.9	17.03

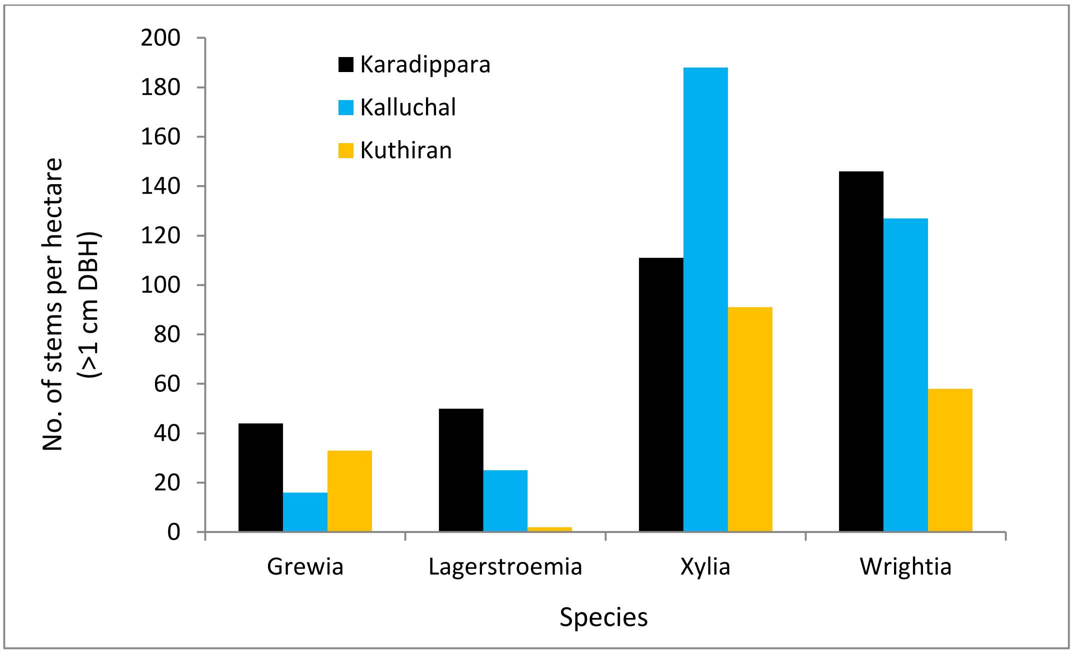

Fig 3. No. of stems per hectare of selected species in three study locations.

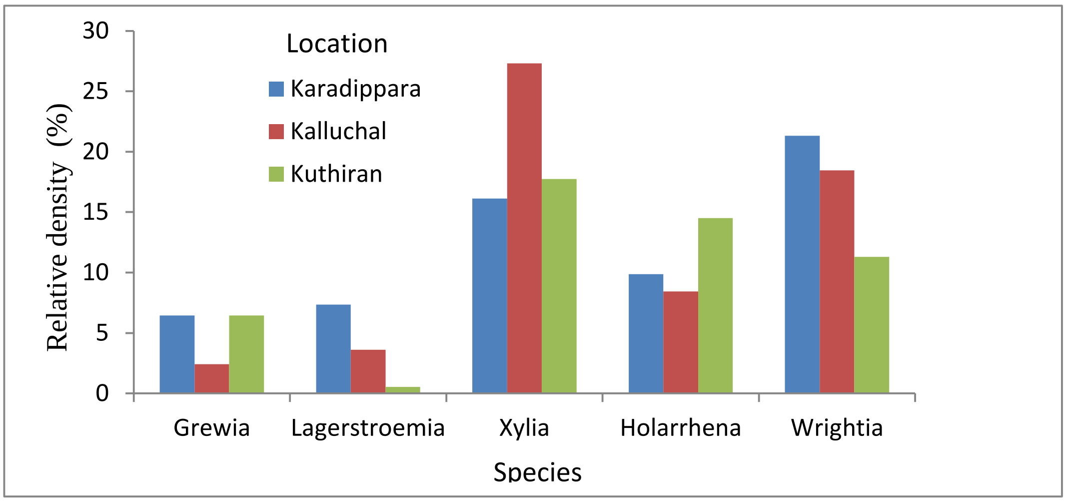

Fig 4. Relative density (RD) of selected species in all study locations

4.4 Basal area (BA) and relative basal area (RBA)

Tree basal area and relative basal area has been computed for each of the prominent species for all the three locations of MDF under study (Table 9).

4.4.1 At location level: Karadippara recorded the highest basal area with a value of 39.95 m^2 ha^{-1} while Kuthiran recorded the lowest value (20.50 m^2 ha^{-1}). Kalluchal had moderate BA value of 33.97 m^2 ha^{-1}. The average BA for all the three locations was 31.47 ± 9.96 m^2 ha^{-1}.

4.4.2 At strata level: The Table also give distribution of BA across the three vertical strata. The average values of basal area were 27.99 ± 8.98, 2.24 ± 0.65 and 1.11 ± 0.58 respectively for upper, middle and lower strata. Upper stratum represented highest BA per ha for all the three location, though it varied considerably among them. For instance, the basal area in the upper stratum ranged between 17.97 m^2 ha^{-1} (Kuthiran) and 35.31 m^2 ha^{-1} (Karadippara).

The Relative Basal Area (RBA) distribution showed that the upper stratum species accounted almost 88.4 to 90.5% of the total basal area for all the three locations. The average values of relative basal area were 89.25 ± 1.10, 7.35 ± 1.41 and 3.38 ± 0.84 percent respectively for upper, middle and lower stratum (Table 8).

Table 9. Basal area and relative basal area distribution of moist deciduous forests (MDF) in Thrissur Forest Division, Kerala

Location	BAPH (m^2 ha^{-1})				RBA (%)		
	All Trees	Upper Stratum	Mid Stratum	Lower Stratum	Upper Stratum	Mid Stratum	Lower Stratum
Karadippara	39.95	35.31	2.99	1.64	88.40	7.49	4.10
Kalluchal	33.97	30.69	1.99	1.22	90.50	5.88	3.61
Kuthiran	20.50	17.97	1.75	0.49	88.85	8.69	2.45
Mean	31.47	27.99	2.24	1.11	89.25	7.35	3.38
SD	9.96	8.98	0.65	0.58	1.10	1.41	0.84

BAPH- Basal area per ha; RBA- Relative basal area

4.4.3 Basal area at species level:

Species-wise information on BAPH of MDF of Thrissur Forest Division is given in Table 10. In Karadippara, the species having the maximum basal area are *Xylia xylocarpa* (10.58 m^2 ha^{-1}), followed by *Lagerstroemia lanceolata* (8.93 m^2 ha^{-1}) and *Dillenia pentagyna* (5.92 m^2 ha^{-1}). The species having the maximum basal area in Kalluchal was *Xylia xylocarpa* (10.03 m^2/ha) followed by *Terminalia paniculata* (7.81 m^2 ha^{-1}). In Kuthiran, *Xylia xylocarpa* (4.14 m^2 ha^{-1}) and *Dillenia pentagyna* (3.81 m^2 ha^{-1}) were the toppers in terms of BA.

Table 10. Basal area per hectare of all species of all three study locations of MDF in Thrissur Forest Division, Kerala

Species	Basal area per hectare (m^2 ha^{-1})		
	Location		
	Karadippara	Kalluchal	Kuthiran
Alstonia scholaris		0.20	
Bombax ceiba	1.79	1.42	2.75
Dalbergia sisoo	1.51	0.001	0.71
Dillenia pentagyna	5.92	2.66	3.81

Grewia tiliifolia	2.21	0.01	1.04
Haldina cordifolia		0.01	
Lagerstroemia lanceolata	8.93	2.67	0.34
Lannea coromandelica	0.38	0.004	0.08
Pterocarpus marsuppium	0.005	0.31	0.50
Radermachera xylocarpa		0.38	
Stereospermum colias		0.18	
Terminalia bellerica	0.84	2.68	0.75
T. crenulata	0.19	0.44	1.04
T. paniculata	2.88	7.81	0.86
Tectona grandis	0.001	1.73	1.62
Tetrameles nudiflora	0.05	0.09	0.27
Xylia xylocarpa	10.58	10.03	4.14
Holarrhena antidysentrica	0.56	0.11	0.22
Wrightia tinctoria	1.07	1.10	0.21
Other species			
Ailanthus tryphysa		0.01	0.78
Annona squamosa			0.003
Aporusa lindeyana	0.38		0.45
Artocarpus hirsutus		0.14	
Bauhinia racemosa	0.05	0.04	
Bixa orellana		0.002	
Bridelia squamosa		0.06	
Careya arborea		0.01	
Cassia fistula	0.02	0.02	0.40
Cleistanthus collinus	1.41	0.66	0.002

Cordia wallichi		0.008	
Diospyros montana		0.003	
Garuga floribunda	0.26	0.04	
Glycosmis pentaphylla			0.002
Hydnocarpus pentandra	0.11		
Litsea	0.002	0.01	
Macaranga peltata	0.28	0.005	0.09
Mallotus philippensis	0.04	0.02	
Naringi crenulata	0.003	0.002	0.005
Olea dioica		0.24	0.005
Sapindus laurifolia	0.08	0.05	
Schleichera oleosa	0.04	0.03	
Spondias pinnata		0.44	
Sterculia guttata	0.07		
Strychnus nuxvomica	0.14	0.02	
Syzygium cumini		0.01	
Tabarnae-montana heyneana		0.001	
Vitex altissima	0.001	0.003	
Xeromphis spinosa		0.11	
Zanthoxylum rhetsa	0.008		
Total Basal Area (m^2/ha)	39.95	33.91	20.22

4.4.4 Relative basal area at species level

The relative basal area (RBA) of all the three study locations of Thrissur Forest Division are given in Table 11. The species having the higher RBA in Karadippara are *Xylia xylocarpa* (26.48%), *Lagerstroemia lanceolata* (22.37%) and *Dillenia pentagyna* (14.82%). In Kalluchal, the order of RBA was maximum for *Xylia xylocarpa* (29.58%) followed by *Terminalia paniculata* (23.03%), *Terminalia bellerica* (7.89%) and *Lagerstroemia lanceolata* (7.87%). The species having the maximum relative basal area in Kuthiran were *Xylia xylocarpa* (20.47%), *Dillenia pentagyna* (18.86%) and *Bombax ceiba* (13.62%).

Table 11. Relative basal area among tree species in the study locations of Thrissur Forest Division, Kerala

Species	Relative basal area (RBA) (%)		
	Location		
	Karadippara	Kalluchal	Kuthiran
Alstonia scholaris	NA	0.60	NA
Bombax ceiba	4.47	4.20	13.62
Dalbergia sisoo	3.77	0.004	3.51
Dillenia pentagyna	14.82	7.85	18.86
Grewia tiliifolia	5.54	0.03	5.18
Haldina cordifolia	NA	0.05	NA
Lagerstroemia lanceolata	22.37	7.87	1.70
Lannea coromandelica	0.96	0.01	0.43
Pterocarpus marsupium	0.01	0.92	2.49
Radarmachera xylocarpa	NA	1.12	NA
Stereospermum	NA	0.54	NA

colias			
Terminalia bellerica	2.10	7.89	3.74
Terminalia crenulata	0.48	1.32	5.14
Terminalia paniculata	7.21	23.03	4.26
Tectona grandis	0.002	5.10	8.04
Trewia nudiflora	0.13	0.28	1.35
Xylia xylocarpa	26.48	29.58	20.47
Hollarhena antidysentrica	1.41	0.34	1.07
Wrightia tinctoria	2.68	3.26	1.05
Other Species			
Ailanthus tryphisa	NA	0.04	3.89
Annona squamosa	NA	NA	0.01
Aporusa lindeyana	0.97	0.001	2.26
Artocarpus hirsutus	NA	0.42	NA
Bauhinia racemosa	0.13	0.13	NA
Bixa orellana	NA	0.005	NA
Bridelia squamosa	NA	0.19	NA
Careya arborea	NA	0.03	NA
Cassia fistula	0.05	0.07	2.01
Cleistanthus collinus	3.55	1.95	0.009
Cordia wallichi	NA	0.025	NA
Diospyrus montana	NA	0.008	NA
Garuga floribunda	0.67	0.12	NA
Glycosmis pentaphylla	NA	NA	0.007
Hydnocarpus	0.28	NA	NA

pentandra			
Litsea	0.07	0.03	NA
Macaranga peltata	0.72	0.002	0.47
Mallotus philippensis	0.11	0.07	NA
Naringi crenulata	0.008	0.04	0.28
Olea dioica	0.001	0.07	0.03
Sapindus laurifolia	0.22	0.15	NA
Schleichera oleosa	0.12	0.10	NA
Spondias pinnata	NA	1.3	NA
Sterculia guttata	0.18	NA	NA
Strychnus nuxvomica	0.36	0.06	NA
Syzygium cumini	NA	0.03	NA
Tabarnaemontana heyneana	NA	0.002	0.002
Vitex altissima	0.004	0.009	0.004
Xeromphis spinosa	NA	0.33	NA
Zanthoxylum rhetsa	0.02	NA	NA
Total RBA	100	100	100

Mean basal area and mean relative basal area of selected species

Among all the tree species recorded in all the three study locations, *Xylia xylocarpa* (8.25 m^2 ha^{-1}) recorded the maximum mean basal area followed by *Dillenia pentagyna* (4.13 m^2 ha^{-1}*),* *Lagerstroemia lanceolata* (3.98 m^2 ha^{-1}) and *Terminalia paniculata* (3.85 m^2 ha^{-1}) (Table 12). The species which recorded the maximum mean relative basal area were *Xylia xylocarpa* (25.40%), *Dillenia pentagyna* (13.75%), *Terminalia paniculata* (11.47%) and *Lagerstroemia lanceolata* (10.64%).

Table 12. Mean basal area and mean relative basal area of selected species recorded in all three study locations of Thrissur Forest Division, Kerala

Species	Mean Basal Area (m^2/ha)	Mean Relative Basal Area (%)
Bombax ceiba	1.99	7.37
Dalbergia sisoo	0.74	2.41
Diospyros pentagyna	4.13	13.75
Grewia tilifolia	1.09	3.56
Lagerstroemia lanceolata	3.98	10.64
Lannea coromandelica	0.15	0.46
Pterocarpus marsupium	0.27	1.13
Terminalia bellerica	1.42	4.56
Terminalia crenulata	0.56	2.29
Terminalia paniculata	3.85	11.47
Tectona grandis	1.12	4.34
Trewia nudiflora	0.14	0.58
Xylia xylocarpa	8.25	25.40
Hollarhena antidysentrica	0.30	0.94
Wrightia tinctoria	0.79	2.33

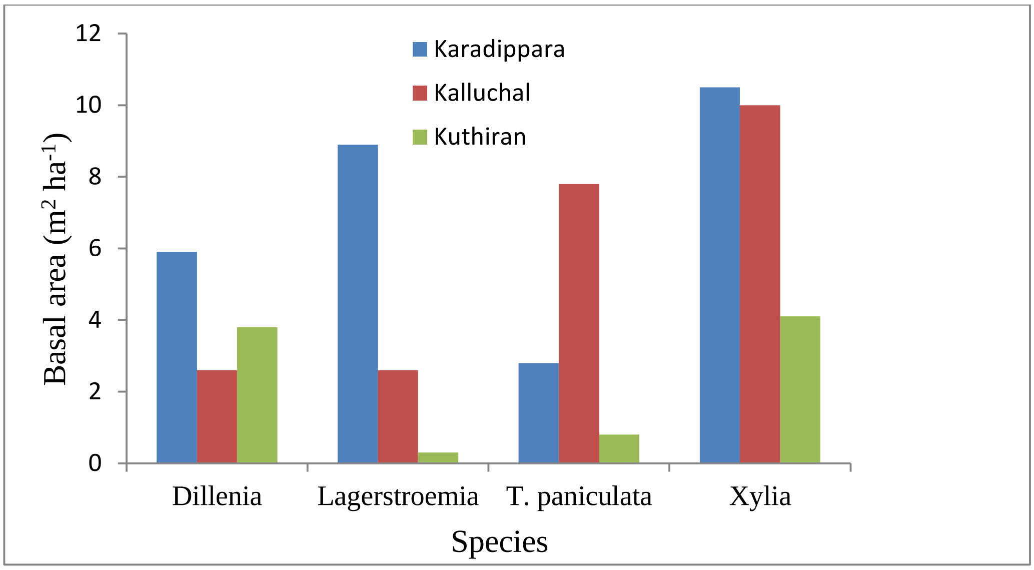

Fig 5. Basal area per hectare of selected species in all study locations.

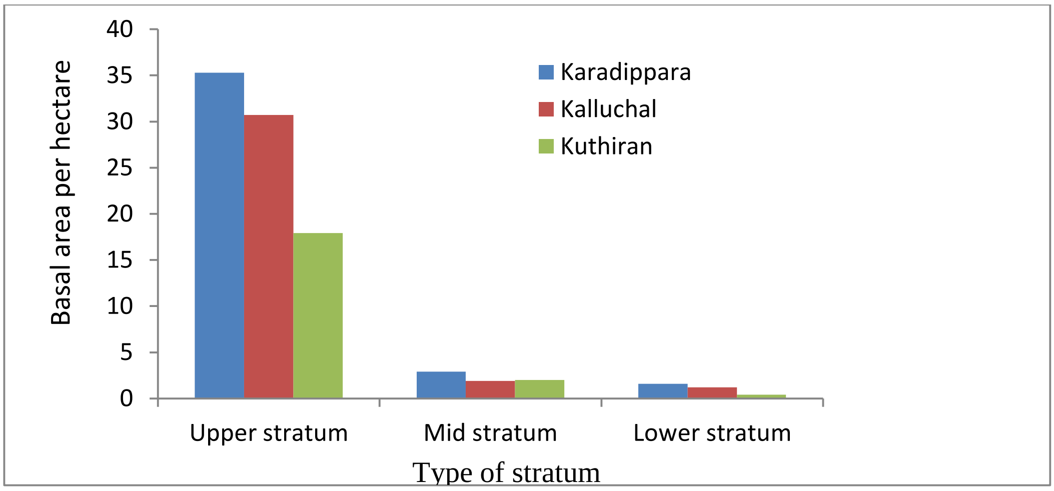

Fig 6. Basal area per hectare in different stratum in all study locations.

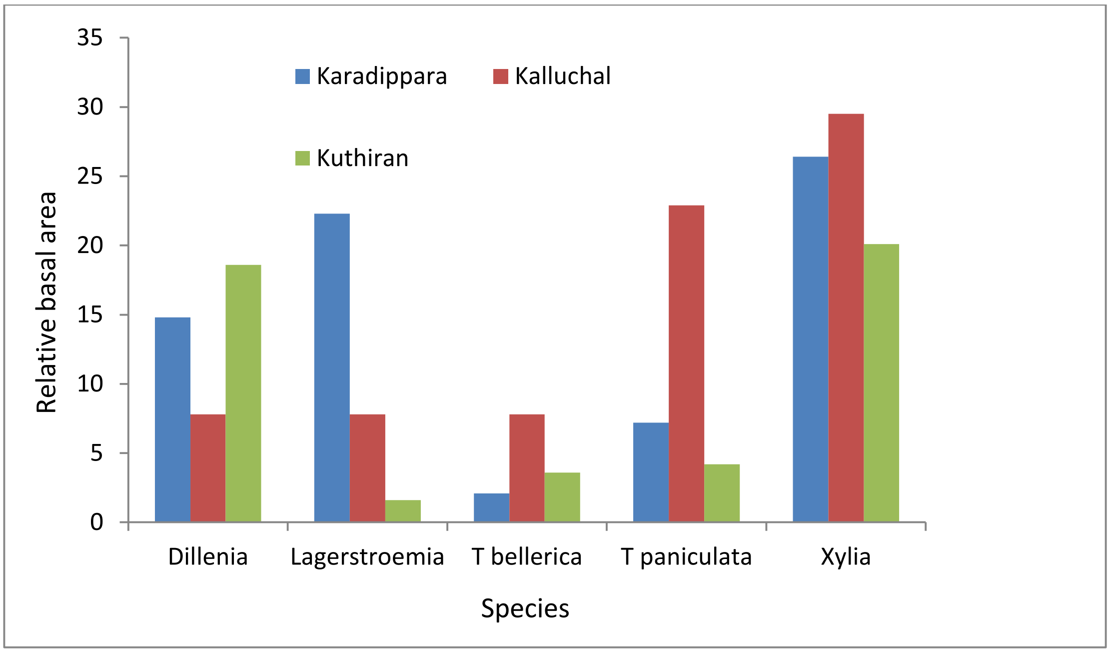

Fig 7. Relative basal area (RBA) of selected species in all study locations.

4.5 Frequency and relative frequency (RF)

The values of frequency and relative frequency (≥ 1 cm DBH) of all species in the various study locations are given in Table 13 and 14. In Karadippara, the species with the highest frequency distribution was *Wrightia tinctoria* (69.14 closely followed by *Xylia xylocarpa* (58.02%), *Holarrhena antidysentrica* (49.38%), *Lagerstroemia lanceolata* (38.27%) and *Grewia tilifolia* (33.33%). The species having the maximum frequency in Kalluchal forests was *Xylia xylocarpa* (80.56%) followed by *Wrightia tinctoria* (66.67%) and *Holarrhena antidysentrica* (49.38%). In Kuthiran the *Xylia xylocarpa* (61.11%) had the highest frequency followed by *Holarrhena antidysentrica* (47.22%) and *Wrightia tinctoria* (36.11%) as shown in Table 14.

Table 13 shows the frequency class distribution of different species of the study locations. Frequency Class I (0-20%) recorded the highest number of species which ranged from 20 to 45 species. The number of species in Class I in Karradippara, Kalluchal and Kuthiran are 30, 45 and 20 species respectively. The number of species drastically declined in class II, III and IV. Surprisingly, there was no representative species belonging to class V (81-100%).

The species having the highest relative frequency (relative proportion of the total frequency) was *Xylia xylocarpa* with values ranging from 11.30% (Karadippara) to 16.79% (Kuthiran) (Table 15). Other prominent species in this respect was lower strata species *Wrightia tinctoria* with value ranging from 9.92% (Kuthiran) to 14.04% (Kalluchal). Among the species of middle stratum, those having the highest relative frequency were *Schleichera oleosa* (6.73%) in Karadippara, *Cleistanthus collinus* (7.60%) in Kalluchal and *Cassia fistula* (4.58%) along with *Olea indica* (4.58%) in Kuthiran (Table 15).

Table 13. Frequency of all species of MDF in various locations in Thrissur Forest Division, Kerala

	Frequency (%)		
Species	Karadippara	Kalluchal	Kuthiran
Alstonia scholaris		2.78	
Bombax ceiba	9.88	5.56	11.11
Dalbergia sisoo	16.05	5.56	5.56
Dillenia pentagyna	20.99	11.11	22.22
Grewia tiliifolia	33.33	13.89	27.78
Haldina cordifolia		2.78	
Lagerstroemia lanceolata	38.27	16.67	2.78
Lannea coromandelica	12.35	8.33	5.56
Pterocarpus marsupium	1.23	8.33	2.78
Radarmachera xylocarpa		2.78	
Stereospermum		2.78	

colias			
Terminalia bellerica	8.64	5.56	2.78
Terminalia crenulata	7.41	2.78	5.56
Terminalia paniculata	9.88	16.67	2.78
Tectona grandis	3.70	2.78	13.89
Trewia nudiflora	6.17	2.78	2.78
Xylia xylocarpa	58.02	80.56	61.11
Hollarhena antidysentrica	49.38	36.11	47.22
Wrightia tinctoria	69.14	66.67	36.11
Other Species			
Ailanthus tryphisa		11.11	8.33
Annona squamosa			5.56
Aporusa lindeyana	13.58	1.17	5.56
Artocarpus hirsutus	1.23	0.58	
Bauhinia racemosa	12.35	0.58	
Bixa orellana		1.17	
Bridelia squamosa		0.58	
Carralia brachiate		0.58	
Careya arborea		0.58	
Cassia fistula	1.23	1.17	16.67
Cleistanthus collinus	6.17	7.60	8.33
Cordia wallichi		0.58	
Diospyros Montana	1.23	1.17	

Garuga floribunda	1.23	0.58	
Glycosmis pentaphylla			2.78
Hydnocarpus pentandra	8.64		
Litsea spp.	1.23	0.58	
Mitragyna. Parvifolia		0.58	
Macaranga peltata	25.93	2.92	13.89
Mallotus philippensis	2.47	0.58	
Naringi crenulata	8.64	0.58	30.56
Olea dioica	3.70	1.75	16.67
Sapindus laurifolia	9.88	0.58	
Schleichera oleosa	34.57	4.68	
Spondias pinnata		0.58	
Sterculia guttata	3.70	0.58	
Sterculia urens	2.47	1.17	
Strychnus nuxvomica	20.99	1.17	
Syzygium cumini	1.23	0.58	
Tabarnaemontana heyneana		0.58	2.78
Vitex altissima	2.47	0.58	2.78
Xeromphis spinosa	1.23	1.75	
Zanthoxylum rhetsa	4.94		

Table 14. Frequency class distribution of all species in all study location in Thrissur Forest Division, Kerala

Frequency Class	Percentage frequency	Number of species		
		Karadippara	Kalluchal	Kuthiran
I	1 -20%	30	45	20
II	21-40%	4	1	4
III	41-60%	2	0	1
IV	61-80%	1	2	1
V	81-100%	0	0	0

Table 15. Relative frequency of all species of MDF in the three study locations at Thrissur Forest Division, Kerala

Species	Relative frequency (%)		
	Karadippara	Kalluchal	Kuthiran
Alstonia scholaris		0.58	
Bombax ceiba	1.92	1.17	3.05
Dalbergia sisoo	3.13	1.17	1.53
Dillenia pentagyna	4.09	2.34	6.11
Grewia tiliifolia	6.49	2.92	7.63
Haldina cordifolia		0.58	
Lagerstroemia lanceolata	7.45	3.51	0.76
Lannea coromandelica	2.40	1.75	1.53
Pterocarpus marsupium	0.24	1.75	0.76
Radarmachera xylocarpa		0.58	

Stereospermum colias		0.58	
Terminalia bellerica	1.68	1.17	0.76
Terminalia crenulata	1.44	0.58	1.53
Terminalia paniculata	1.92	3.51	0.76
Tectona grandis	0.72	0.58	3.82
Trewia nudiflora	1.20	0.58	0.76
Xylia xylocarpa	11.30	16.96	16.79
Hollarhena antidysentrica	9.62	7.60	12.98
Wrightia tinctoria	13.46	14.04	9.92
Other Species			
Ailanthus tryphysa		2.34	2.29
Annona squamosa			1.53
Aporusa lindeyana	2.64	1.17	1.53
Artocarpus hirsutus	0.24	0.58	
Bauhinia racemosa	2.40	0.58	
Bixa orellana		1.17	
Bauhinia squamosa		0.58	
Carralia brachiate		0.58	
Careya arborea		0.58	

Cassia fistula	0.24	1.17	4.58
Cleistanthus collinus	1.20	7.60	2.29
Cordia wallichi		0.58	
Diospyros montana	0.24	1.17	
Garuga floribunda	0.24	0.58	
Glycosmis pentaphylla			0.76
Hydnocarpus pentandra	1.68		
Litsea Spp.	0.24	0.58	
Mitragyna parvifolia		0.58	
Macaranga peltata	5.05	2.92	3.82
Mallotus philippensis	0.48	0.58	
Naringi crenulata	1.68	0.58	8.40
Olea dioica	0.72	1.75	4.58
Sapindus laurifolia	1.92	0.58	
Schleichera oleosa	6.73	4.68	
Spondias pinnata		0.58	
Sterculia guttata	0.72	0.58	
Sterculia urens	0.48	1.17	
Strychnus nuxvvomica	4.09	1.17	

Syzygium cumini	0.24	0.58	
Tabarnaemontana heyneana		0.58	0.76
Vitex altissima	0.48	0.58	0.76
Xeromphis spinosa	0.24	1.75	
Zanthoxylum rhetsa	0.96		
Total	100	100	100

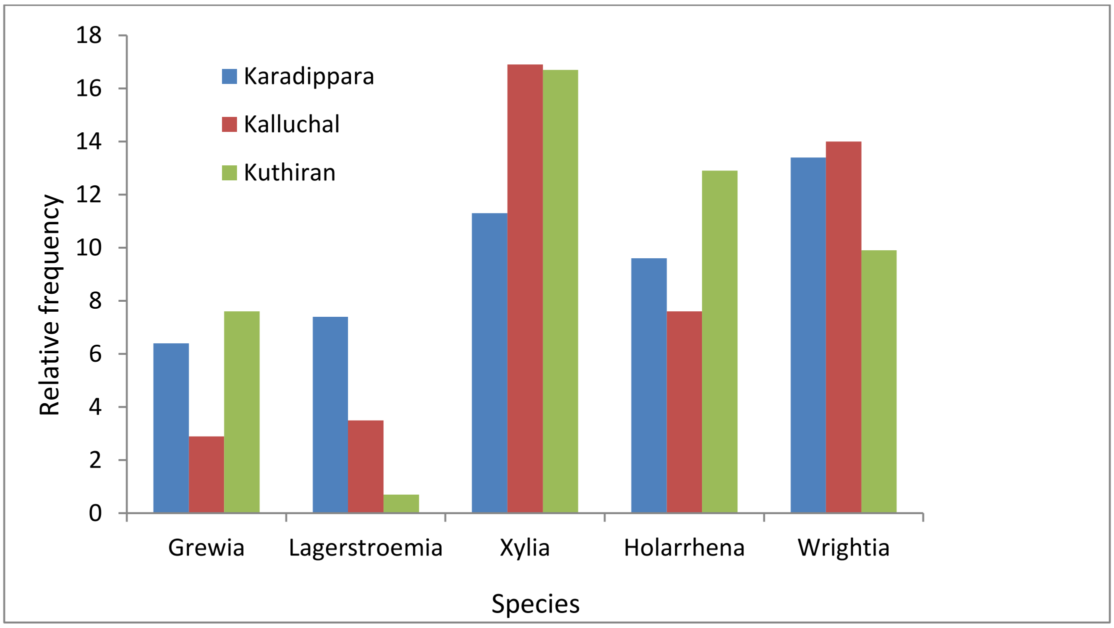

Fig 8. Relative Frequency of selected species in three study locations

4.6 Importance value index (IVI)

Important Value Index has been computed for all the tree species in the MDF of three locations at Thrissur District, Kerala (Table 16).

4.6.1 At location level: The total IVI for the three locations recorded closer values with values 296.76, 299.97 and 298.61 for Karadippara, Kalluchal and Kuthiran respectively. In Karadippara, *Xylia xylocarpa* represented the highest IVI value (53.91). This was followed by *Wrightia tinctoria* (37.47), and *Lagerstroemia lanceolata* (37.17). In Kalluchal also *Xylia xylocarpa* (73.86) registered the highest IVI was also which was followed by *Wrightia tinctoria* (35.77). In Kuthiran too, *Xylia xylocarpa* (54.73) showed maximum IVI value which in turn was followed by *Dillenia pentagyna* (29.55) and *Holarrhena antidysentrica* (28.57).

4.6.2 At stratum level: *Xylia xylocarpa* was the species with highest IVI value in the upper stratum for all the three sites with values 53.91, 73.86 and 54.73 respectively for Karadippara, Ka and Ku sites. The prominent tree species in term of IVI in the middle stratum for various location was Schleichera oleosa (11.51; Karadippara), Cleistanthus collinus (15.19; Kaluchal) and Cassia fistula (10.32; Kuthiran). Lower strata in general showed lesser number of tree species however, they shared high IVI values. For instance, the species with high IVI values in the lower stratum was *Wrightia tinctoria* with values 37.47 and 35.77 for Karadippara and Kalluchal sites respectively and *Holarrhena antidysentrica* (28.57) for Kuthiran site.

Other prominent tree species with high IVI values for Karadippara site were *Dillinea pentagyna* (22.85), *Grivillia taelifolia* (18.48) and for the Kalluchal site were *Terminalia paniculata* (29.76) and *Cleistanthus collinus* (15.19). Other conspicuous species with good IVI values in the Ku site were *Wrightia tinctoria* (22,28) and *Narengia crenulata* (21.26).

4.6.3 Relative IVI

The Relative IVI values for different vertical strata of the MDF are given in Table 17.

At species level: Relative IVI also followed similar trend as that of IVI with *Xylia xylocarpa* showing highest contribution to the total IVI (17.97, 24.62 and 18.24% for Karadippara, Kalluchal and Kuthiran sites respectively) in the upper stratum. This was followed by *Lagerstroemia lanceoata, Terminalia paniculata* and *Dillenia indica*. In the middle stratum, the highest share was from *Cleistanthus collinus* (5.06) in Kalluchal, *Schleichera oleosa* (3.84) in Karadippara and *Cassia fistula* (3.84) in Kuthiran. The other species of middle stratum which also contributed marginally are *Strychnus nuxvomica* and *Olea dioica.* However, in the lower stratum, *Wrightia tinctoria* contributes the highest RIVI in Kalluchal and Karadippara but *Holarrhena antidysentrica* has the highest RIVI in Kuthiran (Table 17). The major share of the IVI was confined to the species in the upper stratum while the middle and lower stratum has a lower and similar trend in IVI distribution. (Table 17).

The average RIVI values for the upper stratum, middle stratum and lower stratum were 59.27, 20.24 and 20.47% respectively. In the upper stratum, the location Karadippara has the highest RIVI (60.13) followed by Kalluchal (59.15) and Kuthiran (58.55). Almost 60% RIVI is contributed by the species of upper stratum alone. The remaining 40% RIVI is contributed by the species of middle and lower stratum. In case of lower stratum, the location Kalluchal has the highest RIVI (23) followed by Karadippara (20.41) and Kuthiran (17.31). In the lower strata, the highest contribution of RIVI is from Kuthiran (24.13) which is followed by Karadippara (19.45) and Kalluchal (17.84). (Table 18).

Table 16. Importance value index (IVI) of all species for all study locations in Thrissur Forest Division, Kerala

Strata I Species	Location		
	Karadippara	Kalluchal	Kuthiran
Upper stratum			
Alstonia scholaris		1.59	
Bombax ceiba	8.36	6.18	19.18
Dalbergia sisoo	10.13	2.38	6.077
Dillenia pentagyna	22.85	11.80	29.55
Grewia tiliifolia	18.48	5.36	19.200
Haldina cordifolia		1.04	
Lagerstroemia lanceolata	37.17	15.00	2.983
Lannea coromandelica	5.33	3.37	3.034
Pterocarpus marsupium	0.43	3.88	3.757
Radarmachera xylocarpa		2.11	
Stereospermum colias		1.53	
Terminalia bellerica	4.86	9.88	4.990
Terminalia crenulata	3.35	2.31	7.685
Terminalia paniculata	10.56	29.76	5.505
Tectona gramdis	1.26	6.10	14.978
Trewia nudiflora	2.05	1.27	2.639
Xylia xylocarpa	53.91	73.86	54.731
Middle stratum			

Ailanthus tryphysa		4.79	7.741
Annona squamosa			2.620
Aporusa lindeyana	5.58	1.97	5.377
Artocarpus hirsutus	0.42	1.41	
Bauhinia racemosa	3.61	1.12	
Bixa orellana		1.98	
Bridelia squamosa		1.18	
Carralia brachiata		0.99	
Careya arborea		1.02	
Cassia fistula	0.47	2.05	10.323
Cleistanthus collinus	5.83	15.19	4.449
Cordia wallichi		1.01	
Diospyros montana	0.42	1.98	
Garuga floribunda	1.09	1.11	
Glycosmis pentaphylla			1.840
Hydnocarpus pentandra	3.21		
Litsea spp.	0.48	1.02	
Mitragyna parvifolia		0.99	
Macaranga peltata	9	5.35	8.584
M. philippensis	0.95	1.06	
Olea dioica	1.26	3.69	8.370
Sapindus laurifolia	3.57	1.14	
Schleichera oleosa	11.51	5.98	
Spondias pinnata		2.29	
Sterculia guttata	1.44	0.99	
Sterculia urens	0.84	1.97	

Strychnus nuxvomica	6.6	2.04	
Syzygium cumini	0.42	1.02	
Tabarnaemontana heyneana			1.300
Trema orientalis		0.99	
Vitex altissima	0.84	1.40	1.304
Xeromphis spinosa	0.42	3.29	
Zanthoxylum rhetsa	1.7		
Lower stratum			
Hollarhena antidysentrica	20.89	16.38	28.57
Naringi crenulata		1.38	21.57
Wrightia tinctoria	37.47	35.77	22.26
Total IVI	296.76	299.97	298.61

Table 17. Relative importance value index of all species for all locations of Thrissur Forest Division, Kerala

Strata I Species	Location Wise (RIVI)		
	Karadippara	Kalluchal	Kuthiran
Alstonia scholaris		0.53	
Bombax ceiba	2.79	2.06	6.39
Dalbergia sisoo	3.38	0.79	2.03
Dillenia pentagyna	7.62	3.93	9.85
Grewia tiliifolia	6.16	1.79	6.40
Haldina cordifolia		0.35	
Lagerstroemia lanceolata	12.39	5.00	0.99

Lannea coromandelica	1.78	1.12	1.46
Pterocarpus marsupium	0.14	1.29	1.25
Radarmachera xylocarpa		0.70	
Stereospermum colias		0.51	
Terminalia bellerica	1.62	3.29	1.66
Terminalia crenulata	1.67	0.77	2.56
Terminalia paniculata	3.52	9.92	1.84
Tectona grandis	0.42	2.03	4.99
Trewia nudiflora	0.68	0.42	0.88
Xylia xylocarpa	17.97	24.62	18.24
Strata II Species			
Ailanthus tryphisa		1.60	2.58
Annona squamosa			0.87
Aporusa lindeyana	1.86	0.66	1.79
Artocarpus hirsutus	0.14	0.47	
Bauhinia racemosa	1.20	0.37	
Bixa orellana		0.66	
Bridelia squamosa		0.39	
Carralia brachiate		0.33	
Careya arborea		0.34	
Cassia fistula	0.16	0.68	3.44
Cleistanthus collinus	1.94	5.06	1.48

Cordia wallichi		0.34	
Diospyros montana	0.14	0.66	
Garuga floribunda	0.36	0.37	
Glycosmis pentaphylla			0.61
Hydnocarpus pentandra	1.59		
Litsea spp.	0.16	0.34	
Mitragyna parvifolia		0.33	
Macaranga peltata	3.00	1.78	2.86
Mallotus philippensis	0.32	0.35	
Olea dioica	0.42	1.23	2.79
Sapindus laurifolia	1.19	0.38	
Schleichera oleosa	3.84	1.99	
Spondias pinnata		0.76	
Sterculia guttata	0.48	0.33	
Sterculia urens	0.28	0.66	
Strychnus nuxvomica	2.20	0.68	
Syzygium cumini	0.14	0.34	
Tabarnaemontana heyneana			0.44
Trema orientalis		0.33	
Vitex altissima	0.28	0.47	0.43
Xeromphis spinosa	0.14	1.10	
Zanthoxylum rhetsa	0.57		
Strata III Species			

Hollarhena antidysentrica	6.96	5.46	9.52
Naringi crenulata		0.46	7.19
Wrightia tinctoria	12.49	11.92	7.42

Table 18. Relative IVI of different strata of all study locations of Thrissur Forest Division, Kerala

Location	Relative IVI		
	Upper stratum	Mid stratum	Lower stratum
Karadippara	60.13	20.41	19.45
Kalluchal	59.15	23.00	17.84
Kuthiran	58.55	17.31	24.13
Mean	59.27	20.24	20.47
SD	0.79	2.84	3.26

4.7 Diversity indices: The values of various indices such as Simpson's Index, Shannon's Index and Margalef Index for the MDF location under study are given in Table 18. The Shannon's Index values suggest highest value for Kalluchal (2.65) followed by Karadippara (2.45) and Kuthiran (2.37). However, Simpson Index showed modest variation across the locations with same value of 0.12 for both Karadippara and Kuthiran and 0.10 in Kalluchal. Nevertheless, the Margalef Richness Index varied considerably with Kalluchal registering highest (5.81) and Kuthiran, the lowest (3.72). Karadippara recorded a moderate value of 4.46 (Table 19).

Table 19. Diversity indices of MDF in Thrissur Forest Division, Kerala

Location	Diversity indices		
	Shannon index	Simpson index	Margalef index
Karadippara	2.45	0.12	4.46
Kalluchal	2.65	0.10	5.81
Kuthiran	2.37	0.12	3.72

4.8 Size class variation in tree species of MDF in Thrissur Forest Division

The size class distribution per hectare of all species in various study locations are presented in Table 21, 22 and 23.

4.8.1 Karadippara location

Table 21 shows the size class distribution of species for the Karadippara location in Thrissur forest division. In Karadippara, the species having the maximum number of individuals per hectare in the upper stratum for all the size classes was *Xylia xylocarpa* with 792 stems ha^{-1} followed by *Grewia tiliaefolia* (323 stems ha^{-1}), *Lagerstroemia lanceolate* (323 stems ha^{-1}). In general, there was gradual reduction in the number of stems with increasing size class. Bulk of the individuals belonging to different species are confined to the lower size class in particular in <50 cm height class, h100, hg100 and d10 size classes. This was particularly true for the above species with larger total number per ha. Among all the size classes, the largest proportion of stems was observed in the lowest size class (<50 cm height class) for all the species. For instance, the number of stems in the <50 cm height class was 412, 179 and 164 respectively for *Xylia xylocarpa*, *Grewia tiliaefolia* and *Lagerstroemia lanceolata.* Adequate representatives were available in all the size classes for few species such as Xylia. Other species such as Grewia and Lagerstroemia also had better distribution of stems across various size classes baring few exceptions. However, there is genuine lack of representation for majority of tree species in various size classes.

Trends were all the more similar in middle stratum with conspicuous change in species. For instance, the maximum total number for all the size classes that was recorded for the middle stratum was *Macaranga peltata* (212) followed by *Schleichera oleosa* (141 stems ha^{-1}). Unlike the upper stratum species, the species in the middle stratum were lesser in density with lesser or no representation especially at higher size classes.

Interestingly, the number of tree species in lower stratum was considerably lower. Amon the three species reported, *W. tinctoria* and *H. antidysentrica* recorded higher total number of stems with values 720 and 602 stems ha^{-1} respectively. As expected, they had representation only in lower size classes upto d30.

4.8.2 Kalluchal location

Table 22 shows the distribution of stems in the various size classes in MDF of Kalluchal location. The general trends in species distribution in the MDF of Kalluchal location was similar to that of Karadippara site. In Kalluchal, the species having the maximum number of individuals in the upper stratum is *Xylia xylocarpa* (1602 stems ha^{-1}) followed by *Grewia tilifolia* (561 stems ha^{-1}) and *Lagerstroemia lanceolata* (549 stems ha^{-1}) respectively. There is a reduction in the number of individuals in all species with increasing size class across all strata. High bulk of individuals can be observed in lower size classes particularly h50, h100 and hg100 size classes. In the upper stratum, there is a genuine lack of representation of individuals in all size classes. The only species having representation in all size classes is *Xylia xylocarpa.* The species of the middle stratum are confined upto the d20 size class with no individuals in the upper size classes.

4.8.3 Kuthiran location

Table 23 shows the number of individuals of all species across all size classes in Kuthiran location. The species having the maximum number of individuals in the upper stratum are *Xylia xylocarpa* (802 stems ha^{-1}) followed by

Grewia tilifolia (354 stems ha^{-1}) and *Dillenia pentagyna* (222 stems ha^{-1}) respectively. In the middle stratum, the species dominating the strata is *Macaranga pelteta* with 319 individuals per ha.

Table 20. Various size classes employed for classification of vegetation

No	Name	Size range
1	h50	Height ≤ 50 cm
2	h100	Height > 50 cm and ≤ 100 cm
3	hg100	Height > 100 cm and DBH < 1 cm
4	d10	DBH ≥ 1 cm and ≤ 10 cm
5	d20	DBH > 10 cm and ≤ 20 cm
6	d30	DBH > 20 cm and ≤ 30 cm
7	d40	DBH > 30 cm and ≤ 40 cm
8	d50	DBH > 40 cm and ≤ 50 cm
9	d60	DBH > 50 cm and ≤ 60 cm
10	dg60	DBH > 60 cm

Plate 5. *Macaranga pelteta* seedlings in Kuthiran forest

Plate 6. *Helectris isora* brushwood in Karadippara

Table 21. Size class distribution per hectare of all species in Karadippara, Thrissur Forest Division, Kerala

Species	Number of trees per ha										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Upper stratum											
Bombax ceiba	44	16	0	5	1	0	0	0	2	4	72
Dalbergia sisoo	0	0	0	13	2	0	0	2	1	1	19
Dillenia pentagyna	63	15	2	5	0	0	4	4	6	10	109
Grewia tiliifolia	179	79	28	17	1	4	6	7	2	0	323
Lagerstroemia lanceolata	164	89	30	19	0	1	0	1	1	18	323
Lannea coromandelica	65	25	7	5	9	2	0	1	0	0	114
Terminalia bellerica	19	6	0	0	0	1	0	2	1	4	33
Terminalia paniculata	41	31	0	0	0	0	0	0	1	9	82
Xylia xylocarpa	412	223	55	63	2	4	5	7	6	15	792
Miscellaneous Species	5	0	0	11	6	0	0	2	1	1	26
Middle stratum											
Aporusa lindeyana	22	7	12	0	0	0	0	0	0	0	41
Cleistanthus	58	26	0	1	0	0	0	1	5	0	74

collinus											
Macaranga peltata	138	51	0	13	4	6	0	0	0	0	212
Olea dioica	7	0	2	4	0	0	0	0	0	0	13
Schleichera oleosa	61	23	32	26	1	0	0	0	0	0	143
Strychnos nuxvomica	39	23	14	13	3	2	0	0	0	0	94
Miscellaneous species	0	0	0	28	12	4	0	0	1	0	45
Lower stratum											
Holarrhena antidysentrica	199	307	30	39	26	1	0	0	0	0	602
Naringi crenulata	0	0	11	9	0	0	0	0	0	0	20
Wrightia tinctoria	221	331	47	80	41	0	0	0	0	0	720

Table 22. Size class distribution per hectare of all species in Kalluchal, Thrissur Forest Division, Kerala

Species	Number of trees per ha										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Upper stratum											
Bombax ceiba	72	30	3	0	0	0	0	0	3	3	111
Dillenia pentagyna	136	72	0	3	0	0	3	0	3	3	220
Grewia tiliifolia	272	219	53	17	0	0	0	0	0	0	561
Lagerstroemia lanceolata	300	202	28	11	0	0	0	0	5	3	549
Lannea coromandelica	64	19	0	8	0	0	0	0	0	0	91
Pterocarpus marsupium	31	8	0	0	0	3	3	0	0	0	45
Terminalia bellerica	31	14	0	3	0	0	0	3	0	3	54
Terminalia	14	17	0	0	0	0	0	3	0	0	34

crenulata											
Terminalia paniculata	144	102	28	0	0	3	0	3	5	11	296
Xylia xylocarpa	725	550	175	103	14	8	3	8	8	8	1602
Miscellaneous Species	0	0	0	14	0	6	3	3	0	3	29
Middle stratum											
A. tryphysa	0	0	0	14	3	0	0	0	0	0	17
Aporus lindeyana	33	14	0	3	0	0	0	0	0	0	50
Bauhinia racemosa	14	3	0	0	3	0	0	0	0	0	20
Cassia fistula	214	150	83	28	3	0	5	0	0	0	483
Garuga floribunda	0	0	0	17	0	0	0	0	0	0	17
Macaranga peltata	133	92	53	11	0	0	0	0	0	0	289
Olea dioica	66	100	42	11	0	0	0	0	0	0	219
Schleichera	47	31	17	19	5	0	0	0	0	0	119

oleosa											
Sterculia guttata	19	17	0	0	0	0	0	0	0	0	36
Sterculia urens	14	3	0	3	0	0	0	0	0	0	20
Strychnos nuxvomica	22	11	0	8	0	0	0	0	0	0	41
Syzygium cumini	8	3	0	3	0	0	0	0	0	0	14
Vitex altissima	11	3	0	2	0	0	0	0	0	0	14
Xeromphis spinosa	30	25	0	5	0	3	0	0	0	0	63
Miscellaneous Species	0	0	0	61	16	3	0	0	0	0	80
Lower stratum											
Holarrhena antidysentrica	192	228	22	44	5	0	0	0	0	0	491
Naringi crenulata	105	122	25	8	0	0	0	0	0	0	260
Tabarnaemontana heyneana	0	0	0	3	0	0	0	0	0	0	3
Wrightia tinctoria	200	253	55	64	42	3	0	0	0	0	617

Table 23. Size class distribution per hectare of all species in Kuthiran, Thrissur Forest Division

Species	Number of trees per ha										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Upper stratum											
Bombax ceiba	58	19	0	0	3	5	3	0	0	3	91
Dillenia pentagyna	128	58	11	5	0	3	3	3	3	8	222
Grewia tiliifolia	191	72	58	8	8	14	3	0	0	0	354
Lagerstroemia lanceolata	53	14	0	0	0	0	3	0	0	0	70
Lannea	36	14	0	0	5	0	0	0	0	0	55
Tectona grandis	105	39	22	0	3	5	3	3	3	0	183
Xylia xylocarpa	419	219	78	5	53	14	5	3	3	3	802
Miscellaneous species	0	0	0	0	0	3	6	6	6	3	24
Middle stratum											

Aporusa lindeyana	0	0	0	5	3	3	3	0	0	0	14
Cassia fistula	0	0	0	0	5	5	0	0	0	0	10
Cleistanthus collinus	30	14	0	11	0	0	0	0	0	0	55
Macaranga peltata	197	81	11	25	5	0	0	0	0	0	319
Olea dioica	14	11	16	19	0	0	0	0	0	0	60
Miscellaneous Species	14	0	3	8	8	8	3	0	0	0	44
Lower stratum											
Hollarhena	47	103	66	58	14	0	0	0	0	0	288
Naringi crenulata	14	39	0	67	3	0	0	0	0	0	123
Wrightia tinctoria	50	111	50	44	14	0	0	0	0	0	269
Miscellaneous Species	0	0	0	44	0	0	0	0	0	0	44

4.8.4 Percentage size class frequencies

The percentage size class frequencies of total number of stems of selected species is given in Table 24. Among the species only two viz. teak and xylia had representatives belonging to all the size classes. Other species with reasonably good distribution across size classes were *Bombax ceiba, Dillenia pentagyna, Lagerstroemia lanceolata* (missing in only one size class). In general, the proportional distribution of stem for all the species declined with increase in size class. Most majority of the tree species had bulk of the stems occupying in the lower most size classes. For instance, species such as B. ceiba, D. pentagyna, G. tiliafolia, L. lanceolata, Lannea, P. marsupium and X. xylocarpa showed more than 80% of the stems occupying lower size classes h50 and h100 (ie., less than 100 cm height). There were several species where the presence of stems was limited to very few size classes. Especially most of the species had conspicuous absence of representatives in the higher size classes. Only species such as T. paniculata and T. Bellerica had reasonably good proportion in the highest size class 'd60' (10.01 and 8.51% respectively).

Importantly some of the species has no representatives in the lowest size class (young regeneration in <50 cm height class). Prominent among this group include *Alstonia scholaris, Dalbergia sisoo, Haldina cordifolia, Radermachera xylocarapa, Sterospermum colias, Tetrameles* nudiflora and *Ailanthus tryphisa.* Furthermore, most of these species had representatives only in one or two larger size classes. Examples include *Alstonia scholaris, Haldina cordifolia, Artocarpus hirsutus, Radermachera xylocarapa, Sterospermum colias and Bixa orellana.*

Table 24. Size class frequencies of selected species in all study locations in Thrissur Forest Division, Kerala

Species	Percentage distribution of total stems (%)									
	Size classes									
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60
Alstonia scholaris	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00
Bombax ceiba	62.88	23.48	0.76	3.03	1.52	1.52	0.76	0.00	2.27	3.79
Dalbergia sisoo	0.00	0.00	0.00	63.64	9.09	4.55	4.55	9.09	4.55	4.55
Dillenia pentagyna	59.11	23.89	2.43	2.83	0.00	0.40	2.02	1.62	2.83	4.86
Grewia tiliifolia	52.61	28.50	10.62	3.88	0.67	1.35	1.01	1.01	0.34	0.00
Haldina cordifolia	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00	0.0
Lagerstroemia lanceolata	53.61	30.93	7.01	3.92	0.00	0.21	0.21	0.21	0.62	3.30
Lannea coromandelica	60.96	21.92	4.11	4.79	6.16	1.37	0.00	0.68	0.00	0.00
Pterocarpus	70	15	0.00	0.00	0.00	5	5	5	0.00	0.00

marsupium										
Radermachera xylocarpa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00
Stereospermum colias	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.00
Terminalia bellerica	55.32	21.28	0.00	2.13	0.00	2.13	0.00	6.38	4.26	8.51
Terminalia crenulata	22.73	27.27	0.00	18.18	4.55	0.00	0.00	18.18	4.55	4.55
Terminalia paniculata	46.22	31.09	8.40	0.00	0.00	0.84	0.00	0.84	2.52	10.08
Tectona grandis	54.29	20.00	11.43	2.86	1.43	2.86	1.43	1.43	2.86	1.43
Tetrameles nudiflora	0.00	0.00	0.00	33.33	50.00	16.67	0.00	0.00	0.00	0.00
Xylia xylocarpa	49.44	30.35	9.01	5.96	1.72	0.73	0.46	0.66	0.60	1.06
Hollarhena antidysentrica	32.12	47.85	7.28	8.97	3.64	0.13	0.00	0.00	0.00	0.00
Wrightia tinctoria	29.82	44.24	8.43	11.53	5.88	0.11	0.00	0.00	0.00	0.00

Other Species										
Ailanthus tryphisa	0.00	0.00	0.00	83.33	16.67	0.00	0.00	0.00	0.00	0.00
Aporusa lindeyana	52.63	19.30	17.54	5.26	1.75	1.75	1.75	0.00	0.00	0.00
Artocarpus hirsutus	0.00	0.00	0.00	50.00	50.00	0.00	0.00	0.00	0.00	0.00
Bauhinia racemosa	53.85	7.69	0.00	30.77	7.69	0.00	0.00	0.00	0.00	0.00
Bixa orellana	0	0	0	100	0	0	0	0	0	0
Cassia fistula	0.00	0.00	0.00	14.29	57.14	28.57	0.00	0.00	0.00	0.00
Cleistanthus collinus	50.37	29.85	11.19	5.60	0.37	0.00	0.75	0.37	1.49	0.00
Macaranga peltata	59.08	26.34	5.88	6.14	1.28	1.28	0.00	0.00	0.00	0.00
Naringi crenulata	27.74	37.42	11.61	22.58	0.65	0.00	0.00	0.00	0.00	0.00
Olea dioica	31.25	35.71	20.54	12.50	0.00	0.00	0.00	0.00	0.00	0.00
Sapindus laurifolia	0.00	0.00	0.00	57.14	42.86	0.00	0.00	0.00	0.00	0.00

Schleichera oleosa	42.59	18.52	19.75	17.28	1.85	0.00	0.00	0.00	0.00	0.00
Sterculia guttata	43.75	37.5	0.00	0.00	12.50	6.25	0.00	0.00	0.00	0.00
Strychnos nuxvomica	43.12	24.77	12.84	14.68	2.75	1.83	0.00	0.00	0.00	0.00
Syzygium cumini	50.00	16.67	0.00	33.33	0.00	0.00	0.00	0.00	0.00	0.00
Tabarnaemontana heyneana	0	0	0	100	0	0	0	0	0	0
Vitex altissima	36.36	9.09	9.09	45.45	0.00	0.00	0.00	0.00	0.00	0.00
Xeromphis spinosa	45.83	37.50	0.00	12.50	0.00	4.17	0.00	0.00	0.00	0.00
Zanthoxylum rhetsa	0	0	0	100	0	0	0	0	0	0

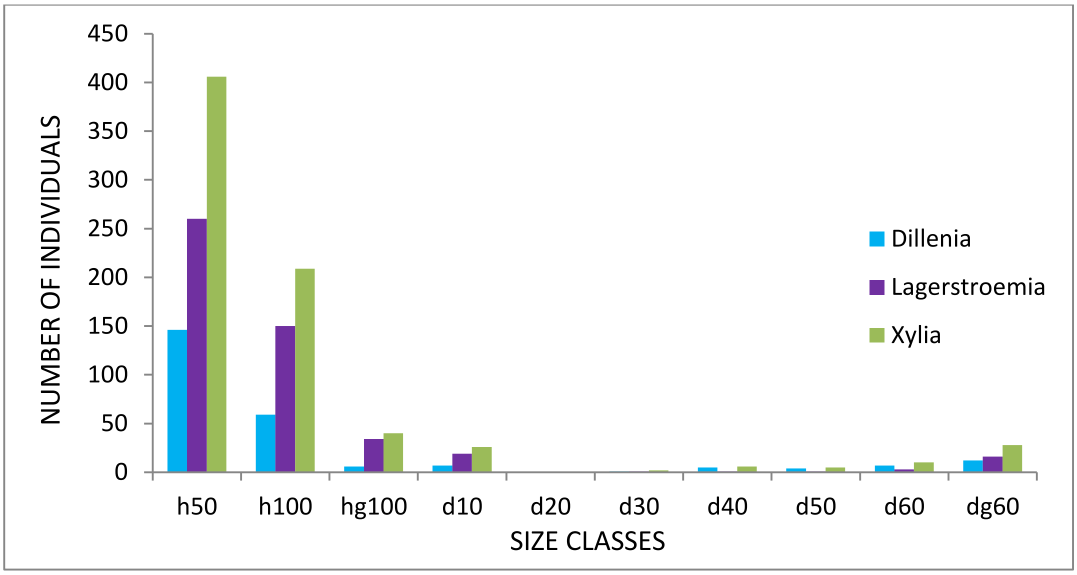

Fig 9. No. of individuals of selected species of upper stratum in all size classes

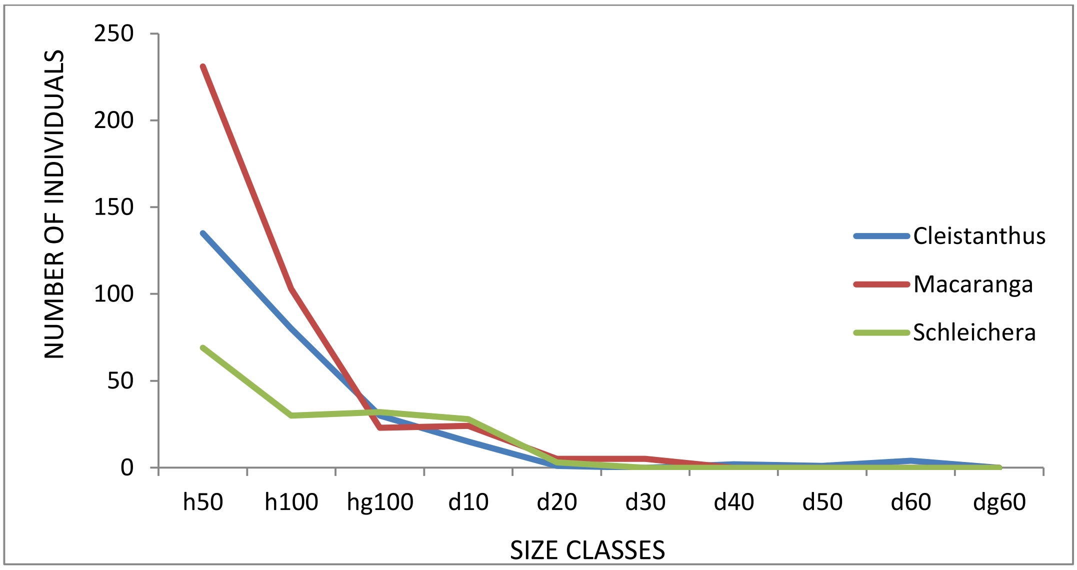

Fig 10. No. of individuals of selected species of middle stratum in all size classes

Fig 11. No. of individuals of selected species of lower stratum in all size classes

4.8.5 Cumulative size class distribution

At location level:

The distribution of vegetation in to various size classes for each location irrespective of the species is given in Table 25. The total number of individuals distributed in various size class was highest for Kalluchal forests (6411 stems ha^{-1}) followed by Karadippara (3903 stems ha^{-1}) and lowest in the Kuthiran region (2972 stems ha^{-1}). As observed earlier tables, characteristic decrease in number of individuals with increase in size class is discernible. Drastic reduction in mid size classes is evident for all the three locations (size class: d30, d40, d50 and d60).

At strata level: Frequency distribution in different size classes for different vertical strata are presented in Tables 26, 27 and 28. The highest number of individuals belonging to different species are found in the upper stratum will maximum total number recorded by Kalluchal MDF forests (3591 stems ha^{-1}) (Table 25). In all the location almost 75 to 85 % of the plants were represented by the seedling/sapling stage (h50 and h100). In the upper stratum, each size class has the representation of individuals. But the number of individuals between d30 and d60 size class has lesser number of individuals than the biggest size class dg60 which proves a gap in the middle size classes. However, there is an exception in Kuthiran where the highest size class dg60 had less number of individuals (Table 25).

In the middle stratum, the total population for all the three locations were considerably lower than that of upper stratum. Among the locations the Kalluchal had larger number of individual in various size classes.   some size classes are under some sort of stress because there is absence of individuals. In the case of upper stratum, the population size reduces considerably with increase in size class but there are no size classes without representation as seen in middle stratum (Table 27). There was conspicuous absence of any woody vegetation in the higher size classes for all the three locations.

Table 28 represents the size class distribution of plants in the lower stratum. Both Karadippara and Kalluchal sites registered similar total number of individuals while the Kt site had just half of the individual tree number of other sites. Yet another aspect of interest in contrast to other two strata is that all the three sites had higher number of individuals in the h100 size class as compared to the lowest size class (h50). Also there is a fairly uniform distribution of vegetation up to the d20 size class.

Table 25. Size class representation of all trees irrespective of strata for all study locations in Thrissur Forest Division, Kerala

Location	Number of stems per ha										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Karadippara	1745.68	1258.02	275.31	354.32	108.64	25.93	14.81	29.63	29.63	61.73	3903
Kalluchal	2900.00	2288.89	583.33	425.00	86.11	27.78	16.67	22.22	25.00	33.33	6411
Kuthiran	1358.33	794.44	316.67	263.89	116.67	52.78	27.78	13.89	13.89	16.67	2972
Mean	2001.33	1447.11	391.77	347.73	103.80	35.49	19.75	21.91	22.84	37.24	4428
SD	802.00	764.96	167.18	80.75	15.84	14.99	7.01	7.87	8.08	22.78	1778

Table 26. Per hectare size class representation of all trees in upper stratum in all locations in Thrissur Forest Division, Kerala

Location	Number of stems per ha in upper stratum										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Karadippara	991.36	483.95	123.46	137.04	20.99	12.35	14.81	28.40	23.46	61.73	1897
Kalluchal	1788.89	1236.11	286.11	155.56	13.89	19.44	11.11	19.44	25.00	33.33	3591
Kuthiran	991.67	436.11	169.44	19.44	72.22	44.44	25.00	13.89	13.89	16.67	1800
Mean	1257.30	718.72	193.00	104.01	35.70	25.41	16.97	20.57	20.78	37.24	2429
SD	460.36	448.70	83.84	73.82	31.82	16.85	7.19	7.32	6.01	22.78	1007

Table 27. Per hectare size class representation in the middle stratum for all locations in Thrissur Forest Division, Kerala

Location	Number of stems per ha in middle stratum										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Karadippara	334.57	135.80	64.20	81.48	20.99	12.35	0.00	1.23	6.17	0.00	656
Kalluchal	613.89	450.00	194.44	150.00	25.00	5.56	5.56	2.78	0.00	0.00	1447
Kuthiran	255.56	105.56	30.56	63.89	13.89	8.33	2.78	0.00	0.00	0.00	480
Mean	401.34	230.45	96.40	98.45	19.96	8.74	4.17	2.00			861
SD	188.26	190.73	86.55	45.49	5.62	3.41	1.96	1.09			515

Table 28. Per hectare size class representation in the lower stratum for all locations in Thrissur Forest Division, Kerala

Location	Number of stems per ha in lower stratum						
	Size classes						
	h50	h100	hg100	d10	d20	d30	Total
Karadippara	419.75	638.27	87.65	135.80	66.67	1.23	1349
Kalluchal	497.22	602.78	102.78	119.44	47.22	2.78	1372
Kuthiran	111.11	252.78	116.67	186.11	30.56	0.00	691
Mean	342.69	497.94	102.36	147.11	48.15	2.00	1137
SD	204.26	213.05	14.51	34.74	18.07	1.09	386

Table 29. Gap size and gap percentage in three study locations in the moist deciduous forests of Thrissur Forest Division, Kerala.

Quadrat No. (Size 10 ×10m^2)	Gap Size (Square metres)		
	Location		
	Karadippara	Kalluchal	Kuthiran
1	30	34.5	48
2	15.5	35.5	71.5
3	21.5	31	76
4	52	48	69
5	22.5	15	75.5
6	73.5	9.5	92
7	33.5	30	48
8	36	38	75
Total gap	284.5	241.5	555
Total Area Studied (m^2)	800	800	800
Gap %	35.56	30.18	69.37

Discussion

5. DISCUSSION

Field investigation was carried out on the vegetation structure and dynamics of the selected locations in the MDF at Thrissur forest division Kerala. Various structural attributes such as species diversity, density, frequency, basal area, IVI and size class distribution of the vegetation were assessed and tabulated in the preceding chapter. The objective of the study also includes the evaluation of the changes in structural and functional attributes of these forests in comparison with the study results of the vegetation structure carried out in the same locations during 1989 (three decades before). The salient findings are discussed hereunder:

5.1 SPECIES DIVERSITY

In moist deciduous forests (MDF) of Thrissur District under observation, on an average species diversity varied from 26 to 48 species among the three locations with total number of 51 species across all locations under study. These values are considerably lower compared to many other MDFs in India. For instance, a recent study in the MDF of eastern India, Odisha revealed 177 tree species belonging to 120 genera and 44 families (Panda et al. 2017). A similar study in the same sites reported 101 species belonging to 78 genera and 37 families (Sahoo et al. 2020). Also low land moist deciduous forests of Tripura reported 134 species belonging to 93 genera and 43 families of woody plants (Majumdar, 2014). A study from the tropical deciduous forests of Northcentral Eastern Ghats, India reported a total of 135 plant taxa (≥15 cm gbh) belonging to 105 genera of 45 families (Naidu et al 2018). The apparent lower diversity observed in the present study could be attributed to the successional status in the MDF forests and the past intensity of logging and disturbances these forest were subjected to.

However, in the earlier study in the same locations, Narayanan (1988) recorded higher number of tree species to the tune of 64 species. Location specific number of species could not be compared between the two periods of study as the corresponding data was not available in the previous study. This indicates large scale depletion in the tree species distribution in MDF during the last thirty years period. A closer analysis of this declining species diversity indicates floristic diversity changes at various vertical strata as well. For instance, in the present study, the species distribution across stratum were 17 species (33.3 %), 28 species (54.9 %) and 6 species (11.7 %) respectively for upper, middle and lower stratum. However, the corresponding values as recorded by Narayanan (1988) in his study in the same location thirty years before were 21, 39 and 4 species in upper stratum, middle stratum and lower stratum respectively.

From the successional perspectives, the tree species forming the community in MDF share diverse ecological requirements (Majumdar *et al.,* 2014). The extent of differences in the ecological niche makes the co-existence of the species in any natural vegetation. In MDF of Thrissur, the conspicuous absence of some species over a period of three decades could be attributed to habitat deterioration and the concomitant failure of the ecosystem to support such species. The classical succession theories agree to the progressive removal vegetation through seral stages in consonance with the changing biophysical environment (Stachowicz, J. J. 2001). However, the changes in vegetation diversity observed over a short period of 30 years in the present study cannot be attributed to such successional process. However, the species diversity has been seriously affected. These observations converge to the conclusion that natural successional process has been seriously influenced due to various biophysical changes in the study locations at Thrissur.

Among the three locations of study of Thrissur, Kalluchal represented the highest tree species diversity (48 species) followed by Karadippara (37 species) and lowest in Kuthiran (26 species). These three locations are situated at varying topographic situations. For instance, Kalluchal and Karadippara forest are at higher elevations while Kuthiran is at moderate elevation. Demographic pressure on these locations are also variable with Kuthiran having highest influence primarily due to proximity to the national highway and resultant high demographic flux. Whereas, the other two locations are isolated and relatively free from human interferences. These variabilities in demographic influence is quite visible in the species diversity as well with Kuthiran representing the lowest diversity.

Historically, MDF are the tropical forest ecosystem that has been seriously affected by human influences primarily on account of their economic utility (Gautam and Tripathi, 2016). Till the early part of 1970s all the MDF in Kerala were subjected to intensive logging for selected commercially important species. However, with the general increase in the awareness in conservation values of natural forests, proactive policy interventions especially the Forest Conservation Act, 1980 and Participatory forest management (PFM) initiative brought dramatic changes in the conservation of these forests. Despite such positive development in containing demographic pressures, the decline in species diversity could be partly due to the possibly lesser time interval 30 years for the manifestation of natural ecorestoration. Furthermore, the imbalance in vegetation structure by the long-term decline in certain specific species may have contributed to the general decline in vegetation dynamics (Gonzalez, P. *et. al*., 2012).

Yet another factor that may have contributed to the changes in vegetation diversity could be on account of climate change on vegetation dynamics especially regeneration status (Sintayehu, D. W., 2018). MDF being one among the most affected forest ecosystems the impacts of climate change may have more affected these ecosystems.

Yet another interesting aspect was the conspicuous variation in species diversity across the stratum with highest species number from the middle stratum (54.9 %) followed by upper stratum (33.3 %) and lowest number in lower stratum (11.7 %). In comparison with the previous study, the trend remains the same in species diversity across the stratum as the highest species number is contributed from the middle stratum (61.29 %) followed by upper stratum (33.87 %) and lowest in lower stratum (6.45%).

5.2 Stand density

In the present study, the general distribution of stand density in MDF of Thrissur as per the study was Kuthiran (163 stems ha^{-1}) followed by Karadippara (158 stems ha^{-1} and the lowest density was reported at Kalluchal (119 stems ha^{-1}) belonging to DBH ≥20 cm. Contrary to this observation, the three-decade old study results reported by Narayanan (1988) from the same locations for the same size class (DBH ≥20 cm) shows that the highest stand density was found in Kalluchal (182 stems ha^{-1}) followed by Karadippara (161 stems ha^{-1}) and the lowest being in Kuthiran (138 stems ha^{-1}) (Table 29). Despite Kuthiran being a region more amenable to human interference, the reduction in such disturbances owing to strict law regulations in this region during the past three decades might have resulted in better biophysical conditions for vegetation growth. Interestingly, Kalluchal site showed the lowest stand density in the present study (119 stems ha^{-1}) while this site showed the highest in the previous study (182 stems ha^{-1}). This obvious reduction at Kalluchal calls for detailed investigations on the ecological underpinnings on the diminution in the larger sized stems. However, the changes in stand density in the Karadippara (Kp) location differed marginally.

The stand density variations for the total trees in the lower size classes (DBH ≥1 cm) were considerably different from the above trends for larger sized stems. For instance, the stand density values were highest in Kalluchal (691.67 stems ha^{-1}) followed by Karadippara (688.89 stems ha^{-1}) and the lowest stand density was reported at Kuthiran (163.89 stems ha^{-1}) (Table 6). Obviously, the larger density was observed for smaller sized individuals in Kalluchal compared to its lowest number of larger sized individuals as compared to the other two sites which indicate a clear shift in vegetation dynamic in this site. The better site factors may have promoted the growth of smaller sized individuals in this site. Yet another aspect is the gross reduction (lowest of all the three sites) in stand density (DBH ≥1 cm) for Kuthiran site contrary to trends for larger size category (DBH ≥20 cm) which incidentally was highest among the three locations. This is a clear indication of the biophysical limitations in the growth of the smaller sized individuals in the Kuthiran site.

However, our values of stand density were lower than that reported for MDF from eastern India, Odisha which incidentally ranged from 355.33–740.53 stems ha^{-1} (Panda, et al. 2017). Yet another study from the same location recorded variable densities for two sites ranging from 185 to 744 stems ha^{-1} (Sahoo, et al. 2020). Nevertheless, our density values were closer to that recorded for MDF in Tripura where the mean density was 648 stems ha^{-1} (Majumdar, et al. 2014) and tropical deciduous forests of Northcentral Eastern Ghats, India (395 to 573 individuals ha^{-1}) (Naidu et al. 2018).

Comparison of the stand density values (DBH ≥1 cm) observed in the present study with that of the same sites 30 years before (Narayanan, 1988) is suggestive of substantial increase in stand density over the period in the Karadippara and Kalluchal sites with Kalluchal site showing higher values during both the periods (Table 7 and Table 29). For instance, Narayanan, (1988) reported stand density 522 stems ha^{-1}, 426 stems ha^{-1} and 363 stems ha^{-1} for Kuthiran, Kalluchal and Karadippara sites respectively. This increase in stand density over the period is clear indicative of improvement in site biophysical attributes congenial for the establishment and growth of the trees in lower size classes in these two sites. However, Kuthiran site did not inflict any perceptible change in density over the period. In Kalluchal and Karadippara, the extent of recovery and ecological improvement was fairly higher as compared to Kuthiran. Probably, the lesser extent of anthropogenic influence in conjunction with biophysical attributes of the soil and climate may have triggered faster rates of recruitment in all the three localities. However, the lower stand density for Kuthiran could be on account of the possible higher human interference as compared to Karadippara and Kalluchal.

The distribution of number of stems across the vertical strata also has shown perceptible variation as compared to previous study by Narayanan thirty years back. For instance, the average number of stems in the present study were 284, 139, 208 stems per hectare respectively for upper, middle and lower stratum (Table 8) while corresponding values were 208, 47 and 181 stems per hectare in the previous study by Narayanan (1988). The glaring observation is the conspicuous lower number in the middle stratum in the earlier study which enhanced to three-fold increase in number (300%) in the present study. This is a clear indication of the ecological advantage that the vegetation experienced during the past decades probably on account of better conservation strategies and policy interventions. This trend is visible for all the three study locations as well.

Overall, the relative density distribution among the various strata in the present study showed uniform distribution while a skewed density distribution was observed in the earlier study by Narayanan, (1988). Interestingly, the reduction in middle stratum was more prominent in Narayanan's study with relative density only 0.25 % for Kuthiran site while the corresponding value in the lower stratum was 65 % for this site. This indicates that there were major ecological factors detrimental to the transition of stems of lower stratum to middle stratum. However, in the present study, after thirty years, there has been substantial improvement in the middle stratum (18.8 %). Overall, the trends indicate a rational balanced improvement in the vegetation development in the MDF of Thrissur over past three decades.

The difference in number of stems per unit area among the different locations could be attributed to several factors such a stage of stand development and anthropogenic pressures like selective felling, timber felling, livestock grazing etc. It could also be attributed to variation in the distribution pattern across the slope and vegetation strata due to multitude of factors especially microenvironment and biotic nature. Furthermore, the stand density also varies depending upon the edaphic attributes such as soil nutrient content, litter biomass and understory vegetation. (Lei, J. *et. al.,* 2019). Also, fire had significant effect on the evolution of stand composition with low severity fires being particularly detrimental for stand productivity (Lecomte, N. *et. al.,* 2006). However, information on extent of fire incidence in these forests during the past three decades has not been analysed in the present study.

Table 30. Descriptive statistics of number of stems per hectare and relative density (Narayanan, 1988)

Location	Stems Per Hectare					Relative Density (RD) ≥ 1 cm DBH		
	≥20 cm DBH	≥1 cm DBH						
	All Trees	All Trees	Upper Stratum	Mid Stratum	Lower Stratum	Upper Stratum	Mid Stratum	Lower Stratum
Karadippara	161.41	363.32	192.27	31.05	140.00	52.91	8.70	38.54
Kalluchal	182.84	426.37	263.48	97.17	65.72	59.87	22.63	15.38
Kuthiran	138.06	522.42	168.75	14.51	339.16	32.45	0.25	65.16
Mean	160.77	437.37	208.16	47.57	181.62	48.41	10.52	39.69
SD	22.39	80.11	49.32	43.73	141.39	14.25	11.30	24.91

5.3 Mean stand density of selected species in Thrissur District, Kerala

In the current study, the species having the highest stand density per hectare was *Xylia xylocarpa* (130 stems) followed by *Wrightia tinctoria* (110 stems) and *Holarrhena antidysentrica* (67 stems) (Table 7). The previous study also showed a similar pattern with the species having the highest density was *Xylia xylocarpa* (72 stems) followed by *Wrightia tinctoria* (61 stems) as given out in Table 31. This signifies that thirty years of time is very minimal for a new species to take over and dominate the older species. However, the mean number of stems of dominant species have increased over time probably due to the better conservation strategies adopted in the recent past. In a similar study in MDF in the Doon Valley, India such improvement in density and regeneration status of dominant species has been reported (Gautam et al, 2014).

Table 31. Descriptive statistics of mean stems and mean relative density of selected species in the moist deciduous forests in Thrissur forests, Kerala.

Species	Mean Stems Per Hectare	Mean Relative Density Per Hectare (%)
Alstonia scholaris	6.76	2.27
Bombax ceiba	11.01	4.61
Dalbergia sisoo	3.10	1.19
Dillenia pentagyna	12.89	4.30
Grewia tiliifolia	16.99	5.75
Haldina cordifolia	5.56	1.33
Lagerstroemia lanceolata	13.67	4.46
Lannea coromandelica	6.03	1.86
Pterocarpus marsupium	3.79	1.35
Radermachera xylocarpa	1.83	0.63
Stereospermum colias	5.38	1.61
Terminalia bellerica	3.09	0.85

Terminalia crenulata	4.62	1.24
Terminalia paniculata	30.22	11.24
Tectona grandis	4.86	1.18
Tetrameles nudiflora	3.61	1.37
Xylia xylocarpa	72.41	24.09
Holarrhena antidysentrica	25.85	8.34
Wrightia tinctoria	61.08	14.36

5.4 Basal Area

Basal area is an important tree growth variable for evaluating the productivity and biomass accumulation in forest ecosystem (Memiaghe, H. R. *et. al.,* 2016). In the present study, highest basal area was recorded at Karadippara (39.95 m^2 ha^{-1}), moderate basal area at Kalluchal (33.97 m^2 ha^{-1}) and the lowest at Kuthiran (20.50 m^2 ha^{-1}) as shown in Table 8. The basal area recorded in the present study is between the range of 20.50 m^2 ha^{-1} to 39.95 m^2 ha^{-1} which is lower than the basal area (48.7 to 104.9 m^2 ha^{-1}) reported in moist deciduous forests by Mishra and Mohanty (2002). However, the basal area is near the value of 38.58 m^2 ha^{-1} as reported by Hareesh and Nagarajaiah (2019) in the moist deciduous forests of Kodagu, Karnataka. Our BA values were also marginally higher than that reported for MDF in Northcentral Eastern Ghats, India (13.05 to 28.42 m^2 ha^{-1}) (Naidu et al. 2018).

However, three decades ago, the basal area recorded at Karadippara, Kalluchal and Kuthiran were much lower as given by 25.89 m^2 ha^{-1}, 18.48 m^2 ha^{-1} and 18.04 m^2 ha^{-1} respectively as shown in Table 30 (Narayanan,1988). The apparent increase in BA in the present study could be attributed to the overall increase in the size of tree species in the higher size classes. Such positive changes in stand basal area has been reported before (Gautham et al. 2014).

The occurrence of higher basal area in Karadippara could be due to presence of larger sized trees at the study site. The presence of higher number of trees of lower size classes at Kuthiran could have led to lower basal area. Selective felling/illegal removal of desired species in Kuthiran forests might have led to the decrease in the growing stock and consequently basal area. It is mainly due to the fact that trees with larger girth are felled in the process of selective felling leaving behind only the saplings and poles which takes several years for further recruitment of these saplings and poles into well-matured trees. In the present study, the variation in the basal area could be attributed to the fact that the area where the basal area was reported to be low might have been subjected to anthropogenic disturbances. Furthermore, the site variation in the locality factors such as climatic, edaphic and the topography may also have contributed to this change (Gautham et al. 2014).

The increase in the basal area in a span of thirty years could be due to death of over mature trees which opens the canopy and facilitates the availability of more light to lower strata and reduces competition for moisture and nutrients by which it stimulates the growth of surviving neighbouring trees. Such increase in basal area has also been reported by Bhat *et al.* (2011) after a span of twenty-four years in tropical moist forests of Uttara Kannada district, Western Ghats.

Despite such changes, the vertical distribution of basal area followed similar trend during the two periods with conspicuous higher distribution of BA to the upper stratum (85-95%). However, the middle stratum at Kuthiran site showed better distribution of BA (1.75 m^2 ha^{-1}) as compared to the observed values three decades back (0.03 m^2 ha^{-1}).

The shifting trend is visible in relative basal area (RBA) also during the two study periods. This is particularly true in the case of middle stratum at Kuthiran site. For instance the RBA at middle stratum 30 years before was 0.18% of the total while in the present study it improved to 8.69% indicating a transformation to better distribution of stems across strata.

Table 32. Descriptive statistics of Basal Area and Relative Basal Area (Narayanan, 1988) (Table 8 in present study)

Location	Basal area (m^2 ha^{-1})				Relative basal area (%)		
	All Trees	Upper Stratum	Mid Stratum	Lower Stratum	Upper Stratum	Mid Stratum	Lower Stratum
Karadippara	25.89	23.34	2.53	2.29	82.81	9.00	8.12
Kalluchal	18.48	16.82	1.54	0.12	90.53	8.26	1.20
Kuthiran	18.04	17.27	0.03	0.74	95.74	0.18	4.08
Mean	20.80	19.14	1.36	1.05	89.69	5.81	4.46
SD	4.41	3.64	1.25	1.11	6.50	4.89	3.47

5.4.1 Mean basal area of selected species

In the present study, the mean basal area (all the three sites combined) was found to be highest for *Xylia xylocarpa* (8.25 m^2 ha^{-1}) followed by *Dillenia pentagyna* (4.13 $m^2 ha^{-1}$) and *Lagerstroemia lanceolata* (3.98 m^2 ha^{-1}) (Table 11). The trend was almost similar thirty years ago with *Xylia xylocarpa* (4.06 m^2 ha^{-1}) showing the highest mean basal area followed by *Terminalia paniculata*, (2.00 m^2 ha^{-1}), *Lagerstroemia lanceolata* (1.72 m^2 ha^{-1}) and *Grewia tilifolia* (1.04 m^2 ha^{-1}) as shown in Table 32. This confirm the fact that *Xylia xylocarpa* is still dominating the forest in terms of basal area. However, there was conspicuous increase in BA for *Xylia xylocarpa*, *Lagerstroemia lanceolata* and *Dillenia pentagyna* in the present study which could be on account of the increase in size of stems over the time in the absence of illicit exploitation of larger sized stems.

The second highest species in terms of BA was Dillenia which however showed poor BA production in the previous study (0.81 m^2 ha^{-1}) indicating that there was substantial increase in the BA for this species over a period of 30 years. Other species with relatively higher BA in Narayanans study were *Terminalia* *paniculata*, *Lagerstroemia lanceolate* and *Grewia tiliafolia* which all showed improvement in BA compared to the previous study. Interestingly the BA of teak was relatively low as compared to other species for both the observation periods though there was slight improvement in the present study. The trends suggest that there has been serious ecological impedance in the emergence and establishment of teak in the MDF of Thrissur district.

The distribution pattern of BA among species for the three locations also showed considerable variation. In general, the Karadippara site registered higher BA for mos of the prominent species. Despite the uniform BA for *X. xylocarpa* in the Karadippara and Kalluchal sites, the Kuthiran site recorded poor BA (4.14 m^2 ha^{-1}). This again reiterate the possible anthropogenic sanctions in the development of this species in the Kuthiran site. Similar was the case with *L. lanceolate* and *T. paniculata*.

Relative BA distribution of important species did not show much variation during the two periods. In both the studies, *Xylia xylocarpa* shared the higher proportion of total stand basal area (25.4 and 33.61 % for present and Narayanan's study respectively). However, *Grewia tiliaefolia* registered lower BA and RBA in the present study as compared to the previous study. Yet another striking observation was the improvement in the BA and RBA for *Dillenia pentagyna* over a period of three decades with BA as 4.13 m^2 ha^{-1} (RBA-6.46%) in the present study as against 0.81 m^2 ha^{-1} (RBA- 13.75%) as reported by Narayanan. Further detailed ecological investigations are required to substantiate the decline in the growth of these species.

Table 33. Descriptive statistics of Mean Basal Area and Mean Relative Basal Area of selected species (Narayanan, 1988)

Species	Mean Basal Area (m^2 ha^{-1})	Mean Relative Basal Area (%)
Alstonia scholaris	0.02	0.34
Bombax ceiba	0.16	2..22
Dalbergia sisoo	0.30	2.68
Dillenia pentagyna	0.81	6.46
Grewia tiliifolia	1.04	9.19
Haldina cordifolia	0.19	1.08
Lagerstroemia lanceolata	1.72	9.56
Lannea coromandelica	0.13	0.86
Pterocarpus marsupium	0.13	1.53
Radermachera xylocarpa	0.02	0.59
Stereospermum colias	0.05	0.86
Terminalia bellerica	0.43	2.03
Terminalia crenulata	0.28	2.01
Terminalia paniculata	2.00	17.67
Tectona grandis	0.67	3.04
Tetrameles nudiflora	0.74	5.52
Xylia xylocarpa	4.06	33.61
Holarrhena antidysentrica	0.03	0.25
Wrightia tinctoria	0.25	1.31

5.5 Frequency and relative frequency (RF)

Frequency and relative frequency are often used to portray the uniformity in the distribution of species in the forest area. In the present study except for few species most majority of the species showed poor spatial distribution which signify poor structural fitness of various species in the MDF at Thrissur forests.

Frequency distribution of various tree species in the MDF under study in the Thrissur forests showed variable patterns of distribution among the different species (Table 12, 13 and 14). For instance, *Wrightia tinctoria* (69.14%) and *Xylia xylocarpa* (58.02%) were the most widely distributed species in the Kp while the same two species were the toppers at Kalluchal region with Xylia xylocarpa showing higher frequency (80.56%). In Kuthiran also the *Xylia xylocarpa* (61.11%) had the highest frequency followed by *Holarrhena antidysentrica* (47.22%). Results indicate the uniformity in distribution pattern with same set of species dominating in all the three locations. Except for a few species mentioned above, most majority (> 60%) of species had frequency less than 10%. Highest proportion of species was in the lowest frequency class (0-20%) which was 81% for Karadippara site, 94% for Kc site and 76% for Kuthiran site. The representation in the higher frequency classes were only nominal for all the three sites. Interestingly, there was no representative species in the highest frequency class.

These observations (figure 10) suggest a skewed spatial distribution of species in the MDF under study. Only limited species (3 to 4 species) were showing uniform spatial representation in these forests. This trend was clear while considering the relative frequency (percentage of total frequency shared by each species). For instance, the species having the highest relative frequency was *Xylia xylocarpa* with values ranging from 11.30% (Karadippara) to 16.79% (Kuthiran). This indicate that the Xylia shared the maximum towards the total frequency while the remaining species had very low contribution. Yet another species that had better relative frequency was *Wrightia tinctoria* with RF ranging form 9.92%

(Kuthiran) to 14.04% (Kalluchal). Out of the total 37 species in the presented study, 14 species represented 80% of the total frequency and the remaining 23 species shared 20% of the total frequency in Karadippara site. In most of the phytosociological studies in MDFs, such skewed distribution in frequency has been reported. For instance, studies in MDF in the eastern forests, Odisha reported 75% of the relative frequency attributed to 50 species while the remaining 25% was shared by 126 species (Panda et al. 2017).

Other studies in MDF of India also indicated similar results with bulk of the species belonging to lowest frequency class. For e.g. reports from MDF in Eastern Ghats, India suggested 82.1% of tree species in A class (0-20%), 8.3% in B class (21% – 40%), 7.1% in C class (41% – 60%) followed by 1.2% in D & E class. (Reddy and Ugle, 2008). Nevertheless, the present results indicate unbalanced distribution of various tree species which may have negative consequences on the structural attributes of MDF in Thrissur division.

5.6 Important Value Index (IVI)

Importance Value is a measure of relative ecological soundness of a species in a forest community. Since it takes into account measures such as relative density, relative frequency and relative basal area, IVI depict the overall fitness of a given species compared to others. The total IVI for the three locations in the present study was similar with values closer to 300.

Considerable species variation in the IVI has been observed at the three locations under study. Among the tree species *Xylia xylocarpa* dominated in all the three locations (Karadippara site- 53.91; Kalluchal site- 73.86; Kuthiran site- 54.73). Important value index being a summation of the relative density, frequency and basal area, it is obvious that Xylia exhibited highest IVI in all the three sites. Most of the MDF in India has reported lower IVI for Xylia (18.6; Naidu et al 2018). Other dominant species tree species with higher IVI include *Wrightia tinctoria* (37.47), and *Lagerstroemia lanceolata* (37.17) at Karadippara, *Dillenia pentagyna* (29.55) and *Holarrhena antidysentrica* (28.57) at Kuthiran.

The higher IVI values associated with tree species such as *Xylia xylocarpa*, *Lagerstroemia lanceolate and Dillenia pentagyna* could be attributed to their larger size and consequent higher relative basal area. Also these species represented higher relative density. However relative frequency contribution to the IVI was fairly low for most of the species except for *Xylia xylocarpa*.

Variability in IVI values has been observed for species in various strata. Invariably *Xylia xylocarpa* dominated the upper stratum for all the three sites reiterating its ecological soundness in the Thrissur forest landscape. Among the other species of the top stratum, the IVI of *Lannea coromandelica* were Kp-5.33, Kalluchal-3.37 and Kuthiran-3.03. The IVI of *Terminalia paniculata* were Karadippara-10.56 and Kalluchal-29.76 and Kuthiran-5.50. The IVI values obtained in the present study are found to be lesser than the values of *Lannea coromandelica* (9.02) and *Terminalia paniculata* (8.48) recorded in the moist deciduous forests of Eastern India. Likewise, the prominent species of the middle stratum *Cleistanthus collinus* recorded an IVI of 5.83, 15.19 and 4.44 in Karadippara, Kalluchal and Kuthiran respectively. The IVI value for *Cleistanthus collinus* as recorded in the Eastern Ghats was 7.81 (Panda *et. al*., 2017). Interestingly, despite the lesser species diversity observed in the lower stratum, the available species showed fairly high IVI values. For instance, the species with high IVI values in the lower stratum was *Wrightia tinctoria* with values 37.47 and 35.77 for Karadippara and Kalluchal sites respectively and *Holarrhena antidysentrica* (28.57) for Kuthiran site. This apparent higher IVI associated with these species were primarily attributed to their higher relative density (DBH >1 cm) as compared with most of the species.

At species level: Relative IVI also followed similar trend as that of IVI with *Xylia xylocarpa* showing highest contribution to the total IVI (17.97, 24.62 and 18.24% for Karadippara, Kalluchal and Kuthiran sites respectively) in the upper stratum. This was followed by *Lagerstroemia lanceoate*, *Terminalia paniculata* and *Dillenia indica*. In the middle stratum, the highest share was from *Cleistanthus collinus* (5.06) in Kalluchal, *Schleichera oleosa* (3.84) in Karadippara and *Cassia* *fistula* (3.84) in Kuthiran. However, in the lower stratum, *Wrightia tinctoria* contributes the highest RIVI in Kalluchal and Karadippara but *Holarrhena antidysentrica* has the highest RIVI in Kuthiran (Table 16).

A closer observation of the relative important value index (RIVI; percentage of total IVI) reveal that out of the total 54 species reported 11, 14 and 11 species represented almost 80% of the total IVI for Karadippara, Kalluchal and Kuthiran sites respectively. However, many reports suggest more uniform distribution of IVI among species. For instance, top ten species accounted for 40 to 47% of the total IVI in Northcentral MDF of Northcentral Eastern Ghats, India (Naidu et al 2018). The present phyto-sociological analysis in the Thrissur MDF suggest that the three sites under study had only limited number of species that enjoy ecologically balanced growth and distribution while almost 80% of the tree species had reduced ecological fitness.

Yet another observation was that almost 60% of the total IVI was shared by tree species in the upper storey (13 species) while middle (21 species) and lower storey (two species) shared 20% each for Karadippara site followed by a similar trend for other two sites. Upper storey species were larger in size with higher RBA and relative density which could be attributed to their higher IVI values. Interestingly the lesser number species in the lower stratum had reasonably higher mean tree IVI as compared to the middle stratum. This is primarily due to the higher relative density of species in the lower stratum as compared to middle stratum.

In the present study, it was revealed that the highest mean relative importance value index (average for all three locations) was reported for upper stratum (59.27), followed by lower stratum (20.47) and middle stratum (20.24) (Table 15). The previous study by Narayanan (1988) also showed the same trend with values 62.48, 21.85 and 15.65% for upper stratum, lower stratum and middle stratum respectively. The trends in distribution of IVI in all the three sites are fairly comparable. However, there was skewness in the distribution of RIVI in the previous study at Kuthiran site with middle storey having lower RIVI while understorey sharing higher RIVI as compared to the present study. Nevertheless, the present study indicates balanced distribution of IVI across the strata. However the distribution of IVI among the tree species seems to be unbalanced.

Table 34. Statistic of Relative IVI (Narayanan, 1988)

Location	Relative IVI		
	Upper stratum	Middle stratum	Lower stratum
Karadippara	57.78	19.09	23.13
Kalluchal	67.65	19.80	12.54
Kuthiran	62.03	8.07	29.90
SD	62.48	15.65	21.85
Mean	4.95	6.57	8.75

5.7 Regeneration

The number of seedlings or the individuals below 1 m height per hectare (size class h50 and h100 together; irrespective of species) varied considerably among the various locations (Table 25). The corresponding values were 3003, 5188 and 2152 per ha for Karadippara, Kalluchal and Kuthiran sites respectively. Our regeneration values are much lower as compared with many other reports from MDF in India. For instance, reports from moist deciduous forests of Eastern India from Nayagarh Forest Division, Odisha revealed higher ranges of regeneration to the tune of 6180 to 14000 per ha (Panda et al. 2017).

Among all the three sites invariably *Xylia xylocarpa* showed highest regeneration potential (Karadippara- 635 plants ha^{-1}; Kalluchal- 1275 plants ha^{-1}; Kuthiran- 638 plants ha^{-1}). However, there was fair variability among the remaining species in regeneration status for different sites. For instance, barring Xylia the other best performers in regeneration status were Wrightia (552 ha^{-1}), Holorhina (506 ha^{-1}), Grewia (258 ha^{-1}) and Lagerstroemia (253 ha^{-1}) at Karadippara site while best performers other than Xylia in Kalluchal site were

Lagerstroemia (502 ha^{-1}), Grewia (491 ha^{-1}), Wrightia (453 ha^{-1}), Holorhina (420 ha^{-1}). The regeneration status in Kuthiran followed the order Macaranga (278 ha^{-1}), Grewia (263 ha^{-1}), *Delinnia pentagyna* (186 ha^{-1}), Holorhina (150 ha^{-1}).

Tree species with moderate regeneration at Karadippara site included Lannia, Dillenia, Bombax, Cleistanthus, Macaranga, Shleichera and Strychonos while the poor regenerating species in this site were *Terminalia bellerica, Olea dioica, Aporosa lyndliana* and *Terminalia paniculata*. Similarly, the moderately regenerating species in the Kalluchal were Bombax, Dillenia, Lannea, Cassia, Macaranga, Olea, Schleichera and the poorly regenerating species included Pterocarpus, Terminalia bellerica, Aporosa, Bauhinia, *Stercullia guttata*, *Sterculia urens*, Strichnos, Syzigium and Vitex. Kuthiran site showed variability in regeneration status with Bombax, Lagerstromea, Cleistanthus, Wrighia and Lannea representing moderate regeneration while Aporosa, Cassia fistula, Olea and N. crenulata were the poor performers in regeneration. Among the species Olea and Aporosa showed low regeneration status in all the three sites. In general, 45% of species in the Karadippara site had good regeneration status while 35% were moderate and 20% had poor regeneration. The values for Ka site were 40%, 27%, 33% for good, moderate and poor regeneration. The corresponding values for Kuthiran sire were 48, 31 and 21 % respectively.

Realistic comparison of our data with the regeneration status of various species at the same location in the MDF of Thrissur thirty years before revealed interesting results. For instance, the corresponding regeneration (sum of h50 and h100) status was 4928.84, 4505.73 and 3195.35 plants ha^{-1} respectively for Karadippara, Kalluchal and Kuthiran sites (Narayanan, 1988). This indicate a gross decline in regeneration status in the Karadippara and Kuthiran sites while there was improvement in overall regeneration in the Kalluchal site. The study assumes importance in this context with the observation that despite the general improvement in the vegetation attributes after 30 years at the three locations, the regeneration status followed undesirable trend with decline in Karadippara and Kuthiran sites. Regeneration is primarily combined influence of edaphic, climatic and biotic factors favouring the regeneration ecology of various plant species in the forest community. The differential regeneration status observed in the present study could be attributed to such changes. The better diversity, structure and stem distribution at Karadippara may have contributed to favourable conditions for better regeneration as well.

The primary source of variation could be attributed to habitat conditions, seed bank, seed predation, germination failure or competitive exclusion and several biotic factors. Apart from these, the availability of light also plays a crucial role in successful regeneration and establishment of the forest. The microclimatic conditions due to opening of the canopy also effects the regeneration of certain species.

5.8 SIZE CLASS DISTRIBUTION

5.8.1 Size class distribution of all trees

The number of tree species in various size classes is an important factor to understand their distribution in to various social classes. In the present study, the mean number of trees per hectare in all locations is reported as 4428 stems ha^{-1} (Table 24) The study location having the highest number of stems was Kalluchal with 6411 stems ha^{-1} followed by Karadippaara, 3903 stems per ha and lowest in Kuthiran with 2972 stems ha^{-1} (Table 24).

The per hectare size class distribution of all trees as reported by Narayanan (1988) is presented in Table 33. The average number of all trees per hectare in all three locations is 5285 stems ha^{-1} which is considerably higher than our mean value for the three sites (4428 stems ha^{-1}). As per the previous study the maximum number of trees recorded among all three study location is in Karadippara with 5913 individuals followed by 5626 stems in Kalluchal and lowest in Kuthiran with 4316 stems. Closer analysis of the data suggests differences in total number in various sites.

For example, there was considerable reduction in total number of stems in the Karadippara and Kuthiran site, with 34% and 31% reduction in total number respectively as compared to the previous study. However, there was 14% increase in the total number of stems at Kalluchal site. The results clearly indicate the variability in the extent of ecological degradation in the given sites. It can be seen that the Karadippara and Kuthiran sites were more amenable to anthropogenic influences as compared to Kalluchal site. Improvement in other phyto-sociological variables such as frequency distribution, density and species diversity are clear indications of improvement in the ecological status of Kalluchal site. Furthermore, the decrease in number of stems in Karadippara with respect to previous study may be because it is heavily dominated by elephants and wild boars which might have hampered the regeneration and subsequently total stems per hectare. The reduction in total stems per hectare in Kuthiran may be because of the anthropogenic disturbance prevailing in the location as it is in close proximity to the highway. With increasing anthropogenic disturbances such as pruning, lopping, fire, grazing, it has a negative impact on plant species diversity, stand structure and forest regeneration (Muthuramkumar *et al*., 2006).

Diameter class distribution in both previous and present study followed the classic negative exponential pattern which is true in most of the tropical forests. For all the three sites the distribution of the number of individuals in the forests was found to be inversely proportional to the increasing diameter class in all the locations. Again, major share of the species density was confined to the lower size classes in particular in <50cm size class followed by h100, hg100 and d10 size classes. Only few species had adequate representation in all the size classes such as *Xylia xylocarpa*. Other species such as *Grewia tiliaefolia* and *Lagerstroemia lanceolate* also had better representation in larger size classes at Karadippara site. In Kalluchal and Kuthiran site proper representation of size classes was observed only for *Xylia xylocarpa* while in the other species the size classes are missing or lacks continuity. However, major share of the total species (> 90%) had only meagre representation in higher size classes.

Table 35. Per hectare size class representation of all trees in the stand (Narayanan, 1988)

Loc	Number of stems per ha										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Karadippara	2272.20	2656.64	623.40	159.98	36.66	47.77	39.99	26.66	22.22	27.77	5913
Kalluchal	2520.00	1985.73	692.88	215.75	28.58	48.59	55.72	40.02	24.30	14.21	5626
Kuthiran	2142.21	1053.14	601.57	368.75	12.50	12.50	42.18	39.06	18.75	25.57	4316
Mean	2311.47	1898.50	639.28	248.16	25.91	36.28	45.96	35.24	21.75	22.51	5285
SD	191.93	805.30	47.68	108.09	12.29	20.60	8.52	7.45	2.80	7.27	851

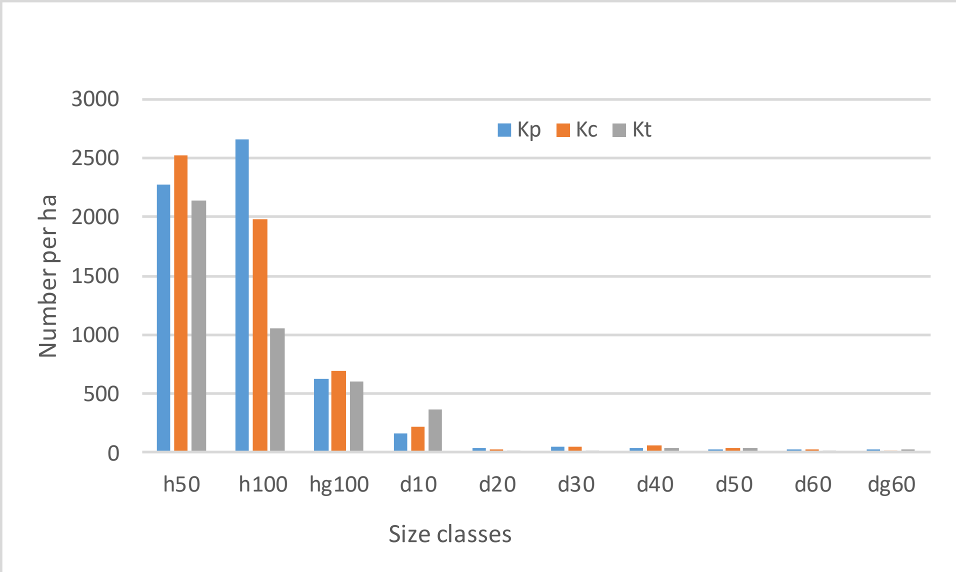

Fig.12. Per hectare size class representation of all trees in the stand (Narayanan, 1988)

Karadippara and Kuthiran had nearly equal number of stems per hectare with 1897 and 1800 stems respectively (Table 25). The per hectare size class distribution of trees in the upper stratum in the same stand 30 years before is given in Table 36 as reported by Narayanan (1988). The average number of all trees per hectare in all three locations is 2678 stems. As observed in the present study, the highest number of trees recorded in any given location is 3341 stems in Kalluchal and lowest in Karadippara with 1931 stems. Kuthiran has a moderate value of 2762 stems per hectare.

Observations reveal that a major decline in number of trees has been observed in Kuthiran region compared to earlier study. It may also be noted that the major decline was happened in the lower size class (h50; seedlings) which may be due to past anthropogenic disturbance, selective felling and livestock grazing. The trends in the distribution of stems across higher sizes classes was more or less uniform among the two periods though the distribution in the present study period was marginally better than before especially for the Kuthiran site.

Table 36. Per hectare size class representation of all stems in the upper stratum in all locations (Narayanan, 1988)

Loc	Number of stems per hectare										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Karadippara	1027.77	563.33	149.98	61.11	5.55	24.43	31.11	23.33	20.00	24.44	1931
Kalluchal	1661.41	1081.42	342.88	81.44	15.72	40.01	50.00	35.73	21.44	11.21	3341
Kuthiran	1801.59	567.20	225.01	29.68	-	12.50	42.18	39.06	18.75	25.57	2762
Mean	1496.92	737.31	239.29	57.41	10.63	25.64	41.09	32.70	20.06	20.40	2678
SD	412.30	298.00	97.24	26.07	7.19	13.79	9.49	8.28	1.34	7.98	708

5.8.2 Size class distribution in the middle stratum

In the present study, the mean number of trees per hectare in the middle stratum for all the three locations is reported as 861 stems ha^{-1}. The study location having the highest number of stems was for Kalluchal with 1447 stems and lowest in Kuthiran with 480 stems as presented in Table 26. Attempt was made to compare the size class distribution of trees in the middle stratum of the same location 30 years before by Narayanan (1988) (Table 37). The average number of all trees per hectare in all three locations is 789 stems which is relatively lower as compared to the present values for middle stratum. The maximum number of trees is recorded in Kalluchal with 1147 stems followed by Karadippara with 940 stems and lowest in Kuthiran with only 281 stems. As against upper stratum, the Karadippara site showed reduction in number of stems in middle stratum (from 940 to 656 stems ha^{-1}) while substantial increase has been observed at Kuthiran site (281 to 480 stems ha^{-1}) after 3 decades. Here also the major share of these reductions in Karadippara site were in the lower size class categories (h50 and h100) categories. However, the Kuthiran site showed an improvement in number of individuals in especially in the lower size classes. During the previous study most of the higher size classes had no representation (from d20 onwards) which seems improved over a period of time.

Table 37. Per hectare size class representation in the middle stratum in all locations (Narayanan, 1988)

Location	Number of stems per hectare										
	Size classes										
	h50	h100	hg100	d10	d20	d30	d40	d50	d60	dg60	Total
Karadippara	519.99	287.76	81.09	18.87			5.55	22.22	1.11	3.33	940
Kalluchal	477.16	335.74	231.43	74.30	7.15	8.58	5.72	4.29	2.86		1147
Kuthiran	164.05	71.87	32.81	12.51							281
Mean	387.06	231.79	115.11	35.22			5.63	13.25	1..98		789
SD	194.32	140.55	103.58	33.98			0.12	12.67	1.23		452

5.8.3 Size class distribution in the lower stratum

Realistic comparison of the total number of plants in the lower stratum in the present study with the previous study 30 years back reveal interesting results (Table 38). These was considerable decline in plant number over a period of three decades for all the three sites. As per Narayanan (1988), the total average number of trees per hectare in the lower stratum recorded in all three locations is 1813 stems. The maximum number of trees in the lower stratum was at Karadippara with 3034 stems followed by Kuthiran with 1273 stems and lowest in Kalluchal with only 1134 stems. However, as per our present findings, the total average number of trees per hectare was 1137 stems. The site having the maximum number of trees of the lower strata was in Kalluchal with 1372 stems/ha followed by Karadippara with 1349 stems. The lowest number of trees was found in Kuthiran with 691 stems. In the lower stratum probably, Karadippara and Kuthiran sites had higher losses (>50%) in different size classes with more reduction in the seedling and sapling stages though decline in the higher size classes were also apparent. In all the sites the general reduction in number with increase in size classes has been observed. Such trends has been reported by many studies in the MDF in India.

Table 38. Per hectare size class representation in the lower stratum of all locations

Location	Number of stems per ha					
	Size classes					
	h50	h100	hg100	d10	d20	Total
Karadippara	724.44	1805.55	393.33	80.00	31.11	3034
Kalluchal	381.43	568.57	118.57	60.01	5.71	1134
Kuthiran	176.57	414.07	343.75	326.56	12.50	1273
Mean	427.48	929.39	285.21	155.52	16.44	1813
SD	276.82	762.69	146.43	148.45	13.15	1059

5.9 DIVERSITY INDEX

Diversity index can be used to characterize the species abundance relationship in a community. The simple measure of species diversity is Shannon's diversity index. In the present study, The Shannon's diversity index value of tree species was found to be higher at Kalluchal (2.65) followed by Karadippara (2.45) and lowest in Kuthiran (2.37) (Table 19). Shannon's diversity index values obtained for different sites are within the reported values of 2.07 to 3.97 for moist deciduous forests (Sahoo *et al*., 2016) and is nearer to the value (2.85) reported in moist deciduous forests of Kodagu (Hareesh and Nagarajaiah, 2019). Lower Shannon's diversity index value could be attributed to dominance of few species while the sites with comparatively higher Shannon's diversity index had relatively more number of species (Table 18).

The Simpson diversity index value was found to be higher at Karadippara (0.12) and Kalluchal (0.12) and lowest in Kuthiran (0.10) presented in Table 16. In the present study, the values of Simpson diversity index recorded are below the values (0.20) reported in moist deciduous forests by Naveenkumar and Sundarapandian (2018). But, it is well above the value (0.084) reported in MDF of Kodagu by Hareesh and Nagarajaiah (2019) and near to the index value (0.10) reported in moist deciduous forests of Tripura by Majumdar *et al*., (2012). Low values of Simpson's diversity index imply that the forests have higher biodiversity indicating the presence of more number of tree species found more or less equally.

Summary

6. SUMMARY

1. A total of 51 tree species have been reported from three study locations in the Moist Deciduous Forests of Thrissur Forest Division whereas a total of 64 species have been reported from eight locations three decades before.
2. Tree density (> 1 cm) showed profound variation across sites with Kalluchal giving the highest number (691 stems per ha) followed by Karadippara (688 stems per ha) and lowest for Kuthiran (516 stems per ha). However, in the previous study three decades before, the highest number of stems was reported from Kuthiran (522 stems per ha) followed by Kalluchal (426 stems per ha) and Karadippara (363 stems per ha).
3. The tree basal area was reported to be highest in Karadippara (39.95 m^2 ha^{-1}) followed by Kalluchal (33.97 m^2 ha^{-1}) and Kuthiran (20.50 m^2 ha^{-1}). In the previous study, the basal area was reported to be lower compared to the current study. Also, in the previous study, the basal area was highest in Karadippara (25.89 m^2 ha^{-1}), followed by Kalluchal (18.48 m^2 ha^{-1}) and Kuthiran (18.04 m^2 ha^{-1}).
4. Among the three locations, the number of stems was reported to be highest in Kalluchal (6411 stems per ha) followed by Karadippara (3903 stems per ha) and Kuthiran (2972 stems per ha). However, the number of stems was highest in Karadippara (5913 stems per ha) followed by Kalluchal (5626 stems per ha) and Kuthiran (4316 stems per ha) in the study done three decades back.
5. In the upper stratum, the number of stems was found to be highest in Kalluchal (3591 stems per ha) followed by Karadippara (1897 stems per ha) and Kuthiran (1800 stems per ha) while the previous study showed maximum number of stems in Kalluchal (3341 stems per ha) followed by Kuthiran (2762 stems per ha) and Karadippara (1931 stems per ha).

6. In the middle stratum, the number of stems was found to be highest in Kalluchal (1447 stems per ha) followed by Karadippara (656 stems per ha) and Kuthiran (480 stems per ha). The number of stems increased in the middle stratum in the current study as compared to the previous study. The number of stems was reported highest in Kalluchal (1147 stems per ha) followed by Karadippara (940 stems per ha) and Kuthiran (281 stems per ha).
7. In case of lower stratum, the number of stems was found to be highest in Kalluchal (1372 stems per ha) followed by Karadippara (1349 stems per ha) and Kuthiran (691 stems per ha). Reports of the previous study however suggested the maximum number of stems in Karadippara (3034 stems per ha) followed by Kuthiran (1273 stems per ha) and Kalluchal (1134 stems per ha)
8. In Kalluchal, the highest contribution was made by Xylia xylocarpa (188 stems/ha) followed by *Wrightia tinctoria* (127 stems) and *Holarrhena antidysentrica* (58 stems).
9. Kuthiran also showed the similar distribution of stems per hectare with maximum number of stems recorded for Xylia xylocarpa (91 stems/ha) followed by Holarrhena antidysentrica (75 stems) and Wrightia tinctoria (58 stems).
10. Mean relative density was highest for upper stratum (44.62%) and 33.07% for the lower stratum and lowest for the middle stratum (22.30%)
11. Among the species xylia xylocarpa recorded the highest relative density (20.39%) followed by Wrightia tinctoria (17%) and Holarrhena antidysenterica (10%).
12. Highest mean Basal area was observed for Upper stratum (89%) followed by middle stratum (7.35%) and lowest for lower stratum (3.38%)
13. Karadippara, Kalluchal and Kuthiran sites represented 30, 45 and 20 species with frequency class I (within 1-20%)
14. There was conspicuous absence of species in the higher frequency class in all the three sites.

15. *Xylia xylocarpa* represented the highest share of total frequency at Kalluchal and Kuthiran sites with 16% of the total while Karadippara site showed maximum frequency for W. tinctoria (13.5%).
16. The major share of the IVI was confined to the species in the upper stratum (58 to 60%) while the middle and lower stratum has a lower and similar trend in IVI distribution (20% each).
17. Size class distribution of among various social classes showed conspicuous absence of majority of tree species in the higher size class suggesting a skewed distribution.
18. Almost 85% of individuals in each species belonged to lower size classes (h50 and h100) which drastically declined with increase in size class.
19. Among the species only two viz. teak and xylia had representatives belonging to all the size classes. Other species with reasonably good distribution across size classes were *Bombax ceiba, Dillenia pentagyna*, L*agerstroemia lanceolata, Terminalia paniculata* and *T. bellerica*.
20. Comparison of density and size class distribution with earlier study suggest that there is serious deterioration in the regeneration dynamics of tree species in all the three sites.

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FLORISTIC DIVERSITY AND REGENERATION STATUS OF MOIST DECIDUOUS FORESTS IN THRISSUR DISTRICT, KERALA: REASSESSMENT AFTER THREE DECADES

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ABSTRACT OF THE THESIS

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ABSTRACT

Moist deciduous forests in Kerala constitute one of the most degraded forest ecosystems consequent to demographic pressure and other bio- physical factors. Field investigation was carried out to study the changes in phytosociology and vegetation dynamics of Moist Deciduous Forests in selected locations in Thrissur Forest Division, Kerala during 2018-19. The primary objective of the study was to assess the changes in floristic diversity, structure and regeneration status of moist deciduous forests compared to a similar study carried out in the same locations prior to three decades. The selected three locations were Karadippara and Kalluchal in Peechi WL sanctuary and Kuthiran in Pattikkad range. The vegetation attributes subjected to detailed assessment included species diversity, density, relative density, basal area, relative basal area, relative frequency and Importance Value Index and size class distribution of vegetation.

A total of 51 species have been reported in various study locations in the Moist Deciduous Forests of Thrissur Forest Division. Kalluchal represented the highest number of woody species (48 species) followed by Karadippara (37 species) and Kuthiran recording the lowest with 26 species. Tree density showed profound variation across sites with Kalluchal giving the highest number (691 stems ha^{-1}) followed by Karadippara (688 stems ha^{-1}) and lowest for Kuthiran (516 stems ha^{-1}). *Xylia xylocarpa* contributed the maximum number of stems in all the three sites followed by *Wrightia tinctoria* and *Holarrhena antidysentrica*. Mean relative density was highest for upper stratum (44.62%) and 33.07% for the lower stratum and lowest for the middle stratum (22.30%). Karadippara, Kalluchal and Kuthiran sites represented 30, 45 and 20 species within frequency class I (within 1-20%) and there was conspicuous absence of species in the higher frequency class in all the three sites. All the three sites had similar total IVI around 300. The major share of the IVI was confined to the species in the upper stratum (58 to 60%) while the middle and lower stratum has a lower and similar trend in IVI distribution (20% each). Size class distribution of among various social l classes

showed conspicuous absence of majority of tree species in the higher size class suggesting a skewed distribution pattern. Almost 85% of individuals in each species belonged to lower size classes (h50 and h100) which drastically declined with increase in size class.

A comparison with the study in the same sites three decades back indicates variable results. There was overall improvement in species diversity and phyto-sociological attributes in the Kalluchal region particularly, the species density and regeneration patterns. However, the number of individuals in the present study at Karadippara and Kuthiran sites, especially in the lower size classes were far lower compared to the previous study implying that the regeneration patterns of many tree species have been seriously affected by the undesirable changes in the past three decades. Probably, apart from human influences, the impact of changing climate may also have affected the regeneration ecology and vegetation dynamics of the MDF forests in Thrissur District which necessitate further detailed investigation in this line.

തൃശ്ശൂർ ജില്ലയിലെ ഇലപൊഴിയും കാടുകളുടെ വൈവിധ്യവും പ്രജനനവും: മൂന്ന് പതിറ്റാണ്ടുകൾക്ക് ശേഷമുള്ള താരതമ്യപഠനം.

സംക്ഷിപ്തം

ഇലപൊഴിയും കാടുകൾ ലോകത്ത് നാശോന്മുഖമായിക്കൊണ്ടി-രിക്കുന്ന പ്രധാനപ്പെട്ട വന ആവാസ വ്യവസ്ഥയാണ്. കൂടിയ തോതിലുള്ള മനുഷ്യ ഇടപെടലുകളും കാലാവസ്ഥ മാറ്റങ്ങളും ഈ കാടുകളെ സാരമായി ബാധിച്ചിട്ടുണ്ട്. കേരളത്തിലെ തൃശ്ശൂർ ജില്ലയിൽ ഉള്ള പീച്ചി വന പ്രദേശത്തുള്ള ഇലപൊഴിയും കാടുകളുടെ പാരിസ്ഥിതികമായ അവസ്ഥകളെക്കുറിച്ച് 2018-19 സമയത്ത് പഠനം നടത്തുകയുണ്ടായി. പ്രധാനമായും ഈ കാടുകളുടെ വൃക്ഷ-വൈവിധ്യം, പ്രത്യുൽപാദനശേഷി എന്നിവയിൽ മൂന്ന് ദശാബ്ദം മുമ്പുണ്ടായിരുന്ന അവസ്ഥയിൽ (1988) നിന്നുണ്ടായ മാറ്റമാണ് പഠനവിധേയമാക്കിയത്. പീച്ചി, പട്ടിക്കാട് വനപ്രദേശങ്ങളിൽ ഉള്ള ഇലപൊഴിയും കാടുകളുള്ള മൂന്നു സ്ഥലങ്ങളാണ് പഠനത്തിനായി തിരഞ്ഞെടുത്തത്. കരടിപ്പാറ, കല്ലൂചാൽ, കുതിരാൻ എന്നീ സ്ഥലങ്ങളിലാണ് അവ.

പഠന വിവരത്തിന്റെ അടിസ്ഥാനത്തിൽ 51-ൽ പരം വൈവിധ്യമാർന്ന വൃക്ഷ ജനുസ്സുകൾ ഈ പ്രദേശത്ത് ഉള്ളതായി കണ്ടെത്തി. ഏറ്റവും ഉയർന്ന വൃക്ഷ വൈവിധ്യം കല്ലുചാൽ കാടുകളിലും (48 ജനുസ്സുകൾ) തുടർന്ന് കരടിപാറയിലും (37 ജനുസ്സുകൾ) ഏറ്റവും കുറവ് കുതിരാൻ മേഖലയിലുമാണ് കണ്ടെത്തിയത്. അതുപോലെ വൃക്ഷ സാന്ദ്രത കൂടുതൽ കല്ലൂചാൽ ഭാഗത്തായിരുന്നു (691 trees/ha).

മുപ്പത് വർഷം മുമ്പ് (1988) ഇതേ സ്ഥലങ്ങളിൽ നടത്തിയ പഠനവുമായി താരതമ്യം ചെയ്യുമ്പോൾ വൃക്ഷ വൈവിധ്യം താരതമ്യേന കുറഞ്ഞതായി കണ്ടു. ഉദാഹരണത്തിന് 30 വർഷം മുമ്പ് 64 ജനുസ്സുകൾ

റിപ്പോർട്ട് ചെയ്തിട്ടുണ്ട്. അതുപോലെ 1988 ലെ പഠനത്തിൽ വൃക്ഷ സാന്ദ്രത ഏറ്റവും കൂടുതൽ കുതിരാൻ വനങ്ങളിൽ ആയിരുന്നു. കരടിപ്പാറ, കല്ലൂചാൽ എന്നിവിടങ്ങളിൽ വൃക്ഷ സാന്ദ്രത കൂടിയതായി കാണാം. വലിയ വൃക്ഷങ്ങളുടെ വളർച്ച 30 വർഷത്തിനു-ശേഷം പൊതുവേ കൂടിയതായി കാണാം. എന്നിരിക്കലും വൃക്ഷ സമ്പത്തിന്റെ ജൈവ-സാമൂഹിക വിഭജനം ശാസ്ത്രീയ ക്രമത്തിലല്ല എന്ന് കണ്ടെത്തി. പൊതുവേ വൃക്ഷ ജനുസ്സുകൾ ചെറു തൈകൾ, ഇടത്തരം തൈകൾ, പോൾ മരങ്ങൾ, ചെറു വൃക്ഷങ്ങൾ, വൻവൃക്ഷങ്ങൾ, പടു വൃക്ഷങ്ങൾ എന്നീ തലങ്ങളിൽ ആവശ്യത്തിന് പ്രാധിനിത്യം ഉണ്ടാകേണ്ടതാണ്. എന്നാൽ പഠന വിധേയമായ ഇലപൊഴിയും കാടുകളിൽ ഈ പ്രാധിനിത്യം വളരെ കുറവുള്ളതായി കണ്ടു. ഇടത്തരം, വൻവൃക്ഷങ്ങളുടെ ഗണങ്ങളിൽ വലിയ ശോഷണം സംഭവിച്ചതായി കണ്ടെത്തി. കാടിന്റെ പ്രജനന തോത് നന്നായി കണ്ടത് ഇരുൾ, ഇലവ്, നായ്ത്തേക്ക് എന്നിവയ്ക്കാണ്. മറ്റുള്ള ജനുസ്സുകൾ എല്ലാംതന്നെ ശോഷിച്ച പ്രജനന തോത് രേഖപ്പെടുത്തി. കേരളത്തിലെ അമൂല്യമായ ഇലപൊഴിയും കാടുകളുടെ പാരിസ്ഥിതികവും ഘടനാപരവുമായ മാറ്റങ്ങൾ കൂടുതൽ പഠനവിധേയമാക്കേണ്ട-താണെന്ന് പഠനം സൂചന നൽകുന്നു.