ECOLOGICAL STATUS OF *NAGEIA WALLICHIANA* (C.PRESL.) KUNTZE, AN ENDANGERED CONIFER OF WESTERN GHATS IN MANKULAM FOREST DIVISION

by

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(2018-17-001)

THESIS

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DECLARATION

I hereby declare that the thesis entitled "Ecological status of *Nageia wallichiana* (C.Presl.) Kuntze, an endangered conifer of Western Ghats in Mankulam Forest Division" is a bonafide record of research done by me during the course of research and that this thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar titles, of any other University or Society.

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INTRODUCTION

The forests of Western Ghats are good representatives of non-equatorial tropical evergreen forests of the world. Even though it's covering only 5% of the total geographical area of the country, it contains more than 4000 species of plants which account for 27% of the total floral wealth of the country (Ramesh *et al*., 1997). The landscapes of Western Ghats are very heterogeneous ranging from the Arabian Sea coast to montane heights of above 2000 m and rainfall ranging from less than 1000 mm to 6000 mm (Chandran, 1997). The Western Ghats is one of the widely studied lands in terms of its flora, fauna as well as ecology. According to Pascal *et al*. (2004), the southern region of Western Ghats is the one with greater biodiversity and contains a number of endemic species because of high rainfall and short dry season. *Nageia wallichiana* is an endangered tree species seen in this part of Western Ghats because of the ideal ecological niche.

Quantitative floristic studies have been identified as an important tool to define forest vegetation around the tropics (Johnston and Gillman, 1995; Pascal and Pelissier, 1996). Among the quantitative floristic studies, analysis of spatial patterns of tree communities has an influential role in determining the forest structure. At the same time, a floristic diversity study is considered as a prerequisite in community ecology which aids in understanding distribution patterns of species and also in modeling species diversity patterns (Giriraj *et al*., 2008). The co-occurrence of certain species or simply the species associations are also known to have greater importance in understanding the forest ecology in detail. The species associations can affect population dynamics and the functioning of the entire community (Wiegand, 2007). One plant species may have significant positive and negative impacts, directly or indirectly, on other organisms which are also important in structuring the plant communities (Hubbell *et al*., 2001). The studies concentrating on the quantitative and qualitative floristics are thus important in understanding the structure, composition and vegetation patterns in an ecosystem.

Evaluation of the regeneration status of rare habitats is crucial in terms of conservation and management aspects of the landscapes. Recruitment of trees in the forest stands is mainly dependent on factors such as soil characteristics, effect of over storey and light gap availability conditions prevailing in the area (Lieffers *et al*., 1999; Dehlin *et al*., 2004). The study of status, abundance and diversity of regenerating species in an area thus gives important clues to the future status of forests. In addition to the regeneration patterns of trees, the soil characters of a forest ecosystem also significantly influence the vegetation type prevailing in that area and the vegetation, in turn, affects the soil characters as well. The naturally regenerated forests are considered as superior in soil quality than the artificial forest plantations and secondary forests (Burton *et al*., 2007).

Nageia wallichiana is considered as a rare arborescent, threatened evergreen conifer species of wet evergreen forests of Western Ghats. It is the only known natural occurrence of a conifer in the Indian subcontinent (Farjon, 2010). Pascal *et al*. (2004), in their study for identifying the wet evergreen forest types of Southern Western Ghats, consider *Nageia wallichiana* as one of the six better indicators of ecological conditions as its ecological amplitude is narrow. In some parts of Kerala, the tree is considered sacred due to the belief from the Holy Bible that the Ark of Noah was made of this tree (Abhilash and Menon, 2009).

The studies on the distribution and status of this tree are very limited other than some casual observations. The floristic studies done in the natural habitats of this species by Abhilash and Menon (2009) revealed that its natural habitats support diverse endemic, endangered, rare, and threatened plants of Western Ghats, a biodiversity hotspot of the world. According to Abhilash and Menon (2009), no special protection measures are suggested for this threatened tree rather than excluding it from felling for timber. Earlier, a large number of trees might be felled under the name of *Mesua ferrea* for timber (Nair, 1991a) and some were also felled for making railway sleepers and packing materials (Antony and Mohanan, 2010). The natural populations of *Nageia wallichiana* are still facing threats from human interventions and the environmental changes happening in their natural habitats.

The ecological studies concentrating on species with narrow distributions are important in identifying the role of the different environmental factors in structuring that plant community. Niche differentiation of a species especially in tropical forest ecosystems is mainly dependent on the availability of resources (Philips *et al*., 2003). Numerous studies have demonstrated the effect of soil conditions, topographical features, and climatic variables in the distribution patterning of flora in tropics (Hubbell and Foster, 1999). *Nageia wallichiana* comes under the threatened category of trees of the Western Ghats and it has a specific ecological niche, edaphic gradients, and much-restricted habitat. For the effective conservation of this species, perfect knowledge of its ecological niche and amplitude of distribution is needed. Ecological amplitude is the ability of a species to establish themselves along an environmental gradient in various habitats. A species with a narrow ecological amplitude has a very restricted range of conditions in which it can survive. *Nageia wallichiana* is such a species which has a significant positive correlation with its habitat and survival outside the specific habitat is not known.

The present study area, Mankulam Forest Division comprises an area of 90.5 sq km that supports a fair population of *Nageia wallichiana* trees. There are no previous studies on the floristic diversity of this region and the distributional status of *N. wallichiana* trees here. The assessment of natural regeneration in the area will be useful in determining the future of this endangered species. The study expected to throw light on the floristics, ecology, and natural regeneration status of *Nageia wallichiana* which can lead to the development of special conservation measures for this threatened tree.

The specific objectives of the study are:

1) To analyze the distributional status and regeneration *of Nageia wallichiana* in Mankulam Forest Division
2) To study the floristic composition and edaphic attributes of the natural habitat of this species.

REVIEW OF LITERATURE

The relevant literature on the study entitled "Ecological status of *Nageia wallichiana* (C.Presl.) Kuntze, an endangered conifer of the Western Ghats in Mankulam Forest Division" is briefly reviewed here. Whenever sufficient literature is not available on the species, results of researches on related species are also cited.

2.1 ECOLOGICAL SIGNIFICANCE OF WESTERN GHATS

The Western Ghats is considered the most important geographical feature of peninsular India which runs along the western margin of the country with a length of 1490 km from north Tapti Valley to south Kanyakumari with an area of approximately 129037 sq km (WGEEP, 2011). The Western Ghats supports a population of about 35 million people and their survival is mainly based on natural resource availability from this tract (Nair, 1991b; Pascal *et al*., 2004).

Older than the great Himalayan mountain chain, India's the Western Ghats is a geomorphic element of enormous global significance. Since the beginning of the Tertiary period, some 65 million years ago, the great scarp of the Western Ghats had been a characteristic feature of the Indian Peninsula. This then was a triangular wedge of land, a piece of Gondwana's ancient landmass, moving towards its great collision with the Asian landmass that culminated in the orogenesis of the Himalayas, the highest mountains in the world (Radhakrishna, 1991; Nair, 1991b; Tiwari *et al*., 2018). Around 65 million years ago, the northern parts experienced massive volcanic eruptions culminating in the creation of the Deccan Traps — a large region of more than 5,00,000 km^2 of rock of basaltic origin that can be seen today (Sahni, 2006).

The Western Ghats forms a parallel chain of mountains to India's west coast interrupted only by a 30 km wide Palghat gap (Radhakrishna, 1991). Phytogeographically the Western Ghats is divided into four on the basis of the floristic composition. The divisions are (i) from river Tapti to Goa, (ii) from Kalinadi to Coorg, (iii) the Nilgiris, and (iv) the Anamalai, Palani, and Cardamom hills (Rao *et al*., 2006). The species richness and diversity of the Western Ghats region can be attributed to factors such as geographical location, equable climate, stable geology, good soil conditions, and heavy rainfall (Swamy *et al*., 2010). The mountains of Western Ghats mediate the rainfall regime of peninsular India by intercepting monsoon storm systems. Areas west of the highest altitudes of the crest get the maximum annual rainfall, 3,000 mm on average, with 80 percent occurring during the southwest monsoon season (from June to September) and the rest during the northeastern or retreating monsoon (from October to November).

According to Myers (1988), Western Ghats is one of the world's 34 biodiversity hotspots and is well known for its environmental and ecological services. The Western Ghat region represents only 6% of the total landmass of India yet contains 30% of all plants and vertebrates of the country. Olson and Dinerstein (1998) identified two hundred most important ecoregions of the world and it includes the Western Ghat's moist forests (Ecoregion 27, considered as critical or endangered) and the Western Ghats streams and rivers (Ecoregion 150). In addition, the regional surveys in the Western Ghats identified about 60 Important Bird Areas (IBAs) and several hotspots of plant diversity there (Rahmani *et al*., 2016). It is estimated that 40% of the total species identified from the Western Ghats are endemic to this region (Myers, 1990; Collins *et al*., 1990; Nair *et al*., 1986). Given its extreme environmental and ecological significance, the Western Ghats, peninsular India's unique life-sustaining system has been declared a UNESCO World Heritage Site for Preservation (Tiwari *et al*., 2018). Reddy *et al*. (2008) defined 18 percent of Western Ghats as being irreplaceable and representing the overlapped area of very dense forest, intact forest, and high biological wealth areas.

The details on the landscapes of Western Ghats are less (Daniels, 1996; Menon and Bhava, 1997). High topographical variation and relative inaccessibility complicate mapping and analysis of this area. Nagendra and Utkarsh (2003) described the distribution of ecotope types in the Western Ghats using remote sensing data. Landscapes were seen as more fragmented in the northern dry region while larger patch size, less fragmentation, and greater biodiversity was found in the southern moist region.

2.1.1 Forest Types of Western Ghats

Champion and Seth (1968) categorized the forests of India into five major groups, 16 groups, and over 200 categories. The Western Ghats is dominated by the major group moist tropical forests and it includes (i) wet evergreen forests marked by densely distributed tall trees, abundance lianas, climbers, mosses, and epiphytes; (ii) semi-evergreen forests with a luxuriant growth of evergreen and deciduous trees blended in the area and dense undergrowth of herbs, ferns, and grasses; (iii) Moist deciduous forests with a predominance of deciduous trees and understorey of evergreen trees and shrubs; (iv) Littoral and swamp forests dominated by halophytic flora (Singh and Chaturvedi, 2017).

Gadgil and Meher-Homji (1986), pointed out the drawbacks of Champion and Seth's classification that it doesn’t consider the physical and anthropogenic influences in vegetation development. The vegetation types associated with evergreen forests of the Western Ghats designated by Gadgil and Meher-Homji (1986) are (i) Shola(Montane) forest and *Gordonia-Schefflera-Meliosma* series; (ii) *Memecylon- Actinodaphne-Syzygium* series; (iii) *Persea- Holigarna- Diospyros* series; (iv) *Dipterocarpus- Mesua – Palaquium* series and (iv) *Cullenia- Mesua- Palaquium* series.

Utkarsh *et al*. (1998) explored the Western Ghats to evaluate the tree diversity patterns and identified 7 vegetation types in the region. These types include closed-canopy evergreen, semi-closed canopy evergreen, stunted evergreen, semi-evergreen, moist deciduous, dry deciduous, and savanna/scrub vegetation. The most diverse tree assemblages of Western Ghats are reported in the semi-evergreen forest types which host a vast number of species shared with other forms of vegetation. The dry deciduous forest, savannas, and stunted evergreen forests display low tree density and diversity values. The study concluded that wetter vegetation types shelter a wide proportion of evergreen and endemic trees.

The region's highly complex geography, rainfall fluctuations from 1000 to 6000 mm, temperature decreases due to altitude differences, and human activities combined created a variety of vegetation types in the Western Ghats. In the western slopes of the region, the natural climax vegetation is tropical evergreen forests while towards the rainshadow region eastwards vegetation changes to semi-evergreen forests, moist deciduous forests and eventually to dry deciduous and thorn forests (Pascal, 1988; Chandran *et al*., 2010). A complex ecosystem with a mosaic of montane evergreen sholas alternating with grasslands is located in altitudes greater than 1500 m (Pascal, 1988). According to Myer (1990), one-fifth of the entire expanse of forests of Western Ghats are found to be evergreen forests that come under 500 m elevation and forests between 500 m and 1500 m are designated as semi-evergreen forests.

2.1.2 Diversity gradients of Flora

Levels of biological diversity vary along different gradients. In the Western Ghats, three kinds of such gradients in the diversity of flowering plants along the hill chain are observed (Gadgil and Meher-Homji, 1990; Pascal, 1988). The diversity of plant species is found to be increasing towards the southern parts from river Tapti to Kanyakumari of the Western Ghats. This is related to the increased number of rainy days towards the southern parts. The diversity of plant species also increases from east to west when one crosses the Western Ghats. This is in conjunction with an increase in total rainfall. The total number of woody plant species is found to be increasing from east to west. Another known gradient is the increase in woody flora with an increase in mean temperature from a higher elevation to coastal plains (Gadgil, 1996).

2.1.3 Floristic diversity of Western Ghats

Floristic diversity of a region refers to the variety and variability of plants found there. It is measurable in different levels starting from global diversity to ecosystems, populations, communities, individuals, and even to genes within a single individual (Rao and Raghavendra, 2012). Floristic diversity study is considered as a prerequisite in community ecology which aids in understanding distribution patterns of species and also in modeling species diversity patterns (Giriraj *et al*., 2008).

The Western Ghats have higher ecological significance due to the high degree of heterogeneity in the environmental factors. According to Pascal (1988), the complex pattern of species diversity and variation in the spatial and structural distribution of forest types of the Western Ghats is due to the geographic and physical intricacy of the area and the associated variation in micro and macroclimatic conditions. Pascal (1988) identified the length of the dry season which falls between the South-West monsoon and North-East monsoon as the most important factor which determines the floristic types of the Western Ghats.

The floristic diversity of the Western Ghats region was studied by Beddomei (1877); Bourdillon (1908); Gamble (1915-1936); Fyson (1932); Govindarajulu and Swamy (1956); Lawrence (1959); Nair (1959); Nair and Daniel (1986); Nayar (1996); Pascal and Ramesh (1987); Pascal (1988), and so on.

Out of the 4000 species of angiosperms in the Western Ghats, 1500 are found to be endemic (Nair and Daniel, 1986; MacKinnon and MacKinnon, 1986). According to Ramesh and Pascal (1997), Western Ghats is a center of rich endemism, and nearly 63% of India’s evergreen woody flora, is endemic to the region. The tree genera that are endemic to the Western Ghats include *Blepharistemma*, *Erinocarpus*, *Meteromyrtus*, *Otenophelium*, *Poeciloneuron*, and *Pseudoglochidion*. Gunawardene *et al.* (2007) give an estimate of endemism that 56% of evergreen trees, 40% of lianas, 43% of liverworts, and 28% of mosses found in the Western Ghats are endemic to this region. There are 58 endemic plant genera in the area, 49 of which are monotypic, and some extremely specious such as *Nilgirianthus* with 20 species. Some prominent genera and families are recorded by huge numbers of endemic species including *Impatiens* with 76 out of 86 species, *Dipterocarpus* with 12 out of 13 species, and *Calamus* with 23 out of 25 species are endemic to the region. Of the 267 species of orchids (representing 72 genera), 130 are endemic to Western Ghats (Raman *et al*., 2006; Nair, 1991). Other genera endemic to the

Western Ghats include *Adenoon, Willisia, Griffithella, Baeolepis, Meineckia, Nanothamnus*, *Campbellia*, *Wagatea*, and *Calacanthus* (Nair, 1991).

Pascal (1988) identified major plant associations in the wet evergreen forests of Western Ghats and it includes eight types at lower elevations (less than 850 m), five at medium elevations (850 to 1,500 m), and three at higher elevations (greater than 1500 m). Swamy *et al*. (2010) in his study on phytodiversity, floristic composition, and structure of tropical evergreen forests of four contiguous hill ranges in the Western Ghats identified the common emergent tree in the moist patches as *Vateria indica* while *Canarium strictum* and *Palaquium ellipticum* were found in higher altitudes in the range of 800-1100 m. The understorey consists of trees like *Actinodaphne hookeri*, *Canthium dicoccum,* and lianas such as *Agrostistachys indica* and *Clematis gouriana*. He also identified the presence of bamboos, canes, epiphytes, and mosses as characteristic in an evergreen ecosystem.

2.1.4 Sub-regions of Western Ghats

Although the Western Ghats extend over 1400 km along the six states, it is geographically divided into three unique sub-regions. The northernmost subregion is Maharashtra Sahyadris which extends from river Tapti to southern Goa. It rises up to an elevation of 900 m to 1200 m and is composed of Deccan lavas. The next subregion starts from the southern parts of Goa and extends about 320 km south to Coorg. The crest line of this region has been eroded down to less than 900 m. The Southern Western Ghats starts from south Canara where the wide Netravati valley forms a wide embayment into the Ghats. The mountains continue unbroken south of the Palghat Gap to the southern tip of the peninsula, the Mahendragiri peak (Nair, 1991)

Floristic studies conducted in the forests of Northern Western Ghats are mainly based on the qualitative description of characters such as forest types, dominant species and physiognomy, and some taxonomic explorations (Sharma and Kulkarni, 1980; Gadgil and Vartak, 1981). In general, the vegetation of Northern Western Ghats is understudied comparing with the continuous quantitative inventories on floristics of the southern parts of Western Ghats. Kanade *et al*. (2008) intensively studied the vegetation composition and woody species diversity at an entire eco-region level in the Northern Western Ghats and recorded a new subtype, *Memecylon-Syzygium-Olea* of the literature already available for the floristic series. Datar and Tetali (2019), studied the potential of hill forts of the northern Western Ghats in supporting and maintaining local biodiversity. Singh and Karthikeyan (2000) studied the flora of Maharashtra and found that the Northern Western Ghats of Maharashtra is home to 23 endemic genera and 815 Indian endemic angiosperms.

The Central parts of Western Ghats are floristically moderately rich and diverse and are characterized by a lower rate of endemism than the southern Western Ghats (Ramesh *et al*., 2010). Bhat *et al*. (2000) studied species richness, basal area, tree density, and species recruitment data in the evergreen and moist deciduous forests of North Kannada district of the central Western Ghats. Chandran *et al.* (2010) studied the ecological significance of kan forests which are considered as the relics of the past extent of the evergreen forests.

2.1.5 Floristic studies in Southern Western Ghats

The southern Western Ghats has peninsular India's oldest known and perhaps most widespread climax vegetation. The wet tropical forests in Southern Karnataka, Kerala, and Tamil Nadu have been some of the best representative locations of Indo-Malayan rainforest formations (Nair, 1991). The higher levels of alpha diversity and plant endemism in the Western Ghats are found to increase towards the southern region (Davidar *et al*., 2005; Ramesh *et al*., 1997). The most suitable climatic conditions in the southernmost regions with heavy, but not extreme, rainfall and short dry season promotes the highest biodiversity and the largest number of endemic species in the Western Ghats (Ramesh *et al*., 1997; Pascal, 1988).

2.1.5.1 Spatial structure of tree communities

In ecological studies, spatial structures of tree communities have an influential role. It includes analysis of different factors such as vertical profiles of the plant community, horizontal plans, height/diameter relationships, height and girth-class distribution of trees, density, basal area, and biomass index of trees (Pascal, 1988). Many of the ecological studies across the Western Ghats and certainly some of the studies in the southern Western Ghats considered the above-mentioned factors to describe the ecosystem structure of forests.

Reddy *et al.* (2008) studied the vegetation structure of different forest types of Mudumalai wildlife sanctuary. Across all the forest types, the study found a clear dominance of small stemmed individuals. The mean basal area in the different types ranged from 6.12 m^2 ha^{-1} to 49.0 m^2 ha^{-1}. The density was found to be 407 and 406 individuals ha^{-1} for moist deciduous and dry deciduous forests respectively. The study also revealed the presence of 65.4 percent of species and 36.4 percent of individuals in the girth class of 30- 60 cm.

In the tropical evergreen forests of Kalakkad – Mundanthurai tiger reserve with *Cullenia – Mesua – Palaquium* as dominant species, Giriraj *et al*. (2008) studied the forest structure and concluded that the majority of the individuals in the area are in the girth class of 10 – 30 cm. The mean density of the area was calculated at 1875 individuals ha^{-1} and the basal area at 47.01 m^2 ha^{-1}. Ayyappan and Parthasarathy (1999) studied the structure of vegetation in large scale permanent plots of evergreen forests in Varagalaiar of Anamalais. The girth class – frequency distribution of trees in the study area revealed the fact that 52 percent of total individuals belong to the lower girth class of 30-60 cm and the species richness as well as abundance decreased with increasing girth classes. Ayyappan and Parthasarathy (2001) done taxa specific research concentrated on the population structure and distribution of Dipterocarps in the Vargalaiar region of Southern Western Ghats. The mean density of all species together in the study area was found to be 447 trees ha^{-1} and that of Dipterocarps was 31 trees ha^{-1}. The mean basal area value for

Dipterocarps was estimated at 16.5 m^2 which accounts for 18.4 percent of the total stand basal area.

The density, basal area, and other spatial characters differ greatly with the ecosystem types. Vidyasagaran *et al*. (2004) recorded 2533 individuals ha^{-1} from the shola forest of Brahmagiri hills and Jose *et al.* (1994) estimated a mean density of 1884 individuals ha^{-1} in the shola forest of Eravikulam national park. Pascal (1988) extensively studied various forest types across the Western Ghats and recorded the range for mean density from 760 to 2250 individuals ha^{-1}. Certain studies in the mid-elevation evergreen forests of Western Ghats recorded 412 individuals ha^{-1} (Pomeroy *et al*., 2003) and 635 individuals ha^{-1} (Pascal and Pelissier, 1996). The basal area also shows a variation in the forest and ecosystem types. While Vidyasagaran *et al*. (2004) reported a total basal area of 73.55 m^2 $ha^{-1}$from the sholas of the Brahmagiri hills, the basal area recorded by Jose *et al*. (1994) was only 48 m^2 ha^{-1} from Eravikulam. The basal area reported for midland evergreen forests in Nelliampathy, Kerala ranged from 49.8 to 61.9 m^2 ha^{-1} (Chandrashekara and Ramakrishnan, 1994).

2.1.5.2 Floristic Diversity

There are numerous studies on the floristic diversity of the Western Ghats region and some of them are concentrated on the medium elevation evergreen forests of Western Ghats. Pascal *et al*. (1988) studied various forest types of Western Ghats and analyzed the diversity, community structure, and phytosociological attributes. He identified the *Cullenia- Mesua – Palaquium* medium elevation evergreen forest type in the Attappady region of Southern Western Ghats and estimated various diversity indices viz., Simpson index of diversity (0.90) and Shannon – Weiner’s diversity index (4.0). Pascal and Pelissier (1996) studied the diversity of dense wet evergreen forests of the Kodagu area by establishing permanent plots and estimated Simpson index of diversity at 0.92 and Shannon – Weiner’s diversity index at 4.56.

Ganesh *et al*. (1996) studied the medium elevation evergreen forests of the Kakachi region of Agasthyamalai and estimated a higher Shannon-Weiner's diversity index of 4.87. Parthasarathy (1999) compared the diversity of disturbed and undisturbed sites of Kalakkad National park of Southern Western Ghats and estimated a higher diversity index value for the undisturbed sites which are coming under the *Cullenia-Mesua – Palaquium* series. In Varagalaiar forests of the Anamalai region, Ayyappan and Parthasarathy (1999) conducted extensive studies on floristic diversity and the values of Simpson's index of diversity and Shannon index estimated were 0.96 and 3.93 respectively. Varghese and Balasubramanyan (1999) recorded the Margalef index value for the evergreen forests of the Agasthyamalai region as 7.07 and an evenness value of 0.89.

In a study conducted in the Kodayar region of Kanyakumari, Simpson's index of diversity and Shannon index was low with values of 0.85 and 2.64 respectively (Sundarapandian and Swamy, 2000). The evenness was found to be higher for the evergreen forests of Kodayar which is 1.69. In the *Cullenia- Mesua – Palaquium* type of forests of the Sengaltheri region of Agasthyamalai, Shannon-Weiner's diversity index value was estimated at 3.69 (Parthasarathy, 2001). Giriraj *et al*. (2008) studied the diversity and floristic attributes of tropical wet evergreen forests of the Kakachi forests of Kalakkd- Mundanthurai tiger reserve and estimated the value of Simson's index of diversity (0.95) and Shannon-Weiner's diversity index (4.89) of flora in this region. The evenness value estimated by Giriraj *et al*. (2008) was 0.79. A recent study conducted in the Amaggal reserve forests of Nilgiris estimated the value of Simpson's index of diversity at 0.95 and the Shannon index at 3.24 (Mohandass *et al*., 2016).

2.1.5.3 Floristic structure and composition

Phytosociology is concerned with the plant populations, their structure, and composition, evolution, and relationships between the constituent species (Pott, 2011). It is an inclusive term which deals mainly with the structure, composition, and patterns of distribution of ecosystems (Saxena and Singh, 1982). In Western Ghats regions numerous studies record the above-mentioned factors of different ecosystems. Pascal and Pelissier (1996) identified the dominant species in the different layers of an evergreen ecosystem in the Uppangala forests of Southern Western Ghats. Each of the four most dominant species is observed to occupy different layers of the canopy. *Dipterocarpus indicus* was the dominant tree identified in the top canopy while *Vateria indica* is the common species in intermediate strata to emergents, *Myristica dactyloides* in the intermediate layer and *Humboldtia brunonis* was the main species of understorey.

In a floristic study by Parthasarathy (1999) in the different disturbance regimes of the Kalakkad National park of Agasthyamalai region, identified 122 woody species in the high elevation evergreen forests. The dominant species of undisturbed areas are found to be *Cryptocarya bourdillonii, Myristica dactyloides, Harpullia arborea, Mangifera indica, Cullenia exarillata,* and *Palaquium ellipticum*. Parthasarathy (2001) studied the patterns of tree diversity and abundance in the undisturbed and human-impacted sites of low and medium elevation tropical evergreen forests in Agasthyamalai ranges of Southern Western Ghats. A total of 125 species in 91 genera and 42 families were identified from the study site. The study found that the various parts of wet evergreen forests are dominated by various combinations of species.

Parthasarathy *et al*. (1992) documented the floristic richness and human effect on the evergreen forests of the Western Ghats in Peninsular India. Chandrashekara and Ramakrishnan (1994) have studied the vegetation and gap dynamics of Nelliampathy Forests of Palghat district in the Southern Western Ghats. At the Mundanthurai Tiger Reserve of Southern Western Ghats, Ganesh *et al.* (1996) conducted a comprehensive study of the species richness and diversity of a middle elevation evergreen forest. He reported species diversity ranking highest among other similar sites in the Western Ghats. Utkarsh *et al*. (1998) illustrated tree diversity trends in the Western Ghats and identified various vegetation types found in different parts of the Ghats. Ayyappan and Parthasarathy (1999) studied the forest at the Varagalaiar area of the Anamalais, where the vegetation was transitional between the *Cullenia-Mesua-Palaquium* and

Dipterocarpus-Mesua-Palaquium types. Chandrashekara and Jayaraman (2002) reported the structure and composition of forest stands of Iringole, Ranni, Goodrickal, and Thenmala in the south of Palghat Gap and Aralam and Nilambur in the north of Palghat gap in Kerala. Sukumar *et al*. (1992) studied the long-term vegetation dynamics in the deciduous forests of the Mudhumalai region and find out the four most dominant species of the area as *Kydia calycina*, *Lagerstroemia microcarpa*, *Terminalia crenulata*, and *Helicteres isora.*

A detailed floristic inventory was carried out by Sharma *et al*. (2002) in New Amarambalam forest reserve which is a continuation of Silent Valley National Park and situated in the north-west side of it. The study recorded 305 taxa in which 32% of this arborescent flora was composed of endemic species. Pascal *et al*. (2004) studied the wet evergreen forests of southern Western Ghats extensively and presented a detailed classification of forest types. Based on the presence of certain species with narrow ecological amplitude, the forests were separated into 3 main groups which correspond to high, medium, and low elevation wet evergreen types. The species considered as better indicators of ecological conditions were *Bhesa indica*, *Cullenia exarillata*, *Dipterocarpus bourdilloni*, *D. indicus*, *Gluta travancorica*, and *Nageia wallichiana.*

Muthukumar *et al*. (2006) conducted an extensive study in the tropical rainforest fragments of the Valparai plateau of Southern Western Ghats. Systematic sampling enumerated 144 species of trees from 4 ha area. The fragments are found to be with substantial plant diversity with the highest value to the undisturbed and large forest fragments. Giriraj *et al.* (2008) studied the patterns of tree diversity and vegetation composition of the Kalkkad-Mundanthurai tiger reserve of southern Western Ghats. 51% of the woody species recorded in the study were endemic to the Western Ghats.

The recent ecological studies in the southern Western Ghats are mainly species-specific and are based on characters such as pollination biology, distribution ecology, phytogeography, and the effect of disturbances in diversity (Irwin *et al*., 2013; Kuriakose *et al*., 2019; Kulkarni *et al*., 2018; Geethakumari *et al*., 2010). Significant floristic inventories and ecosystem studies are also taking place in the southern Western Ghats. Sindhuja and Rajendran (2012) described 130 herbaceous life forms from the Maruthamalai hills of southern Western Ghats. Ramachandran and Swarupanandan (2013) analyzed the forest structure and species composition of old-growth wet evergreen forests of Nelliampathy hills which is situated in the immediate south of the Palghat Gap in the Southern Western Ghats. The study found *Agalaia* and *Litsea* as the most species-rich genera and Euphorbiaceae and Lauraceae as the most species-rich families. Sathish *et al*. (2013) compared the regeneration characteristics of trees in northern and southern Western Ghats and found a higher rate of regeneration, the density of regenerates, and regeneration of threatened and endemic trees in the southern Western Ghats. The rare, endangered, and threatened climbers of Tamil Nadu part of southern Western Ghats were recorded by Sarvalingam and Rajendran (2016). A detailed study on the floristic structure and composition of shola forests of southern Western Ghats was carried out by Mohandass *et al*. (2016).

2.1.5.4 Composition of rare, endemic, and threatened (RET) trees

The rare, endemic, and threatened species (RET) in an ecosystem typically has unique ecological niches, edaphic patterns, and vulnerable habitat (Varghese and Menon, 1999). Most endemic species with a limited geographic range end up as rare species and eventually as endangered ones if their habitat is not secured (Nayar, 1996). The natural habitats of RET species and the proportion of them in an ecosystem have greater ecological significance. Many of the studies in Southern Western Ghats considered the proportion of endemics in the community as an indicator of the ecological status of the area.

Ramesh and Pascal (1997), states that 63% of woody flora in the medium and low elevation evergreen forests of the whole of Western Ghats are endemic. Giriraj *et al*. (2008) reported 51% of trees as endemic in a study conducted in the Agasthyamalai region. Varghese and Menon (1999) in the tropical and montane subtropical forests of Peppara wildlife sanctuary recorded 41% of endemism in the area. Coming to the proportion of threatened trees, Varghese and Menon (1999) identified 8 threatened species out of 151 total tree species from Peppara (5.29%). Das *et al*. (2006) point out the importance of endemic and threatened species of an area in prioritizing conservation areas of a landscape.

2.1.6 Regeneration studies in evergreen forests

Recruitment, development, and survival of young trees are affected by a combination of microclimatic and edaphic factors that vary between different formations of tropical forests (Augspurger, 1984). Recruitment of trees in the forest stands is mainly dependent on factors such as soil characteristics, effect of over storey and light gap availability conditions prevailing in the area (Lieffers *et al*., 1999; Dehlin *et al*., 2004). According to Boring *et al*. (1981), the regeneration potential of trees is greatly influenced by the interaction of biotic factors and environmental factors. The regeneration patterns of trees are important clues to the future status of forests.

The tree regeneration studies in the Western Ghats are mostly connected with the composition of seedling and sapling categories as well as patterns of regeneration. Jayakumar and Nair (2013) assessed the regeneration patterns in different forest formations of Western Ghats. The study identified a higher degree of change in species composition between mature trees and regenerating ones in the disturbed forests than the undisturbed forest patches. The difference in species composition of recruits in the disturbed stands is considered as an indicator of new species composition in the future. Anita *et al*. (2010) studied the regenerating population of trees in a disturbed stand of Nilgiris and concluded that the species composition of regenerating individuals are differing from that of trees and indicates structural degradation and quality loss of habitats.

Chandrasekhara and Ramakrishna (1994) studied the species wise regeneration status of trees in the evergreen forests of Nelliampathy. They identified the formation of canopy gaps as an important factor in deciding the regeneration and establishment of evergreen trees. The study found a higher proportion of *Palaquium ellipticum* and *Mesua nagassarium* in different regenerating stages while *Aglaia exstipulata* and *Mastixia arborea* were present only as mature trees. Osuri *et al*. (2017) studied the effect of fragmentation and overstorey species composition in the regeneration of trees in tropical evergreen forests of the Valparai plateau. The study found a serious decline in the regeneration of old-growth species in the fragmented forests while species richness doesn't show much variation between continuous forests and fragmented ones.

Sathish *et al*. (2013) studied the diversity and regeneration status of tropical rainforests of the Kodagu district of Karnataka with an aim to compare the structure of forests of northern and southern parts of the Western Ghats. The study found a higher regeneration in the southern parts of Western Ghats in comparison with the northern parts while diversity remained the same. Ganesan and Davidar (2003) conducted a comparative assessment of regeneration on the logged and unlogged forests of the Agasthyamalai area of southern Western Ghats. The study was concentrated on six old-growth evergreen tree species including *Cullenia exarillata* and *Palaquium ellipticum*. The ratio of adults to saplings was found higher in unlogged forests of the study area. The logged forests showed lower adult density as well as reduced regeneration potential.

The forest fire was also identified as influential in the regeneration, especially for deciduous forests. Verma *et al*. (2017) studied the effects of fire in the regeneration potential of forests of Mudumalai tiger reserve. The study concluded that fifteen years is needed for regaining the diversity of the forest area after a fire burning. Subashree *et al*. (2020) identified the regeneration potential of constituent tree species as a key element of forest ecosystems. The study conducted in the different forest types of Kanyakumari Wildlife sanctuary concluded that most of the tree species were new recruits while dominant species of over storey had fair to good regeneration potential. Basha (1988) recorded 28 regenerating species per 0.19 ha from evergreen forests of Silent Valley and Abhilash *et al*. (2005) recorded 53 species from 0.15 ha of the sampling area of Goodrical reserve forests.

2.2 CONIFERS IN INDIA

The conifers are monophyletic plant community of approximately 630 species coming under 70 genera belonging to 8 families and with relatively high ecological and economic importance. They occur on all continents except Antarctica (where fossil records of them are known) and in various forest biomes, of which several are dominated by conifers. Among the conifer genera, 35 are confined to the northern hemisphere, 25 occur south of the equator and 10 occur both north and south of the equator. The conifers have a great role in forestry; they account for the majority of sawn timbers in the world economy. Even though many species are widespread, 25% of the conifer species in the world are threatened with extinction (Hiep *et al*., 2004; Farjon, 2010).

Farjon (2008) described conifers as trees or shrubs with secondary wood made of tracheids, narrow rays, and large bordered pits in their cell walls. They are simple leaved with single or parallel veins. Resin is typically formed in wood and often in leaves and is transferred through resin canals. The male and female reproductive organs are seen separated with simple male cones (pollen cones) and reduced or compound female cones (seed cones).

Conifers have a long evolutionary history that dates back to the carboniferous period which is more than 300 million years ago. The conifers have the longest and best-known fossil records of any seed plant group (Taylor *et al*., 2009) and these fossil records indicate that by the beginning of the Mesozoic period conifers spread to worldwide distribution and attained its greatest diversity. During the early cretaceous era, angiosperms emerged and competition with these newcomers resulted in the exclusion of conifers in several areas and habitats (Farjon and Filer, 2013). Farjon (2001; 2010) recognized 8 families in conifers. They are Cupressaceae, Pinaceae, Taxaceae, Cephalotaxaceae, Sciadopityaceae, Podocarpaceae, Araucariaceae, and Phyllocladaceae.

In India, there are approximately 11 genera and 24 species of native conifers mostly distributed in the Himalayan region. Just four genera of them form extensive forests: *Abies, Cedrus, Picea,* and *Pinus* (Dogra, 1985). The conifer genera those forms extensive forests in the Himalayan region are much the same as those occurring in forests across most of the northern hemisphere. *Podocarpus* and *Nageia* are the only two genera with the main distribution in the southern hemisphere and indigenous to southern India, Eastern Himalayas, Andaman and Nicobar Islands, and several countries to the east (Dogra, 1999). The conifers distributed along the Himalayan mountains represents five families, i.e., Pinaceae, Cupressaceae, Podocarpaceae, Taxaceae, and Cephalotaxaceae. Populations of *Podocarpus, Taxus*, and *Cupressus torulosa* are spread along the entire Himalayas but do not cover large areas and flourish only as isolated trees in mixed forests or in small stands. Some rare genera, such as *Amentotaxus* and *Cephalotaxus* are regionally endemic and confined to local areas (Dogra, 1999).

Excluding the Himalayan region which had a different ecological history, the Indian subcontinent is now almost without conifers but has abundant conifer fossils and other gymnosperm types (Farjon, 2010). On its journey through the tropics and arid regions from the southern latitudes as a detached piece of Gondwana, the peninsular Indian landmass lost most of the conifer species. Even though there are plenty of suitable areas for conifers in India demonstrated by the successful conifer plantations, the Indian subcontinent remains a gap in the distribution of conifers (Farjon and Filer, 2013). There is now a single southern conifer in Peninsular India, the *Nageia wallichiana*, which is an Indo-Malesian element spread from South East Asia.

2.3 GENUS NAGEIA: AN OVERVIEW

Nageia is a genus of the second-largest conifer family Podocarpaceae. The Podocarpaceae, with 175 members has a pantropical distribution spreading to temperate regions in the southern hemisphere and a lesser extent in the northern hemisphere (Farjon and Filer, 2013). There are currently 18 genera in this family with the largest, *Podocarpus*, with 98 species recognized (Farjon, 2010). The genus name *Nageia* was derived from the word ‘Nagi’, the vernacular name of the species seen in Japan (Farjon, 2017). Earlier this was placed as a section under the genus *Podocarpus* and later identified as a distinct genus with the type species *Nageia nagi* (Thunb.) O. Kuntze. (de Laubenfels, 1987; Page, 1988). *Nageia* is differentiated from all other Podocarpaceae because of its distinctive, broadly-lanceolate multi-veined leaves which are unique in conifers (Page, 1988). The *Nageia* genus is generally split into the *Nageia* sect. *Nageia*, which is known to be primitive, and *Nageia* sect. *Dammaroideae*, which is comparatively specialized (Mill, 2001). The *N*. section *Nageia* contains N. *nagi*, N. *fleuryi*, N. *maxima*, N. *formosensis,* and N. *nankoensis*. Most of the species included in this section have hypostomatic leaves, excluding N. *maxima*, distinguished by amphistomatic leaves with a few stomata on the adaxial side (Hill and Pole, 1992). The specialized *N*. section *Dammaroideae* consists of *N.wallichiana* and *N. motleyi.* Besides certain populations of *N. wallichiana, N*. section *Dammaroideae* is concentrated at lower altitudes than *N*. section *Nageia*. Both species in the section are amphistomatic with the leaves contains numerous stomata on the adaxial surface (Liu *et al*., 2015). The genus has a general distribution in the tropical and subtropical moist broad-leaved forests (Jin *et al*., 2010).

A few paleobotanical and karyomorphological studies are there concentrating on the genus *Nageia*. Qi-Xing *et al.* (2010) conducted chromosomal studies in three different species from the genus *Nageia* and found the chromosome number to be 2n = 26 with basic chromosome number X = 13 while the basic chromosome number of Podocarpus is X= 19. The study found genus *Nageia* to be the most similar to the *Podocarpu*s and *Afrocarpus* and must be included in the family Podocarpaceae. Jin *et al*. (2010) studied fossil records and discovered a new fossil record of *Nageia* from Southern China. The study concluded that the distribution of both the modern types and fossils of *Nageia* species suggests that this genus may have emerged in the Early Cretaceous period in the northeastern part of Asia and spread to southern China and other northern parts, at least in the Eocene.

2.3.1 Description

The genus consists of monoecious or dioecious evergreen trees and rare shrubs. Leaves consist of narrow resin canals. The bark is hard, thin, and sometimes seen as scaly. Irregular branching is seen with vegetative shoots ending in small buds. Leaves are arranged in a spiral pattern or in a subopposite way on the leading shoots. Leaves are large and flat, leaf shape is described as ovate-elliptic to lanceolate and it lacks a midrib. There will be many parallel and converging veins. Stomata may be arranged on both sides or on the abaxial surface only. Pollen cones single or in small, spicate groups of 2–6 on axillary peduncles. Seed cones are much reduced, either solitary and with long peduncles or with two or more on slender shoots in the axil of a leaf and short peduncle. Each cone consists of one seed fully enclosed by a swollen drupe-like red or purple epimatium (Farjon, 2010; Farjon and Filer, 2013; Page, 1988).

2.3.2 Distribution

Unlike the other conifer genera, *Nageia* is mainly distributed in the southern hemisphere and has an East Asian/ Malesian distribution. Farjon (2013) states that the distribution range of the genus spreads from South India's Western Ghats to the D'Entrecasteaux Islands of the Soloman sea as well as from Honshu in Japan to the Lesser Sunda Islands. In India, the genus has distribution in Assam, Meghalaya, Kerala, and the Nicobar Islands. It is also distributed in South East mainland of China, Japan, Okinawa, Ryukyu Islands, Hainan, Taiwan, Indochina including the Malay Peninsula and in Malaysia from Sumatera to New Guinea excluding most parts of the Lesser Sunda Islands, Western Java, Borneo, Cambodia, New Ireland and New Britain (Farjon, 2010; Farjon and Filer 2013; Page, 1988).

2.4 *NAGEIA WALLICHIANA*

Nageia wallichiana is the most widely distributed species among the seven species in the genus *Nageia* (Farjon and Filer, 2013). If the land areas of China and Japan are excluded, its distribution nearly coincides with that of the genus and includes both the western outliers in India and the easternmost part on Normanby Island. It is one of the most extensive conifer ranges recognized and is similar to *Dacrycarpus imbricatus* and *Podocarpus neriifolius* (Farjon, 2013). Its occurrence in the Western Ghats has higher phytogeographical importance. The presence of the species in the Western Ghats is not only a disjunct locality, but it is also the only known natural occurrence of a conifer in the Indian subcontinent (Farjon, 2010; Farjon and Filer 2013).

2.4.1 Etymology and vernacular names

This species was named after an early student of the Indian flora, Nathaniel Wallich (Farjon, 2010). The various synonyms of the species are *Podocarpus wallichianus*, *Decussocarpus wallichianus*, *Podocarpus latifolius*, and *Nageia latifolia*.

Numerous local names have been reported due to its wide distribution. In China, it is called rou tuo zhu bai and in Vietnam, it is known as Kim giao nui đat (Farjon, 2010; Hiep *et al.*, 2004). In Tamil, it is called as Narambali or Nirambali (Bourdillon, 1908; Sasidharan, 2004). Gamble (1915-1934) reports another name ‘Karunthumbi’.

2.4.2 Description

It is an erect evergreen and glabrous tree tall up to 50 m with a cylindrical stem and thin colourless juice. The bark is smooth with a brown and white mottled appearance and 0.5-inch thickness (Bourdillon, 1908; Gamble, 1915-1934). Farjon (2010) describes the bark as hard and scaly with a dark or reddish-brown colour and peeling into thin flakes. The inner bark is pinkish or reddish in colour with 5-6 mm thickness and slightly fibrous. Bourdillon (1908) and Gamble (1915-1934) describes wood as aromatic, grey coloured, and moderately hard. Bourdillon (1908) explains few anatomical properties of the wood such as extremely fine and numerous rays and faint annual rings. The weight of the wood is recorded as 32 lbs per m^3.

The crown is described as conical by Hiep *et al.* (2004) and irregularly rounded as Farjon (2010). Leaves are opposite decussate, subopposite, or rarely alternate towards the end of branchlets. The length of the leaf is recorded as 3-7 inches and width 0.75- 2 inch by Gamble (1915-1934) while Farjon (2010) states that there is extreme variation in the size and shape of leaves. The petiole is 5- 10 mm long and twisted 90^0 at the base. Leaf shape is narrowly elliptic to ovate-lanceolate with acute or obtuse apex. Leaves are coriaceous, tapering at both ends, and have numerous longitudinal nerves. Leaf colour is dark shining green. Stomata seen on both surfaces and is more conspicuous in the underside (Gamble, 1915-1934; Farjon, 2010)

Pollen cones are arranged axillary, on a 4–10 mm long peduncle in clusters of up to 7–10. The pollen cones become cylindrical at its full length and consist of two pollen sacs. Seed cones are axillary, solitary, and arranged in long peduncles, with a few deciduous bracts near the base of the peduncle. The cone bracts fuse to a green swelling and later red or purplish receptacle. The ovoid seeds with 1-inch length are formed at the end of the receptacle and enclosed in a green epimatium which later turns into a purple coloured fleshy structure (Farjon, 2017; Bourdillon, 1908). Bourdillon (1908) describes that the fruiting season is January to February.

2.4.3 Distribution

Nageia wallichiana is the most widely spread member of the genus *Nageia*, and maybe one of even the most purely tropical of all conifers (Farjon, 2010). It occurs in primary closed evergreen tropical broad-leaved and mixed submontane and montane forests (Hiep *et al*., 2004). According to Farjon (2010), the species is distributed in areas such as Yunnan province of China, Indochina, Malaysia (but not found in Central and Eastern Jawa and on the Lesser Sunda Islands), certain parts of India including Assam, Andaman-Nicobar Islands, and Nilgiri hills and Palani hills of Kerala.

Various floristic inventories in south-East Asia report the occurrence of this species. It has distribution in Cambodia and Laos (Thomas *et al*., 2007), Vietnam (Rushforth, 2007; Hiep *et al*., 2004; Ke Loc *et al*., 2007), South Western China (Liu *et al*., 2015), Malesia (Farjon, 2013), Raja Ampat Island of Indonesia (Webb, 2005), North Moluccas (Heatubun, 2011), Thailand (Akkarasedthanon *et al*., 2017), Wawonii islands of Sulawesi (Sunarti and Rugayah, 2013), and in Kalimantan of Borneo Island (Sidiyasa, 2001).

In India, it is reported from Assam by Barbhuiya (2013) during his study on endemic and threatened vascular plants of southern parts of the state. Khuraijam and Singh (2015) also identified its presence in Assam and Meghalaya of the northeastern parts of India. Dogra (1985) recorded this species under the category of conifers having distribution in large regions of Eastern Himalaya. Gupta *et al*. (2002) rediscovered the species from Campell Bay of Nicobar islands after half of a century. The first record of the species from Nicobar islands was by Sahni (1953). Outside these two locations, the presence of this species in India is identified only in the mid-elevation evergreen forests of Western Ghats.

Nageia wallichiana is observed during the various floristic inventories in the Western Ghats but the records are confined to the southern Western Ghats south of the Palghat gap. Bourdillon (1908) in his book 'Trees of Travancore' identified the presence of the species in Travancore and considered it as rare because of the limited distribution. He reported the species in Mutthukuli vayal and near to the boundary of Travancore and Tinnevelly (Thirunelveli) on the southern side of the Agastyar peak. Gamble (1915-1934) records the distribution of this species as southwards of Nilgiris. Sasidharan (2004) during the biodiversity documentation of Kerala recorded this species from Pathanamthitta, Kollam, and Thiruvananthapuram districts of Kerala in which all the records are to the south of the Palghat gap. Mohanan and Sivadasan (2002) included *Nageia wallichiana* in the flora of Agasthyamala, and Kumar *et al*. (2005) included it in the flora of Pathanamthitta where they located 3 to 4 trees in Kakki hills. Few other locations identified in Kerala includes Goodrical reserve forest (Abhilash *et al*., 2005), Kalakad – Mundanthurai Tiger reserve (Ganesh *et al*., 1996), Anamalai hills (Osuri *et al*., 2017), Sengaltheri (Parthasarathy, 2001), Kottaimalai and Devarmalai of Mlappara (Pascal *et al*., 2004), Kakachi forest range of Agasthyamali region (Giriraj *et al*., 2008) and Periyar Tiger reserve (Augustine, 2000). Pascal *et al*. (1997) identified the presence of *Nageia wallichiana* facies in medium elevation evergreen forests of Kalakad-Mundathurai tiger reserve with an extent of 181 km^2.

2.4.3.1 Phytogeographical significance of the occurrence of Nageia wallichiana in Southern Western Ghats

The Indian peninsular region was believed to be the part of the Gondwana landmass and around 300 million years ago was occupying higher latitudes near to south pole. It got detached from the landmass and about 75 million years ago started drifting towards the northern direction in the Paleogene period. During this northern passage, it was subjected to various climatic stresses and volcanic eruptions which leads to the impoverishment of its flora (Sharma, 2000). Lakhnapal (1970) states that the presence of some southern hemisphere taxa recalls the pre-Cenozoic association between India and Gondwana continents of the south. The aggregation of conifers in the wet tropical forests left them exposed to the climatic changes that occurred in the late Cenozoic, and declines in diversity have happened since the Paleogene in all regions from which fossil records are found (Franco and Brea, 2015).

Bande (1992) reviewed the Paleogene vegetation of peninsular India based on the megafossils and found out elements resembling Podocarpaceae from different assemblages of Deccan intertrappean flora. Lakhnapal (1970) while discussing the tertiary flora of India suggests that the occurrence of certain southern hemisphere forms like *Podocarpus*, Proteaceae, Araucariaceae, and *Casuarina* were characteristic during the Mesozoic era and continued their existence into Cenozoic. *Podocarpus* declined slowly through the tertiary and the only species remained are *Podocarpus wallichianus* in southern India and *P.neriifolius* in eastern India. At the same time, Araucariaceae get completely eliminated from India. The elimination of other conifer species is attributed to their lesser competency with highly productive tropical angiosperms because of their inefficient xylem, poor photosynthetic rates, and leaves with single veins. All the conifers including *Nageia wallichiana* thrive in tropical forests are those which employ anatomical and structural changes to keep the leaves flattened or tiny shoots (Brodribb and Feild, 2008).

Farjon and Filer (2013) state that all the conifers in the Indian landmass that had Gondwanan affinities went extinct during its long journey because of the climate change or the disaster of the Latest Cretaceous Deccan Traps. The presence of *Nageia wallichiana* in south India is considered as the outcome of repopulation from Asian landmass because of the Indo Malayan connection of the species. It is considered to be the result of a westward dispersal that occurred from a population of *Nageia wallichiana* within its wide range to the east (Farjon, 2010).

2.4.4 Ecology

Nageia wallichiana is considered as the most truly tropical of all conifers in the world because of its occurrence from the sea level dipterocarp forests near the equator to montane forests thriving above 2100 m. Usually, the species have a distribution in the altitudinal range from 900-1500 m in India (Gupta *et al*., 2002) while in Vietnam the altitudinal range is specified as 500 m to 2100 m AMSL (Hiep *et al*., 2004). The species is seen in closed tropical evergreen broad-leaved forests and mixed submontane and montane forests with mean annual temperature $14\text{-}32^{0}$ C and annual rainfall above 1700 m. The ideal soil types as suggested by Hiep *et al*. (2004) is granite and silicate derived soils. In the lowland forests, the species is expected to have straight bole lifting its foliage into the top canopy (Farjon, 2010). The species is not considered as a long-lived emergent because of the usually slender boles and absence of buttresses. The bole height may reach 50 m and girth at breast height may be up to 1 m (Bourdillon, 1908; Gamble, 1915-1934). The growth of the species become stunted in certain conditions like in the edges of the peat swamps, in the mossy forests of the sandstone plateaus of Sarawak, and on the mountain cliffs with sand or clay between the rocks (Farjon, 2010). *Nageia wallichiana* is found to be more abundant in ‘kerangas’ (forests on leached sandy soils) than in close canopy rainforests (Farjon and Filer, 2013).

Abhilash *et al*. (2005) consider it as a species of low ecological amplitude and with a specific ecological niche. Pascal *et al*. (2004) while describing the wet evergreen forest types of southern Western Ghats considered *Nageia wallichiana* as a better indicator of ecological conditions because of its narrow ecological amplitude along with *Bhesa indica*, *Cullenia exarillata*, *Dipterocarpus bourdilloni*, *D. indicus,* and *Gluta travancorica.* This species is considered characteristic of special facies in southern western Ghats which is termed as *Nageia wallichiana* facies by Pascal *et al*. (2004). This is a subtype of *Cullenia exarillata – Mesua ferrea – Palaquium ellipticum – Gluta travancorica* vegetation type (CMPG). Its distribution is restricted to the east side of the crest of the western ghats between 8^0 20′ N and 9^0 30′ N and an altitude above 1000 m.

Abhilash and Menon (2009) studied the distribution pattern of trees in natural habitats *Nageia wallichiana* and from the ratio of abundance to the frequency, find out that the species shows random distribution which is seen in the uniform environments according to Odum (1971). The floristic studies by Abhilash and Menon (2009) show that the natural habitats of this species harbor a large number of rare, endemic and threatened plants.

2.4.4.1 Tree Associations

In Vietnam, the species is found associated with *Dacrycarpus imbricatus*, *Cephalotaxus mannii*, *Podocarpus neriifolius,* and *Taxus wallichiana* (Hiep *et al*., 2004). In Kerangas it is seen associated with conifers such as *Agathis* (Araucariaceae), *Dacrydium*, *Dacrycarpus, Falcatifolium falciforme*, and *Sundacarpus amarus* as well as certain angiosperms of the Myrtaceae family (Farjon, 2010).

In Southern China, it is seen in tropical forests dominated by *Castanopsis* and *Quercus* on hillsides and not in mountains of high elevation. In New Guinea, it is often associated with *Araucaria* and *Podocarpus* in mixed conifer forests, which also have members of the Fagaceae family, especially in the genus *Castanopsis* (Farjon, 2010).

Abhilash and Menon (2004) found the dominant species in natural *N. wallichiana* habitats as *Palaquium ellipticum*, *Cullenia exarillata*, *Gomphandra coriaceae*, *Meiogyne pannosa,* and *Mesua ferrea.* The study showed a low dominance of *Nageia wallichiana* in its habitats but as an established species in the community. Pascal *et al*. (2004)

identified other tree species characteristic of *Nageia wallichiana* facies in the southern Western Ghats as *Diospyros atrata*, *Elaeocarpus venustus*, *Eugenia floccosea*, *Aglaia bourdillonii*, *Actinodaphne campanulata*, and *Syzygium microphyllum*. An endemic palm, *Bentinckia conddapanna* is also identified in the various natural habitats of *N. wallichiana* (Augustine, 2000; Pascal *et al*., 2004).

2.4.4.2 Regeneration

Akkarasedthanon *et al*. (2017) suggest that the success of regeneration in conifers requires success in each stage of the life cycle consisting of pollination, seed dispersal, seed germination, and seedling survival. They studied the factors affecting the regeneration of four Podocarpaceae members including *Nageia wallichiana*. The depth of soil is identified as the most supportive character in the regeneration of *N. wallichiana*. A positive relationship was found between the amount of soil nitrogen, the slope of the area, the depth of the soil, and the occurrence of saplings of the species. Another interesting finding was that the sapling occurrence increased with the amount of soil phosphorous in *N. wallichiana* while for all the other three species it showed a decline. Hiep *et al*. (2004) state that the regeneration of *N. wallichiana* is occasional and seedlings are rare in Vietnam.

In the study conducted by Abhilash *et al*. (2005) in Goodrical reserve forests of southern Western Ghats, *N. wallichiana* showed a high regeneration status and found abundant in the young seedling stage. But a high mortality rate is seen for the species from unestablished to the established stage. Augustine (2000) identified a viable proportion of regeneration of *N. wallichiana* to the south of the Mlappara region of Periyar tiger reserve due to the presence of a large number of seedlings. Sundarapandian and Swamy (1999) during the litter dynamics study in Kodayar identified the presence of seedlings in that area.

Antony and Mohanan (2010) compared the ex-situ conservation methods for this species and find out the vegetative propagation through tip cuttings without applying rooting hormones as the successful method of multiplication of the species. The ideal potting mixture for the species is found to be humus-rich soil: river sand: dried cow dung in the ratio 1:1:1.

2.4.5 Edaphic characters of natural habitats

Even though the studies on edaphic attributes of *Nageia wallichiana* growing habitats are very few, some studies concentrate on the soil properties of conifer and Podocarp habitats. Brodribb and Hill (1998) suggested that the distribution of conifers are constrained by their drought tolerance capabilities and the available soil moisture content. Warde *et al*. (2008) give possible reasons for higher organic carbon content in the soils of natural habitats of conifers including the genus *Nageia*. He suggested that the fibrous leaves of Podocarps are slow in decomposition and it results in the accumulation of organic matter in the soil and will leads to a higher organic carbon percent and an increased ratio of carbon to phosphorous.

The Podocarps are known to be restricted to the poor soils with low nutrients because of its adaption to acquiring and retaining nutrients to a higher degree (Coomes and Bellingham, 2010). According to Aerts (1995), the plants in Podocarps groups salvage only about 50% of nitrogen and 60% of phosphorus from leaves during abscission. From the above-mentioned factors, the podocarp growing soils are identified as low in nitrogen and Phosphorus content.

Akkarasedthanon *et al*. (2017) studied the various edaphic factors affecting the occurrence of saplings of four different Podocarpaceae members in which one of them was *Nageia wallichiana*. The presence of *Nageia wallichiana* was found increasing with lower pH levels. The species was positively correlated with the depth of soil too. According to Akkarasedthanon *et al*. (2017), *Nageia wallichiana* was seen more frequently in soils with higher organic carbon content as well as higher nitrogen.

2.4.6 Uses

Nageia wallichiana is considered as a timber tree with highly valuable wood, particularly where it grows into straight, tall trees with a clear long bole. It is traded as Podocarp wood. Long timber is sawn into planks primarily for house construction. Other wood uses include veneer, plywood, furniture making, interior finishing, and often the construction of small canoes in areas like Fly River, Wagu, and Papua New Guinea. Short stems are utilized for making household utensils (Farjon, 2010)

According to Hiep *et al*. (2004), the wood is highly appreciated for musical instruments, fine crafts, chopsticks, and household instruments. The leaves are used for cough as a conventional remedy in Vietnam, and the tree is considered as highly ornamental. Pandey *et al.* (2009) report the ethnomedical use of *N.wallichiana* leaves in the Andaman-Nicobar Islands. The decoction of leaves is taken orally for curing joint pains by Nicobarese. Bourdillon (1908) also suggests that the timber is good but reports that it is not used in Travancore.

2.4.7 Threats

According to the IUCN conservation strategy, *Nageia wallichiana* is a Least Concern (LC) species because of its widespread nature. Its population shows a decreasing trend in the case of mature individuals. The total population size of this species is not known and it is likely to have declined due to large-scale habitat loss. The population is found to be severely fragmented. The global threats include the cultivation of annual and perennial non-timber crops and wood and pulp plantations in the natural habitats. Logging and wood harvesting are also endangering the survival of this species (Farjon, 2013). Globally there are no action recovery plans or systematic monitoring schemes for this species. According to Hiep *et al*. (2004), the threats to the species in Vietnam include the conversion of land for agricultural purposes as well as logging.

The national status of *N. wallichiana* in Vietnam is revised and listed as Vulnerable (Hiep *et al*., 2004; Ke Loc *et al*., 2007). The conservation status of the species in India is 'Endangered'(EN) according to ENVIS center on floral diversity.

Bourdillon (1908) and Gamble (1915-1934) consider it as a rare species in the Western Ghats. Earlier, a large number of trees are expected to be felled under the name of *Mesua ferrea* for timber (Nair, 1991) and some were also felled for making railway sleepers and packing materials (Antony and Mohanan, 2010). According to Nair (1991), no special protection measures are suggested for this threatened tree in its natural habitats in the Western Ghats rather than excluding it from felling for timber.

2.5 SOIL PROPERTIES RELATED TO FLORISTIC COMPOSITION

The soil characters of a forest ecosystem significantly influence the vegetation type prevailing in that area and the vegetation, in turn, affects the soil characters as well. The forest stands with different species composition plays an influential role in maintaining the litter quality in forest floor and amount of root exudates to the soil (Chandra *et al*., 2016). In the end, this difference causes a divergence in soil properties. According to Barton *et al*. (2007), the naturally regenerated forests are considered as superior in soil quality than the artificial forest plantations and secondary forests.

2.5.1 Soil Bulk density

Plants respond to changes in bulk density by thriving at an intermediate density (Boone, 1986). Under very hard soil, water and nutrient absorption can become limiting, because roots have trouble penetrating the soil. Root length is not impaired in very soft soil, but contact between the plant and the soil can be so poor that the movement of water and nutrients is reduced (Herkelrath *et al*., 1977; Kooistra *et al*., 1992). The disturbances in forest soils are found to increase the bulk density of soils (Kolka and Smidt, 2004). Soil density and porosity are the two most important parameters when measuring anthropogenic soil changes (Hao *et al*., 2006).

A recent study by Subhasree *et al*. (2019) calculated the bulk density of soil samples collected from Kanyakumari Wildlife Sanctuary and the values estimated were 1.59 and 1.32 respectively for evergreen and semi-evergreen forests respectively. Rahman *et al.* (2012) estimated the bulk density of semi-evergreen forests of the Nilambur area at 1.6. In the disturbed forest soils of Bandipur national park, the estimated bulk density value is 1.38 (Mehta *et al*., 2008)

2.5.2 Soil moisture content

Water in the soil serves both as a lubricant and as a binding agent between soil particulate matter, thereby influencing the structural integrity and strength of the soil and geological materials. Biological production from the forest as well as agricultural soils is mainly affected by the moisture content of soils (Topp *et al*., 2006). Measuring the soil moisture content is then specifically important for quantifying the water balance, determining the plant water status, and characterizing certain physical, chemical, and biological processes in the soil.

Soil moisture content is found to be higher in intact evergreen forests in comparison with those forests having canopy gaps and a higher degree of disturbances (Devagiri *et al*., 2016). The moisture content value obtained for forests with canopy gaps was 10.2 and for intact forests, it was 13.2. Rajesh *et al*. (1996) estimated the moisture content percent of forests of the Sholayar range at 19.21. A study conducted by Venkatesh *et al*. (2011) in the Uthara Kannada district of Western Ghats analyzed the changes in soil moisture content in different land covers. The study doesn’t find any significant difference in moisture content between different land covers but identified its influence with depth in forested areas.

2.5.3 Soil pH

For standard soil analysis, soil pH is one of the most basic and important measurements. Many soil chemical and biological reactions in balance with the soil particle surfaces are governed by the pH of the soil solution (Hendershot *et al*., 2006).

Many of the studies concentrating on the soil characters of forest vegetations of Western Ghats give details of soil pH. The pH range of soil in different evergreen forest formations of Western ghats is from 3.5 to 5.5. Rajesh *et al*. (1996) analyzed the soil characters of selection felled gaps of forests in the Sholayar range and estimated soil pH at 4.75. In the disturbed soils of Bandipur national park, the soil pH was estimated at 5.33 indicating highly acidic soil (Mehta *et al*., 2008). Giriraj *et al*. (2008) estimated the soil pH of medium elevation evergreen forests of the Kakachi area at 4.63. The soil pH value of the semi-evergreen forests of Nilambur is slightly higher and the recorded vale is 5.91 (Rahman *et al*., 2012). The study by Devagiri *et al*. (2016) recorded soil pH values of 5.64 and 5.62 for forests with canopy gaps and intact forests respectively.

2.5.4 Soil Organic Carbon

Forest soils are repositories of organic and inorganic sources of carbon. In a variety of types, carbonate comprises the inorganic portion of total carbon (TC), while the organic carbon (OC) portion is composed of a spectrum of organic molecules (Skjemstad and Baldock, 2006). The soil organic carbon is defined as the sum of all organic materials present on and within the soil (Stevenson, 1994; Baldock and Nelson, 1998). In the later definitions, Oades (1988) excluded charcoal and charred materials and MacCarthy *et al*. (1990) removed non-decayed plant and animal tissues, their partial products of decomposition, and live soil biomass from the context of organic carbon.

Knowing about the distribution and control of organic carbon fractions of soils in forests is important in assessing the dynamics of ecosystems (Sreekanth *et al*., 2013). It varies significantly under different forest categories. Sreekanth *et al.* (2013) studied the organic carbon content of soils in different forest ecosystems in Chinnar and the highest amount was obtained from shola forests while the minimum was in riparian forests. Subhasree *et al*. (2019) also came to similar conclusions that soil organic carbon varies greatly with different forest formations. The study found higher organic carbon content in the soils of tropical dry deciduous forests in comparison with tropical evergreen forests.

Devagiri *et al*. (2016) recorded soil organic carbon percent of 1.77 and 2.14 from the forests with canopy gaps and intact forests respectively. The soil organic carbon percent of the semi-evergreen forests of Nilambur was estimated at 2.3 by Rahman *et al*. (2012). The soil organic carbon percent recorded from different forest areas includes 1.14 from Kakachi forests (Giriraj *et al*., 2008), 2.44 from Bandipur national park (Mehta *et al*., 2008), and 3.44 from the Sholayar range (Rajesh *et al*., 1996).

2.5.5 Total Soil Nitrogen

Both types of inorganic and organic soil Nitrogen compose total soil Nitrogen. Inorganic Nitrogen comprises soluble forms, exchangeable NH_4, and non-exchangeable clay-fixed NH_4. Organic Nitrogen content contains various recognizable and unidentifiable types (Stevenson, 1986) and can be identified by the difference between total soil N and inorganic soil N content (Rutherford *et al*., 2006). Saynes *et al*. (2005) studied the nitrogen dynamics of Mexican forests in different successional stages and concluded that late-successional or primary forests have the lowest nitrogen pools and cycling. He suggested that the variations in N cycling between forests seem to reflect the aboveground N flux in litterfall and the relative importance of leguminous trees in the area.

The total nitrogen percent in forests of Western Ghats were recorded by various studies. Rahman *et al.* (2012) estimated the total nitrogen of semi-evergreen forests of Nilambur at 0.16 percent. The nitrogen percent of medium elevation evergreen forests of the Kakachi area was comparatively less and calculated at 0.017 percent. In the selection felled gaps of the Sholayar range, it was 0.35 percent (Rajesh *et al*., 1996). Total soil nitrogen percent in four different forest categories of the Sringeri area was in the range of 0.30 to 0.77 in which secondary evergreen forests have maximum total nitrogen content (Swamy and Proctor, 1994).

MATERIALS AND METHODS

The current study entitled “Ecological status of *Nageia wallichiana* (C.Presl.) Kuntze, an endangered conifer of the Western Ghats in Mankulam Forest Division” was undertaken to analyze the distributional status and regeneration of *Nageia wallichiana* in the Mankulam Forest Division. The study also investigated the floristic structure of its natural habitat as well as the edaphic characters of natural growing patches of this species.

3.1 STUDY AREA

Nageia wallichiana is a conifer species peculiar to mid-elevation tropical evergreen forests. The evergreen forests of Southern India is confined to the hilly areas of Western Ghats. The dense patches of wet evergreen forests are found on the Western side of the Western Ghats which extends up to the tip of the Ghats. Mankulam Forest division with an altitudinal range of 340 m to 1740 m above MSL which comes under the high range circle of Kerala is an ideal region for finding *Nageia wallichiana* (GoK, 2011).

3.1.1 Location

The study area, Mankulam Forest Division lies between 10^0 0’ and 10^0 10’ North Latitude and 76^0 50’ and 77^0 0’ East longitude. On the northern side, it has the Munnar forest range of Munnar territorial division, east and southern boundaries are shared with various tea estates and the western boundary runs along with the eastern boundary of the Adimaly range of Munnar division. The Mankulam Forest division has a total area of 9005.82 ha (22,253.37 acres) and it comprises of two ranges namely Mankulam and Anakkulam (GoK, 2011)

The vegetation in the division is a combination of west-coast tropical evergreen forests, southern tropical semi-evergreen forests, grasslands, southern montane wet temperate forests and ochlandra reed brakes. Among these forest types, the tropical evergreen forests and semi-evergreen forests provide ideal habitat for *Nageia* *wallichiana*. The present study aimed to reveal the floristic, as well as the edaphic attributes of this endemic species in the Mankulam forests of southern Western Ghats.

3.1.2 Climate

The temperature in the study area varies from 5^0C to 30^0C and the variation is mainly due to the altitude. The forests of the division receive rainfall from two distinct monsoons namely South-West Monsoon and North-East Monsoon. The rainfall regime is identified with a heavy rainfall period alternating with a dry season with occasional rains. During the winter season, mist and frost are common in the study area (GoK, 2011).

3.1.3 Geology and Soil

Rock formations of the Mankulam forest division are composed of gneiss of granite nature and often consist of feldspar, quartz, and biotite. Due to the moist tropical conditions of the area, the gneiss undergone metamorphism and reddish-brown coloured laterite is formed intermitted with small pockets of yellowish clay (GoK, 2011)

Four soil types are found in this region viz. a) Laterite b) Forest loam c) Red loams and d) Riverain alluvium. The rate of erosion is found to be very high and there is the least chance for the formation of thick laterite cappings.

3.1.4 Vegetation

Based on the classification of forest types of India which was revised by Chandrasekharan (1962) and Champion and Seth (1968), five forest types are seen in Mankulam Forest Division. They are (a) West coast tropical evergreen forests - 1A/C4; (b) West coast semi-evergreen forests - 2A/C2; (c) Grass Lands – 11A/C1/DS2; (d) Southern Montane Wet Temperate Forests – 11A/C1; and (e) Ochlandra reed brakes – 8A/E1.

3.1.4.1 West coast tropical evergreen forests - 1A/C4

This forest type occurs throughout the tropical parts of Southern India endowed with well-distributed rainfall. The mean annual temperature is about 27^0 C and the annual rainfall varies from 2000 mm to 3300 mm. The number of rainy days can vary from 118 to 150 (Champion and Seth, 1968). The major portion of the Mankulam Forest Division comes under this forest type and is characterized by the luxuriant growth of evergreen trees with varying sizes arranged in a vertical mixture (GoK, 2011). Some of the common trees seen in this area are *Canarium strictum, Mesua ferrea, Cullenia excelsa, Vateria indica, Palaquium ellipticum, Cinnamomum malabaricum, Elaeocarpus serratus, Myristica attenuate, Aporusa lindleyana,* and *Sterculia nobilis.*

3.1.4.2 West coast semi-evergreen forests - 2A/C2

This type of forest is generally found in the Western Ghats between the wet evergreen and moist deciduous types only as a narrow strip (Champion and Seth, 1968). In the Mankulam forest division, this type of forest is generally found in the over-exploited areas and the forests near to occupied land. These are high forests with closed canopy and a heterogeneous mixture of deciduous and evergreen species with a clear dominance of evergreen species in the lower storey. The overwood consists of *Hopea parviflora*, *Mesua ferrea*, *Vateria indica*, *Elaeocarpus tuberculatus*, *Hydnocarpus pentandra*, *Macaranga peltata*, *Cinnamomum malabatrum*, *Sterculia guttata* and *Aporusa lindleyana* (GoK, 2011).

3.2 SAMPLING METHOD

3.2.1 Preliminary Survey

A preliminary reconnaissance survey of the whole Mankulam forest division was conducted and previous working plans were studied to identify the patches of *Nageia wallichiana* trees so that the survey will take into account the spatial distribution. The preliminary survey was done by perambulating the forest patches where the *Nageia wallichiana* population is expected. The position of individual trees, as well as saplings, were recorded using GPS. A descriptive map was made using QGIS software and the patches were identified for further study.

3.2.2 Purposive Sampling

The present study employed purposive sampling which is a non-probability sampling technique in which the researcher himself is choosing a sample of units or subjects from a population (Etikan *et al*., 2016). As per the map prepared after the preliminary survey, the densely populated *Nageia wallichiana* habitats were purposively identified for the comprehensive study. The *N. wallichiana* growing patches were selected according to the presence of mature trees as well as the abundance of its regeneration both in seedling and sapling stages. The selected patches for data collection were Idathattu, Kannadipara, and Pullumala.

3.2.3 Laying out sample plots

Main plots of 20 m x 50 m were laid out covering 0.1 ha land area in the identified *Nageia wallichiana* growing patches including every possible mature tree of this species. From the various growing patches viz. Kannadipara, Idathattu, and Pullumala, a total of 6 plots were taken inside which measurements of trees were made.

Four subplots of 5 m x 5 m were laid out in four corners of each 50 m x 20 m plot for recording saplings. Nine nested plots of 1 m x1 m were laid on the opposite corners of subplots and also one at the center of the main plot for recording seedlings (Anitha *et al*., 2010).

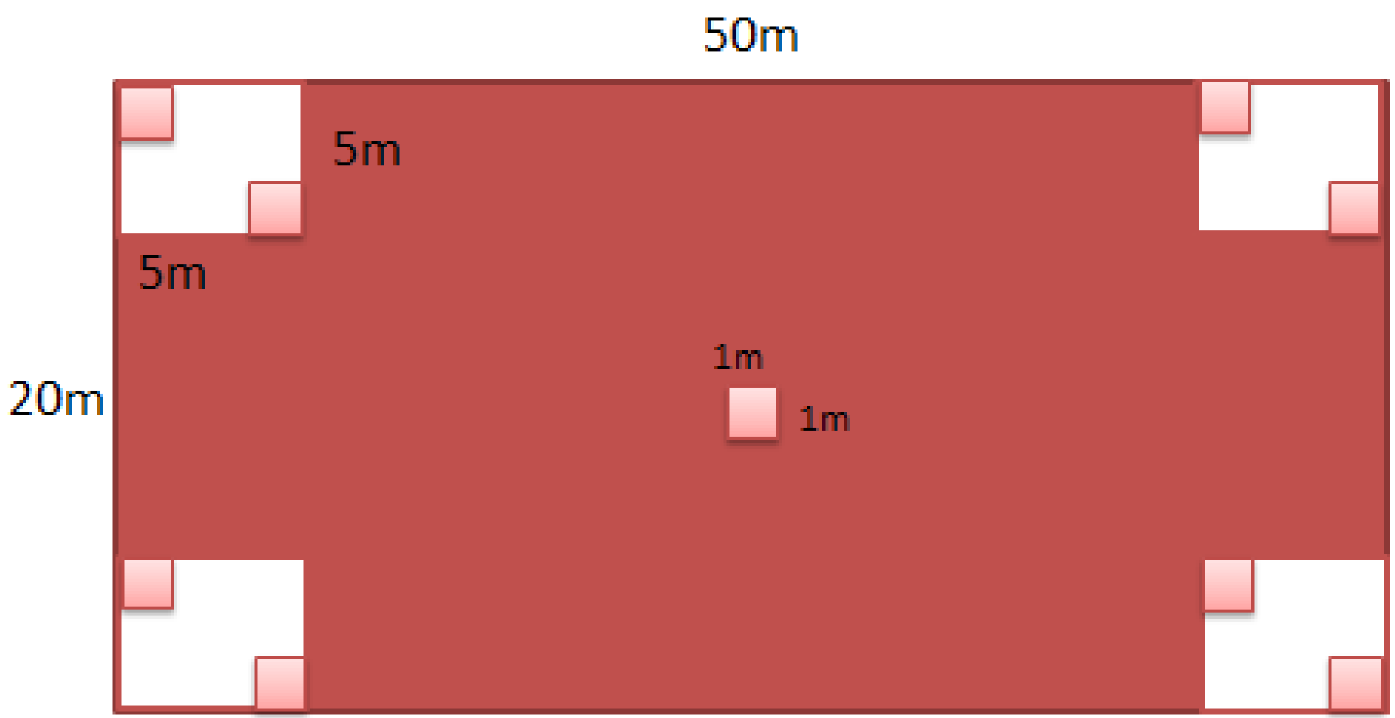

Plate 1. Layout of sample plots; 50 m x 20 m main plot for assessment of trees above 31 cm girth; 5 m x 5 m subplot for assessing saplings; 1 m x 1 m nested plot for assessment of seedlings.

3.2.4 Estimation of tree diversity

From the main plots of 20 m x 50 m, all the trees above 30.1 cm girth at breast height were identified and their GBH and height were recorded. The trees in the study area were identified using different software such as Kerala Trees (KFRI), Flowering plants of Kerala (KFRI), India Biodiversity portal and Western Ghats trees V.1.0 (BIOTIK) and standard floras such as Field Key to the identification of Indigenous Arborescent Species of Kerala Forests (Balasubramanyan *et al*., 1985), Forest trees of Kerala (Sasidharan, 2004) and A field key to the trees and lianas of the evergreen forest of the Western Ghats (Pascal and Ramesh,1987). Species names were updated with reference to The Plant List (Version 1.1, http://theplantlist.org).

3.2.5 Regeneration study

From the 5 m x 5 m subplots in the four corners of main plots, all trees with GBH ranging from 10.1 cm to 30.0 cm were considered and designated as saplings (Chandrasekhara *et al*., 1988). Their GBH were recorded and identified up to species level.

From the nine nested plots of 1 m x 1 m, all tree seedlings with a girth less than 10 cm and height less than 1m were identified up to species level and their girth was recorded (Chandrasekhara *et al*., 1988).

3.2.6 Collection of soil samples

From each main plot of 20 m x 50 m, two random topsoil samples each from 0-20 cm and 20-40 cm depth were collected for chemical and physical analysis.

3.2.7 Control plots

Twelve control plots of 10 m x 10 m were taken randomly outside the identified *Nageia wallichiana* growing patches in order to compare the species diversity as well as edaphic characteristics.

3.3 VEGETATION ANALYSIS

3.3.1 Phytosociological Analysis

Frequency, density, and abundance of individual species were recorded following Curtis and McIntosh (1950), separately for mature trees, saplings, and tree seedlings and the relative values were summed up to calculate the importance value index (Phillips, 1959). IVI was calculated separately for different growing patches and the result was compared. The phytosociological analysis was done as given below:

The density of a species (Ds) = $\frac{Total\ number\ of\ individuals\ of\ a\ species}{Total\ area\ of\ Quadrats\ studied}$

Frequency of a species (Fs) = $\frac{Number\ of\ quadrats\ in\ which\ a\ species\ occurs}{Total\ number\ of\ quadrats\ studied} \times 100$

The relative density of a species (RDs) = $\frac{Density (Ds) of\ a\ species}{Total\ density\ of\ all\ species} \times 100$

Relative frequency of a species (RFs) = $\frac{Frequency\ (Fs) of\ a\ species}{Sum\ of\ frequencies\ of\ all\ species} \times 100$

Relative dominance of a species (RBAFs) = $\frac{Total\ basal\ area\ of\ a\ species}{Total\ basal\ area\ of\ all\ species} \times 100$

IVI of a species (IVIs) = $RDs + RFs + RBAFs$

3.3.2 Analysis of tree diversity

Shannon–Wiener diversity index (Shannon and Weiner, 1963), Margalef richness index (Margalef, 1958), and Simpson index (Simpson, 1949) were calculated for understanding the diversity of *Nageia wallichiana* growing patches as well as the control plots. The indices were calculated for different patches separately in order to compare the different *Nageia wallichiana* growing patches in terms of diversity. The diversity indices were validated using PAST (PAleontological STatistics) software.

a) Shannon-Wiener diversity index = $\sum[pi \times \ln(pi)]$

b) Margalef Richness Index = $\sum_{i}[(\frac{ni}{N}\log_{10}(\frac{ni}{N})]$

c) Simpson Diversity Index = $\frac{\sum_{i} n_{i}(n_{i}-1)}{N(n-1)}$

Pi = proportion of total sample represented by species i

n_i - Number of individuals of the species i

N – Total number of individuals

3.3.3 Estimation of evenness

The evenness was calculated in terms of Pielou's Equitability Index (Pielou, 1969). It was done as below

Pilou's Equitability Index = $\frac{\sum_{i}[\frac{ni}{N}\ln\ (\frac{ni}{N})]}{N}$

ni - Number of individuals of the species i

N – Total number of individuals

3.3.4 Distribution pattern of the Species

The ratio of abundance to frequency was calculated to establish the distribution pattern of each species (Curtis and Cottom, 1956).

3.3.5 Similarity index

The similarity between plots taken in *Nageia wallichiana* growing areas and control plots was estimated using Sorenson's similarity index (Greig-Smith, 1983).

Sorensen index = $\frac{2a}{2a+b+c}$

Where,

a = number of species in both sites

b = number of species in the second site only

c = number of species in the first site only

3.3.6 Ecological distance between sites

The ecological distance between different plots was calculated in R studio using the BiodiversityR package. Bray-Curtis distance also known as Odum distance, or the one-complement of the Steinhaus similarity was used to analyse the differences in species composition (Kindt and Coe, 2005).

The commands used to perform the analysis are as follows.

```
> bray.distance <- vegdist(X,method=”bray”)

>bray.distance
```

In the commands, X is the species dataset. The ecological distances between similar and different plots were analysed using t-test in R. The commands used were

```
> var.test(X~Group)

> t.test(X~Group,var.equal=TRUE)
```

3.3.7 Cluster Analysis

Hierarchical clustering was done in the species dataset, X for analyzing the differences in species composition of the different plots. The commands used as per Kindt and Coe (2005) are:

```
distmatrix <- vegdist(X, method=’bray’)

distmatrix

Cluster.1 <- agnes(distmatrix, method=’single’)

summary(Cluster.1)
```

3.3.8 Ecological distance analysis by Ordination techniques

Different ordination methods including Principal component analysis (PCA) and Detrended correspondence analysis (DCA) were done in the species matrix to analyse the ecological distance and species assemblages. The PCA was done using the XLSTAT software of Microsoft. DCA was done in RStudio. The commands used are as follows (Kindt and Coe, 2005);

For DCA:

```
> decorana(X, type = “text”)
```

3.4 SOIL ANALYSIS

3.4.1 Estimation of soil pH

The collected soil samples from different plots and two different depths were first sieved using a sieve of 2 mm mesh size. A soil solution was prepared by adding 25 mL of water into 10 g soil and stirring the solution continuously for half an hour. The soil pH was estimated from this solution using a digital pH meter.

3.4.2 Estimation of soil organic carbon

The soil organic carbon content in various soil samples was determined by chromic acid wet oxidation methods suggested by Walkley and Black (1934). The oxidizable matter in the soil samples was first oxidized using a 1N $K_2Cr_2O_7$ solution. The remaining $K_2Cr_2O_7$ was then titrated with ferrous sulphate. The titrated value was used to estimate the organic carbon content of each soil sample.

3.4.3 Estimation of total nitrogen

The total nitrogen in the different soil samples was estimated following Micro-Kjeldahl Method (Piper, 1966). 0.2g oven-dried sample of soil was transferred to a digestion tube and 10ml of concentrated sulphuric acid was mixed with it in a digestion tube. Potassium sulphate and Copper sulphate in a ratio of 5:0.1g was used as the catalyst. After overnight digestion, the digestion tube was fitted into an auto analyzer. The nitrogen is liberated in the form of ammonia as the analyzer is adding alkali into the solution. Liberated ammonia is absorbed in boric acid and titrated with Bromocresol-green as an indictor which was used to final estimation of the amount of nitrogen in the sample.

3.4.4 Estimation of soil moisture content

The soil moisture content is estimated as the ratio of the mass of water held in the soil to the dry soil. The fresh weight of collected soil samples was taken as fast as possible after collection. The weighed samples are then oven dried for 48 hours at 110^0C. then the dry weight of soil was also measured accurately using an electronic weighing balance. From the recorded values, soil moisture content was estimated.

3.4.5 Estimation of Bulk Density

Soil bulk density is calculated as the ratio of the dried mass of soil to its total volume (Han *et al*., 2016). For estimating bulk density, a soil sample was collected using a core sampler. The fresh weight of the soil sample was estimated using an electronic weighing balance and then the soil was oven dried for 48 hours at 110^0 C. After drying, the soil sample was again weighed and recorded the values. The volume of the soil samples was obtained by measuring the size of the core sampler. The ratio of the dried mass and its total volume was calculated to find out the bulk density of different samples from each plot.

The dry soil bulk density (ρ_b) was calculated using the following formula:

$$\rho_b = \frac{Ms}{Vs}$$

Ms is the weight of dry soil sample in mg

Vs is the volume of the soil sample in m^3.

3.4.6 Relation of soil physio-chemical parameters with the species-site matrix using Canonical Correlation Analysis (CCA)

The relation of different soil physio-chemical parameters with the species site matrix was analyzed using Canonical Correlation Analysis (CCA) in XLSTAT software. The analysis was done using two different datasets containing species – site data and species- soil parameter data.

RESULTS

The current study was conducted during 2019-2020 to understand the ecological status of the only native conifer of the Western Ghats, *Nageia wallichiana* in the natural habitats of the Mankulam forest division. The results obtained from the study are given below.

4.1 DISTRIBUTION STATUS OF *NAGEIA WALLICHIANA* IN MANKULAM FOREST DIVISION

Mankulam Forest Division with an altitudinal range of 340 m to 1740 m above MSL comes under the high range circle of Kerala. The major forest types of the area are west coast tropical evergreen forests and west coast semi-evergreen forests. The preliminary survey in the division recognized four *Nageia wallichiana* growing patches in the study area (Table 1, Fig.1). The study recorded 24 mature trees (with girth >30 cm), 92 saplings (girth between 10 cm and 30 cm), and 130 seedlings of *N.wallichiana* from the four identified patches. The Kallar patch consists of the maximum number of individuals both in case of mature trees (14 individual trees) and regenerating individuals (141 individuals) while the Pullumala patch has the least number of individuals (4 individuals) of *Nageia wallichiana* (Table 1).

Table 1. *Nageia wallichiana* growing patches in Mankulam Forest Division

***N.wallichiana* growing patch**	**Altitude in meters (Mean)**	**Number of mature trees**	**Number of saplings and seedlings**
Kannadipara	1329	3	42
Idathattu	1430	5	39
Pullumala	1375	2	2
Kallar	1140	14	141

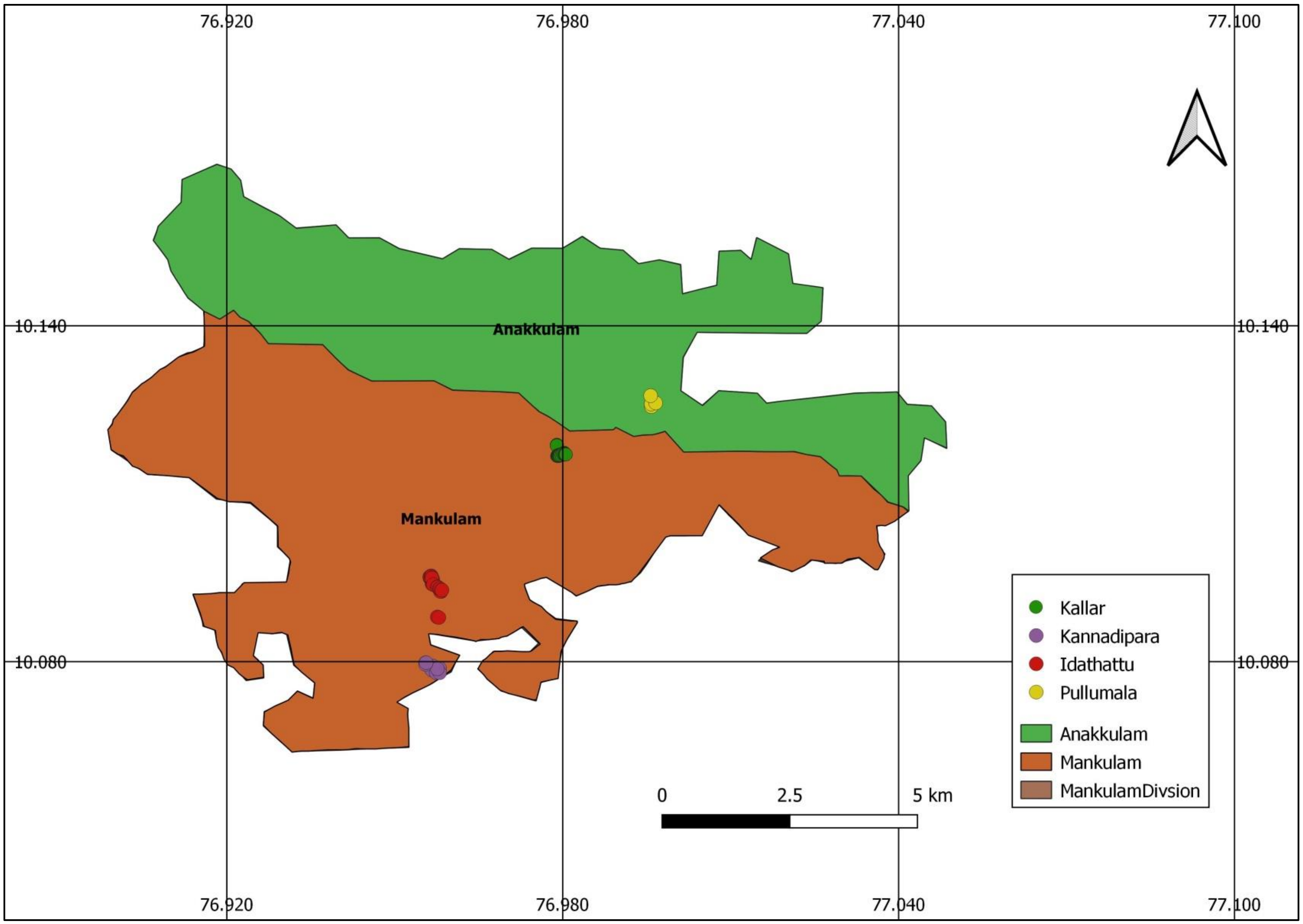

Figure 1. Map showing different *Nageia wallichiana* growing patches of Mankulam forest division

4.1.1 General description

Nageia wallichiana is known as Nirambali or Nilambali among the local people of Mankulam. Another local name recorded during the preliminary survey is 'Karadiyoori'. The maximum girth observed for the tree in the study area is 190 cm and the maximum height recorded is 22 m. The major identification features noted in *N.wallichiana* trees in the field include distinctive drooping of branches and leaves, dark green colour of leaves, absence of midrib, and flaking bark. The bark is mottled greyish brown in colour and peeling off as flakes. The bole has exceptional coolness in touching. Leaves are glabrous, oppositely, or suboppositely arranged with short petioles. Lamina long and narrow, tapered at both ends. Leaf apex is acute to acuminate. Young leaves are distinctly lighter in colour.

4.1.2 Girth distribution

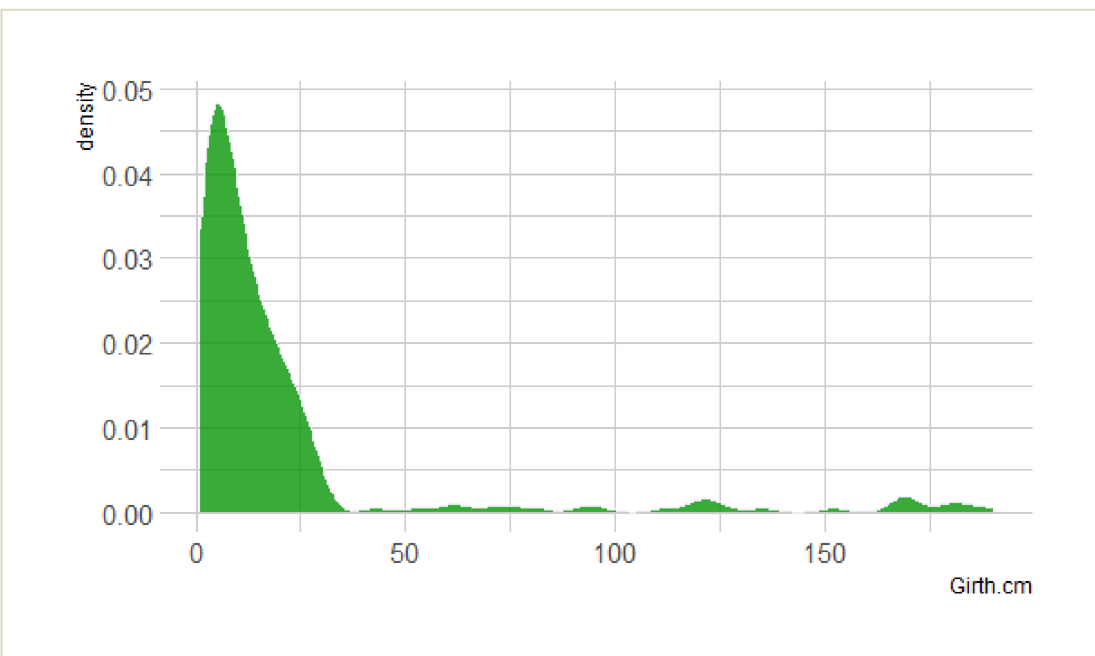

Figure 2. Girth distribution of *Nageia wallichiana* in the study area

The girth-class distribution of *N.wallichiana* trees in the study area (Fig.2) showed an inverse J-shaped curve in which 90.6 % of individuals are in girth class below 50 cm.

4.1.3 Altitudinal range

The minimum altitude in which the species was found is 934 m above MSL and the maximum altitude recorded was 1463 m above MSL (Fig.3). The mean altitude of distribution of *N.wallichiana* trees in the study area is 1224.89. The mean altitude of the Kannadipara, Idathattu, Kallar, and Pullumala patches is 1329 m, 1430 m, 1140 m, and 1375 m respectively (Table 1).

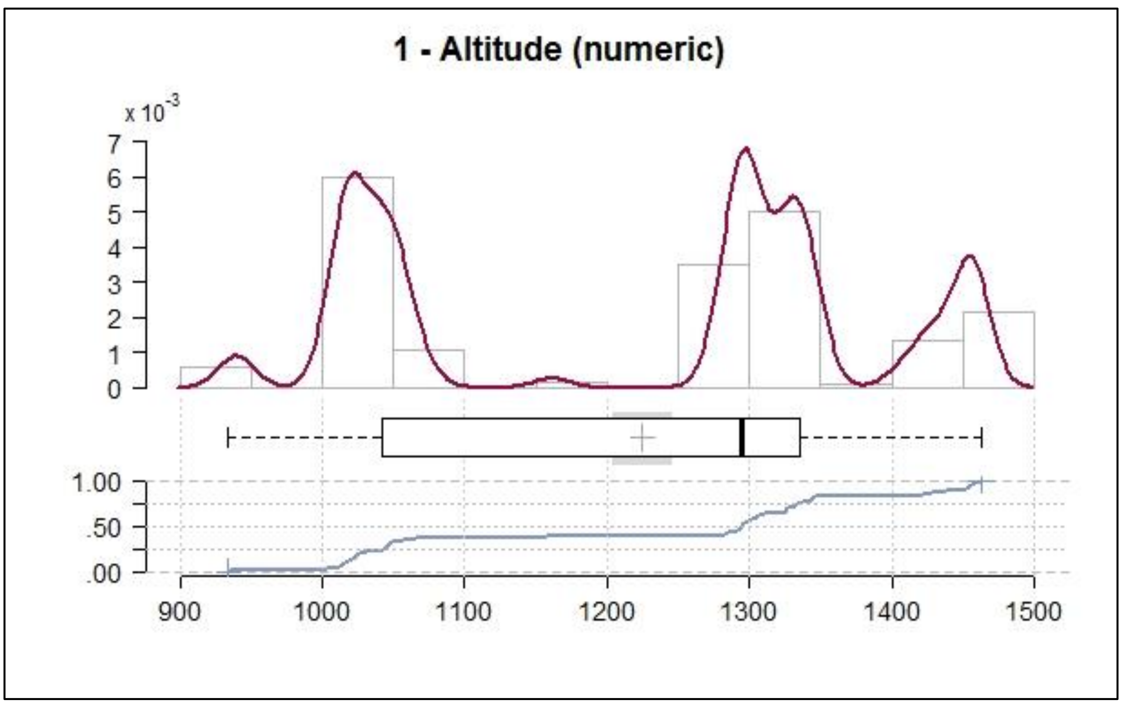

Figure 3. Altitudinal range of *N. wallichiana* in the study area

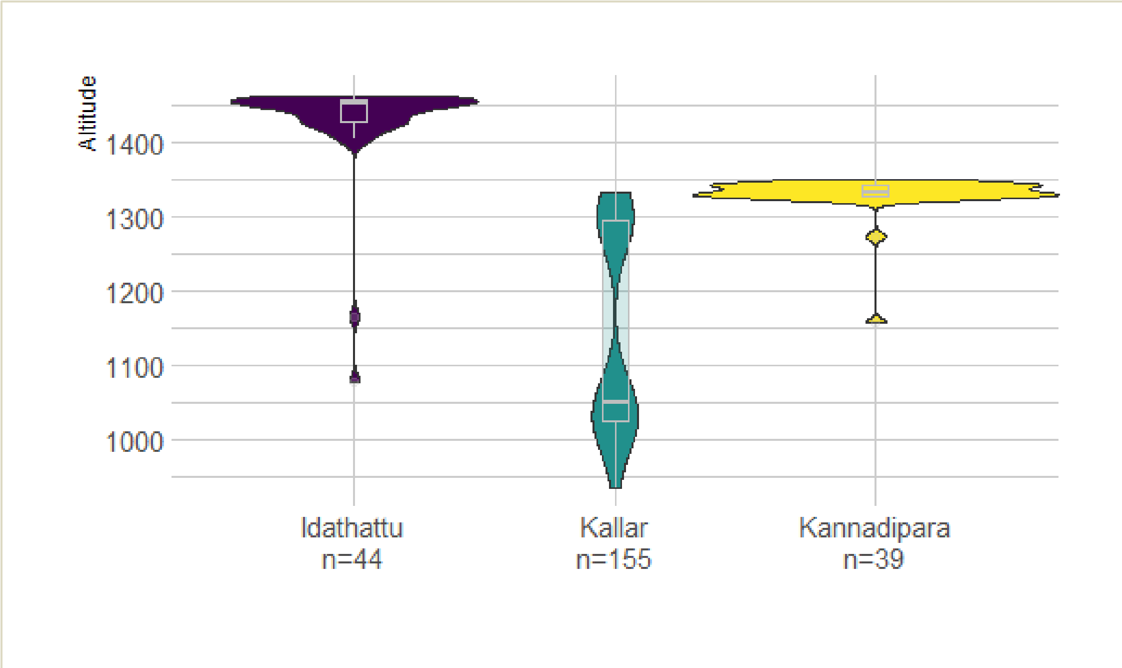

Figure 4. The Violin chart showing the altitudinal range of *N. wallichiana* in different patches.

The altitudinal distribution of *N. wallichiana* in different patches are distinct (Fig.4). Among the different patches, *N. wallichiana* is distributed in a higher altitude in the Idathattu patch followed by the Kannadipara patch. In the Kallar patch, the trees are distributed more or less uniformly in a comparatively lower altitude.

4.2 FLORISTIC COMPOSITION AND COMMUNITY STRUCTURE OF TREES IN THE STUDY AREA

The community structure and floristic composition were studied in *Nageia wallichiana* growing areas (NG) as well as areas without *Nageia wallichiana* (WNG). The data from *Nageia wallichiana* growing areas (NG) were taken from 6 main plots of 20 m x 50 m and data from areas without *Nageia wallichiana* (WNG) were taken from 12 plots of 10 m x 10 m.

4.2.1 Spatial structure of tree communities in NG

4.2.1.1 Girth distribution

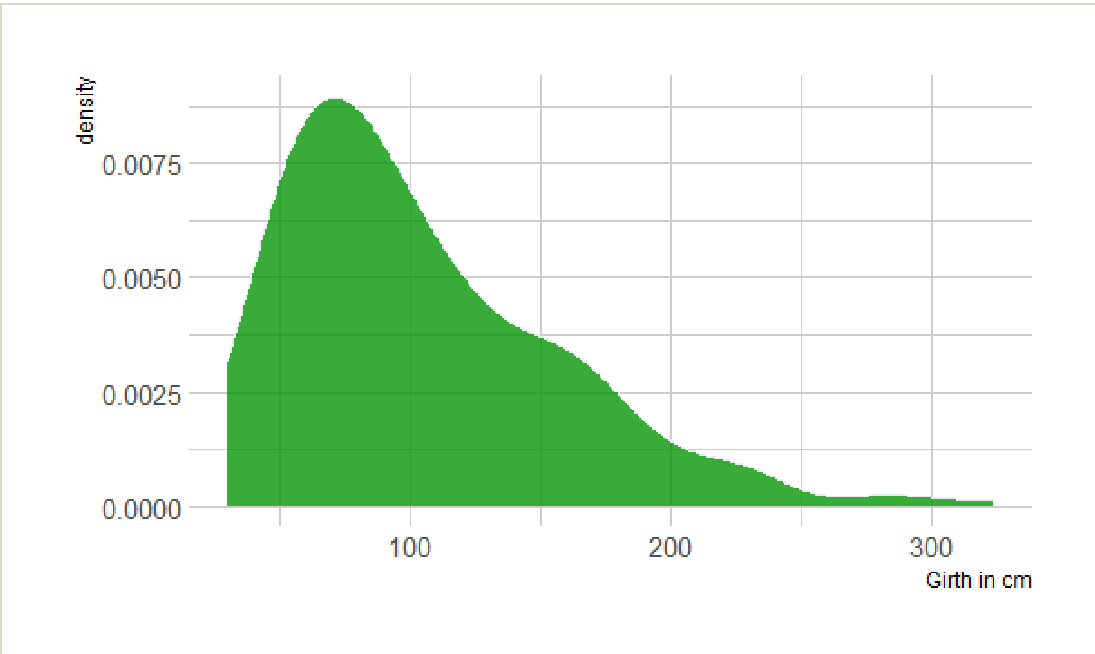

Figure 5. Girth distribution pattern of individual trees in NG

The girth classes for the total number of individual trees in NG plots showed a negatively skewed distribution. The maximum number of individuals are distributed in a range of 50 cm to 100 cm girth range and it accounts for 47.8 percent of the total individuals. The number of individuals with a girth higher than 200 cm is 11 which is just 5.8% of total individuals and the number of individuals in the lower girth classes (30 cm to 50 cm) is 19 which accounts for 10.1 percent of total individuals (Fig.5).

4.2.1.2 Density and Basal area

The total number of individuals recorded from 0.6 ha area of sample plots is 188 with a density of 313 individuals ha^{-1}. The basal area of trees in NG is at 30.53 m^2 ha^{-1} (Table 2).

4.2.2 Spatial structure of tree communities in WNG

4.2.2.1 Girth class distribution

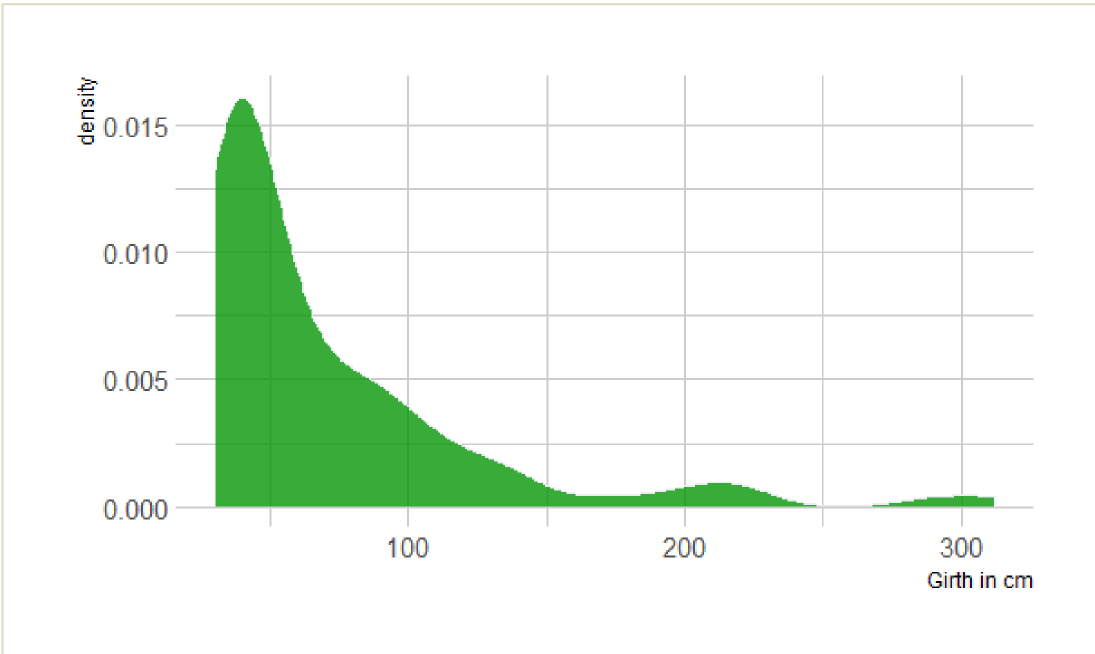

Figure 6. Girth distribution pattern of individual trees in WNG

The girth distribution pattern for the total number of individual trees in WNG is roughly inverse J-shaped (Fig.6). The number of individuals is maximum in the lower girth classes i.e., from 30 cm to 60 cm and this accounts for 61 percent of the total number of individuals. The number of individual trees with girth greater than 200 cm is only 5 which is 5.3 percent of total individuals.

4.2.2.2 Density and Basal area

The total number of individuals recorded from 0.12 ha area of sample plots in WNG is 94 with a density of 783.3 individuals ha^{-1}. The basal area of trees in WNG was estimated at 45.08 m^3 ha^{-1} (Table 2).

Table 2: Summary of tree density and basal area of NG and WNG plots

	Total number of Individuals	Tree Density (individuals $ha^{-1)}$	Total Basal area (m^2)	Basal area per ha ($m^2\ ha^{-1}$)
NG (0.6 ha)	188	313	18.32	30.53
WNG(0.12 ha)	94	783.3	5.41	45.08

4.2.3 Floristic structure of *Nageia wallichiana* growing areas (NG)

4.2.3.1 Floristic composition

From a total sampling area of 6000 m^2 (0.6 ha), 67 species of trees belonging to 28 different families were identified (Table 3). Among the 67 species, 9 species are endemic to Southern Western Ghats i.e. south of Palghat gap and 25 species are endemic to the Western Ghats. The conservation status of 8 species was found to be “Vulnerable’. *Beilschmiedia wightii* and *Syzigium caryophyllathum* are the Endangered tree species recorded from the area. The most abundant species in NG is *Mesua ferrea* with 11 individuals.

Table 3. Details of recorded tree species from NG

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
1	*Acronychia pedunculata*	NF	Rutaceae	NE	Not Endemic	Rao *et al*., 2019
2	*Actinodaphne bourdillonii*	Eeyoli, Malavirinji	Lauraceae	NE	Southern Western Ghats	Ramesh and Pascal, 1997
3	*Actinodaphne malabarica*	Kambilivirinji	Lauraceae	VU	Western Ghats	Ramesh and Pascal, 1997
4	*Actinodaphne tadulingamii*	NF	Lauraceae	Rare	Western Ghats	Ramesh and Pascal, 1997
5	*Agrostistachys borneensis*	Kozhivalan	Euphorbiaceae	NE	Not Endemic	Rao *et al*., 2019
6	*Aidia densiflora*	Meenkara	Rubiaceae	NE	Not Endemic	Rao *et al*., 2019
7	*Alseodaphne semecarpifolia*	Mulakunari	Lauraceae	NE	Not Endemic	Rao *et al*., 2019
8	*Aporosa lindleyana*	Vetti	Euphorbiaceae	NE	Not Endemic	Rao *et al*., 2019
9	*Artocarpus gomezianus*	Kattukadaplavu	Moraceae	NE	Not Endemic	Rao *et al*., 2019
10	*Artocarpus heterophyllus*	Plavu	Moraceae	NE	Not Endemic	Rao *et al*., 2019
11	*Beilschmiedia wightii*	Nagaramaram	Lauraceae	EN	Western Ghats	Ramesh and Pascal, 1997
12	*Bhesa indica*	Penali	Celastraceae	NE	Not Endemic	Rao *et al*., 2019
13	*Calophyllum apetalum*	NF	Clusiaceae	NE	Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019

(NF- Not Found; NE- Not Evaluated; VU- Vulnerable; EN – Endangered; LC – Least Concern)

Table 3 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
14	*Calophyllum astroindicum*	NF	Clusiaceae	NE	Southern Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
15	*Calophyllum calaba*	Cherupunna	Clusiaceae	NE	Not Endemic	Rao *et al*., 2019
16	*Calophyllum polyanthum*	Malampunna	Clusiaceae	NE	Not Endemic	Rao *et al*., 2019
17	*Casearia ovata*	Malampavatta	Flacourtiaceae	NE	Not Endemic	Rao *et al*., 2019
18	*Cinnamomum keralaense*	Karuva	Lauraceae	NE	Southern Western Ghats	Rao *et al*., 2019
19	*Cinnamomum malabatrum*	Ilavangam	Lauraceae	NE	Western Ghats	Rao *et al*., 2019
20	*Clerodendrum infortunatum*	Vatta-perivalam	Verbenaceae	NE	Not Endemic	Rao *et al*., 2019
21	*Croton laccifer*	Theppadi	Euphorbiaceae	NE	Not Endemic	Rao *et al*., 2019
22	*Cryptocarya wightiana*	NF	Lauraceae	NE	Western Ghats	Rao *et al*., 2019
23	*Cullenia exarillata*	Vediplavu	Malvaceae	VU	Western Ghats	Rao *et al*., 2019
24	*Dimocarpus longan*	Chempoovam	Sapindaceae	NE	Not Endemic	Rao *et al*., 2019

(NF- Not Found; NE- Not Evaluated; VU- Vulnerable; EN – Endangered; LC – Least Concern)

Table 3 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
25	*Diospyros atrata*	NF	Ebenaceae	VU	Southern Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
26	*Diospyros bourdillonii*	Karikkodal	Ebenaceae	NE	Western Ghats	Rao *et al*., 2019
27	*Diospyros nilagirica*	Karimthuvara	Ebenaceae	NE	Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
28	*Diospyros foliolosa*	Kattupanachi	Ebenaceae	NE	Southern Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
29	*Drypetes confertiflora*	Kaduvapidukkan	Euphorbiaceae	VU	Western Ghats	Rao *et al*., 2019
30	*Drypetes oblongifolia*	Malampayin	Euphorbiaceae	VU	Western Ghats	Rao *et al*., 2019
31	*Drypetes wightii*	Vellakasavu	Euphorbiaceae	VU	Southern Western Ghats	Rao *et al*., 2019
32	*Dysoxylum malabaricum*	Vellakil	Meliaceae	NE	Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
33	*Elaeocarpus tuberculatus*	Adraksham	Elaeocarpaceae	NE	Not Endemic	Rao *et al*., 2019

(NF- Not Found; NE- Not Evaluated; VU- Vulnerable; EN – Endangered; LC – Least Concern)

Table 3 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
34	*Garcinia pushpangadaniana*	NF	Clusiaceae	NE	Southern Western Ghats	Rao *et al*., 2019
35	*Gomphandra coriacea*	Kambilichedi	Icacinaceae	NE	Not Endemic	Rao *et al*., 2019
36	*Gordonia obtusa*	Kattukarana, Kattutheyila	Theaceae	NE	Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
37	*Harpullia arborea*	Chittilamadakku	Sapindaceae	NE	Not Endemic	Rao *et al*., 2019
38	*Hopea ponga*	Kambakam	Dipterocarpaceae	LC	Western Ghats	Rao *et al*., 2019
39	*Hydnocarpus alpina*	Pinervetty	Flacourtiaceae	VU	Not Endemic	Rao *et al*., 2019
40	*Hydnocarpus pentandrus*	Marotti	Flacourtiaceae	LC	Western Ghats	Rao *et al*., 2019
41	*Hymenodictyon orixense*	Perumtholi	Rubiaceae	NE	Not Endemic	Rao *et al*., 2019
42	*Isonandra lanceolata*	NF	Sapotaceae	NE	Not Endemic	Rao *et al*., 2019
43	*Isonandra perrottetiana*	Karimpala	Sapotaceae	VU	Southern Western Ghats	Rao *et al*., 2019
44	*Knema attenuata*	Kattu Jathikka	Myristicaceae	LC	Western Ghats	Rao *et al*., 2019

(NF- Not Found; NE- Not Evaluated; VU- Vulnerable; EN – Endangered; LC – Least Concern)

Table 3 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
45	*Lepisanthes tetraphylla*	Kalpoovathi	Sapindaceae	NE	Not Endemic	Rao *et al*., 2019
46	*Litsea coriacea*	Kanayooram	Lauraceae	NE	Western Ghats	Ramesh and Pascal, 1997
47	*Litsea floribunda*	Pattuthali	Lauraceae	NE	Western Ghats	Rao *et al*., 2019
48	*Litsea wightiana*	Manjakudala	Lauraceae	NE	Southern Western Ghats	Rao *et al*., 2019
49	*Macaranga peltata*	Vatta	Euphorbiaceae	NE	Not Endemic	Rao *et al*., 2019
50	*Mastixia arborea*	Kattukarppooram	Cornaceae	NE	Western Ghats	Rao *et al*., 2019
51	*Meliosma simplicifolia*	Chenthanam	Sabiaceae	NE	Not Endemic	Rao *et al*., 2019
52	*Memecylon malabaricum*	NF	Melastomataceae	NE	South India	Rao *et al*., 2019
53	*Memecylon umbellatum*	Kayampoomaram	Melastomataceae	NE	Not Endemic	Rao *et al*., 2019
54	*Mesua ferrea*	Churuli	Clusiaceae	NE	Not Endemic	Rao *et al*., 2019
55	*Nageia wallichiana*	Nirambali	Podocarpaceae	NE	Not Endemic	Rao *et al*., 2019
56	*Ormosia travancorica*	Malamanchadi	Fabaceae	NE	Western Ghats	Rao *et al*., 2019
57	*Palaquium ellipticum*	Pali	Sapotaceae	NE	Western Ghats	Rao *et al*., 2019

(NF- Not Found; NE- Not Evaluated; VU- Vulnerable; EN – Endangered; LC – Least Concern)

Table 3 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
58	*Reinwardtiodendron anamalaiense*	Cheeralam	Meliaceae	NE	Western Ghats	Rao *et al*., 2019
59	*Schefflera racemosa*	NF	Araliaceae	NE	Western Ghats	Rao *et al*., 2019
60	*Schleichera oleosa*	Poovam	Sapindaceae	NE	Not Endemic	Rao *et al*., 2019
61	*Syzygium caryophyllatum*	Cherunjara	Myrtaceae	EN	Not Endemic	Rao *et al*., 2019
62	*Syzygium hemisphericum*	Venjara	Myrtaceae	NE	Not Endemic	Rao *et al*., 2019
63	*Syzygium malabaricum*	Kattuchamba	Myrtaceae	NE	Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
64	*Turpinia cochichinensis*	Kanali	Staphyleaceae	NE	Not Endemic	Rao *et al*., 2019
65	*Turpinia malabarica*	Pambaravetti	Staphyleaceae	NE	Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
66	*Vateria indica*	Vellappain	Dipterocarpaceae	LC	Western Ghats	Ramesh and Pascal, 1997; Rao *et al*., 2019
67	*Vernonia arborea*	Malanperuva	Asteraceae	NE	Not Endemic	Rao *et al*., 2019

(NF- Not Found; NE- Not Evaluated; VU- Vulnerable; EN – Endangered; LC – Least Concern)

4.2.3.2 Relative Importance of species in NG

Table 4. IVI values of different tree species in NG

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	RFs	BA	RBAs	IVI
1	*Cullenia exarillata*	0.053	0.11	16.67	5.32	0.50	2.73	2.23	12.19	20.24
2	*Mesua ferrea*	0.059	0.12	18.33	5.85	0.50	2.73	1.19	6.48	15.06
3	*Bhesa indica*	0.048	0.05	15.00	4.79	1.00	5.46	0.84	4.61	14.85
4	*Calophyllum calaba*	0.032	0.05	10.00	3.19	0.67	3.64	1.05	5.71	12.54
5	*Palaquium ellipticum*	0.037	0.07	11.67	3.72	0.50	2.73	1.07	5.83	12.28
6	*Garcinia pushpangadaniana*	0.037	0.06	11.67	3.72	0.67	3.64	0.78	4.25	11.61
7	*Turpinia malabarica*	0.048	0.14	15.00	4.79	0.33	1.82	0.35	1.89	8.50
8	*Calophyllum astroindicum*	0.016	0.03	5.00	1.60	0.50	2.73	0.69	3.78	8.11
9	*Agrostistachys borneensis*	0.037	0.11	11.67	3.72	0.33	1.82	0.43	2.33	7.87
10	*Diospyros bourdillonii*	0.043	0.13	13.33	4.26	0.33	1.82	0.27	1.45	7.53
11	*Macaranga peltata*	0.032	0.06	10.00	3.19	0.50	2.73	0.19	1.03	6.95
12	*Syzygium hemisphericum*	0.016	0.05	5.00	1.60	0.33	1.82	0.62	3.38	6.79
13	*Litsea wightiana*	0.021	0.03	6.67	2.13	0.67	3.64	0.16	0.87	6.64
14	*Syzygium caryophyllatum*	0.021	0.04	6.67	2.13	0.50	2.73	0.32	1.77	6.63
15	*Elaeocarpus tuberculatus*	0.021	0.13	6.67	2.13	0.17	0.91	0.60	3.27	6.31

Table 4 continued

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	RFs	BA	RBAs	IVI
16	*Acronychia pedunculata*	0.027	0.05	8.33	2.66	0.50	2.73	0.15	0.81	6.20
17	*Actinodaphne bourdillonii*	0.016	0.05	5.00	1.60	0.33	1.82	0.35	1.90	5.31
18	*Knema attenuata*	0.011	0.03	3.33	1.06	0.33	1.82	0.43	2.35	5.23
19	*Calophyllum apetalum*	0.016	0.10	5.00	1.60	0.17	0.91	0.47	2.58	5.08
20	*Calophyllum polyanthum*	0.016	0.05	5.00	1.60	0.33	1.82	0.22	1.20	4.62
21	*Hopea ponga*	0.011	0.06	3.33	1.06	0.17	0.91	0.43	2.35	4.33
22	*Litsea coriacea*	0.016	0.05	5.00	1.60	0.33	1.82	0.15	0.81	4.22
23	*Drypetes confertiflora*	0.005	0.03	1.67	0.53	0.17	0.91	0.44	2.40	3.84
24	*Aporosa lindleyana*	0.016	0.05	5.00	1.60	0.33	1.82	0.05	0.30	3.71
25	*Hymenodictyon orixense*	0.011	0.06	3.33	1.06	0.17	0.91	0.21	1.14	3.11
26	*Aidia densiflora*	0.011	0.06	3.33	1.06	0.17	0.91	0.21	1.13	3.10
27	*Vernonia arborea*	0.016	0.10	5.00	1.60	0.17	0.91	0.11	0.60	3.10
28	*Clerodendrum infortunatum*	0.011	0.03	3.33	1.06	0.33	1.82	0.03	0.18	3.06
29	*Lepisanthes tetraphylla*	0.016	0.10	5.00	1.60	0.17	0.91	0.06	0.35	2.85
30	*Croton laccifer*	0.011	0.06	3.33	1.06	0.17	0.91	0.12	0.64	2.61

Table 4 continued

Sl No	Species	AB	AB/F	Ds	RDs	Fs	RFs	BA	RBAs	IVI
31	*Vateria indica*	0.011	0.06	3.33	1.06	0.17	0.91	0.11	0.61	2.58
32	*Dimocarpus longan*	0.005	0.03	1.67	0.53	0.17	0.91	0.19	1.04	2.49
33	*Harpullia arborea*	0.011	0.06	3.33	1.06	0.17	0.91	0.09	0.47	2.44
34	*Diospyros nilagirica*	0.011	0.06	3.33	1.06	0.17	0.91	0.08	0.42	2.39
35	*Schleichera oleosa*	0.005	0.03	1.67	0.53	0.17	0.91	0.17	0.93	2.37
36	*Drypetes oblongifolia*	0.011	0.06	3.33	1.06	0.17	0.91	0.07	0.38	2.35
37	*Litsea floribunda*	0.005	0.03	1.67	0.53	0.17	0.91	0.15	0.84	2.28
38	*Artocarpus gomezianus*	0.005	0.03	1.67	0.53	0.17	0.91	0.15	0.82	2.26
39	*Beilschmiedia wightii*	0.005	0.03	1.67	0.53	0.17	0.91	0.14	0.76	2.20
40	*Diospyros foliolosa*	0.005	0.03	1.67	0.53	0.17	0.91	0.13	0.71	2.15
41	*Casearia ovata*	0.011	0.06	3.33	1.06	0.17	0.91	0.03	0.15	2.12
42	*Palaquium bourdillonii*	0.005	0.03	1.67	0.53	0.17	0.91	0.12	0.68	2.12
43	*Schefflera racemosa*	0.005	0.03	1.67	0.53	0.17	0.91	0.12	0.64	2.08
44	*Turpinia cochichinensis*	0.005	0.03	1.67	0.53	0.17	0.91	0.10	0.55	2.00
45	*Dysoxylum malabaricum*	0.005	0.03	1.67	0.53	0.17	0.91	0.08	0.44	1.88

Table 4 continued

Sl No	Species	AB	AB/F	Ds	RDs	Fs	RFs	BA	RBAs	IVI
46	*Drypetes wightii*	0.005	0.03	1.67	0.53	0.17	0.91	0.08	0.42	1.86
47	*Reinwardtiodendron anamalaiense*	0.005	0.03	1.67	0.53	0.17	0.91	0.07	0.40	1.84
48	*Actinodaphne tadulingamii*	0.005	0.03	1.67	0.53	0.17	0.91	0.07	0.37	1.81
49	*Syzygium malabaricum*	0.005	0.03	1.67	0.53	0.17	0.91	0.07	0.37	1.81
50	*Actinodaphne malabarica*	0.005	0.03	1.67	0.53	0.17	0.91	0.06	0.35	1.79
51	*Meliosma simplicifolia*	0.005	0.03	1.67	0.53	0.17	0.91	0.06	0.34	1.78
52	*Alseodaphne semecarpifolia*	0.005	0.03	1.67	0.53	0.17	0.91	0.06	0.33	1.77
53	*Isonandra lanceolata*	0.005	0.03	1.67	0.53	0.17	0.91	0.05	0.29	1.73
54	*Memecylon talbotianum*	0.005	0.03	1.67	0.53	0.17	0.91	0.05	0.27	1.71
55	*Cinnamomum keralaense*	0.005	0.03	1.67	0.53	0.17	0.91	0.05	0.25	1.69
56	*Ormosia travancorica*	0.005	0.03	1.67	0.53	0.17	0.91	0.04	0.23	1.67
57	*Gomphandra coriacea*	0.005	0.03	1.67	0.53	0.17	0.91	0.04	0.22	1.66
58	*Mastixia arborea*	0.005	0.03	1.67	0.53	0.17	0.91	0.04	0.22	1.66
59	*Memecylon umbellatum*	0.005	0.03	1.67	0.53	0.17	0.91	0.04	0.21	1.65
60	*Hydnocarpus alpina*	0.005	0.03	1.67	0.53	0.17	0.91	0.04	0.21	1.65

Table 4 continued

Sl No	Species	AB	AB/F	Ds	RDs	Fs	RFs	BA	RBAs	IVI
61	*Gordonia obtusa*	0.005	0.03	1.67	0.53	0.17	0.91	0.04	0.20	1.64
62	*Cinnamomum malabatrum*	0.005	0.03	1.67	0.53	0.17	0.91	0.03	0.14	1.58
63	*Artocarpus heterophyllus*	0.005	0.03	1.67	0.53	0.17	0.91	0.02	0.14	1.58
64	*Hydnocarpus pentandrus*	0.005	0.03	1.67	0.53	0.17	0.91	0.02	0.12	1.56
65	*Cryptocarya wightiana*	0.005	0.03	1.67	0.53	0.17	0.91	0.01	0.08	1.52
66	*Diospyros atrata*	0.005	0.03	1.67	0.53	0.17	0.91	0.01	0.07	1.51

(AB – Relative abundance, Ds – Density of the species; RDs – Relative density of the species; Fs- Frequency of the species; RFs – Relative frequency of the species; BAs –Basal area of the species; RBA – Relative basal area of the species; IVI – Importance Value Index)

The dominant species of the area excluding *Nageia wallichiana* are *Cullenia exarillata* (IVI= 20.24), *Mesua ferrea* (IVI = 15.06), and *Bhesa indica* (IVI= 14.85) (Table 4). None of the species in the area showed an IVI above 50. The higher IVI value of *Cullenia exarillata* is attributed to it's higher basal area while that of *Mesua ferrea* both basal area and relative density have a roughly equal contribution (Fig.7). Among all the species, *Bhesa indica* has the highest frequency.

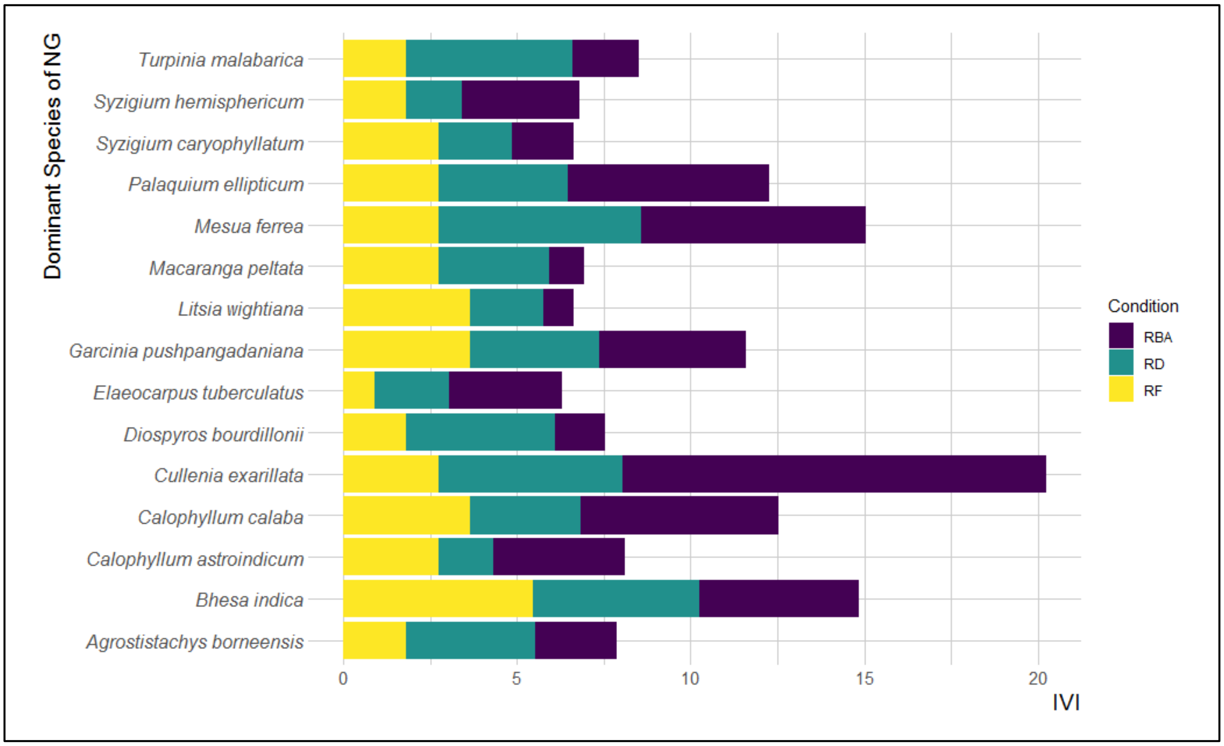

Figure 7. IVI distribution of most dominant tree species in NG

4.2.3.3 Relative Importance of families in NG

Table 5. IVI values of different plant families in NG

Sl No.	Family	Ds	RDs	Fs	RFs	BA	RBAs	IVI
1	Clusiaceae	55.00	17.55	1.00	8.00	4.40	24.12	49.67
2	Euphorbiaceae	36.67	11.70	1.00	8.00	1.37	7.52	27.22
3	Lauraceae	30.00	9.57	1.00	8.00	1.23	6.73	24.30
4	Malvaceae	16.67	5.32	0.50	4.00	2.23	12.25	21.57
5	Podocarpaceae	16.67	5.32	1.00	8.00	1.43	7.83	21.15
6	Celastraceae	15.00	4.79	1.00	8.00	0.84	4.63	17.42
7	Sapotaceae	15.00	4.79	0.50	4.00	1.24	6.83	15.61
8	Ebenaceae	20.00	6.38	0.67	5.33	0.49	2.66	14.38
9	Myrtaceae	13.33	4.26	0.50	4.00	1.01	5.55	13.80
10	Staphyleaceae	16.67	5.32	0.50	4.00	0.45	2.46	11.78
11	Sapindaceae	11.67	3.72	0.33	2.67	0.51	2.80	9.19
12	Dipterocarpaceae	6.67	2.13	0.33	2.67	0.54	2.97	7.77
13	Rutaceae	8.33	2.66	0.50	4.00	0.15	0.81	7.47
14	Rubiaceae	6.67	2.13	0.33	2.67	0.42	2.28	7.07
15	Elaeocarpaceae	6.67	2.13	0.17	1.33	0.60	3.29	6.75

Table 5 continued

Sl No.	Family	Ds	RDs	Fs	RFs	BA	RBAs	IVI
16	Myristicaceae	3.33	1.06	0.33	2.67	0.43	2.36	6.09
17	Flacourtiaceae	6.67	2.13	0.33	2.67	0.09	0.47	5.27
18	Meliaceae	3.33	1.06	0.33	2.67	0.17	0.85	4.58
19	Moraceae	3.33	1.06	0.33	2.67	0.15	0.53	4.26
20	Melastomataceae	3.33	1.06	0.33	2.67	0.09	0.48	4.21
21	Verbenaceae	3.33	1.06	0.33	2.67	0.03	0.18	3.91
22	Asteraceae	5.00	1.60	0.17	1.33	0.11	0.60	3.52
23	Araliaceae	1.67	0.53	0.17	1.33	0.12	0.63	2.50
24	Sabiaceae	1.67	0.53	0.17	1.33	0.06	0.34	2.20
25	Fabaceae	1.67	0.53	0.17	1.33	0.04	0.23	2.09
26	Cornaceae	1.67	0.53	0.17	1.33	0.04	0.22	2.08
27	Icacinaceae	1.67	0.53	0.17	1.33	0.04	0.22	2.08
28	Theaceae	1.67	0.53	0.17	1.33	0.04	0.19	2.06

(Ds – Density of the species; RDs – Relative density of the species; Fs- Frequency of the species; RFs – Relative frequency of the species; BAs –Basal area of the species; RBA – Relative basal area of the species; IVI – Importance Value Index)

The most dominant family in NG is Clusiaceae (IVI = 49.67) followed by Euphorbiaceae (IVI = 24.65) and Lauraceae (IVI = 24.30) (Table 5). Clusiaceae is the only family having an IVI greater than 30. Apart from this Euphorbiaceae, Lauraceae and Malvaceae have an IVI greater than 20 (Fig.8).

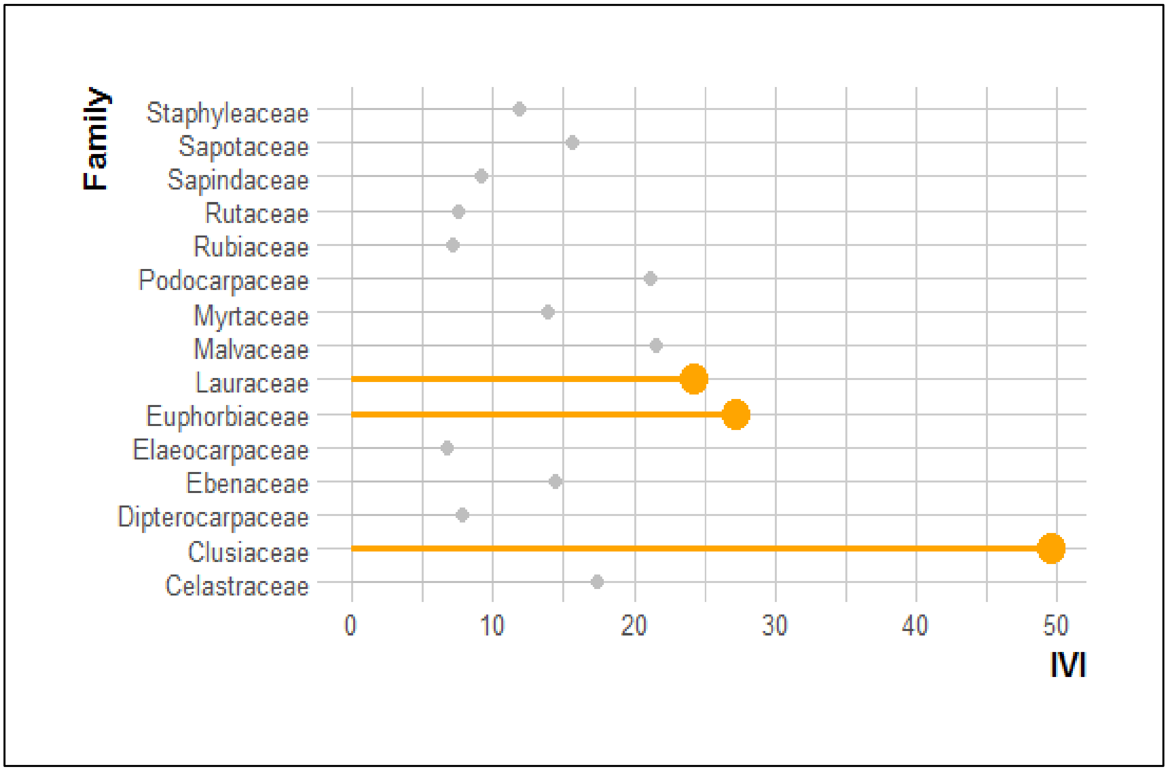

Figure 8. IVI values of dominant families of NG

4.2.3.4 Abundance-frequency ratio

Twenty-one different tree species in the study area showed an abundance-frequency ratio above 0.05. All other 46 tree species of the area have an abundance-frequency ratio in a range between 0.025 and 0.05 (Table 4).

4.2.4 Floristic structure of areas without *Nageia wallichiana* (WNG)

4.2.4.1 Floristic composition

Twelve plots of dimension 10 m x 10 m were selected from different localities where the presence of *Nageia wallichiana* was not identified in the Mankulam forest division. The plots were selected randomly across the division. From a total sampling area of 1200 m^2, 46 species of trees belonging to 25 different families were identified. Among the 46 species of trees, three species are endemic to the southern Western Ghats and 11 species are endemic to the Western Ghats region. Among the identified species, three were categorized as vulnerable and one is in the Endangered category. The most abundant species in WNG are *Gordonia obtusa* and *Vateria indica* (Table 6).

Table 6**.** Details of recorded tree species from WNG

Sl No	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
1	*Actinodaphne bourdillonii*	Malavirinji	Lauraceae	NE	Southern Western Ghats	Rao *et al*., 2019
2	*Alseodaphne semecarpifolia*	Mulakunari	Lauraceae	NE	Not Endemic	Rao *et al*., 2019
3	*Antidesma menasu*	Putharaval	Euphorbiaceae	NE	Not Endemic	Rao *et al*., 2019
4	*Artocarpus hirsutus*	Anjili	Moraceae	NE	Western Ghats	Ramesh and Pascal,1997; Rao *et al*., 2019
5	*Canarium strictum*	Kunthirikkam	Burseraceae	NE	Not Endemic	Rao *et al*., 2019
6	*Psydrax dicoccos*	Irumbarappan	Rubiaceae	VU	Not Endemic	Rao *et al*., 2019
7	*Cinnamomum camphora*	Karpuramaram	Lauraceae	NE	Not Endemic	Rao *et al*., 2019
8	*Cinnamomum malabatrum*	Illavangam	Lauraceae	NE	Western Ghats	Ramesh and Pascal,1997; Rao *et al*., 2019
9	*Clerodendron infortunatum*	Vattaperivalam	Verbenaceae	NE	Not Endemic	Rao *et al*., 2019
10	*Cryptocarya lawsonii*	Chembalamaram	Lauraceae	NE	Southern Western Ghats	Ramesh and Pascal,1997; Rao *et al*., 2019
11	*Cullenia exarillata*	Vediplavu	Malvaceae	VU	Not Endemic	Rao *et al*., 2019

(NF- Not Found; NE – Not Evaluated; VU – Vulnerable; LC – Least Concern)

Table 6 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
12	*Dillenia pentagyna*	Malampunna	Dilleniaceae	NE	Not Endemic	Rao *et al*., 2019
13	*Dysoxylum malabaricum*	Vellakil	Meliaceae	NE	Western Ghats	Ramesh and Pascal,1997; Rao *et al*., 2019
14	*Elaeocarpus serratus*	Bhadraksham	Elaeocarpaceae	NE	Not Endemic	Rao *et al*., 2019
15	*Elaeocarpus tuberculatus*	Adraksham	Elaeocarpaceae	NE	Not Endemic	Rao *et al*., 2019
17	*Ficus exasperata*	Therakam	Moraceae	NE	Not Endemic	Rao *et al*., 2019
18	*Ficus hispida*	Parakam	Moraceae	NE	Not Endemic	Rao *et al*., 2019
19	*Ficus virens*	Cherla	Moraceae	NE	Not Endemic	Rao *et al*., 2019
20	*Garcinia wightii*	Attukaruka	Clusiaceae	VU	Western Ghats	Ramesh and Pascal,1997; Rao *et al*., 2019
21	*Gordonia obtusa*	Kattukarana	Theaceae	NE	Western Ghats	Ramesh and Pascal,1997
22	*Hydnocarpus pentandrus*	Marotti	Flacourtiaceae	LC	Western Ghats	Rao *et al*., 2019
23	*Knema attenuata*	Kattu jathi	Myristicaceae	LC	Western Ghats	Rao *et al*., 2019
24	*Litsea bourdillonii*	NF	Lauraceae	NE	Western Ghats	Rao *et al*., 2019

(NF- Not Found; NE – Not Evaluated; VU – Vulnerable; LC – Least Concern)

Table 6 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
25	*Litsea coriaceae*	Kanayooram	Lauraceae	NE	Western Ghats	Rao *et al*., 2019
26	*Litsea floribunda*	Pattuthali	Lauraceae	NE	Western Ghats	Rao *et al*., 2019
27	*Litsea keralana*	NF	Lauraceae	NE	Southern Western Ghats	Rao *et al*., 2019
28	*Litsea wightiana*	Manjakudala	Lauraceae	NE	Western Ghats	Rao *et al*., 2019
29	*Macaranga peltata*	Vatta	Euphorbiaceae	NE	Not Endemic	Rao *et al*., 2019
30	*Madhuca longifolia*	Ilippa	Sapotaceae	NE	Not Endemic	Rao *et al*., 2019
31	*Madhuca neriifolia*	NF	Sapotaceae	EN	Not Endemic	Rao *et al*., 2019
32	*Maesa indica*	Kothamalli	Myrsinaceae	NE	Not Endemic	Rao *et al*., 2019
33	*Melicope lunu-ankenda*	Kanala	Rutaceae	NE	Not Endemic	Rao *et al*., 2019
34	*Meliosma pinnata*	NF	Sabiaceae	NE	Not Endemic	Rao *et al*., 2019
35	*Meliosma simplicifolia*	Chenthanam	Sabiaceae	NE	Not Endemic	Rao *et al*., 2019
36	*Mesua ferrea*	Churuli	Clusiaceae	NE	Not Endemic	Rao *et al*., 2019
37	*Myristica malabarica*	Chorapali	Myristicaceae	LC	Western Ghats	Rao *et al*., 2019
38	*Nothapodytes nimmoniana*	Peenari	Icacinaceae	NE	Not Endemic	Rao *et al*., 2019
39	*Olea dioica*	Edana	Oleaceae	NE	Not Endemic	Rao *et al*., 2019
41	*Palaquium ellipticum*	Pali	Sapotaceae	NE	Western Ghats	Rao *et al*., 2019

(NF- Not Found; NE – Not Evaluated; VU – Vulnerable; LC – Least Concern)

Table 6 continued

Sl No.	Name of species	Vernacular name	Family	Conservation status	Endemism	Reference
42	*Polyalthia fragrans*	Nedunar	Annonaceae	NE	Western Ghats	Ramesh and Pascal,1997; Rao *et al*., 2019
43	*Schleichera oleosa*	Poovam	Sapindaceae	NE	Not Endemic	Rao *et al*., 2019
44	*Sterculia guttata*	Thondi	Malvaceae	NE	Not Endemic	Rao *et al*., 2019
45	*Turpinia malabarica*	Pambaravetti	Staphyleaceae	NE	Western Ghats	Ramesh and Pascal,1997; Rao *et al*., 2019
46	*Vateria indica*	Vellappayin	Dipterocarpaceae	LC	Western Ghats	Rao *et al*., 2019

(NF- Not Found; NE – Not Evaluated; VU – Vulnerable; LC – Least Concern)

4.2.4.2 Relative importance of species

Table 7. IVI values of different tree species in WNG

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	RFs	Bas	RBAs	IVI
1	*Dysoxylum malabaricum*	0.04	0.13	33.33	4.26	0.33	5.41	1.641	30.32	39.98
2	*Vateria indica*	0.05	0.16	41.67	5.32	0.33	5.41	0.344	6.36	17.09
3	*Polyalthia fragrans*	0.01	0.13	8.33	1.06	0.08	1.35	0.670	12.37	14.79
4	*Myristica malabarica*	0.04	0.26	33.33	4.26	0.17	2.70	0.412	7.61	14.57
5	*Meliosma simplicifolia*	0.04	0.17	33.33	4.26	0.25	4.05	0.230	4.25	12.56
6	*Macaranga peltata*	0.03	0.13	25.00	3.19	0.25	4.05	0.167	3.09	10.33
7	*Elaeocarpus serratus*	0.03	0.19	25.00	3.19	0.17	2.70	0.207	3.82	9.71
8	*Gordonia obtusa*	0.05	0.21	41.67	5.32	0.25	4.05	0.013	0.24	9.61
9	*Clerodendron infortunatum*	0.04	0.17	33.33	4.26	0.25	4.05	0.060	1.10	9.41
10	*Canarium strictum*	0.04	0.17	33.33	4.26	0.25	4.05	0.056	1.03	9.33
11	*Litsea bourdillonii*	0.02	0.13	16.67	2.13	0.17	2.70	0.194	3.59	8.42
12	*Madhuca neriifolia*	0.03	0.38	25.00	3.19	0.08	1.35	0.196	3.63	8.17
13	*Mesua ferrea*	0.02	0.13	16.67	2.13	0.17	2.70	0.132	2.44	7.27
14	*Artocarpus hirsutus*	0.02	0.13	16.67	2.13	0.17	2.70	0.112	2.08	6.91
15	*Actinodaphne bourdillonii*	0.03	0.19	25.00	3.19	0.17	2.70	0.044	0.82	6.71
16	*Alseodaphne semecarpifolia*	0.03	0.19	25.00	3.19	0.17	2.70	0.036	0.67	6.57

Table 7 continued

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	RFs	Bas	RBAs	IVI
17	*Nothapodytus nimmoniana*	0.03	0.19	25.00	3.19	0.17	2.70	0.027	0.50	6.39
18	*Ficus hispida*	0.02	0.13	16.67	2.13	0.17	2.70	0.080	1.48	6.31
19	*Meliosma pinnata*	0.02	0.13	16.67	2.13	0.17	2.70	0.073	1.34	6.17
20	*Elaeocarpus tuberculatus*	0.02	0.13	16.67	2.13	0.17	2.70	0.057	1.06	5.89
21	*Cullenia exarillata*	0.02	0.26	16.67	2.13	0.08	1.35	0.107	1.98	5.46
22	*Hydnocarpus pentandra*	0.02	0.13	16.67	2.13	0.17	2.70	0.018	0.33	5.16
23	*Litsea keralana*	0.02	0.13	16.67	2.13	0.17	2.70	0.008	0.15	4.98
24	*Litsea wightiana*	0.02	0.26	16.67	2.13	0.08	1.35	0.029	0.53	4.01
25	*Cryptocarya lawsonii*	0.02	0.26	16.67	2.13	0.08	1.35	0.028	0.52	4.00
26	*Knema attenuata*	0.02	0.26	16.67	2.13	0.08	1.35	0.027	0.51	3.99
27	*Schleichera oleosa*	0.02	0.26	16.67	2.13	0.08	1.35	0.017	0.32	3.80
28	*Maesa indica*	0.02	0.26	16.67	2.13	0.08	1.35	0.016	0.29	3.77
29	*Turpinia malabarica*	0.01	0.13	8.33	1.06	0.08	1.35	0.070	1.30	3.72
30	*Sterculia guttata*	0.01	0.13	8.33	1.06	0.08	1.35	0.046	0.85	3.26
31	*Ficus virens*	0.01	0.13	8.33	1.06	0.08	1.35	0.045	0.83	3.24
32	*Melicope lunu-ankenda*	0.01	0.13	8.33	1.06	0.08	1.35	0.038	0.70	3.12
33	*Garcinia rubro-echinata*	0.01	0.13	8.33	1.06	0.08	1.35	0.034	0.62	3.04
34	*Oreocnide integrifolia*	0.01	0.13	8.33	1.06	0.08	1.35	0.033	0.60	3.02
35	*Psydrax dicoccos*	0.01	0.13	8.33	1.06	0.08	1.35	0.025	0.46	2.88
36	*Ficus exasperata*	0.01	0.13	8.33	1.06	0.08	1.35	0.018	0.32	2.74

Table 7 continued

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	RFs	Bas	RBAs	IVI
37	*Palaquium ellipticum*	0.01	0.13	8.33	1.06	0.08	1.35	0.017	0.31	2.73
38	*Antidesma menasu*	0.01	0.13	8.33	1.06	0.08	1.35	0.013	0.25	2.66
39	*Litsea floribunda*	0.01	0.13	8.33	1.06	0.08	1.35	0.013	0.25	2.66
40	*Dillenia pentagyna*	0.01	0.13	8.33	1.06	0.08	1.35	0.012	0.22	2.64
41	*Cinnamomum malabatrum*	0.01	0.13	8.33	1.06	0.08	1.35	0.012	0.22	2.64
42	*Cinnamomum camphora*	0.01	0.13	8.33	1.06	0.08	1.35	0.011	0.21	2.63
43	*Litsea coriaceae*	0.01	0.13	8.33	1.06	0.08	1.35	0.011	0.21	2.62
44	*Madhuca longifolia*	0.01	0.13	8.33	1.06	0.08	1.35	0.008	0.14	2.56
45	*Olea dioica*	0.01	0.13	8.33	1.06	0.08	1.35	0.004	0.08	2.49

(AB – Relative abundance; Ds – Density of the species; RDs – Relative density of the species; Fs- Frequency of the species; RFs – Relative frequency of the species; BAs –Basal area of the species; RBA – Relative basal area of the species; IVI – Importance Value Index)

The most dominant species in the area was *Dysoxylum malabaricum* with an IVI value of 39.98. The other dominant tree species were *Vateria indica* (17.09), *Polyalthia fragrans* (IVI = 14.79), *Myristica malabarica* (17.11), and *Meliosma simplicifolia* (14.57) (Table 7). The dominance of *Dysoxylum malabaricum* in the study area was mainly attributed to its higher basal area in comparison with other trees of the area. The presence of *Polyalthia fragrans* as the dominant species of the area is also because of its higher basal area. For *Vateria indica* and *Myristica malabarica*, density and frequency are also contributing to its IVI. Only 6 species in the area have an IVI greater than 10 (Fig.9)

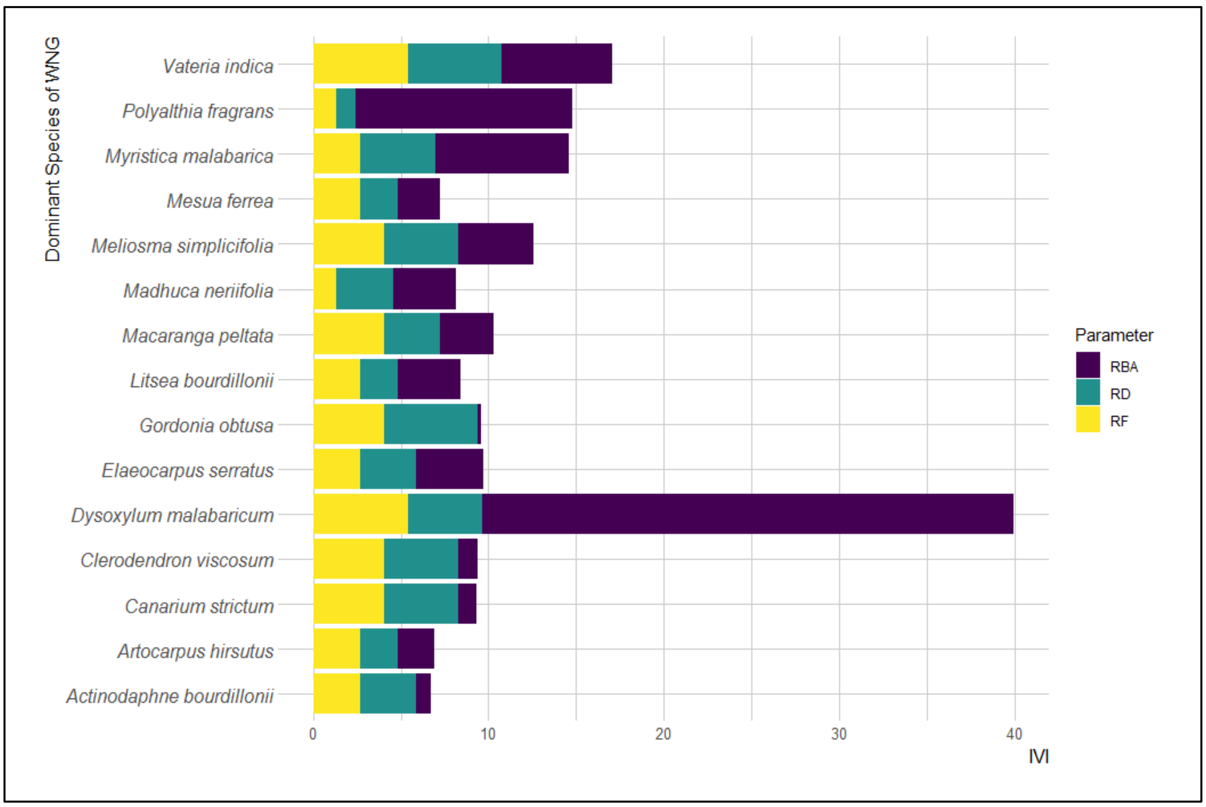

Figure 9. IVI distribution of most dominant tree species of WNG

4.2.4.3 Relative importance of families

Table 8. IVI values of different families of WNG

Sl No.	Family	Ds	RDs	Fs	RFs	BAs	RBAs	IVI
1	Meliaceae	33.33	4.26	0.33	6.15	1.641	31.47	41.87
2	Lauraceae	150.00	19.15	0.75	13.84	0.388	5.94	38.93
3	Sabiaceae	50.00	6.38	0.42	7.69	0.303	5.74	19.81
4	Myristicaceae	50.00	6.38	0.25	4.61	0.439	7.36	18.36
5	Dipterocarpaceae	41.67	5.32	0.33	6.15	0.344	6.60	18.07
6	Moraceae	50.00	6.38	0.33	6.15	0.255	4.75	17.28
7	Annonaceae	8.33	1.06	0.08	1.54	0.670	12.84	15.44
8	Elaeocarpaceae	41.67	5.32	0.25	4.61	0.264	4.86	14.79
9	Sapotaceae	41.67	5.32	0.25	4.61	0.221	3.72	13.65
10	Euphorbiaceae	33.33	4.26	0.25	4.61	0.181	3.25	12.12
11	Clusiaceae	25.00	3.19	0.25	4.61	0.166	3.10	10.91
12	Theaceae	41.67	5.32	0.25	4.61	0.013	0.25	10.18
13	Verbenaceae	33.33	4.26	0.25	4.61	0.060	1.14	10.01
14	Burseraceae	33.33	4.26	0.25	4.61	0.056	1.06	9.93
15	Malvaceae	25.00	3.19	0.17	3.08	0.153	2.93	9.20
16	Icacinaceae	25.00	3.19	0.17	3.08	0.027	0.52	6.79

Table 8 continued

Sl No.	Family	Ds	RDs	Fs	RFs	BAs	RBAs	IVI
17	Flacourtiaceae	16.67	2.13	0.17	3.08	0.018	0.34	5.55
18	Sapindaceae	16.67	2.13	0.08	1.54	0.017	0.33	4.00
19	Myrsinaceae	16.67	2.13	0.08	1.54	0.016	0.30	3.96
20	Staphyleaceae	8.33	1.06	0.08	1.54	0.070	1.35	3.95
21	Rutaceae	8.33	1.06	0.08	1.54	0.038	0.73	3.33
22	Urticaceae	8.33	1.06	0.08	1.54	0.033	0.63	3.23
23	Rubiaceae	8.33	1.06	0.08	1.54	0.025	0.48	3.08
24	Dilleniaceae	8.33	1.06	0.08	1.54	0.012	0.23	2.83
25	Oleaceae	8.33	1.06	0.08	1.54	0.004	0.08	2.68

(Ds – Density of the species; RDs – Relative density of the species; Fs- Frequency of the species; RFs – Relative frequency of the species; BAs –Basal area of the species; RBA – Relative basal area of the species; IVI – Importance Value Index)

The most dominant family of the area is Meliaceae (IVI = 41.87) followed by Lauraceae (IVI = 38.93) and Sabiaceae (IVI = 19.81) (Table 8). Only two families are having an IVI of more than 20. The different families showed much variation in IVI values. Most of the families are having IVI greater than 10 but less than 20 (Fig.10).

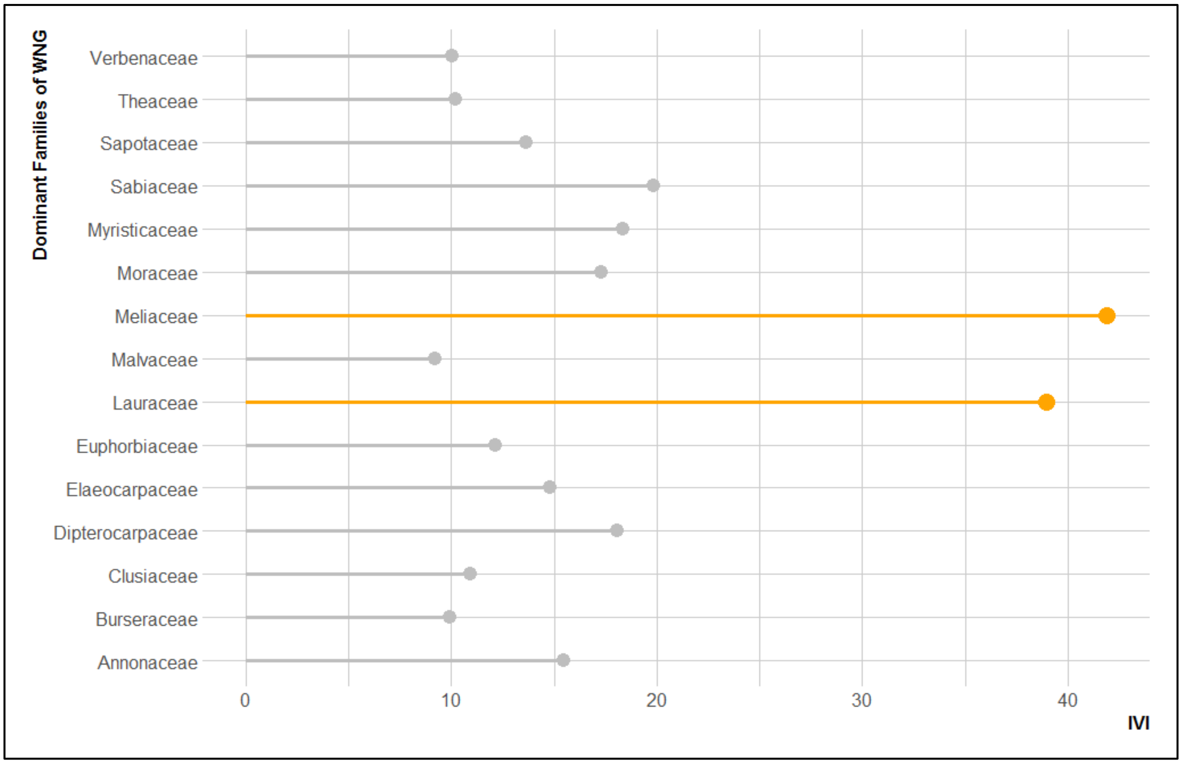

Figure 10. IVI values of dominant families of WNG

4.2.4.4 Abundance-frequency ratio

All the 45 species in WNG have an abundance frequency ratio greater than 0.05. The highest value of AB/F was obtained for *Madhuca neriifolia* (Table 7).

4.2.5 Percentage composition of endemic trees in NG and WNG

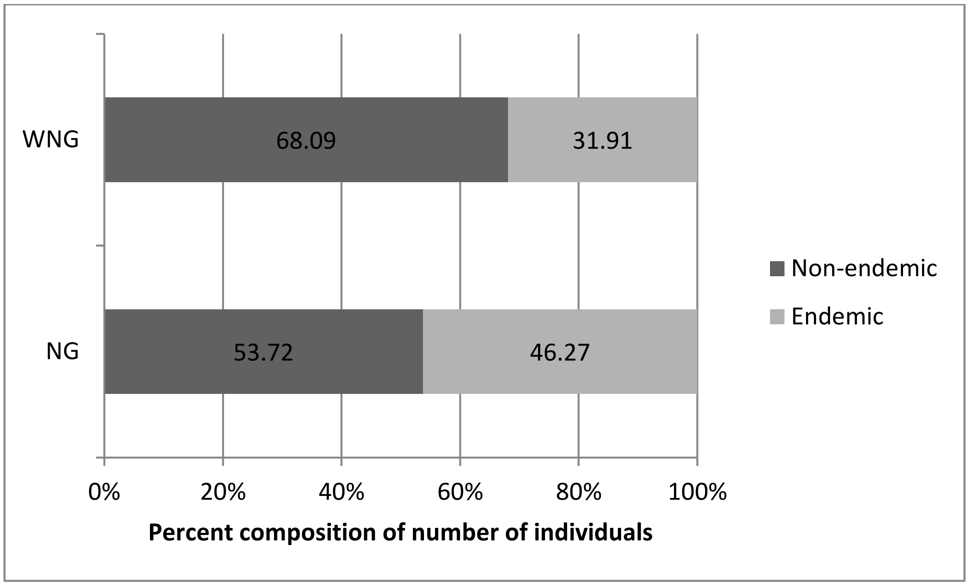

Figure 11. Percentage composition of endemic trees in the total number of individuals of NG and WNG

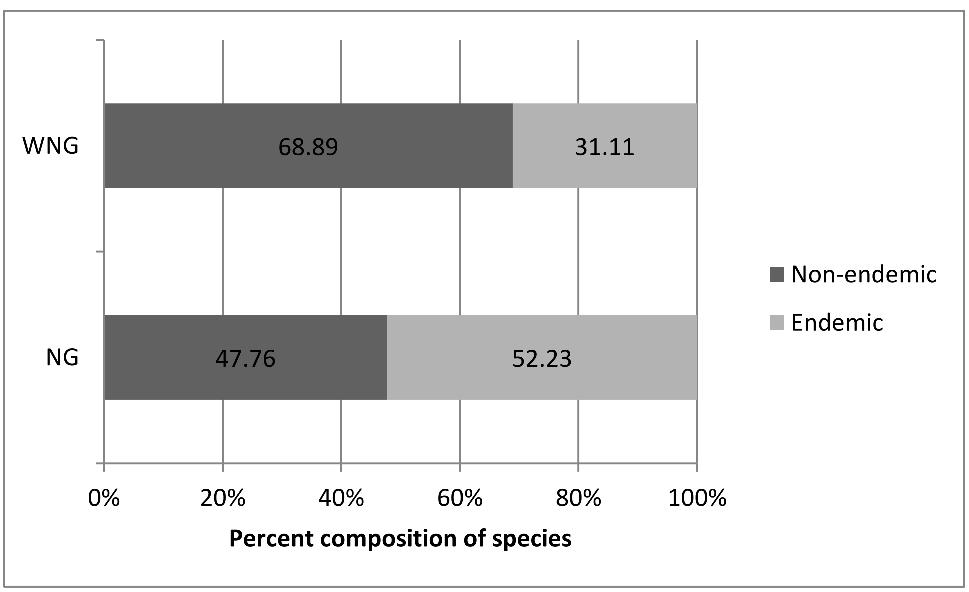

Figure 12. Percentage composition of endemic tree species in NG and WNG

Considering the total number of individuals, NG has the maximum proportion of endemic trees which accounts for 46.72 percent. For WNG, the proportion of endemic trees are 31.91 percent of the total number of individuals (Fig.11).

Comparing the composition of endemic tree species in NG and WNG, NG had 52.23 percent of total species as endemic and WNG had 31.11 percent of total species as endemics (Fig.12).

4.2.6 Composition of threatened trees in NG and WNG

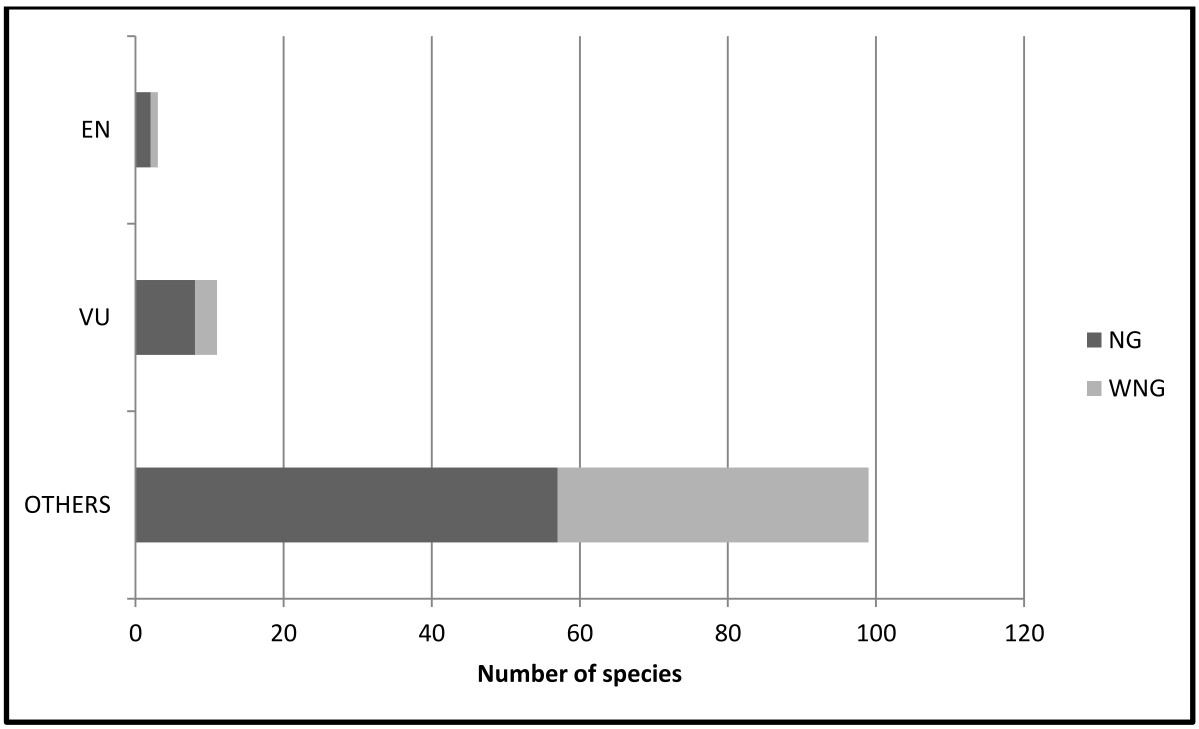

Figure 13. Composition of Endangered (EN) and Vulnerable (VU) trees in the study area

The Vulnerable and Endangered category of tree species was also found higher in NG compared to WNG but its proportion is less in the whole set of species (Fig.13).

4.2.7 Floristic diversity of *Nageia wallichiana* growing areas (NG) and areas without *Nageia wallichiana* (WNG)

The various diversity indices calculated using PAST (PAleontological STatistics) software are given in Table 9. Diversity indices were calculated for both NG and WNG for comparing the floristic diversity of both areas.

Table 9. Diversity indices for NG and WNG

	NG	WNG
Taxa_S	67	45
Individuals	186	94
Dominance_D	0.028	0.029
Simpson_1-D	0.972	0.971
Shannon_H	3.85	3.66
Margalef	12.63	9.68
Evenness_e^H/S	0.70	0.86
Equitability_J	0.91	0.96
First-order jack-knife gamma diversity	104.5	67.9

Simpson's index for NG and WNG is 0.972 and 0.971 respectively. The Shannon-Wiener's index for NG is 3.85 while for WNG it is 3.66. NG showed a higher Margalef index of 12.63 while it is 9.68 for WNG. Evenness is higher for WNG (9.68) (Table 9, Fig.14). The equitability index (J) also showed a higher value in WNG. The first order jack-knife gamma diversity for the entire study area was estimated to be 104.5 for NG plots and 67.9 for WNG plots which give the expected species richness for the entire study area (Table 9).

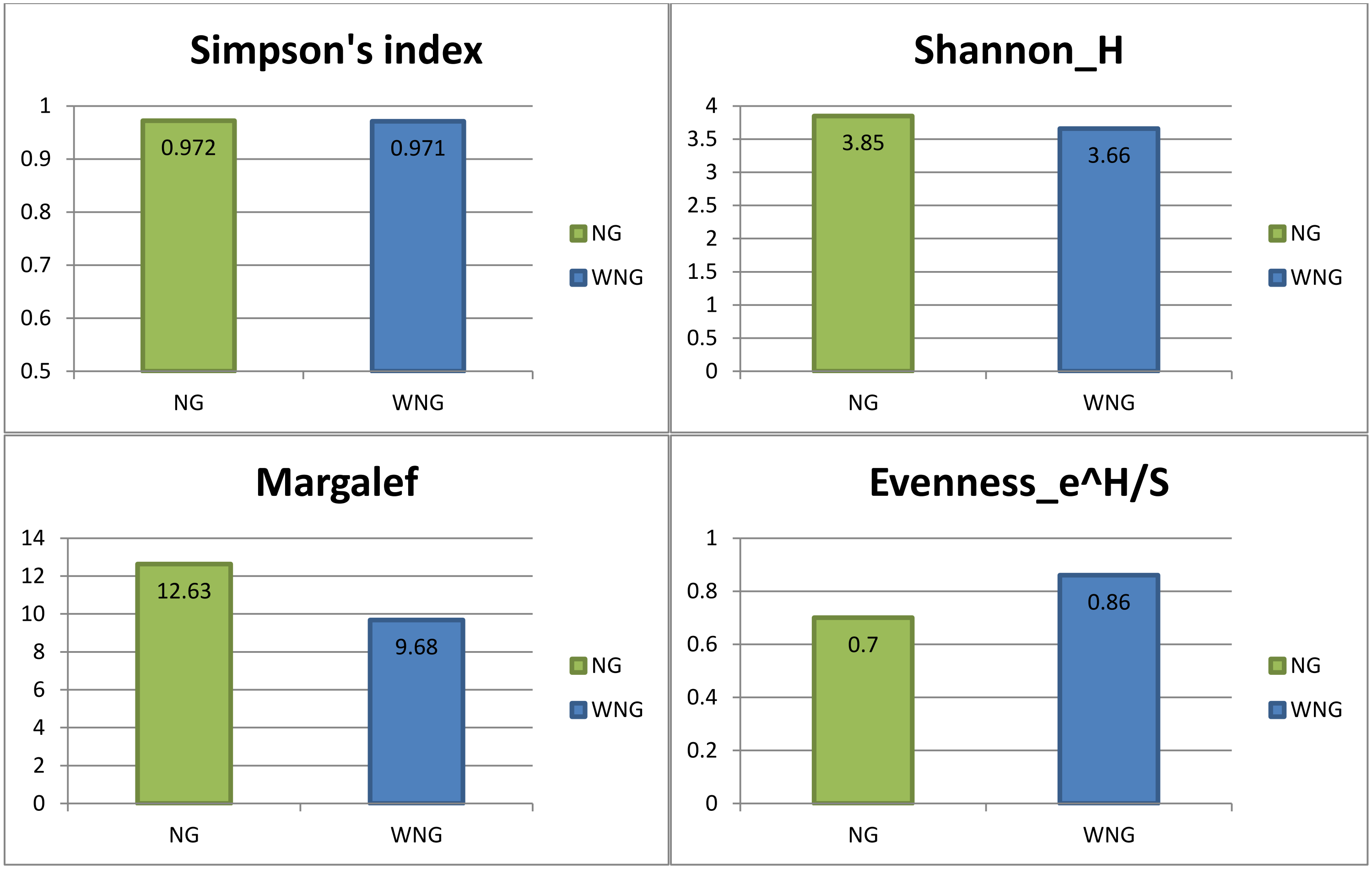

Figure 14. Diversity indices (Margalef, Simpson's, Shannon and Evenness) for NG and WNG

4.2.8 Floristic diversity of different *Nageia wallichiana* growing patches

Various diversity indices were calculated for different *Nageia wallichiana* growing patches viz; Kannadipara, Idathattu, and Pullumala.

Table 10. Diversity indices for different *Nageia wallichiana* growing patches

	Idathattu	**Kannadipara**	**Pullumala**
Taxa_S	46	25	21
Individuals	91	63	34
Dominance_D	0.030	0.073	0.069
Simpson_1-D	0.969	0.926	0.931
Shannon_H	3.657	2.872	2.867
Margalef	9.976	5.793	5.672
Evenness_e^H/S	0.842	0.707	0.837
Equitability	0.955	0.892	0.941

Simpson's index is highest for Idathattu (0.969) and lowest for Kannadipara (0.931). Shannon-Weiner's index also showed a similar trend with the highest value of 3.657 represents the diversity of the Idathattu area and the lowest value of 2.872 represents the diversity of the Kannadipara area. The Margalef index is significantly higher for the Idathattu area (9.976). Evenness is also higher for Idathattu (0.842) followed by Pullumala (0.837) and Kannadipara (0.707) (Table 10, Fig.15)

The Renyi plot for different sites in NG was calculated for comparing the richness and evenness of various *Nageia wallichiana* growing patches (Fig.16). The diagram showed the higher diversity as well as evenness of the plots of the Idathattu patch as numbered 1,2 and 3 are showing a stable line which is starting at a higher point in the diagram.

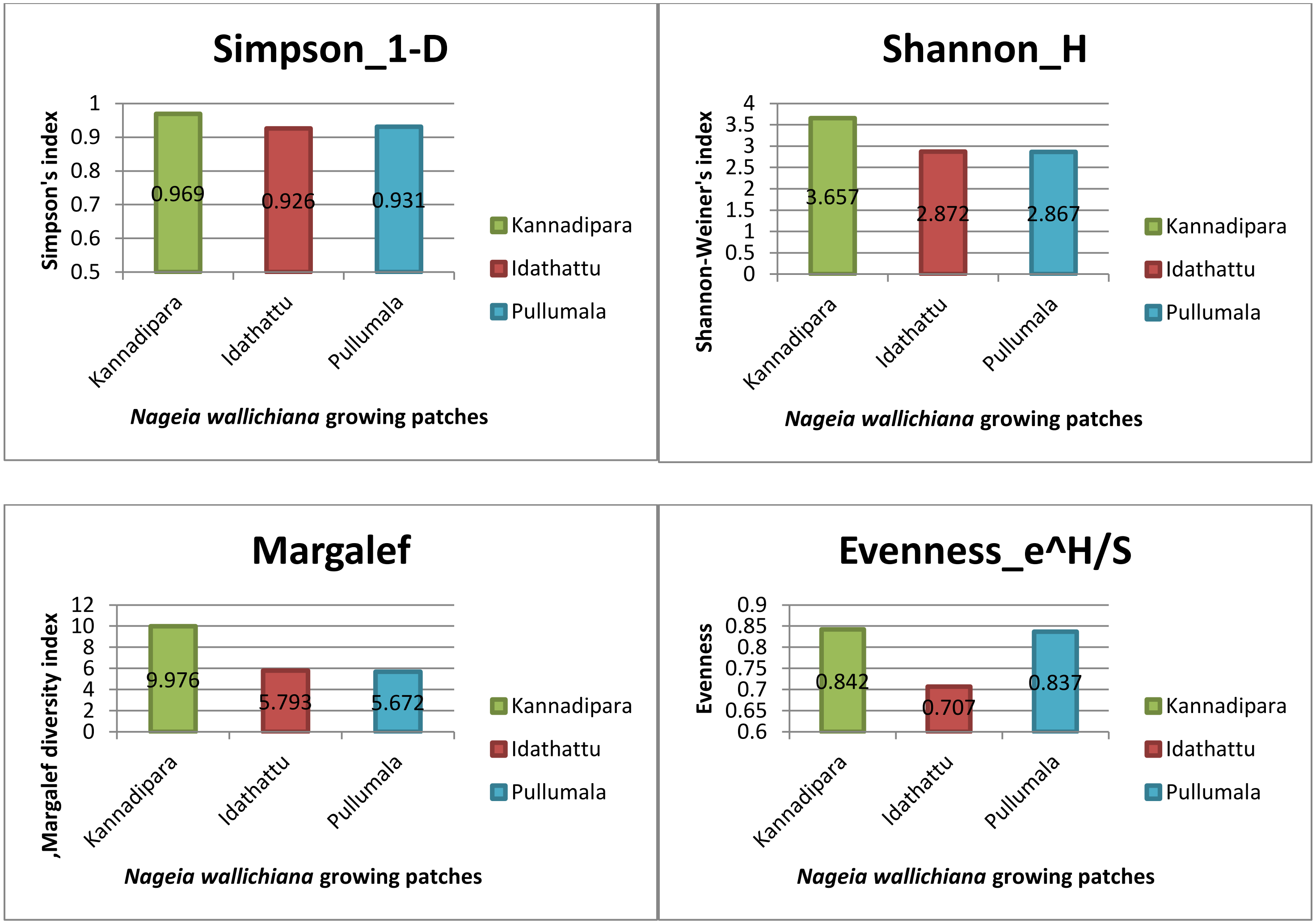

Figure 15. Diversity indices for different *Nageia wallichiana* growing patches

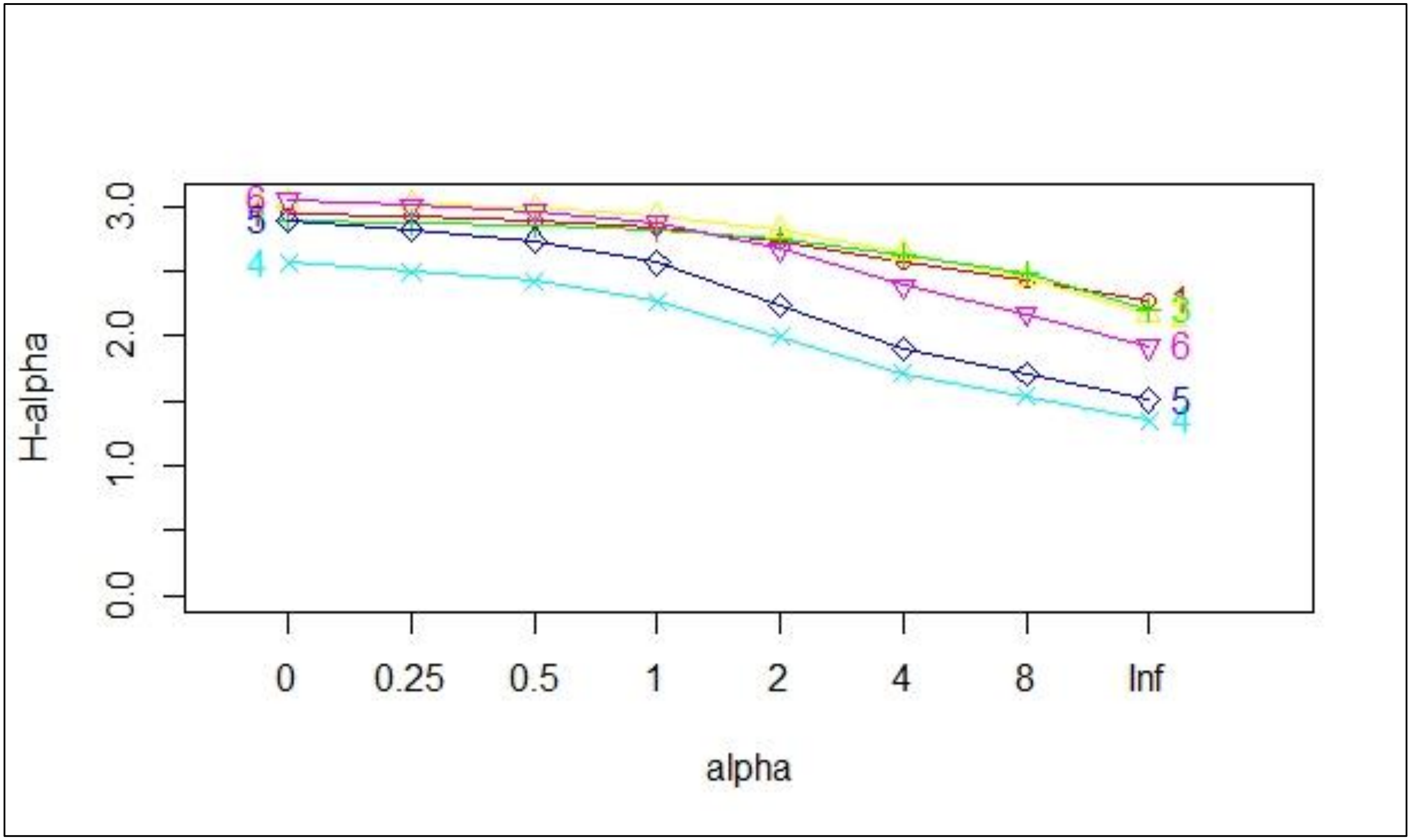

Figure 16. Renyiplot for different sites in NG (1: Idathattu plot1; 2: Idathattu plot 2; 3:Idathattu plot 3; 4: Kanadipara plot 1; 5: Kannadipara plot 2; 6: Pullumala plot 1)

4.2.9 Analysis of differences in species composition of NG and WNG

4.2.9.1 Sorenson's similarity index

The similarity between NG and WNG was found out using Sorenson's similarity index. The similarity index between NG and WNG is 0.217.

4.2.9.2 Ecological distance: Bray-Curtis distance

Ecological distance is a measure that gives differences in species composition. The maximum ecological distance found is 1.00 which was estimated for 65 different pairs. The minimum ecological distance is 0.5714 which is between plot 1 and plot 4 of WNG (Table 11).

The ecological distance values between plots of the same category and between plots of different categories (NG and WNG are the different categories considered) were compared using the student's t-test. The p-value for the f-test for comparison of variances was estimated at 8.009e-12. The p-value for the two sampled t-test was estimated at 5.364e-05 which indicates a significant difference in ecological distance between plots of the same category and plots of different categories. The mean value of ecological distances between plots of the different categories was found to be 0.956 and for the same category, it was 0.895.

Table 11. Ecological distance between all sites of NG and WNG

	WNG1	WNG2	WNG3	WNG4	WNG5	WNG6	WNG7	WNG8
WNG2	0.857							
WNG3	1.000	0.667						
WNG4	0.571	0.833	1.000					
WNG5	0.867	1.000	1.000	1.000				
WNG6	0.867	1.000	1.000	1.000	0.857			
WNG7	1.000	1.000	1.000	1.000	0.889	1.000		
WNG8	1.000	1.000	1.000	1.000	1.000	1.000	0.778	
WNG9	1.000	1.000	1.000	1.000	1.000	1.000	0.875	0.833
WNG10	0.789	1.000	0.882	0.765	0.889	1.000	0.909	0.778
WNG11	0.889	0.875	1.000	0.750	1.000	0.882	0.905	1.000
WNG12	0.889	0.875	1.000	0.750	1.000	1.000	0.905	0.882
NG13	0.945	1.000	1.000	1.000	1.000	0.889	0.950	1.000
NG14	0.953	0.902	0.951	0.951	0.952	0.952	0.870	0.905
NG15	0.939	1.000	1.000	1.000	1.000	1.000	0.944	1.000
NG16	0.943	1.000	1.000	1.000	0.941	0.941	0.947	0.941
NG17	0.954	1.000	1.000	1.000	0.953	0.860	1.000	0.953
NG18	0.905	1.000	1.000	1.000	0.951	0.902	0.956	0.805

Table 11. Continued

	WNG9	WNG10	WNG11	WNG12	NG13	NG14	NG15	NG16	NG17
WNG2									
WNG3									
WNG4									
WNG5									
WNG6									
WNG7									
WNG8									
WNG9									
WNG10	0.750								
WNG11	1.000	0.905							
WNG12	1.000	0.905	0.900						
NG13	1.000	0.950	0.949	1.000					
NG14	0.950	0.957	0.911	0.911	0.875				
NG15	1.000	0.889	1.000	1.000	0.741	0.800			
NG16	1.000	1.000	0.946	0.892	0.893	0.839	0.846		
NG17	1.000	1.000	0.957	0.870	0.754	0.831	0.803	0.714	
NG18	0.949	0.911	0.864	0.864	0.841	0.739	0.864	0.672	0.600

4.2.9.3 Ecological distance by clustering

Cluster analysis using the BiodiversityR package was done in RStudio for arranging the different sites into groups. The result of clustering the 18 plots of NG and WNG together are given in Fig.17.

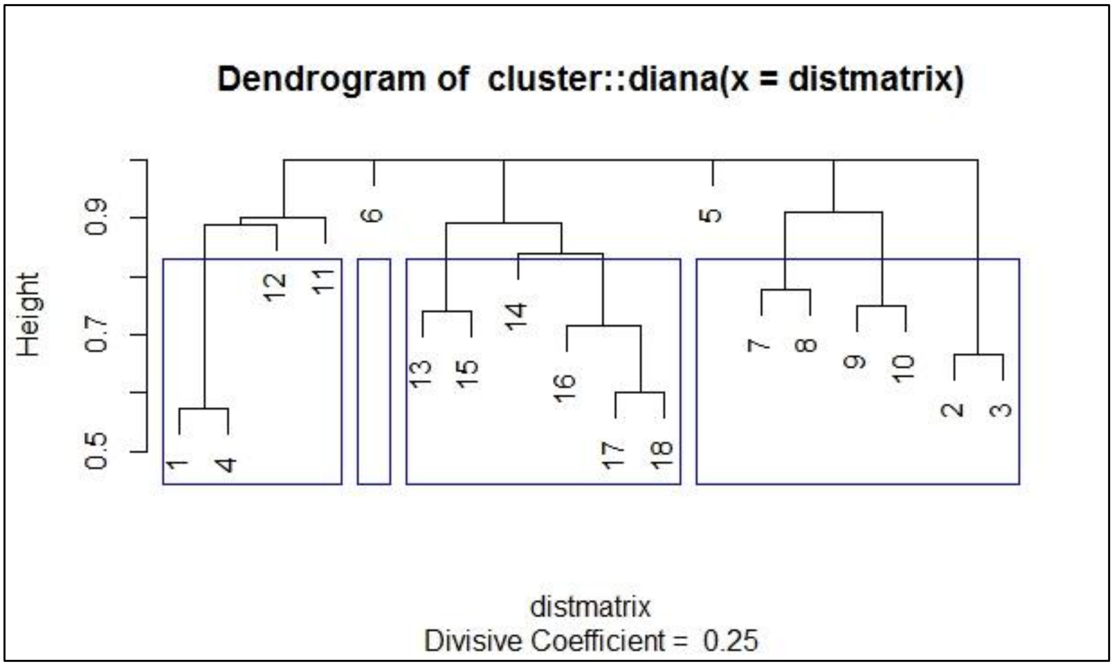

Figure 17. Cluster analysis of different plots taken in NG and WNG (Plots 1 to 12 are taken in WNG; plot 13 to 18 are from NG)

The cluster analysis divided the whole group of 18 plots into 4 based on similarities in species composition. Plot 1, Plot 4, Plot 11, and Plot 12 were grouped into one cluster. Plot 6 alone was grouped into another cluster. The plots in *Nageia wallichiana* habitat i.e., plots 13, 14, 15, 16, 17 and 18 were grouped together while plots 2, 3, 7, 8, 9 and 10 were placed in a single cluster (Fig.17)

4.2.10 Principle component analysis of site-species matrix for the whole study area

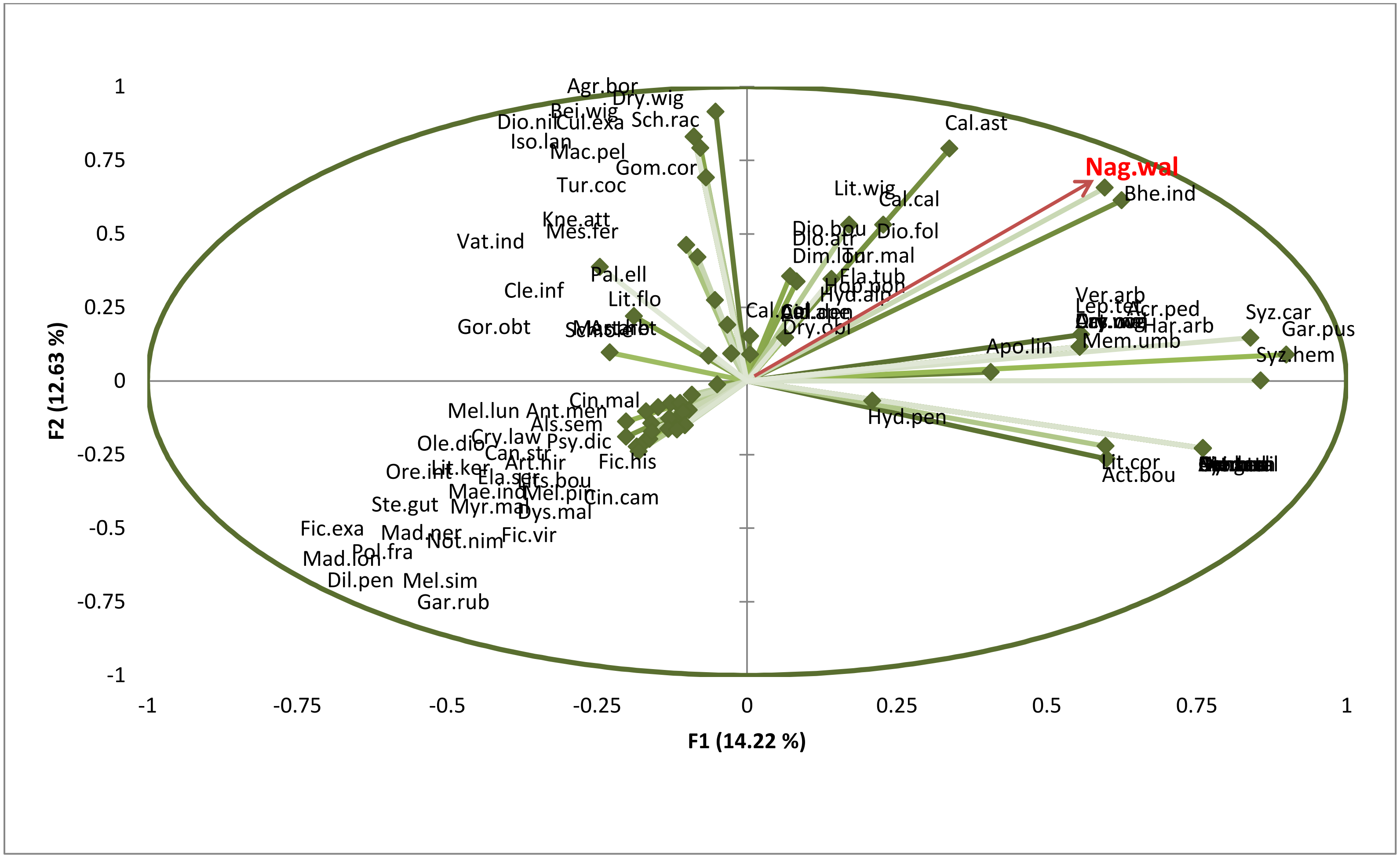

Figure 18. Principle component analysis of species in NG

4.2.10 Species assemblages of *Nageia wallichiana* growing habitat and areas without *Nageia wallichiana*

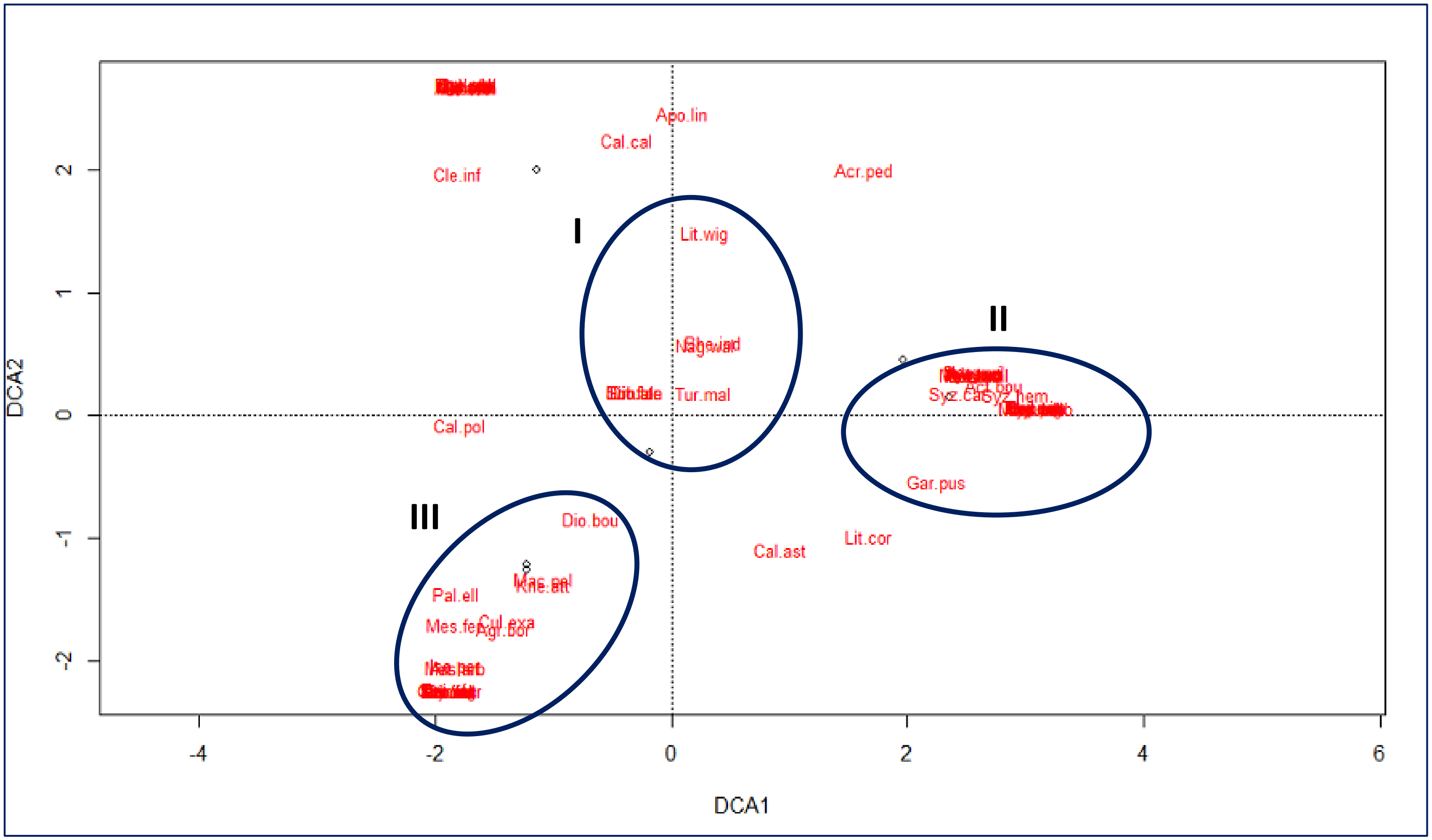

Figure 19. Ordination plot of different *Nageia wallichiana* growing patches using Detrended correspondence analysis (DCA) showing different species assemblage

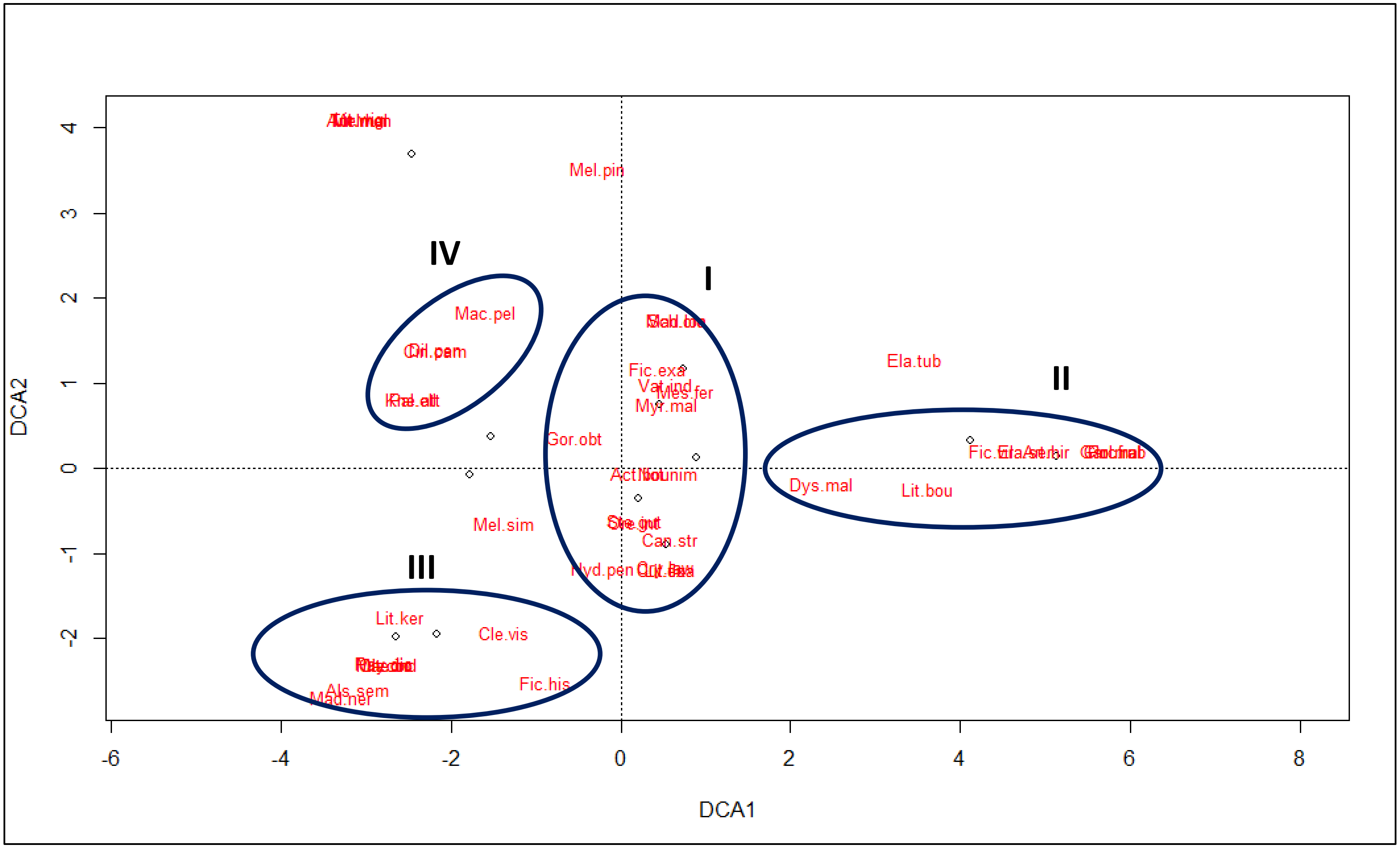

Figure 20. Ordination plot of WNG using Detrended correspondence analysis (DCA) showing different species assemblages.

The ordination plot of *Nageia wallichiana* habitats showed three different species assemblages in the area (Fig.19). The assemblage that includes *Nageia wallichiana* constitutes *Bhesa indica*, *Litsea wightiana* and *Turpinia malabarica*. Some of the species that constitute the second assemblage are *Syzygium hemisphericum, Syzygium caryophyllatum* and *Garcinia pushpangadaniana*. The third assemblage is constituted by *Cullenia exarillata*, *Mesua ferrea*, *Palaquium ellipticum*, *Agrostistachys borneensis*, *Diospyros bourdillonii* and *Knema attenuata.*

The detrended correspondence analysis of WNG identified four different species assemblages in the area (Fig.20). The first assemblage constitutes species such as *Vateria indica*, *Mesua ferrea*, *Ficus exasperata*, *Myristica malabarica*, *Gordonia obtusa*, *Canarium strictum*, *Actinodaphne bourdillonii*, and *Hydnocarpus pentandra*. The second assemblage consists of species such as *Dysoxylum malabaricum*, *Litsea bourdillonii* and *Elaeocarpus serratus.* The third species assemblage had certain species including *Litsea keralana*, *Clerodendron infortunatum*, *Ficus hispida*, *Alseodaphne semecarpifolia*, and *Madhuca neriifolia*. The fourth assemblage was identified based on the presence of *Macaranga peltata*, *Dillenia pentagyna* and *Knema attenuata*.

4.3 REGENERATION STATUS OF TREES IN *NAGEIA WALLICHIANA* GROWING AREAS

The regeneration status of trees in NG was studied by taking subplots of 5 m x 5 m and nested plots of 1 m x 1 m inside the main plots. A total of 108 individual seedlings and 125 saplings were recorded from the study site. In the lower regenerating categories i.e. seedlings, the maximum individuals were in the established seedlings category which is 90 while unestablished seedlings (8 individuals), as well as advanced growth (10 individuals), were very less.

4.3.1 Density of regenerating individuals

4.3.1.1 Density of saplings

The total number of saplings recorded from 600 m^2 (0.06 ha) area is 125. The sapling density was estimated as 2083 individuals ha^{-1} (Table 12).

4.3.1.2 Density of seedlings

The total number of seedlings recorded from 54 m^2 area is 110 with a density of 20400 seedlings per hectare (Table 12).

Table 12. Density of saplings and seedlings in NG

	Total number of individuals	Density (individuals ha^{-1})
Saplings (600 m^2)	125	2083
Seedlings	110	20400

4.3.2 Floristic structure of saplings in NG

4.3.2.1 Floristic composition

From a total sampling area of 600 m^2 (0.06 ha), 125 individual saplings of 43 different species were identified. Fig.21 shows the distribution of the number of individuals per species of the saplings in the study area. The most abundant species is

Nageia wallichiana followed by *Agrostistachys borneensis* and *Dysoxylum malabaricum.* 20 different species in the study area are represented by single individuals while 12 species are represented by only two individuals.

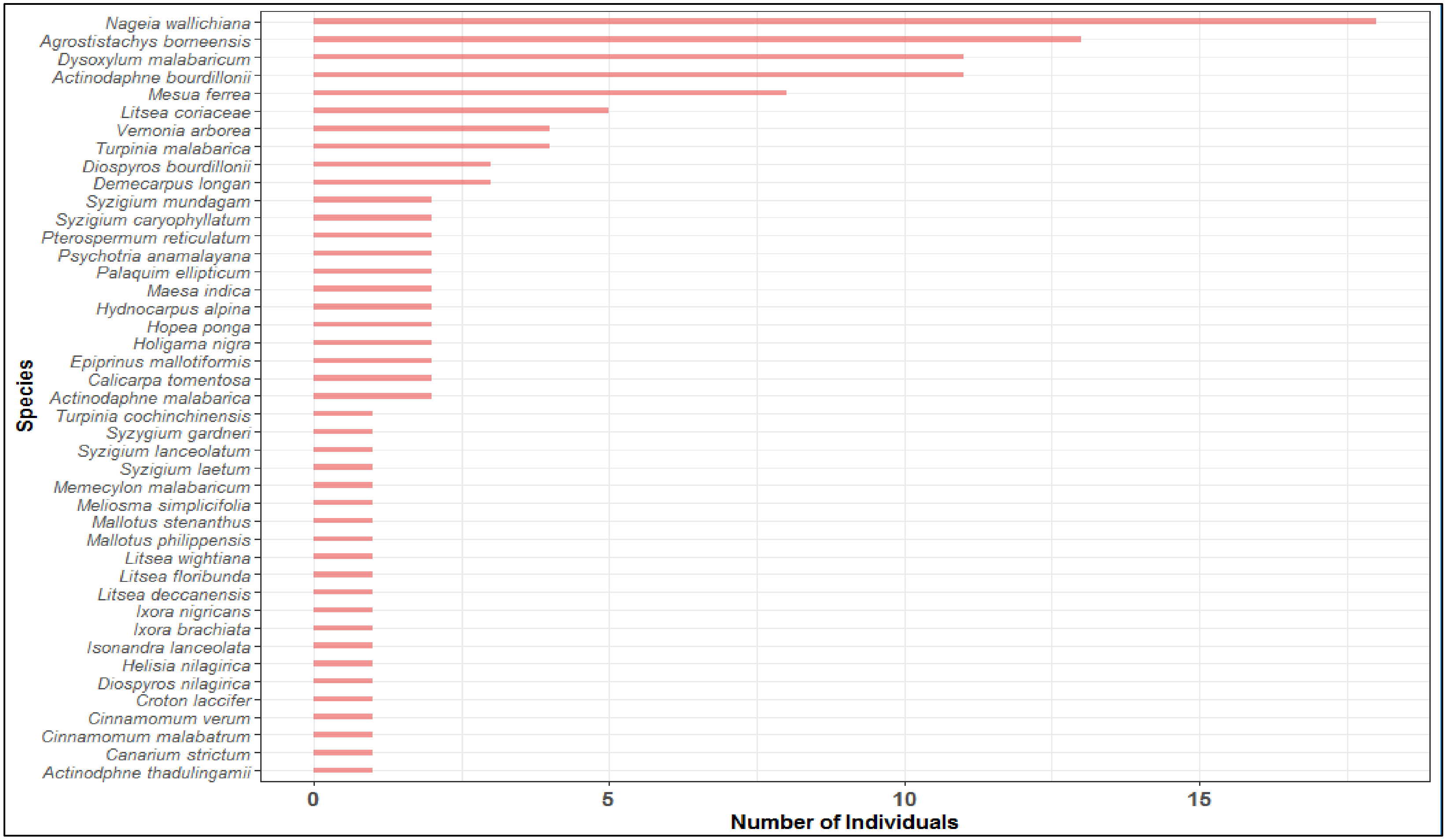

Figure 21. Distribution of the number of individuals per species of saplings in the study area

4.3.2.2 Relative importance of species

Table 13. The relative importance of different species of saplings recorded from NG

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	DFs	IVI
1	*Nageia wallichiana*	0.141	0.307	300.00	14.40	0.458	11.234	25.63
2	*Agrostistachys borneensis*	0.102	0.244	216.67	10.40	0.417	10.212	20.61
3	*Actinodaphne bourdillonii*	0.086	0.258	183.33	8.80	0.333	8.170	16.97
4	*Dysoxylum malabaricum*	0.086	0.344	183.33	8.80	0.250	6.127	14.93
5	*Mesua ferrea*	0.063	0.300	133.33	6.40	0.208	5.106	11.51
6	*Litsea coriaceae*	0.039	0.234	83.33	4.00	0.167	4.085	8.08
7	*Turpinia malabarica*	0.031	0.188	66.67	3.20	0.167	4.085	7.28
8	*Vernonia arborea*	0.031	0.250	66.67	3.20	0.125	3.064	6.26
9	*Diospyros bourdillonii*	0.023	0.188	50.00	2.40	0.125	3.064	5.46
10	*Demecarpus longan*	0.023	0.281	50.00	2.40	0.083	2.042	4.44
11	*Actinodaphne malabarica*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
12	*Calicarpa tomentosa*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
13	*Epiprinus mallotiformis*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
14	*Holigarna nigra*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
15	*Maesa indica*	0.016	0.188	33.33	1.60	0.083	2.042	3.64

Table 13 continued

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	DFs	IVI
16	*Palaquim ellipticum*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
17	*Pterospermum reticulatum*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
18	*Syzigium caryophyllatum*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
19	*Syzigium mundagam*	0.016	0.188	33.33	1.60	0.083	2.042	3.64
20	*Hopea ponga*	0.016	0.375	33.33	1.60	0.042	1.021	2.62
21	*Hydnocarpus alpina*	0.016	0.375	33.33	1.60	0.042	1.021	2.62
22	*Psychotria anamalayana*	0.016	0.375	33.33	1.60	0.042	1.021	2.62
23	*Actinodphne thadulingamii*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
24	*Canarium strictum*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
25	*Cinnamomum malabatrum*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
26	*Cinnamomum verum*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
27	*Croton laccifer*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
28	*Diospyros nilagirica*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
29	*Helisia nilagirica*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
30	*Isonandra lanceolata*	0.008	0.188	16.67	0.80	0.042	1.021	1.82

Table 13 continued

Sl No.	Species	AB	AB/F	Ds	RDs	Fs	DFs	IVI
31	*Ixora brachiata*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
32	*Ixora nigricans*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
33	*Litsea deccanensis*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
34	*Litsea floribunda*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
35	*Litsea wightiana*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
36	*Mallotus philippensis*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
37	*Mallotus stenanthus*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
38	*Meliosma simplicifolia*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
39	*Memecylon malabaricum*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
40	*Syzigium laetum*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
41	*Syzigium lanceolatum*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
42	*Syzygium gardneri*	0.008	0.188	16.67	0.80	0.042	1.021	1.82
43	*Turpinia cochinchinensis*	0.008	0.188	16.67	0.80	0.042	1.021	1.82

(AB – Relative abundance; Ds – Density of the species; RDs – Relative density of the species; Fs- Frequency of the species; RFs – Relative frequency of the species; IVI – Importance Value Index)

The most dominant species in the area is *Nageia wallichiana* with an IVI value of 25.63 followed by *Agrostistachys borneensis* (20.61) and *Actinodaphne bourdillonii* (16.97) (Table 13). Among the different species in the sapling category, only 5 species are having an IVI value greater than 10 which are *Nageia wallichiana*, *Agrostistachys borneensis*, *Actinodaphne bourdillonii*, *Dysoxylum malabaricum*, and *Mesua ferrea* (Fig.22).

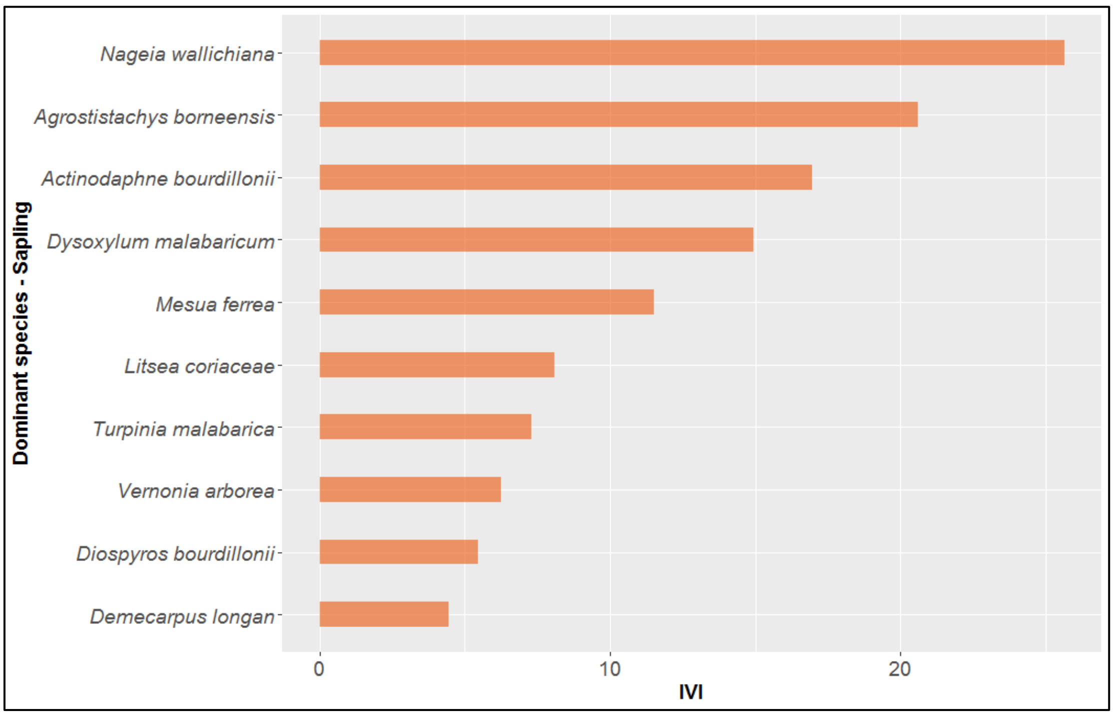

Figure 22. IVI values of most dominant species of tree saplings in the study area.

4.3.2.3 Abundance-Frequency ratio

All the species in the study area showed an abundance-frequency ratio (AB/F) greater than 0.05 (Table 13).

4.3.2.4 Floristic diversity of saplings

Various diversity indices were calculated for the saplings in the study area. The Simpson index (1-D) value for the saplings of the study area is 0.966 while Shannon-

Weiner's index is 3.48. The margalef richness index is estimated at 8.73, evenness at 0.905, and equitability at 0.972 (Table 14).

Table 14. Diversity indices of saplings in the study area

Taxa_S	36
Individuals	55
Dominance_D	0.034
Simpson_1-D	0.966
Shannon_H	3.484
Margalef	8.734
Evenness	0.905
Equitability	0.972

4.3.3 Floristic diversity of saplings in different *Nageia wallichiana* growing patches

Various diversity indices for saplings were calculated for different *Nageia wallichiana* growing patches in order to compare the diversity. Idathattu patch showed higher values for the Simpson index of diversity (1-D), Shannon-Weiner's index and Margalef index while the Pullumala patch had the maximum evenness for saplings (Table 15).

Table 15. Diversity indices of saplings for different *N. wallichiana* growing patches

	Idathattu	**Kannadipara**	**Pullumala**
Taxa_S	29	20	11
Individuals	61	49	18
Dominance_D	0.064	0.100	0.111
Simpson_1-D	0.935	0.899	0.889
Shannon_H	3.061	2.625	2.293
Margalef	6.811	4.882	3.46
Evenness_e^H/S	0.736	0.689	0.900

4.3.4 Floristic structure of seedlings in NG

4.3.4.1 Species composition

From a sampling area of 54 m^2, 107 individual seedlings of 35 different families were recorded. A maximum number of seedlings was observed for *Nageia wallichiana* followed by *Actinodaphne bourdillonii* and *Dysoxylum malabaricum* (Fig.23).

The distribution of the number of individuals per species is given in Fig.23. The distribution showed an L shaped curve. Fifteen species of the study area were represented by one individual only and 8 species were represented by just 2 individuals.

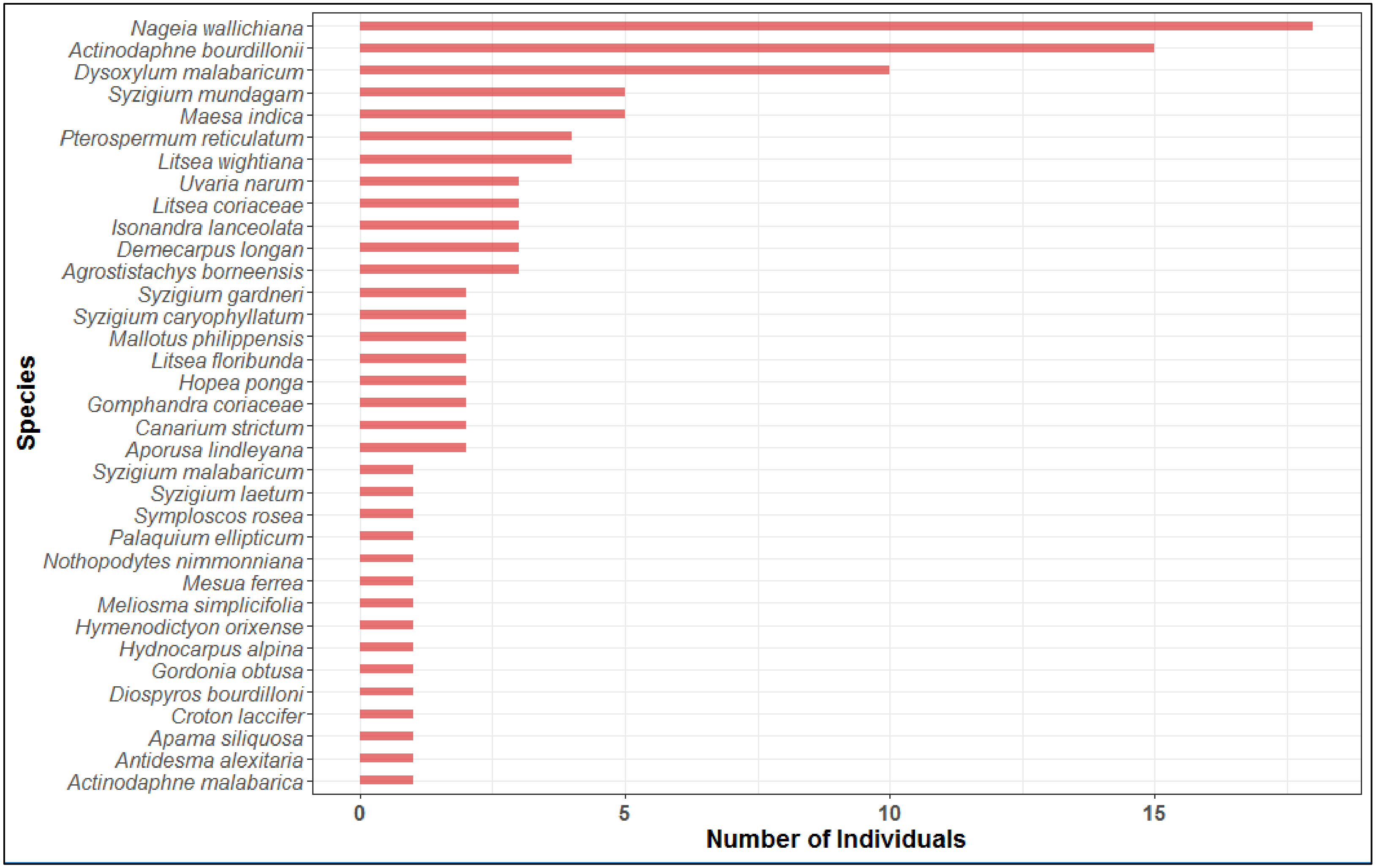

Figure 23. Distribution of the number of individuals per species of seedlings in the study area

4.3.4.2 Relative importance of species

Table 16. The relative importance of seedling of various species in NG

Sl. No.	Species	Abundance	AB	AB/F	Ds	RDs	Fs	RFs	IVI
1	*Nageia wallichiana*	18	0.164	0.589	3333.33	16.822	0.278	15.605	32.428
2	*Actinodaphne bourdillonii*	15	0.136	0.526	2777.78	14.019	0.259	14.565	28.584
3	*Dysoxylum malabaricum*	10	0.091	0.818	1851.85	9.346	0.111	6.242	15.588
4	*Maesa indica*	5	0.045	0.491	925.93	4.673	0.093	5.202	9.875
5	*Syzigium mundagam*	5	0.045	0.491	925.93	4.673	0.093	5.202	9.875
6	*Litsea wightiana*	4	0.036	0.491	740.74	3.738	0.074	4.161	7.900
7	*Pterospermum reticulatum*	4	0.036	0.655	740.74	3.738	0.056	3.121	6.859
8	*Demecarpus longan*	3	0.027	0.491	555.56	2.804	0.056	3.121	5.925
9	*Isonandra lanceolata*	3	0.027	0.491	555.56	2.804	0.056	3.121	5.925
10	*Litsea coriaceae*	3	0.027	0.491	555.56	2.804	0.056	3.121	5.925
11	*Uvaria narum*	3	0.027	0.491	555.56	2.804	0.056	3.121	5.925
12	*Agrostistachys borneensis*	3	0.027	0.736	555.56	2.804	0.037	2.081	4.884
13	*Aporusa lindleyana*	2	0.018	0.491	370.37	1.869	0.037	2.081	3.950
14	*Canarium strictum*	2	0.018	0.491	370.37	1.869	0.037	2.081	3.950
15	*Gomphandra coriaceae*	2	0.018	0.491	370.37	1.869	0.037	2.081	3.950
16	*Hopea ponga*	2	0.018	0.491	370.37	1.869	0.037	2.081	3.950
17	*Mallotus philippensis*	2	0.018	0.491	370.37	1.869	0.037	2.081	3.950
18	*Syzigium caryophyllatum*	2	0.018	0.491	370.37	1.869	0.037	2.081	3.950
19	*Syzigium gardneri*	2	0.018	0.491	370.37	1.869	0.037	2.081	3.950
20	*Litsea floribunda*	2	0.018	0.982	370.37	1.869	0.019	1.040	2.910
21	*Actinodaphne malabarica*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
22	*Antidesma alexitaria*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975

Table 16 continued

Sl. No.	Species	Abundance	AB	AB/F	Ds	RDs	Fs	RFs	IVI
23	*Apama siliquosa*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
24	*Croton laccifer*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
25	*Diospyros bourdilloni*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
26	*Gordonia obtusa*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
27	*Hydnocarpus alpine*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
28	*Hymenodictyon orixense*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
29	*Meliosma simplicifolia*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
30	*Mesua ferrea*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
31	*Nothopodytes nimmonniana*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
32	*Palaquium ellipticum*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
33	*Symploscos rosea*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
34	*Syzigium laetum*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975
35	*Syzigium malabaricum*	1	0.009	0.491	185.19	0.935	0.019	1.040	1.975

(AB- Relative abundance; Ds – Density of the species; RDs – Relative density of the species; Fs- Frequency of the species; RFs – Relative frequency of the species; IVI – Importance Value Index)

The most dominant species in the case of seedlings in the area is *Nageia wallichiana* with an IVI value of 32.42 closely followed by *Actinodaphne bourdillonii* (28.58) and *Dysoxylum malabaricum* (15.58) (Table 16). Only three species in the study area showed an IVI value greater than 10 which are *Nageia wallichiana*, *Actinodaphne bourdillonii*, and *Dysoxylum malabaricum* (Fig.24)

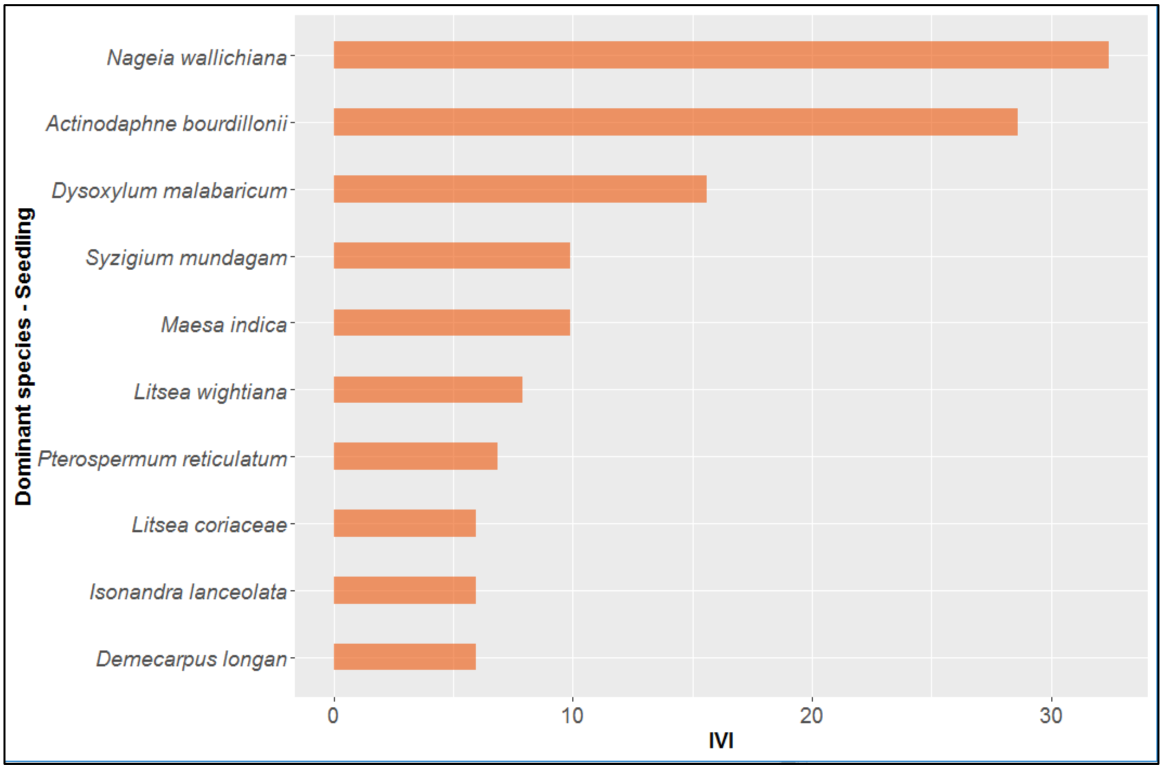

Figure 24. IVI values of most dominant species of tree seedlings in the study area.

4.3.4.3 Abundance-Frequency ratio

All the seedling species of the study area have an Abundance-Frequency ratio greater than 0.05. The maximum Abundance-frequency ratio is estimated for *Litsea floribunda* followed by *Dysoxylum malabaricum* and *Agrostistachys borneensis* (Table 16).

4.3.4.4 Floristic diversity

Various diversity indices were calculated for the recorded seedlings of *Nageia wallichiana* growing areas. The Simpson index (1-D) value for the saplings of the study area is 0.92 while Shannon- Weiner's index is 3.08. The margalef richness index is estimated at 7.28 and evenness at 0.62 (Table 17).

Table 17. Floristic diversity of seedlings in NG

Taxa_S	35
Individuals	107
Dominance_D	0.072
Simpson_1-D	0.92
Shannon_H	3.08
Margalef	7.28
Evenness	0.62
Equitability	0.87

4.3.6 Floristic diversity of *Nageia wallichiana* growing patches

Various diversity indices of seedlings were calculated for different *Nageia wallichiana* growing patches in order to compare the diversity. Idathattu patch showed higher values for the Simpson index of diversity (1-D), Shannon-Weiner's index, and Margalef index while the Pullumala patch had the maximum evenness for seedlings (Table 18).

Table 18. Diversity indices of seedlings for different *Nageia wallichiana* growing patches

	Idathattu	**Kannadipara**	**Pullumala**
Taxa_S	24	15	12
Individuals	54	34	22
Simpson_1-D	0.904	0.882	0.900
Shannon_H	2.772	2.409	2.39
Margalef	5.766	3.97	3.559
Evenness_e^H/S	0.665	0.741	0.909

4.3.7 Comparison of diversity indices of trees, saplings and seedlings of the study area

Comparing the various diversity indices for tree, seedling, and sapling categories in NG Simpson index of diversity, Shannon-Weiner's diversity index and Margalef index was found to be maximum for trees followed by saplings and seedlings (Fig.25). The evenness index was highest for saplings and lowest for seedlings.

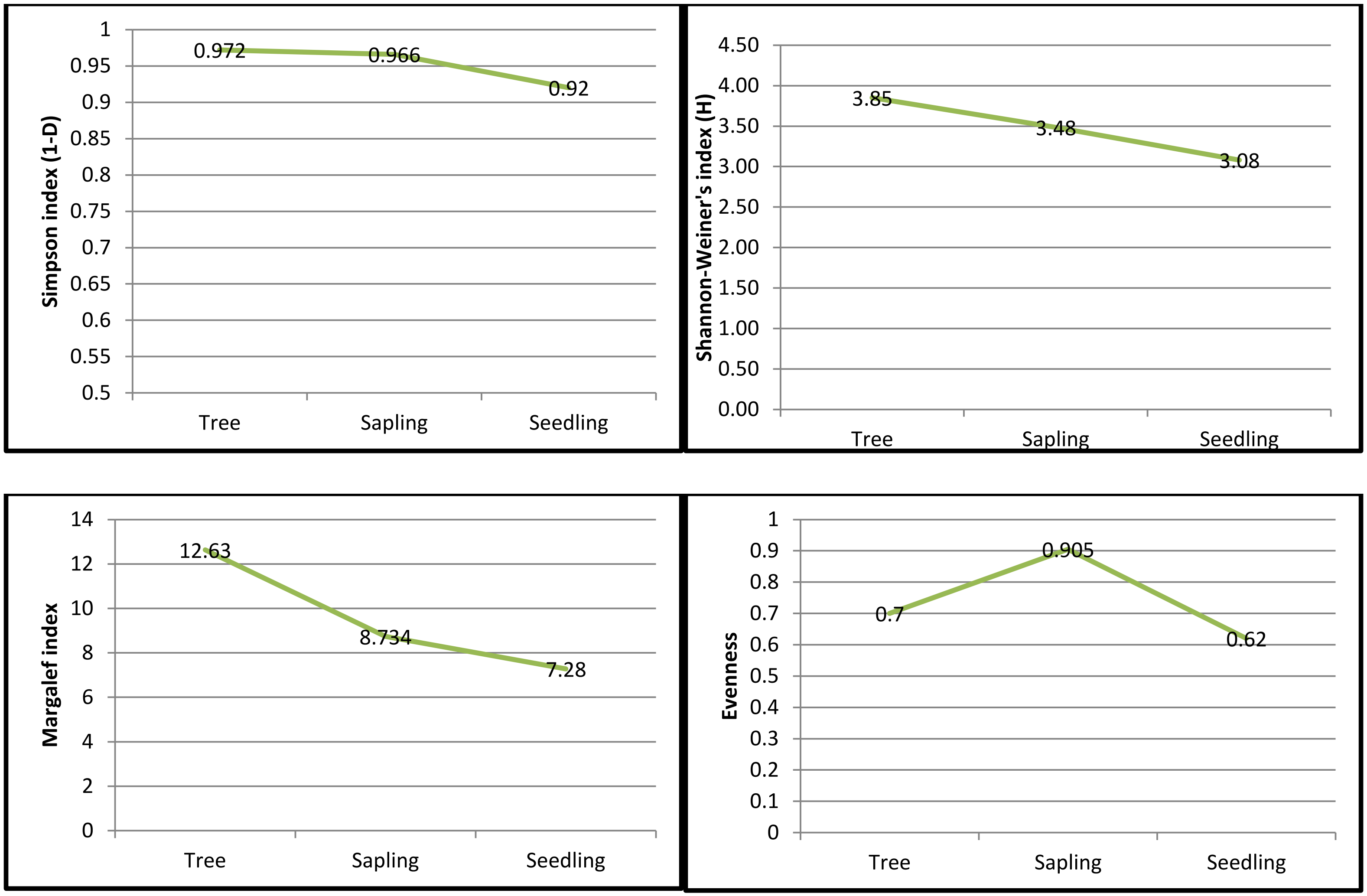

Figure 25. Diversity indices for trees, seedlings, and saplings of NG

4.3.8 Comparison of the floristic diversity of trees, seedlings, and saplings of different *Nageia wallichiana* growing patches

For trees and saplings, the maximum value of the Simpson index of diversity, as well as Shannon-Weiner's diversity index, was shown by the Idathattu patch followed by the Kannadipara patch but for seedlings, the Pullumala patch had a higher diversity of seedlings than the Kannadipara patch (Fig.26 and Fig.27). For saplings and seedlings categories evenness was higher for the Pullumala patch while for trees highest evenness was showed by the Idathattu patch (Fig.28).

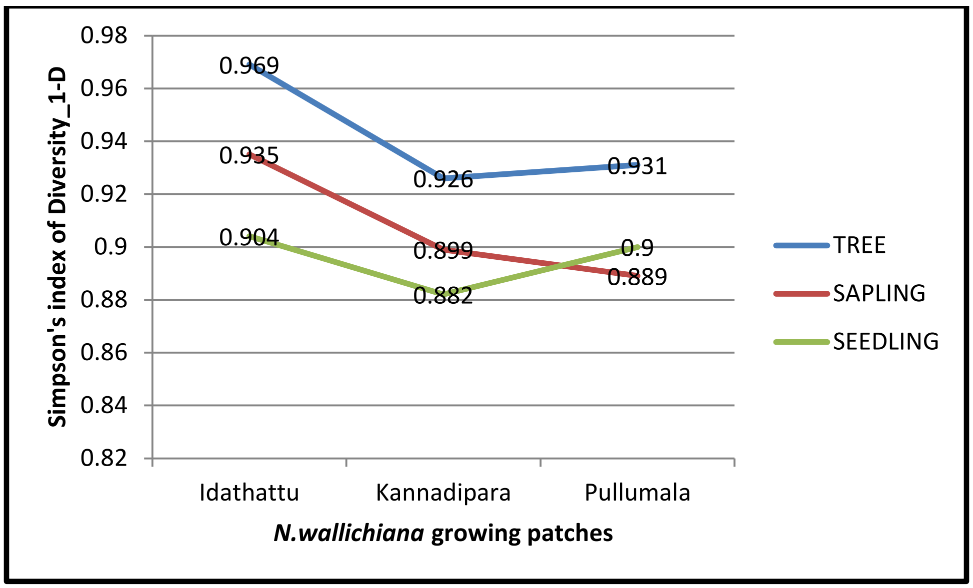

Figure 26. Simpson index of diversity for different categories in different patches

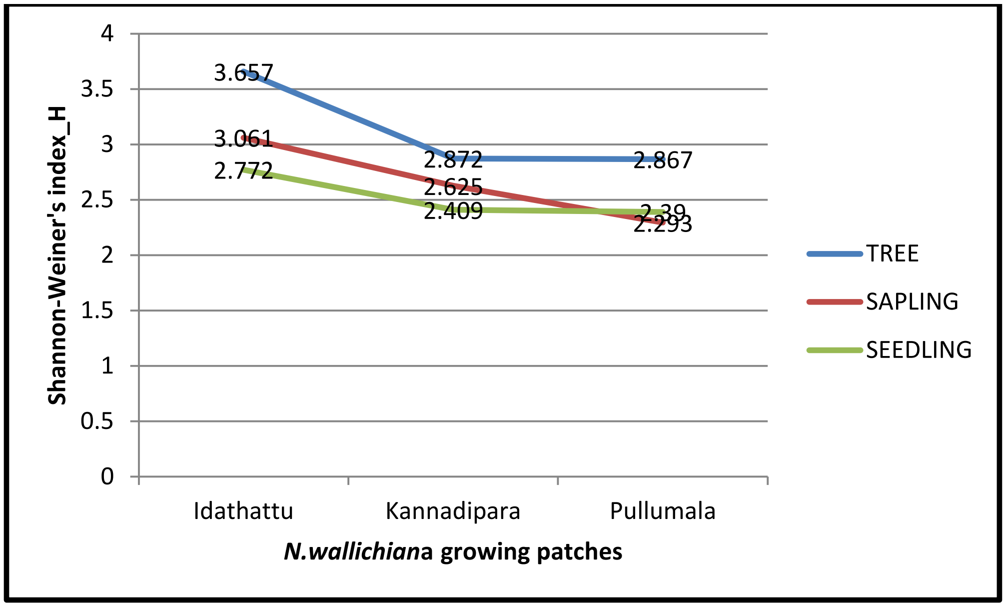

Figure 27. Shannon-Weiner's index of diversity for different categories in different patches

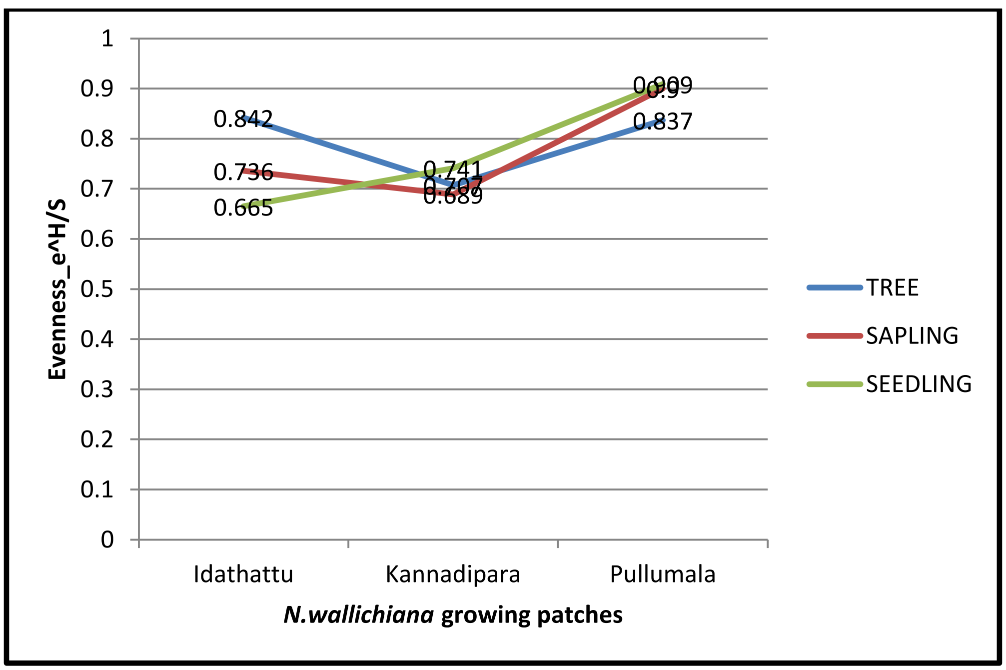

Figure 28. Evenness index for different categories in different patches

4.3.9 Species assemblages of saplings and seedlings in the study area

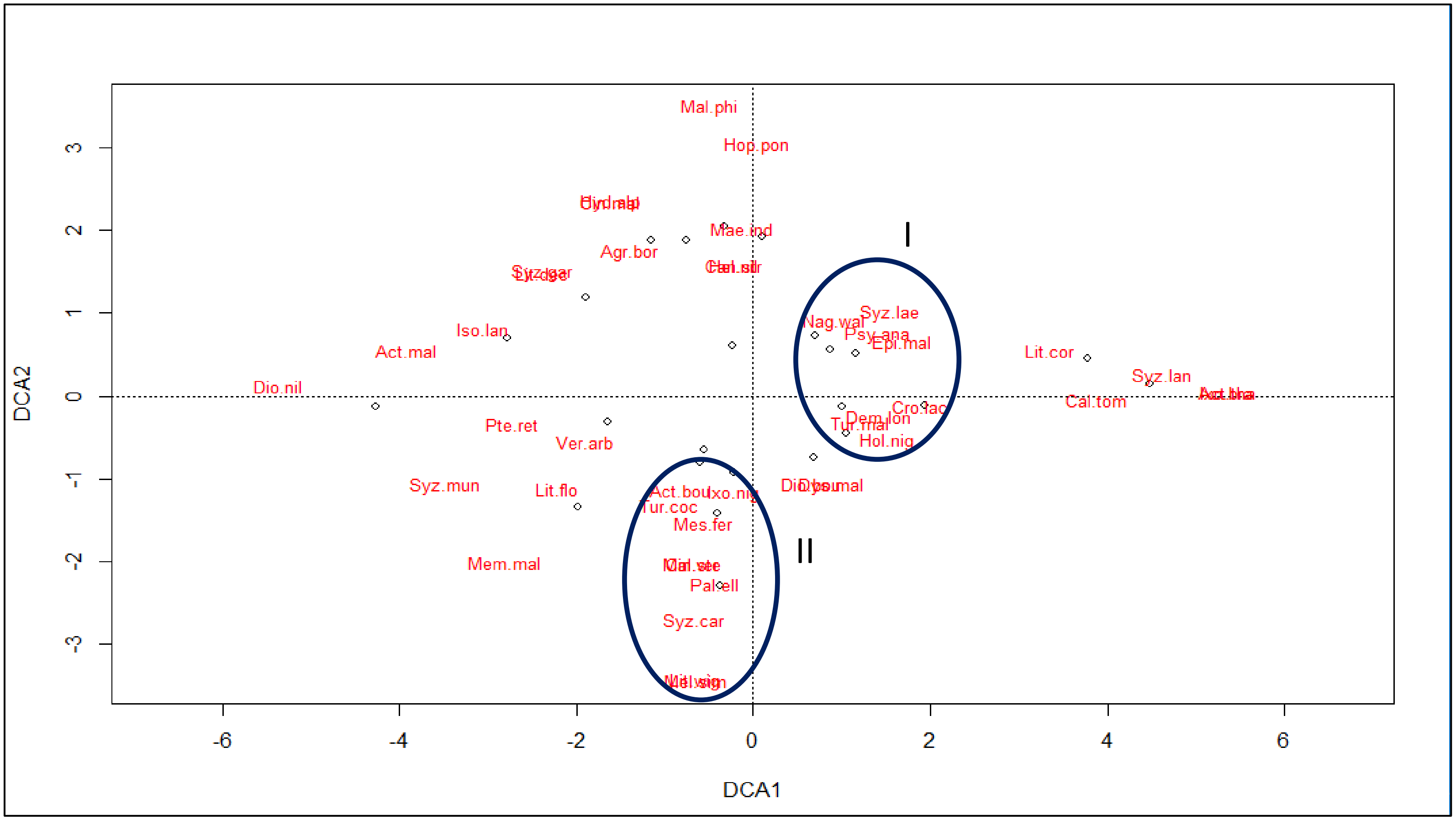

Figure 29. DCA showing different species assemblages for the regenerating species in the study area

For regenerating individuals in the study area, two species assemblages are identified in which the first assemblage consists of species such as *Nageia wallichiana*, *Syzygium laetum*, *Psychotria anamalayana*, *Epiprinus mallotiformis*, *Croton laccifer* and *Demecarpus longan*. The second assemblage consisted of species such as *Actinodaphne bourdillonii*, *Turpinia cochinchinensis*, *Mesua ferrea*, and *Syzygium caryophyllatum*. A large number of individuals were distributed as scattered minor groups in the plot (Fig.29).

4.4 SOIL PROPERTIES

Various soil properties such as pH, Bulk density, Moisture content, organic C, and total Nitrogen were estimated for soil samples collected from different plots.

4.4.1 Soil Physical properties

4.4.1.1 Bulk density

The soil bulk density from two different depths (0-20 cm and 20-40 cm) in both NG and WNG were estimated and compared.

Table 19. Comparison of soil bulk density values in g/cc for NG and WNG plots

	Soil Bulk Density (g/cc) (0-20 cm depth)		Soil Bulk Density (g/cc) (20-40 cm depth)	
	Mean	SD	Mean	SD
NG	1.225	0.05	1.347	0.044
WNG	1.128	0.50	1.043	0.404
p value	0.5219		0.065	

The mean value of soil bulk density in NG at the depth of 0-20 cm is estimated as 1.225 g/cc and the standard deviation is 0.05. For soil samples from WNG, the mean value of bulk density is 1.128 g/cc and the standard deviation is 0.50. (Table 19, Fig.30).

The mean value of soil bulk density from different plots of NG at 20-40 cm is 1.347 g/cc and the standard deviation is 0.044. For WNG, the mean value of bulk density was estimated at 1.043 g/c, and the standard deviation at 0.404 (Table 19, Fig.31). For both depths, the soil bulk density values between NG and WNG didn’t show a significant difference.

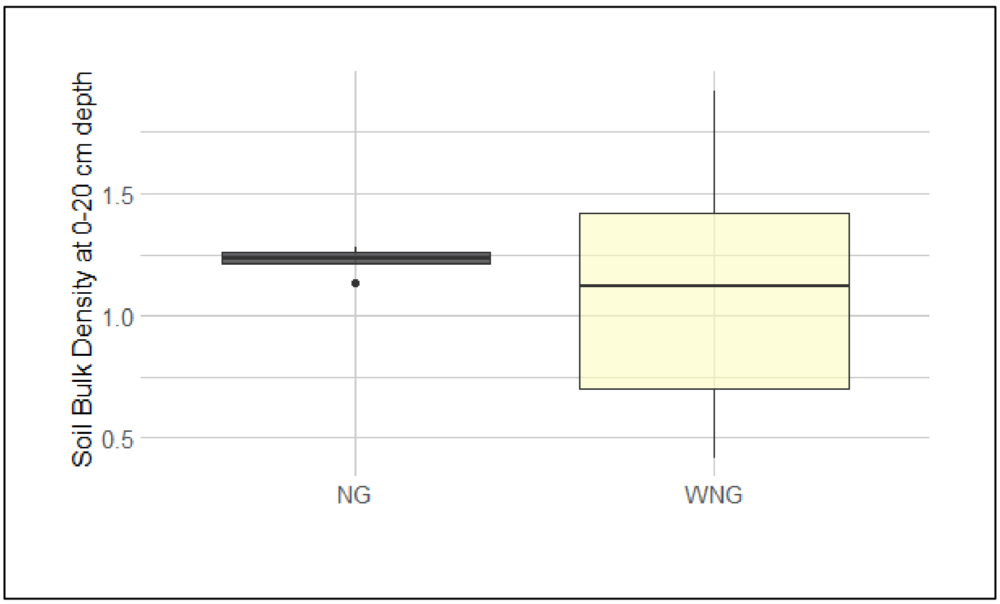

Figure 30. Boxplot comparing soil bulk density of NG and WNG at 0-20 cm depth

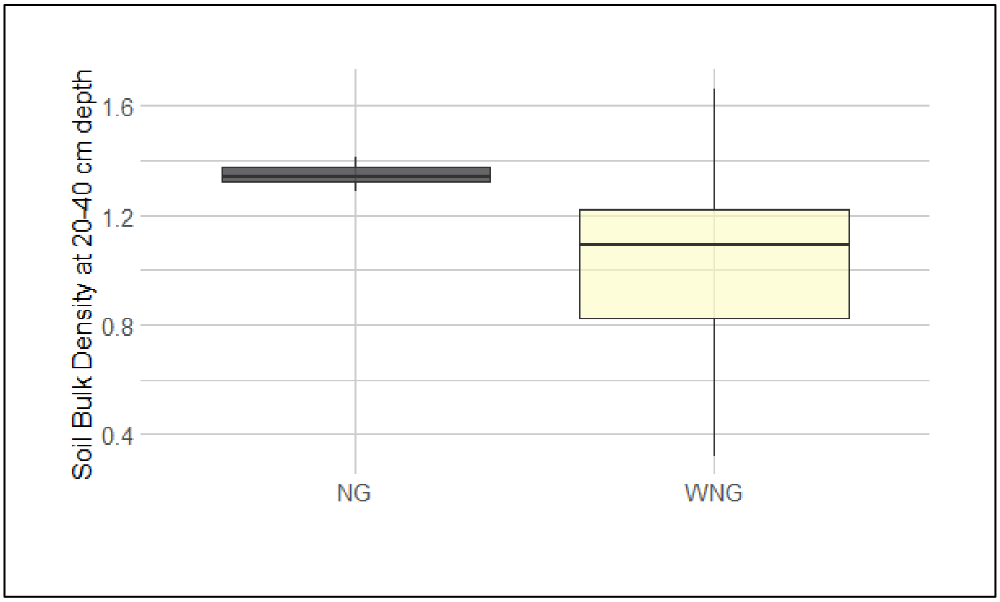

Figure 31. Boxplot comparing soil bulk density of NG and WNG at 20 - 40 cm depth

4.4.1.2 Moisture content

The soil moisture content from two different depths (0-20 cm and 20-40 cm) in both NG and WNG were estimated and compared.

Table 20. Comparison of soil moisture content values in percent for NG and WNG plots

	Soil Moisture Content (%) (0-20 cm depth)		Soil Moisture Content (%) (20-40 cm depth)	
	Mean	SD	Mean	SD
NG	25.61	2.03	20.61	2.30
WNG	10.107	6.84	10.981	6.80
p value	3.902e-06**		0.0005004**	

The mean value of soil moisture content from different plots of NG at 0-20 cm is 25.61 percent and the standard deviation is 2.03. For WNG, the mean value of moisture content was estimated at 10.107 percent, and the standard deviation at 6.84. The values of soil moisture content for NG and WNG at 0-20 cm depth showed a significant difference at 1 % confidence interval (Table 20, Fig.32).

The mean value of soil moisture content from different plots of NG at 20-40 cm is 20.61 percent and the standard deviation is 2.30. For WNG, the mean value of moisture content was estimated at 10.981 percent with a standard deviation of 6.80. The values of soil moisture content for NG and WNG at 20-40 cm depth showed a significant difference at 1 % confidence interval (Table 20, Fig.33).

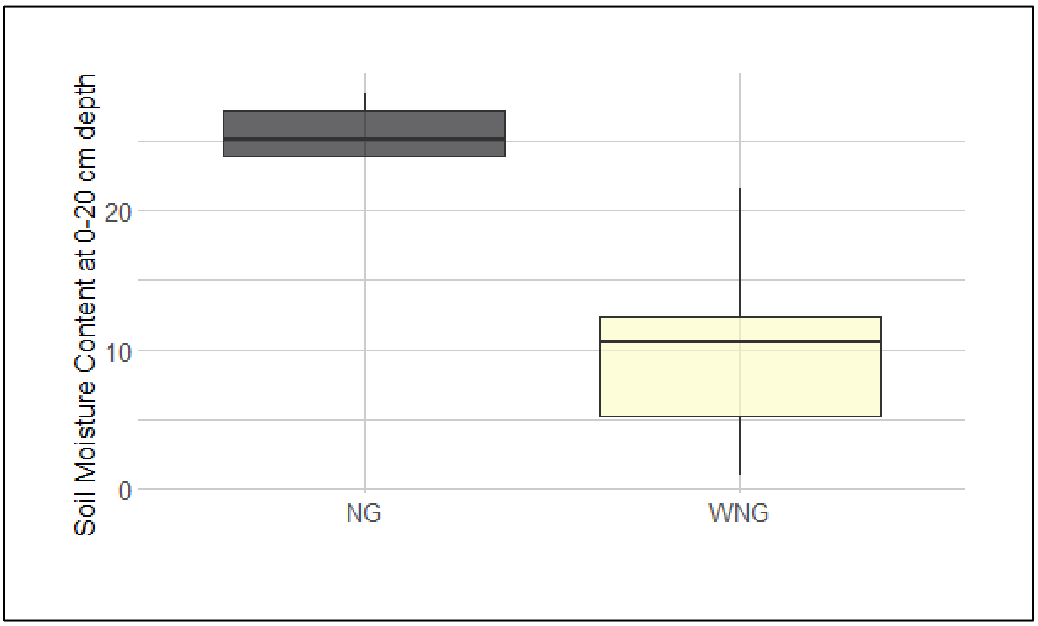

Figure 32. Boxplots comparing soil moisture content values of NG and WNG at 0-20 cm depth

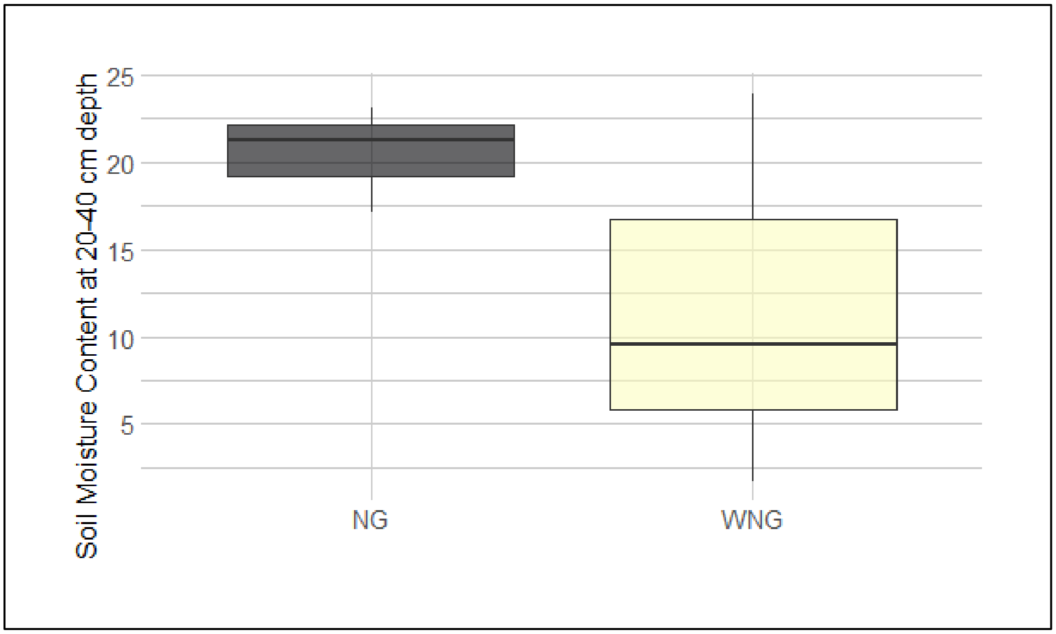

Figure 33. Boxplots comparing soil moisture content values of NG and WNG at 20-40 cm depth

4.4.2 Soil Chemical Properties

4.4.2.1 Soil pH

The soil samples from two depths in different sample plots were collected and analyzed for determining pH.

Table 21. Comparison of soil pH values for NG and WNG plots

	Soil pH (0-20 cm depth)		Soil pH (20-40 cm depth)	
	Mean	SD	Mean	SD
NG	3.967	0.52	4.27	0.20
WNG	3.58	0.426	4.60	0.41
p value	0.481		0.08468	

The mean value of soil pH from different plots of NG at 0-20 cm is 3.967 and the standard deviation is 0.52. For WNG, the mean value of pH was estimated at 3.583, and the standard deviation at 0.426 (Table 21, Fig.34).

The mean value of soil pH from different plots of NG at 20-40 cm is 4.27 and the standard deviation is 0.20. For WNG, the mean value of pH was estimated at 4.60, and the standard deviation at 0.41 (Table 21, Fig.35). The soil pH values at 0-20 cm, as well as 20-40 cm depth for NG and WNG, didn't show any significant difference.

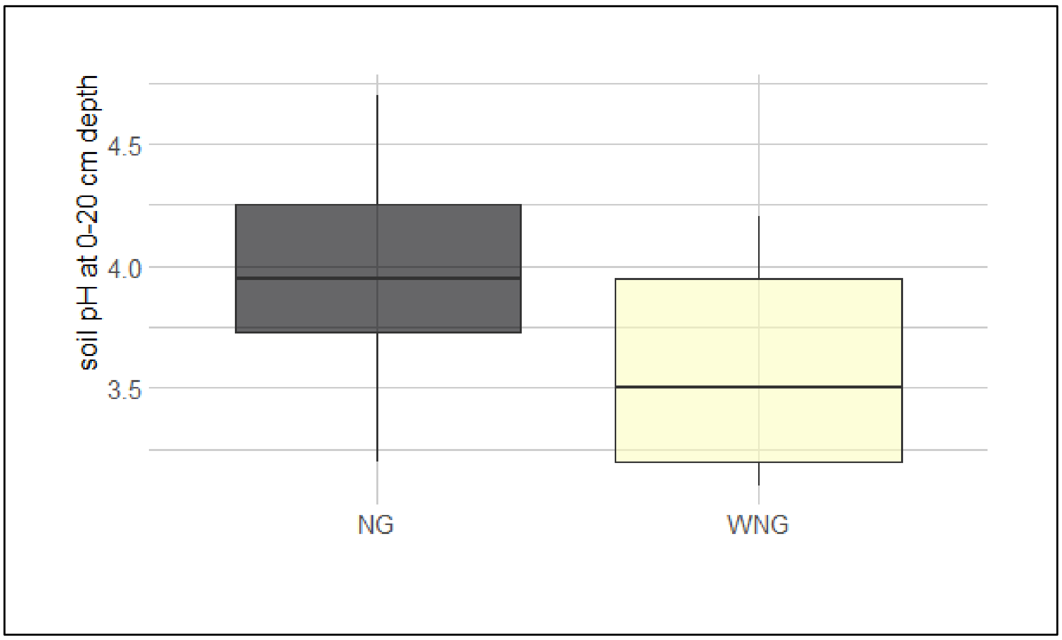

Figure 34. Boxplots comparing soil pH values of NG and WNG at 0-20 cm depth

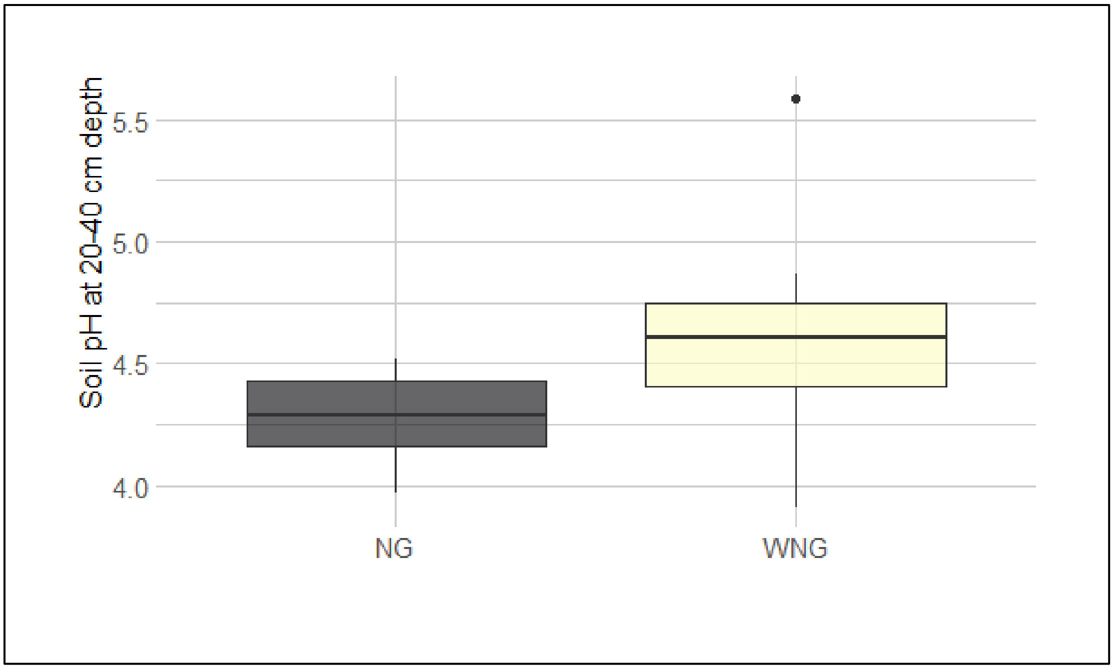

Figure 35. Boxplots comparing soil pH values of NG and WNG at 20-40 cm depth

4.4.2.2 Soil Organic Carbon

The soil samples from two depths in different sample plots were collected and analyzed for determining soil organic Carbon.

Table 22. Comparison of soil organic carbon percent values for NG and WNG plots

	Soil Organic Carbon (%) (0-20 cm depth)		Soil Organic Carbon (%) (20-40 cm depth)	
	Mean	SD	Mean	SD
NG	6.358	1.70	2.48	1.13
WNG	3.10	0.96	1.89	1.14
p value	8.139e-05**		0.3552	

The mean value of soil organic Carbon percent from different plots of NG at 0-20 cm is 6.358 and the standard deviation is 1.70. For WNG, the mean value of soil organic Carbon percent was estimated at 3.10, and the standard deviation at 0.96. The soil organic carbon percent values at 0-20 cm depth for NG and WNG was found to be significantly different at 1 % confidence interval (Table 22. Fig.36).

The mean value of soil organic Carbon percent from different plots of NG at 20-40 cm is 2.479 and the standard deviation is 1.13. For WNG, the mean value of soil organic Carbon percent was estimated at 1.893 and the standard deviation at 1.14. The soil organic carbon percent values at 20-40 cm depth for NG and WNG doesn't show a significant difference (Table 22. Fig.37).

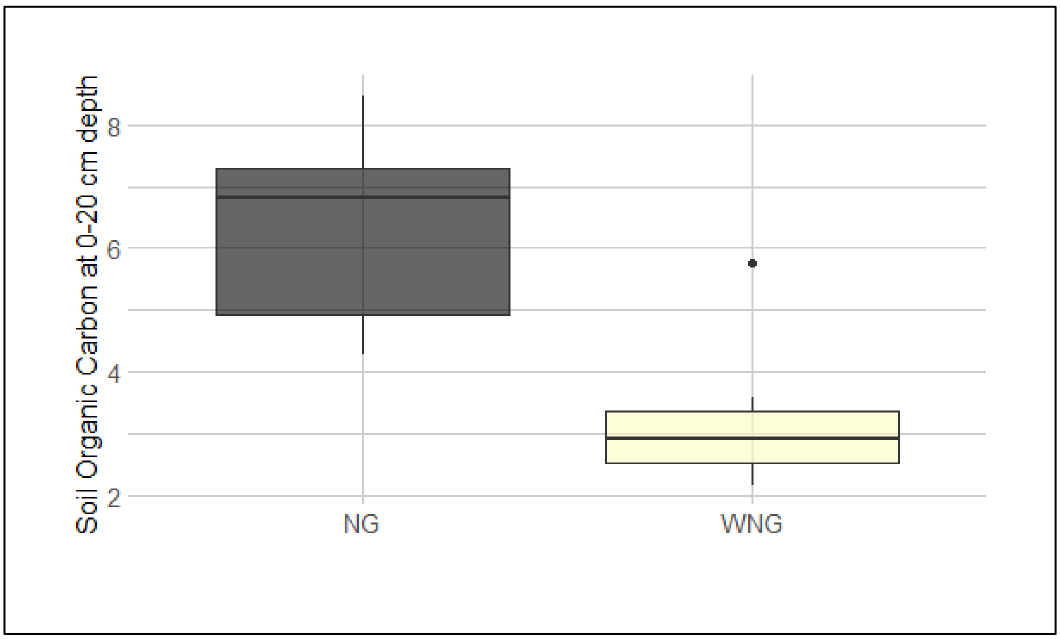

Figure 36. Boxplots comparing soil organic Carbon percent of NG and WNG at 0-20 cm depth

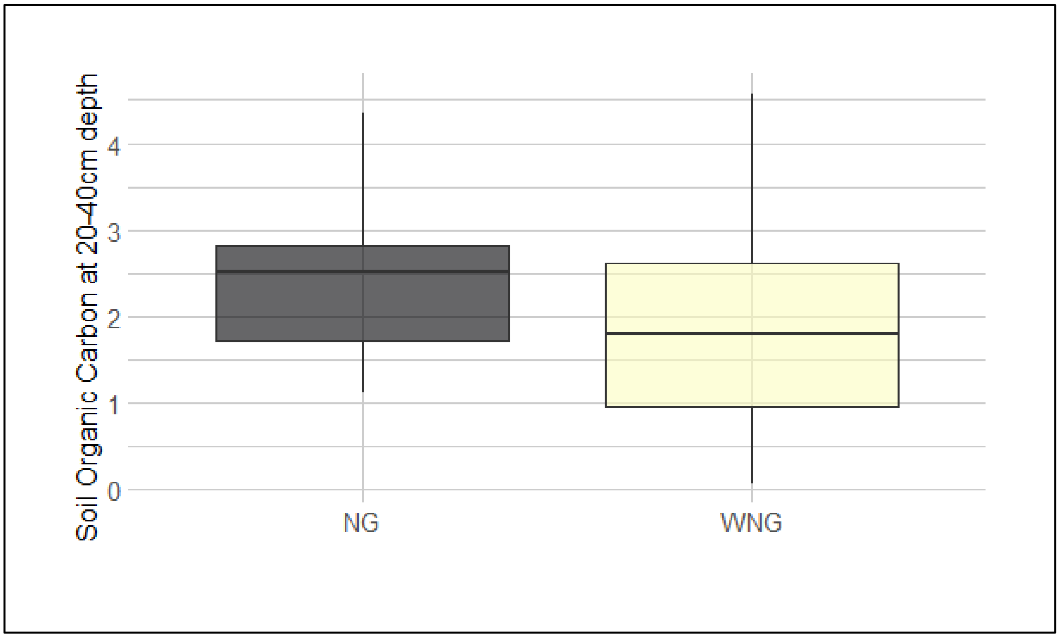

Figure 37. Boxplots comparing soil organic Carbon percent of NG and WNG at 20-40 cm depth

4.4.2.3 Total Soil Nitrogen

The soil samples from two depths in different sample plots were collected and analyzed for determining total soil Nitrogen.

Table 23. Comparison of total soil Nitrogen values for NG and WNG plots

	Total Soil Nitrogen (%) (0-20 cm depth)		Total Soil Nitrogen (%) (20-40 cm depth)	
	Mean	SD	Mean	SD
NG	0.687	0.117	0.601	0.110
WNG	2.087	1.27	1.79	0.96
p value	0.002988*		0.001268*	

The mean value of total soil Nitrogen percent from different plots of NG at 0-20 cm depth is 0.687 and the standard deviation is 0.117. For WNG, the mean value of total soil Nitrogen percent was estimated at 2.087 and the standard deviation at 1.27. The values of NG and WNG at 0-20 cm depth were found significantly different at a 5 % confidence interval (Table 23, Fig.38).

The mean value of total soil Nitrogen percent from different plots of NG at 20-40 cm depth is 0.601 and the standard deviation is 0.110. For WNG, the mean value of total soil Nitrogen percent was estimated at 1.79 and the standard deviation at 0.96. The values of NG and WNG at 20-40 cm depth were found significantly different at a 5 % confidence interval (Table 23, Fig.39).

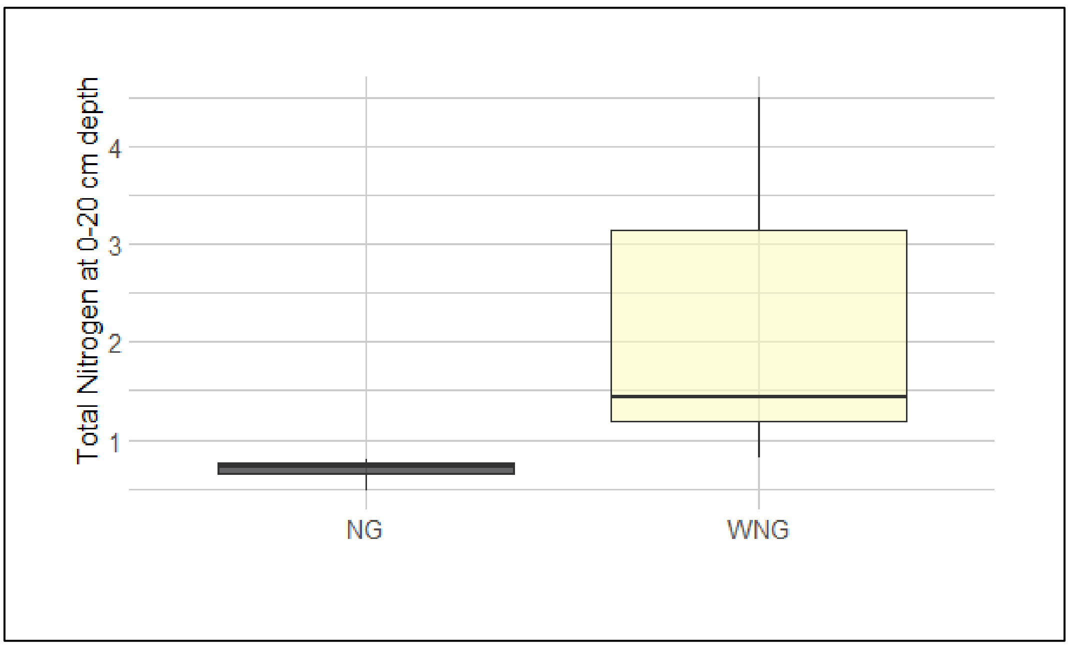

Figure 38. Boxplots comparing total soil Nitrogen of NG and WNG at 0-20 cm depth

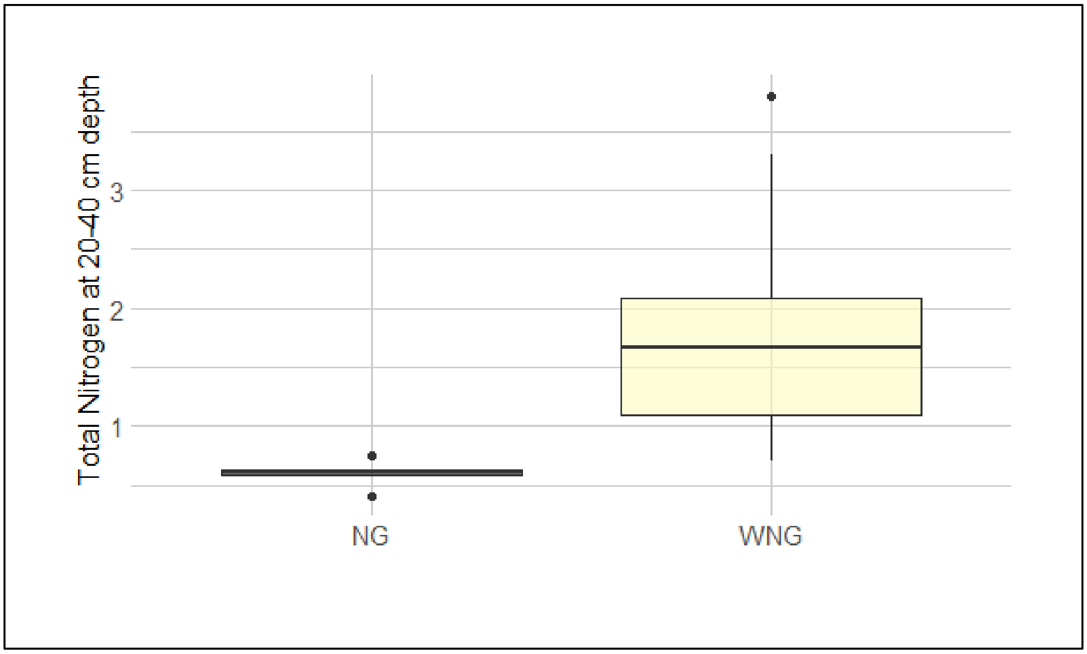

Figure 39. Boxplots comparing total soil Nitrogen of NG and WNG at 20-40 cm depth

4.4.3 Relation of soil physio-chemical parameters with the species-site matrix using Canonical Correlation Analysis (CCA)

Canonical correlation analysis (CCA) was performed to examine the main ways in which the properties of soil were related to those of vegetation. The analysis was done using two different matrix, one containing the species-site data and the other one with the site- soil parameter data.

Table 24. Canonical correlations and redundancy coefficients of the data matrix

	F1	F2
Canonical correlations	1.020	1.000
Redundancy coefficients (vegetation)	0.047	0.088
Redundancy coefficients (soil parameters)	0.199	0.320

The canonical correlations for the first and second canonical functions (or variates) were 1.020 and 1.000, respectively, which were significant using Bartlett's test at a 5 percent significance level (Table 24). The redundancy result in table 24 shows that the redundancy coefficient for first canonical variates for soil properties shows 19 percent of variance and the second canonical variate showed 32 percent variance. The redundancy coefficient for first canonical variates for vegetation data showed 4 percent of variance and the second canonical variate showed 8 percent variance.

Table 25. Intraset correlations between soil variables and the first two CCA axes and correlation matrix of analysed soil variables.

Soil Variables	**Axis 1**	**Axis 2**	**BD**	**MC**	**pH**	**SOC**	**TN**
BD	**0.751**	-0.509	1	0.075	-0.232	0.206	0.361
MC	0.044	**-0.613**	0.075	1	0.004	**0.646**	-0.402
pH	0.242	**0.661**	-0.232	0.004	1	-0.228	-0.189
SOC	-0.241	**-0.688**	0.206	**0.646**	-0.228	1	-0.293
TN	0.523	0.232	0.361	-0.402	-0.189	-0.293	1

In table 25, two canonical variates were extracted and each is identified by soil components with loadings exceeding 0.60. The first canonical variate of soil properties loaded positively and heavily on bulk density while the second canonical variate loaded positively in pH and negatively in moisture content and soil organic carbon.

Table 26. Correlation matrix showing *Nageia wallichiana* and different soil variables.

	Axis 1	**Axis 2**	**BD**	**MC**	**pH**	**SOC**	**TN**
Nageia wallichiana	-0.196	-0.678	0.103	0.748	-0.160	0.733	-0.528

The second canonical variate of vegetation studies loaded negatively and heavily in *Nageia wallichiana*. For *Nageia wallichiana*, the maximum correlation was seen with soil moisture content and organic carbon content. It showed a negative correlation with soil pH value and total nitrogen

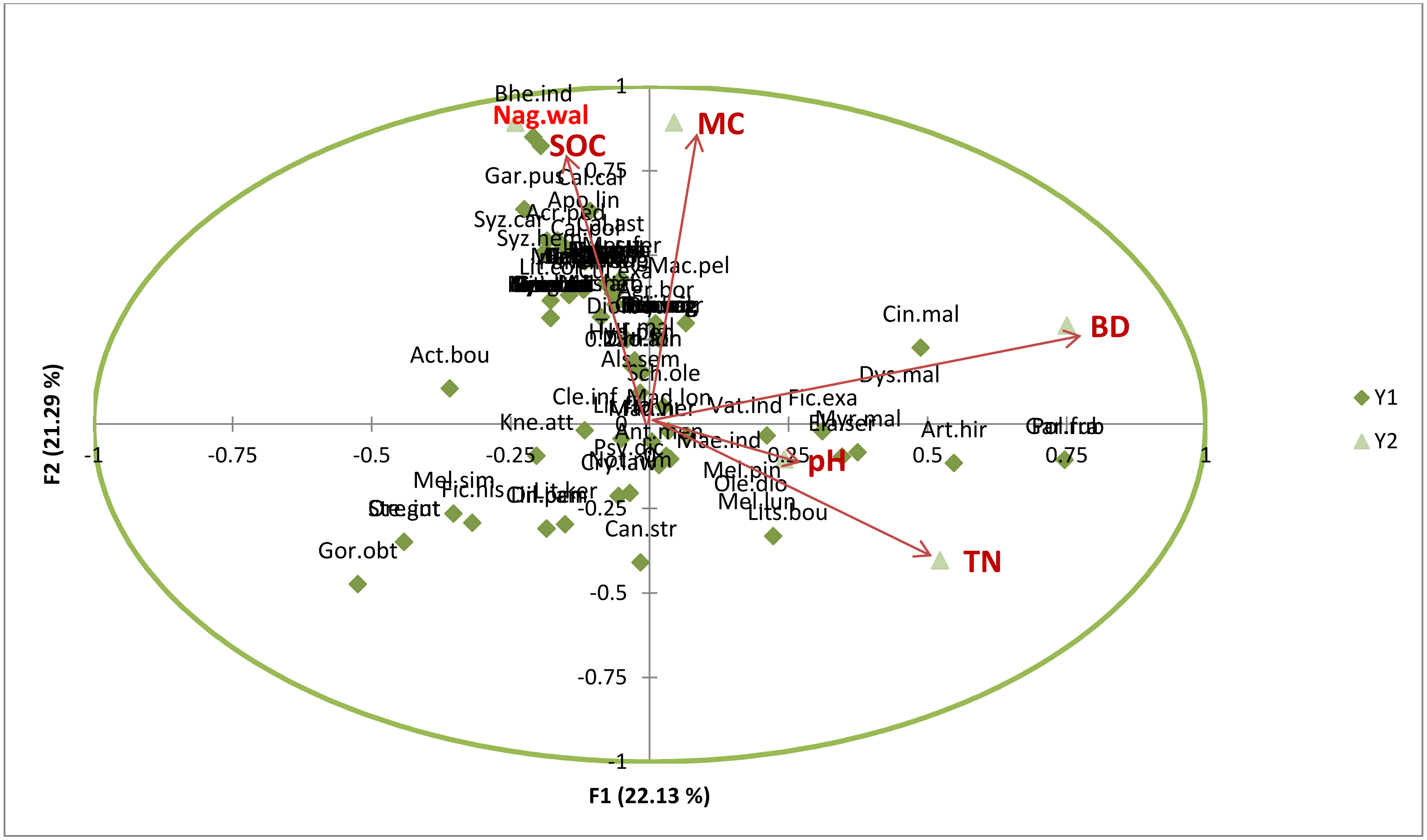

Figure 40. Canonical correlation analysis showing the relation of various soil parameters with the different species.

The canonical correlation analysis using the species-site matrix and soil parameters are shown in the Fig.40. *Nageia wallichiana* and *Bhesa indica* are showing maximum relation with soil organic carbon. Most of the species are distributed near to the axis of moisture content and soil organic carbon which includes *Garcinia pushpangadaniana*, *Calophyllum calaba*, *Aporosa lindleyana*, *Syzygium hemisphericum*, *Syzygium caryophyllatum*, and *Acronychia pedunculata*. *Macaranga peltata* and *Actinodaphne bourdillonii* are distributed in the axis of moisture content.

The various species distributed near to the axis for bulk density are *Vateria indica*, *Ficus exasperata*, *Dysoxylum malabaricum*, and *Cinnamomum malabatrum*. The species seen near to the axes of pH and total nitrogen are *Maesa indica*, *Meliosma pinnata*, *Olea dioica*, *Melicope lunu-ankenda*, and *Litsea bourdillonii*.

DISCUSSION

The result of the study entitled "Ecological status of *Nageia wallichiana* (C.PRESL.) KUNTZE, an endangered conifer of Western ghats in Mankulam forest division is discussed below.

5.1 DISTRIBUTIONAL STATUS OF *NAGEIA WALLICHIANA* IN MANKULAM FOREST DIVISION

The total number of mature trees of *Nageia wallichiana* recorded from the study area was 24 (Table 1) which indicates a lower density of species in the whole Mankulam forest division. The total geographical area of the Mankulam forest division is 9005.72 ha and hence the density of *N. wallichiana* in the area is 0.002 individuals ha^{-1}. The low density of the species can be because of its narrow ecological amplitude (Pascal *et al*., 2004). According to Varghese and Menon (1999) species with low ecological amplitude has a very localized distribution and their growth is dependent on a narrow range of ecological conditions. From the present study, it is clear that the distribution of this species is highly restricted to certain patches of Mankulam forest division where the ecological conditions are ideal and the species can be treated as a 'habitat specialist'.

Hiep *et al*. (2004), described the habitat of *Nageia wallichiana* as primary closed evergreen tropical broad-leaved and mixed submontane and montane forests. According to GoK (2011), the forest types of Mankulam forest division are west coast tropical evergreen forests and west coast semi-evergreen forests which coincides with the habitat specification given by Hiep *et al.* (2004). The previous records of this species in the Western Ghats are from the middle elevation evergreen forests south to Palghat Gap (Osuri *et al*., 2017; Abhilash *et al*., 2005; Kumar *et al*., 2005; Sasidharan, 2004; Pascal *et al*., 2004; Mohanan and Sivadasan, 2002; Augustine, 2000; Ganesh *et al*., 1996). The current study is also not an exception to this.

5.1.1 Altitudinal range of distribution

The present study revealed that the altitudinal range of this species as 934 m – 1463 m above MSL in the Mankulam Forest Division. According to Gupta *et al*. (2002), the altitudinal range of this species is 900-1500 m in India and it is found to be 500 m – 2100 m in Vietnam (Hiep *et al*., 2004). Pascal *et al*. (2004) specified the altitudinal distribution of *Nageia wallichiana* facies as above 1000 m. The altitudinal range founded in the current study is highly comparable to the other studies in the natural habitats of this species.

Fig.3 shows the altitudinal range of this species across the division. A gap is seen in 1100 m to 1250 m which may be due to the absence of ideal ecological conditions for the survival of species as well as due to the higher disturbances from tea cultivation in these altitudinal ranges. The mean altitude of the distribution of *Nageia wallichiana* in the study area is 1295 m above MSL.

While comparing the altitudinal range of this species in different *N. wallichiana* growing patches, a slight difference is observed. In Idathattu as well as the Kannadipara area the distribution was concentrated in higher elevation which is more than 1300 m, while in the Kallar area the distribution was concentrated in 1000-1100 m above MSL (Fig.4). In the Kallar area, the higher elevation forests are highly disturbed. The area had *Alnus* plantations in the earlier time and the remnants of the plantations are still visible. Tea plantations in the forest edges are also prominent in the Kallar area. All the trees observed in this region are deep inside the forests. Still, a few individuals are reported in the altitudinal range of 1300-1400 m in the Kallar area. Even though there are slight variations in the altitudinal range, it is not much significant when comparing to the overall altitudinal distribution of this species.

5.1.2 Girth-class distribution

The girth class frequency-distribution of *N. wallichiana* in the study area (Fig.2) revealed that 90% of the individuals are in girth classes less than 30 cm. With increasing girth class after 30 cm, the number of individuals showed a sudden decrease. Different girth classes from 30 cm to 200 cm are represented by one or two individuals only. The girth class distribution showed an L shaped curve. The distribution is showing a good condition of regeneration for the species but the unusual absence of trees in higher girth classes is a serious matter of concern.

A higher mortality rate or slow growth of trees in intermediate girth classes can be reasons for this kind of distribution (West *et al*., 1981). Podocarps are usually considered as slow-growing because of it's long-lived leaves and low photosynthetic capacity per unit leaf mass (Coomes and Bellingham, 2010). Ogden and Stewart (1995) had given evidence for the slow diameter growth of Podocarpus trees by comparing it with angiosperms in a similar habitat. For Podocarpus species, height growth under optimal conditions is 3‑7 cm yr^{-1}versus 11‑17 cm $yr^{-1}$for subcanopy angiosperms which also indicates the very slow growth rate of the species (Gaxiola *et al*., 2008). Dalling *et al*. (2016) provided the reasons for the slow growth rate of conifers including podocarps as higher leaf mass per unit area and comparatively low mass-based photosynthetic levels, vascular restrictions on leaf size and small conifer wood conduit diameters limiting maximum conductance rates. The mortality rate of Podocarps is identified as less than 1% but the height growth is strongly suppressed by shade (Coomes and Bellingham, 2010). The current distribution pattern showed by *N. wallichiana* in the Mankulam forest division can be attributed to the above-mentioned factors. The Podocarps of cool mountain rainforest in New Zealand have an annual mortality rate of only 2.7%, which means that about 5% of seedlings survived for at least 100 years, but the growth in height was so slow that almost no individuals had gone beyond the seedling stage in the shade (Bellingham and Richardson, 2006). The case of *N. wallichiana* in the present study may be the same where the seedlings are not showing a considerable increase in height for a long time which leads to a discontinuous stand structure of this species in the study area.

The larger trees of *N. wallichiana* were found mostly in areas with short canopy openings and open hilltops in the study area. This pattern in the distribution of the *N.*

wallichiana trees may be the consequence of direct competition for light with other well-established evergreen species such as *Cullenia exarillata* or *Palaquium ellipticum*. In a study done by Akkarasedthanon *et al*. (2017), the maximum number of individual trees of *Nageia wallichiana* observed were in the diameter classes of 0-20 cm GBH and 10-20 cm GBH which accounted for 51% of the total trees encountered in the study. It points out a general trend of this species to have a higher regeneration but a poor growth rate. The study also indicated a positive relationship between the occurrence of *N. wallichiana* seedlings and the canopy cover which disclosed the shade-tolerant nature of the species. Coomes and Bellingham (2010) suggested that while competition from angiosperms excluded the imbricate leaved Podocarpus from lowland tropical forests, the genus *Nageia* because of its broad leaves and anastomosing veins are shade tolerant and they can regenerate below-closed canopy.

5.2 FLORISTIC STRUCTURE OF THE STUDY AREA

5.2.1 Spatial structure of tree communities in the study area

The girth class distribution of the tree communities in the *Nageia wallichiana* growing areas (Fig.5) and areas without *N. wallichiana* (Fig.6) are totally different. In NG, with an increase in size class, the number of individuals first showed a sudden increase, and then it was decreasing gradually. The distribution curve can be better described as a negatively skewed distribution or simply as a convex one which is comparable to Saxena and Singh (1982). The bulging of the curve in the early middle region may indicate less mortality and a fast growth rate of trees in the intermediate girth classes (West *et al*., 1981; Saxena and Singh, 1982). The current distribution showed more number of individuals in the intermediate girth classes and it was decreasing towards both sides. According to Knight (1975), such a distribution represents infrequent reproduction of the trees in the community and also the trees are not reproducing as well as in the past.

In WNG, the distribution showed an L shaped curve with very few numbers of individuals in the larger girth classes. This structure represented a frequent regeneration of the trees in this area (Knight, 1975). The individual tree species in this area were more or less capable of reproducing in the understory. The vegetation in this area might have become more abundant in the later stages.

While comparing NG and WNG, the number of individuals per hectare and basal area per hectare is highest for areas without *Nageia wallichiana* (WNG). The difference is mainly because of the presence of a large number of trees in lower girth classes in WNG. Memiaghe *et al*. (2016), suggested that high levels of diversity within small diameter groups can provide high levels of resistance to the anthropogenic or natural disturbance in these forests which can be true in the case of WNG in the present study. The density of trees in NG is estimated at 313 individuals ha^{-1} which is low compared to the density of trees in *Nageia wallichiana* habitats of Goodrical reserve forest which was reported as 588 individuals ha^{-1} (Abhilash and Menon, 2009). Jeyakumar *et al*. (2017), while comparing logged and unlogged forests of southern Western Ghats found roughly similar values for the basal area in both categories and it accounts for 43.2 and 51 m^2 ha^{-1} respectively. The values are much higher than the current study.

From the details on girth class distribution, density, and basal area, the *Nageia wallichiana* growing areas in the present study can be considered in a late-successional stage. According to Franklin *et al*. (2002), large persistent trees are defining characteristics of late-successional forests. The *N.wallichiana* growing areas are showing wide variation in tree density and size across the landscape which also indicates the late-successional stage of the forest in the study area (Kane *et al*., 2011). At the same time, the areas without *N. wallichiana* (WNG) are showing a large number of individuals in lower girth classes and very few individuals with girth greater than 200 cm. According to Arroya-Mora (2002), the canopy of forests in the intermediate successional stages is two-layered and with an average height of 10 m which is comparable with the areas without *Nageia wallichiana*. The area can be considered in an intermediate successional stage. *N.*

wallichiana might have invaded these areas as well due to the accomplishment of ideal ecological conditions.

In a study by Osuri *et al*. (2020), the tree density, as well as basal area, was found positively correlated with species richness but the current study is an exception to this in which NG having the highest species richness was found to be low in tree density and basal area. They also found a lower value of tree density and basal area in disturbed forests. The tree growth is considered as highly variable in tropical forests (Feeley *et al*., 2007). In order to further understand the growth variations of tree species in the forest, a detailed assessment of species distribution, environmental and genetic factors, ecological history, and prevailing management practices is needed (Padmakumar *et al.*, 2018).

5.2.2 Floristic composition and community structure of trees of NG and WNG

The present study recorded 67 different species of trees from 0.6 ha of *N.wallichiana* habitat (Table 3). A similar study conducted in natural habitats of *N. wallichiana* in Goodrical reserve forest by Abhilash and Menon (2009) recorded 43 and 41 species each from two different sites of 0.5 ha. The species richness of the two studies is comparable.

5.2.2.2 Floristic diversity

The floristic diversity of the study area was analyzed using various diversity indices (Table 9). The diversity indices quantify the biodiversity based on two important features – species richness and evenness (Stirling and Wilsey, 2001). In the present study, four different measures of diversity were calculated for comparing the sites. From the estimated values of a first-order jack-knife, gamma diversity for both sites, expected species richness for the entire study area of NG is found to be 104.5 and for WNG it is 67.9. From this, it is evident that *Nageia wallichiana* habitats are expected to be higher in species richness compared to WNG (Table 9).

Table 27. Comparison of Diversity indices of various studies in Southern Western Ghats

Study Sites	**Reference**	**Simpson's index(1-D)**	**Shannon index**	**Remarks**
Amaggal reserve forest, Nilgiris	Mohandass *et al*., 2016	0.95	3.24	Mid-elevation tropical montane evergreen forests (sholas)
Kakachi forests of KMTR	Giriraj *et al*., 2008	0.956	4.89	Mid elevation evergreen forest belonging to the *Cullenia–Mesua–Palaquium* type
New Amarambalam reserve forests	Sharma *et al*., 2002	0.93		Wet evergreen forests
Sengaltheri, Agasthyamalai	Parthasarathy, 2001		3.69	*Cullenia–Mesua–Palaquium* type
Kodayar, Kanyakumari	Sundarapandian and Swamy, 2000	0.85	2.64	Mid elevation evergreen forests
Varagalaiar, Anamalais	Ayyappan and Parthasarathy (1999)	0.966	3.93	Tropical evergreen forests- *Cullenia-Mesua-Palaquium* and *Dipterocarpus-Mesua-Palaquium* type
Kalakad National park	Parthasarathy, 1999		3.66	Undisturbed sites -*Cullenia–Mesua–Palaquium*
Kalakad National park	Parthasarathy, 1999	-	3.67	Disturbed sites
Kaka chi forest, Agasthyamalai	Ganesh *et al*., 1996	-	4.87	Mid elevation evergreen forest: *Cullenia–Aglaia– Palaquium*
Uppangala forest, Kodagu district	Pascal and Pelissier, 1996	0.92	4.56	Wet evergreen forests: *Dipterocarpus-Kingiodendron- Humboldtia* type
Attappadi RF	Pascal, 1988	0.90	4.0	Mid elevation evergreen forest: *Cullenia–Mesua–Palaquium* type
NG (current study)		**0.972**	**3.85**	
WNG (current study)		**0.971**	**3.66**	

The indices are aimed at defining the general properties of communities that allow the researcher to keep comparing different regions (Morris *et al*., 2014). Table 18 gives the Shannon and Simpson index of different studies from different sites of medium elevation evergreen forests of Southern Western Ghats. The habitat type is nearly comparable to the present study. Many of the sites described in the table are included in the *Cullenia–Mesua– Palaquium* series described by Pascal (1988) which is applicable to the current study site also. Simpson's diversity index of the study site is slightly higher than other studies across the southern Western Ghats. The value of Simpson's index as 0.97 indicates that among the randomly selected 100 individuals from the site, 97 individuals will be of different species. The usual value of Simpson's index of diversity in the other sites ranged from 0.90 to 0.96 (Table 27) which is not very different from the present study. Comparing NG and WNG based on Simpson's index showed that the difference in diversity of the sites is negligible.

The Shannon-Weiner's index H' is 3.85 and 3.66 for NG and WNG respectively. This corresponds to good value for the evergreen formations of the southern Western Ghats. The mid-elevation evergreen forests of Western Ghats is showing a wide range of Shannon-Weiner's index values from 2.5 to 4.9 (Table 27). The comparatively medium value of Shannon-Weiner's index value (H') of the current study can be attributed to the fact that H' is more sensitive to the effect of rare species (Abhilash and Menon, 2009). Shannon's index is distributed around 3.6 and 4.3 for the Western Ghats' climax evergreen forest (Varghese and Balasubramanyan, 1999) which is comparable with the current study also. From the H' value, it is clear that even if NG is slightly more diverse than WNG, the difference is not much significant.

The Margalef index evaluates species richness and is particularly susceptible to sample size as it tries to compensate for the effects of sampling (Magguran, 2004). In the present study, a higher value of the Margalef index was estimated for NG (12.63) comparing to WNG (9.68) but the difference may be due to the higher area sampled for NG as the index gives the estimate of species richness. The Margalef diversity index for moist deciduous and dry deciduous forests of Mudhumalai was estimated as 8.31 and 6.28 respectively (Reddy *et al*., 2008) which is lower than the current study. Varghese and Balasubramanyan (1999) recorded the Margalef index value for the evergreen forests of the Agasthyamalai region as 7.07. Margalef species richness in the *N. wallichiana* growing patches of Goodrical reserve forest was estimated as 22.7 and 22.1 in two different sites (Abhilash and Menon, 2009). These estimates indicate that the Margalef index is highly dependent on the sample size and the direct comparison based on this is often difficult.

Evenness is the degree to which individuals are divided among species with low values suggesting that one or more species dominate, and high values mean that fairly equal numbers of individuals belong to each species (Morris *et al*., 2014). In the present study, evenness is higher for WNG compared to NG (Table 9) which means that NG is dominated by a few species while WNG has a more or less equal distribution of individuals in each species. Varghese and Balasubramanyan (1999) recorded an evenness value of 0.89 in the evergreen forests of the Agasthyamalai region which is higher compared to the present study. The evenness is further higher for the evergreen forests of Kodayar which is 1.69 (Sundarapandian and Swamy, 2000). The evenness value estimated by Giriraj *et al*. (2008) was 0.79 in wet evergreen forests of the Kakachi range of Agasthyamalai. The evenness value for moist deciduous forests of the Veerakkal area of Nilgiris was estimated as 2.18 (Ramya *et al*., 2020). Evenness is comparatively lower for the present study which indicates a less even distribution of individuals among species in the present study.

5.2.2.3 Community structure of trees

The most dominant tree species in NG is *Cullenia exarillata* followed by *Mesua ferrea,* and *Bhesa indica* (Table 4, Fig.7). This is highly comparable with the *Nageia wallichiana* habitats of Goodrical reserve forests (Abhilash and Menon, 2009). *Cullenia exarillata* was the second most dominant species in their study while *Palquium ellipticum* was the most dominant one. In the present study, *Palquium ellipticum* is in the sixth position of dominance. *N. wallichiana, C. exarillata,* and *B.indica* are three of the six better indicators of ecological conditions described by Pascal *et al*. (2004). These three species are designated as better indicators because of it's narrow ecological amplitude. This shows the importance of the study area as well as the peculiarity of these species as habitat specialists. The dominance of *N. wallichiana* in the study area may be an effect of purposive sampling in the study site. IVI is a measure of Relative density, relative frequency, and relative basal area of each species (Curtis and McIntosh, 1950; Phillips, 1959) and all these factors were being affected by purposive sampling. Even though *N. wallichiana* was showing a higher density and basal area, its dominance cannot be considered as significant. Among the three most dominant species of NG, none of them are endemic to the Western Ghats or included in the threatened category of trees. The dominant species in WNG are *Dysoxylum malabaricum, Vateria indica,* and *Polyalthia fragrans* (Table 7, Fig.9). All of these three species are endemic to the Western Ghats but are having a wide range of occurrences in their habitat. The higher IVI of *Dysoxylum malabaricum* is mainly because of it's large basal area. One of the secondary species such as *Macaranga peltata* was also having a higher contribution of IVI in WNG regions.

The species composition of the study area (NG) indicated its similarity to the medium elevation evergreen forest types described by Pascal (1991). The forests of NG can be included in the *Cullenia exarillata- Mesua ferrea – Palaquium ellipticum* type defined by an altitudinal range of 700-1400m, latitudinal range of 8^0 20'-11^0 55', annual rainfall ranging from 3000 mm -5000 mm, and with a dry season of 2 to 5 months. Comparison of the phytosociological aspects of the present study with the forests categorized as *Cullenia- Mesua –Palaquium* is expected to give valid conclusions.

The most dominant species identified in Varagalaiar (Ayyappan and Parthasarathy, 1999) are *Drypetes longifolia, Dipterocarpus indicus, Poeciloneuron indicum,* and *Reinwardtiodendron anamallayanum* which all belong to different storeys of wet evergreen forest. Among these species, *Reinwardtiodendron anamallayanum* is the only species reported in the current study that too with a low IVI value. Giriraj *et al*.

(2008) identified the most dominant species in Kakachi forests of KMTR as *Cullenia exarillata* followed by *Palaquium ellipticum* and *Aglaia bourdillonii.* The IVI of *Cullenia exarillata* (33.35) in the Kakachi forest is significantly higher than the present study. According to Parthasarathy (2001), the predominant species in undisturbed medium elevation evergreen forests of Sengaltheri of the Agasthyamalai region were *Toona ciliata* and *Litsea stocksii* which are not reported in the current study. The dominant trees in Kalakad national park reported by Parthasarathy (1999) are *Cryptocarya bourdillonii*, *Myristica dactyloides, Harpullia arborea, Mangifera indica, Cullenia exarillata,* and *Palaquium ellipticum.* The dominant species have similarities with the present study. In a study by Ganesh *et al*. (1996) in the Agasthyamali region, the dominant species identified are *Cullenia exarillata*, *Aglaia elaeagnoidea,* and *Palaquium ellipticum*. *Agrostistachys borneensis* is also an important species in the area with an IVI of 18.94. The IVI value of *Cullenia exarillata* in the study is 40.18 which is much higher compared to the present study. In the Uppangala forests of Kodagu district, the dominant species identified were *Vateria indica*, *Myristica dactyloides,* and *Humboldtia brunonis* (Pascal and Pelissier, 1996) which is totally different from the current study. The dominant species identified by Pascal (1988), in the Attappady area were *Cullenia exarillata*, *Aglaia anamallayana*, and *Palaquium ellipticum*. The IVI value of *C. exarillata* in the Attappady area was recorded as 39.6. Various studies in the medium elevation evergreen forests of Western Ghats identified *Cullenia exarillata* and *Palaquium ellipticum* with some other characteristic species as the most dominant ones. The present study is also not an exception to this. In the *N. wallichiana* habitats of Mankulam, apart from *Cullenia exarillata*, *Mesua ferrea* and *Bhesa indica* contributed to the floristic composition to an higher extent.

The most important families in NG are Clusiaceae, Euphorbiaceae, and Lauraceae (Table 5, Fig. 8). The highest family importance value for Clusiaceae is because of the presence of *Mesua ferrea*, *Garcinia pushpangadaniana,* and four different species of *Calophyllum*. Seven different species including *Agrostistachys borneensis* and *Drypetes* contribute to the dominance of the Euphorbiaceae family. A higher diversity with the presence of 11 different species makes Lauraceae an important family in the area. Pascal (1991) described the dominant families in medium elevation evergreen forests as Bombacaceae (with the presence of *Cullenia exarillata*), Sapotaceae (*Palaquium ellipticum* and related species) and Clusiaceae (*Mesua*, *Calophyllum*, and *Garcinia*). In the present study Malvaceae (present family of *Cullenia*) as well as Sapotaceae are having a comparatively lower dominance while Clusiaceae dominated the area with a Family Importance Value of 49.67. According to Pascal (1991), Euphorbiaceae is identified as one of the characteristic family of *Cullenia-Mesua-Palaquium* type, while Lauraceae members become more abundant with an increase in altitude. The important families in WNG are Meliaceae and Lauraceae with 41.8 and 38.9 family importance values respectively (Table 8, Fig. 10). The dominance of Meliaceae is mainly attributed to the higher basal area and density of *Dysoxylum malabaricum* alone while the dominance of Lauraceae is because of the higher abundance of different species of the family. The dominance of Lauraceae may be due to the fact that some of the plots in WNG was at a higher altitude.

5.2.2.4 Distribution pattern of different species

The abundance to frequency ratio (AB/F) in a floristic community is a measure of contiguousness or the distribution pattern of different species in the area. The values less than 0.025 indicates a regular distribution pattern, values in between 0.025 and 0.05 indicates the random distribution and values greater than 0.05 points out the contiguous distribution (Curtis and Cottom, 1956). In the current study, 37 species of NG are showing random distribution and 30 species are showing the contiguous distribution pattern (Table 4). According to Odum (1971), contiguous distribution is the commonest distribution seen in nature while random distribution occurs in the uniform environment. Abhilash and Menon (2009) recorded contiguous and random distribution mostly in *N.wallichiana* growing areas of Goodrical forests but very few individuals in the study showed regular distribution also. The study doesn't record any species having regular distribution. In WNG all the species are showing contiguous distribution (Table 7). The uniform environment conditions of NG may be the reason for the random distribution of the majority of species there. *Nageia wallichiana* is showing an AB/F value of 0.05 which is exactly equal to the value provided by Abhilash and Menon (2009) indicating a random distribution pattern of the species. Looman (1979) states that the pattern of distribution that exists in a given community partly depends on the habitat and its history and partly on the characteristics of the species in that community.

5.2.2.1 Proportion of endemic and threatened trees

The endemic trees in NG accounted for 52.23% of the total tree species in the study area and 46.27% of total individuals (Fig.11 and Fig.12). The percent of endemism is comparatively less in WNG which is 31.91 and 31.11 for the total number of individuals and number of species respectively (Fig.11 and Fig.12). The proportion of endemic trees is highly comparable with other studies done in wet evergreen forests of Southern Western Ghats. The higher proportion of endemic trees in the *Nageia wallichiana* habitats were reported by Abhilash and Menon (2009) also. The composition of endemic trees in their study in Goodrical reserve forests accounted for 54.4% and 60.2% of total woody flora in two different *N. wallichiana* growing sites. Giriraj *et al*. (2008) reported 51% of trees as endemic in a study conducted in the Agasthyamalai region. According to Nayar (1996; 1997), the endemic species in a geographic region's flora reflects the area's biogeography, the center of speciation, and adaptive evolution. Neikha and Nagaraja (2019) identified 26 tree species out of 68 species as endemics of Western Ghats. Ramesh and Pascal (1997), stated that 63% of woody flora in the medium and low elevation evergreen forests of Western Ghats are endemic. The study by Varghese and Menon (1999) in the tropical and montane subtropical forests of Peppara wildlife sanctuary recorded 41% of endemism in the area. Varghese and Menon (1999) specified that the number of endemic trees is greater in climax forests than in secondary forests or intermediate successional stages. The study reported a low percentage of endemism in southern secondary forests (10.25%). Bhagwat *et al.* (2005) also reported a higher proportion of endemics in primary forests than in other land-use types. Das *et al*.

(2006) also pointed out the importance of endemic trees in identifying and prioritizing conservation areas of Western Ghats. In the current study, a higher level of endemism in NG indicated the climax condition of the habitat while lower endemism percentage in WNG can be due to its characteristics as secondary forest. The higher degree of endemism in *N. wallichiana* habitats may be due to unique specialized niches and micro-climatic conditions prevailing in these forests (Odum, 1971; Varghese and Menon, 1999).

While analyzing the presence of threatened category tree species in NG and WNG (Fig.13), NG consists of 8 vulnerable tree species and 2 endangered trees which accounted for 11.9 % and 2.9 % of total trees encountered in the area respectively. In WNG, the proportion of threatened trees is considerably low. Three trees in the ‘Vulnerable’ category and one species in the ‘Endangered’ category were identified from the study area which accounts for 6.5% and 2.17 % of total species respectively. Varghese and Menon (1999) identified 8 threatened species out of 151 total tree species from Peppara (5.29%) which is a lower proportion compared to the present study. The discovered threatened species in their study were from climax evergreen forests and Myristica swamp forests, while the secondary forests lack the rare and threatened species. This result pointed out the healthy ecological conditions of forests in *N. wallichiana* growing areas. The categorization of threatened species is mainly based on different factors such as geographical range, population, and fragmentation (IUCN,1994).

5.3 DIFFERENCE IN SPECIES COMPOSITION OF NG AND WNG

Sorenson similarity index was used for the primary analysis of the distribution of species similarity between NG and WNG in the current study. The obtained value of similarity index 0.217 indicated a greater difference in the species composition of both sites. Ayyappan and Parthasarathy (1999) recorded the similarity between thirty 1 ha plots in the tropical evergreen forests of Varagaliar and the Sorenson similarity index value obtained was in the range of 0.7 to 0.9 which indicated the homogeneity in species composition of the area. Jeyakumar *et al*. (2017) got the range of Sorenson's similarity index from 0.41 to 0.76 and maximum similarity was observed between unlogged plots of the study area. Soosairaj *et al.* (2005) in a vegetation study at Pachaimalai hills of Thiruchirappalli estimated the maximum value of similarity as 0.5 between dry evergreen and semi-evergreen forests of the area. The value obtained in the present study is roughly equal to the Sorenson index value between semi-evergreen forests and dry deciduous forests in the study at Pachaimamali hills (Soosiraj *et al*., 2005). This indicates a higher difference in species composition between NG and WNG in which both can be considered as totally different ecosystems.

The ecological distance between two sites is a single statistic that is calculated for expressing the difference in species composition. This is a measure used by ecologists to assess the dissimilarity between plots to explore the mechanism of community assembly (Ricotta and Podani, 2017). The ecological distance would be minimal between locations that share much of their species. The ecological distance should be large if sites have little species in common (Kindt and Coe, 2005). The present study calculated the Bray-Curtis distance between all the 18 plots in the study area. When the distance equals 1 they are completely dissimilar, which means that they do not share any species. For 65 different pair-wise comparisons the Bray-Curtis distance value was calculated as 1.000 which indicates that none of those plots have common species to share (Table 11). The Bray-Curtis distance is calculated from differences in the abundance of each species. Because of this calculation method, the final distance will be influenced more by species with the largest differences in abundances (Kindt and Coe, 2005). From the results of the t-test on ecological distance values within the plots of NG & WNG and between the plots of NG & WNG, a significant difference was found (p-value:5.364e-05). This indicated a significant difference in species composition between NG and WNG.

A cluster analysis was done for understanding the differences in species composition further. The cluster analysis organizes the sites into groups. Clusters are created from sites that are identical in the composition of species, as determined by a specified ecological distance. Cluster analysis gives an overview of the similarities in the composition of different species in various sites. Sites grouped into one cluster are more similar in the composition of species than sites grouped into different clusters (Kindt and Coe, 2005). The different plots are clustered at a divisive coefficient of 0.25, the sites are classified into 4 groups (Fig.17). Among the sites 13, 14, 15, 16, 17, and 18 were plots in *N. wallichiana* habitats and all of them are grouped together. The results clearly indicated that the species composition in the plots of NG is significantly distinct from that of WNG.

5.4 SPECIES ASSOCIATIONS OF *NAGEIA WALLICHIANA*

As a conifer species with distribution across the wide geographical range in the Southern Hemisphere (Farjon, 2010; Farjon and Filer, 2013), the species associations of this tree may significantly vary between its occurrence ranges. The present study analyzed the major species association of *N. wallichiana* using different ordination techniques. From the PCA and DCA plots of the species and sites of NG, it is evident that *Bhesa indica* is a major association of *N. wallichiana* in the study area (Fig.18 and Fig.19).

Ordination techniques geometrically arrange sites and species so that distance between them represents the ecological distances. The ordination plots reflect the correlation between species in a better way. The species are expected to have a small angle between their vectors to be strongly correlated. Species with vector angles of 90 or 270 degrees are not supposed to be correlated and species with angles of 180 degrees are predicted to be strongly negatively correlated (Kindt and Coe, 2005). From Fig.18, the species that are having a strong correlation with *N. wallichiana* are *Bhesa indica*, *Turpinia malabarica*, *Diospyros foliosa*, *Diospyros bourdillonii*, *Litsea wightiana*, *Calophyllum calaba*, *Acronychia pedunculata*, *Vernonia arborea*, *Lepisanthes tetraphylla* and *Aporosa lindleyana*. Some of the negative correlates of *Nageia wallichiana* was identified as *Ficus hispida*, *Ficus virens*, *Cinnamomum malabatrum*, *Maesa indica*, *Sterculia guttata*, *Dillenia pentagyna* and *Melicope-lunu-ankenda* among which many of them are secondary species in an evergreen ecosystem. At the same time, the most dominant tree species of NG such as *Cullenia exarillata*, *Mesua ferrea,* and *Palaquium ellipticum* were found not to be correlated with *Nageia wallichiana*.

The detrended correspondence analysis (DCA) was also applied in the site-species data matrix in order to check the magnitude of change in species composition along the ordination axis (Hegazy *et al*., 2008). The DCA ordination of the species matrix of NG (Fig.19) shows the separation of species into three different species assemblages. The assemblage constituting *Nageia wallichiana* has other species such as *Bhesa indica*, *Turpinia malabarica,* and *Litsea wightiana*, which demonstrates the strong species, associates, with *Nageia wallichiana*. *Cullenia exarillata*, *Mesua ferrea* and *Palaquium ellipticum*, the members of one of the strong species association in medium elevation evergreen forests of the Western Ghats identified by Pascal (1988) are grouped into a single assemblage in the study area. In WNG, four different species assemblages were identified (Fig.20). This may be because of the fact that WNG covers a range of altitude and a variety of forest patches across the whole Mankulam forest division. None of the assemblages in WNG showed similarities to the assemblages in NG.

In Vietnam, *Nageia wallichiana* is found associated with *Dacrycarpus imbricatus*, *Cephalotaxus mannii*, *Podocarpus neriifolius,* and *Taxus wallichiana* (Hiep *et al*., 2004) in which all of them are Coniferae members. In Kerangas also it is seen associated with conifers (Farjon, 2010). In Southern China as well as in New Guinea, the associates of this tree are members of Fagaceae, *Podocarpus,* and *Araucaria* (Farjon, 2010). Pascal *et al*. (2004) identified the tree species characteristic of *Nageia wallichiana* facies in the southern Western Ghats as *Diospyros atrata*, *Elaeocarpus venustus*, *Eugenia floccosea*, *Aglaia bourdillonii*, *Actinodaphne campanulata,* and *Syzygium microphyllum.* None of the species mentioned by Pascal *et al.,* (2004) were recorded in the current study. A few floristic studies in Southern Western Ghats reported the occurrence of *Bentinckia condapanna* along with *N. wallichiana* (Pascal *et al*., 2004; Parthasarathy, 2001; Giriraj *et al*., 2008). But the current study didn’t find any individuals of *Bentinckia condapanna* in natural habitats of *N. wallichiana* in the Mankulam forest division. The presence of one of the endemic Garcinia species, *Garcinia pushpangadaniana* in NG was significant. It is present in 4 out of 6 plots of NG and found to be a good associate of *Nageia wallichiana* in the study area (Fig.18). The species was first described from the Kadalar region (Sabu *et al*., 2013) which is nearer to the present study area. It is identified as endemic to the semi-evergreen forests of the Southern Western Ghats of Kerala (Thiruvananthapuram, Idukki and Wayanad districts) and Tamil Nadu (Coimbatore district) in elevations between 850 and 1400 m.

5.5 REGENERATION OF TREES IN *N.WALLICHIANA* HABITATS

Regeneration of the trees belong to upper strata has greater importance in deciding the future of the forest community. Biotic factors such as density on seed and seedling survival and recruitment are considered to be critical in sustaining the diversity of tropical humid forests (Connel, 1978). The current study attempt to analyze the condition of regeneration of predominant tree species in natural habitats of *N. wallichiana*. The forest regeneration status was evaluated by analyzing various characteristics (species richness, diversity, and assemblages) of the present tree populations (large trees) with the regenerating tree species populations (seedlings and saplings) following Anitha *et al*. (2010).

From a total sampling area of 654 m^2, 233 regenerating individuals belonging to 54 different species were recorded and the maximum number of individuals were in the sapling stage (125) followed by established seedlings (90). The area surveyed for saplings was greater than seedlings which may be the reason for a higher number of saplings encountered in the study area. Abhilash *et al*. (2005) recorded 1659 individuals in *N. wallichiana* habitats of Goodrical reserve forest from an area of 0.15 ha. Chandrasekhara and Ramakrishnan (1994) recorded 135 individuals per 0.15 ha in the wet evergreen forests of Nelliyampathy and Osuri *et al*. (2017) observed 651 regenerating individuals per 0.15 ha in Valparai forests. The density of regenerating individuals in the current study is 534 individuals per 0.15 ha which is considerably low compared to Abhilash *et al*. (2009) and Osuri *et al*. (2017) but higher than

Chandrasekhara and Ramakrishnan (1994). Basha (1988) recorded 28 regenerating species per 0.19 ha from evergreen forests of Silentvalley and Abhilash *et al*. (2005) recorded 53 species from 0.15 ha of the sampling area. The number of regenerating species recorded by Osuri *et al*. (2017) was 110 from a sampling area of 0.225 ha. The number of species encountered is comparatively higher in the present study. The higher establishment rate, as well as the slow growth rate of species under the shaded canopy, maybe a reason for the higher number of seedlings in the established category.

In the regeneration analysis done in Nelliyampathy forests (Chandrasekhara and Ramakrishnan, 1994) the number of species was reported to lesser for seedlings (11) while density was higher. In the study at Goodrical reserve forest (Abhilash *et al*., 2005), the maximum proportion of regenerating categories was unestablished seedlings followed by advanced growth. But the current study showed a completely reverse pattern with a maximum number of individuals has established seedling and sapling categories. The results showed a high rate of seedling establishment in the study area.

5.5.1 Spatial structure of seedlings and saplings

The density of saplings in the study area was found to be 2083 individuals per ha while that of seedlings was 20400 individuals ha^{-1} (Table 12). Chandrasekhara and Ramakrishnan (1994) recorded the density of saplings and seedlings as 900 individuals ha^{-1} and 20500 individuals ha^{-1} respectively. Saplings density was comparatively higher in the present study while seedling density was almost similar to other studies. Higher sapling diversity is also indicating a higher rate of seedling establishment in the study area which may be due to the ideal edaphic conditions and light availability.

5.5.2 Seedling and sapling diversity

The higher value of the Simpson diversity index is calculated for trees (0.97) followed by saplings (0.96) and least for seedlings (0.92) (Fig.25). The Simpson diversity index showed high value for all three categories. The difference in the Simpson diversity index value between trees and saplings are very negligible. The Simpson index of diversity reported by Chandrasekhara and Ramakrishnan (1994) for trees, seedlings, and saplings are 0.91, 0.89, and 0.87 respectively which is comparatively lower than the current study. The difference in diversity between all three categories is less in this study also. The Simpson index of diversity for saplings and seedlings in the *N.wallichaiana* habitats of Goodrical reserve forest is calculated as 0.93 and 0.90 in one site and 0.96 and 0.92 in another site (Abhilash *et al*., 2005).

The Shannon-Weiners index is also showing a similar pattern for different categories in the study area (Fig.25). The values are given by Chandrasekhara and Ramakrishnan (1994) and Abhilash *et al*. (2005) are much lower than the present study. Anitha *et al*. (2010) gave the values of the Shannon-Weiner index for trees, saplings, and seedlings as 3.84, 3.32, and 3.36. This study shows a different case of higher diversity for seedlings than saplings. The values are highly comparable to the present study. The higher diversity of regenerating individuals in the study area is an indicator of ideal ecological conditions and continuity of essential ecological processes such as pollination and seed dispersal in the study area (Anitha *et al*., 2010).

The Margalef index value for trees, saplings, and seedlings in the present study is 12.63, 8.73, and 7.28 respectively (Fig.25) while that of Goodrical reserve forest was 18.89 and 18.35 for saplings and seedlings respectively. The comparatively lower Margalef index value of the current study site can be attributed to the less sampling area. From the analysis of diversity indices, it is evident that the study area had a higher diversity of regenerating categories in comparison with other similar studies. The diversity of saplings is always higher than seedlings and the tree and sapling diversity are almost comparable. The evenness value is found higher for saplings than trees and seedlings (Fig.25) which indicates a better condition of established seedlings of different species in the area.

The regeneration of species is identified as an indicator of the well-being of the forests (Murthy *et al*., 2002). The diversity of regenerating individuals is known to have a negative correlation with the disturbance factors such as illicit felling, grazing, looping, and fuelwood collection (Anitha *et al*., 2010). The regeneration is mostly affected by a forest fire (Sukumar *et al*., 1992) and logging (Guariguata and Dupuy, 1997). The higher diversity as well as the density of regenerating individuals in the present study indicated that the disturbances are less in the study area. The area is also devoid of forest fires and logging which may be the reason for the healthy regeneration of the study area.

5.5.3 Phytosociological analysis of regenerating species

The distribution of the number of individuals per species of saplings and seedlings is given in Fig.21 and Fig.23 respectively. The maximum number of individuals for both seedlings and saplings category was of *Nageia wallichiana*. The high abundance of species may be due to purposive sampling although the condition of regeneration of *Nageia wallichiana* is good. The other most abundant species in the seedling stage are *Actinodaphne bourdilloni* and *Dysoxylum malabaricum* while in the sapling stage it is *Agrostistachys borneensis* and *Actinodaphne bourdillonii*. The distribution pattern for seedlings and saplings can be considered as reverse J shaped. It is observed that the poor regeneration of *Cullenia exarillata*, which is the most dominant species of the overstorey in the area as it is absent in both seedling and sapling categories. According to Devy (2006), the seeds of *Cullenia exarillata* is known to be dispersed mechanically or by certain mammal species such as Lion-tailed macaques. The pollination is also dependent on mammals. In fragmented areas, the rate of pollination and seed dispersal is lower because of the loss of non-volant mammals for seed dispersal and pollination (Devy, 2006). The evergreen forest habitats are fragmented in the present study area and this may be a reason for the lower abundance of regenerating individuals of *Cullenia exarillata* in the study area. it is also noted that the dominancy of certain species as seedlings/saplings is primarily dependent on its density (Fig.21 and Table 13). It is also evident that the adult and juvenile similarity is less as many of the species that are well represented in the area as mature trees are absent in the regenerating class.

The most dominant species in the case of both seedling and sapling categories are *Nageia wallichiana*, *Actinodaphne bourdillonii,* and *Dysoxylum malabaricum*. The dominant regenerating species in Goodrical reserve forests were identified as *Dichapetalum gelanoides*, *Cinnamomum keralense*, and *Nageia wallichiana* by Abhilash *et al*. (2005). In both studies, the dominancy of *Cullenia exarillata* as a mature tree was not noticed in the seedling and sapling stages. In the Goodrical reserve forest, *N. wallichiana* was having a low dominance as a mature tree but the high dominance of the species in the regenerating category is indicated its high regenerative potential of the species. The presence of a few of the secondary species such as *Clerodendron infortunatum* as dominant regenerating species in both studies indicated that the area is subjected to degradation.

The abundance to frequency ratio (AB/F) in a floristic community is a measure of contiguousness or the distribution pattern of different species in the area. In the current study, AB/F values of all the species in seedling, as well as sapling categories, showed a value greater than 0.05 (Table 13 and Table 16). This indicates that all the regenerating individuals in the study area showed contiguous distribution. According to Odum (1971), contiguous distribution occurs in the areas where competition between individuals is high. The study by Abhilash *et al*. (2005) recorded contiguous distribution for seedling and sapling categories of *Nageia wallichiana* which is similar to the present study. But a preponderance of random distribution was recorded by Abhilash *et al*. (2005) in the case of other species which indicates uniform environment conditions of that area.

The DCA ordination plot of regenerating species in the study area showed two different species assemblages (Fig.31). The associative species of *Nageia wallichiana* are totally different from the tree populations in the case of regenerating individuals. The associates include *Syzygium laetum*, *Psychotria anamalayana*, *Epiprinus mallotiformis* and *Turpinia malabarica*. Among these *Turpinia malabarica* are the only species that is represented in the association in over storey. *Bhesa indica*, the strong tree associate of *Nageia wallichiana* is not represented in the case of saplings. The presence of scattered minor groups in the DCA plots indicates the likelihood of splitting up large contiguous habitats into smaller habitats. In the later stages, the persistence of habitat specialists will be difficult in the new habitats (Diamond *et al*., 1976).

5.5.4 Regeneration status of trees in different *Nageia wallichiana* growing patches

The characteristics of regeneration in natural habitats of *N. wallichiana* in the Mankulam forest division was studied as three different patches. Fig. 26, 27, and 28 compared the diversity of trees, seedlings, and saplings of three different patches. Species diversity showed a similar trend for Kannadipara and Idathattu patch, but for Pullumala the sapling diversity was showing lower value than seedling diversity. This is comparable to the case of regenerating classes in the human-impacted sites of Nilgiris (Anitha *et al*., 2010). In Pullumala, the undergrowth is periodically removed for the sake of Cardamom cultivation in the nearby areas. This is affecting the sapling population of the area but seedling density and diversity are not affected as prolific regeneration is happening in the area. The establishment of seedlings in the Pullumala patch may be difficult in the future which may lead to degradation of the habitats. For all the categories, evenness is lowest in the Kannadipara patch while its highest for Pullumala. Evenness refers to the similarity of frequencies of the different units making up a population and a higher evenness is one of the indications of greater diversity.

5.6 SOIL CHARACTERISTICS OF *NAGEIA WALLICHIANA* GROWING AREAS

The physicochemical properties of soil are important in structuring the community composition of forests. The present study analyzed a few soil physical and chemical characteristics of *N. wallichiana* growing areas namely, soil bulk density, soil moisture content, soil pH, Organic Carbon (%), and Total Nitrogen (%) in two different soil depths (0-20 cm and 20-40 cm). Among the different soil attributes, soil moisture content, Organic carbon and Soil Nitrogen was found to be significantly different between NG and WNG areas in 0-20 cm depth (Table 20, Table 22 and Table 23). Soil moisture content and total nitrogen were the only parameters that are found significantly different between NG and WNG in deep soil (20-40 cm) (Table 20 and Table 23).

The species *N. wallichiana* was found to occupy areas with a higher moisture content which indicated a drought-sensitive nature of the species. Brodribb and Hill (1998) suggested that the distribution of conifers are constrained by their drought tolerance capabilities and the available moisture content. The study also indicated that decreased water availability may be a possible reason for the restriction and extinction of conifers in tropical regions. These results pointed out the possibility of restricted distribution of *Nageia wallichiana*, the only conifer of Western Ghats in the moist patches of medium elevation evergreen forests. According to Nepstad *et al*. (1996), lower moisture content influences seedling mortality. So the germination and growth of *N.wallichiana* seedlings may not be possible in a condition with low water availability. The bulk density of soil is not significant in the study as there is no significant difference between the values for NG and WNG (Table 19).

The current study doesn't show any effect of pH on the occurrence of *N. wallichiana* in the study area. But the study by Akkarasedthanon (2017) suggests that lower pH values contributed to the increased occurrence of *N. wallichiana* in Thailand.

Comparing the organic carbon percent values of NG and WNG, the amount is significantly higher in the *N. wallichiana* growing habitats. The findings of Wardle *et al*. (2008) on the leaf structure of Podocarps can be used for explaining this. The fibrous leaves of the *Nageia* and other Podocarps are slow in decomposition and it results in the accumulation of organic matter in the soil and will leads to a higher organic carbon percent and an increased ratio of carbon to phosphorous. According to Wang *et al.* (2018) and Subashree *et al*. (2019). The soil organic carbon is highly influenced by the vegetation composition of the area which shows that there may be an influence of *N. wallichiana* in the organic carbon content of the area.

The Podocarps are considered as tolerant of poor soils and also as successful competitors for belowground resources. They are well adapted to acquiring and retaining nutrients and sometimes considered as species restricted to poor soils (Coomes and Bellingham, 2010). Grubb (1977) described that in the mountains, nitrogen and phosphorus are likely to be limiting which may benefit the growth of Podocarps. In the current study, the better adaption of *N. wallichiana* in the soils with low Nitrogen content can be because of this fact (Fig. 38). The species is better in utilizing the resources than other angiosperms. The Podocarpus species including *N. wallichiana* generally have endomycorrhizal symbionts for nutrient uptake (Russell *et al*., 2002). So the species is better at absorbing nutrients and it can thrive well even in nutrient-poor soils. According to Aerts (1995), the plants in Podocarpus groups salvage only about 50% of nitrogen and 60% of phosphorus from leaves during abscission by efficient nutrient conservation mechanisms. This may also be a reason for the low level of soil Nitrogen in *N. wallichiana* growing areas. Several studies have emphasized that excess N in forest ecosystems lowers tree vitality due to increased soil acidification, declines in essential mineral elements, and nutritional imbalances in trees (Huttl and Frielinghaus, 1994; Nakaji *et al*., 2001). Saynes *et al*. (2005) found out that the primary forests are having a low nitrogen pool than the early and mid successional forests. The characteristics of NG as a primary forest can be related to this. As a contradiction to the findings of the present study, the occurrence of *N. wallichiana* increased with soil Nitrogen content in Thailand (Akkarasedthanon,2017).

Some of the other factors described by Akkarasedthanon (2017) regarding the occurrence of *N. wallichiana* saplings were soil P, soil depth, and canopy cover all of which had a positive correlation. For the presence of *N. wallichiana* soil depth was identified as the single best determining character. Coomes and Grubb (2000) stated that Podocarpus may exclude other plants through below-ground processes in nutrient-poor soils unless there is strong competition for light. In the present study, the competition for light is higher in the closed-canopy forests of the study area hence there will be no chance for such an exclusion.

Table 28 compares the different soil parameters of various studies across the Western Ghats. The bulk density in the study area for both NG and WNG is showing a lower value in comparison with other studies (Mehta *et al*., 2008; Rahman *et al*., 2012;

Subashree *et al*., 2019). This indicates a better condition of soils in the study area with the loose porous condition and high organic matter content. Moisture content is also exceptionally higher in NG areas while values of WNG are comparable with other studies (Devagiri *et al*., 2016; Rajesh *et al*., 1996). The pH values of different studies were in a range of 3.5 to 5.6 which is expected in tropical forests.

Table 28. Comparison of soil parameters of various studies in the Western Ghats

Sites	**Reference**	**BD**	**MC**	**pH**	**Organic C%**	**Total N**	**Remarks**
Kanyakumari district	Subashree *et al*., 2019	1.59 1.32	-	-	0.9 1.9	-	Evergreen forest Semi-evergreen forests
Kodagu, Karnataka	Devagiri *et al*., 2016	-	10.2 13.2	5.64 5.62	1.77 2.14	-	With canopy gaps Intact forests
Vazhikkadavu, Nilambur	Rahman *et al*., 2012	1.6	-	5.9	2.3	0.16	Semi-evergreen forests
Kakachi forests	Giriraj *et al*., 2008	-	-	4.63	1.14	0.017	Presense of *N.wallichiana*
Bandipur national park	Mehta *et al*., 2008	1.38	-	5.33	2.44	-	Disturbed soil
NG	Present study	1.22 1.35	25.61 20.61	3.96 4.27	6.36 2.48	0.68 0.60	0-20 cm 20-40 cm
WNG	Present study	1.13 1.04	10.11 10.98	3.58 4.60	3.10 1.89	2.09 1.79	0-20 cm 20-40 cm

The amount of organic carbon in NG of the present study is higher than in other studies. The higher amount of soil organic carbon improves soil structure, rooting depth, available water capacity, soil biodiversity, elemental cycling, and nutrient reserves (Lal *et al*., 1998) which may be highly beneficial to the prevalent vegetation in the area. The nitrogen content of the soils of NG is comparable with the other studies while in WNG it is much higher. According to Likens and Bormann (1995), the key N sources in forest soils include plant and animal litter, root litter and exudates, free and symbiotic Nfixation, and N deposition from the atmosphere. Reich *et al*. (1997) are giving evidence for higher soil nitrogen content under hardwoods than in conifers which can be a probable reason for the differences in NG and WNG.

5.6.1 Relation of different soil parameters to the vegetation of the study area

The ordination plot of canonical correlation analysis (CCA) of the matrices with vegetation and soil data is shown in Fig.40. CCA starts with two data matrices (vegetational and environmental data) and finds linear compounds that expose the two matrices' joint or common structure (Gauch and Wentworth, 1976). The analysis of soil and vegetation using multivariate analytical techniques such as canonical correlation analysis is known to produce easily interpretable results (Mazlum *et al*., 1999).

The redundancy coefficient for the first canonical variate for soil properties indicated that 19 percent of the variance in vegetation characteristics on the first canonical variate was accounted by the variability in soil properties and the redundancy coefficient for the second canonical variate for soil properties indicated a 32 percent of the variance in vegetation which was accounted by variability in soil properties. The redundancy results for vegetation showed that only four and eight percent of the variance in soil properties on the first and second canonical variate was accounted for by the variability in vegetation characters (Table 24).

The second canonical variate of soil properties loaded negatively and heavily on moisture content and soil organic carbon while it loaded positively on soil pH. The second linear combination of vegetation loaded negatively and highly on *Nageia wallichiana*. This implied that a strong correlation exists between moisture content, soil organic carbon and *Nageia wallichiana* while pH has a negative correlation with *N. wallichiana*. Other factors don’t have a strong correlation with the species (Table 25 and Table 26). The CCA ordination plot also proved the strong positive correlation of *Nageia wallichiana* and it’s associate *Bhesa indica* with the soil moisture content and organic carbon (Fig.40). From the results, it is evident that the canonical correlation analysis gives easily interpretable results on the relation of vegetation and environmental variables.

5.7 FUTURE LINE OF WORK

The present study considered only a single population of *Nageia wallichiana* in southern Western Ghats which is in Mankulam Forest Division. It is known to have different sub-populations in Agasthyamalai region (Bourdillon, 1908), Periyar tiger reserve (Augustine, 2000), Kalakkad-Mundanthurai tiger reserve (Ganesh *et al*., 1996), and Anamalai hills (Osuri *et al*., 2017). Detailed study on natural habitats of all the sub populations of *Nageia wallichiana* in Southern Western Ghats may give insights to the associated flora and ecological conditions. Exploring the influence of major and minor soil nutrients including P, K, Mg, Ca and the soil depth on the presence of *Nageia wallichiana* is also important as few studies recorded that increase in soil depth, canopy cover and soil P influences the occurrence of *Nageia wallichiana* seedlings (Akkarasedthanon *et al*., 2017).

Detailed study on dispersal mode and overstorey species influence on regeneration may give details on regeneration patterns of this species. According to Osuri *et al*. (2017), seed dispersal mode of *Nageia wallichiana* is still unknown. Phylogenetic studies considering the different isolated populations of *Nageia wallichiana* to find the genetic relationships between individuals of different populations may be important as the the presence of this species in Western Ghats is considered as a disjunct locality.

SUMMARY

The study entitled 'Ecological status of *Nageia wallichiana* (C.Presl.) Kuntze, an endangered conifer of Western Ghats in Mankulam Forest Division' was carried out to analyze the distributional status and regeneration of *Nageia wallichiana* in Mankulam Forest Division. The study also aims to understand the floristic composition and edaphic attributes of the natural habitat of this species.The results obtained from this study are summarized as follows

1. In the whole Mankulam Forest Division, the density of *Nageia wallichiana* is low with only 0.002 individuals ha^{-1}. The distribution of this species is restricted to certain patches of the forest division including Idathattu, Kannadipara, Pullumala, and Kallar. The patchy distribution of the species indicates its narrow ecological amplitude.
2. The altitudinal range of the occurrence of *Nageia wallichiana* in the study area is 934 m to 1463 m above MSL with a mean altitudinal distribution of 1224.89 m.
3. The girth distribution of individuals of *Nageia wallichiana* in the study area showed that 90.6 percent of individuals are having a girth less than 50 cm which indicates the slow growth rate of this Podocarpaceae member in the area.
4. The density, as well as basal area per hectare, is highest for areas without *Nageia wallichiana* (WNG) in comparison with *Nageia wallichiana* growing areas (NG). The density and basal area for WNG are 783.3 individuals ha^{-1} and 45.08 m^3 ha^{-1} respectively while for NG it is 313 individuals ha^{-1} and 30.3 m^2 ha^{-1}.
5. In comparison with the areas without *Nageia wallichiana* (WNG), the *Nageia wallichiana* growing areas (NG) shows a higher proportion of endemic as well as threatened tree species. The proportion of endemic species in NG is 52.23 percent of the total tree species in the study area.
6. The most dominant tree species of *Nageia wallichiana* growing areas are *Cullenia exarillata*, *Mesua ferrea,* and *Bhesa indica* in which all are late-successional species of medium elevation evergreen forests of southern Western Ghats.

7. The diversity indices for both *Nageia wallichiana* growing areas (NG) and areas without *Nageia wallichiana* (WNG) are roughly similar with slightly more diversity for NG.
8. Among the three different *Nageia wallichiana* growing patches, the Idathattu patch shows the maximum diversity of tree species with a higher value of both Simpson index of diversity (1-D) and Shannon-Weiner's diversity index (H).
9. The Sorenson's similarity index, Bray-Curtis distances between NG and WNG and cluster analysis indicates a significant difference in species composition between *N. wallichiana* growing habitats and areas without *N. wallichiana*
10. The most strong species associate of *N. wallichiana* was identified as *Bhesa indica* from the Principal component analysis and detrended correspondence analysis done in the species-site data matrix.
11. Comparing the diversity of different classes, the maximum diversity was found for trees followed by saplings and least for seedlings in *N.wallichiana* habitats. The most dominant species in the study area for both sapling and seedling category is *Nageia wallichiana.*
12. From the analysis of soil properties, soil samples from *Nageia wallichiana* habitats were found to be higher in moisture content and organic carbon and lower in total nitrogen content. Soil pH and bulk density don't have any effect on the occurrence of *N. wallichiana*.

REFERENCE

Abhilash, E.S. and Menon, A. R. R. 2009. Status survey of *Nageia wallichiana* (Presl.) O. Ktze. in natural habitats of Goodrical reserve forests, Western Ghats, India. *Indian For.*, 135(2): 281-286.

Abhilash, E.S., Menon, A.R.R., and Balasubramanian, K. 2005. Regeneration status in natural habitats of *Nageia wallichiana* (Presl.) O. Ktz., Goodrical reserved forest of Western Ghats of India. *Indian For.*, 131(2): 183-200.

Aerts, R. 1995. The advantages of being evergreen. *Trends Ecol. Evol.*, 10(10): 402-407.

Akkarasedthanon, J., Chuea-Nongthon, C., and Grote, P.J. 2017. Factors Affecting Size Distribution and Sapling Occurrence of Podocarpaceae at Khao Yai National Park, Thailand. *Trop. Nat. Hist.*, 17(2): 94-110.

Anitha, K., Joseph, S., Chandran, R.J., Ramasamy, E.V., and Prasad, S.N., 2010. Tree species diversity and community composition in a human-dominated tropical forest of Western Ghats biodiversity hotspot, India. *Ecol. Complex.*, 7(2):217-224.

Antony, R. and Mohanan, N. 2010. Ex-situ conservation and multiplication of Podocarpus wallichianus Presl.-a threatened conifer of Western Ghats. *Indian J. For.*, 33(1): 131-134.

Arroyo-Mora, P. 2002. Forest cover assessment, fragmentation analysis and secondary forest detection for the Chorotega Region, Costa Rica. Master of Science Thesis. University of Alberta, Edmonton, 111 pp.

Augspurger, C.K. 1984. Seedling survival of tropical tree species: interactions of dispersal distance, light-gaps, and pathogens. *Ecology*, 65(6): 1705-1712.

Augustine, J. 2000. Floristic and ethnobotanical studies of Periyar tiger reserve. [PhD Thesis]. Department of Botany, University of Calicut, 1204p.

Ayyappan, N. and Parthasarathy, N. 1999. Biodiversity inventory of trees in a large-scale permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India. *Biodivers. Conserv.*, 8(11): 1533-1554.

Ayyappan, N. and Parthasarathy, N. 2001. Composition, population structure and distribution of Dipterocarps in a tropical evergreen forest at varagalaiar, anamalais, Western Ghats, South India. *J. Trop. For. Sci.* : 311-321.

Balasubramanyan, K., Swarupanandan, K., and Sasidharan, N. 1985. Field Key to the Identification of Indigenous Arborescent Species of Kerala Forests. KFRI Research Report No: 33, Kerala Forest Research Institute, Peechi, 175p.

Baldock, J.A. and Nelson, P.N. 1998. Soil organic matter. In: Sumner, M (ed.), *Handbook of Soil Science*. CRC Press, Boca Raton, FL, pp. B25–B84.

Bande, M.B. 1992. The Palaeogene vegetation of peninsular India (Megafossil eVidences). *Palaeobotanist,* 40: 275-284

Barbhuiya, H.A. 2013. Study and assessment of threatened and endemic vascular plants of southern Assam [PhD Thesis], Assam University, 388p.

Basha, C. S. 1999. Forest types of Silent Valley. In: Manoharan, T. M., Biju, S. D., Nayar, T. S., and Easa, P. S. (eds). *Silent Valley Whispers of Reason*. Kerala Forest Department, Thiruvananthapuram. pp. 109–116.

Beddomei, R.H. 1877. The forest and flora of the Tinnevelly district. *Indian For.,* 3: 19-24.

Bellingham, P.J. and Richardson, S.J. 2006. Tree seedling growth and survival over 6 years across different microsites in a temperate rain forest. *Can. J. For. Res.*, *36*(4): 910-918.

Bhagwat, S.A., Kushalappa, C.G., Williams, P.H., and Brown, N.D. 2005. The role of informal protected areas in maintaining biodiversity in the Western Ghats of India. *Ecol. Soc.,* 10(1).

Boone, F.R. 1986. Towards soil compaction limits for crop growth. *NJAS-Wagen. J. Life Sci.*, *34*(3): 349-360.

Bourdillon, 1908. *The Forest Trees of Travancore.*The Travancore government press, Trivandrum, 456p.

Brodribb, T. and Hill, R.S. 1998. The photosynthetic drought physiology of a diverse group of southern hemisphere conifer species is correlated with minimum seasonal rainfall. *Funct. Ecol.*, *12*(3): 465-471.

Brodribb, T.J. and Feild, T.S. 2008. Evolutionary significance of a flat-leaved Pinus in Vietnamese rainforest. *New. Phytol.*, 178(1): 201-209.

Burton, J., Chen, C., Xu, Z. and Ghadiri, H., 2007. Gross nitrogen transformations in adjacent native and plantation forests of subtropical Australia. *Soil Biol. Biochem.*, *39*(2), pp.426-433.

Champion, H.G. and Seth, S.K. 1968. *A Revised Survey of the Forest Types of India.* Government of India Publications, Delhi, 404p.

Chandra, L.R., Gupta, S., Pande, V. and Singh, N., 2016. Impact of forest vegetation on soil characteristics: a correlation between soil biological and physico-chemical properties. *3 Biotech*, *6*(2): 188.

Chandran, M.S. 1997. On the ecological history of the Western Ghats. *Curr. Sci.*, 1: 146-155.

Chandran, M.S., Rao, G.R., Gururaja, K.V., and Ramachandra, T.V. 2010. Ecology of the swampy relic forests of Kathalekan from central Western Ghats, India. *Bioremediation, Biodiversity and Bioavailability [Global Science Books]*, *4*, pp.54-68.

Chandrasekhara, U.M., Menon, A.R.R., Nair, K. K.N., Sasidharan, N., and Swarupanandan, K. 1998. Evaluating Plant Diversity in Different Forest Types of Kerala by Laying out Permanent Sample Plots. KFRI Research Report 156, Kerala Forest Research Institute, Peechi, 86p.

Chandrashekara, U.M. and Jayaraman, K. 2002. *Stand structural diversity and dynamics in natural forests of Kerala*. KFRI Research Report No.232, pp. 10-11

Chandrashekara, U.M. and Ramakrishnan, P.S. 1994. Vegetation and gap dynamics of a tropical wet evergreen forest in the Western Ghats of Kerala, India. *J. Trop. Ecol.*, : 337-354.

Collins, N.M., Sayer, J.A. and Whitmore, T. (eds). 1990. *Conservation Atlas of Tropical Forests - Asia and the Pacific*. Macmillan, London, UK for International Union for Conservation of Nature and Natural Resources, Gland, Switzerland, and the World Conservation Monitoring Centre, Cambridge, UK, 90p.

Connell, J.H. 1978. Diversity in tropical rain forests and coral reefs. *Science*, 199(4335): 1302-1310.

Coomes, D. and Bellingham, P. 2010. Ecology of tropical podocarps, chapter Temperate and tropical podocarps: how ecologically alike are they. *Sm. C. Bot.*, 95(95): 119-140.

Coomes, D.A. and Grubb, P.J. 2000. Impacts of root competition in forests and woodlands: a theoretical framework and review of experiments. *Ecol. Monogr.*, 70(2): 171-207.

Curtis, J.T. and Cottom, G. 1956. Plant Ecology Workbook – Laboratory Field Reference Manual, Burgess publishing company, Minneapolis, 172p.

Curtis, J.T. and McIntosh, R.P. 1950. The interrelations of certain analytic and synthetic phytosociological characters, *Ecology*, 31: 434-455.

Dalling, J.W., Heineman, K., Lopez, O.R., Wright, S.J. and Turner, B.L., 2016. Nutrient availability in tropical rain forests: the paradigm of phosphorus limitation. In *Tropical tree physiology* (pp. 261-273). Springer, Cham.

Daniels, R.R. 1996. A landscape approach to conservation of birds. *J. Bioscience.*, *19*(4): 503-509.

Das, A., Krishnaswamy, J., Bawa, K.S., Kiran, M.C., Srinivas, V., Kumar, N.S., and Karanth, K.U. 2006. Prioritisation of conservation areas in the Western Ghats, India. *Biol. Conserv.*, 133(1): 16-31.

Datar, M.N. and Tetali, P. 2019. Hill Forts: Abodes of Endemic Plants and Potential Priority Conservation Areas of Northern Western Ghats. *Natl. Acad. Sci. Lett.*, *42*(4): 375-378.

Davidar, P., Puyravaud, J.P., and Leigh Jr, E.G. 2005. Changes in rain forest tree diversity, dominance and rarity across a seasonality gradient in the Western Ghats, India. *J. Biogeogr*, 32(3): 493-501.

De Laubenfels, D.J. 1987. Revision of the genus Nageia (Podocarpaceae). *Blumea*, *32*(1): 209-211.

Dehlin, H., Nilsson, M.C., Wardle, D.A. and Shevtsova, A. 2004. Effects of shading and humus fertility on growth, competition, and ectomycorrhizal colonization of boreal forest tree seedlings. *Can. J. For. Res.*, *34*(12): 2573-2586.

Devagiri, G.M., Khaple, A.K., Mohan, S., Venkateshamurthy, P., Tomar, S., Arunkumar, A.N. and Joshi, G. 2016. Species diversity, regeneration and dominance as influenced by canopy gaps and their characteristics in tropical evergreen forests of Western Ghats, India. *J. For. Res.*, 27(4): 799-810.

Devy, M.S. 2006. *Effects of Fragmentation on a Keystone Tree Species in the Rainforest of KalakadMundanthurai Tiger Reserve, India*. Project report submitted to Rufford. Ashoka Trust for Research in Ecology and the Environment, Bengaluru, 20p.

Diamond, J.M., Terborgh, J., Whitcomb, R.F., Lynch, J.F., Opler, P.A., Robbins, C.S., Simberloff, D.S., and Abele, L.G. 1976. Island biogeography and conservation: strategy and limitations. *Science*, *193*(4257):1027-1032.

Dogra, P.D. 1999. Regional action plan: Conifers of the Himalayas and their endangered genetic resources. In: Farjon, A. and Page, C.N (eds). *Status Survey and Conservation Action Plan: Conifers*. IUCN/SSC Conifer Specialist Group, Gland, pp:50-54.

Dogra, P.D., 1985. Conifers of India and their wild gene resources in relation to tree breeding. *Indian For.*, 111(11): 935-955.

Etikan, I., Musa, S.A., and Alkassim, R.S. 2016. Comparison of convenience sampling and purposive sampling. *Am. J. Theor. Appl. Stat.*, 5(1): 1-4.

Farjon, A. 2001. *World Checklist and Bibliography of Conifers(2nd Ed.).* Royal Botanical Gardens, Kew, Richmond.316p.

Farjon, A. 2008. *A natural history of conifers*. Timber Press, 304p.

Farjon, A. 2010. A *Handbook of the World's Conifers 2 vols.*(2nd Ed.) Brill, Leidon-Boston, 1111p.

Farjon, A. and Filer, D., 2013. *An Atlas of the World's Conifers: An Analysis of their Distribution, Biogeography, Diversity and Conservation Status*. Brill, Leiden, 512p.

Farjon, A. 2013. *Nageia wallichiana*. *The IUCN Red List of Threatened Species* 2013: e.T42484A2982369. https://dx.doi.org/10.2305/IUCN.UK.20131.RLTS.T42484A2982369.en. Downloaded on 11 May 2020

Farjon, A., 2017. *A Handbook of the World's Conifers 2 vols.*(2nd Ed.) Brill, Leidon-Boston, 1153p.

Feeley, K.J., Joseph Wright, S., Nur Supardi, M.N., Kassim, A.R., and Davies, S.J. 2007. Decelerating growth in tropical forest trees. *Ecol. Lett.*, 10(6): 461-469.

Franco, M.J. and Brea, M. 2015. First extra-Patagonian record of Podocarpaceae fossil wood in the Upper Cenozoic (Ituzaingó Formation) of Argentina. *New Zeal. J. Bot.*, 53(2): 103-116.

Franklin, J.F., Spies, T.A., Van Pelt, R., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C., and Bible, K. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecol. Manag.*, 155(1-3): 399-423.

Fyson, P.F. 1932. The Flora of the South Indian Hill Stations Ootacamund, Coonoor, Kotagiri Kodaikanal, Yercaud and the country round [2 volumes]. Madras Government Press, 611p.

Gadgil, M. 1996. Documenting diversity: An experiment. *Curr. Sci., 70*(1), pp.36-45.

Gadgil, M. and Meher-Homji, V.M. 1990. Ecological diversity. In: Daniels, J.C. and Serraro, J.S. (eds) *Conservation in Developing Countries - Problems and Prospects,* Proceedings of the Centenary Seminar of the Bombay Natural History Society, Bombay Natural History Society and Oxford Universtly Press, Bombay, pp. 175- 198.

Gadgil, M. and Meher-Homji, V.M., 1986. Localities of great significance to conservation of India's biological diversity. *Proceedings of the Indian Academy of Science (Animal Science/Plant Science) Supplement*, *1986*, pp.165-180.

Gadgil, M. and Vartak, V.D. 1981. Sacred groves of Maharashtra: an inventory. In: *Glimpses in India Ethnobotany*, pp.279-294.

Gamble, J.S. 1915-1934. *Flora of Presidency of Madras* (3 volumes). Adlard & Son, Limited, London, 2017p.

Ganesan, R. and Davidar, P., 2003. Effect of logging on the structure and regeneration of important fruit bearing trees in a wet evergreen forest, southern Western Ghats, India. *J. Trop. For. Sci.*: 12-25.

Ganesh, T., Ganesan, R., Devy, M.S., Davidar, P., and Bawa, K.S. 1996. Assessment of plant biodiversity at a mid-elevation evergreen forest of Kalakad–Mundanthurai Tiger Reserve, Western Ghats, India. *Curr. Sci.*: 379-392.

Gauch, H.G. and Wentworth, T.R. 1976. Canonical correlation analysis as an ordination technique. *Vegetatio*, 33(1): 17-22.

Gaxiola, A., Burrows, L.E., and Coomes, D. A. 2008. Tree fern trunks facilitate seedling regeneration in a productive lowland temperate rain forest. *Oecologia*, 155: 325–335.

Geethakumary, M.P., Pandurangan, A.G., and Shaju, E.S.T. 2010. Of southern Western Ghats, India. *Indian J. For.*, 33(1): 127-130.

Giriraj, A., Murthy, M.S.R., and Ramesh, B.R. 2008. Vegetation composition, structure and patterns of diversity: a case study from the tropical wet evergreen forests of the Western Ghats, India. *Edinb. J. Bot.*, *65*(3): 447.

GOK [Government of Kerala]. 2011. Mankulam Forest Division Working plan [on-line]. Available: http://www.forest.kerala.gov.in/index.php/forest/forest-management/working-plans [accessed on: 30 March 2020].

Govindarajulu, E. and Swamy, B.G.L. 1956. Enumeration of plants collected in Mundanthurai and its neighbourhood. *J. Madras University*, 26B: 583-588.

Greig-Smith, P. 1983. Quantitative Plant Ecology [3rd Ed.]. University of California press, Berkeley, 354p.

Grubb, P.J. 1977. Control of forest growth and distribution on wet tropical mountains: with special reference to mineral nutrition. *Ann. Rev. Ecol. Syst.*, *8*(1): 83-107.

Guariguata, M.R. and Dupuy, J.M. 1997. Forest Regeneration in Abandoned Logging Roads in Lowland Costa Rica 1. *Biotropica*, 29(1): 15-28.

Gunawardene, N.R., Daniels, A.E., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., Karunakaran, P.V., Nayak, K.G., Prasad, S., Puyravaud, P., Ramesh, B.R., Subramanian, K.A. and Vasanthy, G. 2007. A brief overview of the Western Ghats--Sri Lanka biodiversity hotspot. *Curr. Sci.*, 93(11): 1567-1572.

Gupta, S., Padalia, H., Chauhan, N., and Porwal, M.C. 2002. Rediscovery of Podocarpus wallichianus: A rare gymnosperm from tropical rainforests of Great Nicobar Island. *Curr. Sci.*, 83(7): 806-807.

Han, Y., Zhang, J., Mattson, K.G., Zhang, W., and Weber, T.A. 2016. Sample sizes to control error estimates in determining soil bulk density in California forest soils. *Soil Sci. Soc. Am. J.*, 80(3): 756-764.

Hao, X., Ball, B.C., Culley, J.L.B., Carter, M.R., and Parkin, G.W. 2006. Soil density and porosity. In: Carter, M.R. and Gregorich, E.G. (eds). *Soil Sampling and Method of Analysis.* Canadian society of soil science, CRC press, Boca Raton, pp. 743-759.

Heatubun, C.D. 2011. A new species of Ptychosperma from Halmahera, North Moluccas. *Palms*, 55(4): 183-189.

Hegazy, A.K., Mussa, S.A.I., and Farrag, H.F. 2008. Invasive plant communities in the nile delta coast. *Glob. J. Environ. Res.*, 2(1): 53-61.

Hendershot, W.H., Lalande, H., and Duquette, M. 2006. Soil reaction and exchangeable acidity. . In: Carter, M.R. and Gregorich, E.G. (eds). *Soil Sampling and Method of Analysis.* Canadian society of soil science, CRC press, Boca Raton, pp. 173-178.

Hiep, N.T., Loc, P.K., Luu, N.D.T., Thomas, P.I., Farjon, A., Averyanov, L. and Regalado, J. 2004. *Vietnam Conifers: Conservation Status Review 2004*. Fauna & Flora International, Vietnam Programme, Hanoi, 129p.

Hill, R.S. and Pole, M.S. 1992. Leaf and shoot morphology of extant Afrocarpus, Nageia and Retrophyllum (Podocarpaceae) species, and species with similar leaf arrangement, from Tertiary sediments in Australasia. *Aust. Syst. Bot.*, 5: 337–358.

Hubbell, S.P. and Foster, R.B. 1986. Biology, chance, and history and the structure of tropical rain forest tree communities. In: Diamond, J. and Case, T.J. (eds). *Community Ecology*. Harper & Row, New York, pp. 314–329.

Hubbell, S.P., Ahumada, J.A., Condit, R., and Foster, R.B. 2001. Local neighborhood effects on long-term survival of individual trees in a neotropical forest. *Ecol. Res.*, 16(5): 859-875.

Hüttl, R.F. and Frielinghaus, M. 1994. Soil fertility problems—an agriculture and forestry perspective. *Sci. Total Environ.*, 143(1): 63-74.

Irwin, S.J., Narasimhan, D., and Suresh, V.M. 2013. Ecology, distribution and population status of *Elaeocarpus venustus* Bedd.(Oxalidales: Elaeocarpaceae), a threatened tree species from Agasthiyamalai Biosphere Reserve, southern Western Ghats, India. *J. Threat. Taxa*, 5(9): 4378-4384.

IUCN. 1994. IUCN Red list Categories, IUCN publications, Gland, Switzerland

Jayakumar, R. and Nair, K.K.N. 2013. Species diversity and tree regeneration patterns in tropical forests of the Western Ghats, India. *ISRN Ecology*, 2013:1-14.

Jayanthi, P. and Rajendra, A. 2013. Life-forms of Madukkarai hills of southern Western Ghats, Tamil Nadu India. *Life Sci. Leafl.*, 9: 57-61.

Jeyakumar, S., Ayyappan, N., Muthuramkumar, S., and Rajarathinam, K. 2017. Impacts of selective logging on diversity, species composition and biomass of residual lowland dipterocarp forest in central Western Ghats, India. *Trop. Ecol.*, 58(2): 315-330.

Jin, J., Qiu, J., Zhu, Y.A., and Kodrul, T.M. 2010. First fossil record of the genus Nageia (Podocarpaceae) in south China and its phytogeographic implications. *Plant Syst. Evol.*, 285(3-4): 159-163.

Johnston, M. and Gillman, M. 1995. Tree population studies in low-diversity forests, Guyana. I. Floristic composition and stand structure. *Biodiv. Conserv.*, 4(4): 339-362.

Jose, S., Sreepathy, A., Kumar, B.M. and Venugopal, V.K. 1994. Structural, floristic and edaphic attributes of the grassland-shola forests of Eravikulam in peninsular India. *Forest Ecol. Managt.*, 65(2-3): 279-291.

Kalacska, M., Sanchez-Azofeifa, G.A., Calvo-Alvarado, J.C., Quesada, M., Rivard, B. and Janzen, D.H., 2004. Species composition, similarity and diversity in three successional stages of a seasonally dry tropical forest. *Forest Ecol. Manag.*, 200(1-3): 227-247.

Kanade, R., Tadwalkar, M., Kushalappa, C., and Patwardhan, A. 2008. Vegetation composition and woody species diversity at Chandoli National Park, northern Western Ghats, India. *Curr. Sci.*: 637-646.

Kane, V.R., Gersonde, R.F., Lutz, J.A., McGaughey, R.J., Bakker, J.D., and Franklin, J.F. 2011. Patch dynamics and the development of structural and spatial heterogeneity in Pacific Northwest forests. *Can. J. For. Res.*, 41(12): 2276-2291.

Ke Loc, P., Hiep, N.T., Luu, N.D.T., Thomas, P.I., Farjon, A., Averyanov, L.V., Regalado Jr, J.C., Khang, N.S., Magin, G., Mathew, P., and Oldfield, S. 2007. Vietnamese Conifers and Some Problems of their Sustainable Utilization. In: Proceedings of 3rd Global Botanic Gardens congress, Wuhan, China.

Khuraijam, J.S. and Singh, R. 2015. Gymnosperms of Northeast India: distribution and conservation status. *Pleione*, 9(2): 283-288.

Kindt, R. and Coe, R. 2005. *Tree Diversity Analysis. A Manual and Software for Common Statistical Methods for Ecological and Biodiversity Studies.* Nairobi: World Agroforestry Centre (ICRAF), 196p.

Knight, D.H. 1975. A phytosociological analysis of species-rich tropical forest on Barro Colorado Island, Panama. *Ecol. Monogr.*, 45(3): 259-284.

Kolka, R.K. and Smidt, M.F. 2004. Effects of forest road amelioration techniques on soil bulk density, surface runoff, sediment transport, soil moisture and seedling growth. *Forest Ecol. Manag.*, 202(1-3): 313-323.

Kulkarni, A., Upadhye, A., Dahanukar, N., and Datar, M.N. 2018. Floristic uniqueness and effect of degradation on diversity: A case study of sacred groves from northern Western Ghats. *Trop. Ecol.*, 59(1): 119-127.

Kumar, J.N., Kumar, R.N., Bhoi, R.K. and Sajish, P.R., 2010. Tree species diversity and soil nutrient status in three sites of tropical dry deciduous forest of western India. *Trop. Ecol.*, 51(2): 273-279.

Kumar, N.A., Sivadasan, M., and Ravi, N. 2005. *Flora of Pathanamthitta*. Daya Publishing house, Delhi, 640p.

Kuriakose, G., Sinu, P.A., and Shivanna, K.R. 2019. Floral traits predict pollination syndrome in Syzygium species: a study on four endemic species of the Western Ghats, India. *Aust. J. Bot.*, 66(7): 575-582.

Lakhanpal, R.N. 1970. Tertiary floras of India and their bearing on the historical geology of the region. *Taxon*, 19(5): 675-694.

Lal, R., Kimble, J., and Follett, R.F. 1998. Pedospheric processes and the carbon cycle. In: Lal, R., Kimble, J.M., Follett, R.F., and Stewart, B.A. (eds) *Soil Processes and the Carbon Cycle*. CRC Press, Boca Raton, Fla. pp. 1–8.

Lawrence, C.A. 1959. Observations on the Flora of Marunduval malai, Cape Comorin. *J. Bombay Nat. Hist. Soc.*, 56: 95-100.

Lieffers, V.J., Messier, C., Stadt, K.J., Gendron, F. and Comeau, P.G. 1999. Predicting and managing light in the understory of boreal forests. *Can. J. For. Res.*, 29(6): 796-811.

Likens, G.E. and Bormann, F.H. 1995. *Biogeochemistry of a Forested Ecosystem*, Springer-Verlag, New York, 159p.

Liu, X.Y., Gao, Q., and Jin, J.H. 2015. Late Eocene leaves of Nageia (section Dammaroideae) from Maoming Basin, South China and their implications on phytogeography. *J. Syst. Evol.*, 53(4): 297-307.

Looman, J. 1979. On pattern in vegetation. *Phytocoenologia*, 6: 37-48.

MacCarthy, P., Malcolm, R.L., Clapp, C.E., and Bloom, P.R. 1990. An introduction to soil humic substances. In: McCarthy, P. (ed.), *Humic Substances in Crop and*

Soil Science: Selected Readings. Soil Science Society America, Madison, WI, pp. 1–12.

MacKinnon, J. and MacKinnon, K. 1986. *Review of the protected areas system in the Indo-Malayan realm*, IUCN. Gland, Switzerland, 63p.

Magurran, A.E. 2004. *Measuring Biological Diversity*. Blackwell Publishing, London, 215p.

Mani, M.S. (ed.). 1974. *Ecology and Biogeography in India*. Dr. W. Junk b.v. publishers, The Hague, 773p.

Margalef, D.R. 1958. Information Theory in Ecology. *Memorias de la Real Academica de ciencias y artes de Barcelona*, 32: 374-559.

Mazlum, N., Ozer, A., and Mazlum, S. 1999. Interpretation of water quality data by principal components analysis. *Turk. J. Eng. Environ. Sci.*, *23*(1): 19-26.

Mehta, V.K., Sullivan, P.J., Walter, M.T., Krishnaswamy, J., and DeGloria, S.D. 2008. Impacts of disturbance on soil properties in a dry tropical forest in Southern India. *Ecohydrology*, 1(2): 161-175.

Memiaghe, H.R., Lutz, J.A., Korte, L., Alonso, A., and Kenfack, D. 2016. Ecological importance of small-diameter trees to the structure, diversity and biomass of a tropical evergreen forest at Rabi, Gabon. *PloS one*, 11(5), p.e0154988.

Menon, S. and Bawa, K.S. 1997. Applications of geographic information systems, remote-sensing, and a landscape ecology approach to biodiversity conservation in the Western Ghats. *Curr. Sci.*, 73(2): 134-145.

Mill, R.R. 2001. A new sectional combination in Nageia Gaertn.(Podocarpaceae). *Edinb. J. Bot.*, 58(3): 499-501.

Mohanan, N and Sivadasan, M. 2002. *Flora of Agasthyamala*. Bishen Singh Mahendra Pal Singh, Dehra Dun, 889p.

Mohandass, D., Hughes, A.C., Mackay, B., Davidar, P., and Chhabra, T. 2016. Floristic species composition and structure of a mid-elevation tropical montane evergreen forests (sholas) of the western ghats, southern India. *Trop. Ecol.*, 57(3): 533-543.

Morris, E.K., Caruso, T., Buscot, F., Fischer, M., Hancock, C., Maier, T.S., Meiners, T., Müller, C., Obermaier, E., Prati, D., and Socher, S.A. 2014. Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. *Ecol. Evol.*, 4(18): 3514-3524.

Muthuramkumar, S., Ayyappan, N., Parthasarathy, N., Mudappa, D., Raman, T.S., Selwyn, M.A., and Pragasan, L.A. 2006. Plant community structure in tropical rain forest fragments of the Western Ghats, India 1. *Biotropica*, 38(2): 143-160.

Myers, N. 1988. Threatened biotas: 'hot spots' in tropical forests. *Environmentalist*, 8: 187-208.

Myers, N. 1990. The biodiversity challenge: expanded hot spots analysis. *Environmentalist*, 10: 243-256.

Nagendra, H. and Utkarsh, G. 2003. Landscape ecological planning through a multi-scale characterization of pattern: studies in the Western Ghats, South India. *Environ. Monit. Assess.*, *87*(3): 215-233.

Nair, K.S.S., Gnanaharan, R. and Kedharnath, S. (eds). 1986. Ecodevelopment of the Western Ghats. In: Proceedings of a seminar held at Peechi, Kerala, 17-18 October 1984. Kerala Forest Research Institute, Peechi.

Nair, N.C. and Daniel, P. 1986. The floristic diversity of the Western Ghats and its conservation: a review. In: *Proceedings of the Indian Academy of Sciences (Animal Science/Plant Science) Supplement*, pp. 127–163.

Nair, R. 1991a. *Podocarpus wallichiana* (Presl.). In: *Proceedings of Symposium on Rare, Endangered and Endemic Plants*, Kerala forest department, Trivandrum, pp. 70-71.

Nair, S.C. 1991b. *The Southern Western Ghats: A Biodiversity Conservation Plan*. Indian National Trust for Art and Cultural Heritage, New Delhi, 92p.

Nakaji, T., Fukami, M., Dokiya, Y., and Izuta, T. 2001. Effects of high nitrogen load on growth, photosynthesis and nutrient status of Cryptomeria japonica and Pinus densiflora seedlings. *Trees*, 15(8): 453-461.

Nayar, M. P. 1996. *Hotspots of Endemic Plants of India, Nepal and Bhutan*. Tropical Botanical Garden and Research Institute, Thiruvananthapuram, 252p.

Nayar, M.P. 1959. The vegetation of Kanyakumari, Kanyakumari Dist., *Bullet. Bot. Surv. India*, 1: 122-126.

Nayar, M.P. 1997. Biodiversity challenges in Kerala and Science of conservation biology. In: Puspangadan, P and Nair, K.S.S. (eds) *Biodiversity of tropical forests the Kerala Scenario*. STEC, Kerala, Trivandrum, pp.14-17.

Neikha, V. and Nagaraja, B.C. 2019. Tree Diversity and Endemism Pattern in Makutta Wildlife Range, Western Ghats, India. *Indian For.*, 145(7): 631-636.

Nepstad, D.C., Uhl, C., Pereira, C.A., and Da Silva, J.M.C. 1996. A comparative study of tree establishment in abandoned pasture and mature forest of eastern Amazonia. *Oikos*, 1: 25-39.

Oades, J.M. 1988. The retention of organic matter in soils. *Biogeochemistry,* 5: 35–70.

Odum, E.P. 1971. *Fundamentals of Ecology*. W.B.Saunders Co., Philadelphia, 574p.

Ogden, J. and Stewart, G. H. 1995. Community dynamics of the New Zealand conifers. In: Enright, N. J. and Hill, R. S. (eds) *Ecology of the Southern Conifers*, Melbourne University Press, Carlton, Australia, pp. 64–80.

Olson, D.M. and Dinerstein, E. 1998. The global 200: a representation approach to conserving the earth's most biologically valuable ecoregions. *Conserv. Biol.*, 12 (3): 502–515.

Osuri, A.M., Chakravarthy, D., Mudappa, D., Raman, T.R.S, Ayyappan, N., Muthuramkumar, S., and Parthasarathy, N. 2017. Successional status, seed dispersal mode and overstorey species influence tree regeneration in tropical rain-forest fragments in Western Ghats, India. *J. Trop. Ecol.*, 33(4): 270-284.

Osuri, A.M., Machado, S., Ratnam, J., Sankaran, M., Ayyappan, N., Muthuramkumar, S., Parthasarathy, N., Pélissier, R., Ramesh, B.R., DeFries, R., and Naeem, S. 2020. Tree diversity and carbon storage cobenefits in tropical human-dominated landscapes. *Conserv. Lett.*, 13(2), p.e12699.

Padmakumar, B., Sreekanth, N.P., Shanthiprabha, V., Paul, J., Sreedharan, K., Augustine, T., Jayasooryan, K.K., Rameshan, M., Mohan, M., Ramasamy, E.V., and Thomas, A.P. 2018. Tree biomass and carbon density estimation in the tropical dry forest of Southern Western Ghats, India. *For. Biogeosci. For.*, *11*(4): 534.

Page, C.N. 1988. New and maintained genera in the conifer families Podocarpaceae and Pinaceae. *Notes RBG Edinb.*, 45(2): 377-395.

Mill, R.R. 1999. A new combination in *Nageia* (Podocarpaceae). *Novon*, 9:77–78

Pandey, R.P., Rasingam, L., and Lakra, G.S. 2009. Ethnomedicinal plants of the Aborigines in Andaman & Nicobar Islands, India. *Nelumbo*, 51: 5-40.

Parthasarathy, N. 1999. Tree diversity and distribution in undisturbed and human-impacted sites of tropical wet evergreen forest in southern Western Ghats, India. *Biodivers. Conserv.*, 8(10), 1365-1381.

Parthasarathy, N. 2001. Changes in forest composition and structure in three sites of tropical evergreen forest around Sengaltheri, Western Ghats. *Curr. Sci.*, 389-393.

Parthasarathy, N., Kinhal, V., and Kumar, P.L. 1992. *Indo-French Workshop on Tropical Ecosystem, Natural Functioning and Anthropological Impact.* French Institute, Pondichery. pp. 26-27.

Pascal, J.P. 1988. *Wet Evergreen Forests of the Western Ghats of Lndia . Ecology, Structure, Floristic Composition and Succession*, Institute Francam de Pondicherry, Pondicherry, 345p.

Pascal, J.P. 1991. Floristic composition and distribution of evergreen forests in the Western Ghats, India. *Paleobotanist*, 39(1): 110-126.

Pascal, J.P. and Pelissier, R. 1996. Structure and floristic composition of a tropical evergreen forest in south-west India. *J. Trop. Ecol.*, 1:191-214.

Pascal, J.P. and Ramesh, B.R. 1987. *A Field Key to the Trees and Lianas of the Evergreen Forests of the Western Ghats, India*. Institut Francais de Pondiche´ry, India, 236p.

Pascal, J.P., Ramesh, B.R., and Franceschi, D.D. 2004. Wet evergreen forest types of the southern Western Ghats, India. *Trop. Ecol.*, 45(2): 281-292.

Philips, A. E. 1959. *Methods of Vegetation Study*, Henry Holt & Co.Inc., USA, 107p.

Phillips, O.L., Vargas, P.N., Monteagudo, A.L., Cruz, A.P., Zans, M.E.C., Sanchez, W.G., Yli-Halla, M., and Rose, S. 2003. Habitat association among Amazonian tree species: a landscape-scale approach. *J. Ecol.*, 91(5): 757-775.

Pielou, E.C. 1969. *An Introduction to Mathematical Ecology*. John Wiley & Sons, New York, 286p.

Piper, C.S. 1966. *Soil and Plant Analysis: A Laboratory Manual of Methods for the Examination of Soils and the Determination of the Inorganic Constituents of Plants*. Hans Publishers, Bombay, India.

Pomeroy, M., Primack, R. and Rai, S.N. 2003. Changes in four rainforest plots of the Western Ghats, India, 1939–93. *Conserv. Soc.*: 113-135.

Pott, R. 2011. Phytosociology: A modern geobotanical method. *Plant Biosyst.*, *145*(sup1): 9-18.

Qi-Xing, Z. and Zhi-Jian, G. 2001. Karyomorphology of Podocarpus sl in China and its systematic significance. *Caryologia*, 54(2): 121-127.

Radhakrishna, B.P. 1967. The western ghats of the Indian Peninsula. In: *Proceedings of the Seminar on Geomorphological Studies in India, 1967*. Sagar.

Radhakrishna, B.P. 1991. An excursion into the past:'the decan volcanic episode'. *Curr. Sci.*: 61(9-10): 641-647.

Rahman, P.M., Varma, R.V., and Sileshi, G.W. 2012. Abundance and diversity of soil invertebrates in annual crops, agroforestry and forest ecosystems in the Nilgiri biosphere reserve of Western Ghats, India. *Agrofor. Syst.*, 85(1): 165-177.

Rahmani, A.R., Islam, M.Z., and Kasambe, R.M. 2016. *Important Bird and Biodiversity Areas in India: Priority Sites for Conservation* (Revised and updated). Bombay Natural History Society, Indian Bird Conservation Network, Royal Society for the Protection of Birds and BirdLife International (U.K.), 1992p.

Rajesh, N., Kumar, B.M., and Vijayakumar, N.K. 1996. Regeneration characteristics of selection felled forest gaps of different ages in the evergreen forests of Sholayar, Kerala, India. *J. Trop. For. Sci.*, 1: 355-368.

Ramachandran, V.S. and Swarupanandan, K. 2013. Structure and floristic composition of old-growth wet evergreen forests of Nelliampathy Hills, Southern Western Ghats. *J. For. Res.*, 24(1): 37-46.

Raman, T.R.S., Datta, A. and Krishnaswamy, J. 2006. Western Ghats: sub-cluster nominations. In: *India's Tentative List of Natural Heritage Properties to be Inscribed on the UNESCO World Heritage List*. pp.22-69.

Ramesh, B.R. and Pascal, J.P. 1997. *Atlas of the endemics of the Western Ghats (India): Distribution of tree species in the evergreen and semi evergreen forests*. Institue Francais de Pondichery, Publications du department d ecologie, 403p.

Ramesh, B.R., Menon, S. and Bawa, K.S. 1997. A Vegetation Based Approach to Biodiversity Gap Analysis in the Agastyamalai Region,Western Ghats, India. *Ambio*, 26(8): 529-536.

Ramesh, B.R., Swaminath, M.H., Patil, S., Aravajy, S., and Elouard, C. 2009. Assessment and Conservation of Forest Biodiversity in the Western Ghats of Karnataka, India. 2. Assessment of Tree Biodiversity, Logging Impact and General Discussion. Institut Français de Pondichéry, Pondy Papers in Ecology no. 7, Head of Ecology Department, Institut Français de Pondichéry, pp. 65-121.

Ramesh, B.R., Swaminath, M.H., Patil, S.V., Pélissier, R., Venugopal, P.D., Aravajy, S., Elouard, C., and Ramalingam, S. 2010. Forest stand structure and composition in 96 sites along environmental gradients in the central Western Ghats of India: Ecological Archives E091-216. *Ecology*, 91(10): 3118-3118.

Ramya, E.K., Sharmila, S., and Mownika, S. 2020. Phytosociological assessment of tree vegetation in tropical moist deciduous forest of Veerakkal area, Nilgiris, Western Ghats, India. *Indian J. Ecol.*, 47(2): 480-484.

Rao, S.K., Swamy, R.K., Kumar, D., Singh, A.R., and Bhat, G.K. 2019. Flora of Peninsular India. http://peninsula.ces.iisc.ac.in/plants.php. Downloaded on 2 February 2020.

Rao, R.R. and Raghavendra, R. 2012. *Floristic diversity in Western Ghats: Documentation, conservation and bioprospection—A priority agenda for action. Sahyadri E-News*. Indian Institute of Science, 37p.

Rao, R.R., Murugan, R., Syamasundar, K.V., and Srinivasalu, B. 2006. Western Ghats, - A major emporium of wild aromatic plants: diversity, conservation and bioprospection. In: Todaria, N.P., Chamola, B.P., and Chauhan, D.S. (eds). *Concepts in Forestry Research*. pp. 267-278.

Reddy, C.S., Ugle, P., Murthy, M.S.R., and Sudhakar, S. 2008. Quantitative structure and composition of tropical forests of Mudumalai Wildlife Sanctuary, Western Ghats, India. *Taiwania*, 53(2): 150-156.

Reich, P.B., Grigal, D.F., Aber, J.D., and Gower, S.T. 1997. Nitrogen mineralization and productivity in 50 hardwood and conifer stands on diverse soils. *Ecology*, 78(2): 335-347.

Ricotta, C. and Podani, J. 2017. On some properties of the Bray-Curtis dissimilarity and their ecological meaning. *Ecol. Complex.*, 31: 201-205.

Rushforth, K. 2007. Notes on the Cupressaceae in Vietnam. *Tap Chi Sinh Hoc*, 29(3): 32-39.

Russell, A.J., Bidartondo, M.I., and Butterfield, B.G. 2002. The root nodules of the Podocarpaceae harbour arbuscular mycorrhizal fungi. *New phytol.*, 156(2): 283-295.

Rutherford, P.M., McGill, W.B., Arocena, J.M., and Figueiredo, C.T. 2006. Total nitrogen. In: Carter, M.R. and Gregorich, E.G. (eds). *Soil Sampling and Method of Analysis.* Canadian society of soil science, CRC press, Boca Raton, pp.239-250.

Sabu, T., Mohanan, N.N., Krishnaraj, M.V.N., Shareef, S.M., Shameer, P.S., and Roy, P.E. 2013. *Garcinia pushpangadaniana* (Clusiaceae), a new species from the southern Western Ghats, India. *Phytotaxa*, 116(2): 51-56.

Sahni, B. 2006. The deccan traps : An episode of the tertiary era. *Everyman's Sci.*, 41(5): 298-314.

Sahni, K.C. 1953. Botanical Exploration in the Great Nicobar Island. *Indian For.*, *79*(1): 3-16.

Sarvalingam, A. and Rajendran, A. 2016. Rare, endangered and threatened (RET) climbers of Southern Western Ghats, India. *Revista chilena de historia natural*, 89(1): 9.

Sasidharan, N. 2004a. *Biodiversity Documentation of Kerala Part 6: Flowering Plants*. Kerala Forest Research Institute, Peechi.

Sasidharan, N. 2004b. *Forest Trees of Kerala*, Kerala Forest Research Institute, Peechi, 191p.

Sathish, B.N., Viswanath, S., Kushalappa, C.G., Jagadish, M.R. and Ganeshaiah, K.N., 2013. Comparative assessment of floristic structure, diversity and regeneration status of tropical rain forests of Western Ghats of Karnataka, India. *J. Appl. Nat. Sci.*, 5(1): 157-164.

Saxena, A.K. and Singh, J.S. 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetatio*, 50(1): 3-22.

Saynes, V., Hidalgo, C., Etchevers, J.D., and Campo, J.E. 2005. Soil C and N dynamics in primary and secondary seasonally dry tropical forests in Mexico. *Appl. Soil Ecol.*, 29(3): 282-289.

Shannon, C.E. and Wiener, W. 1963. The Mathematical Theory of Communication. Urbana, University of Illinois Press. 117p.

Sharma, B.D. 2000. Affinities- Paleobotanical and geological evidences, relationship with adjacent regions, past and recent plant migration. In: Singh, N.P., Singh, D.K., Hajra, P.K., and Sharma, B.D. (eds) *Flora of India, Introductory Volume* [Part 3], Botanical Survey of India, New Delhi, 433p.

Sharma, B.D. and Kulkarni, B.G. 1980. Floristic composition and peculiarities of Devrais (sacred groves) in Kolhapur district, Maharashtra. *J. Econ. Taxon Bot.*, *1*: 11-32.

Sharma, J.K., Nair, K.K.N., Mathew, G., Ramachandran, K.K., Jayson, E.A., Mohanadas, K., Nandakumar, U.N., and Nair, P.V. 2002. *Studies on the Biodiversity of New Amarambalam Reserved Forests of Nilgiri Biosphere Reserve*, KFRI Research Report No.247, Kerala Forest Research Institute, Peechi, 230p.

Sidiyasa, K. 2001. Tree diversity in the rain forest of Kalimantan. In: Hillegers, P.J.M. and De Iongh, H.H. (eds) *The Balance Between Biodiversity Conservation and Sustainable Use of Tropical Rain Forests.* Tropenbos International, Wageningen, pp: 69-78.

Simpson, E.H. 1949. Measurement of diversity. *Nature*, 163(4148): 688-688.

Sindhuja, R., Rajendran, A., and Jayanthi, P. 2012. Herbaceous life forms of Maruthamalai Hills, Southern Western Ghats, India. *Int. J. Medic. Aromat. Plants*, 2(4): 625-631.

Singh, J.S. and Chaturvedi, R.K. 2017. Diversity of ecosystem types in India: a review. In: *Proceedings of the Indian National Science Academy*, *83*, pp.569-594.

Singh, N.P and Karthikeyan, S. 2000. *Flora of Maharashtra State, Dicotyledonae* [Vol 1] Botanical Survey of India, Calcutta, 236p.

Skjemstad, J.O. and Baldock, J.A. 2006. Total and organic carbon. In: Carter, M.R. and Gregorich, E.G. (eds). *Soil Sampling and Method of Analysis.* Canadian society of soil science, CRC press, Boca Raton, pp. 225-237.

Soosairaj, S., Britto, S.J., Balaguru, B., Natarajan, D., and Nagamurugan, N. 2005. Habitat similarity and species distribution analysis in tropical forests of eastern ghats, Tamil Nadu. *Trop. Ecol.*, 46(2): 183-192.

Sreekanth, N.P., Prabha, V.S., Babu, P. and Thomas, A.P. 2013. Soil carbon alterations of selected forest types as an environmental feedback to climate change. *Int. J. Environ. Sci.*, 3(5): 1516-1530.

Stevenson, F.J. 1986. Cycles of Soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. John Wiley & Sons, New York, NY.

Stevenson, F.J. 1994. *Humus Chemistry. Genesis, Composition, Reactions*. [2nd Ed] John Wiley & Sons, New York, NY, 256p.

Stirling, G. and Wilsey, B. 2001. Empirical relationships between species richness, evenness, and proportional diversity. *Am. Nat.*, 158(3): 286-299.

Subashree, K., Dar, J.A., and Sundarapandian, S. 2019. Variation in soil organic carbon stock with forest type in tropical forests of Kanyakumari Wildlife Sanctuary, Western Ghats, India. *Environ. Monit. Assess.*, 191(11): 690.

Sukumar, R., Dattaraja, H.S., Suresh, H.S., Radhakrishnan, J., Vasudeva, R. and Nirmala, S. 1992. Long-term monitoring of vegetation in a tropical deciduous forest in Mudumalai, southern India. *Curr. Sci.*, 62(9): 608-616.

Sunarti, S. and Rugayah, R., 2013. Keanekaragaman Jenis Gymnospermae di Pulau Wawoni, Sulawesi Tenggara. *J. Biologi Indonesia*, *9*(1).

Sundarapandian, S.M. and Swamy, P.S. 1999. Litter production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India. *Forest Ecol. Manag.*, 123(2-3): 231-244.

Sundarapandian, S.M. and Swamy, P.S. 2000. Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. *J. Trop. For. Sci.*, 104-123.

Swamy, H.R. and Proctor, J. 1994. Litterfall and nutrient cycling in four rain forests in the Sringeri area of the Indian Western Ghats. *Glob. Ecol. Biogeogr. Lett.*: 155-165.

Swamy, S.L., Dutt, C.B.S., Murthy, M.S.R., Mishra, A., and Bargali, S.S. 2010. Floristics and dry matter dynamics of tropical wet evergreen forests of Western Ghats, India. *Curr. Sci.*, *99*(3): 353-364.

Taylor, E.L., Taylor, T.N., and Krings, M. 2009. *Paleobotany*: *The Biology and Evolution of Fossil Plants*. Academic Press, 1252p.

Thomas, P., Sengdala, K., Lamxay, V., and Khou, E. 2007. New records of conifers in Cambodia and Laos. *Edinb. J. Bot.*, 64(1): 37-44.

Tiwari, V.M., Padmalal, D., and Prakash, T.N. 2018. Western Ghats: Evolution and Environmental Issues–An Overview. *J. Geol. Soc. India*, 92(5): 515-516.

Tiwari, V.M., Varma, R.A., and Padmalal, D. 2016. Workshop on Western Ghats: Evolution and environmental issues. *J. Geol. Soc. India*, 88(6): 811.

Topp, G.C., Parkin, G.W., and Ty Ferre, P.A. 2006. Soil water content. In: Carter, M.R. and Gregorich, E.G. (eds). *Soil Sampling and Method of Analysis.* Canadian society of soil science, CRC press, Boca Raton, pp.939-961

Tothmeresz, B. 1998. On the characterization of scale-dependent diversity. *Abstracta Botanica*, 149-156.

Utkarsh, G., Joshi, N.V., and Gadgil, M. 1998. On the patterns of tree diversity in the Western Ghats of India, *Curr. Sci.*, 75(6).

Varghese, A.O. and Balasubramanyan, K. 1999. Structure, composition and diversity of the tropical wet evergreen forest of the Agasthyamalai region of Kerala, Western Ghats. *J. South Asian Nat. Hist.*, 4(1): 87-98.

Varghese, A.O. and Menon, A.R.R. 1999. Ecological niches and amplitudes of rare, threatened and endemic trees of Peppara Wildlife Sanctuary. *Curr. Sci.*, 76(9):1204-1208.

Venkatesh, B., Lakshman, N., Purandara, B.K. and Reddy, V.B. 2011. Analysis of observed soil moisture patterns under different land covers in Western Ghats, India. *J. Hydrol.*, 397(3-4): 281-294.

Vidyasagaran, K., Gopikumar, K. and Ajithkumar, M. 2004. Phytosociological Analysis of Selected Shola Forests of the Nil Girl Hills of Western Ghats. *Indian For.*, *130*(3): 283-290.

Walkley, A. and Black, I. A. 1934. An examination of the detjareff method for determining soil organic matter and a proposed modification to the chronic acid titration method. *Soil Sci*., 37:29–38.

Wang, S., Zhuang, Q., Jia, S., Jin, X., and Wang, Q. 2018. Spatial variations of soil organic carbon stocks in a coastal hilly area of China. *Geoderma*, *314*, pp.8-19.

Wardle, P. 2008. New Zealand forest to alpine transitions in global context. *Arct. Antarct. Alp. Res.*, 40(1): 240-249.

Webb, C.O., 2005. Vegetation of the Raja Ampat Islands, Papua, Indonesia. *A Report to The Nature Conservancy*.28p.

West, D.C., Shugart, H.H., and Ranney, J.W. 1981. Population structure of forests over a large area. *Forest Sci.*, *27*(4): 701-710.

WGEEP [Western Ghats Ecology Expert Panel]. 2011. *Report of the Western Ghats Ecology Expert Panel*. The Ministry of Environment and Forests, Government of India, 327p.

Wiegand, T., Gunatilleke, S., and Gunatilleke, N. 2007. Species associations in a heterogeneous Sri Lankan dipterocarp forest. *Am. Nat.*, 170(4): E77-E95.

ECOLOGICAL STATUS OF *NAGEIA WALLICHIANA* (C.PRESL.) KUNTZE, AN ENDANGERED CONIFER OF WESTERN GHATS IN MANKULAM FOREST DIVISION

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Nageia wallichiana (C.Presl.) Kuntze is a lesser-known rare arborescent, threatened evergreen conifer species of wet evergreen forests of Western Ghats. A study on the distributional status and ecology of this species was conducted in the natural habitats in Mankulam Forest Division. The study aimed at understanding the floristic composition and natural regeneration patterns in the natural habitats of *Nageia wallichiana*. The additional objective was to assess the physicochemical properties of the soil in the *Nageia wallichiana* growing areas. The purposive sampling of vegetation was done in 20 x 50 m main plots in *Nageia wallichiana* growing areas (NG) and control plots were taken in areas without *Nageia wallichiana* (WNG). The regeneration pattern of trees was studied by taking 5 m x 5 m subplots for saplings and 1 m x 1 m nested plots for seedlings inside the main plots of NG. From NG, a total of 188 individual trees belonging to 67 different species and 28 different families were identified from three different *Nageia wallichiana* growing patches, viz., Kannadipara, Idathattu, and Kallar. In WNG, 94 individual trees belonging to 46 species and 25 different families were identified.

The altitudinal range of occurrence of *Nageia wallichiana* in the study area was found to be 934 –1463 m above MSL. The girth class distribution of the species showed an L-shaped curve with 90 percent of individuals below 50 cm girth. The floristic studies in the area showed that the natural habitats of *Nageia wallichiana* harbor a large number of trees in endemic and threatened categories. The typical evergreen species, *Cullenia exarillata* showed the maximum dominance in NG followed by *Mesua ferrea* and *Bhesa indica.* In WNG, the most dominant species were *Dysoxylum malabaricum*, *Vateria indica* and *Polyalthia fragrans.* The comparison of tree diversity between NG and WNG didn’t reveal any significant variations. The ecological distance analysis and clustering showed significant difference in species composition between NG and WNG. The ordination plots proved *Bhesa indica* as a strong species associate of *Nageia wallichiana*.

The regeneration study showed a lower diversity of regenerating individuals in the study area than mature trees and a difference in species composition was also observed. The analysis of soil properties found that the soils from *Nageia wallichiana* habitats were higher in moisture content and organic carbon and lower in total nitrogen content. The study didn't found any relation for soil pH and bulk density on the occurrence of *N.wallichiana*.

The study identified the habitat specialist nature of *Nageia wallichiana* from the restricted distribution of the species in certain patches of the study area. The occurrence of this only conifer of the Western Ghats in the Mankulam forest Division indicates the importance of the area because *Nageia wallichiana* is considered as a better indicator of ecological conditions. The study also observed a higher rate of regeneration for this species in the study area indicating the presence of ideal ecological conditions. However, a more focused study considering the disturbance levels in the study area and some extra parameters such as soil depth, soil nutrient contents, frequency of fire occurrence etc. will give a better understanding of the restricted occurrence of this species in the study area and it may contribute in the development of specialized conservation strategies.