Chapter

Forest Vegetation and Dynamics Studies in India

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Abstract

Forests across the globe have been exploited for resouces, and over the years the demand has increased, and forests are rather exploited instead of sustainable use. Focussed research on vegetation and forerst dynamics is necessary to preserve biodiversity and functioning of forests for sustanence of human life on Earth.This article emphasis that the India has a long history of traditional knowledge on forest and plants, and explorations from 17th century on forests and provided subsequent scientific approach on classification of forests. This also explains the developments of quantitative approach on the understanding of vegetation and forest diversity. Four case studies viz., Mudumalai, Sholayar, Uppangala, Kakachi permanent plots in the forests of Western Ghats has been explained in detail about their sampling methods with a note on the results of forest monitoring. In the case of deciduous forests, the population of plant species showed considerable fluctuations but basal area has been steadily increasing over time, and this is reflecting carbon sequestration. In Sholayar, a total of 25390 individuals of 106 woody species was recorded for < 1 cm diameter at breast height in the first census of the 10 ha plot in the tropical evergreen forest. In Uppangala, 1) a 27- year long investigation revealed that residual impact of logging in the evergreen forests and such forests would take more time to resemble unlogged forests in terms of composition and structure; 2) across a similar temporal scale, the unlogged plots trees < 30 cm gbh showed a more or less similar trend in mortality (an average of 0.8% year-1) and recruitment (1%). The Kakachi plot study revealed that 1) endemic species showed least change in stem density and basal area whereas widely distributed species showed greater change in both; 2) The overall recruitment of trees was 0.86 % per year and mortality 0.56% per year resulting in an annual turnover of 0.71% ; 3) majority of the gap species had high levels of recruitment and mortality resulting in a high turnover.Such studies can be used as early warning system to understand how the response of individual plants, species and forests with the climatic variability. In conclusion, the necessity of implementation of national level projects, the way forward of two such studies: 1) impact of climate change on Indian forests through Indian Council of Forestry Research and Education (ICFRE) colloborations and 2) Indian long term ecological observatorion, including the sampling protocols of such studies. This will be the first of its kind in India to address climate change issues at national and international level and helps to trace footprints of climate change impacts through vegetation and also reveals to what extent our forests are resilient to changes in the climate.

Keywords: climate change, episodic recruitment, monitoring, permanent plots, trees, Western Ghats

1. Introduction

Forests across the globe have been utilized and many times exploited by humans ever since life style changed from nomadism to settled agri-based system. Forests used to supply many resources including fuel wood, medicine, timber, food etc. But over the years the demand has increased and forests are rather exploited instead of sustainable use.

Historically Indian forests attracted traders for its diversity in spices. The discovery of sea route to India resulted in exodus of European traders. The Portuguese, English, Dutch, French and Germans arrived in India in their quest for the plant species that were important as spices. Records are available that Romans and Arabs were briskly trading with Kings especially along the Western Ghats for variety of spices such as pepper, ginger, cardamom and other condiments.

1.1 Vegetation studies in India

India is richly endowed with climatic, edaphic and orographic gradients. Geographical extent of India ranges from tropical latitude to temperate latitude with tropic of Cancer passing through India dividing into almost half with one part predominantly tropical nature while the other is subtropical and temperate in nature. Hence the natural vegetation of India is also ranging from rainforests in the Western Ghats and Eastern Himalayas to desert in Rajasthan.

Ancient description of vegetation largely confined to composition of species primarily of medicinal use and utilization in rituals. Ancient India had a rich tradition of life sciences. There are reviews relating to the knowledge of plant sciences in ancient India [1]. The study of plants in ancent India was mainly under two heads namely, 1. Plants utilized for medicinal purposes and 2. Plants relating to agriculture [1]. However, the study on description of plants and animals was not popular. Takshashila University encouraged the collection, identifying and description of plants found around Takshashila. The traditional medicine in India which is primarily plant based has description of several plant species occurring in different forest types. Though, the descriptions largely confined to medicinal properties and parts of the plants used.

1.2 Studies on plant systematics

Significant contribution to botany of India was made during the colonial period with a strong pursuit of harvesting botanical resources. There were several European botanists and explorers contributed to the knowledge of botanical resources of India. Van Rheede H. A. (17th Century) the then Dutch Governor of Cochin made an effort to scientifically document the wealth of plants and indigenous medical knowledge with the native Malabaris. He produced a well written book, '*Hortus Malabaricus*' published during 1678–1693 [2]. This book contained scientific description and life size illustrations of about 742 native plants in Malabar (Kerala) and of which about 650 are of medicinal value. This book was used by several European botanists such as Linnaeus, De Candole, De Jussieu, Adanson, Blume and Wight to describe many species from India and Asia [3]. Some of the important names include, Johann Gerhard Koenig (1768) who made extensive collections from India, Robert Kydd (1787) who was instrumental in starting the Royal Botaical Gardens at Calcutta and Sir Joseph Hooker who wrote monumental book "*Flora of British India*" and Gamble and Fischer (1915-36) who wrote a comprehensive flora for the region of the presidency of Madras [4]. There were several Europeans who made collections and described many plant species from different parts of India. The development of science under colonial period is well described by Kochhar [4, 5]. Important component in development of plant science in India under colonial rule was establishment of botanical gardens not only in Calcutta but in several places across India with major focus on breeding and maintenance of economically important species from different colonial parts of southeast Asia.

1.3 Indian forest types

First systematic classification of Indian forest types was by Sir. H.G. Champion in 1936 which was later revised in the year 1968 by Champion H.G. and S.K. Seth [6]. They identified 16 major forest types based on rainfall and temperature (**Table 1**). Contemporaneously, the French Institute of Pondicherry (IFP; http://www.ifpindia.org) produced vegetation maps at the one million scale for peninsular India (by publishing 12 sheets between 1959 and 1973) in collaboration with Indian Council of Agricultural Research. Subsequently published six vegetation maps (scale 1: 250000) covering south and central Western Ghats region in collaboration with state forest departments of Karnataka, Kerala and Tamil Nadu [7–12]. These maps were produced considering bioclimate of the region, floristic series (dominant species based on climax species, structural and floristic composition) of the forest types, limits of forest types, altitudinal zonation, degree of degradation of forests, relationships between different stages of succession and the potentiality of a disturbed forest to return to the climax. Since then there are studies to improve the classification of forest types considering the feasibility for the forest managers to manage their forests. Attempts have been made by the Forest Survey of India (FSI) to revisit different forest types and reassign the forest types based on ground survey [13] (**Table 2**). In 2014, Indian Council of Forestry Research and Education (ICFRE) has revisited Champion and Seth [6] forest type classification by rapid assessment mode.

1.4 Major developments in understanding vegetation of India

There was a discernible change in describing vegetation in India. The trend was not to describe species found in any vegetation type but quantitatively describe the vegetation of a locality. There were several studies on quantitative description of vegetation in India. It was initiated by Rai [16], who inventoried all trees ≥10 cm dbh in four plots of 2.7, 2.7, 2.63 and 1.09 hectares respectively at Devimane, Malemane, Kodkani and Katlekan areas of the Western Ghats. Most such studies in the Indian evergreen forests have been conducted during the last decade of the 20th century, and many of them are once census plots. Interest in tree mortality and forest dynamics has increased recently because forest dynamics is thought to be involved in determining tree species diversity [17], and also thought to be related to global climate change, in particular [18]. Phillips and Gentry (*l.c.*) concluded that tree turnover rates have increased in tropical forests during the latter part of the 20th century. This has proved to be a controversial finding (e.g. [19, 20]), but one which could have important implications for biodiversity and atmospheric change. Apart from the global plot networks such as CTFS and Rainfor, India also made

Category 1: Moist Tropical Forests	
Group 1: Tropical Wet Evergreen Forests	
Sub group 1A: Southern Tropical Wet Evergreen Forests	Includes giant evergreen forests, moist forests of Andamans, montane forests of southern India, west coast evergreen forests. Imortant species include *Palaquium ellipticum, Cullenia exarillata, Vateria indica, Hopea* sp., *Dipterocarpus indicus, Calophyllum* sp., *Diospyros* sp., *Mesua ferrea.*
Sub group 1B: Northern Tropical Wet Evergreen Forests	Forests in Assam Valley, Upper Assam Valley Evergreen forests, Cachar evergreen forests (Dima Hasao district, Assam). Important species include *Michelia montana, Mesua ferrea, Dysoxylon binecteriferum, Dipterocarpus* sp., *Shorea assamica, Litsea monopetala, Artocarpus chaplasha, Garcinia pedunculata.*
Sub group 1C: Edaphic and seral types of evergreen forests	Includes cane brakes, wet Bamboo and pioneer Euphorbiaceous scrub.
Group 2: Tropical Semi-evergreen Forests	
Sub group 2A: Southern tropical semi-evergreen forests	Includes Andaman's semi-evergreen forests, west coast semi-evergreen forests, west coast secondary evergreen Dipterocarp forests. Some of the dominant species include *Terminalia paniculata, Olea dioica, Knema attenuata, Litsea* sp., *Syzygium* sp., *Diospyros* sp., *Artocarpus hirsutus, Mesua ferrea.*
Sub group 2B: Northern tropical semi-evergreen forests	Assam valley and alluvial semi-evergreen forests, sub-Himalayan secondary et mixed forests, Cachar and Orissa semi-evergreen forests. Important species are *Shorea robusta, Haldina cordifolia, Mesua ferrea, Litsea monopetala, Casearia graveolens, Syzugium* sp.,*Terminalia bellerica, Tetrameles nudiflora.*
Sub group 2C: Edaphic and seral types of semi-evergreen forests	Moist bamboo brakes, lateritic semi-evergreen forests, secondary moist bamboo brakes. Important species are *Pterocarpus marsupium, Anogeissus latifolia, Syzygium cumini, Phoenix acaulis* etc.
Group 3: Tropical Moist Deciduous Forests	
Sub group 3A: Andaman's moist deciduous forests	Andaman's moist and secondary moist deciduous forests. Dominant species include *Pterocarpus dalbergioides, Diospyros oocarpa, Celtis wightii, Terminalia bialata, Lagerstroemia hypoleuca*
Sub group 3B: South Indian moist deciduous forests	Moist teak bearing forest, southern moist mixed and secondary mixed deciduous forest. Important species include *Terminalia paniculata, Xylia xylocarpa, Terminalia bellirica, Lagersroemia microcarpa, Grewia tiliifolia, Dillenia pentagyna, Holigarna* sp., *Diospyros* sp., *Tectona grandis.*
Sub group 3C: north Indian moist deciduous forests	Moist Sal forests founding east Himalayas, Khasi hills, Siwalik hills and Assam. Dominant species include *Shorea robusta, Buchanania lanzan, Garuga pinnata, Schima wallichii, Madhuca latifolia, Mallotus philippensis, Lagerstroemia speciosa* (Syn. *L. macrocarpa*), *Gmelina arborea.*
Sub group 3D: Edaphic and seral types of moist deciduous forests	*Terminalia tomentosa* forests. Some of the species are *Tectona grandis, Dalbergia latifolia, Shorea robusta, Anogeissus latifolia, Lagerstroemia* sp.

Category 1: Moist Tropical Forests	
Group 4: Littoral and swamp forests	
Sub-group 4A: Littoral forests	Some of the common species are *Manilkara littoralis, Thespesia, Spinifex, Littoreus, Casuarina equisetifolia, Pandanus, Borassus, Phoenix, Callophyllum littoralis, Barringtonia, Pongamia,* twiners, climbers etc.
Sub-group 4B: Tidal swamp forests	Mangrove scrub, Mangrove forests. Dominant species are *Rhizophora* sp., *Avicennia* sp., *Bruguieria gymnorrhiza, Excoecaria agallocha*.
Sub-group 4C: Tropical fresh water swamp forests	*Myristica* swamp forests. Important species are *Myristica fatua, Gymnocranthera canarica, Mastixia arborea, Semecarpus travancorica, Hopea whitiana, Lophopetalum whitiana, Holigarna graham, Syzygium laetum* etc.
Category 2: Dry Tropical Forests	
Group 5: Topicl dry deciduous forests	
Sub-group 5A: Southeren tropical dry deciduous forests	Dry teak bearing forest, dry teak forest, dry red-sanders bearing forest, southern dry mixed deciduous forest. Some of the important species include *Tectona grandis, Anogeissus latifolia, Terminalia* sp., *Shorea roxburghii, Schleichera oleosa, Diospyros* sp., *Pterocarpus marsupium, Pterocarpus santalinus, Lagerstroemia* sp.
Sub-group 5B: northern tropical dry deciduous forests	Dry Sal- bearing forest, dry Siwalik Sal forest, Dry plains Sal forest, Dry peninsular sal forest, Northern mixed dry deciduous forest. Some of the important species are *Shorea robusta, Terminalia* sp., *Anogeissus latifolia, Anogeissus pendula, Anthocephalus chinensis, Albizia* sp., *Careya arborea, Sterculia villosa, Lannea coromandelica, Boswellia serrata* etc.
Sub-group 5C: Degrdation of tropical deciduous forests, edaphic type of dry eciduous forests and general seral types.	Dry deciduous scrub, dry savanna forest, dry tropical riverain forest, secondary dry deciduous forest. Important species are *Anogeissus latifolia, Terminalia chebula, Albizia* sp., *Pterocarpus marsupium* etc.
Group 6: Tropical thorn forests	
Sub-group 6A: Southern tropical thorn forests	Southern thon forest, southern thorn scrub, Important species include *Acacia* sp., *Ziziphus* sp., *Albizia chinensis*, *Diospyros montana*, *Erythroxylon monogynum*, *Bauhinia racemosa*, *Premna tomentosa*, etc.
Sub-group 6B: Nothern tropical thorn forests	Desrt thorn forest, riverain thorn forest, tropical *Euphorbia* scrub. Dominant species include *Acacia* sp., *Albizia* sp., *Butea monosperma, Prosopis* sp.,
Sub-group 6C: Genral degraded edaphic seral types.	*Acacia senegal* forest, *Salvdora* scrub, desert dune forest. Important species include *Salvadora oleoides, Acacia* sp., *Prosopis* sp., *Capparis* sp., etc.
Category 3: Montane subtropical forests	
Sub-group 8A: Southern subtropical broadleaved hill forests	Nilgiri subtropical hill forest, western subtropical hill forest, central Indian subtropical hill forests. Important species include *Persea macrantha, Neolitsea zeylanica, Litsea* sp., *Turpinia malabarica, Symplocos* sp., *Ilex denticulata* etc.

Category 3: Montane subtropical forests	
Sub-group 8B: Northern subtropical broadleaved hill forests	East Himalayan subtropical wet hill forest, Khasi subtropical wet hill forest. *Rhododendron arboreum, Myrica esculenta, Symplocos paniculata, Quercus leucotrichophora, Lyonia ovalifolia, Quercus lanata, Engelhardia spicata, Prunus nepalensis* etc.
Group 9: Subtropical Pine forests	Himalayan subtropical pine forest, Assam subtropical pine forests. Dominant species are *Cedrus deodara, Quercus* sp., *Alnus nepalensis, Acer oblongum, Pinus kesiya, Larix griffithii, Schima wallichii* etc.
Group 10: Subtropical dry evergreen forests	Subtropical dry evergreen forest. Dominant species are *Acacia* sp., *Olea cuspidata, Canthium dicoccum, Diospyros ebenum, Holoptelea integrifolia.*
Category 4: Montane temperate forests	
Sub-group 11A: Southern montane wet temperate forests	Southern montane wet temperate forest.Dominant species are *Lindera neesiana, Litsea* sp., *Cinnamomum* sp., *Isonandra candolleana, Symplocos* sp., *Beilschmiedia wightii, Daphniphylum neilgherrense, Syzygium* sp., etc
Sub-group 11B: Northern montane wet temperate forests	East Himalayan wet temperate forests, Naga hills wet temperate forests. Dominant species are *Pinus kesiya, Acer oblongum, Schima wallichii, Quercus serrata, Castonopsis* sp., *Magnolia campbellii.*
Group 12: Himalayan moist temperate forests	Lower western Himalyan tempeate forest, upper Himlayan temperate forest, East Himalayan temperate forest, East Himalayan mixed coniferous forest. Some of the important species include *Acer campbellii, Magnolia campbellii, Quercus pachyphylla, Michelia doltsopa, Betula alnoides, Actinodaphne microptera, Gordonia obtusa* etc.
Group 13: Himalayan dry temperate forests	1. Western type: Dry broad-leaved and confireous forest, dry temperate coniferous forest, west Himalayan dry temperate deciduous forest, west Himalayan high level dry blue pine forest, west Himalayan dry Juniper forest, east Himalayan dry temperate conifer forest, east Himalayan Juniper/birch forest. Dominant species are *Cedrus deodara, Pinus gerardiana, Pinus wallichiana, Picea smithiana, Rhododendron campanulatum, Juniperus macropoda, Larix griffithii, Tsuga dumosa* etc.
Group 14: Sub-alpine forests	West Himalayan sub-alpine birch/fir forest, east Himalayan sub-alpine birch/fir forest. The subalpine forests occur throughout the Himalaya above 3000 m elevation up to the tree limit., rainfall 83-600 mm. The forests are mainly evergreen, *Rhododendron* is common constituent. Tall trees are conifers; *Betula utilis* is present as the largest deciduous tree and associated with genera like *Quercus semecarpifolia*, *Sorbus* and *Rhododendron* sp. Western Himalaya sub-alpine forests are found in Jammu and Kashmir, Himachal Pradesh, and Uttrakhand. In the western Himalaya there are two types of forests (i) *Abies spectabilis* and *Betula utilis*, (ii) west Himalayan sub-alpine birch/fir forest.

Category 6: Alpine scrub	
Group 15: Moist alpine scrub	Birch/Rhododendron scrub forest, deciduous alpine scrub, alpine pastures Moist Alpine Scrub occurs throughout Himalaya, above timber line to 5500 m altitude, composed entirely of species of *Rhododendron* with some birch (*Betula*) and other deciduous trees. The tree trunks are short and highly branched, moss and ferns cover the ground. A thick layer of humus is present and soil is generally wet. In Kumaun, Uttrakhand, *Betula utilis* and *Rhododendron campanulatum* scrub forest occur. *Rhododendron-Lonicera* association occurs in Uttrakhand, in inner Himalaya. In eastern Himalaya, dense Rhododendron thickets occur at 3350-4600 m altitude. These forests are reported from Arunachal Pradesh, Sikkim and West Bengal.
Group 16: Dry alpine scrub	They are found in Jammu and Kashmir, Himachal Pradesh, Uttrakhand, and Arunachal Pradesh. Vegetation predominantly xerophytic dwarf shrubs; rainfall < 370 mm per year. Important species *Juniperus wallichiana*, *Lonicera* sp. *Potentilla* sp. Vegetation along the streams is composed of *Salix, Myricaria*, and *Hippophae rhamnoides*. In eastern Himalaya *Juniperus recurva* and *Juniperus wallichiana* occur at an altitude ranging from 3000 to 4600 m.

Table 1.
Major forest types in India with their sub types according to Champion and Seth [6] and characterstic species composition of different forests. Species composition follows Reddy et al. [14, 15].

efforts to understand the vegetation and its dynamics. There are some examples describing the efforts to understand the vegetation.

2. Forest dynamics study by Indian Institute of Science (IISc), Bengaluru, Karnataka, India

India's first biosphere reserve the Nilgiri Biosphere Reserve (NBR) was established in 1986 and the responsibility of conducting research was given to Center for Ecological Sciences (CES), Indian Institute of Science (IISc). As a principle institute responsible in setting NBR, IISc has a commitment towards ecological research in the biosphere. The climatic and altitudinal gradient in NBR harbours different vegetation types ranging from dry thorn forests to rainforests. The altitudinal range has dry forests in the lower elevation to high altitude montane forests. Hence there is a tremendous variation in species composition across both climatic and altitudinal gradient.

When IISc began its research in NBR there were several issues regarding the choice of study area. Based on both logistical and academic reasons, IISc decided to join the international network of 50-ha forest dynamics plots promoted by Prof. Hubbell [21]. CES selected species poor deciduous forests of Mudumalai for variety of reasons. Firstly, Mudumalai would complement plot at Barro Colorado Island (BCI), Panama (tropical semi-evergreen forest, neotropics) and Malaysian plot,

Sl No	Forest types	Area in Sq. Km	Percent area
1	Group 1: Tropical wet evergreen forests	20,054	2.61
2	Group 2: Tropical semi-evergreen forests	71,171	9.27
3	Group 3: Tropical mist deciduous forests	135,492	1.65
4	Group 4: Littoral and Swamp forests	5596	0.73
5	Group 5: Tropical dry deciduous forests	313,617	40.86
6	Group 6: Tropical thorn forests	20,877	2.72
7	Group 7: Tropical dry evergreen forests	937	0.12
8	Group 8: Subtropical broadleaved hill forests	32,706	4.26
9	Group 9: Subtropical pine forests	18,102	2.36
10	Group 10: Subtropical dry evergreen forests	180	0.02
11	Group 11: Montane wet temperate forests	20,435	2.66
12	Group 12: Himalayan moist temperate forests	25,743	3.35
13	Group 13: Himalayan dry temperate forests	5627	0.73
14	Group 14: Sub alpine forests	14,995	1.96
15	Group 15: Moist alpine scrub	959	0.13
16	Group 16: Dry alpine scrub	2922	0.38
17	Plantation/TOF	64,839	8.45
	Total forest cover+ scrub	754,252	98.26
18	Grassland in different forest type groups (without forest cover)	13,329	1.74
	Grand total	767,581	100.00

Table 2.
Standard forest types of India according Forest Survey of India (FSI) classification.

FRIM, Malaysia (equatorial rainforest). Secondly the factors influencing the dynamics in dry forests are totally different from factors influencing dynamics of forests at both Panama and Malaysia [22].

2.1 Choice of the site

IISc has selected 50 hectare area in 17th compartment of the Kargudi range in Mudumalai Tiger Reserve as because, 1. The area is relatively free of anthropogenic disturbances as settlements are far off, 2. This area was selectively felled during late 1960s and we could identify the trees that were removed from the plot. They could identify the species of the stumps left behind and map them spatially in the plot, 3. This area lies in the transition zone between dry and moist deciduous vegetation and has both elements represented in the plot.

2.2 Methods

Establishment of plot involved two steps a. gridding and b. enumeration of the plot. Gridding involves dividing the plot into blocks of 20 X 20 metres after correcting for slope. Correction for slope is important to give equal opportunity for all individuals to compete for resources.

Enumeration involves measuring of all woody individuals and mapping them. Block of 20 X 20 meters is further divided into blocks of 10 X 10 meters temporarily by laying ropes. All woody individuals >1 cm dbh (diameter at breast height) are identified, measured for size, marked with unique number and mapped by taking X and Y coordinates. Point of measurement (POM) was marked where size measurement was made.

2.3 Results

There were 25,929 stems duing the first census belonging to 71 species. Most abundant species was understorey tree *Kydia calycina* (Malvaceae) with 5175 individuals accounting for 20% of total abundance. Dominant canopy species such as *Anogeissus latifolia* (2280), *Lagerstroemia microcarpa* (3980). *Tectona grandis* (2143) and *Terminalia crenulata* (2776) accounted for 55.9% of total abundance. The genus *Ficus* (Moraceae) had five species and followed by *Terminalia* (Combretaceae) with three species. Relative abundance cumulative abundance of top ten species is listed in the **Table 3**. Top ten species accounted for 87.52% of the total abundance. There were 21 species with less than 10 individuals in the plot and 7 species had one individual in the entire 50 hectare plot (**Table 3**).

Most species showed clumped dispersion. *Kydia calycina, Lagerstroemia microarpa, Terminalia elliptica, Helicteres isora, Anogeissus latifolia, Catunaregam spinosa* and *Shorea roxburghii* are species that showed highly clumped distribution at 1 hectare scale while species such as *Tectona grandis, Emlica officinalis, Grewia tiliifolia, Syzygium cumini, Diospyros montana, Schleichera oleosa, Terminalia chebula* and *Gmelina arborea* showed lesser degree of clumping at one hectare scale.

2.4 Forest dynamics (1988–2016)

Population of woody species in the plot has shown considerable fluctuations over different census periods. Population has grown from 25,935 individuals >1 cm dbh in 1988 to 48,360 individuals in 2016 (**Figure 1**). The population across

Species	Family	Abundance (50 ha)	Relative abundance (%)	Cumulative abundance (%)
Kydia calycina Roxb.	Malvaceae	5175	19.96	19.96
Lagerstroemia microcarpa Wt.	Lythraceae	3980	15.35	35.31
Terminalia elliptica Willd. (syn. *Terminalia crenulata* Roth)	Combretaceae	2776	10.71	46.01
Helicteres isora L.	Malvaceae	2571	9.91	55.93
Anogeissus latifolia (Roxb. ex DC.) Wall. Ex Guill & Perr.	Combretaceae	2280	8.79	64.72
Tectona grandis L.f.	Lamiaceae	2143	8.26	72.99
Cassia fistula L.	Fabaceae	1881	7.25	80.24
Catunaregam spinosa (Thunb.) Tirveng. [syn. *Randia dumetorum* (Retz.) Lam., *Xeromphis spinosa* (Thunb.) Keay, *Randia spinosa* (Thunb.) Poir.]	Rubiaceae	770	2.97	83.21
Phyllanthus emblica L.	Phyllanthaceae	577	2.22	85.44
Grewia tiliifolia Vahl	Tiliaceae	539	2.08	87.52

Table 3.
Top ten dominant species in the plot during the first census (1988–1989).

different census years has shown fluctuations. There was a negative trend during 1988–1992 (−31.9%), 1992–1996 (−13.2%) and 2000–2004 (−14.2%). There was huge surge of 138.9% in populations between 2004 and 2008 census. There was a positive trend during 1996–2000 (18.3%), 2008–2012 (1.1%), 2012–2016 (28.7%).

There is an overall increase of 86.4% with the total population during 1988–2016. However, individual species showed an interesting trend in the populations (**Table 4**). Among canopy species *Dalbergia latifolia* has shown a large change of 469.3% (population changed from 75 individuals in 1988 to 427 individuals in 2016). Among the four dominant canopy species except for *Lagerstroemia microcarpa* (13.4%) others such as *Anogeissus latifolia* (−25.3%), *Tectona grandis* (−17.4%) and *Terminalia elliptica* (22.2%) have shown negative change. Other species that have significant change include *Gmelina arborea* (−72.8%), *Ougeinia oojensis* (89.3%) and *Shorea roxburghii* (82.0%).

Among the understorey species, *Helicteres isora* (776.1%) and *Randia dumetorum* (679.0%) registered exceptionally higher population growth. *Helicteres isora* increased from 2573 individuals in 1988 to 22,543 individuals in 2016 while *Randia dumetorum* from 770 individuals in 1988 to 5999 individuals in 2016. There was a significant reduction in population of *Eriolaena quinquelocularis* from 249 individuals in 1988 to 7 individuals in 2016.

2.4.1 Patterns in mortality and recruitment

Entire plot (50 hectares) was annually censused for mortality and recruitment till 2008. Since 2009, annual census was done in sample plots of 40 meters X 40 meters inside the plot. There were 100 such randomly placed plots accounting for little more than 1/3rd of the total area. The reports on annual mortality for the plot from sample plots from 1989 to 2016 were published [23].

The community wide mean annual mortality rate was 7.67±5.75% (range 1.57–21.5%, N = 28) while mean annual recruitment rate was 11.1±14.0%

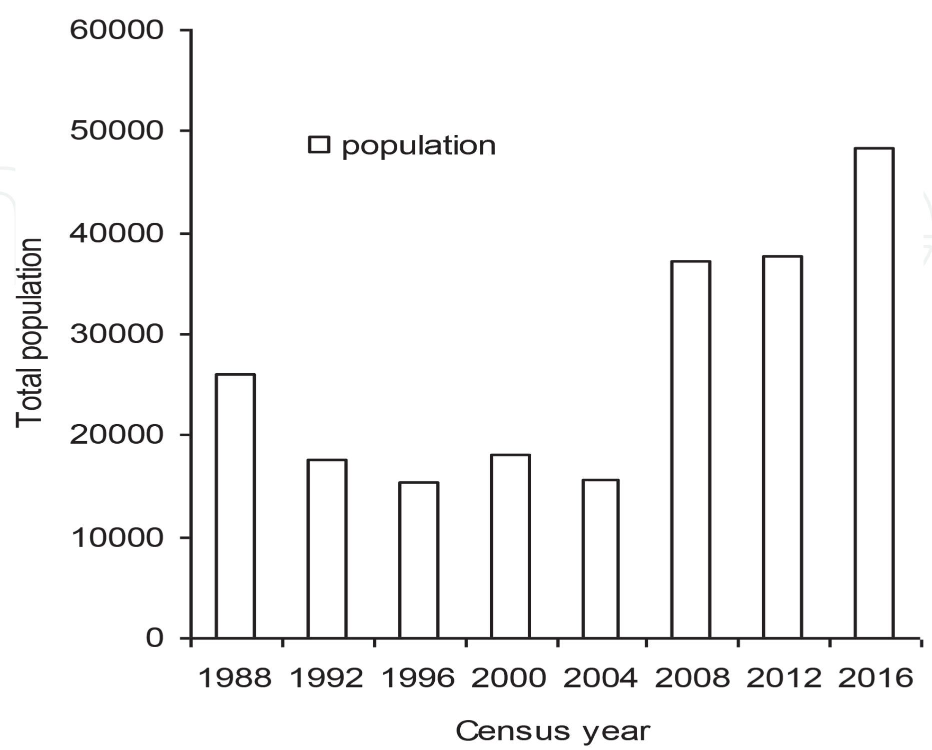

Figure 1.
Total population in different census years (all woody stems >1 cm dbh).

Species	Family	Census 1988	Census 2016	% Change
Canopy species				
Anogeissus latifolia (Roxb. ex DC.) Wall. Ex Guill& Perr.	Combretaceae	2281	1702	−25.38
Dalbergia latifolia Roxb.	Fabaceae	75	427	469.33
Diospyros montana Roxb.	Ebenaceae	130	135	3.85
Gmelina arborea Roxb.	Lamiaceae	59	16	−72.88
Grewia tiliifolia Vahl	Tiliaceae	540	592	9.63
Lagerstroemia microcarpa Wt.	Lythraceae	3982	4516	13.41
Ougeinia oojeinensis (Roxb.) Hochr.	Fabaceae	113	12	−89.38
Schleichera oleosa (Lour.) Oken	Sapindaceae	75	96	28.00
Shorea roxburghii G. Don (Syn. *Shorea talura* Roxb.)	Dipterocarpaceae	78	14	−82.05
Stereospermum personatum (Hassk.) Chatterjee	Bignoniaceae	112	129	15.18
Syzygium cumini (L.) Skeels.	Myrtaceae	414	442	6.76
Tectona grandis L.f.	Lamiaceae	2141	1768	−17.42
Terminalia elliptica Willd.	Combretaceae	2771	2154	−22.27
Understory species				
Cassia fistula L.	Fabaceae	1887	3025	60.31
Cordia oblique Willd.	Bignoniaceae	192	281	46.35
Eriolaena quinquelocularis (Wight & Arn.) Wight	Malvaceae	249	7	−96.39
Helicteres isora L.	Malvaceae	2573	22,543	776.14
Kydia calycina Roxb.	Malvaceae	5167	1018	−80.30
Lagerstoemia parviflora Roxb.	Lythraceae	94	51	−45.74
Phyllanthus emblica L.	Phyllanthaceae	576	296	−48.61
Catunaregam spinosa (Thunb.) Tirveng. [syn. *Randia dumetorum* (Retz.) Poir.]	Rubiaceae	770	5999	679.09
Radrmachera xylocarpa (Roxb.) K. Schum.	Bignoniaceae	358	356	−0.56
Terminalia chebula Retz.	Combretaceae	62	22	−64.52

Table 4.
Population changes observed among several canopy and understorey species in the 50 ha plot, Mudumalai.

range = 0.65–58.5%, N = 28). Though recruitment rate was higher than the mortality rate, recruitment rate had high variability compared to mortality rate. There was considerable fluctuation in the mortality and recruitment rate across census periods (**Table 5**). Mean annual mortality due to fire across different census years was 2.87±5.75% (range = 0–20.6%, N = 28). Elephants resulted in mortality rate of 2.33±2.04% (range = 0.28–7.56%, N = 28) while mortality due to other causes was 2.47±2.49 (range = 0.46–12.58%). Mortality rates due to fire spiked in the years of dry season fire (1991, 1992, 1996, 2002 and 2010), resulting in mortality rates over 10%. Highest mortality of 12.58% was seen in the year 2016 where there was no dry season fire. Elephant related mortality was high in year 2008 after the massive "episodic recruitment" observed in one of the favoured speies *Helicteres isora*.

Parameter	Census 1	Census 2	Census 3	Census 4	Census 5	Census 6	Census 7
Mortality (%)	11.57 ± 3.48	7.91 ± 5.45	3.38 ± 1.45	8.98 ± 8.18	6.91 ± 3.74	9.85 ± 8.79	5.14 ± 5.80
Recruitment (%)	2.30 ±1.17	3.98 ± 1.62	9.19 ± 4.25	5.75 ± 5.54	38.76 ± 15.74	11.87 ± 10.98	10.70 ± 12.29

Table 5.
Mean overall mortality and recruitment rates in the 50 hectare forest dynamics plot, Mudumalai.

Parameter	Census 1	Census 2	Census 3	Census 4	Census 5	Census 6	Census 7
Fire (%)	4.48 ± 2.86	4.92 ± 6.08	0.03 ± 0.05	5.13 ± 9.64	0.00 ± 0.00	5.54 ± 10.10	0.00 ± 0.00
Elephant (%)	4.62 ± 1.88	1.73 ± 0.69	1.38 ± 0.69	0.76 ± 0.43	4.22 ±2.55	2.52 ± 2.77	1.09 ± 0.19
Others (%)	2.48 ± 0.75	1.26 ± 0.47	1.97 ± 0.81	3.08 ± 2.76	2.70 ± 1.74	1.78 ± 2.06	4.05 ± 5.75

Table 6.
Mean mortality rate due to different causes in the 50 hectare forest dynamics plot, Mudumalai.

The community wide mean mortality rate was high during the first census (1989–1992) which had two years of consecutive dry season fires across different census period. Lowe mortality rate with low variability was seen during the third census (1996–2000). Recruitment rate also showed considerable fluctuation across different census periods ranging from as low as 2.3% during first census (1989–1992) to 38.76% during fifth census (2004–2008). Variability was high during the seventh census (2012–2016) (**Table 5**).

Mean mortality rates due to different causes across census periods is tabulated in the **Table 6**. Mean rate of mortality due to fire during the census period between (2004–2008) and (2012–2016) was zero suggesting fire did not result in the mortality of any individual. There was a considerable variability in mortality rates across other census periods (**Table 6**). Elephant related mortality rate was high during the first census period (1989–1992) and 5th census period (2004–2008) owing to abundance of elephant favoured species such as *Kydia calycina* and *Helicteres isora*. The mortality rate inflicted by other causes also showed considerable fluctuation with high variability during the 7th census period (2012–2016).

2.4.2 Basal area changes and biomass across census periods

The basal area in the plot has been steadily increasing over time (**Figure 2**). Above Ground Biomass (AGB) and hence carbon stock also shows a similar trend (**Figure 3**), with both the native woody vegetation and invasive ground vegetation showing increment. Basal area changes do not necessarily translate to AGB changes: for instance, the slight decline in basal area during 1992–1996 is not reflected in AGB, which may be partly due to differences in wood densities (e.g. hardwoods growing more than softwoods). Native woody vegetation biomass in 2004 shows a slight reduction owing to a severe drought in the preceding years and a large fire in 2002. However, the invasive *Lantana camara* L. increased substantially following the drought, and therefore the total biomass remained at the 2000 census level. Large increment in biomass were seen in all subsequent censuses: 2008, which followed a period of higher than average precipitation and no fires, 2012, despite a fire in 2010 and only 807 mm precipitation in 2012 (compared to the long-term

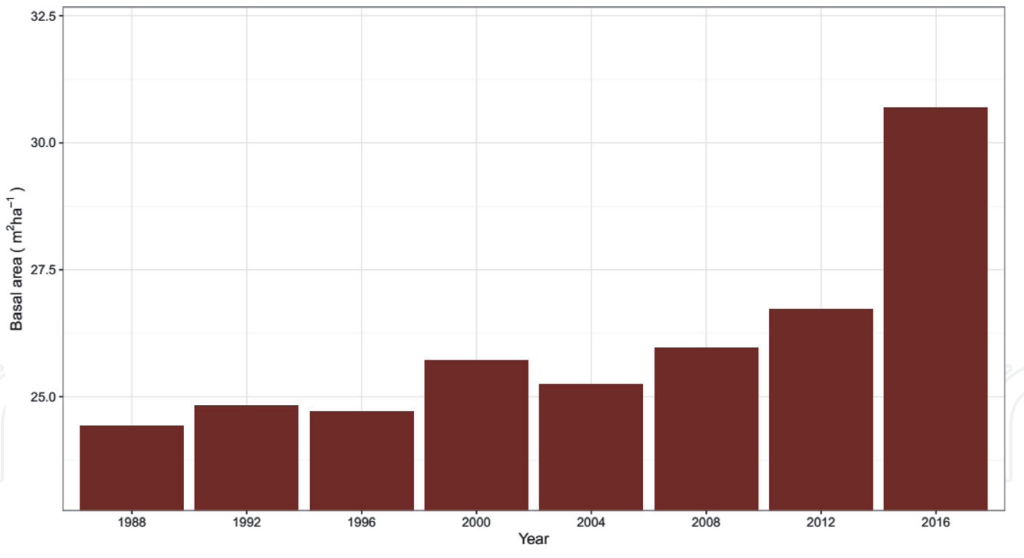

Figure 2.
Native woody-plant basal area (per hectare) in the 50-ha plot.

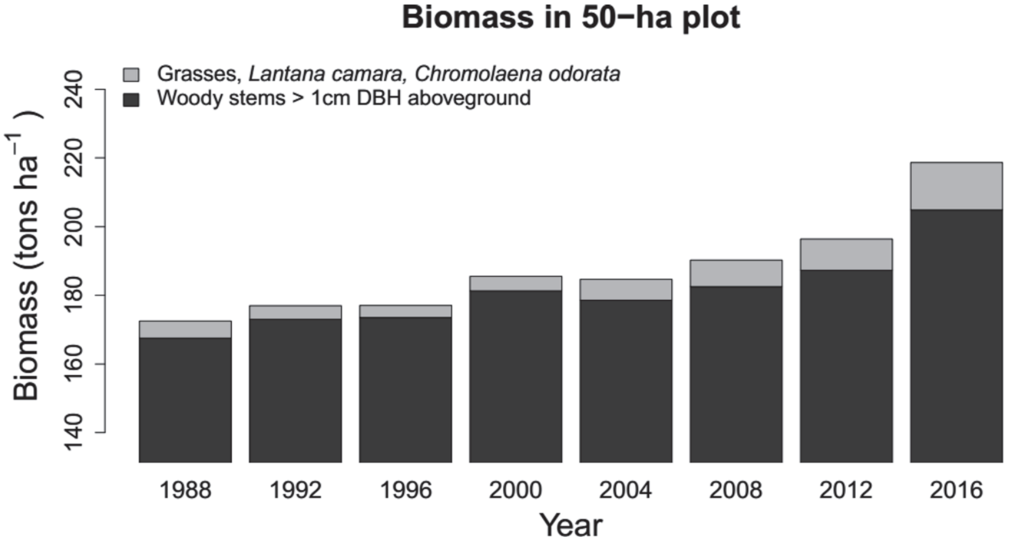

Figure 3.
Aboveground biomass (per hectare) in the 50-ha plot, showing contributions from native woody-plants as well as other ground vegetation.

average of 1260 mm), and 2016, which follows a fire-free census interval. The estimates for basal area and biomass for the census period 2016 to 2020 is based is based on first 10 Ha.

3. Long-term monitoring programme of Kerala Forest Research Institute (KFRI), Peechi, Thrissur, Kerala

Being a part of Western Ghats range of mountains, one of the global biodiversity hotspots, Kerala has bestowed with diverse forest ecosystem with high degree of endemism. Kerala Forest Research Institute (KFRI) currently having more than 40 permanent plots across the state representing all major forest ecosystems (**Figure 4**) and more plots are coming up as a part of various ongoing research projects. KFRI Long-term monitoring programme represents all major ecosystems like mangrove, moist deciduous, dry deciduous, wet evergreen, montane shola forests and grasslands. As of now, the programme covers 50,309 woody individuals of more than 350 species. Majority of our plots are smaller in size (≤1 ha) in which survey would be conducted at five year intervals. These plots were established in different time periods under various research projects undertaken by KFRI. The oldest set of plots was established was during 2000–2002. Recently a large 10 Ha permanent plot was established in wet evergreen forests, Sholayar range. Vazhachal Forest Division, Kerala (**Figure 4**).

3.1 Sholayar 10 ha plot

A permanent plot of 10 ha (500 × 200 m^2) size was established in a tropical evergreen forest at Karadichola, Sholayar Range, Vazhachal Forest Division, Kerala in Southern Western Ghats. Plot establishment and baseline data collection were done based on the Forest-GEO [24] (CTFS) protocol during 2016–2017. Comparison of Sholayar plot with other sites which are following Forest-GEO protocol is

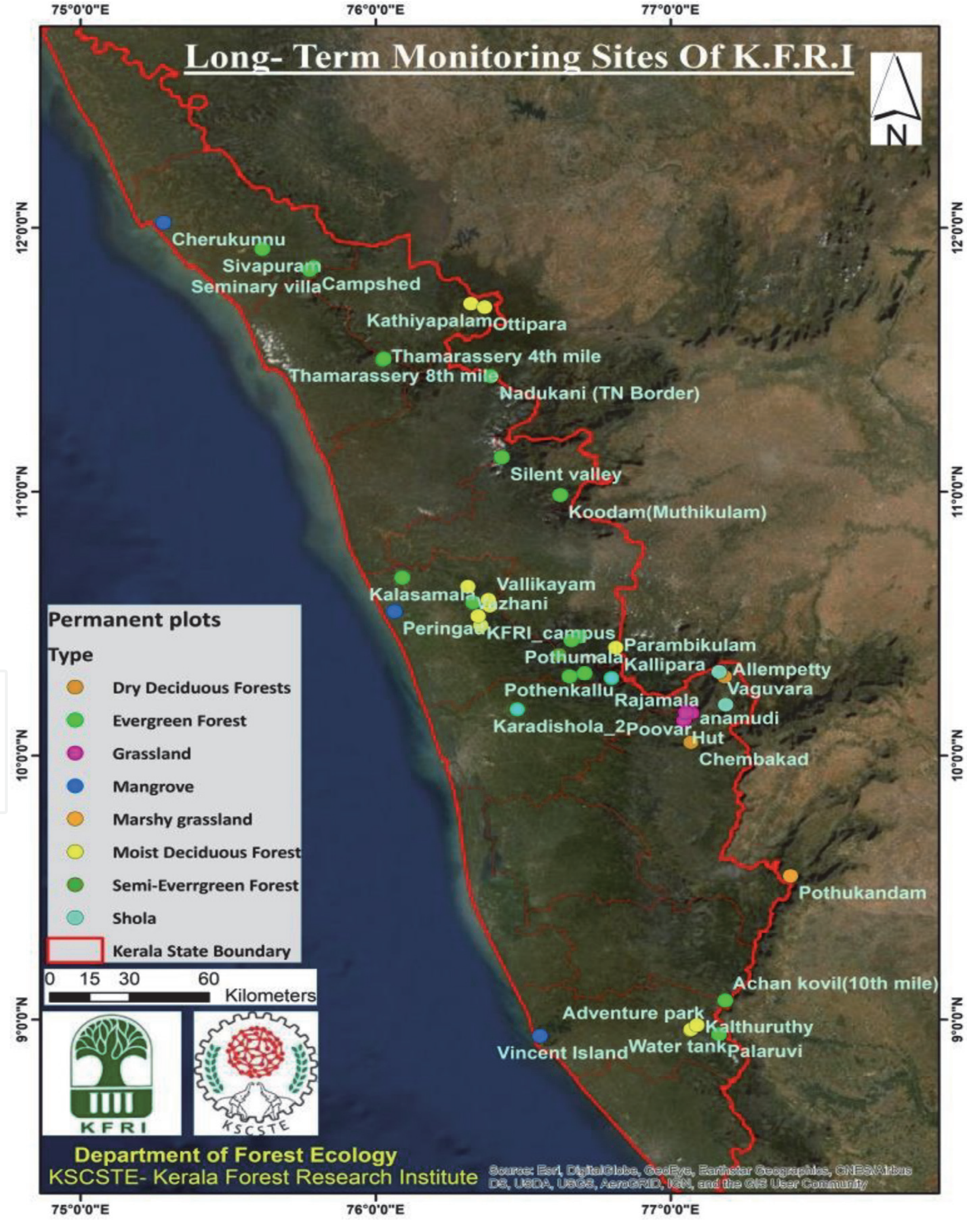

Figure 4.
Distribution of Long-term monitoring plots of KFRI in Southern Western Ghats.

CTFS plot location	Latitude	Mean elevation (m)	Land type*	Plot size (ha)	No. of species	No. of families	Trees/ ha	Basal area (m^2/ha)
Lambir, Malaysia	4.19	170	I	52	1182	83	6915	43.5
Yasun, Ecuador	−0.69	230	M	50	1114	81	3026	33.0
Pasoh, Malaysia	2.98	80	M	50	814	82	6708	31.0
Khao Chong, Thailand	7.54	140	M	24	593	Na	5063	Na
Korup, Cameroon	5.07	200	M	50	494	62	6580	32.0
Ituri, Dem. Rep. of Congo	1.44	780	M	404	445	Na	7200	Na
Palanan, Philippines	17.04	110	I	16	335	60	4125	39.8
Bukit Timan, Singapore	1.25	150	I	2	329	62	5950	34.5
BCI, Panama	9.15	140	M	50	299	58	4168	32.1
Mo Singto, Thailand	14.43	770	M	30.5	262	Na	Na	Na
HuaiKhaKhaeng, Thailand	15.63	590	M	50	251	58	1450	31.2
La Planada, Colombia	1.16	1840	M	25	240	54	4216	29.8
Dinghushan, China	23.16	350	M	20	210	Na	3581	Na
Sinharaja, Sri Lanka	6.4	500	I	25	204	46	7736	45.6
DoiInthanon, Thailand	18.52	1700	M	15	192	Na	4913	Na
Luquillo, Puerto Rico	18.33	380	I	16	138	47	4194	38.3
Nanjenshan, Taiwan	22.06	320	I	3	125	41	12,133	36.3
Ilha do Cardoso, Brazil	−25.1	5	M	10	106	Na	Na	Na
Mudumalai, India	11.6	1050	M	50	72	29	510	25.5
Laupahoehoe, USA	19.93	1150	I	4	21	15	3078	67.36
Palamanui, USA	19.74	240	I	4	15	15	3487	8.6
Sholayar, India (KFRI PLOT)	10.29	950	M	10	106	44	2539	47.7

**I - Island, M - Mainland, Na - not available.*

Table 7.
Comparison of vegetation parameters of 10 ha plot at Sholayar, Kerala with other Forest-GEO (CTFS) sites around Globe.

summarized as **Table 7**. Complete inventory of woody individuals ≥1 cm dbh were done and each individual was permanently tagged with sequentially numbered aluminium tags. In the 10-ha plot, a total of 25,390 individuals of 106 woody species were recorded [25]. These individuals were belonging to 44 families and 81 genera. Small-diameter class (1 cm ≤dbh<10 cm)were 3.6 times more abundant than large-diameter (dbh ≥10 cm) ones. There were 19,975 small-diameter plants (78.67% of all stems), averaging 1997 individuals/ha, while large-diameter trees had an abundance of 5415 plants and density of only 546 individuals/ha. The family Rubiaceae, is the most abundant, with densities >900 individuals/ha, followed by Euphorbiaceae, Urticaceae, Sapotaceae, Meliaceae, Malvaceae, and Putranjivaceae. Among tree genera *Palaquium, Cullenia*, of family Sapotaceae and Malvaceae respectively, were the most abundant, with >100 individuals/ha, followed by *Drypetes, Mesua, Aglaia, Vateria, Syzygium* and *Agrostistachys*. At tree species level, *Palaquium ellipticum, Cullenia exarillata, Mesua ferrea* were the most abundant, followed by *Aglaia tomentosa* and *Vateria indica*. Out of the 106 species, 38 species are endemic to Western Ghats and 20 are listed in IUCN categories. Among trees, *Palaquium ellipticum*, *Cullenia exarillata* and *Vateria indica* were dominant in terms of Importance Value Index (IVI) while among shrubs *Psychotria nudiflora* was the dominant, followed by *Dendrocnide sinuata* and *Psychotria anamalayana*. Total basal area (in 10 ha) was 477.24 m^2 (47.72± 7.58 m^2/ha) and family wise it was higher in Malvaceae (9.69 m^2/ha) and Sapotaceae (9.6 m^2/ha) followed by Dipterocarpaceae, Calophyllaceae, Putranjivaceae and Sapindaceae. The dominant genera by basal area were *Cullenia, Palaquium, Vateria, Mesua, Drypetes* and *Dimocarpus*. At species level, *Cullenia exarillata* and *Palaquium elipticum* were the most important followed by *Vateria indica, Mesua ferrea, Dimocarpus longan, Drypetes wightii* and *Holigarna nigra*. Small-diameter trees contributed 4.89% of the total basal area. Species level contribution to density and importance value index is summarized in **Table 2**. Girth class distribution pattern indicates it as a relatively undisturbed forest patch with healthy regeneration. Ecological and Ecophysiological studies are ongoing on the structure, function and dynamics of this system in the context of climate change (**Table 8**).

Sl. No.	Species	No. of Individuals (10 Ha)	IVI
1.	*Actinodaphne bourneae* Gamble	11	0.1939
2.	*Actinodaphne malabarica* N.P.Balakr.	42	0.9148
3.	*Aglaia lawii* (Wight) C.J. Saldanha	48	0.7948
4.	*Aglaiaper viridis* Hiern	30	0.515
5.	*Aglaia simplicifolia* (Bedd.) Harms	39	0.6217
6.	*Aglaia* sps.	22	0.4034
7.	*Aglaia tomentosa* Teijsm. & Binn.	706	7.2858
8.	*Agrostistachys borneensis* Becc.	594	6.7618
9.	*Alstonia scholaris* (L.) R.Br.	1	0.0206
10.	*Ancistrocladus heyneanus* Wall. ex J.Graham	62	0.6279
11.	*Antidesma montanum* Blume	249	4.3758
12.	*Aphanamixis polystachya* (Wall.) R.Parker	3	0.0590
13.	*Aporosa acuminate* Thwaites	163	1.8734
14.	*Aporosa cardiosperma* (Gaertn.) Merr.	12	0.1705
15.	*Aporosa* sp.	229	2.9408
16.	*Ardisia pauciflora* B.Heyne ex Roxb.	246	3.1307
17.	*Artocarpus heterophyllus* Lam.	1	0.0221
18.	*Atlantia racemosa* Wight ex Hook.	2	0.0391

Sl. No.	Species	No. of Individuals (10 Ha)	IVI
19.	*Baccaurea courtallensis* (Wight) Müll.Arg.	2	0.0434
20.	*Bhesa indica* (Bedd.) Ding Hou	109	2.4132
21.	*Bischofia javanica* Blume	2	0.1796
22.	*Boehmeria glomerulifera* Miq.	55	0.5937
23.	*Calophyllum polyanthum* Wall. ex Planch. &Triana	15	0.6838
24.	*Canarium strictum* Roxb.	22	0.5249
25.	*Canthium angustifolium* Roxb.	7	0.1210
26.	*Caryota urens* L.	1	0.0358
27.	*Chassalia curviflora* var. *ophioxyloides* (Wall.) Deb & B. Krishna	15	0.2601
28.	*Cinnamomum malabatrum* (Burm.f.) J. Presl	12	0.2231
29.	*Cipadessa baccifera* (Roth) Miq.	3	0.0603
30.	*Clausena anisata* (Willd.) Hook.f. ex Benth.	4	0.0854
31.	*Clausena austroindica* B.C.Stone & K.K.N. Nair	2	0.0392
32.	*Coscinium fenestratum* (Goetgh.) Colebr.	2	0.0416
33.	*Croton zeylanicus* Müll.Arg.	514	4.0406
34.	*Cullenia exarillata* A.Robyns	1027	27.9277
35.	*Dendrocnides inuata* (Blume) Chew	1376	11.0712
36.	*Dichapetalum gelonioides* (Roxb.) Engl.	1	0.0194
37.	*Dimocarpus longan* Lour.	373	8.2856
38.	*Diospyros paniculata* Dalzell	118	2.6948
39.	*Diospyros* sp.	27	0.6139
40.	*Drypetes malabarica* (Bedd.) Airy Shaw	413	6.8282
41.	*Drypetes wightii* (Hook.f.) Pax & K. Hoffm.	600	9.2968
42.	*Dysoxylum malabaricum* Bedd. ex C. DC.	390	5.2566
43.	*Elaeocarpus tuberculatus* Roxb.	32	1.3709
44.	*Elaeocarpus variabilis* Zmarzty	63	1.6316
45.	*Eugenia mooniana* Wight	130	1.4946
46.	*Fagraea ceilanica* Thunb	3	0.0853
47.	*Garcinia morella* (Gaertn.) Desr.	190	3.0605
48.	*Glycosmis macrocarpa* Wight	47	0.7725
49.	*Goniothalamus rhynchantherus* Dunn	106	1.5670
50.	*Holigarna arnottiana* Hook.f.	1	0.0403
51.	*Holigarna nigra* Bourd.	115	4.6342
52.	*Isonandra lanceolata* Wight	33	0.4739
53.	*Kunstleria keralensis* C.N. Mohanan & N.C. Nair	134	1.6989
54.	*Lasianthus rostratus* Wight	396	4.0462
55.	*Leea indica* (Burm. f.) Merr.	139	1.7541
56.	*Lepisanthes erecta* (Thwaites) Leenh.	3	0.0596
57.	*Litsea bourdillonii* Gamble	328	4.8171
58.	*Litsea* sp.	14	0.3211

Sl. No.	Species	No. of Individuals (10 Ha)	IVI
59.	*Litsea wightiana* (Nees) Hook.f.	208	2.8858
60.	*Luvunga eleutherandra* Dalzell	63	0.9326
61.	*Macaranga peltata* (Roxb.) Müll.Arg.	28	0.8126
62.	*Mallotus atrovirens* Wall. ex Müll.Arg.	167	2.5887
63.	*Mallotus aureopunctatus* (Dalzell) Müll.Arg.	180	2.2228
64.	*Mallotus philippensis* (Lam.) Müll.Arg.	35	0.7248
65.	*Mallotus* sps.	13	0.2298
66.	*Mangifera indica* L.	15	0.3446
67.	*Mastixia arborea* (Wight) C.B.Clarke	148	2.1348
68.	*Meiogyne pannosa* (Dalzell) J. Sinclair	360	3.8657
69.	*Meiogyne ramarowii* (Dunn) Gandhi	29	0.4852
70.	*Meliosma simplicifolia* (Roxb.) Walp.	145	2.6122
71.	*Memecylon* sp.	27	0.4366
72.	*Mesua ferrea* L.	878	14.255
73.	*Micrococca beddomei* (Hook.f.) Prain	8	0.1290
74.	*Microtropis stocksii* Gamble	1	0.0195
75.	*Myristica malabarica* Lam.	28	0.6579
76.	*Myristica attenuata* Wall.	362	5.6289
77.	*Nothopegia* sp.	1	0.0221
78.	*Ocotea lancifolia* (Schott) Mez	354	4.6706
79.	*Oreocnide integrifolia* (Gaudich.) Miq.	108	1.2404
80.	*Otonephelium stipulaceum* (Bedd.) Radlk.	61	0.9228
81.	*Palaquium ellipticum* (Dalzell) Baill.	1257	28.6825
82.	*Pavetta* sp.	1	0.0194
83.	*Persea* sp.	1	0.0201
84.	*Piper* sp.	6	0.1162
85.	*Polyalthia coffeoides* (Thwaites) Hook.f. & Thomson	23	0.5240
86.	*Psychotria anamalayana* Bedd.	604	5.0707
87.	*Psychotria nudiflora* Wight &Arn.	8340	37.6802
88.	*Sabia limoniacea* Wall. ex Hook.f. & Thomson	28	0.3739
89.	*Salacia fruticosa* Wall.	1	0.0196
90.	*Saprosma glomeratum* (Gardner) Bedd.	1	0.0193
91.	*Semecarpus travancorica* Bedd.	13	0.4371
92.	*Smythea bombaiensis* (Dalzell) S.P.Banerjee & P.K. Mukh.	43	0.7766
93.	*Spondias pinnata* (L.f.) Kurz	1	0.1700
94.	*Strobilanthes barbatus* Nees	37	0.2613
95.	*Strobilanthes* sp.	660	3.3360
96.	*Strychnos dalzellii* C.B.Clarke	188	2.1646
97.	*Symplocos macrophylla* Wall. ex A. DC ssp. *rosea* (Bedd.) Nooteb.	131	1.7905

Sl. No.	Species	No. of Individuals (10 Ha)	IVI
98.	*Syzygium lateum* (Buch.-Ham.) Gandhi	517	5.2191
99.	*Syzygium munronii* (Wight) N.P.Balakr.	73	1.2097
100.	*Syzygium* sp.	5	0.2121
101.	*Tetrastigma leucostaphylum* (Dennst.) Alston	22	0.3552
102.	*Thottea siliquosa* (Lam.) Ding Hou	121	1.4741
103.	*Toddalia asiatica* (L.) Lam.	11	0.1927
104.	*Turpinia malabarica* Gamble	145	4.1535
105.	*Vateria indica* L.	605	16.4577
106.	*Xanthophyllum arnottianum* Wight	1	0.0195

Table 8.
Species- level contribution to the community in the 10 ha. plot, Sholayar, Kerala.

4. Forest dyanmics study by the French Institute of Pondicherry

4.1 A case study: Uppangala Permanent sampling plots

Since the early 1980s, the French Institute of Pondicherry has been in collaboration with the Forest Department of Kerala and Karnataka to explore structure and diversity of wet evergreen forests of the Western Ghats. In 1979–80, a total of 147 trees ≥ 30 cm girth at breast height was monitored untill 1982 for growth (with a precision of 0.02 mm) at monthly intervals in a 0.2 ha plot at Attapadi. Monitoring the plot in the region was stopped for logistic reasons. Subsequently, IFP has established two sets of sample plots in low elevation wet evergreen forest in Kadamakkal RF, Sampaje Range, Kodagu (ca. 12°32′15″N, 12° 33’ N, 75°39’4″E; **Figure 1a**). Currently this area comes under the Pushpagiri Wildlife Sanctuary in Kodagu district. The study area, the Uppangala was subjected to selective logging, between 1974 and 1983 [26]. During the logging operation, the forest was divided into compartments of 28 ha each, 237 to 359 large trees (stems ≥ 180 cm) of medium wood (> 0.5 but ≤ 0.72 g cm^{-3}) *Dipterocarp* species viz., *Dipterocarpus indicus* and *Vateria indica* were logged per compartment. An average of 8 to 13 dipterocarp trees ha^{-1} were logged manually and hauled using elephants locally, a method that causes much less damage than mechanized skidding. A few patches of forest remain unlogged. The elevation ranges between 400 and 600 m a.s.l. It belongs to the *Dipterocarpus indicus-Kingiodendron pinnatum-Humboldtia brunonis* type of wet evergreen forests and is a part of the West Coast Tropical Forests of Champion and Seth’s classification. Uppangala receives slightly more than 5100 mm per year and the dry season lasts 4.5 months.

The first set of sample plots was installed in 1984 to study the post-logging effects on the forest dynamics of a once logged 30-ha compartment (**Figure 5b**). It consists of 14 plots of 600 m^2 (20 x 30 m). All trees ≥ 10 cm girth at breast height (gbh) were recorded during the first census. All the plots were recensused (except 4 plots, which were recorded as burnt) in 1988 and 1993 for recruitment and mortality. In 1989, a second set of sample plots was established in another 30-ha compartment (**Figure 5c**), which had escaped logging operation due to the ban on selective felling from 1987 in the forest of Western Ghats.

The unlogged compartment probably represents the last example of old-growth low-elevation *Dipterocarp* forest in the entire Western Ghats. Five north–south oriented transects (viz., A, B, C, D and E; **Figure 5c**) of 20 m wide, 180 to 370 m

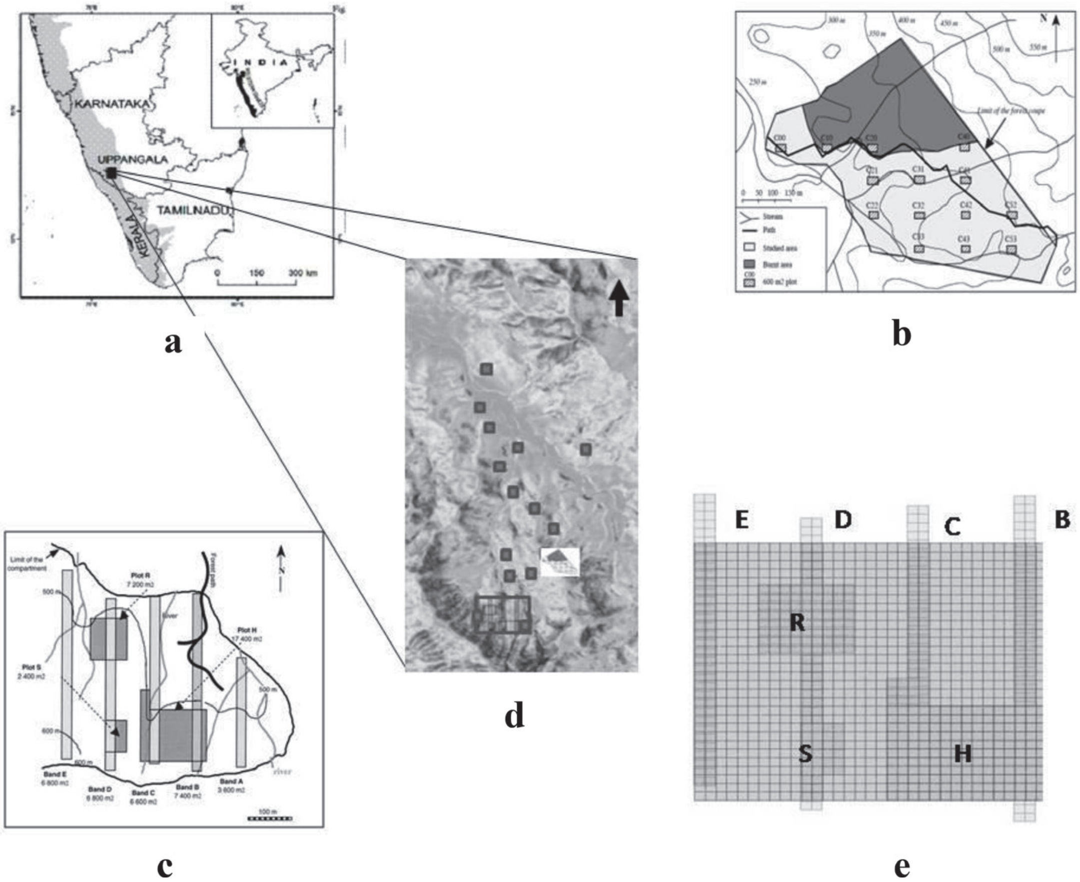

Figure 5.
(a-e) Uppangala study site, (a) Location of Uppangala study site in the central Western Ghats, Karnataka, India. Sampling designs for the inventory of trees: (b) systematic sampling in logged and (c) sampling plots and transects in unlogged (d) fifteen 1 ha plots in both compartments and (e) contiguous 9.9 ha plot in the unlogged compartment of the low elevation wet evergreen forests.

long and 100 m apart from each other were established to inventory trees ≥30 cm gbh. Collectively they represent a 3.12 ha^{-1} systematic sample. Subsequently, additional rectangular sampling plots viz., H, R and S, which overlap with sampling area of the transects and represent an additional area of 1.95 ha, were established between 1990 and 1993 to study the forest dynamics according to topography (slope and more or less flat terrain). Totally 3870 trees were identified, mapped and installed with dendrometric belt (precision of 0.2 mm) for growth monitoring, which has no equivalent in any other tropical forest in the world. The sampling area has been monitored annually for recruitment and mortality. In 2010–2011, fifteen 1 ha plots was established to appraise allometric relationship of tree diameter and tree crown (for trees ≥ 30 cm gbh) and to estimate above ground biomass. These 1 ha plots were sampled randomly in both the logged and unlogged forests. Of these, four plots were selected to understand the residual impact of logging on species composition, population structure and biomass. In 2013–2014, the sampling area of the unlogged compartment has been increased to 9.9 ha and all trees ≥ 30 cm gbh were inventoried within a 330 x 300 m^2 area (**Figure 5d**). All the trees were identified, girth measured and mapped.

4.2 Results of three decade long research in Uppangala

4.2.1 Tree density and diversity

The systematic sampling plots of logged compartment was recorded with a total of 2748 trees ≥ 10 cm girth at breast height (gbh) during the first census in 1985 [27].

Similarly, a total of 1981 trees ≥ 30 cm gbh were recorded with 91 species in the first census of 3.14 ha area of the unlogged compartment in 1990 [28]. Pronounced species hierarchy is another characteristic feature of the forest. Just 10 most abundant species contributed 71% for the forest stand (**Table 9**). Subsequent additional sampling area allow us to monitor more number of trees in the unlogged compartment. Totally 3870 trees were enumerated in the 5.07 ha during 1994 census and all those trees fitted with stainless dendrometric belts for measuring growth with a precision of 0.2 mm. At present we are monitoring 6672 trees (of which 3127 trees were installed with dendrometer bands) representing 111 species in the unlogged forest plot. The forest is characterized by high tree density and basal area (661 stems ha^{-1}; 43 m^2 ha^{-1}). Pronounced species hierarchy is another characteristic feature of the forest. Just four species namely, *Dipterocarpus indicus* (emergent layer), *Vateria indica* (upper canopy and emergent), *Myristica dactyloides* (intermedidate) and *Humboldtia brunonis* (understorey) dominate the forest stand, and they collectively account for greater than 50% of density and basal area of the forest.

4.2.2 Impact of logging on tree diversity

A decade long monitoring of logged and unlogged forest for trees ≥ 30 cm gbh revealed the logged compartment had 347 trees and 54 species in 0.6 ha (1986) whereas the unlogged compartment had 1891 trees and 88 species in 3.12 ha in 1990 [29]. Initial stand density and basal area of the trees were slightly lower in the logged forest (578 stems ha^{-1}; 34.8 m^2 ha^{-1}) than in the unlogged forest (606 stems ha^{-1}; 39.3 $m^2 ha^{-1}$). Mean density and basal area for the 20 × 30 m^2 samples of the two compartments displayed no significant difference (t-tests, P>0.25). The mortality rate was more or less similar for the compartments (0.89% for logged and 0.87% for unlogged), which is lower than the rates observed in other tropical forests. Annual recruitment rate of logged (1.68%) and unlogged forests (1.34%) were not significantly different. Mean diameter increment was 2.1 mm and 2.9 mm $yr.^{-1}$ for unlogged and logged compartments. In the logged forest, *Antiaris toxicaria*, *Aphanamixis polystachya*, *Beilschmiedia wightii* disappeared while *Cinnamomum malabatrum*, *Holigarna arnottiana*, *Microtropis stocksii*, *Sterculia*

Species (Family)	Family	Abundance	Relative abundance (%)	Cumulative abundance
Vateria indica L.	Dipterocarpaceae	329	17	23
Humboldtia brunonis Wall.	Caesalpiniaceae	294	15	31
Myristica dactyloides Gaertn.	Myristicaceae	263	13	45
Knema attenuata (J.Hk. & Th.) Warb.	Myristicaceae	118	6	51
Palaquium ellipticum (Dalz.) Baill.	Sapotaceae	98	5	56
Drypetes elata (Bedd.) Pax. & Hoffm.	Euphorbiaceae	79	4	60
Dipterocarpus indicus Bedd.	Dipterocarpaceae	67	3	63
Reinwardtiodendron anamalaiense (Bedd.) Mabb.	Meliaceae	62	3	66
Mesua ferrea L.	Clusiaceae	56	3	69
Garcinia morella (Gaertn.) Desr.	Clusiaceae	44	2	71

Table 9.
Top-ten dominant species in the unlogged compartment plot during the first census 1990.

guttata and *Vitex altissima*. In the same time, unlogged plots showed no disappearance of species and appearance of three new species namely, *Agrostistachys borneansis*, *Clerodendrum viscosum* and *Syzygium hemisphericum*. This decade long investigation suggested that the logged compartment gradually recovered and resemble unlogged forest within 20 years. However the recent inventories of the logged compartment at 1 ha scale shows the residual impact of logging even after 27 years (**Table 10**; [30]). Logged plots had low floristic similarity between them (0.45 to 0.56%) and also with the unlogged plots (0.41 to 0.43%). Mantel and partial Mantel tests proved that logging was the main driver for the species composition rather than the elevation and spatial distance. Higher abundance of species belonging to canopy, intermediate and light wood categories and lower density of emergent, understory and medium wood types were recorded in the logged plots. As compared to unlogged plots, logged plots had 20–59% less above ground biomass (AGB) due to paucity of large trees, especially in the emergent and medium wood types. However, the logged plots had higher AGB in canopy and hardwood categories. These findings indicated that the compositional shifts has occurred in the logged patches and the recovery process may depend on the resurgence of emergent and medium wood categories (**Figure 6**).

4.2.3 Forest dynamics in unlogged forest

In the unlogged forest, over the study period of 1990–2016, mortality rates ranged from 0.7 to 1.2% yr.$^{-1}$ with an average of 0.8% yr.$^{-1}$ while the recruitment ranged from 0.4 to 1.2% yr.$^{-1}$ with an average of 1% yr.$^{-1}$ (**Figure 7**). The basal area of the stand showed a loss of 13.8% due to tree death and an addition of 21.6% basal area by growth of trees. Overall, it shows an increment by 7.8% of the stand basal area. During the period of 26 years, four species *Memecylon wightii* Thwaites, *Goniothalamus cardiopetalus* (Dalz.) J. Hk. & Thoms., *Clerodendrum viscosum* Vent. and *Walsura trifolia* (A. Juss.) Harms. disappeared by tree deaths and one species *Diospyros assimilis* Bedd. appeared by new recruits. A total of 73 species have registered either recruitment and/or mortality, while population density of the remaining 18 species was unchanged during 26 year period. Of these, 44 species showed decline in population density. Notable among them includes *Myristica dactyloides, Humboldtia brunonis, Palaquium ellipticum* and *Knema attenuata*, lost more than 10 individuals during the study period. Nineteen species showed increase in population density. They include *Kingiodendron pinnatum, Holigarna nigra*, *Diospyros bourdillonii* and *Leptonychia caudata* each was recorded with increase in population density of 5 individuals.

Variables	Logged plots				Unlogged plots		Total (mean)
	LP1	LP2	LP3	LP4	UP1	UP2	
Number of species	59	72	66	56	53	57	126 (60.5)
Number of families	32	28	25	23	24	25	41 (26.2)
Stem density	572	513	636	672	665	680	3738 (623.0)
Basal area (m^2 ha^{-1})	28.15	39.3	41.37	48.23	51.19	51.01	259.24 (43.21)
AGB (Mg ha^{-1})	268.05	396.71	454.84	491.44	611.59	649.82	2872.45 (478.74)

Table 10.
Impact of selective logging on tree species richness, composition and structure, after 27 years in comparison with unlogged forest at 1 ha scale (based on census 2010–2011; [30]).

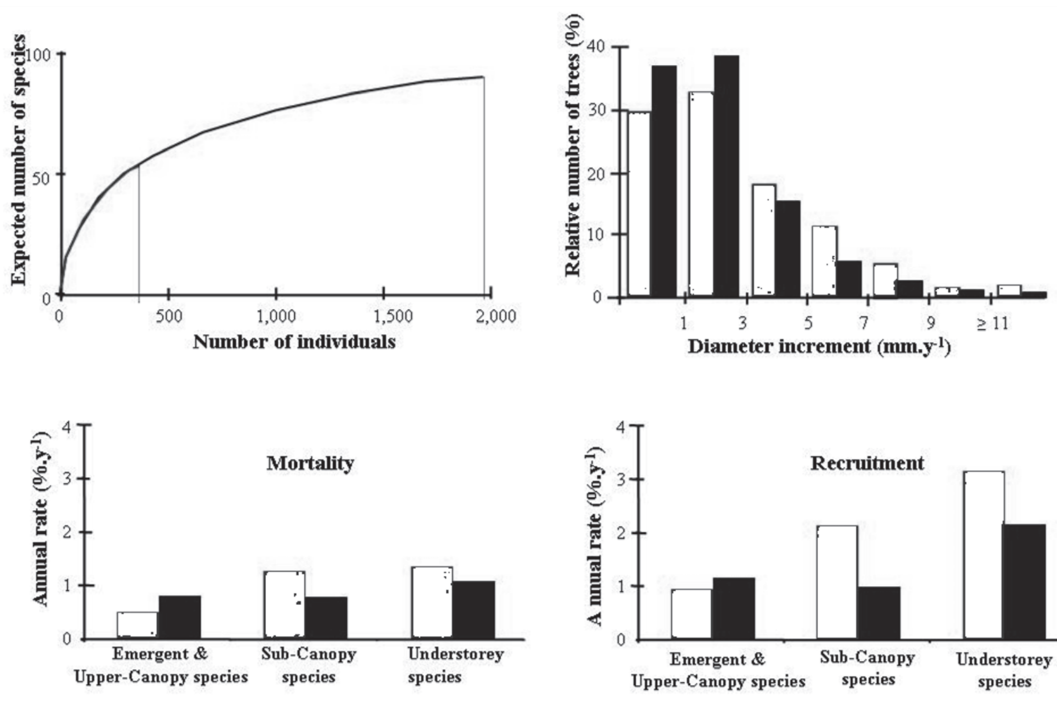

Figure 6.
Summarized results of a decade long monitoring study of logged and unlogged plots [31].

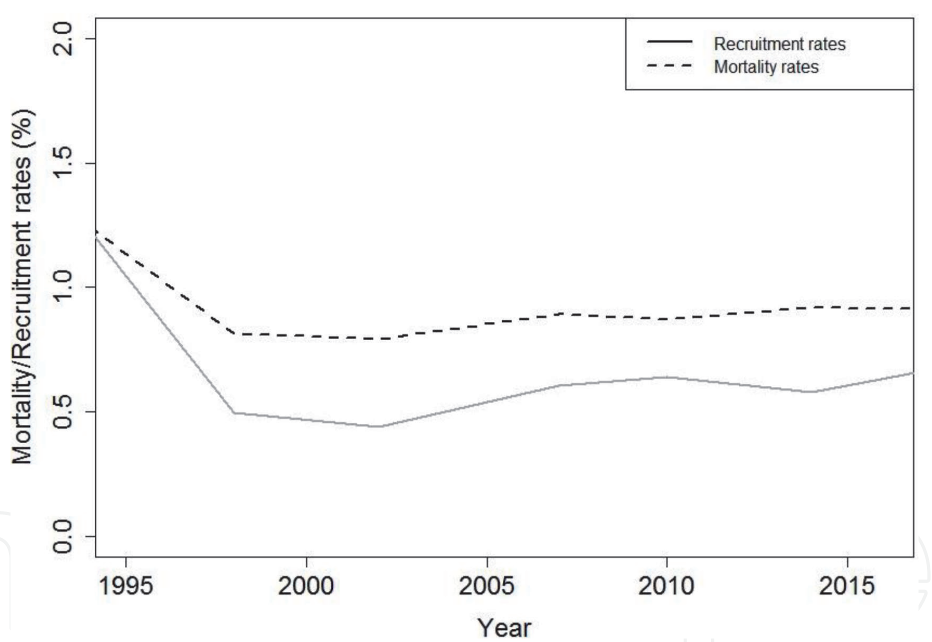

Figure 7.
Recruitment and mortality rates for trees ≥ 30 cm gbh in the unlogged forest.

4.2.4 Biomass estimation

Live Above Ground Biomass (AGB) of individual trees were determined using the regression equation of tropical moist forest stands: AGB = exp.(−2.977 + ln (ρD2H)).

Where D is the diameter at breast height in cm, H is total height in m and ρ is wood density in g cm^{-3} [32]. The estimated value ranged from 268 to 491 Mg ha^{-1} for those plots in the logged compartments and 611 to 649 Mg ha^{-1} for the unlogged compartment **Table 10**. The AGB ha^{-1} of unlogged plots of the present study is high compared to the available data on Indian forests and the other tropical forests across the continents: a mean of 287.8 ± 105.0 Mg ha^{-1} for South America, 393 ± 109.3 Mg ha^{-1} in Asia and 418 ± 91.8 Mg ha^{-1} in Africa for trees ± 10 cm dbh [33].

In summary, the continued monitoring of the plot will enhance our capacities to understand the forest dynamics in space and time, and response of the forest to the influence of climate change.

5. Forest dynamics plots in Kakachi forest, Kalakad Mundanthurai Tiger Reserve, Western Ghats

Small scale forest dynamic plots were established in the wet evergreen forest at Kakachi in Kalakad Mundanthurai Tiger Reserve (hereafter KMTR) (8° 33' N. Lat. 77°23'E. Long, **Figure 8**). It covers an area of 887 km^2 along the eastern slopes of Agasthyamalai range. The altitude ranges from 100 to 1890 m with generally steep slopes and deep valleys. KMTR supports large stretches of evergreen forests, which are contiguous to the rest of the WG, and endowed with large number of endemic and rare plant species, and provide habitats for rare animals such as Lion Tailed Macaque, Nilgiri langur, Tiger, Elephants etc. KMTR receives both South-West and North-East monsoons and being a major watershed, seven major rivers originates from the forest. These rivers meet the water requirements of the arid regions of south Tamil Nadu. Kakachi is located at 1300 m amsl and receives an annual rainfall of over 3500 mm. The rainfall is spread over 8 to 10 months in a year. The spread out of the rainfall in the study site is due to Southwest monsoon and Northeast monsoon rains. Mean maximum temperature is 24° C and minimum about 16° C [34].

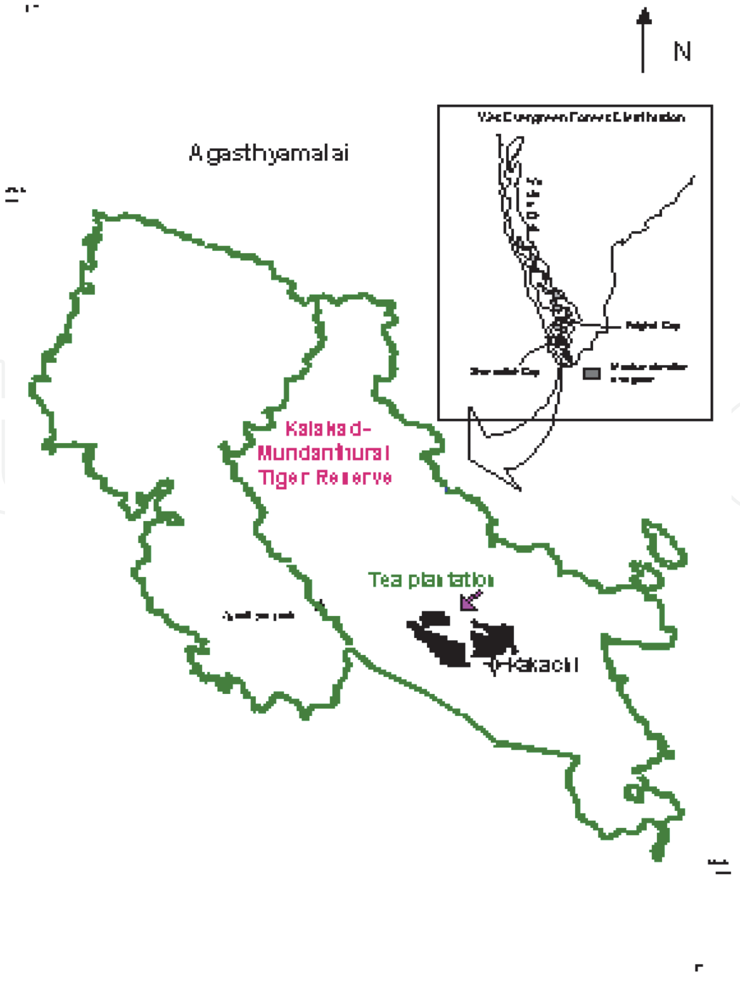

Figure 8.
Forest Dynamics Plots in Kakachi forest, Kalakad Mundanthurai Tiger Reserve, Western Ghats.

The terrain is highly undulating and is traversed by numerous mountain streams. The vegetation is characterized by three dominant tree species, *Cullenia exarillata, Palaquium ellipticum* and *Aglaia bourdillonii* [34]. Between 1993 and 1994 three 1 ha forest dynamic plots were established in an undisturbed wet evergreen forests at Kakachi, Kalakad Mundanthurai Tiger Reserve (KMTR) of Agasthyamalai range.

The principal objective of this study was to measure the changes in diversity, structure, recruitment and mortality of tree species compared to other forests within WG as well as globally. Following are the specific objectives:

(1) Determine the diversity and population structure of trees at Kakachi (2) Compare diversity and density of endemic with the widely distributed species in the site (3) Determine the overall recruitment, mortality and turnover rates of tree species.

Three 1-ha plots of 250 m x 40 m dimension were established within the wet evergreen forest during 1993 and 1994. A minimum distance of 1 km, spatially separated these plots. The plots were permanently marked using PVC pipes and all trees above 10 cm dbh at 1.3 m above ground were enumerated and tagged.

5.1 Floristics and species diversity

A total of 68 tree species >10 cm dbh were recorded from the 3 ha. The sixty-eight tree species belonged to 52 genus and 31 families. The most species rich family was Lauraceae with 12 species followed by Euphorbiaceae (7 sp.) and Myrtaceae (6 sp.). Seventeen families had only one species. *Syzygium* was the most common genus with 6 species followed by *Litsea* with 4 species. Genus with single species represented over 90% of the total genus. Shannon diversity index was 2.79 (=4.02 $\log^2$) and the evenness index was 0.66. The number of species recorded per ha was 46.

5.2 Stem density

A total of 2116 live stems were encountered in the 3 ha at an average of 705 stems ha^{-1}. Three species *Agrostistachys borneensis* (19%), *Cullenia exarillata* (16%) and *Palaquium ellipticum* (13%) represented 45% of the stems, while the other 65 species accounted for the remaining 55%. The species abundance relationship shows that majority of the species had a density between 4 and 8 individuals per 3 ha. Seventy percent of the species had less than 10 individuals in the 3 ha plot and only 10% (7 species) had over 100 individuals. Over 3.5% of the stems were dead during the first enumeration.

5.3 Basal area

Total basal area of all the trees was 60.51 m^2ha^{-1}. Two dominant species *Cullenia exarillata* and *Palaquium ellipticum* accounted for over 58% of the total basal area, while all other species individually accounted for less than 5%. Mean basal area of individual trees was 0.0769 m^2 ha^{-1} and ranged from 0.026 m^2 ha^{-1} to 0.3233 m^2 ha^{-1}.

5.4 Life forms

Of the 68 tree species 42 were canopy trees and 23 (35%) were understorey trees. Maximum height of canopy trees was 40 m. The tallest species is *Cullenia exarillata* with a mean height of 22 m. Canopy trees were at a higher density than understorey trees. Many of the common canopy trees were dominant component of the stand. Canopy species such as *Cullenia exarillata, Aglaia bourdillonii* and *Palaquium ellipticum* accounted for 66% (808) of the canopy trees. Among the understorey tree species *Agrostistachyis borneensis, Gomphandra coriacea,* and *Epiprinus mallotiformis* accounted for over 80% (663) of the total stems. Canopy trees were also larger in girth besides being more abundant, therefore contributed to higher total basal area 49.04 m^2 ha^{-1} compared to understorey trees 8.4 m^2 ha^{-1}.

5.5 Habitat

In terms of habit preferences there were 36 closed forest species and 33 gap species. Nineteen of the closed forest trees were canopy species and remaining 17 were gap invaders. Similarly in the understorey 14 were closed canopy species and 15 were gap species. The closed forest species were 11 times (1840) more abundant than gap species (144) and majority of the gap species contributed to less than 7 individuals per ha. Basal area of closed forest species was 22 times greater than gap species.

5.6 Endemic species richness gradient

5.6.1 Species

Thirty-three of the total 68 identified tree species (49%) in the plots were endemic to the Western Ghats. The endemic species richness increases from localised endemics to more widely distributed endemic species. Greater proportion (76%) of the species were endemic to the entire Western Ghats (EWGE, Entire Western Ghats Endemic), 18% to southern Western Ghats, (SWGE Southern Western Ghats Endemic comprising of Nilgiris and south of the Palghat gap) and 6% to Agasthyamalai (AGME Agasthyamalai Endemic) region alone (localized endemic). Some of the common endemic species are *Palaquium ellipticum*- endemic to whole of Western Ghats, *Litsea keralana* - restricted to southern Western Ghats and *Aglaia bourdillonii* - endemic to Agasthyamalai.

5.6.2 Density

Endemic species of the Western Ghats accounted for 51% (1079) of the total stems encountered in the 3 ha. EWGE were the most numerous, and accounted for 83% (893) of the stems followed by 16% (172) for AGME species and only 1.3% (14) to SWGE. The density of trees under the 3 endemic gradients is significantly different (KW = 9.84, $p < 0.01$). The WGE species were significantly more abundant than SWG species (Dunn's test $p < 0.01$). The median density value was 8 for EWGE species and 2 for SWGE species. Localized AGME species such as *Aglaia bourdillonii* was at high density. Contrary to species richness, density is high for local endemic species and highest for EWGE species but very low for SWGE species.

5.6.3 Basal area

Basal area of endemic species accounted for 94% of the total basal area, of which 95% were EWGE, 0.6% SWGE endemic and 5% AGME. Though there were only two species endemic to Agasthyamalai, one of them *Aglaia bourdilonii* was a high-density species but accounted for only 3.3% of the basal area. Trend in basal area was also similar to density; EWGE highest followed by AGME and finally SWGE.

	Total	Plot 1	Plot 2	Plot 3
Recruitment	0.86	0.05	1.84	0.96
Mortality	0.56	0.59	0.61	0.49
Turnover	0.71	0.32	1.22	0.73

Table 11.
Demographic parameters across the 3 one ha plots.

5.7 Changes in recruitment, mortality and turnover of tree species over time

Endemic species showed least change in stem density and basal area whereas widely distributed species showed greater change in both. The overall recruitment of trees was 0.86% per year and mortality 0.56% per year resulting in an annual turnover of 0.71% (**Table 11**). Thirty-three species did not show any recruitment and mortality. Forty species showed no recruitment and 37 species no mortality. The dominant species such as *Cullenia exarillata, Palaquium ellipticum, Agrostistachys borneensis* and *Aglaia bourdillonii* had low recruitment and mortality rate.

Majority of the gap species had high levels of recruitment and mortality resulting in a high turnover. Some closed forest and canopy species such as *Nageia wallichiana* (Podocarpus), *Elaeocarpus tuberculatus* and understorey species such as *Antidesma menasu, Syzygium mundagam* and *Miliusa wightiana* showed high levels of recruitment. Gap species had higher mortality and recruitment than closed forest species. Recruitment and mortality was not significantly different between canopy and understorey species. In general gap species was the major contributor to the turnover in the forest.

6. Way forward

Long-term data is essential for undestanding vegetation dynamics. Vegetation dynamics is directly related to climate variability that an ecosystem experience. Extreme events such as floods, drought and snowfall forms part of long-term variability in climate. Vegetation response to such extreme events depends upon the type and intensity of an event. Government of India has initiated two major national projects to undestand and combat the impacts of varibility in climate through understanding natural vegetation dynamics. They are, (a) Indian Long-Term Ecological Obsevatories (ILTEO) and (b) Studies of impact of climate change on Indian Forest System through long-term monitoring, an All India Coordinated Research Project (AICRP) managed by Indian Council for Forestry Research and Education (ICFRE), Dehradun. ICFRE with its nine Institutes, Forest Research Institute (FRI), Dehradun, Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore, Institute of Wood Science and Technology (IWST), Bengaluru; Institute of Forest Biodiversity (IFB), Hyderabad; Rain Forest Research Institute (RFRI), Jorhat; Tropical Forest Research Institute (TFRI), Jabalpur; Himalayan Forest Research Institute (HFRI), Shimla; Institute of Forest Productivity (IFP), Ranchi; and other Institutions like Ashoka Trust for Research in Ecology and Environment (ATREE), Bengaluru; Indian Institute of Science (IISc) Bengaluru; French Institute, Pondicherry; and Kerala Forest Research Institute (KFRI), Peechi, Thrissur, Kerala have initiated long-term ecological monitoring studies on the effects of climatic variability on the forest ecosystem. This will be the first of its kind in India to address climate change issues at national and international level and helps to trace footprints of climate change impacts through vegetation and also reveals to what extent our forests are resilient to change in the climate. Further it will also address the issues flagged by UNFCCC, IPCC, NAPCC, SAPCC etc.

Major objectives of the programme includes establishment of Permanent Preservation Plots (PPP) to observe and understand the changes in species diversity, composition and growth pattern due to climate change over a period of time. The methodology for selection and laying of sample plots, assessment, identification and tagging of plants is based on Centre for Tropical Forest Science (CTFS) protocol. Aimed at precision, uniformity, and large scale of international acceptance, it was decided to laydown country wide permanent plots (preferably 10 Hectare size) in major forest types of the country wherein woody individuals >1 cm diamter at breast height (DBH) would be monitored for vital parameters such as recruitment, mortality and growth in relation to climate. The study also includes dendrochronology, edaphic factors, survivality, regeneration, invasive species, dynamics of soil microflora, phenological studies, insect-pest incidence, disease infection, pollinators etc in the pemanent plot and surrounding forest area.

Complementary to this initiative Indian Government launched a new pan India research program- Indian Long Term Ecological Observatories (ILTEO) with a larger goal of assessing the influence of climate change on the biodiversity at national level. To address issues related to climate change the Government of India has set up Indian Network for Climate Change Assesment (INCCA) to provide frame work to monitor impacts of climate change, assess the drivers of climate change and to develop decision support system. It is been recognzed that climate change of one of major drivers, Long-term ecological monitoring is required to identify pattern and drivers of change. Moreover long term monitoring is required to frame the national policies and signing international conventions such as United Nations Framework Convention on Climate Change (UNFCC). There are several isolated programs monitoring the changes. However, there is a need for unified multidisplinery national level program to address the issues of climate change. All India Coordinated Research project under ICFRE is one such national level effort to address encouragement and research to climate change.

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