VEGETATION DYNAMICS ACROSS LANDSCAPES IN KODAGU REGION OF WESTERN GHATS, SOUTH INDIA

Thesis submitted to Bangalore University
for the award of the Degree of

Doctor of Philosophy in Environmental Science

VIMHASENO NEIKHA

Under the Supervision of
Dr. B. C. NAGARAJA
Assistant Professor

DEPARTMENT OF ENVIRONMENTAL SCIENCE
BANGALORE UNIVERSITY
BANGALORE - 560 056

October, 2019

DECLARATION

This is to declare that the thesis titled **"Vegetation Dynamics across Landscapes in Kodagu Region of Western Ghats, South India"** which is being submitted for the award of Degree of Doctor of Philosophy (Ph.D) in Environmental Science is the outcome of the research carried out by me under the supervision of Dr. B.C.Nagaraja, Department of Environmental Science, Bangalore University, Bangalore. The information, views and opinions taken from the existing literature and cited in the thesis have been indicated and duly acknowledged. I further declare that this thesis, either wholly or in part, has not been submitted to Bangalore University or any other University or Institution for the award of any other Degree or Diploma.

Date:

Place: Vimhaseno Neikha

Bangalore University

Department of Environmental Science

Jnanabharathi, Bangalore- 560 056

☎ 080-2296 1365 (O)
080-23473349 (R)
09886490778 (M)
Email: nagenvi@gmail.com
Web: www.bangaloreuniversity.ac.in

Dr. B.C. Nagaraja
Assistant Professor

Date:

CERTIFICATE

This is to certify that the thesis entitled **"Vegetation Dynamics across Landscapes in Kodagu Region of Western Ghats, South India"** submitted by **Ms. Vimhaseno Neikha** for the award of **Doctor of Philosophy** in Environmental Science, is based on the original results of the studies carried out by her under my supervision. It is also certified that the thesis or any other part thereof has not been previously submitted for any other degree or diploma to this or any other University or Institution.

B.C. NAGARAJA

Table of Contents

Acknowledgement

I thank Supervisor, Dr. B.C. Nagaraja, for introducing me to biodiversity hotspots of Western Ghats and suggesting me to pursue research in Protected Area landscapes of Kodagu. I thank him for the guidance, constant motivation and help rendered to me during the course.

I thank Dr. Nandini. N. Professor and Chairman of the Department of Environmental Science for her advice and support given during the research period.

I thank the teachers, Dr. R.K. Somashekhar, Dr K.L. Prakash, Dr. N. Sunitha, Dr. D. Paramesha Naik, Dr. M. Kumar, Dr. S. Sivasakthivel, Dr. P. Ravikumar, Dr. M. Raghavendra for their valuable help and support during the course of study.

I thank the Ministry of Tribal Affairs, Government of India for the award of National Fellowship of Higher Education (NFHE) for Scheduled Tribe Students from 2015-2020, without this I would not have completed my field, laboratory and writing work.

I thank University examination branch, library and administrative authorities for providing accommodation and necessary support during the course.

I thank PCCF Wildlife, Government of Karnataka for providing necessary permission to undertake field work in the protected areas. I also thank the RFOs, DRFOs of Brahmagiri and Pushpagiri Wildlife Sanctuary.

I thank forest guards and watchers: Mr. Ashik, Mr. Jeevan, Mr. Manohar, Mr. Theertaram, Mr. Pradeep, Mr. Madhu, Mr. Sunil, Mr. Mohan, Mr. Ganesha, Mr. Sharad, Mr. Shivanna, Mr. Ashok, Mr. Praveen and Mr. Premnath for helping me in identification of species, laying plots and measurements.

I thank Dr. H.C. Chetan, Dr. C. Sunil, Dr. Prasanna Kumar, Dr. Pramod Kumar, Dr. Shivaprasad and Dr. Harish for their timely help and suggestions. I thank Mr. Gopi, Mr. Venkat, Mr. Venugopal and Mr. Tarakesh for their help in the field work.

I thank Mrs. Deepthi, fellow research scholar for being with me in all my field work. It wouldn’t have been possible to complete without her support. I thank Mr. Krishnakanth B.N, for encouraging me to pursue PhD and for all the help and support during the course.

I am grateful to all my PhD colleagues Mrs. Sumarani, Mrs. Alka, Mrs. Shilpashree, Mrs. Tabassum, Mr. Kumar Naik, Mr. Kumarswamy and Mr. Ravishankar for their support.

I thank all the non-teaching staffs, Mr. Cheluvaraj, Mr. Devaraj, Mr. Manju, Mrs. Ratnamma and Mrs. Mangalamma for their support.

I thank all my friends, family and relatives for their support. I especially thank Apo Kezho for his constant prayers and support.

Lastly, I want to thank Apo and Ave for having faith in me and giving me the opportunity to study further. I am always grateful to my siblings Acha, Atsei, Alo and Kevi for always being there to support and encourage me.

Vimhaseno Neikha

List of Abbreviations

AGB	Above Ground Biomass
AGC	Above Ground Carbon
BGB	Below Ground Biomass
BGC	Below Ground Carbon
BWS	Brahmagiri Wildlife Sanctuary
CBD	Convention on Biological diversity
CEPF	Critical Ecosystem Partnership Fund
CO_2	Carbon dioxide
ESZ	Eco-Sensitive Zone
FAO	Food and Agricultural Organisation
GBH	Girth at Breast Height
GHGs	Green House Gases
GIS	Geographical Information System
GoK	Government of Karnataka
IMFN	International Model Forest Network
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature and Natural Resource
IVI	Importance Value Index
KSRSAC	Karnataka State Remote Sensing and Application Centre
LULC	Land Use Land cover
NDVI	Normalized Difference Vegetation Index
NRSA	National Remote Sensing Agency
PWS	Pushpagiri Wildlife Sanctuary
UNCED	United Nations Conference on Environment and Development
UNESCO	United Nations Educational Scientific and Cultural Organization

List of figures

List of Tables

List of Appendix

SUMMARY

Mountain ecosystems are important biological diversity centres with half of the world's biodiversity hotspots concentrated in these areas. Vegetation types that are usually found over long distances are observed over short distances in mountains. Thus, species richness studies in altitudinal gradients have become increasingly popular in recent years. Understanding the structure, composition and diversity of a forest is an essential feature in assessing the sustainability, ecological importance and its implication for conservation and management. Studies on regeneration are a useful tool in understanding the present vegetation and also give an insight into the future vegetation composition. Forests also play an important role in the mitigation of climate change by sequestering carbon in biomass and soil.

India's recognition as one of the four mega-diversity countries of Asia is derived largely from two of its most important biodiversity 'hot-spots': the Himalaya including the north-eastern hills along the northern border, and Western Ghats in the peninsular India. Western Ghats is one of the main mountain ranges in India and is a region of immense global importance for the conservation of biological diversity. Kodagu district which lies in the central part of the Western Ghats has witnessed a rapid expansion of plantation crops. The indiscriminate development, expansion of coffee plantations and commercialization of property to homestays and resorts has led to a decrease in tree cover over the years. The original native trees have been removed to grow fast growing commercial trees for timber and shade purposes in coffee plantations, which have also led to a decrease in the avian diversity and bee colonies in the region.

The vegetation of the protected areas of Brahmagiri Wildlife Sanctuary (BWS) and Pushpagiri Wildlife Sanctuary (PWS) along an elevational gradient was carried out and the carbon stock and carbon sequestration potential was estimated. The tree species were recorded by laying down three quadrats of 20 x 20 m at 20 m apart from each other at every 100 m elevation. A total of 93 quadrats covering an area of 3.72 ha were laid for vegetation study. In each quadrat all the species with girth ≥30 cm was measured. The regenerating individuals were sampled by laying down 1 x 1 m at the four corners and one at the centre of 20 x 20 m quadrat. A total of 465 sub quadrats were laid for regeneration study. All the individuals <10 cm were considered as seedlings and ≥10cm to <30 cm were considered as

saplings. Soil samples were collected from a depth of 0-30 cm from 31 sites and were analysed for carbon content and nutrient availability.

Land use and land cover for two decadal changes was carried out for three protected areas along with the adjoining Reserve Forests. Study revealed that areas having habitat with vegetation and agricultural plantations increased and the tree groves decreased. Normalized Difference Vegetation Index showed that there has been a decrease in the forest cover in the past two decades. Although the change in the land cover in these areas is minimal in the past two decades, coffee expansion to higher elevations on fringes of protected areas should be restricted.

On the basis of elevational gradient, the study area was divided into Low (100-500 m), mid (600-1000 m) and high elevation (1100-1700 m) ranges. Species richness was found to be highest in mid elevation range in BWS and high elevation range in PWS. The dominant species in low elevation range was *Vepris bilocularis* in BWS and *Knema attenuata* in PWS, mid elevation was *Olea dioica* in BWS and *Vateria indica* in PWS, High elevation was *Ligustrum perrottetii* in BWS and *Litsea mysorensis* in PWS.

A total of 1708 individuals belonging to 132 tree species, 95 genera and 46 families were recorded in both protected areas of which 26.25 % of the total species and 48.42 % of the families was found to be common between two protected landscapes. *Hopea parviflora* and *Dimocarpus longan* were the dominant species common to both the landscapes. In BWS, a total of 884 individuals belonging to 94 tree species, 83 genera and 39 families respectively were recorded from 100 to 1500 m with 39 tree species endemic to the Western Ghats. In PWS, 824 individual belonging to 85 species, 64 genera and 37 families respectively were recorded from 200 m to 1700 m with 36 species endemic to the Western Ghats. Species richness varied along the elevational gradients and ranged from 3 to 27 in BWS and 8 to 22 in PWS. The maximum species richness occurred at 400 m with 27 species in BWS and in PWS at 700 m and 1000 m with 22 species each. The relation between species richness and elevation showed a negative correlation both in BWS and PWS with a decrease in the species richness with elevation.

A total of 52 out of 132 tree species recorded in two landscapes were found to be endemic to the Western Ghats. A total of 439 individuals belonging to 39 endemic tree species and 22 families were recorded in BWS and 431 individuals belonging to 36 endemic tree species and

20 families were recorded in PWS respectively. The number of endemic species in the elevational sites varied from 2 to 15 in BWS and 3 to 14 in PWS. The endemic species with the highest number of individuals in BWS included the species *Vepris bilocularis, Hopea parvilfora* and in PWS it included species such as *Litsea mysorensis* and *Palaquium ellipticum.*

In this study, majority of the species had contagious (91.62 %) distribution pattern followed by random (7.82%) and regular distribution (0.56 %) pattern. *Diospyros nilagarica*, *Knema attenuata*, *Ligustrum perrottetti*, *Myristica malabarica* and *Vitex altissima showed contagious distribution. Actinodaphne bourdilloii*, *Cinnamomum riparium*, *Calophyllum apetalum* showed contagious random distribution pattern.

The stand density was higher in BWS than in PWS as there was more number of individuals recorded in BWS although PWS had more number of elevational sites. The basal area was highest at 500 m with 113.18 m^2/ha in BWS and 1200 m with 110 m^2 /ha in PWS respectively. There was a negative correlation between basal areas with elevation in BWS. However there was no correlation in PWS. *Hopea parviflora* and *Pallaqium elipticum* had the highest basal area in BWS and PWS respectively.

A total of 46 families were recorded for both BWS and PWS with 39 families recorded in BWS and 37 families in PWS. Anacardiaceae was the dominant family in BWS with 8 species (8.51 %) and Lauraceae with 9 species (10.71 %) in PWS. The Family Importance Value was highest for Dipterocarpaceae in BWS and Lauraceae in PWS. The Importance Value Index of the species showed that the vegetation distribution was dominated by *Olea dioica* (15.90) in BWS and *Palaquium ellipticum* (20.82) in PWS.

The Shannon-Wiener diversity Index (H`) was found to be higher in BWS (3) than PWS (2.86).The Simpson's Index (D) was greater in BWS, however there was no significant relationship between Simpson's diversity Index with elevation in both the landscapes. Pielou's evenness Index (E) was found to be greater in the higher elevations, 1000 m (0.95) in BWS and 900 m and 1100 m (0.94) in PWS with no significant correlation between evenness and elevation.

In BWS, 70.25 % were understorey trees, 21.72 % mid and 8.3 % top canopy trees. In PWS, 74 % of the trees were understorey trees, 22% mid and 3 % constituted the top canopy trees. The tree canopy in both the landscapes composed mostly of understorey trees with *Litsea* *floribunda* as the dominant species in both BWS and PWS, *Kingiodendron pinnatum* was the dominant mid canopy tree in BWS and *Holigarna arnottiana* in PWS and *Palaquium ellipticum* was the dominant top canopy in both BWS and PWS. In both the sanctuaries, 30-60 cm girth class recorded the highest number of individuals with 428 individuals in BWS and 420 individuals in PWS respectively.

A total 1050 individuals belonging to 55 species and 31 families were recorded in both BWS and PWS for regenerations studies. In BWS, 46 species with 571 individuals and 30 species with 479 individuals in PWS were recorded respectively. Regeneration individuals were found to be highest at 500m with 68 individuals in BWS and 1000m in PWS with 47 individuals. The dominant species in BWS was *Drypetes venusta* with 51 (10.83%) individuals and *Diospyros ebenum* with 64 (13.36%) individuals was dominant in PWS. Regenerating individuals was found to decrease with increase in elevation. The study showed a healthy regeneration population with higher number of seedlings than saplings although most of the individuals do not reach the matured or adult stage.

The soil in both the landscapes was found to be acidic in nature. The nutrient availability of the soils was found to be higher in BWS than PWS, however the Organic Carbon and the moisture content in the soil was found to be higher in PWS than in BWS, which is due to various factors such as slopes, soil profile, rainfall, aspect and climate.

A total carbon stock of 6006 t and standing biomass of 12011 t were recorded in both the landscapes. Carbon stock was found to be higher in low elevation range in BWS, but it was found to be higher in mid elevation range in PWS. The carbon stock was found to be higher in BWS than PWS. The carbon stock in BWS was estimated at 224.8 t/ha of which 181.2 t/ha contributed to AGC and 43.6 t /ha contributed to BGC. The maximum carbon stock of 673.3 t/ha was recorded at 100 m in BWS. Whereas in PWS, the tree carbon stock was estimated at 164.6 t/ha out of which 132.3 t/ha contributed to the AGC and 32.2 t/ha contributed to the BGC and the maximum carbon stock of 454.8 t/ha was recorded at 1200 m in PWS. *Ficus virens* (21.53 t/ha) had the highest carbon stock in BWS and *Ficus nervosa* (46.74 t/ha) in PWS respectively. The carbon stock decreased with elevation in both BWS and PWS, which is due to decrease in the temperature, edaphic and climatic factors. The carbon sequestration potential in both the landscapes was estimated at 710 t/ha. The carbon sequestration potential of the forests of BWS and PWS was recorded at 824 and 604 t/ha respectively. The carbon stock across the elevational ranges was found to be higher in low elevation range in BWS but it was found to be higher in the mid elevation range in PWS.

The vegetation across the two landscapes showed presence of a diverse flora and a healthy regeneration population. Maximum species diversity occurred in the lower elevations with a peak in mid elevations and decreased higher up the elevation, whereas endemic species were found to be more abundant in the higher elevations. The forest structure and composition of the vegetation change along the elevational gradients with a decrease in tree height and girth size of the trees with increase in elevation. The study concludes that elevation plays a major role in vegetation type and composition of species.

The organic content in the soil was found to be more in the higher elevations compared to lower elevations. The carbon stock varied across the elevational gradients and the species with larger girth size contributed more to carbon stock. Both the landscapes had good potential for carbon sequestration with BWS having higher carbon stock than PWS. These forests thus act as carbon sinks which is helpful in the mitigation of climate change.

Hence protected areas are important in the conservation of biological diversity and climate regulation by acting as carbon sink. The conservation of the forest in these landscapes relies mostly on forest department policies and protective actions against encroachments, fire, grazing and other anthropogenic factors. Therefore continued conservation efforts and site specific management plans needs to be implemented to conserve the biodiversity of these protected areas.

Chapter - 1

INTRODUCTION

1.1 Biodiversity and Mountain Ecosystem

Biodiversity is defined as "the variability among living organisms from all sources which includes diversity within species, between species and of ecosystems" (CBD, 1992). It represents the variety and heterogeneity of organisms from molecules to ecosystems (Morris *et al*., 2014). Wilson (1988) stressed on treating biodiversity as a global resource, to be indexed, used and preserved above all. Biological diversity has however continued to decrease despite efforts over the past two decades mainly from habitat destruction, over-harvesting, pollution and inappropriate introduction of foreign plants and animals (UNCED, 1992). Mittermeier *et al*., (2008) suggests that focusing conservation efforts on areas with the greatest concentrations of biodiversity and the likelihood of losing significant portions of biodiversity will achieve maximum impact for conservation investment. Mountains cover about one-third of the Protected Areas in the world and support about one quarter of terrestrial biodiversity with nearly half of the world's biodiversity hotspots concentrated in mountains (Spehn *et al*., 2010). Terrestrial ecosystems are constituted by a complex array of interacting communities and occupy 28 % of the Earth's surface (Herrera-Estrella, 2014). Forest ecosystems include the living organisms of the forest and it extends vertically upward into forest canopies and downward to the lowest soil layers (Waring & Running, 2007).

Mountain ecosystems are important biological diversity centres (Price *et al*., 2011) and are important to the survival of the global ecosystem. These ecosystems play a crucial role with about 10% of the world's population depending on them for water, food, minerals and agricultural products (CBD, 1992). Mountain ecosystems belong to the most endangered ecosystems in the world (Gabriele & Keplin, 2005). Mountains are also home to a significant number of distinct ethnic groups, with distinct cultural traditions, environmental knowledge and habitat adaptations. As a result, mountains host some of the world's most complex agricultural diversity and traditional management practices (Spehn *et al*., 2010). Mountain environment are essential for the survival of global biodiversity. Agenda 21 identified two programme areas for sustainable mountain development one of which was generating and strengthening knowledge about the ecology and sustainable development of mountain ecosystems and another one on promoting integrated watershed development and alternative livelihood opportunities (UNCED, 1992).

The different vegetation types which are usually found over hundreds of kilometers distance longitudinally or latitudinally at low elevations can be found over a few kilometers distance in mountains (Peterson *et al*., 1997) which makes it ideal for studying different ecological and biogeographical hypotheses (Korner, 2000). The latitudinal and altitudinal distribution of vegetative zones was first described by Von Humboldt (Turner, 1989). The latitudinal gradient was the pattern that first attracted scientific attention to species diversity (Huston, 1994) and studies on species richness patterns have been attracting increased attention (Grytnes, 2003; Guo *et al*., 2013). Latitudinal gradients of biodiversity are biogeographic patterns that quantify the ways in which taxonomic, phylogenetic, functional, genetic, or phenetic biodiversity change with latitudinal position on the surface of the earth (Willig & Presley, 2018). Topography-based analyses in mountain regions are insightful due to terrain related heterogeneity (Bunyan *et al*., 2015) relative elevation, slope convexity (Titshall *et al*., 2000; Sri-Ngernyuang *et al*., 2003) and soil properties (Tange *et al*., 1998) which influence the presence of species. Understanding the distribution of tree species and their assemblages plays an important role in elucidating distribution patterns of biodiversity (Utkarsh *et al*., 1998), it is also important in conservation science as it allows one to identify regions of exceptional richness (Ashton, 1992).

1.2 Western Ghats of India

There are four terrestrial biodiversity hotspots in India viz., the Himalayan, Indo-Burma, Western Ghats and Sri Lanka, Andaman and Nicobar Island, of which the Himalayas and the Western Ghats form the major mountain ranges in India. The Western Ghats are a chain of mountains recognized as one of the world's eight 'hottest hotspots' of biological diversity (Myers *et al*., 2000) and also as a region of immense global importance for conservation of biological diversity. The Western Ghats present one of the best examples of tropical monsoon ecosystem on the planet with its characteristic montane forest ecosystem which influence monsoon weather patterns (UNESCO, 2019). It runs for about 1600 Km roughly in a North-South direction through the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu and covers an area of 140,000 Km^2. The highest peak of the Western Ghats is the Anamudi peak at 2695 MSL located in Eravikulam National Park of Kerala. UNESCO (2012) recently declared 39 sites in the Western Ghats as World Heritage Sites of which 20 are in Kerala, 10 in Karnataka, 5 in Tamil Nadu and 4 in Maharashtra respectively.

Western Ghats are known for their high levels of endemism both at higher and lower taxonomic levels (Daniels, 1997) and supports a variety of tropical forest ecosystems because of their geographical location, stable geological history, favorable climate and good soil conditions (Sundarapandian & Swamy, 2000). A total of 325 globally threatened species occur in the Western Ghats of which 129 are classified as Vulnerable, 145 as Endangered and 51 as Critically Endangered (UNESCO, 2012). It also harbours 7388 species of flowering plants, of these, 5584 are indigenous (2242 species are Indian endemics and 1261 are the Western Ghats endemics), 377 are exotic naturalized and 1427 are cultivated or planted (Nayar *et al*., 2014). However, the primary forests of Asia, particularly those of the Western and the Eastern Ghats of peninsular India are disappearing at an alarming rate due to anthropogenic pressure with the forests being replaced by inferior species or change in the land use pattern (Parthasarathy, 1999). Biodiversity in the Western Ghats is threatened by a variety of human pressures with the existing forest being highly fragmented and facing the prospect of increasing degradation (Bawa *et al*., 2007).

1.3 Vegetation Dynamics

Vegetation dynamics is the change in composition of species across different environmental gradients. An understanding of vegetation dynamics is basic to manage plant communities (Niering, 1987). Topography and elevation influence vegetation across biomes in terms of species composition and assemblages (Bunyan *et al*., 2015). In India, the first work on vegetation was carried out by Champion (1936) and later revised by Champion and Seth (1968). Vegetation needs to be studied in relation to its surroundings at both species and community levels as it is the expression of environment in a specific habitat at a specific time (Khan *et al.,* 2012). Vegetation composition, diversity of species and the structure of a forest is seen as an essential feature in assessing the sustainability of species conservation, ecological significance and the development of management policies for forest ecosystems (Kacholi, 2014).

Trees are used for species-area and species-individual relationship because they are easy to locate precisely and count (Condit *et al*., 1996). Studies on tropical plant species are important as it is useful in understanding the extent of plant biodiversity across the tropics and also for conservation and management (Parthasarathy *et al*., 2007). Tree species diversity is a fundamental component of total biodiversity in many ecosystems because trees are ecosystem engineers that provide resources and habitats for almost all other forest organisms (Huston, 1994) and it also reflects the carrying capacity of the ecosystem (Kumaraguru *et al*., 2016). Whittaker (1972) suggested that number of species is the most simple and appropriate measure of diversity. Trees form the major structural and functional basis of tropical forest ecosystems and can serve as robust indicators of changes and stressors at the landscape scale (Khan *et al*., 1997). The diversity of tree species in tropical forests varies by geography, habitat parameters, and levels of disturbance (Whitmore, 1998). An understanding of the species diversity and distribution patterns is important for helping managers to evaluate the complexity and resources of forests (Jayakumar & Nair, 2013).

Studies on species richness have been assessed for decades, where diversity and endemism play important roles in the conservation and understanding of the overall biodiversity (Gentry, 1992; Vetaas & Grytnes 2002; Fu *et al*., 2006). Species diversity is scale dependent and can have higher diversity at lower elevation and lower diversity at higher elevation due to climatic extremes at higher elevations (Oommen & Shanker, 2005; Bhattarai & Vetaas, 2006) whereas species endemism is maximum at higher elevation due to isolation governed by terrain (Shrestha & Joshi, 1996). The trends in species richness and endemism also depends on a number of other factors such as topography, inclination of slope, aspect, soil types (Shanks & Nooris 1950; Mandal & Joshi, 2014), niche width, niche differentiation with respect to light availability and soil resources (Bisht & Bhat, 2013). Besides climatic and geographic location, species diversity of a given forest area also depends on site representativeness, plot dimensions and the extent of human interaction in the past and present (Parthasarathy, 2001). Studies on species diversity are important as they affect the functioning of ecosystems (Chapin *et al*., 2000; Rana & Gairola, 2009), provide baseline information for conservation and management of the present forest (Sahu *et al*., 2012; Premnavi *et al*., 2014).

Regeneration is the process of silvigenesis by which trees and forests survive overtime. The future composition of the forests depends on the potential regenerative status of tree species within a forest stand in space and time (Henle *et al*., 2004). Regeneration of any species is confined to a particular range of habitat conditions and the extent of those conditions is a major determinant of its geographic distribution (Grubb, 1977). The population structure is characterized by the presence of sufficient population of seedlings , saplings and adults which indicates regeneration of forest species (Saxena & Singh, 1984) and the presence of saplings under the canopies of adult trees also indicates the future composition of a community (Pokhriya *et al*., 2010). Regeneration in many Indian forests including those forests of the Western Ghats is inadequate to replace the adults (Sukumar *et al*., 1992). Studies on regeneration pattern can be helpful in analyzing the existing trend in vegetation succession and obtain a foresight into the future vegetation composition (Karthik & Viswanath, 2012). Detailed studies on the regeneration status are necessary to manage and restore these vanishing resources as they form the basis for future plan (Sundarapandian & Swamy, 2000).

1.4 Tree Species Endemism

The Western Ghats are home to a large number of endemic species with nearly 63% of the total tree species found in the low and medium elevation evergreen forests being endemic (Ramesh *et al*., 1997). About 4500 plant species are known in the Western Ghats of which 35 % are endemic (Daniels, 1997). The reasons for the high diversity of endemic species in the Western Ghats can be due to isolation from other moist formations (Mehr-Homji, 1983), increase in the number of dry months from North to South, decrease in temperature with increase in altitude and local topographic variations (Ramesh & Pascal, 1997). Also, the high ranging hills of the Western Ghats are ideal for survival of some species when the climatic conditions become drier. Analysis of endemic species revealed that Western Ghats being much older in age compared to Himalayan Mountains support a large majority of paleo endemics (Rao, 2012). Endemism is mostly concentrated in isolated patches of unusual habitat in cloud forests, topographically dissected montane areas and on continental fragment island. An obvious approach to conserving plant biodiversity is to map distributional patterns and look for concentration of diversity and endemism (Gentry, 1992). Endemic species if lost from their native habitat, they will be lost forever as they will not be found anywhere else in the world and so they deserve conservational priority (Chitale *et al*., 2014).

1.5 Spatio-temporal Analysis

Forest mapping has become more important in view of the shrinkage and degradation of forest cover (Singh *et al*., 2002). Land Use Land Cover Change (LULCC) has become a central and important component in current strategies for managing natural resources and monitoring environmental changes and it serves as an effective tool for scientists and policy makers for efficient land management plans (George *et al*., 2016; Alsaaideh *et al*., 2011). With the change in climate and over demand of the growing inhabitants there has been a significant change in Land Use Land Cover (LULC) globally (Singh *et al*., 2012) and studies on LULC have received a lot of interest in the past few decades. Forest covers are lost globally in the developing countries of the tropics due to anthropogenic activities (Kusimi, 2008). Use of remote sensing and increased satellite resolutions has revolutionized the study of LULCC as it is a more cost effective method and is suitable to monitor change detection at varying spatial ranges (Singh *et al*., 2002; Roy & Roy 2010; Singh *et al*., 2012). Digital change detection techniques based on multi-temporal and multi-spectral remotely sensed data have demonstrated a great potential as a means to detect, identify, map, and monitor differences in land use and cover patterns over time, irrespective of the causal factors (Rawat *et al*., 2013).

1.6 Forest and Climate change

The past few decades has seen the effect of climate change and the threat it poses to the environment and the quality of human life all over the world. Biodiversity has been impacted to a great extent due to the abrupt hike in the level of Green House Gases (GHGs) (Mitra, 2013). Deforestation alone accounts for about 17 % of global GHGs emissions (IPCC, 2007). Among the primary GHGs which are CO_2, NOx, CH_4 and Water vapour; CO_2 is of major concern as it is mainly due to fossil fuel burning, industrial processes and human induced impacts (IPCC, 2014). With the rise in GHGs in the atmosphere, there has been an urgent need to quantify the forest carbon stock for better monitoring and management of the forests (Pragasan, 2015). Thus, forests which cover approximately 30-40% of the Earth (Waring & Running, 2007) play an important role in the mitigation and adaptation of climate change. The concept of using forests for the mitigation of climate change was first proposed by Dyson (1977) in the 1970's. It has also been implemented in the Kyoto protocol and it suggests that management of natural terrestrial carbon sinks, primarily afforestation and reforestation at a global scale can increase sink strength and thus reduce atmospheric CO_2 (Schulze *et al*., 2000). Forests act as carbon sinks by storing large amounts of carbon from the atmosphere and retain it in biomass and soil (Bravo *et al*., 2008; Whitehead, 2011). Understanding forest management and the effect it can have on the carbon cycle is crucial to incorporate carbon storage into management strategies to mitigate climate change (Pandey, 2012). Tropical forests including vast areas of degraded lands also function as carbon sinks (Brown & Lugo, 1992).

Forest ecosystems are the largest terrestrial carbon sink on earth (Ahirwal & Maiti, 2018). The Global Forest Resources Assessment (FRA) reported that the world's forest area decreased from 31.6 % of the global land area to 30.6 % between 1990 and 2015 but that pace of loss has slowed down in recent years (FAO, 2018). Estimates made for Forest Resource Assessment show that the world's forests store around 650 billion tons of carbon which is higher than what is found in the atmosphere (FAO, 2015). Overall forests contain just over half of the carbon residing in terrestrial vegetation and soil amounting to some 1200 Gigatonne (Gt) of Carbon (FAO, 2010). Terrestrial ecosystems store about 2500 Petagram of Carbon (PgC) with 500 PgC in vegetation and 2000 PgC in soil (Alexandrov, 2008). Terrestrial ecosystem is a major biological scrubber of atmospheric CO_2 that can be significantly increased by careful management (Melkania, 2009), it acts as a major ecological parameter in determining carbon sequestration and carbon sink function (Aishan *et al*., 2018). Tropical forests store about 46 % of the world's living terrestrial carbon pool and 11 % of the world's soil carbon pool (Brown & Lugo, 1982). The carbon stocks stored in the forests of India from 1995 to 2005 have increased from 6244.78 to 6621.55 million tonnes (Kishwan *et al*., 2007).

1.7 Carbon Sequestration

Carbon sequestration is a term used to describe both natural and deliberate process by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments and geologic formations (Sundqvist *et al*., 2008). It is one of the best and practical ways for removal of carbon from the atmosphere. Knowledge on carbon accumulation in any ecosystem will also help predict future global climate change

(Shedayi *et al*., 2016). The carbon sequestration potential of a forest is determined by its biomass production which indicates the potential of a forest to absorb atmospheric CO_2 and reduce global warming and the standing biomass of a forest reflects on the amount of carbon sequestered during its lifetime (Sundarapandian *et al*., 2013). Biomass production depends on the interaction between edaphic, climatic and topographic factors of the specified area and the species that occur in the specific area (Kamruzzaman, 2018). Carbon allocation in above ground and below ground components of plants is one of the important processes of carbon cycling (Chen *et al*., 2015). Above Ground Biomass is a key variable in the annual and long term changes in the global terrestrial carbon cycle and other earth system interactions (Terakunpisut *et al*., 2007). The concentration of CO_2 in the atmosphere has increased by 31% since the beginning of the industrial era (IPCC, 2001). Deforestation and forest degradation contribute 15-20 % of global carbon emissions and most of that contribution comes from tropical regions (Weier & Herring, 2000). The rate of increase of atmospheric CO_2 in the future will depend on the anthropogenic activities, interaction of biogeochemical and climate process of the carbon cycle and carbon pools (Crichton, 2012) and continued increase in the concentration of CO_2 is predicted to lead to significant changes in climate (Cox *et al*., 2000).

Chapter - 2

REVIEW OF LITERATURE

2.1 Landscape Modifications using Geospatial Techniques

Land cover was originally referred to the kind and state of vegetation but it has broadened in subsequent usage to include human structures such as buildings and other aspects of the natural environment such as soil type, biodiversity and surface and groundwater (Meyer, 1995). Land cover is defined as observed physical features on the Earth's surface, when an economic function is added to it; it becomes land use (FAO, 2015). LULC are distinct yet closely linked characteristics of the Earth's surface (Meyer, 1995). The last three centuries has seen the face of the earth being drastically altered because of anthropogenic activities (Roy & Roy, 2010). The change in land use occurs due to physical needs on one hand and natural potential of land on the other (Ram & Kolarkar, 1993). The change in the land use pattern affects biodiversity, structure and composition of natural communities which in turn affects the ecosystem functioning and services (Martinez *et al*., 2009).

Remote sensing together with GIS (Geographic Information System) forms a potential tool for monitoring the changes in the land cover at regional as well as global scale by identifying conservation hotspots, deforestation rate and quantification of overall forest cover at finer scale (Kumar, 2011). Remote sensing images are suitable for quantifying and analyzing land cover dynamics especially for forest cover change (Ghebrezgabher *et al*., 2016).

Studies on LULCC have become a central and important component in current strategies for managing natural resources and monitoring environmental changes (Tiwari & Saxena, 2011). LULCC can be done on a temporal scale to assess the changes in landscape caused due to human activities at low cost, speed and accuracy (Gibson & Power, 2000; Singh *et al*., 2002; Rawat & Kumar, 2015). Studies on change detection helps in proper management of landscapes and natural resources leading to sustainable development and sustainable use of resources as it forms a potential tool at research, policy formulation and implementation level (Munsi *et al*., 2010). LULCC databases are also being prepared as they are helpful in macro level decision making, working plan maps (Jiyuan *et al*., 2002; Kumar *et al*., 2014).

In India, a number of studies have been carried out in various parts of the country to understand and address changes in urban cities, vegetation cover, forest encroachment, forest corridor and burnt area mapping (Somashekar *et al*., 2009; Singh *et al*., 2012; Hemanjali *et al*., 2015;Mallegowda *et al*., 2015; Mir *et al*., 2016). Garcia *et al*., (2009) studied the LULC of Kodagu district for two decades and reported a 30 % decrease in the forest cover due to the intensification of coffee cultivation in the species rich wet evergreen belt of the district of Kodagu.

Several indices are used for vegetation assessment, but NDVI (Normalized Difference Vegetation Index) is the most commonly used vegetation index (Weier & Herring, 2000; Shahrokhnia & Ahmadi, 2019) which is applied for a wide range of natural resource mapping including studies such as, crop yield assessment (Groten, 1993; Panda et al., 2010), deforestation (Othman *et al*., 2018), drought assessment (Karnieli *et al*., 2010), climate change (Bounoua *et al*., 2000), phenological variability (Reed *et a*l., 1994) and vegetation change (Gandhi *et al*., 2015; Zaitunah *et al*., 2018). NDVI is an indicator of vegetation health as the degradation of the vegetation ecosystem or decrease in greenness would reflect in a decrease in the NDVI value (Meneses-Tovar, 2011). NDVI quantifies vegetation by measuring the difference between near infrared and red light and is used as an indicator to describe the relative density and health of vegetation (NRSC, 2014; Drisya *et al*., 2018). It is based on the reflectance properties of vegetation in comparison with water, snow and clouds, rocks and bare soil (Waikhom *et al*., 2019). Michener and Houhoulis (1997) studied the detection of vegetation changes associated with extensive flooding in a forested ecosystem and reported that vegetation changes were more accurately identified by image differencing of NDVI data.

2.2 Vegetation Dynamics across Elevational Gradients

According to McCain and Grytnes (2010) there are four main trends in elevational species richness: decreasing richness with increasing elevation, plateaus in richness across low elevations then decreasing with or without a mid-elevation peak and a unimodal pattern with a mid-elevational peak. Among various patterns, monotonic decline and hump-shaped pattern of species richness are most commonly recognized (Rahbek, 2005). Lomolino (2001) pointed out that many components of climate and local environments vary along the elevation gradients and ultimately create the variation in species richness. Although altitude proved to be the most important variable explaining differences in species distribution across the transect, it must influence the occurrence of species indirectly through interactions with temperature, humidity, snow duration, soil, and topography (Holten,1998). Various anthropogenic disturbances both at the local and broader scales influence the vegetation composition and structure (Ribichich & Protomastro, 1998). It is thus imperative to understand the patterns of distribution of plant species and the influencing factors at different scales (Bai *et al*., 2004). The structure, function, and ecosystem services of tropical forest depends on its species richness, diversity, dominance, and the patterns of changes in the assemblages of tree populations over time (Anitha *et al*., 2010).

Understanding elevational distribution pattern of species and the factors governing the same would help to understand biodiversity and aid in conservation (Hunter & Yonzon, 1993). In recent years biogeographers are carrying out investigations on general pattern and search for common cause of species richness along the spatial and environmental gradients.

Topographical variables have been used to determine species richness, regional biodiversity patterns, forest health, species distributions and gradients of exotic species (Bunyan *et al*., 2015). Trigas *et al*., (2013) found that area alone is responsible for the variation in the species richness; species richness monotonically decreases with increasing elevation, while endemic species richness has a unimodal response to elevation showing a peak at mid-elevation intervals. An understanding of succession is required for forest resource management. The structure and composition of the vegetation not only reflects the nature of basic trophic structure but also forms habitat for numerous organisms. Therefore, information on these parameters become quite valuable in a variety of ecological problems such as an input to Environmental Impact statements, in monitoring the management practices or as a basis for predicting possible changes (Rawat & Bhainsora,1999).

Altitudinal gradients are ideal for studying several ecological and biogeographical hypothesis as even a small geographical area can have a large environmental variation (Körner, 2000). An understanding of the species richness pattern will help in the management of species diversity in a world that may become warmer due to human impact. In recent years, studies on altitudinal gradients have become increasingly popular for investigating the species richness patterns but there is also a lack on studies on altitudinal gradients that are directly comparable which makes it difficult to assess whether the variation are real or due to sampling artefacts (Grytnes, 2003). Lomolino (2001) calls for studies comparing altitudinal trends between mountain ranges using the same sampling regimes for all transects and standardized plot sizes within transects.

Taxa richness, number of endemic and threatened species decreased with the increase in altitude while the indicator species for each zone increased with altitudinal elevation in the Atlantic deciduous forest (Rezende *et al*., 2015). Kessler (2000) studied the elevational gradients in species richness and endemism of selected plant groups in the central Bolivian Andes and found that endemism was high for terrestrial taxa. Lieberman *et al*., (1996) studied the tropical forest structure and composition on a large scale altitudinal gradient in Costa Rica and found that there was a progressive decrease both above and below this altitude in species richness, species diversity, number of families and the number of species per family. Grytnes (2003) studied on the species-richness patterns of vascular plants along seven altitudinal transect in Norway and concluded that even if a standard sampling regime with a standard plot size is used, both humped and monotonically decreasing trends of richness appear.

Studies on species richness patterns in the Himalayas showed a unimodal pattern with altitude with peak richness in the middle elevations (Oommen & Shanker 2005; Acharya *et al*., 2011). A study on the comparative assessment of floristic structure, diversity and regeneration status of tropical rain forests of Western Ghats of Karnataka showed that richness and regeneration of tree species was comparatively higher in southern part of Western Ghats compared to northern part (Sathish *et al*., 2013). Khan *et al*., (2013) in their study on plant species and communities across environmental gradients in the Western Himalayas found that plant species diversity is optimal at middle altitudes (2800–3400 m) in contrast to lower altitudes (2400–2800 m) where anthropogenic impact is greater and at higher altitudes (3400–4100 m) it was affected by shallow soils and high summer grazing pressure. The study also found that the pattern of plant community in the valley is largely determined by aspect and slope. Davidar *et al*., (2005) reported that seasonality and not annual rainfall was found to be the variable that drives tropical forest tree diversity in the Western Ghats.

Acharya *et al*., (2011) studied on the distribution pattern of trees along an elevation gradient of Eastern Himalaya, India and observed that tree species richness depicted unimodal pattern. Joseph *et al*., (2012) in his study on the southern region of the Western Ghats found that altitudinal gradient was prevalent in partitioning the major vegetation communities into sub-communities such as montane shola, evergreen, semi- evergreen, moist deciduous, dry deciduous and thorny scrub and that rainier areas maintain higher species diversity. Srinivas and Parthasarathy (2000) in their study on the tropical lowland evergreen forest of Agumbe of the Central Western Ghats reported a decrease in species richness with increasing altitude which could possibly be due to the role played by edaphic factors and altitude. Utkarsh *et al*., (1998) studied 7 vegetation types in the Western Ghats and found that evergreen forest type had the most diverse species assemblages with species extensively shared with other vegetation types. Studies on floristic composition are fundamental for conservation of natural areas (Singh *et al*., 2016), understanding the structure of forest (Gentry, 1988; Ozcelik, 2009) distribution patterns of species (Giriraj *et al*., 2009) comparing the composition of species (Kadavul & Parthsarathy, 1999; Joseph *et al*., 2012; Naidu & Kumar, 2016); biodiversity conservation (Singh *et al*., 2002; Baraloto *et al*., 2013) and guidance in the management of the Protected Areas (Suratman, 2012).

2.3 Carbon Stock in Forest and Soil

Mountain ecosystems play an important role as being the local source and sink of Carbon and Nitrogen for global climate change. Forest absorbs 2.6 billion tonnes of CO_2 every year which is approximately one-third of the CO_2 released from burning fossil fuels. Estimates also show that nearly two billion hectares of degraded land across the world offer opportunities for restoration (IUCN, 2019). Increasing and maintaining forests is therefore an essential solution to climate change (Rizvi *et al*., 2015). Carbon dioxide levels are higher today than any point in at least the past 800,000 years. The concentration of CO_2 in the atmosphere has increased dramatically from 315 ppm in 1958 to 408 ppm in 2018 (Lindsey, 2019).

Forests are therefore important carbon pools which continuously exchange CO_2 with the atmosphere, due to both natural processes and human action and are an essential solution to climate change. Carbon pool is defined as a system which has the capacity to accumulate or release carbon FAO (2003). IPCC (2006) has recognized five carbon pools viz., Above ground biomass, Below ground biomass, Deadwood, Litter and Soil organic carbon.

Forests play an important role in maintaining the carbon balance between terrestrial ecosystem and the atmosphere. Kyoto Protocol acknowledged forests as carbon sinks that act as effective channels for offsetting greenhouse gas emissions. Assessing and monitoring the state of the earth surface is a key requirement for global climate change research. Classifying and mapping vegetation is an important technical task for managing natural resources as vegetation provides a base for all living beings and plays an essential role in affecting global climate change (Xie, 2008). To reduce global warming, an effort must be made to reduce the atmospheric concentrations of these gases, particularly CO_2.

Mountain biological diversity is of high importance for a number of ecological functions. The integrity of soils is the prime capital for ecosystem services and human needs. Soil retention and slope stability are closely connected with the extent of above-ground and below-ground vegetation, both essential to ecosystem resilience after disturbance (CBD, 2003). The carbon present in soil carbon helps in determining the fertility of a study site as it helps maintain the physical and chemical properties in the form of cation exchange capability (Reeves, 1997). Studies on biomass of forest vegetation are vital for studies on carbon cycle and also provide inputs for regional and global carbon and climate models (Behera *et al*., 2016). Osuri *et al*., (2014) evaluated the above ground carbon stocks in contiguous and fragmented forests of Kodagu and found that fragmented forests store 40 % less carbon than contiguous forests which can be related to lower tree density, basal area, lower average height in fragments and compositional shifts with lower wood densities.

Carbon accumulation potential in forests is large and the period of carbon retention is long and so they are one of the major carbon mitigation sectors (Bhat & Ravindranath, 2011). Forest in the Sundaland region of Southeast Asia are not only the most diverse in the tropics but also amongst the most carbon dense (Sullivan *et al*., 2017). Total carbon stored in Indian forests is estimated at 9585 x 10^6 t C of which vegetation and soil accounts for 44% and 56% respectively (Ravindranath *et al*., 1997) and in 2017 it was estimated at 7082 x 10^6 Tc (FSI, 2007). Natural forests pose great potential in reducing the gases as they are undisturbed ecosystems (Sundarapandian *et al*., 2013). Carbon storage in terrestrial vegetation is one of the promising natural phenomena in regard to carbon mitigation strategy (Pragasan, 2016). Estimation of the accumulated biomass in the forest ecosystem is important for assessing the productivity and sustainability of the forest (Vashum & Jayakumar, 2012; Salunkhe *et al*., 2018). Most tropical forests are now affected by one or the other form of human interventions, the density diameter distribution of trees would be an important determinant of carbon stock in forests (Baishya *et al*., 2009).

The total estimated carbon stock varied from 3325 to 3161 Mt during the years 2003 to 2007 respectively in the forests of India although there has been a slight increase in the forest cover and so increasing the forest cover will not help in REDD+ (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) implementations unless deforestation and degradation is reduced (Sheik *et al*., 2011). Forests forms an important part of the global carbon cycle and it influences climate change and is influenced by climate change as well. Thus, improper management or destruction of the forests will have a significant impact on the course of global warming in the 21st century (FAO, 2011).

CHAPTER - 3

SCOPE AND OBJECTIVES

3.1 Scope of the study

Kodagu district is one of the most densely forested districts in the country. It is also known for its forest cover, landscape, sacred groves, coffee, spices, oranges and others. It lies in the Central part of the Western Ghats and has three UNESCO heritage sites located in the district. However, the past few decades has seen a drastic change in the land use land cover pattern of the region. The continued increase in the expansion of coffee plantations and other commercial activities has led to a decrease in the green cover. The private forest covers are being cleared and converted into coffee estates and it has extended even to the fringes of the Protected Areas at higher elevations. Along with coffee estates, there has also been a boom in the tourist sector in the district as a result of which there is a conversion of land into home stays and resorts. Studies have shown that the forest cover has reduced by 30 % (Garcia *et al*., 2007) and coffee plantations occupy 33% of the area of the district (Garcia *et al*., 2009). The anthropogenic activities has led to a decrease in the forest cover from 60% to 45 % which is the minimum required to be preserved in mountain regions according to the National Forest Policy (GoI, 1988).

A number of studies have been carried out to understand the vegetation in the coffee plantations and the sacred groves in the recent past; however the vegetation study in the Protected Areas is limited. Protected areas are important as they are essential for biodiversity management and conservation. Studies on the vegetation composition of the Protected Areas will help in the documentation of species and management of forests and prepare species specific plans for conservation. Hence the present study is aimed to understand the land use and land cover changes in the Protected Areas and the Reserve Forests of Kodagu in the last two decades. It is also aimed to understand the vegetation composition of Brahmagiri Wildlife Sanctuary (BWS) and Pushpagiri Wildlife Sanctuary (PWS) along altitudinal gradients and assess the carbon sequestration potential of montane forests.

3.2 Objectives of the study

The present study has been undertaken to study the following objectives.

Objective 1: Assesing two decadal land use and land cover changes using geo-spatial techniques

Objective 2: Assessing vegetation dynamics across Elevation gradients

Objective 3: Assessing carbon stock in vegetation and soil

Chapter - 4

STUDY AREA

4.1 Physical Features of Kodagu District

Kodagu is a mountainous region located in the Central part of the Western Ghats. It is also commonly known as “Coorg” (name under British rule) and is the second smallest district in Karnataka. The name ‘Kodagu’ is derived from the word ‘Kodimalenad’ which means dense forest land on steep hills. It is also called as the “Scotland of India” which was termed by the British planter community because of the resemblance in landscape and weather between the two places. Kodagu covers an area of 4102 Km^2 and is located in the South Western border of Karnataka State of India and it is divided into three taluks viz., Somvarpet, Madikeri and Virajpet. The district lies between 12°15` to 12°45`N and longitude 75°25` to 76°14` E (Fig 1). The altitude of the district ranges from 850 to 1875 m. The average rainfall is 2725 mm and decreases from West to the East due to hilly terrain. Eighty percent of the rainfall is received from the southwest monsoon from June to the end of September (GoK, 2010). Kodagu has the lowest population of 5,54,519 in the State (Census of India, 2011). Kodagu is bounded by Hassan district in the North, Kerala in the South and Dakhshina Kannada in the West and Mysore in the East. It is located on the leeward side of the Western Ghats and is bordered by the Western Ghats to the West and South. Kodagu is also the origin of the River Cauvery which is one amongst the seven most sacred rivers of the country and also the lifeline of water supply to millions of people living in the Southern part of India. Kodagu is known for its coffee, oranges and spices; it is also popular for its scenic beauty and attracts a large number of tourists.

Kodagu district is a part of the International Model Forest Network since 2003 and is the first model forest program for India. The diversity of the landscape, biological organisms and unique management systems has contributed as the first model forest site. As per Forest Survey of India (FSI, 1995), the net forest area of Kodagu district is 1920 Km^2 of which forest cover is 1770 Km^2. Of the net forest area, 75% is covered with dense to moderately dense forest and 15% is covered with open forest. According to India State of Forest Report (FSI, 2017) Kodagu has lost 189 Km^2 of forest area since 2015. Although there has been an increase in the very dense forest (more than 70% tree cover in a patch of land) which is attributed to the increase in conservation of forest patches and restoration efforts. However, moderately dense (40-70% tree cover in a patch of land) and open forests (10-40% tree cover) has been reduced by over 654 Km^2. The indiscriminate development, conversion to coffee plantations and commercialization of property has led to the decrease in tree cover.

4.2 Forest and Biodiversity

Champion and Seth (1968) classified the vegetation of the Western Ghats into four major types which includes moist tropical forests, dry tropical forests, montane subtropical forests and montane temperate forests. The International Model Forest Network (IMFN, 2003) categorized the forest land in Kodagu into three major types which includes reserve forests, private forests which support a wide variety of vegetation and other forests which include sacred groves, paisaries, uruduves, jamma malaise and coffee saguvali malaise areas.

The Western Ghats is acknowledged as one of the 36 biodiversity hotspots in the world (CEPF, 2016), and is also recognised as a World UNESCO heritage site (UNESCO, 2012). The many diverse kind of vegetation found in the district makes Kodagu one of the micro hotspots of diversity within the larger hotspots of the Western Ghats. It is home to 8 % of India's and 35% of Karnataka's plant resources (Murthy & Yoganarasimhan, 1990). Natural vegetation in these areas spread across several floristic types ranging from wet evergreen forests to dry woodlands and thickets (Pascal, 1988).

Kodagu could be regarded as the hotspot of sacred grove tradition in the world (Kushalappa & Bhagwat, 2001) also referred to as "Devarakaadus" locally (Ambinakudige & Sathish, 2009). Sacred groves are community managed informal conservation sites as the indigenous communities of the district are nature and ancestral worshipers. A survey carried out by the state forest department estimated the presence of 1214 sacred groves covering an area of 2500 ha which is about 2% of the total geographical area of Kodagu. The Kodagu Forest Model has been an active catalyst of the sacred groves revival program with the involvement of the local stakeholders attached to these temple forests (Kushalappa & Raghavendra, 2012).

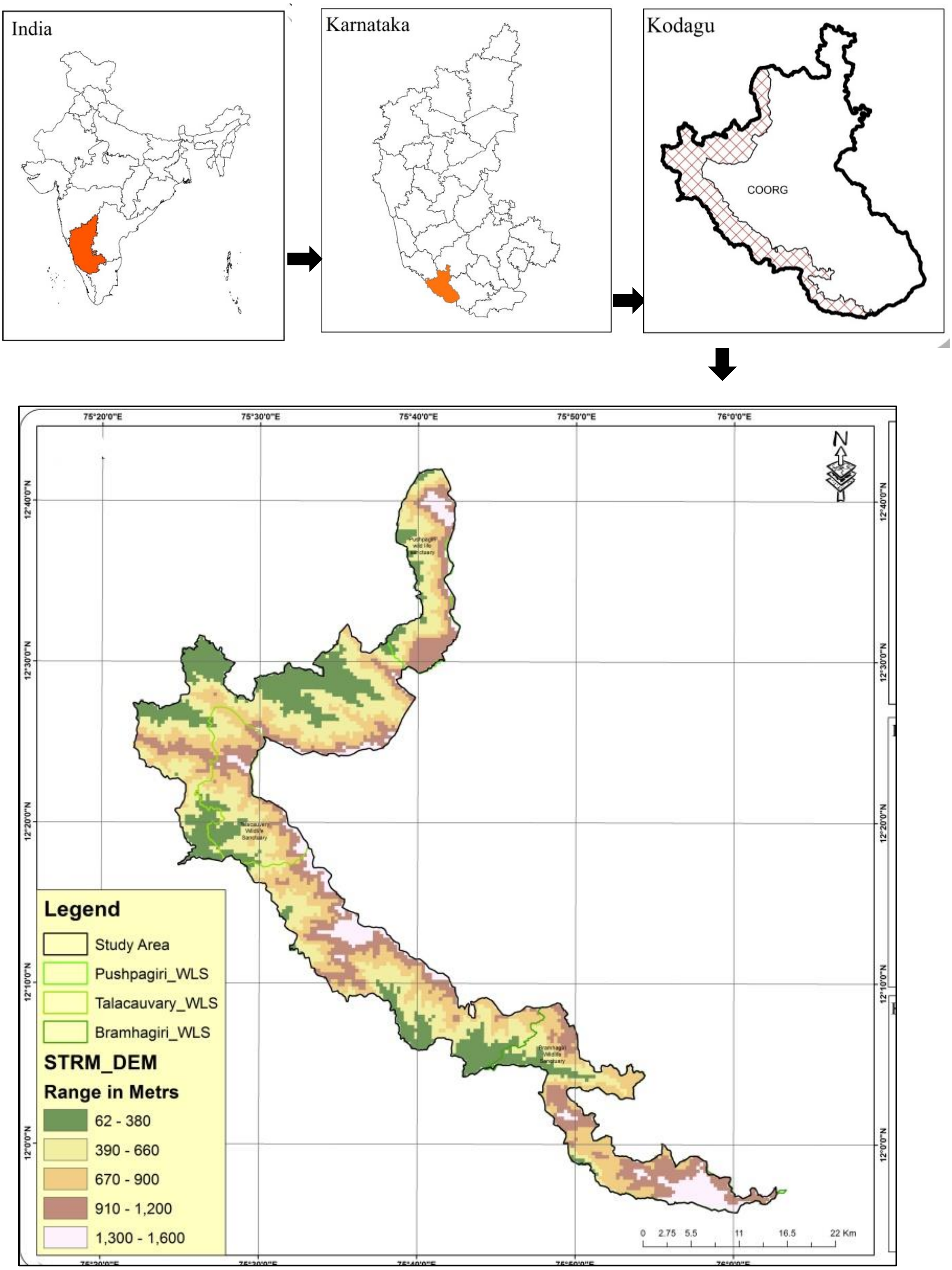


Fig 1. Protected Areas and adjoining Reserve Forests in Kodagu district, Karnataka.

4.3 Protected areas of Kodagu District

Kodagu has three Wildlife Sanctuaries and a National Park viz., Pushpagiri Wildlife Sanctuary, Brahmagiri Wildlife Sanctuary, Talacauvery Wildlife Sanctuary and Rajiv Gandhi National park which is shared with Mysore. All these three Protected Areas were declared as UNESCO sites for conservation (UNESCO, 2012). The vegetation study was carried out in Brahmagiri and Pushpagiri Wildlife Sanctuary. The LULC study included the three wildlife sanctuaries and the adjoining Reserve Forests which acts as corridors for the mammals.

Talacauvery Wildlife Sanctuary

Talacauvery Wildlife Sanctuary is located in Kodagu district between 12°18' to 12°27' N latitude and 75°26' to 75°35' E longitude. The Sanctuary is named after the birth place of river Cauvery that originates inside the Sanctuary. The Sanctuary was carved out of Padinalknad and Pattighat Reserve Forests and was declared as Sanctuary on 31st August 1987 but the final notification was issued on 13th June 1994. The major forest types found in the Sanctuary are Southern Tropical Wet Evergreen Forests, Southern Tropical Semi Evergreen Forests, Southern Hilltop Tropical Evergreen Forests (Sholas) and The South Indian Subtropical Hill Savanna (Grasslands). It is also recognized as one of the most important areas for bird, as 13 out of the 16 endemic birds present in the Western Ghats are found in the Sanctuary (GoK, 2008). The Eco-Sensitive Zone (ESZ) covers an area of 213.07 Km^2 varying from 1 to 16 km around the boundary of the Sanctuary (GoI, 2017a).

Brahmagiri Wildlife Sanctuary

BWS was carved out of two reserve forests namely Brahmagiri Ghat and Urti Reserve Forest and was notified as a Sanctuary in the year 1974. BWS is connected to Talacauvery Wildlife Sanctuary by Kerti Reserve Forest (7904 ha) and Padinalknad Reserve Forest (18.476 ha). It lies between 11^{0}55` 12$^0$ 19`N and 75^{0}44` 76$^0$04`E with a total area of 181.29 Km^2 (Fig 2). The ESZ of the Sanctuary covers an area of 136.60 Km^2 and extends from 1 to 15 Km around the boundary of the Sanctuary (GoI, 2017b). The Sanctuary also acts as an important corridor for elephants to move between Rajiv Gandhi National park and Talacauvery Wildlife Sanctuary in Karnataka and Wayanad and Aralam Sanctuaries in Kerala.

The Sanctuary has a rich diversity of flora and fauna ranging from small insects and rodents to mammoth elephants and birds from tailor bird to the endemic Malabar hornbill. The Sanctuary has an undulating terrain and the altitude varies from 65 to 1507 MSL. The highest peak of the Sanctuary is the Narimale peak at an altitude of 1507 m. The mean rainfall in the Sanctuary ranges from 2500 to 6000 mm. The rivers Laxmanthirtha and Ramthirtha which originates from the Sanctuary form tributaries of the river Cauvery and river Borapole bifurcates Urty Reserve Forest and Brahmagiri Reserve Forest. The main forest types found in the Sanctuary according to Champion and Seth (1968) includes tropical Wet evergreen forests: *Calophyllum apetalum,* Semi Evergreen forests: *Diospyros ebenum, Holigarna arnottiana,* Moist deciduous forests: *Syzigium gardneri, Lagerstroemia lanceolata,* Shola forests: *Calophyllum inophylum* and Grasslands (GoK, 2010).

Brahmagiri Wildlife Sanctuary (BWS) is divided into two wildlife ranges viz., Srimangala wildlife range and Makutta wildlife range. Srimangala wildlife range covers an area of 129.4 Km^2 at $11^o55^`$ to $12^o$ 19\` N and 75^o 44\` to $76^o$ 04\`E. The area has an average rainfall of 4000 to 7000 mm with temperature ranging from 10^o to 34^oC. The types of forest present are Tropical evergreen forests, Tropical semi evergreen forests, Sholas and Grasslands. The soil profile consists of deep loamy soil with varying depth from place to place and also lateritic or lateritic bright red or yellow in colour in some patches. Makutta wildlife range is located between Wayanad district of Kerala on the south and Karnataka district on the north side ranging from 11^o55\` to $12^o$19\`N and 75^o44\` to $76^o$04\`E. The area has an average rainfall of 3000 to 5000 mm. It covers an area of 55 Km^2 and comprises of evergreen forests with grassy patches and sholas at higher elevations (Fig 3).

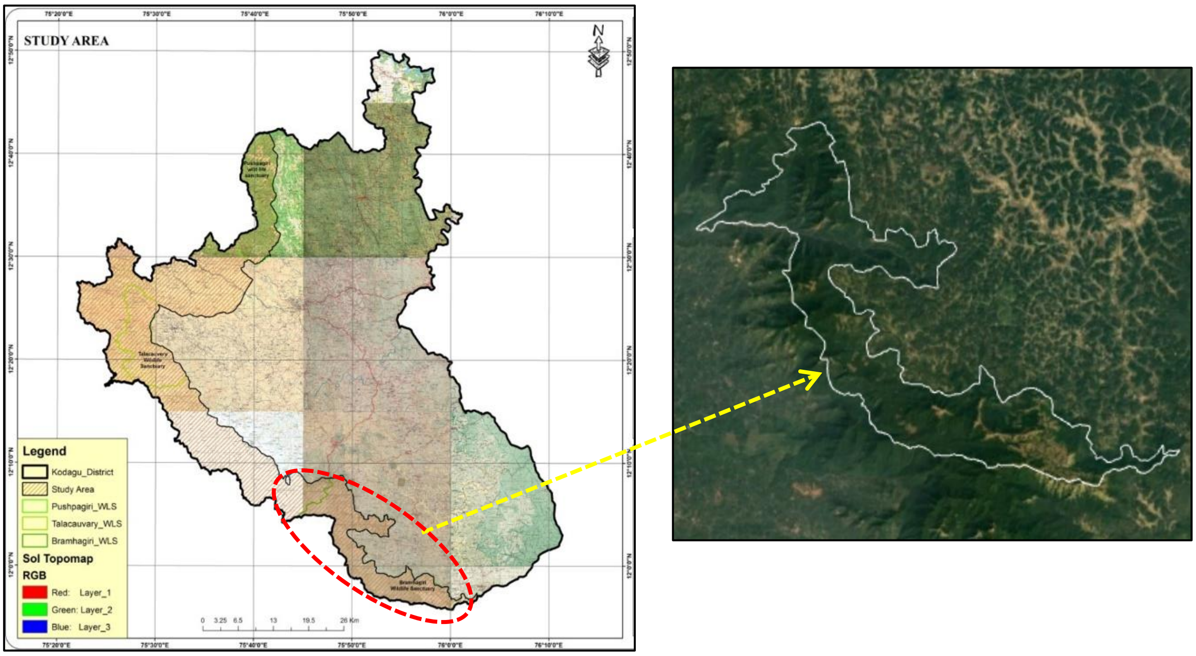


Fig 2. Brahmagiri Wildlife Sanctuary in Kodagu district, Karnataka.

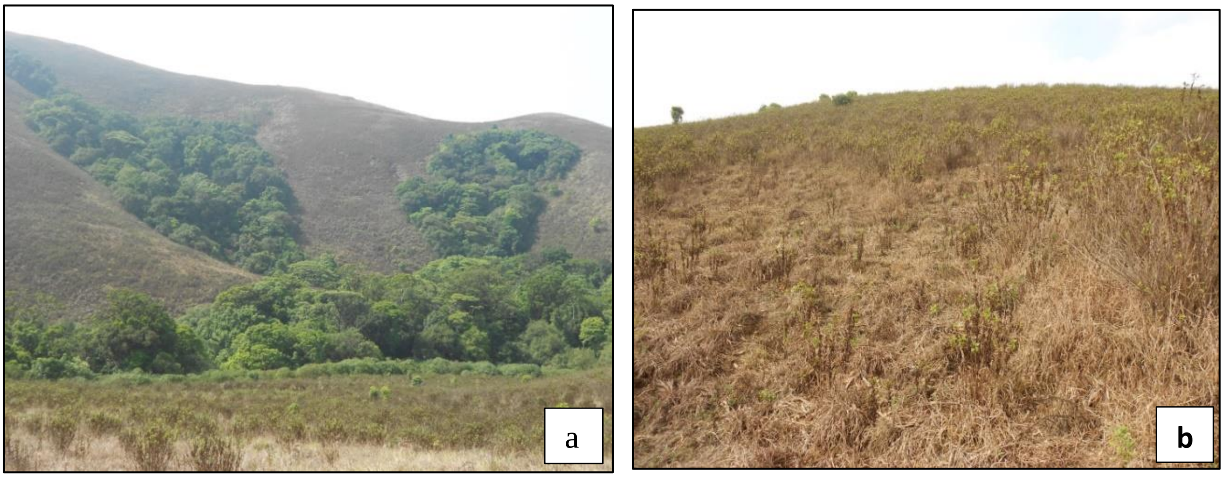


Fig 3. Shola forests (a) and Grassland ecosystem (b) in BWS of Kodagu district, Karnataka.

Pushpagiri Wildlife Sanctuary

Pushpagiri Wildlife Sanctuary was carved out from Kadamakal Reserve Forests and was declared a Sanctuary on 31st August 1987 and the final notification was issued on 13th June 1994. It is named after the birth place of the river Lingadahole that originates from Pushpagiri peak and has been a place of great cultural and religious significance. It covers an area of 102 Km^2 and is located between $12^0 25$\` to $12^0$ 40\` N and 75^0 39\` to $75^0$ 45\`E (Fig 4). The mean annual rainfall ranges from 6000 to 7000 mm with temperature ranging from 10^o to 34^oC. Pushpagiri hill at 1712 m is the highest peak of this Sanctuary. The soil is deep loamy with varying depth and some patches of the soil with lateritic or lateritic bright red or yellow in colour. The climate of the Sanctuary is characterized by long rainy season with very heavy torrential rainfall and strong winds. The ESZ of the Sanctuary covers an area of 199.37 Km^2 varying from 1 to 10 Km around the boundary of the Sanctuary (GoI, 2017c). The Sanctuary has a diverse flora and fauna with many large mammals such as Elephant, Tiger, Leopard, Indian Giant squirrel, Lion tailed Macaque and birds like the endemic Malabar hornbills and other birds like the Grey breasted laughing thrush, Black and Orange flycatcher and Nilgiri flycatcher (GoK, 2008).

The floristic composition of the Pushpagiri Sanctuary as per Champion and Seth (1968) comprises of Southern tropical Wet Evergreen forest, Southern tropical semi-evergreen forest, Southern hill top tropical evergreen forests (Sholas) and South Indian subtropical hill savanna (Grasslands) (Fig 5). As per the classification by Pascal (1988), the following types of tree species are found in the forests and include Plains and low altitude forest type having *Dipterocarpus indicus, Kingiodendron pinnatum, Humboldtia brunonis,* medium altitude forest types having *Mesua ferrea, Palaquium ellipticum* and high altitude types having *Schefflera wallichiana, Meliosma arnottiana, Gordonia obtusa.*

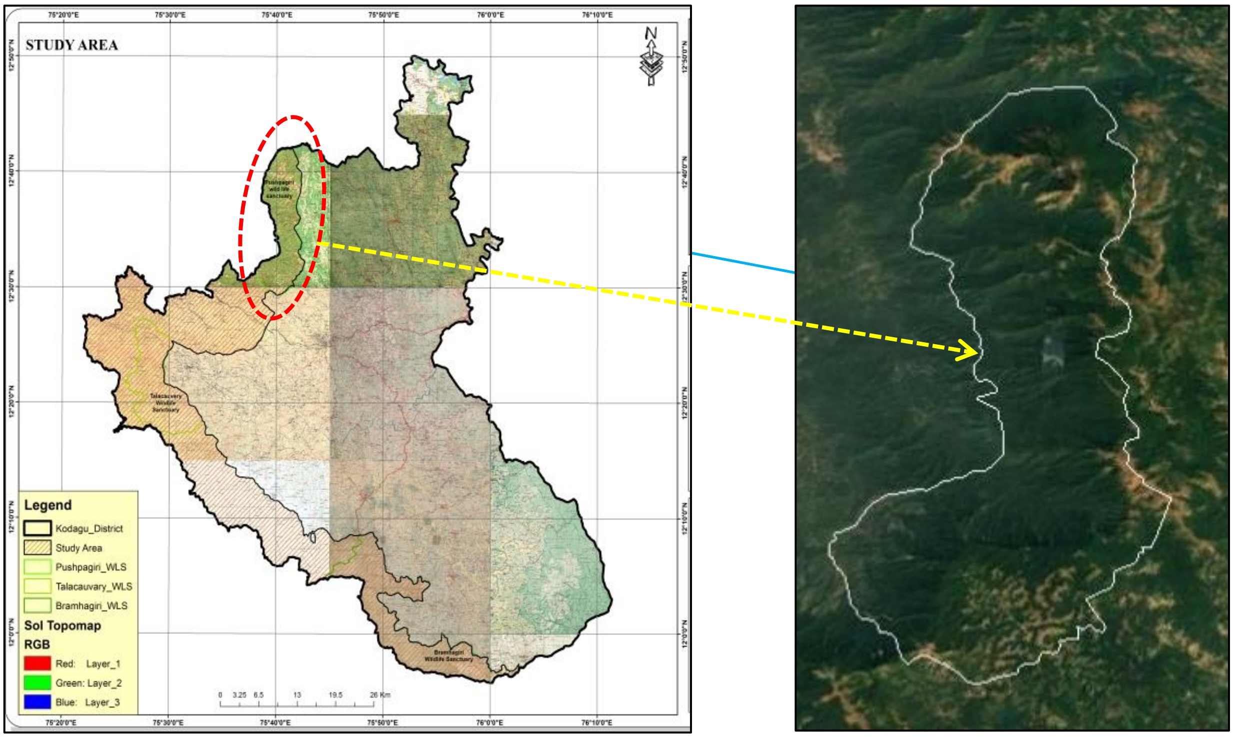


Fig 4. Pushpagiri Wildlife Sanctuary in Kodagu district, Karnataka.

Fig 5. Landscape elements in PWS of Kodagu district, Karnataka.

Chapter - 5

MATERIALS AND METHODS

5.1 Land use Land cover and NDVI

Toposheets for the district of Kodagu were procured from Survey of India (SOI). The toposheets of 1: 50,000 scale were then scanned and georeferenced. Satellite data for 1995, 2005 and 2015 (Landsat TM, IRS P6 LISS III/IV) were procured from Karnataka State Remote Sensing and Application Centre (KSRSAC) Bangalore. Ground truthing was carried out in the selected areas from 2016 to 2018. ERDAS (Version 9.1) and ARC GIS (Version 10.3) were used in the present study. The various land use land cover categories were identified on the basis of standard image interpretation keys such as tone, texture, shape and size (Tomar & Singh, 2012). The steps followed for the geospatial analysis is given in Fig 6.

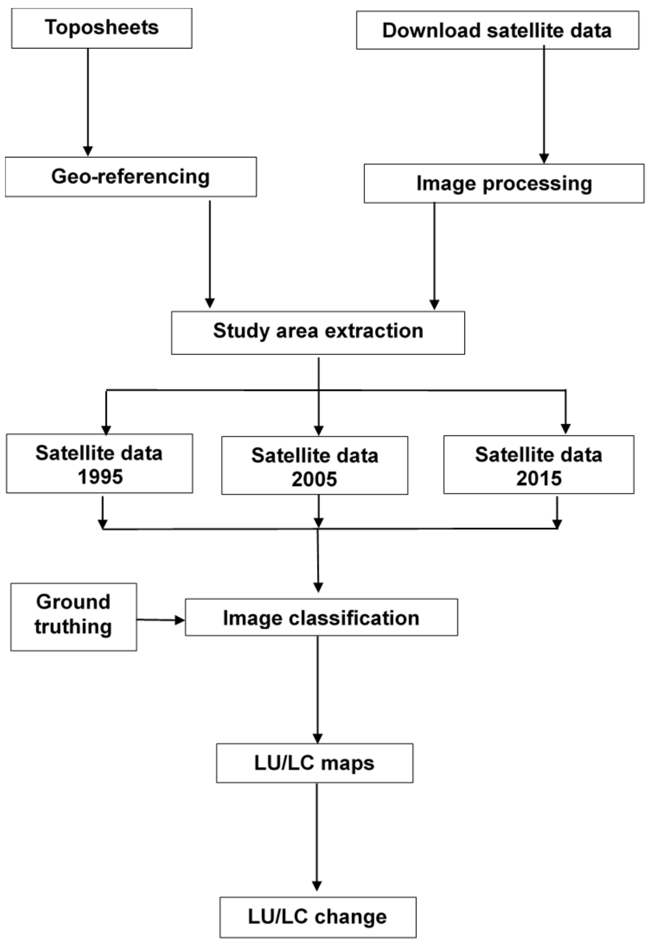


Fig 6. Land Use Land Cover mapping methodology.

NDVI

Vegetation mapping was carried out using the Normalized Difference Vegetation Index (NDVI) for two decades.

NDVI was calculated using the formula

$$\frac{NIR - R}{NIR + R}$$

where, NIR = Near Infrared light, R= Red light

The NDVI value ranges between +1 and -1. Higher NDVI values imply more vegetation coverage, lower values less or non-vegetated coverage and zero indicates rock or bare land (Jin *et al*., 2008; Saravanan *et al*., 2019).

5.2 Vegetation Assessment

A proposal was prepared and submitted to the Forest Department to obtain permission to carry out field work in Protected Areas of Kodagu. The permission was granted from May 2015 - May 2016 and May 2017 - May 2019. Preliminary field works were carried out in Brahmagiri Wildlife Sanctuary in February 2016 and Pushpagiri Wildlife Sanctuary in November 2017. The progress of the work was presented before the Research Advisory Committee in 2017 at the State Forest Department and on satisfactory work extended the permission for another two years. The study was carried between 2015-2018 with 5 visits to Brahmagiri Wildlife Sanctuary and 5 visits to Pushpagiri Wildlife Sanctuary.

Sampling Design

The vegetation composition was assessed using quadrat method following the approach of Misra (1968). The sampling sites in BWS were considered from 100 to 1500 m and in PWS it was considered from 200 to 1700 m. Since the study area was carried out along an altitudinal gradient, quadrats were laid at every 100 m interval as we walked towards the highest elevation point of the Sanctuary. At each elevation, three quadrats of 20 x 20 m plot were laid at 20 m distance from each other using a nylon rope which was already measured to 20 m and tied with a red colour thread for better visualization (Fig 7). Depending on the availability of suitable plots and accessibility in the hilly terrain, the plots were laid accordingly. However in the highest elevation of 1500 m at BWS, only one plot could be laid in the Shola forest as the other Shola patches were not accessible. Therefore, the data from one quadrat sampled at 1500 m was replicated twice for uniformity in the analysis. A total of 93 quadrats were laid in BWS and PWS covering a total area of 3.72 ha out of which 45 quadrats were laid in BWS and 48 quadrats were laid at PWS. In each quadrat, all the trees ≥ 30 cm Girth at Breast Height (GBH) and 1.3 m above the ground were measured with the help of a measuring tape (Fig 8). Latitude and longitude were noted using GPS in each quadrat (Table 1). The height of the tress was estimated visually. For buttressed trees, the measurement of the girth was taken above the buttresses. For trees with multiple stems, the basal area was calculated separately and summed and for trees with multiple stems and connected near the ground, they were counted as a single individual (Ayyapan & Parthasarathy, 1999).

The species were identified with the help of field monographs and local floras (Pascal &Ramesh, 1987; Murthy & Yoganarasimhan, 1990; Neginhal, 2011). For some of the species which could not be identified in the field, photographs were taken and samples were brought and consulted with experts and specimens were cross checked with the herbarium at ATREE (Ashoka Trust for Research in Ecology and the Environment) and GKVK (Gandhi Krishi Vignana Kendra). Tree endemism was recorded by referring published literature for Western Ghats (Ramesh & Pascal, 1997).

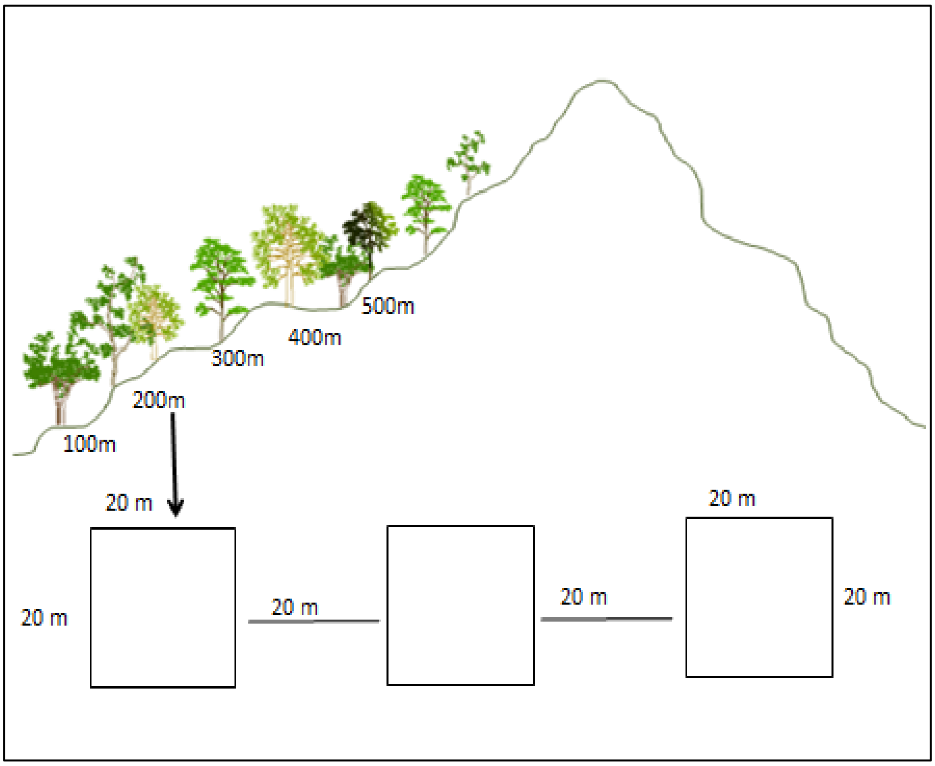


Fig 7. Sampling design for Vegetation assessment across Elevations.

Table 1 : Latitude and Longitude of sampling locations in BWS and PWS of Kodagu district

Sl.No	Elevation (m)	BWS		PWS	
		Latitude	Longitude	Latitude	Longitude
1	100	N 12° 08'68.17"	E 75°75'45.33"	-	-
2	200	N 12°08'67.67"	E 75°76'06.67"	N 12°37' 71.4"	E 75° 38.852"
3	300	N 12° 08'81.00"	E 75°76'27.83"	N 12°37' 69.1"	E 75° 39.172"
4	400	N 12° 09'02.00"	E 75°76'82.84"	N 12°37' 67.7"	E 75° 39.414"
5	500	N 12° 10'74.33"	E75°77'99.50"	N 12°37'67.5"	E 75° 39.577"
6	600	N 12°11'91.50"	E 75°79'38.67"	N 12°37' 55.9"	E 75° 39.665"
7	700	N 12° 12'53.83"	E 75°78'79.33"	N 12°37'43.4"	E 75°40.374"
8	800	N 12° 13'30.33"	E 75°80'11.17"	N 12°37’55.7”	E 75°40. 575”
9	900	N 11° 58'31.1"	E 75°58'98.7"	N 12°37' 68.2"	E 75° 40.809"
10	1000	N 11° 58'13.3"	E 75°58' 87"	N 12°39' 80.0"	E 75° 42.279"
11	1100	N 11° 57'92.5"	E 75°58'81.5"	N 12°39' 56.9"	E 75°42.220"
12	1200	N 11° 57'81.2"	E 75°58'45"	N 12°40' 17.1"	E 75° 41.492"
13	1300	N 11° 57'65.2"	E 75° 58'13.7"	N 12°40' 25.6"	E 75° 41.149"
14	1400	N 11° 57'41.1"	E 75° 57'99.9"	N 12°40' 09.2"	E 75° 41.126"
15	1500	N 11° 55'98.2"	E 75° 59'56.9"	N 12°40' 02.6"	E 75° 40.868"
16	1600	-	-	N 12°39' 92.9"	E 75° 40.947"
17	1700	-	-	N 12°39'70.9"	E 75°41. 204"

Fig 8. Field inventory of trees in Protected Areas of Kodagu District, Karnataka.

Phytosociological Analysis

The data collected from the quadrats were pooled and analyzed to understand the variation in the vegetation dynamics along an elevational gradient for both the Sanctuaries. The vegetation data were analyzed quantitatively and tabulated for Density, Frequency and Abundance following the methods by Curtis and McIntosh (1950).

$$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied}}$$

$$\text{Frequency} = \frac{\text{Total number of quadrats in which the species occured}}{\text{Total number of quadrats studied}} \text{ x } 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats in which the species occured}}$$

Basal area was calculated using the formula

$$\text{Basal area} = \frac{(GBH)^2}{4\pi}$$

where, GBH = Girth at breast height

Importance Value Index (IVI)

It was calculated using the sum of Relative density, Relative frequency, Relative dominance. IVI was developed to express the dominance and ecological success of any species with a single value (Misra, 1968).

$$\text{Relative density (\%)} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} \text{ x } 100$$

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \text{ x } 100$$

$$\text{Relative Dominance (\%)} = \frac{\text{Total Basal area of a species}}{\text{Total Basal area of all species}} \text{ x } 100$$

$$\text{IVI} = \text{Relative frequency (\%)} + \text{Relative density (\%)} + \text{Relative dominance (\%)}$$

Family Importance Value Index (FIV)

It was calculated following Mori *et al*., (1983). It gives a measure of the dominance of a family in a given forest community.

$$\text{FIV} = \text{Relative diversity (\%)} + \text{Relative density (\%)} + \text{Relative dominance (\%)}$$

$$\text{Relative diversity (\%)} = \frac{\text{Number of species in a family}}{\text{Total number of species}} \text{ x } 100$$

Shannon-Wiener Diversity Index (H`)

It was calculated using the formula by Shannon (1948)

$$H` = -\sum(Pi)[\log(Pi)]$$

where, $Pi = \frac{ni}{N}$

(n_i= number of individuals of a species, N = total number of individuals of all species)

Simpson Index of Diversity (D)

It was calculated as per Simpson (1949).

$$D = 1- \Sigma\, Pi^2$$

where, $Pi = \frac{ni}{N}$

(n_i= number of individuals of a species, N = total number of individuals of all species)

Pielou's Evenness Index (E)

The evenness was calculated according to Pielou (1975).

$$E = \frac{H`}{\ln S}$$

where, H` = Shannon wiener index, S = No of species present

Abundance to frequency (A/F) ratio

The A/F for different species was determined by following Whitford (1949). The ratio indicates regular (< 0.025), random (>0.025-0.05), and contagious (> 0.05) distribution pattern.

Sorenson Index of Similarity

It was carried out as per Sorenson (1948).

$$\text{Soresnson Index of Similarity} = \frac{2C}{A + B} \text{ X } 100$$

where, C = number of species common to the two sites
A = total number of species in site A
B = total number of species in site B

Regeneration Assessment

To study the regeneration, five 1 x 1 m sub-quadrat were laid at the four corners and one at the center of the 20 x 20 m quadrat (Fig 9). All the individuals <10cm GBH were considered as seedlings and the individuals ≥10 cm and <30 cm GBH were considered as saplings. The GBH was measured at the collar of the individuals with the help of a Vernier caliper (Fig 10). A total of 450 sub-quadrats were laid in both the sanctuaries with 210 laid out in BWS and 240 in PWS respectively.

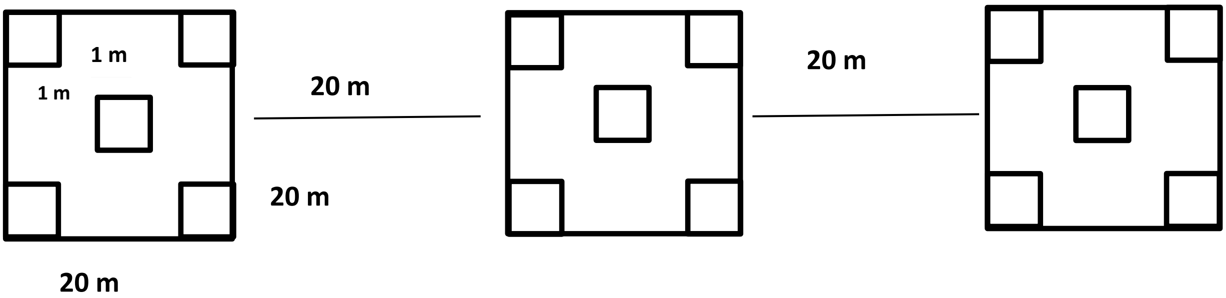


Fig 9. Sampling design for Regeneration assessment.

Fig 10. Inventory of Regeneration in two Protected Areas of Kodagu, Karnataka.

The regeneration of trees was grouped into four regeneration classes (Karthik & Viswanath, 2012; Sathish *et al*., 2013; Hedge *et al*., 2015): Class I: Individuals below 40 cm height, Class II: Individuals between 40 -100 cm height, Class III: Individuals more than 100 cm in height and less than 10 cm GBH and Class IV: Individuals more than 10 cm GBH and less than 30cm GBH.

5.3 Soil sampling and Analysis

A total of 31 soil samples were collected from the forests of BWS and PWS. At each elevational site, soil samples were collected from each of three quadrats. In each quadrat, soil samples were collected at a depth of 0-30 cm from the four corners and one at the centre of the quadrat. The soils collected from the three quadrats in each elevation were then mixed to get a composite sample. The soils were then brought to the laboratory which was sieved (passed through 2 mm sieve), air dried and kept in tight plastic bags for analysis. The bulk density of the soils was calculated based on published data's reported in the Western Ghats (Reddy *et al*., 2012; Ramachandra *et al*., 2012a).

The physical and chemical parameters of the soil were analysed following the manual of soil testing methods in India (GoI, 2011). Chemical soil analysis of the soil samples were carried out at the laboratory following standard procedures. The soil samples were analysed for pH which gives a measure of the acidity, neutrality or the alkalinity of a soil. Soil pH was measured with the help of a digital pH meter. The soil was oven dried and the moisture content in the soil was determined by gravimetric method. Total Nitrogen (N) content was analysed following Kjeldahl method. Phosphorus (P) was analysed following Olsen's method (Olsen, 1954) for alkaline soils and Potassium (K) was analysed following Flame photometric method (Toth & Prince, 1949). The carbon content in the soil was estimated using Walkey and Black method (1934).

5.4 Biomass and Carbon Estimation

Above Ground Biomass (AGB)

Carbon stored by individual trees was estimated using a general allometric equation for tropical forests trees given by Chave *et al*., (2005). The carbon stored per elevation was calculated by summing up the carbon stored by all the trees within each sampled quadrat and expressed per-hectare. The wood density values for biomass calculation was obtained from published literatures in the Western Ghats (Osuri *et al*., 2014), (Udayakumar *et al*., 2016), global wood database (Zanne *et al*., 2009), FAO database (Brown, 1997), tropical trees database (Reyes *et al*., 1992) and World forestry Centre online database. For the species whose wood density values were not available, family-level data mean values was used (Baker *et al*., 2004).

Biomass

$$\text{Biomass (Kg)} = \exp(-2.2997 + \ln(WD \times (DBH)^2 \times H)$$

where, DBH = Diameter at Breast Height (cm), H = tree height (m).

Below Ground Biomass (BGB)

BGB was calculated following the method given by Cairns *et al*., (1997).

$$BGB = \exp(-1.0587 + 0.8836 \times \ln AGB)$$

where, AGB = Above Ground Biomass

Carbon Storage

It is the estimation of CO_2 removed from the atmosphere and stored in the trees. The carbon stored was calculated as 50 percent of the biomass.

$$\text{Carbon storage (C)} = 0.5 \text{ X } B$$

Carbon Sequestration

Carbon sequestration was calculated by multiplying the total carbon value with 3.67 since 1 Kg of carbon is equivalent to approximately 3.67 kg of CO_2 (Pearson *et al*., 2007)

$$\text{Total Carbon (TC)} = AGB + BGB$$

$$\text{Carbon sequestered} = TC \times 3.67$$

where, AGB = Above Ground Biomass , BGB = Below Ground Biomass

Chapter - 6

RESULTS AND DISCUSSION

6.1 Spatio-temporal Analysis

Land use Land cover (LULC) study was carried out in Kodagu district which included three Wildlife Sanctuaries and adjoining Reserve Forests covering an area of 98242 ha. The study was carried over a period of two decades and was analysed using geospatial techniques with level 1 and 2 classification for the LULC categories. The chosen study area represent wildlife corridor which connects Rajiv Gandhi National Park and Nilgiri Biosphere in the south to Kudremukh National park in the North.

LULC maps were prepared with level 1 classification with eight classes for the year 1995 and 16 classes with level 2 classification for the years 2005 and 2015. The analysis of the LULC showed that more than 85 % of the land was under forest cover in all the three years studied although there has been a decrease in the forest cover over the years. The area under forest cover was highest in 1995 with 88.52 %, 86.21 % in 2005 and 85.91 % in 2015 (Table 2). The rural built up area did not show any changes across the two decades with 37 ha in each of the years studied. However there has been a drastic increase in the areas having habitat with vegetation especially for the year 2015. There has also been a gradual increase in the expansion in the agricultural land from 1537 ha in 1995 to 1637 in 2005 and 1763 in 2015. The barren lands decreased from 197 ha in 1995 to 126 ha 2005 and increases to 190 ha in 2015.

LULC study revealed that forest land decreased by 2.31% i.e., 2273 ha of the total land area between 1995-2005 (Table 3). There was also a decrease in wasteland of about 71 ha which accounted for 0.07 % decrease in the total area. The decrease in the land area was accounted for with an increase in agricultural land, tree groves and habitat with vegetation. There were no significant change in the built up areas, grasslands and the water bodies. The LULC of 1995, 2005 and 2015 is given in Fig 11, Fig 12 and Fig 13.

Table 2: LULC of Protected Areas in Kodagu District, Karnataka

Sl.No	LULC categories	Area (ha & %)					
		1995	%	2005	%	2015	%
1	Agricultural land	1537	1.56	1637	1.67	1763	1.79
2	Rural built-up	37	0.04	37	0.04	37	0.04
3	Forest Land	86965	88.52	84692	86.21	84837	86.36
4	Grassland/Grazing land	6489	6.61	6489	6.61	6326	6.44
5	Barren Rocky/Wastelands	197	0.20	126	0.13	190	0.19
6	Water Bodies	682	0.69	682	0.69	679	0.69
7	Habitation with Vegetation	2335	2.38	2352	2.39	3553	3.62
8	Others	-	-	2143	2.18	857	0.87

Table 3: Decadal LULC change from 1995-2005 in the Protected Areas in Kodagu district, Karnataka

Sl.No	LULC categories	Area (ha)		Difference	%
		1995	2005		
1	Agricultural land	1537	1637	100	0.1
2	Built up	37	37	0	0
3	Forest Land	86965	84692	-2273	-2.31
4	Grassland/Grazing land	6489	6489	0	0
5	Barren Rocky/Wastelands	197	126	-71	-0.07
6	Water Bodies	682	682	0	0
7	Habitation with Vegetation	2335	2352	17	0.02
8	Others	0	2227	2227	2.27

The decrease in land area between 2005-2015 was found to be highest for tree groves with 1.39 % i.e., 1362 ha of the total area (Table 4). Land with scrub, grassland and mixed vegetation forest also showed a decrease in the land area whereas areas having habitat with vegetation showed an increase of 1.22 % i.e., 1201 ha. There was also an increase of 126 ha in the agricultural land which consists of agricultural plantation and crop land. There was no change in the moist and dry deciduous forest and rural built up areas.

Table 4. Decadal LULC from 2005-2015 in the Protected Areas in Kodagu district, Karnataka.

Sl.No	LULC categories	Area (ha)			
		2005	2015	Difference	%
1	Agricultural Plantation	1474	1579	105	0.107
2	Barren Rocky / Stony Waste	126	190	64	0.065
3	Crop land	163	184	21	0.021
4	Degraded Forest	392	431	39	0.040
5	Evergreen /Semi evergreen Forest	79177	79252	75	0.076
6	Forest Plantations	3637	3686	49	0.050
7	Grass land / Grazing land	6489	6326	-163	-0.166
8	Habitation with Vegetation	2352	3553	1201	1.222
9	Lake / Tanks	1	0	-1	-0.001
10	Land with scrub	84	76	-8	-0.008
11	Mixed Vegetation	1113	1097	-16	-0.016
12	Moist & Dry Deciduous Forest	10	10	0	0.000
13	River / Stream	681	679	-2	-0.002
14	Rural Built-up	37	37	0	0.000
15	Scrub Forest	363	361	-2	-0.002
16	Tree Groves	2143	781	-1362	-1.386

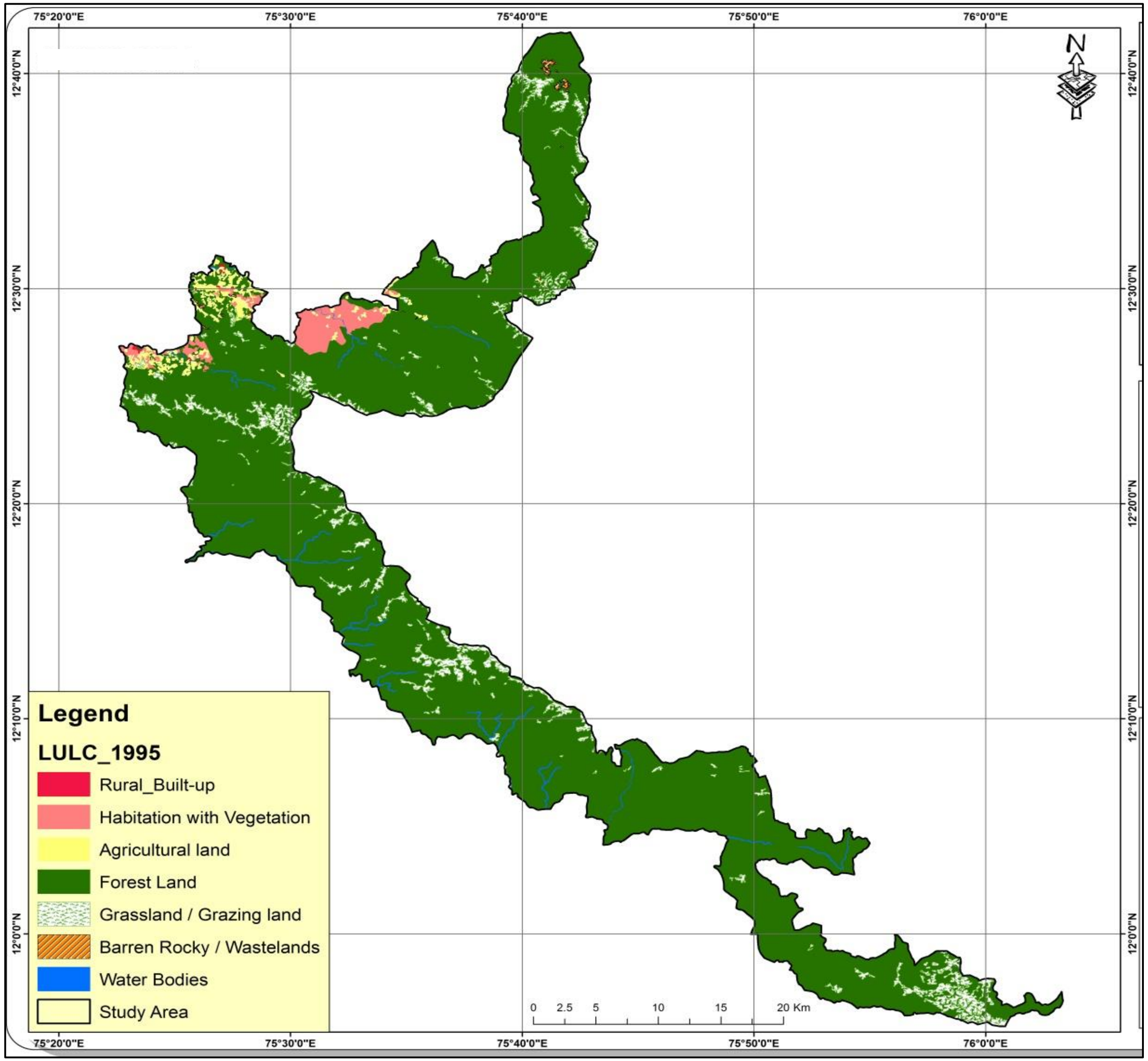


Fig 11. LULC map of Protected Areas for 1995 in Kodagu district, Karnataka.

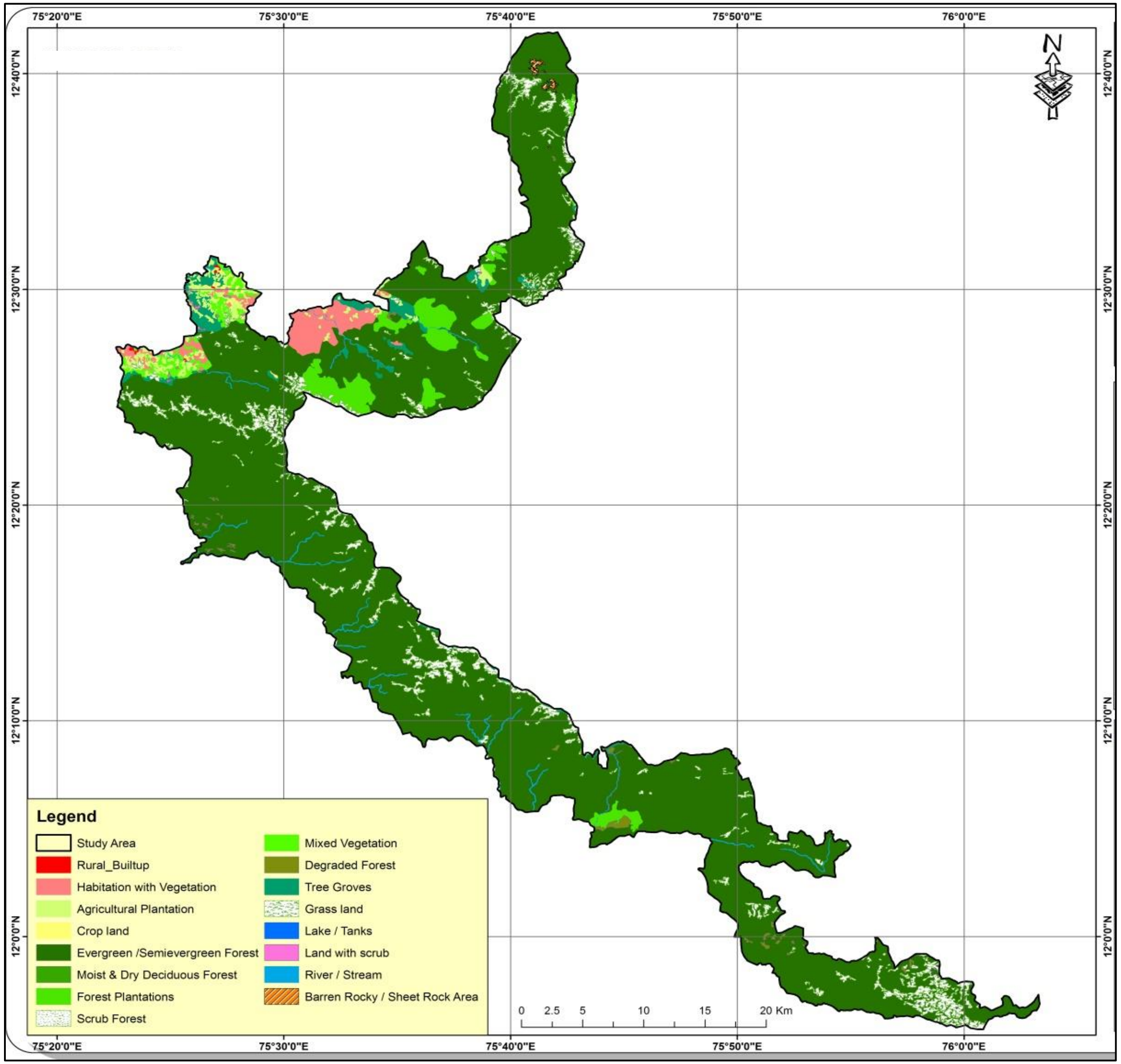


Fig 12. LULC map of Protected Areas for 2005 in Kodagu district, Karnataka.

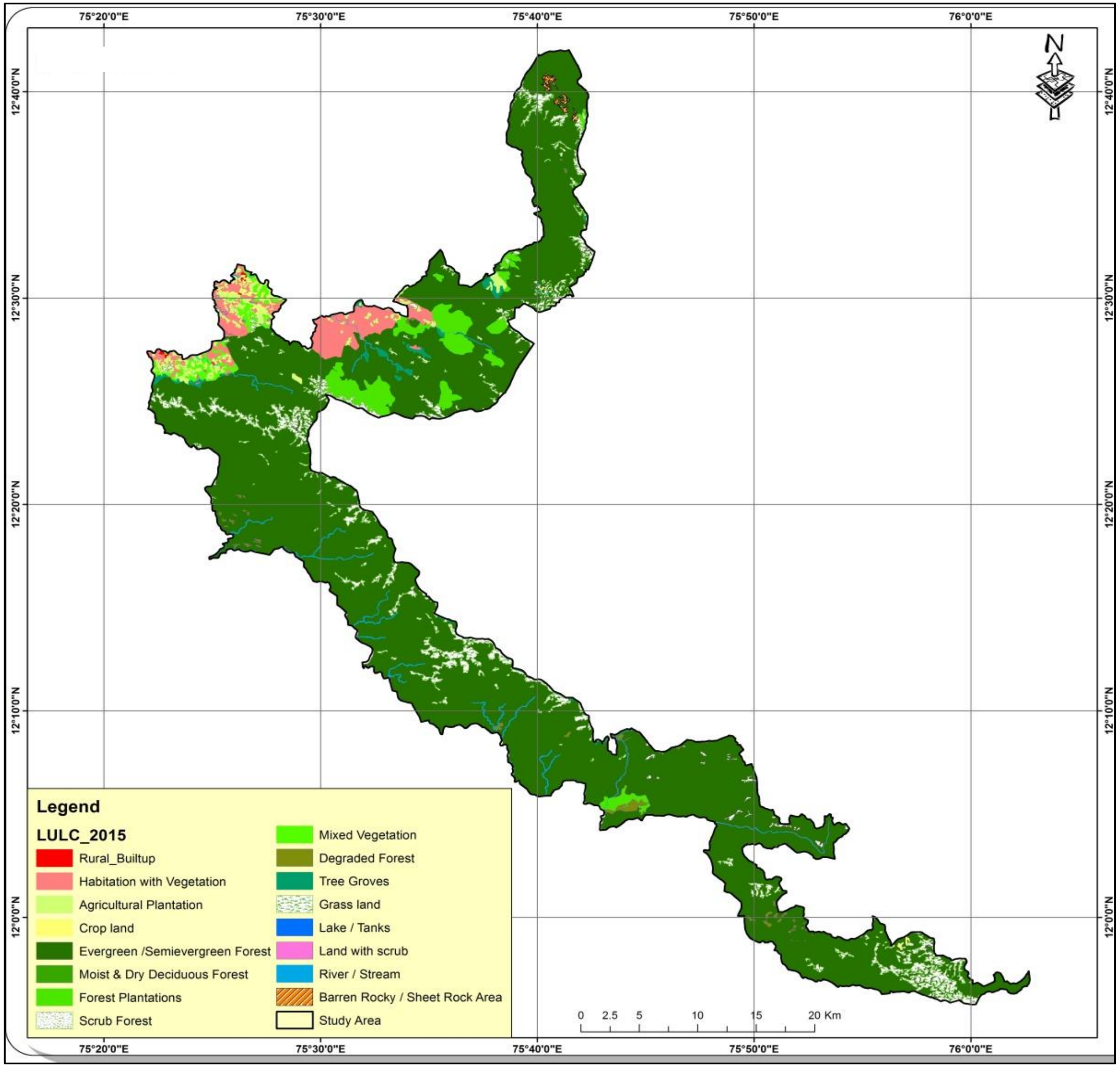


Fig 13. LULC map of Protected Areas for 2015 in Kodagu district, Karnataka.

The decrease in forest cover shows that there have been disturbances in the forest land. The decrease can be due to plantation of fast growing trees in the coffee plantations for timber and also growing spices like pepper which uses the stem of the trees for support. The plantation of native tree species for canopy cover in the coffee plantation have also reduced due to the shift from *Coffea arabica* to *Coffea robusta* due to better management of the species (Raghuramulu, 2006). Studies have shown a decrease in the forest cover in the species rich wet-evergreen forests which has been lost due to the intensification of coffee plantations as a result of which landscape fragmentation, habitat loss and biodiversity depletion are continuing (Garcia *et al*., 2007). There was no increase in the rural built up areas in the past two decades, however there has been an increase in habitat with vegetation which can be due to the conversion of the private forests lands in the fringes of the Protected Areas into coffee estates and homestays. The major cause of encroachment in the district is the expansion of agricultural activity (Kumar *et al*., 2013). The overall LULCC in the Protected Areas and the adjoining forests shows an increase in the habitation around the Protected Areas and also an increase in agricultural plantations. These Protected Areas are important for flora and fauna to grow and live in their natural habitat and are important for biological conservation.

NDVI

NDVI was carried out to study the changes in the vegetation cover over a two decadal period. Landsat TM images with a spectral resolution of 30 m were used. Topographical maps of 1:50000 were used for geometric correction. The NDVI classification was done for three different years viz., 1995, 2005 and 2015 using satellite images downloaded from USGS (United States Geological Survey). The NDVI value in 1995 ranged from 0.14 to 0.65 (Fig 14), 0.35 to 0.7 in 2005 (Fig 15) and 0.23 to 0.60 in 2015 (Fig 16) respectively. The red pixels indicate a decrease in the vegetative reflectance and the green pixels indicate an increase in the vegetative reflectance. The higher values (>0.6) indicates dense vegetation. The results from the NDVI analysis shows that there has been a decrease in the forest cover in the last two decades (Fig.17).

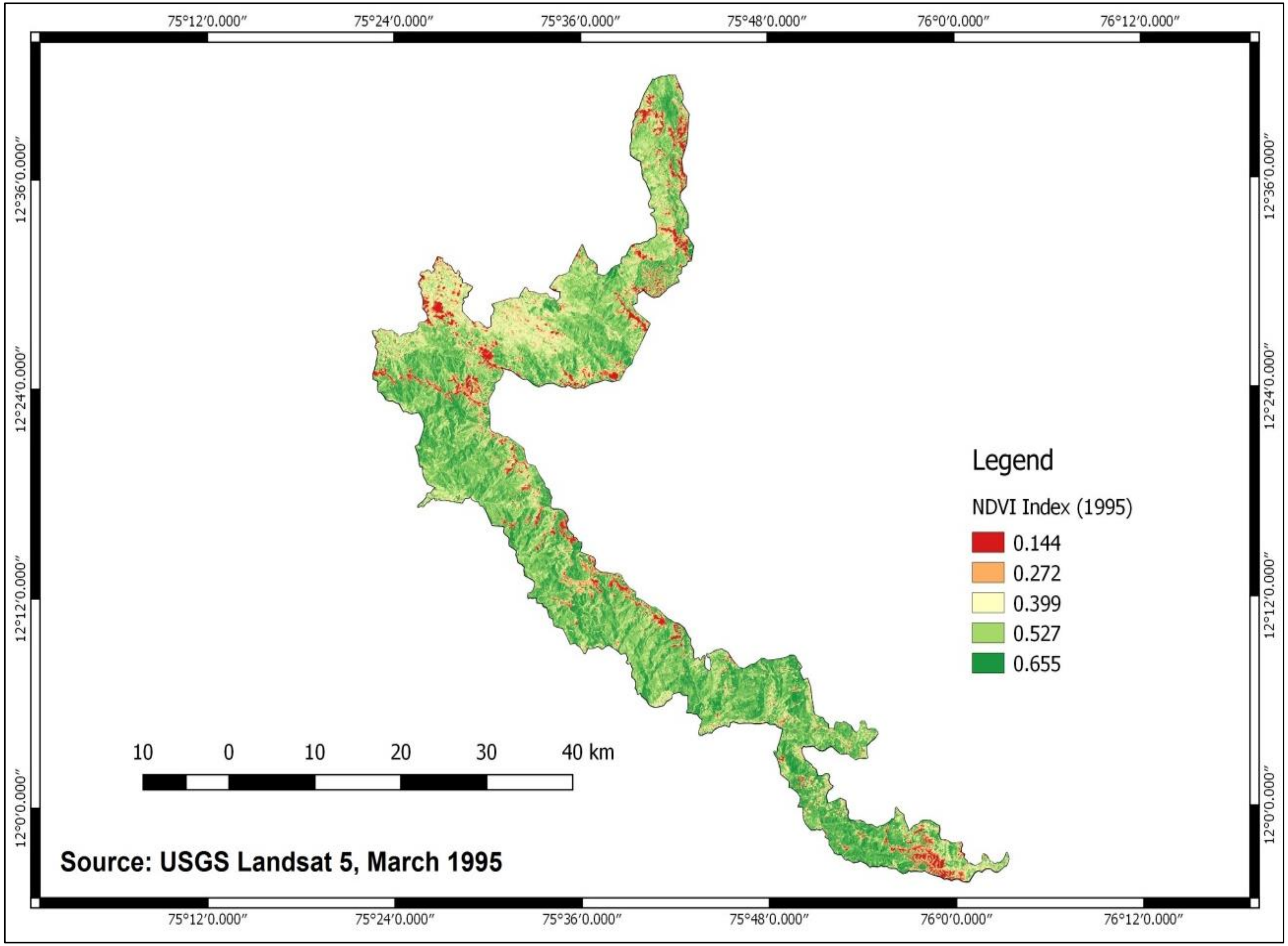


Fig 14: NDVI map of Protected Areas for 1995 in Kodagu district, Karnataka.

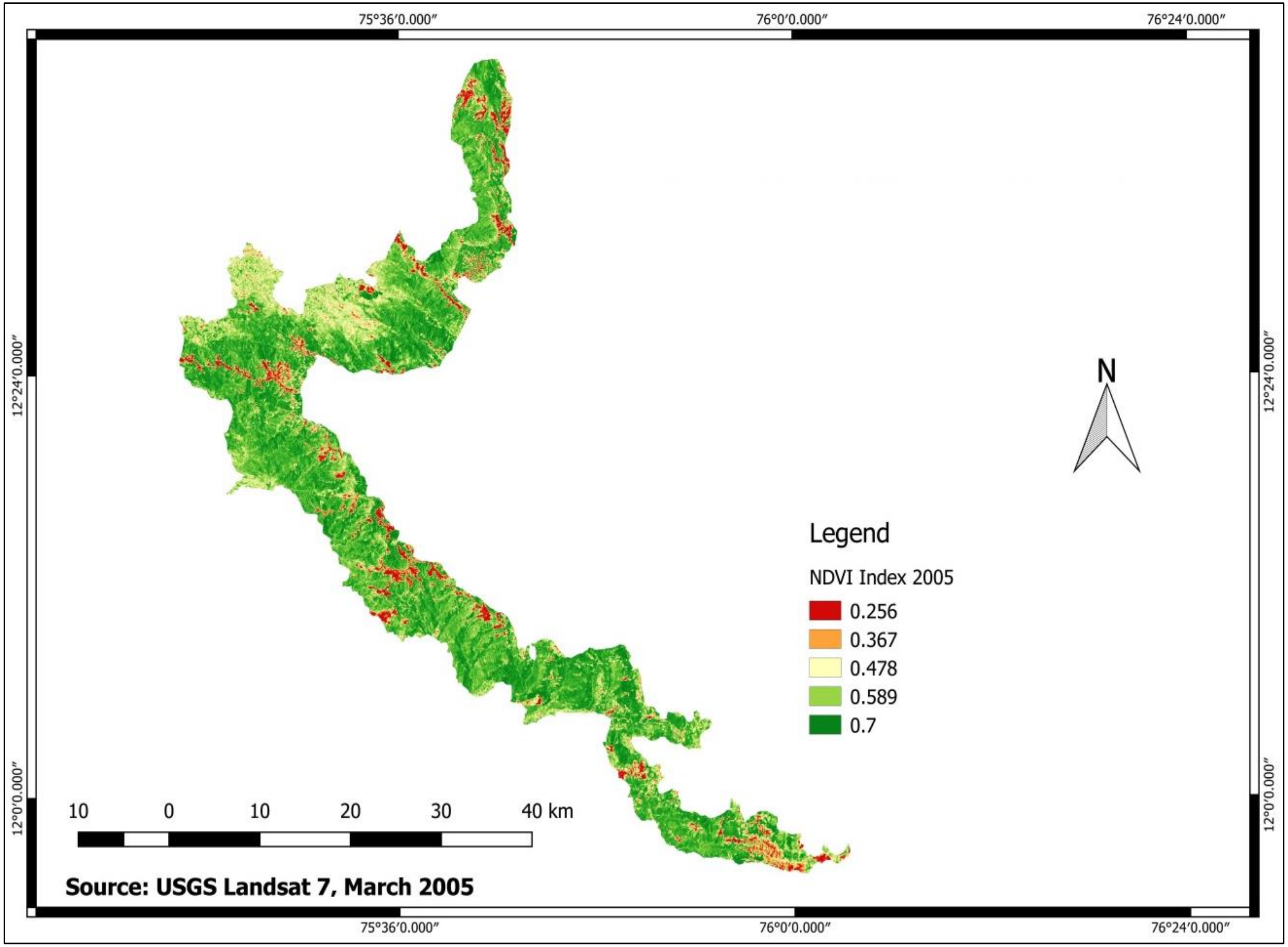


Fig 15: NDVI map of Protected Areas for 2005 in Kodagu district, Karnataka..

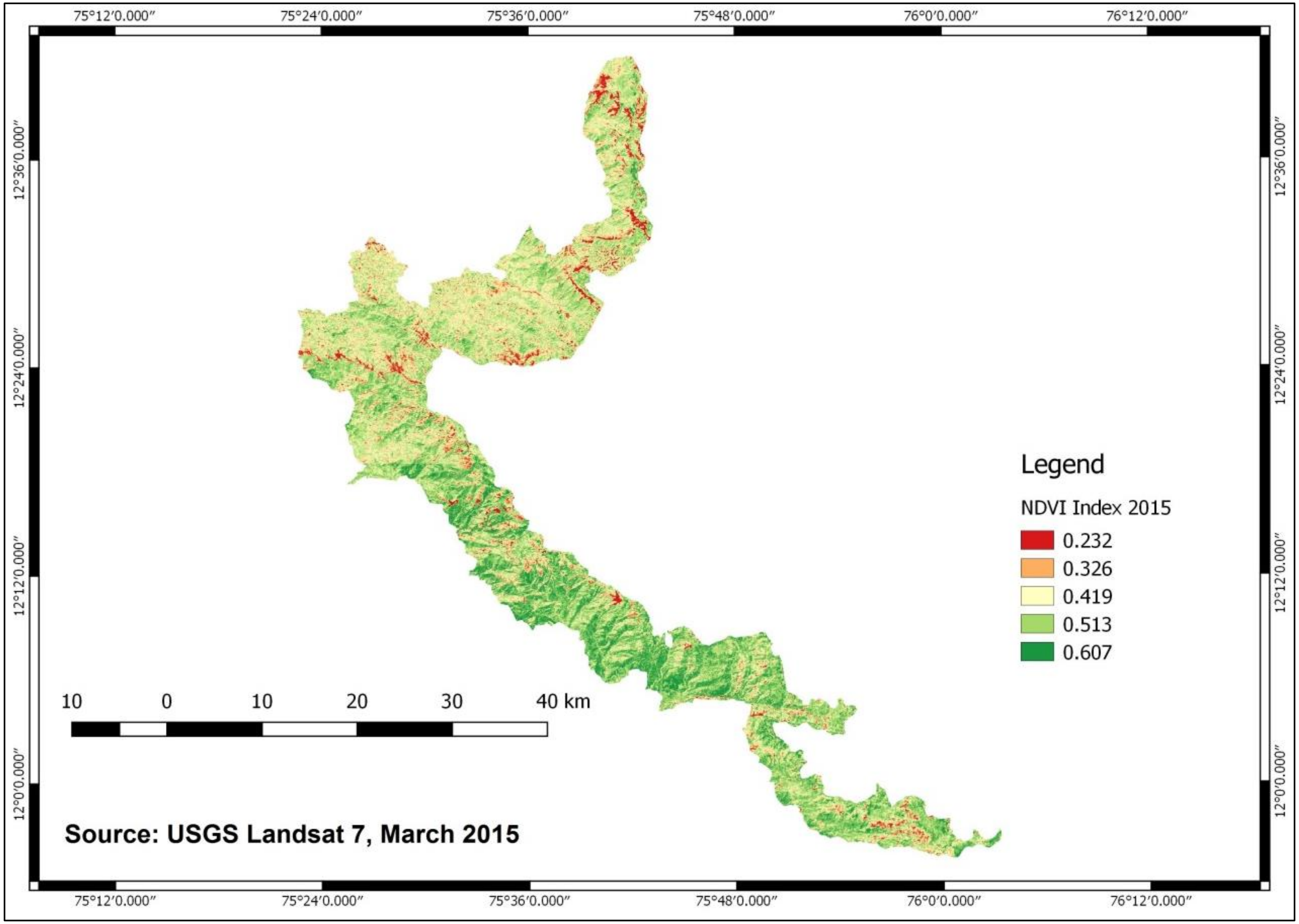


Fig 16: NDVI map of Protected Areas for 2015 in Kodagu district, Karnataka.

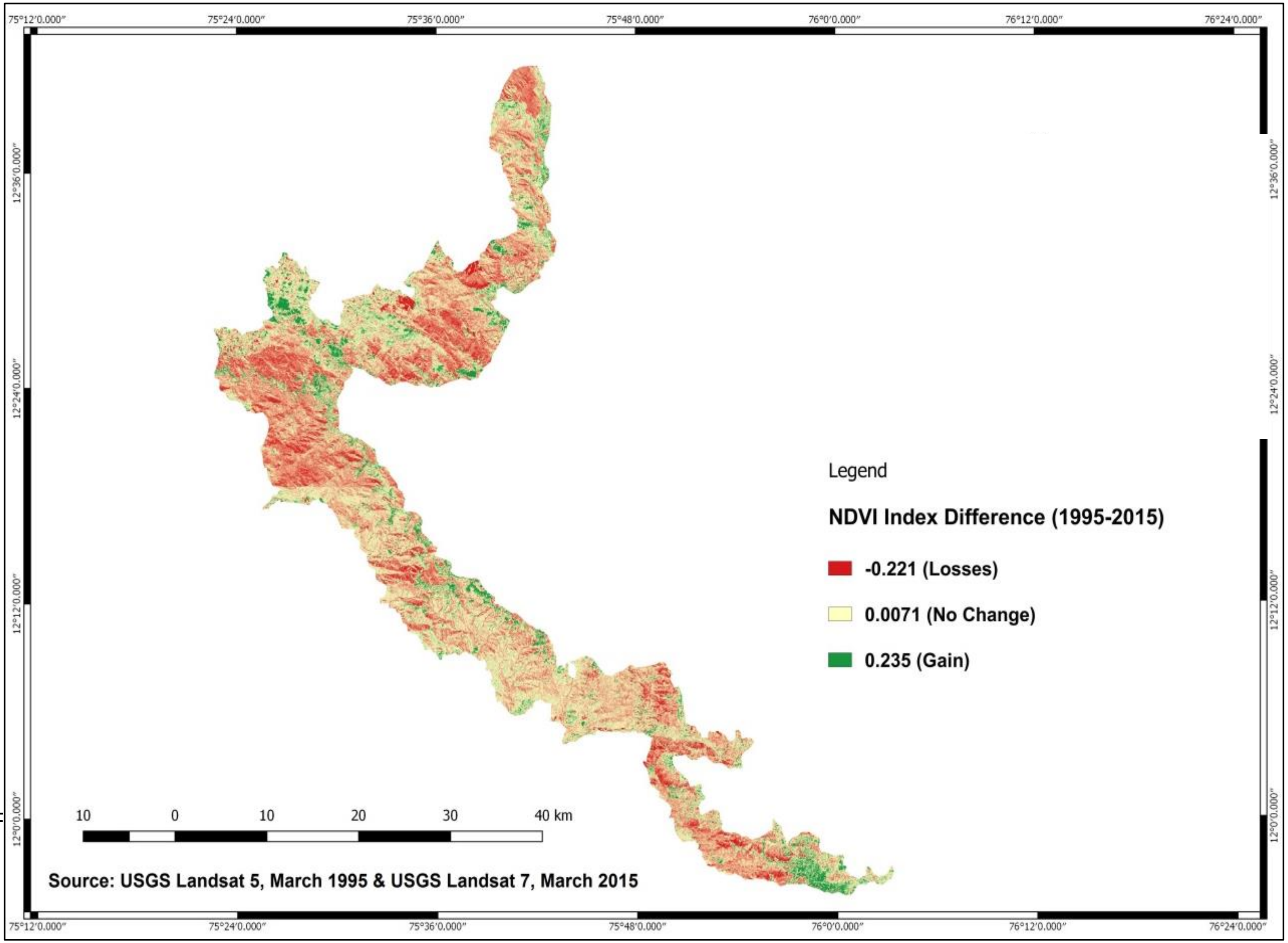


Fig 17: NDVI map of Protected Areas for 1995-2015 in Kodagu district, Karnataka.

The study demonstrated changes in the LULC for three different years, 1995, 2005 and 2015. The image classification and NDVI analysis indicated that the vegetation cover decreased over two decades with the vegetation cover in 1995 being higher compared to 2005 which in turn is higher than 2015. One of the reasons for the decrease in the vegetation can be attributed to the expansion of coffee plantations and habitation to forest areas (Kumar *et al*., 2013; Ambinakudige & Satish, 2009). Kodagu district is known for coffee plantations, cardamom, pepper, oranges as the nature of the soil and the climate suitable for cultivation. Coffee has been the main agricultural crop and source of export for earnings for the last 100 years. However the past decade has seen the use of chemical fertilizers and pesticides, decrease of tree cover and the development of irrigation which has let to environmental degradation such as biodiversity loss, increased human elephant conflict and soil erosion (Aubert *et al*., 2012).There has been an increase in the commercialization of property for setting up homestays, resorts and eco-tourism areas. The forests of the region have also been affected by flooding and landslides in last couple of years and altered the landscape of Kodagu.

6.2 Vegetation Characteristics across two Landscapes

A total of 2758 individuals were recorded in both BWS and PWS of which 1708 individuals belonging to 132 tree species, 95 genera and 46 families were recorded for vegetation study and 1050 individuals belonging to 55 species, and 31 families were recorded for regeneration study.

Vegetation across Elevational Ranges

To understand the distribution of species in different Elevational ranges, the Elevational Gradients of the study area were divided into three ranges viz., Low (100-500m), Mid (600-1000m) and High elevation (1100-1700m) range. The low elevation range for BWS was considered from 100 m and 200 m for PWS. The high elevation range for BWS was up to 1500 m and in PWS, it was till 1700 m. Among the three elevation ranges, the number of species was found to be highest in mid elevation range in BWS and high elevation range in PWS (Table 5). In BWS, *Vepris bilocularis* was dominant in the low elevation range, *Olea dioica* in the mid elevation range and *Ligustrum perrottetii* in the high elevation range. The dominant species in the low elevation was *Knema attenuata*, *Vateria indica* in mid and *Litsea mysorensis* in the high elevation range in PWS.

Table 5: Overall Vegetation Characteristics across Elevation Ranges of BWS and PWS of Kodagu district, Karnataka

		Elevation classes					
Sl.No	**Characteristics**	**Low**		**Mid**		**High**	
		BWS	**PWS**	**BWS**	**PWS**	**BWS**	**PWS**
1.	No. of species	49	35	61	54	36	55
2.	No. of families	28	26	29	23	25	26
3.	Stand density (m^2/ha)	617	423	520	457	337	413
4.	Basal area (m^2/ha)	47.61	15.98	28.42	23.44	17.63	33.37
5.	No. of endemic species	25	16	26	25	11	27
6.	No. of families (Endemic)	16	12	15	16	9	14
7.	Stand density (m^2/ha) (Endemic)	390	175	195	257	132	226
8.	Basal area (m^2/ha) (Endemic)	26.28	6.37	8.18	10.40	7.89	21.71

Common Species

A total of 47 species which accounted to 26.25% of the overall species recorded was found to be common between the two landscapes. Species such as *Olea dioica* and *Dimocarpus longan* was found to be common between the two landscapes (Fig 18). The number of common families was 46 which comprised of 48.42% of the total number of families recorded. In BWS, the most common species across the elevations is *Olea dioica* which was recorded in 9 elevational gradients followed by *Cinnamomum riparium, Dimocarpus longan, Garcinia gummi-guttta, Myristica malabarica* and *Vepris bilocularis* which was found to be common in 7 of the 15 elevational gradients. This indicates that these species adaptability range is very high compared to other species in the region. Out of the 16 elevational gradients in PWS, *Holigarna arnottiana* and *Persea macrantha* were found to be common in 10 elevational gradients and *Dimocarpus longan* and *Myristica malabarica* was found to be common in 9 of the elevational gradients. None of the species occurred across the elevational gradients in both the sanctuaries indicating that altitude plays a key factor in species distribution.

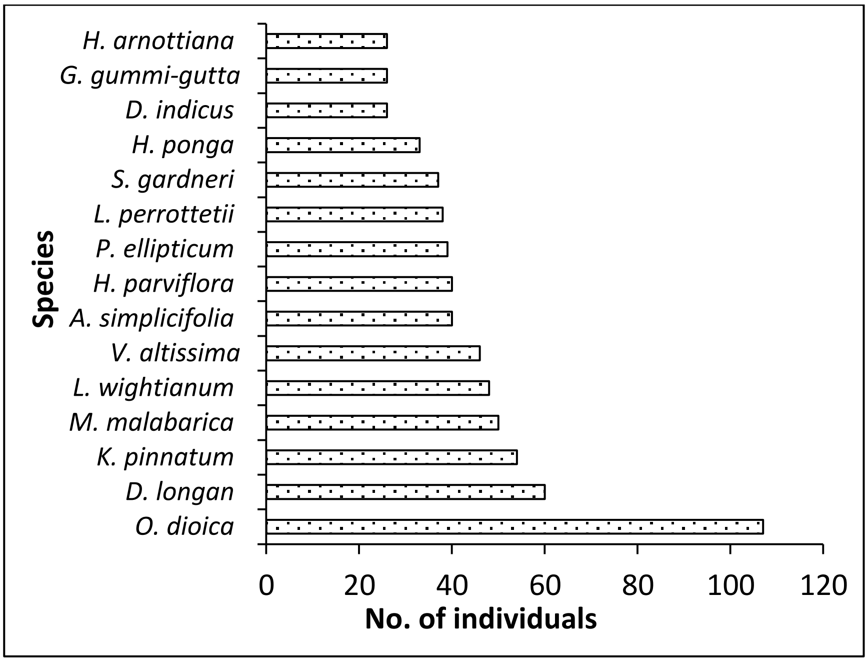


Fig 18. Density of top 15 species in BWS and PWS of Kodagu district, Karnataka.

Species Composition and Species Area Curve

In BWS, a total of 884 individuals belonging to 94 tree species, 83 genera and 39 families respectively were recorded from 100 m to 1500 m with 39 tree species endemic to the Western Ghats (Appendix 1). In PWS, 824 individual belonging to 85 species, 64 genera and 37 families respectively were recorded from 200 m to 1700 m with 36 species endemic to the Western Ghats (Appendix 2). Species richness varied along the elevational gradients and ranged from 3 to 27 species in BWS and 8 to 22 species in PWS respectively. The maximum species richness occurred at 400 m with 27 species in BWS and 22 species each at 700 m and 1000m in PWS. The minimum species richness occurred at 1500 m with 3 species in BWS and at 1700 m with 8 species in PWS respectively. The relation between species richness and elevation showed a negative correlation both in BWS and PWS with a decrease in species richness with elevation (Fig 19).

The number of species recorded from the two landscapes in the present study is comparable with the number of species recorded in other areas of the Western Ghats (Ganesh *et al*., 1996; Kadavul & Parthasarathy, 1999; Parthasarathy, 2001). The decrease in tree diversity with increased altitude is a general trend found in tropical forests (Vazquez & Givnish, 1998; Srinivas & Parthasarathy, 2000; Rana & Gairola, 2009). The distribution pattern of the species varied along the elevational gradients with a peak in the middle elevations, it is comparable with studies from the Eastern Himalaya (Manish *et al*., 2017) and Western

Himalaya (Oommen & Shanker, 2005). The variation in species richness pattern of trees can be due to a variety of factors such as altitude, climate (Ganesh *et al*., 1996; Sharma *et al*., 2009; Bunyan *et al*., 2015), age structure of forest types, level of anthropogenic pressure (Parthasarathy 2001; Dar & Sundarapandin, 2016), slope (Eilu & Obua, 2005), disturbance gradients and vegetation characteristics (Kunwar & Sharma, 2004).

The forests were characterized by multi-storeyed trees, lianas and shrubs which exhibited very diverse vegetation. The grassland areas of BWS were colonized by *Ageratina adenophora* and the higher elevations in PWS was colonized by *Strobilanthes kunthiana* in PWS (Fig 20).

The species area curve for both the sanctuaries showed an increase in the number of species as area increased. In BWS, species area curve started to reach an asymptote only at 1500 m. In PWS, the curve did not reach an asymptote even at the highest elevational site i.e., 1700 m (Fig 21) indicating that the area studied was not sufficient to sample all the species in the Sanctuary.

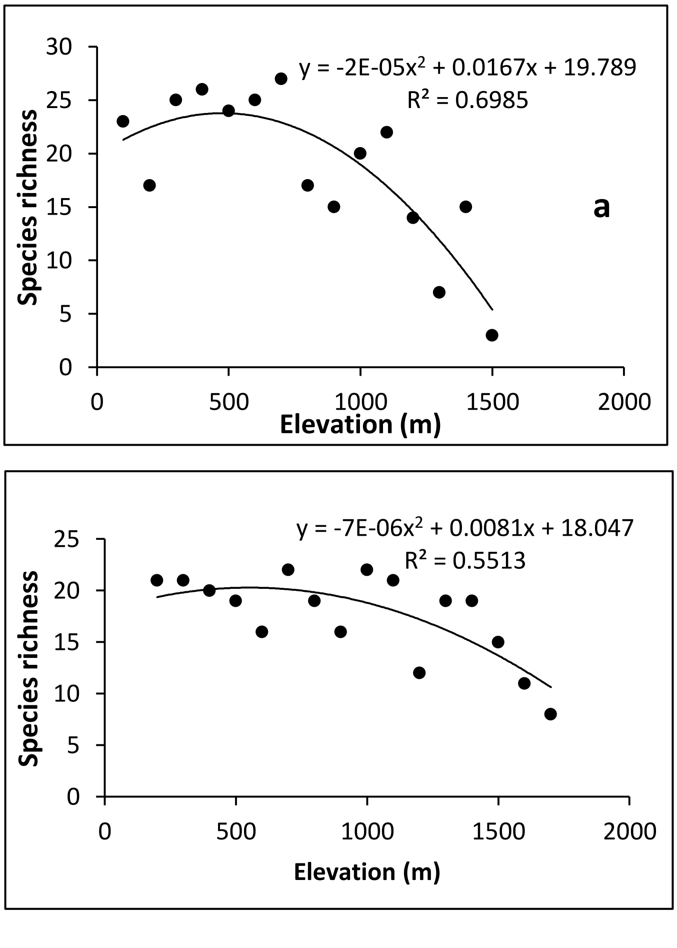


Fig 19. Species richness across elevations of BWS(a) and PWS (b) in Kodagu district, Karnataka.

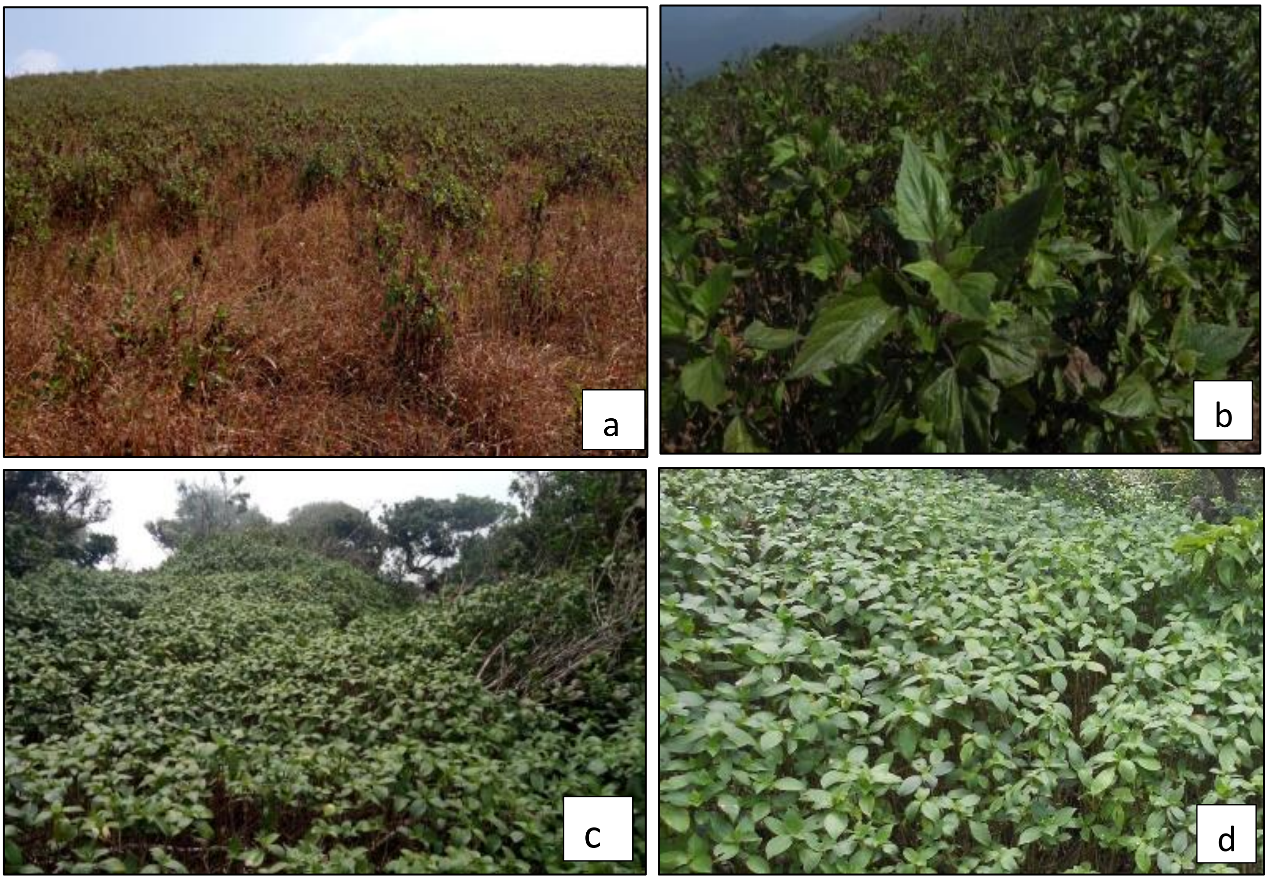


Fig 20: *Ageratina adenophora* in the Grasslands of BWS (a & b) *Strobilanthes kunthiana* in the higher elevations of PWS (c & d) Kodagu district, Karnataka.

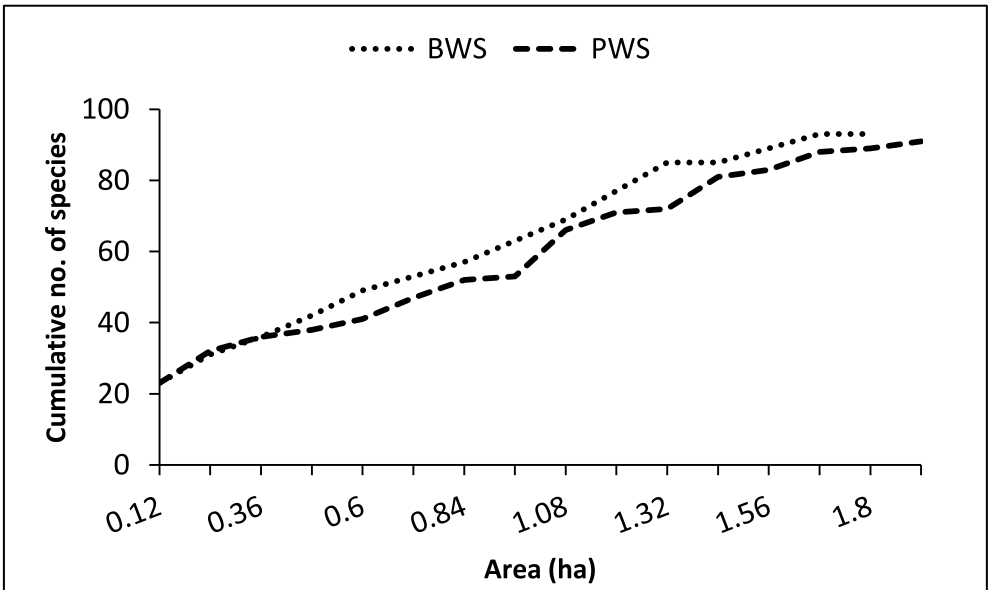


Fig 21. Species area curve of BWS and PWS in Kodagu district, Karnataka.

Stand Density and Basal Area

The overall stand density of the trees in BWS and PWS ranged from 192 to 850 trees/ha along the elevational gradients. In BWS, the stand density ranged from 192 to 850 trees/ha along the elevational gradients with a mean stand density of 491 trees/ha. The maximum stand density was recorded at 600 m with 850 trees/ha followed by 300 m with 725 trees/ha and the lowest stand density was found at 1300 m with 192 trees/ha whereas in PWS, the stand density in the sites varied from 250 to 667 trees/ha with a mean stand density of 429. The stand density was highest at 1200 m with 667 trees/ha followed by 567 trees/ha at 1300 m and 550 trees/ha at 600 m and the lowest stand density was at 1700 m with 250 trees/ha respectively (Fig 22). The stand density was higher in BWS than in PWS as there was more number of individuals recorded in BWS although PWS had more number of elevational gradients for study.

The mean tree density was estimated at 491±51.92 trees/ha in BWS and 429±27.68 trees/ha in PWS which is higher than the evergreen and semi-evergreen forest of the Western Ghats (Utkarsh *et al*., 1998), but lower than the undisturbed forests of tropical wet evergreen forest of Western Ghats (Chandrashekara & Ramakrishnan, 1994; Parthasarathy, 1999), Semi-evergreen forest of the Eastern Ghats (Kadavul & Parthasarathy, 1999) and the Eastern Himalaya (Acharya *et al.*, 2011).

The total basal area ranged between 5.83 to 113.18 m^2/ha in the elevational gradients of the Wildlife Sanctuaries. The basal area was found to be higher in BWS along the elevational gradients and it ranged from 11.18 m^2/ha to 113.18 m^2/ha with a mean basal area of 51.40±7.91 m^2/ha. The basal area was highest at 500 m with 113.18 m^2/ha and 1500 m with 11.18 m^2/ha had the lowest basal area. *Hopea parviflora* contributed the highest basal area with 8.55 m^2/ha followed by *Lophopetalum wightianum* with 5.57 m^2/ha (Fig 23a) and *Bridelia retusa* with 0.007 m^2/ha had the lowest basal area. The basal area in PWS ranged between 5.83 and 110 m^2/ha and had a mean basal area of 38.12 m^2 /ha. The basal area was highest at 1200 m with 110 m^2/ha, it can be attributed to the presence of the species *Palaquium ellipticum* at 1200 m with a large girth size of 5.8 m. *Palaqium ellipticum* was predominant in this elevation with 20 individuals and contributed to 10.93 m^2/ha of the basal area followed by *Ficus nervosa* with 5.43 m^2/ha (Fig 23b). *Cinnamomum sulphuratum* contributed to 0.007 m^2/ha out of the total 21.91 m^2/ha at 400 m in the lowest basal area.

The basal area in BWS showed a negative correlation with elevation however there was no relation between basal area with elevation in PWS (Fig 24).

Pascal (1988) reported that of all the evergreen forests types in India, the southern wet evergreen forest of medium elevation dominated by *Palaquium ellipticum* was best conserved as it was located in regions not easily accessible. The mean basal area of 52±7.92 m^2/ha in BWS and 38±7.31 m^2/ha in PWS is comparable with studies done in the evergreen and semi-evergreen forests of the Western Ghats (Joseph *et al*., 2012), Eastern Ghats (Reddy & Ugle, 2008) and the Western Himalayas (Gairola *et al*., 2011). It is higher compared to Dawkins (1959) where the average basal area for tropical lowland evergreen forest was estimated at 36 m^2/ha. The decrease in basal area with elevation can be due to decrease in girth size and height of trees with elevation, change in climatic conditions and edaphic factors with elevation which hinder the growth of trees. It may also be due to species composition, age of trees, extent of disturbances, successional strategies of the stands (Naidu & Kumar, 2016) and difference in the sampling size (Jayakumar & Nair, 2013).

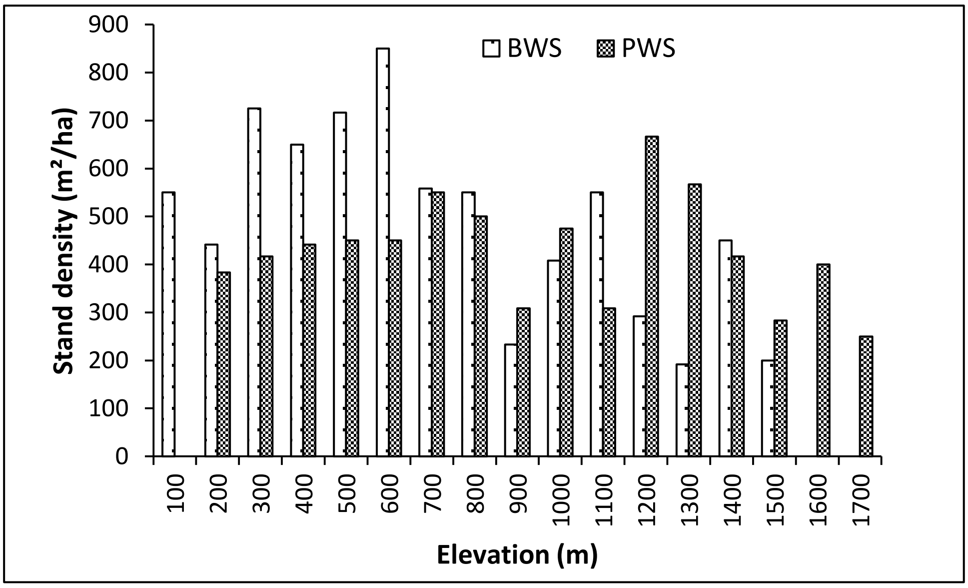


Fig 22. Stand density across Elevational Gradients of BWS and PWS of Kodagu district, Karnataka.

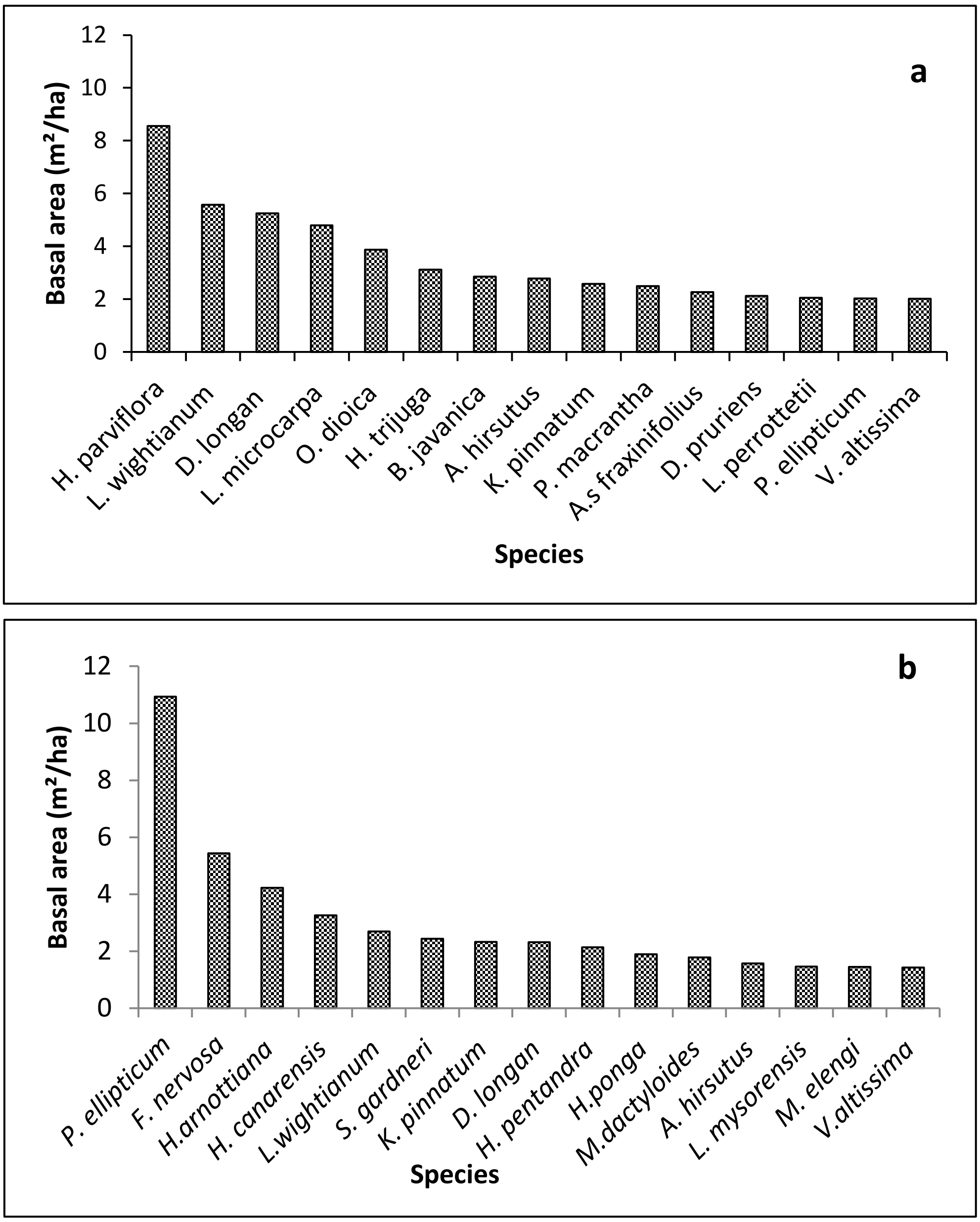
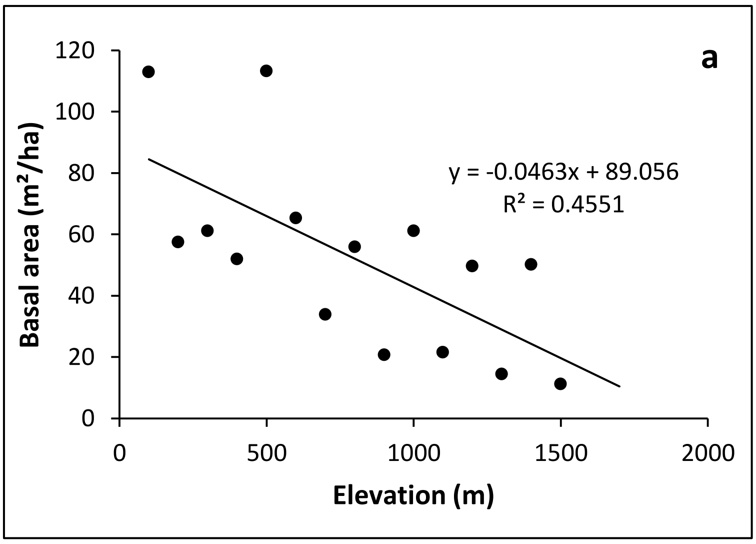


Fig 23. Basal area of the top 15 species in BWS (a) and PWS (b) in Kodagu district, Karnataka.



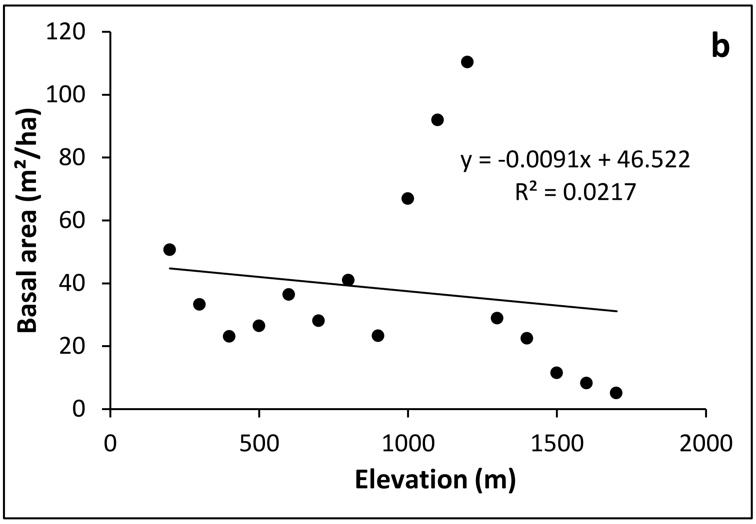


Fig 24: Basal area across Elevational gradients of BWS (a) and PWS (b) in Kodagu district, Karnataka.

Species Diversity

The Shannon Wiener Diversity Index (H`) varied between 0.74 - 3 in BWS and PWS. The diversity index calculated for BWS varied between 0.74 - 3 and the highest species diversity was recorded at 400 m (3.00). In PWS the index varied from 1.80 to 2.86 and 1100 m (2.86) recorded the highest species diversity. The lowest species diversity was recorded at 1500 m (0.74) and 1700 m (1.80) in BWS and PWS respectively. The Shannon-Wiener index showed a negative correlation with elevation for both the Sanctuaries (Fig 25). The species diversity (H`) of 3.00 in BWS and 2.86 in PWS is comparable with values from other forest areas of the Western Ghats (Varghese & Menon, 1998; Ayyapan & Parthasarathy, 1999; Joseph *et al*., 2012; Jayakumar & Nair, 2013) but lower than the tropical rainforest of Malaysia (Suratman, 2012).

The Simpson's Diversity Index (D) takes into account the number of species present as well as the relative abundance of each species. The Index varied between 0.42 - 0.95 in BWS and 0.81 - 0.93 in PWS. The index was highest at 100 m, 400 m, 500 m and 1000 m with 0.95 each and it was lowest at 1500 m with 0.42 in BWS. In PWS it was highest at 200 m and 1100 m with 0.93 each and lowest at 1700 m with 0.81. There was no significant relationship between elevation and Simpson' diversity index in both BWS and PWS (Fig 26).

Pielou's Evenness Index (E) was used to understand how evenly the species were distributed across the elevational gradients in two landscapes. The index ranges between 0 and 1 with the value closer to 1 having more evenness in distribution. The evenness index varied between 0.67 - 0.95. In BWS, the species evenness was highest at 1000 m (0.95) and lowest at 1500 m (0.67) and in PWS, the evenness was highest at 900 and 1100 m with a value of 0.94 and lowest at 700 m with 0.83. There was no significant correlation between Pielou's evenness index with elevation both in BWS and PWS (Fig 27).

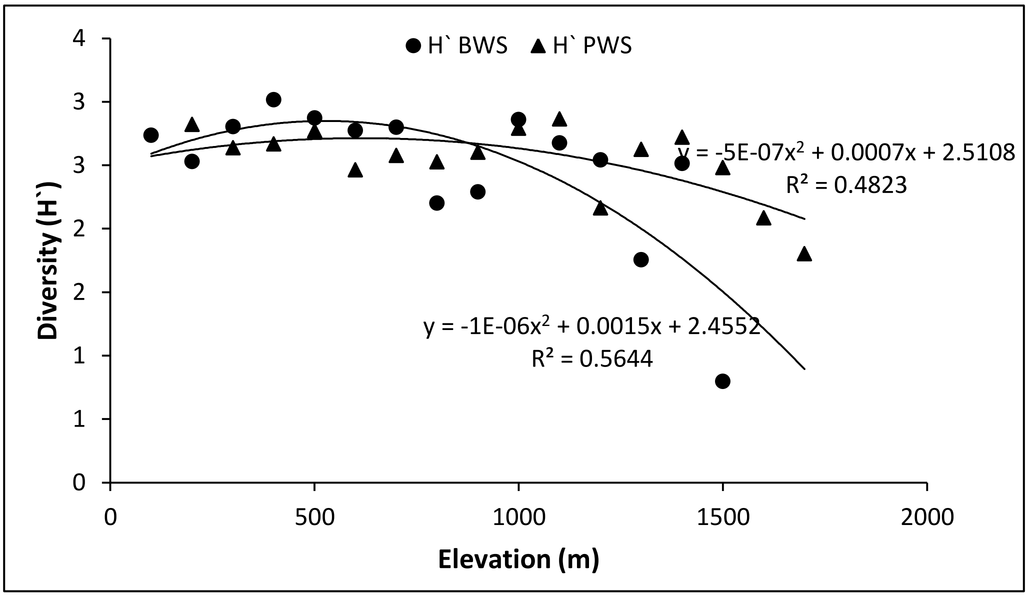


Fig 25. Species diversity Index across Elevational Gradients of BWS and PWS in Kodagu district. Karnataka.

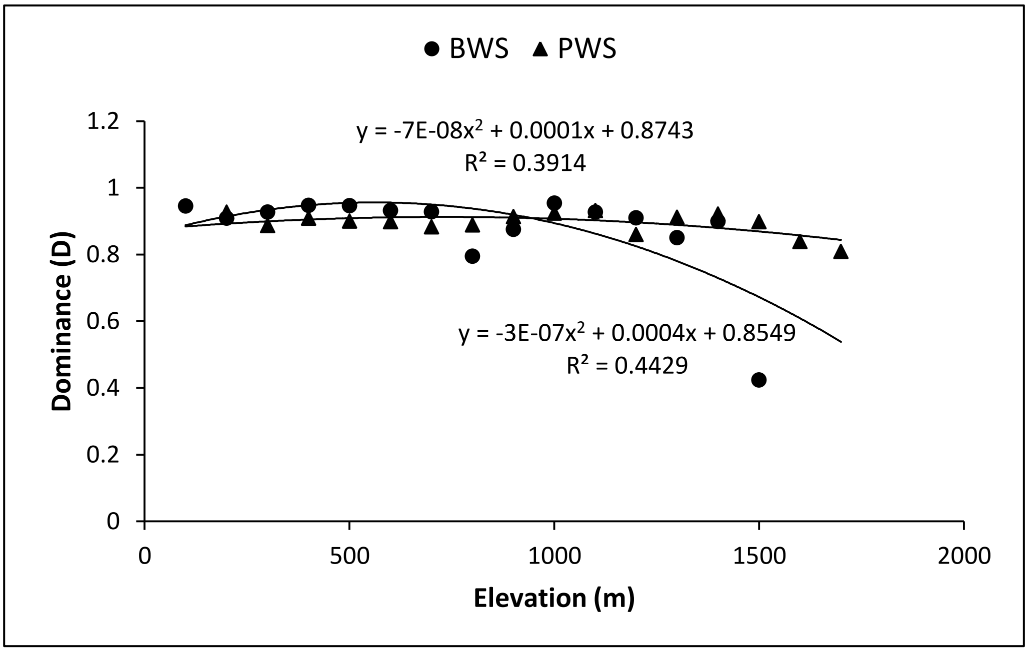


Fig 26. Simpson's diversity Index across Elevational Gradients in BWS & PWS in Kodagu district,Karnataka

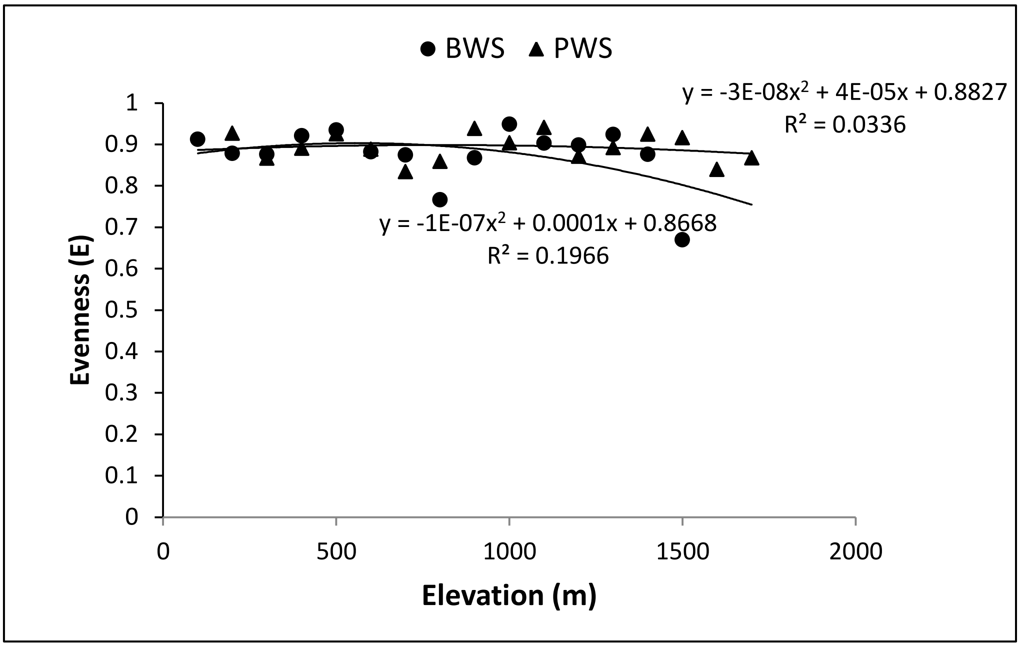


Fig 27. Pielou's evenness Index across Elevational gradients in BWS and PWS in Kodagu district, Karnataka.

Tree Height and Stratification

The average tree height in BWS and PWS ranged between 2 - 17.28 m across the elevational gradients. In BWS, the average tree height varied from 2 - 17.28 m whereas in PWS, the average tree height varied from 3.58 - 16.97 m across the elevational gradients. There was a significant negative correlation between average tree height with elevation in BWS whereas in PWS, there was a moderate negative correlation between tree height with elevation. The regression drawn between average tree height and elevational gradients showed that tree height was significantly affected by elevation with a decrease in the height of the trees as elevation increased in BWS whereas in PWS, tree height peaked at the mid elevations and then decreased with increase in elevation (Fig 28).The tree heights in the lower and mid elevations were taller (Fig 29) than the trees in the higher elevations which had stunted growth (Fig 30). The decrease in height of the trees can be due to the decrease in temperature, water and light availability in the higher elevations.

The matured tree species were grouped into three classes based on their height: top (>25 m), mid (15-25 m) and understory (<15 m) canopy (Chandrashekara & Ramakrishnan, 1994). The results from this study showed that out of the 1708 individuals recorded, 72.13 % belonged to understorey trees, 22.19 % to mid canopy and 5.68 % to top canopy (Table 6).

In BWS, 70.25 % were understorey trees, 21.72 % mid canopy and 8.3 % top canopy trees. In PWS, 74 % of the trees were understorey trees, 22% mid canopy trees and 3 %

constituted the top canopy (Fig 31 & 32). *Litsea floribunda* was found to be the dominant species in both the landscapes for understorey trees, *Kingiodendron pinnatum* for mid canopy in BWS and *Palaquium ellipticum* was found to be the dominant species for both mid and top in BWS and for top canopy in PWS.

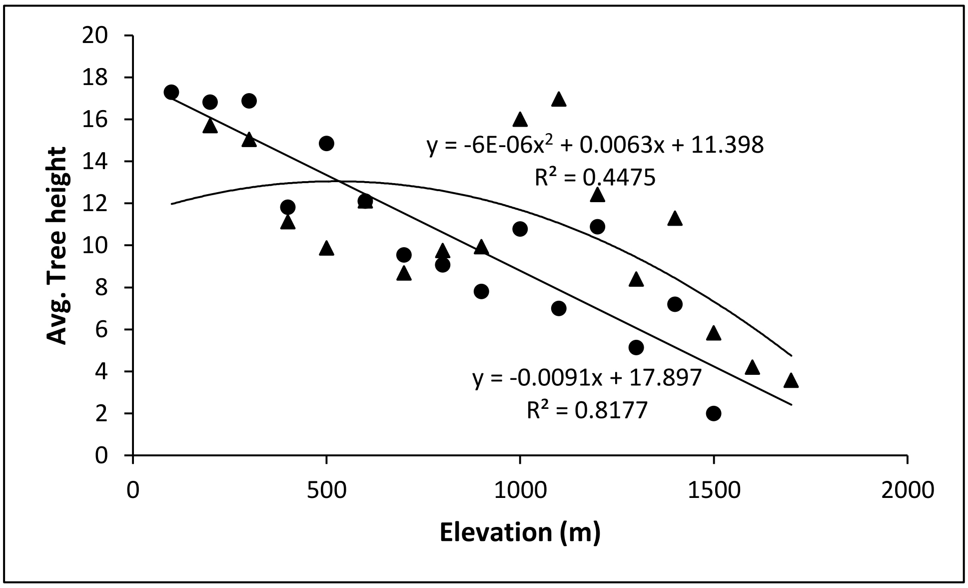


Fig 28: Tree height across Elevational gradients in BWS and PWS of Kodagu district, Karnataka.

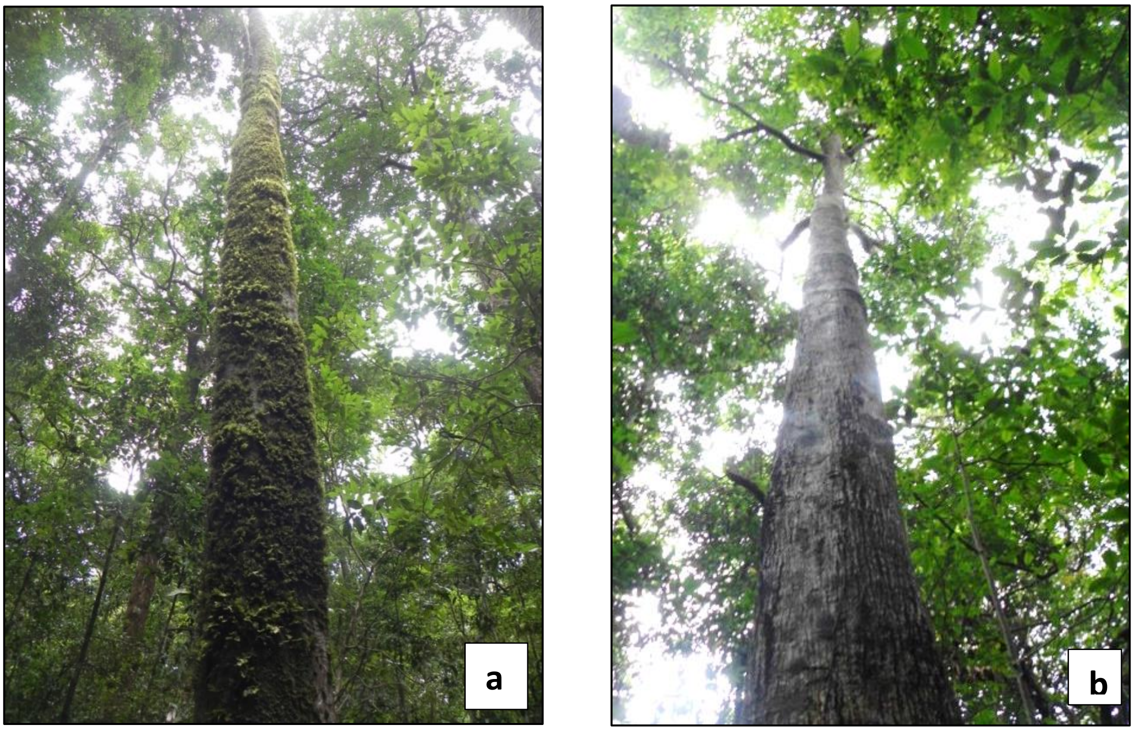


Fig 29. Tree height in the lower and mid elevations (a) and (b).

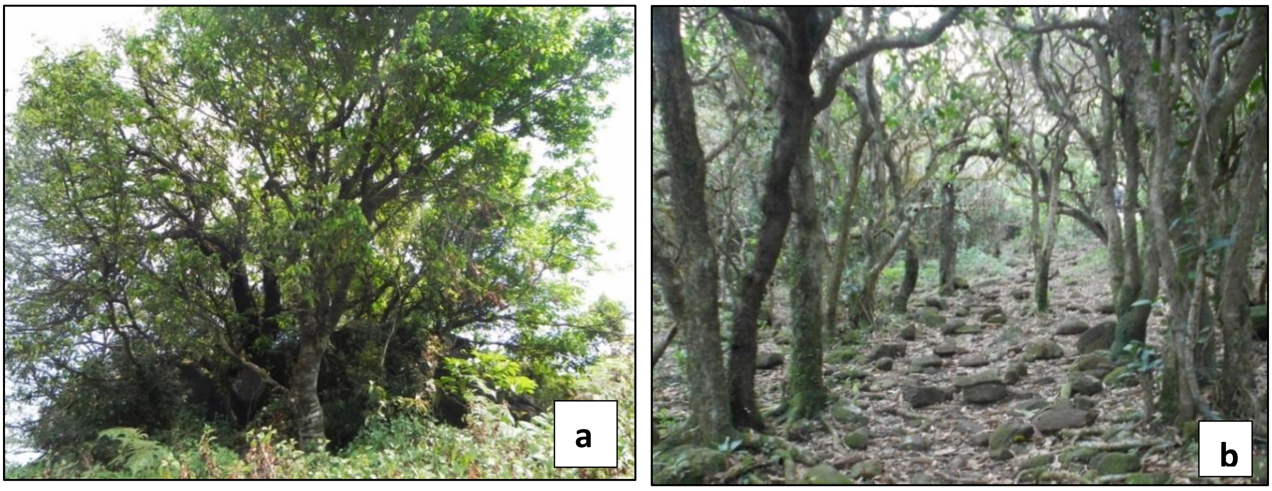


Fig 30.Trees at higher Elevations with stunted growth (a) and (b).

Table 6. Tree Canopy Structure wise Species across Elevational Gradients of BWS and PWS of Kodagu district, Karnataka.

Elevation (m)	Understorey (<15m)		Mid canopy (15-25m)		Top canopy (>25m)	
	BWS	PWS	BWS	PWS	BWS	PWS
100	27	-	20	-	19	-
200	20	26	24	13	9	7
300	42	23	21	24	24	3
400	50	40	27	12	1	1
500	42	42	35	10	9	2
600	68	37	29	16	5	1
700	57	56	10	10	0	0
800	60	47	6	12	0	1
900	23	28	5	9	0	0
1000	40	24	7	28	2	5
1100	65	13	1	19	0	5
1200	26	57	7	22	2	1
1300	23	66	0	2	0	0
1400	54	40	0	10	0	0
1500	24	34	0	0	0	0
1600	-	48	-	0	-	0
1700	-	30	-	0	-	0

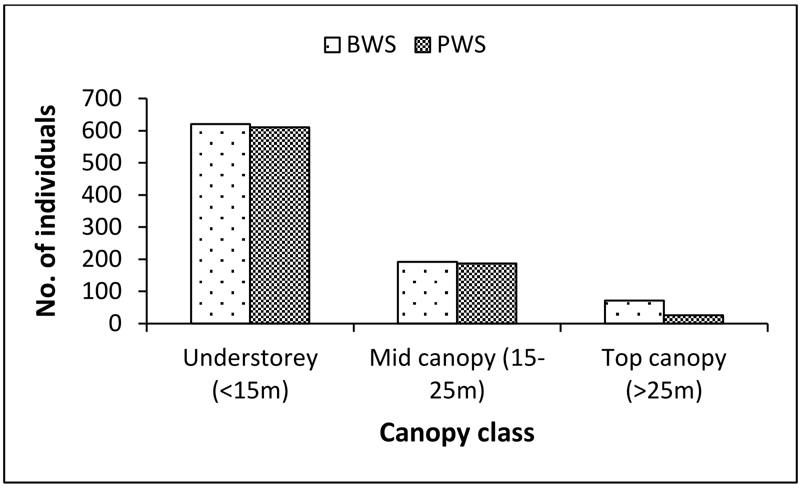


Fig 31.Tree Canopy class in BWS and PWS of Kodagu District, Karnataka.

Fig 32: Tree canopy structure in PWS (a) and BWS (b & c) (Understorey, Mid and top canopy).

Importance Value Index of Species and Family

The IVI depicts the overall phytosociological structure of a species in the community and a measure of the dominance of a species in a community. The higher the value of IVI, the more ecological significance it has in a particular forest community. The IVI values ranged between 0.47 to 15.96 in BWS and 0.49 to 20.92 in PWS. In BWS, it was highest for *Olea dioica* (15.90) followed by *Hopea parviflora* (15.19) (Fig 33a) in BWS. The minimum IVI value recorded for *Aphanamixis polystachya*, *Aporosa cardiosperma*, *Bridelia retusa*, *Glycosmis macrocarpa*, *Holigarna grahamii* and *Zanthoxylum rhetsa* (0.50) (Appendix 3).

In PWS, the IVI was highest for *Palaquium ellipticum* (20.82) followed by *Holigarna arnotianna* (12.23) and *Dimocarpus longan* (9.78) (Fig 33b). The minimum IVI value was recorded for *Cinnamomum sulphuratum* (0.48)(Appendix 4).

A total of 46 families were recorded for both BWS and PWS. The number of families recorded in BWS was 39 and it varied from 3 to 20 families along the elevational gradients (Fig 34). The number of families was highest at 700 m with 20 families and lowest at 1500 m with 3 families. The number of species in a family varied from 1 to 8 and Anacardiaceae had the highest representation with 8 species (8.51%) followed by Lauraceae with 7 species (7.45%) and lowest for Annonaceae, Arecaceae, Asteraceae, Bignoniaceae, Burseraceae, Celastraceae, Combretaceae, Dilleniaceae, Lamiaceae, Lythraceae, Melastomaceae, Oleaceae, Putranjivaceae, Rhizophoraceae, Sabiaceae, Salicaceae, Stemonuraceae and Xanthophyllaceae with one species each. The family with the most number of individuals was Lauraceae with 84 individuals followed by Oleaceae with 76 individuals. Family Importance Value (FIV) showed that the most dominant family was Lauraceae followed by Dipterocarpaceae (Fig 35a).

In PWS, a total of 37 families were recorded and it varied from 6 to 18 families along the elevational gradients (Fig 34). The number of families was highest at 200 m with 18 families and lowest at 1600 m elevational site with 6 families. The number of species in a family varied from 1 to 9 and Lauraceae with 9 tree species (10.71%) was the dominant family in terms of species richness followed by the family Anacardiaceae with 7 tree species (8.33 %) and the family with only one species was present for Annonaceae, Arecaceae Cannabaceae, Celastraceae, Dilleniaceae, Erythroxylaceae, Flacourtiaceae, Lamiaceae, Malvaceae, Melastomataceae, Mimosoideae, Myrsinaceae, Putranjivaceae, Rhizophoraceae, Rutaceae, Sapindaceae, Stemonuraceae, Symplocaceae and Theaceae. The family with the most number of individuals was Lauraceae with 113 individuals followed by Dipterocarpaceae and Oleaceae with 61 individuals. FIV showed that the most dominant family was Lauraceae followed by Dipterocarpaceae (Fig 35b).

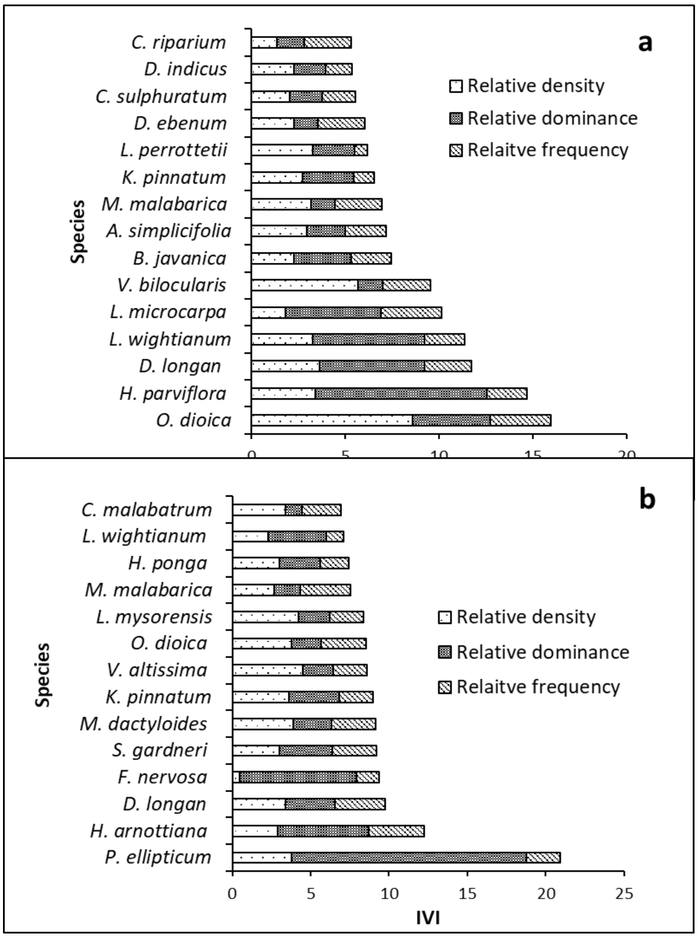


Fig 33. IVI of the top 15 species in BWS (a) and PWS (b) of Kodagu district, Karnataka.

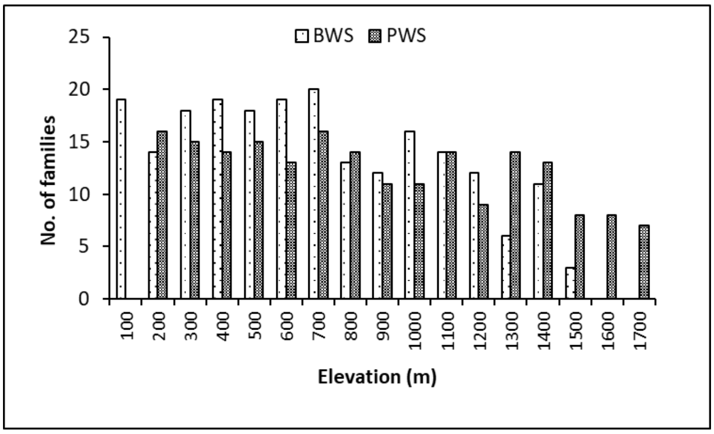
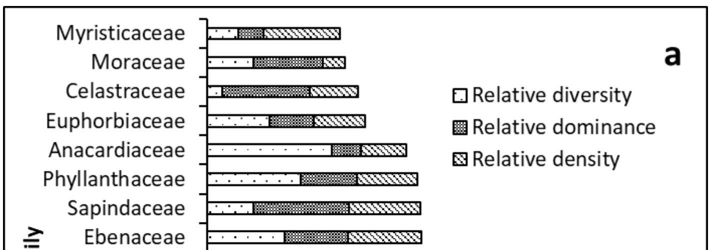


Fig 34. Relationship between families with Elevation in BWS (a) and PWS (b) of Kodagu district, Karnataka.



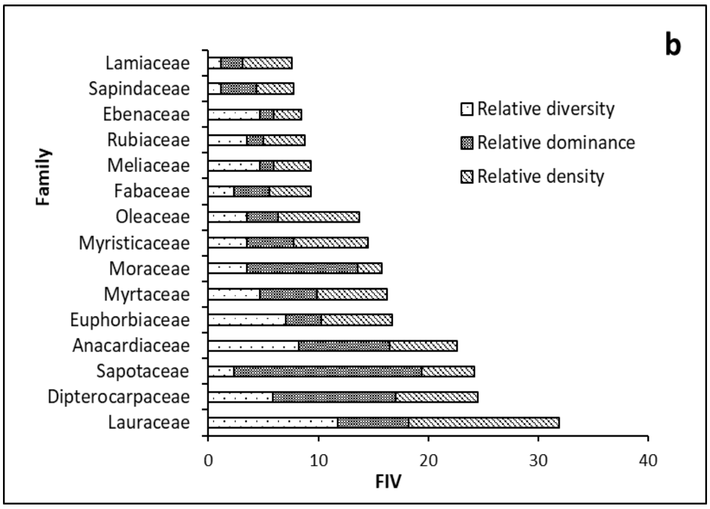


Fig 35. FIV of the top 15 families in BWS (a) and PWS (b) of Kodagu district, Karnataka.

Forest Stand Structure

The growth of a forest is indicated by the distribution of trees in various girth classes. The girth of the trees were divided into seven classes viz., 30-60, 60-90, 90-120, 120-150, 150-180,180-210,210-240, 240-270, 270-300 and >300 cm. In BWS, a total of 395 individuals were present in the girth class of 30-60 cm, which contributed to 45 % of the overall girth class, 22 % in 60-90 cm , 12 % in 90-120 cm , 8 % in 120-150 cm , 5 % in 150- 180 cm, 3 % in 180-210 cm, 2 % in 210-240 cm, 2 % in 240-270 cm, 1 % in 270-300 cm and 2 % in >300 cm respectively. *Olea dioica* was found to be the dominant species in 30-60, 60-90 and 90-120 cm classes. *Hopea parviflora* was found to be the dominant species in 120-150,150-180, 210-240 and >300 cm classes. *Kingiodendron pinnatum* was found to be the dominant species in 180-210 cm, *Lophopetalum wightianum* in 240-270 cm and *Artocarpus hirsutus* in 270-300 cm class.

In PWS, a total of 420 individuals were present in the girth class of 30-60 cm, which contributed to 51 % of the overall girth class, 22 % in 60-90 cm , 11 % in 90-120 cm , 7 %

in 120-150 cm , 4 % in 150- 180 cm, 2 % in 180-210 cm, 2 % in 210-240 cm, 1 % in 240-270 cm, 1 % in 270-300 cm and 2 % in >300 cm respectively. *Vitex altissima* was found to be the dominant species in 30-60 cm, *Garcinia gummi-gutta* in 60-90 cm, *Kingiodendron pinnatum* in 90-120 cm class and *Palaquium ellipticum* was found to be dominant for the rest of the classes.

In both the sanctuaries, 30-60 cm class recorded the highest number of individuals. The stand structure of the forests showed a reverse ‘J’ shape curve with higher density of trees in the lower girth class which indicates that the forest harbours a growing and a healthy population with a normal distribution of stems across the girth classes (Fig 36). The lower elevations had larger girth classes as compared to the higher elevations (Fig 37). The J shaped curve is similar to studies reported from other areas of the Western Ghats (Pascal & Pellisir, 1996; Ganesh *et al*., 1996).

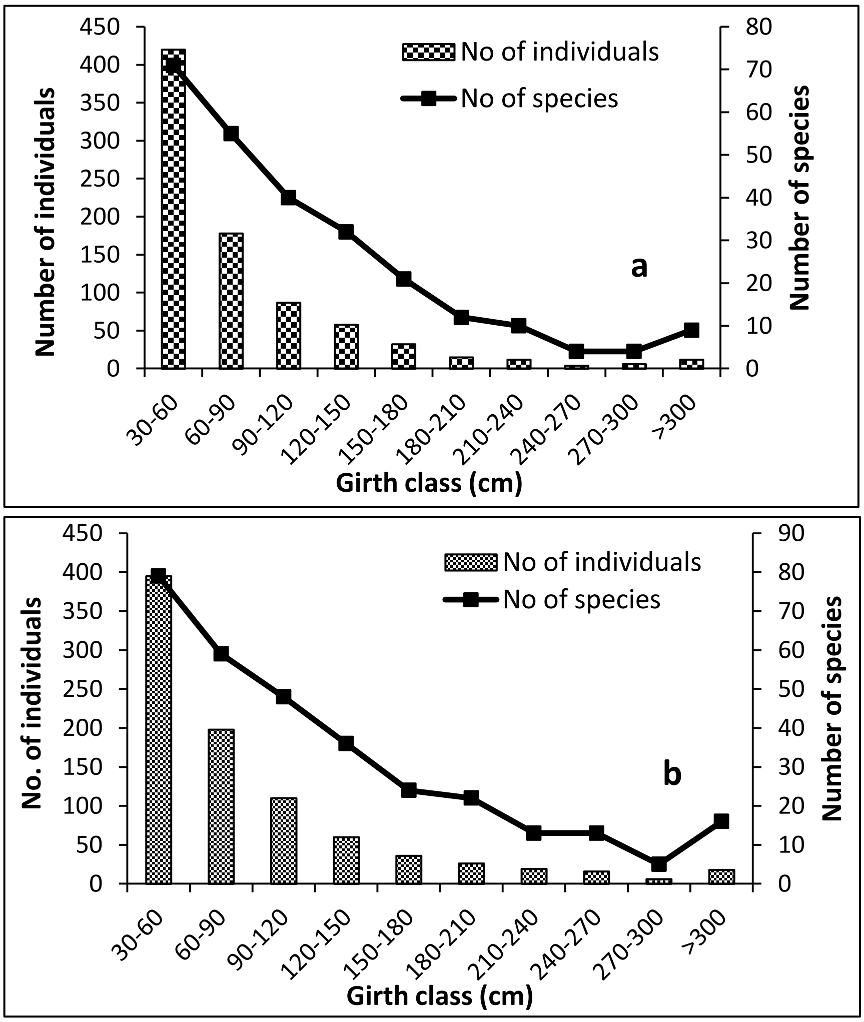


Fig 36. Relationship between species and number of individuals with Girth classes in BWS and PWS of Kodagu district, Karnataka.

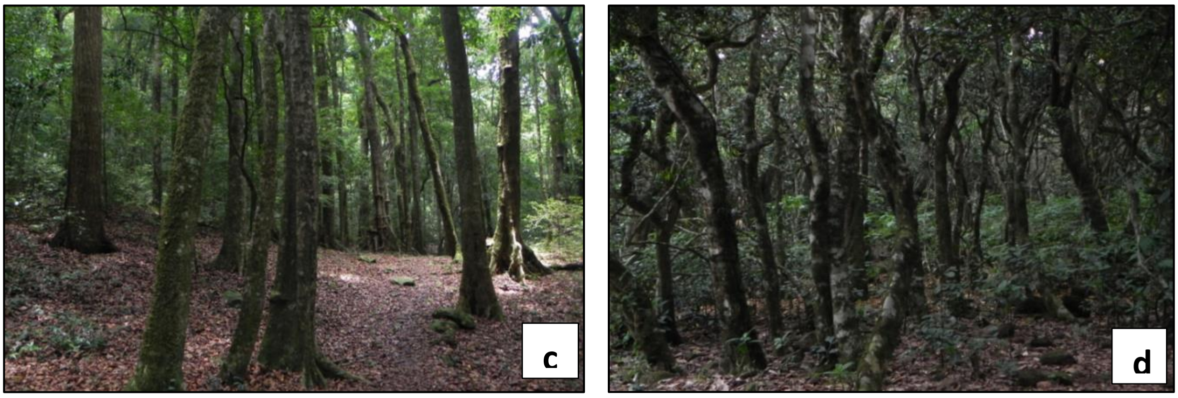


Fig 37. Stand structure across Elevations: *Ficus virens* (a) *Vitex altissima* (b) Stand structure in the lower elevations (c) and higher elevations (d).

Species Endemism

A total of 53 out of 132 species recorded in the present study were endemic to the Protected Areas. A total of 870 individuals were recorded in both the landscapes of which 22 tree species and 11 families were common to both the sanctuaries. A total of 439 individuals belonging to 39 endemic tree species and 22 families were recorded in BWS and 431 individuals belonging to 36 endemic tree species and 20 families were recorded in PWS. The number of endemic species in the elevational gradients varied from 2 to 15 species in BWS and 3 to 14 species in PWS (Fig 38). The number of endemic species was highest at 500 m with 15 species in BWS and 1000 m with 14 species in PWS. The stand density for the endemic species in BWS varied between 42 to 567 /ha and was highest at 600 m. In

PWS, the tree density varied between 100 to 475 /ha and 1200 m with 475 /ha was the highest in PWS (Fig 39).

The species with the highest number of individuals in BWS include species such as *Vepris bilocularis*, *Hopea parviflora* and species such as *Litsea mysorensis* and *Palaquium ellipticum* had high number of individuals in PWS. The IVI of the species was highest for *Hopea parviflora* (31.87) in BWS and *Palaquium ellipticum* (40.14) in PWS (Fig 40). The FIV was highest for Dipterocarpaceae in BWS and Lauraceae in PWS (Fig 41).

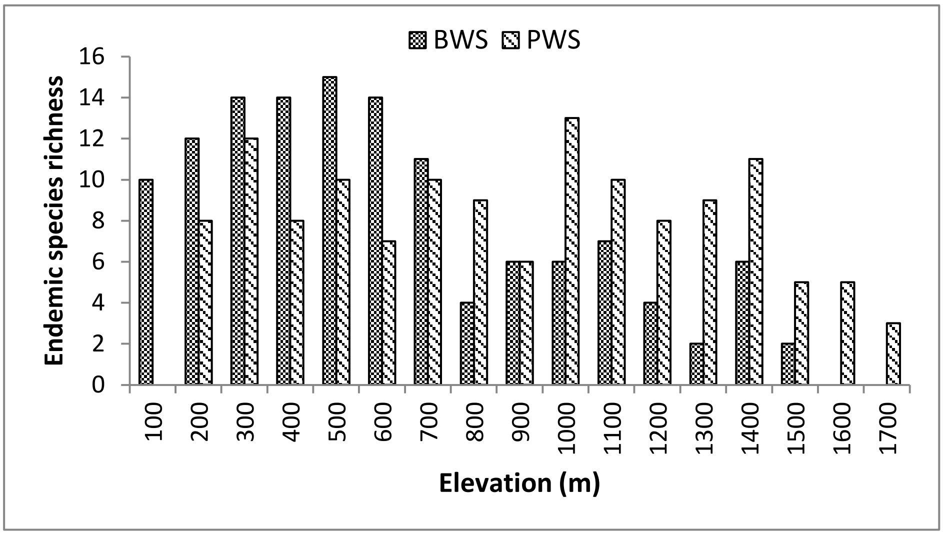


Fig 38. Endemic Species distribution across Elevational Gradients in BWS and PWS of Kodagu district, Karnataka.

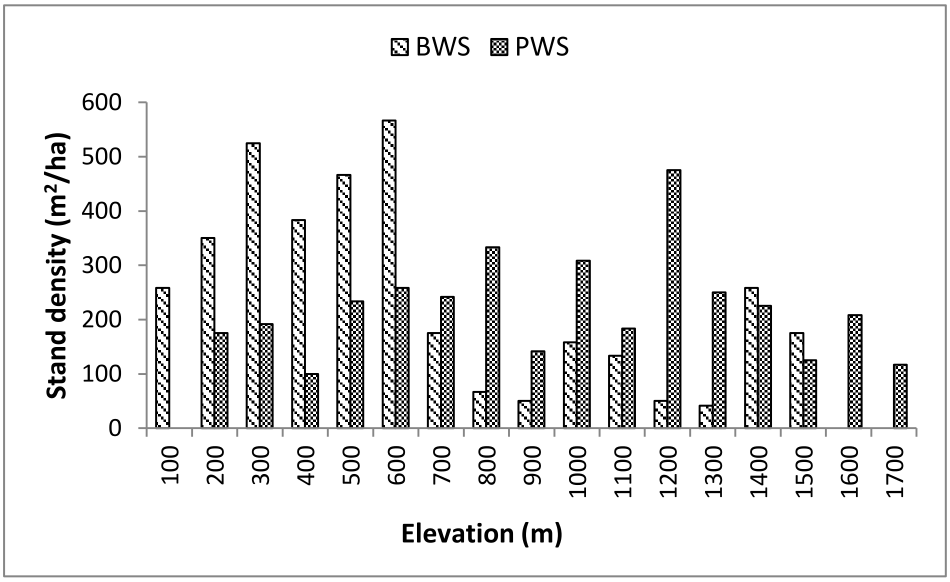
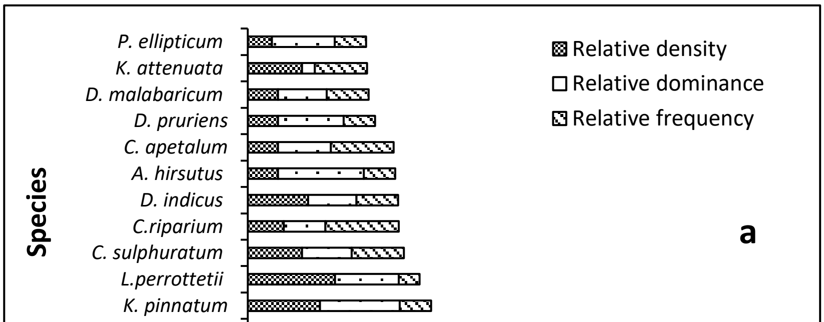


Fig 39. Stand density across Elevational Gradients in BWS and PWS of Kodagu district, Karnataka.



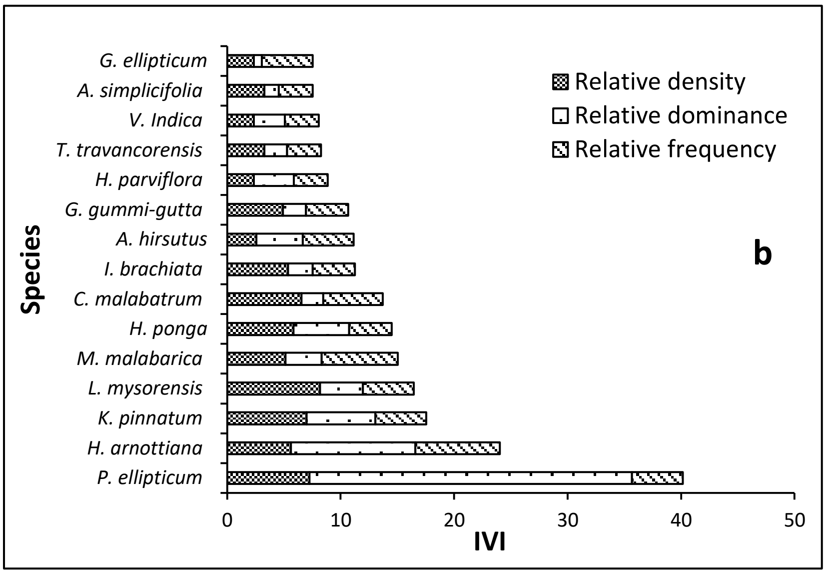
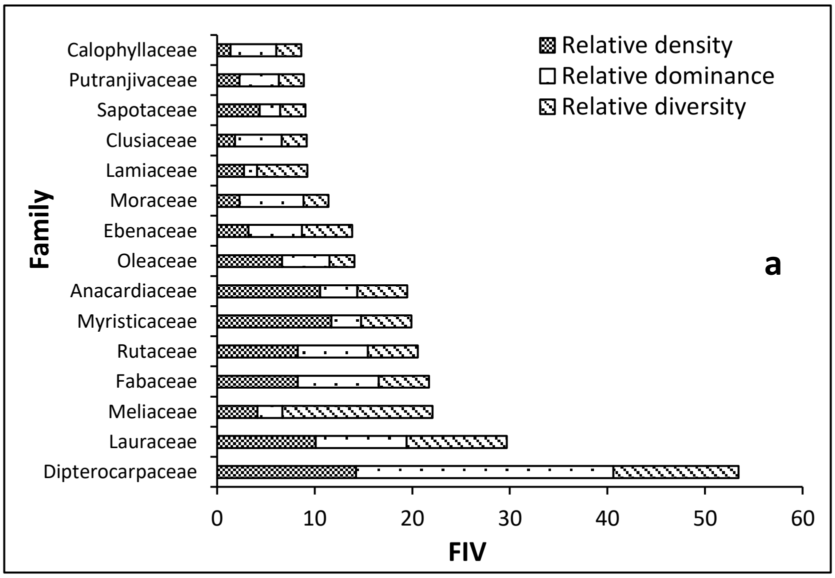


Fig 40. IVI of Endemic species present in BWS (a) and PWS (b) of Kodagu district, Karnataka.



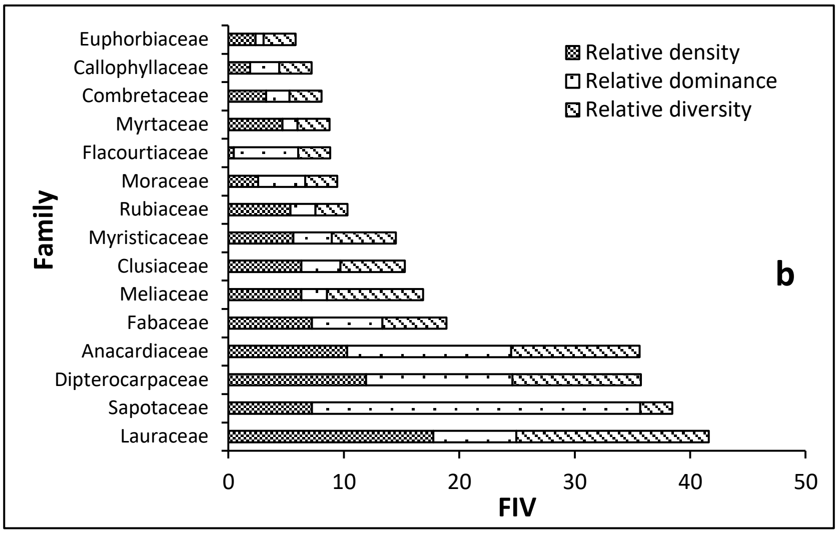


Fig 41: FIV of Endemic tree species in BWS (a) and PWS (b) of Kodagu district, Karnataka.

Fig 42: Endemic species *Kingiodendron pinnatum* (a) *Baccaurea courtalensis*(b) *Garcinia gummi-gutta* (c) *Artocarpus hirsutus*(d).

Distribution Pattern and Raunkier's Classification

The ratio of abundance and frequency as a measure of contagiousness among plant population was widely accepted and it was determined following Whitford (1949). The ratio indicates regular (<0.025), random (0.025-0.05) and contagious (>0.05) distribution pattern of the trees. As a general rule, higher frequency and lower abundance indicates regular distribution pattern whereas the reverse indicates the contagious distribution.

In this study, overall 91.62 % of the species recorded showed contagious distribution, 7.82 % showed a random distribution and 0.56 % showed regular distribution. In BWS, out of the 94 species recorded 6 (6.38%) species showed random distribution, 88 (93.61%) species showed contagious distribution pattern and species in regular distribution was absent (Fig 43). Species which showed random distribution included *Actinodaphne bourdilloii*, *Cinnamomum riparium*, *Calophyllum apetalum*, *Macaranga indica*, *Lagerstroemia microcarpa* and the species which showed contagious distribution includes *Bischofia javanica*, *Diospyros nilagarica*, *Knema attenuata*, *Ligustrum perrottetti*, *Myristica malabarica* and *Vitex altissima*.

In PWS, out of the 85 species recorded one (1.18 %) species, *Knema attenuata* showed regular distribution, 8 (9.41%) species showed random distribution and included species *Artocarpus hirsutus*, *Holigarna arnottiana* and *Garcinia indica*, 76 (89.41%) species showed contagious distribution with species such as *Lophopetalum wightianum* and *Mallotus phillipensis* (Fig 43). The clumped distribution pattern of the forests suggests high abundance of species but low frequency of occurrence which is due to insufficient seed dispersal, topography and soil factors which affect the distribution pattern (Tripathi & Tripathi, 2010).

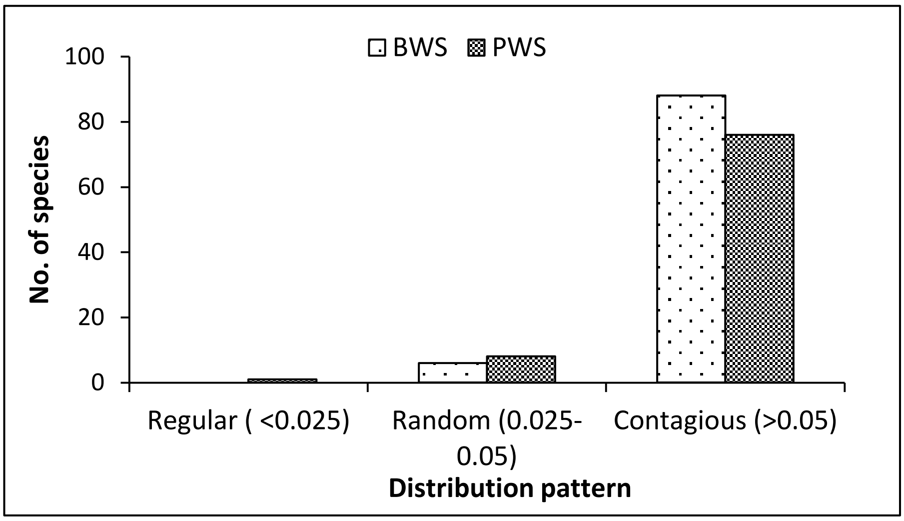


Fig 43. Distribution pattern of species in BWS and PWS of Kodagu district, Karnataka.

Based on the frequency distribution of the species, Raunkier (1934) classified a community into five frequency classes viz., A = 1-20, B = 21-40, C = 41-60, D =41-60 and E = 81-100. It is useful as a simple indication of uniformity or homogeneity within a stand or between several stands of vegetation. The overall frequency for species falling in Class A was 67, Class B was 23, Class C was 9, Class D was 2 and there was no species in Class E in both the landscapes.

In BWS, the frequency ranged from 7 to 67. The percentage of species falling in Class A was 70, Class B had 22, Class C had 6, Class D had 2 of the total species and there was absence of species in Class E (Fig 44). In PWS, frequency ranged from 6 to 62. The percentage of species falling in Class A was 64, Class B had 25, Class C had 9, Class D had 2 of the total species and there was absence of species in Class E. Raunkier's frequency analysis revealed that most of the species had low frequency of occurrence which is generally seen in species abundance distribution in tropical forests (Kumar *et al., 2006*).

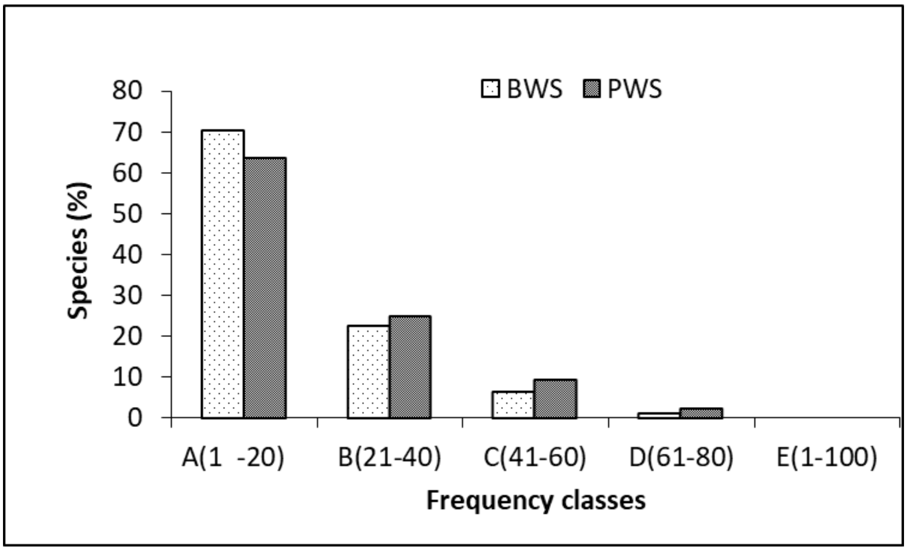


Fig 44. Frequency classes of Species in BWS and PWS of Kodagu district, Karnataka.

Sorenson's Index of Similarity

The similarity between BWS and PWS was calculated using Sorensen's coefficient. The Sorensen's index value ranges from 0 to 1 with a value of 1 showing similar species composition between the two sites and 0 means they share none. In this study the Sorenson's coefficient with a value of 0.525 shows that both the sanctuaries shared 50% similarity in their species composition.

Regeneration across Elevational Gradients

A total of 1050 individuals belonging to 55 species and 31 families were recorded in BWS and PWS (Appendix 5 & 6). The number of regeneration tree species recorded in BWS and PWS was 46 with 571 individuals and 30 species and 479 individuals respectively. Regeneration individuals were found to be highest at 500 m with 68 individuals and lowest at 1300 m with 2 individuals in BWS whereas in PWS it was highest at 1000m with 47 individuals and lowest at 1100 m with 16 individuals (Table 7). The species richness was highest at 600 m with 16 species and it was lowest at 1300 and 1400 m with 2 species each in BWS. It was highest at 200 m site with 11 species followed by 1300 and 1400 m with 9 species in PWS. In BWS, the most dominant species was *Drypetes Venusta* with 51 (10.83%) individuals followed by *Atalantia monophylla* with 48 (10.19%) individuals and the lowest number of regenerative individuals with 1 (0.18%) regenerative individual each was found for *Acrocarpus fraxinifolius, Baccaurea courtalensis, Dalbergia spp, Persea macrantha, Phyllanthus emblica, Psychotria nilgirensis, Scolopia crenata, and Vernonia arborea.* The most dominant species in PWS was *Diospyros ebenum* and *Kingiodendron pinnatum* with 63 (13.15%) and 62 (13.15%) individuals respectively. The lowest number of regenerative individuals is 1(0.21%) found for *Myristica dactyloides, Olea dioica, Raphanea striata, Symplocos cochinchinensis, Terminalia spp.* and *Vitex altissima.*

The low number of regenerative individuals for some of the species such as *Acrocarpus franxifolius, Baccaurea courtalensis, Myristica malabarica, Olea dioica* may be a threat to its existence in near future as a dominant species. However species which are present in both the higher and lower girth class such as *Diospyros ebenum, Kingiodendron pinnatum* may develop as a canopy in the present forest. The similarity in the tree species between the adult and regenerating individuals showed a varied proportion similar to results done in other parts of the Western Ghats (Bharathi & Prasad, 2015). The variation in number of individuals in the regenerative classes among different elevational gradients may be ascribed to the prevailing environmental factors determined by the altitude and degree of disturbance (Hedge *et al*., 2015).

The regeneration classes were classified based on the height and DBH of the regeneration individuals at each elevation. All the four regeneration classes were found to be present at 500 m, 600 m, 700 m and 800 m in BWS and 200 m and 300 m in PWS respectively. The presence of regeneration in all the four classes indicated the presence of the seedlings surviving and growing into the adult stage. A decreasing order of regeneration from class 1 to 4 was observed in most of the elevations in both the sanctuaries. There was absence of class 4 in some sites even though there were high number of individuals in class 1 which showed that even with high number of regeneration individuals, it depends on the growing conditions for the species to survive. However in many of the elevational gradients, there was absence of regeneration individuals in all the four classes or in some of the classes which indicates that all the seedlings don't survive and reach the adult stage or they don't survive past the seedling stages. The overall population structure of the regenerating individuals based on their height and girth in both the study sites reveal that the contribution of class 1 was highest followed by class 2, 3 and 4 (Fig 45). According to the classification, it shows that the plants in the see dling stages are more and it reduces as the girth and the height of the trees increases.

In both the Sanctuaries class 1 had the highest number of individuals, 437 in BWS and 272 in PWS. However in class 2 and 3, PWS had higher number of individuals than BWS with 136 and 64 individuals for class 2 and 3 in PWS and 93 and 33 in BWS for class 2 and 3 respectively and in Class 4, BWS had 8 and PWS had 7 individuals. The regeneration classes showed a reverse 'J' shaped pattern in both the sanctuaries which indicates a healthy regeneration population. The number of regeneration individuals in class 4 was less in both the sanctuaries which indicates that most of the individuals do not reach the mature or adult stage. The species with higher number of individuals for regeneration was *Drypetes venusta* in BWS and *Diospyros ebenum* in PWS (Fig 46).

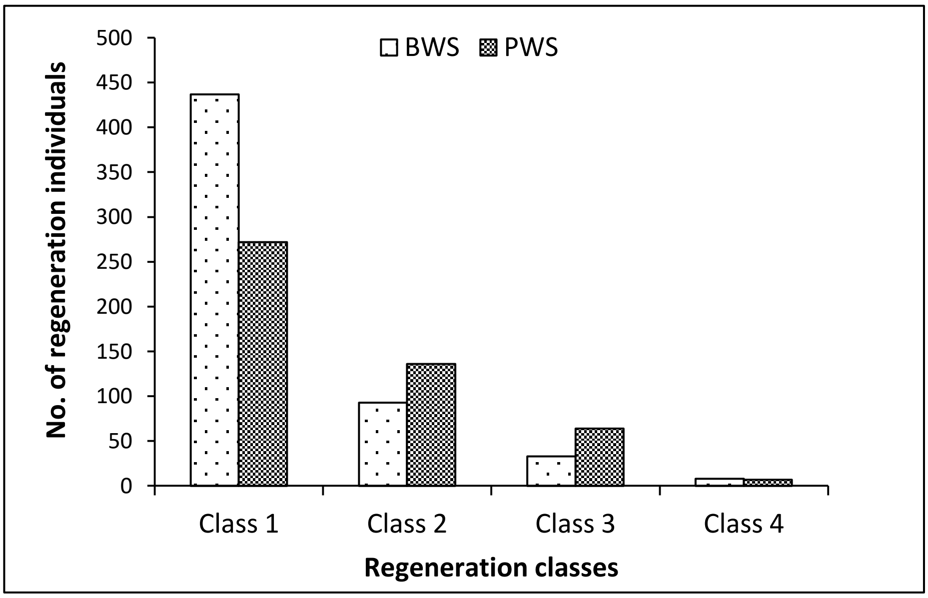
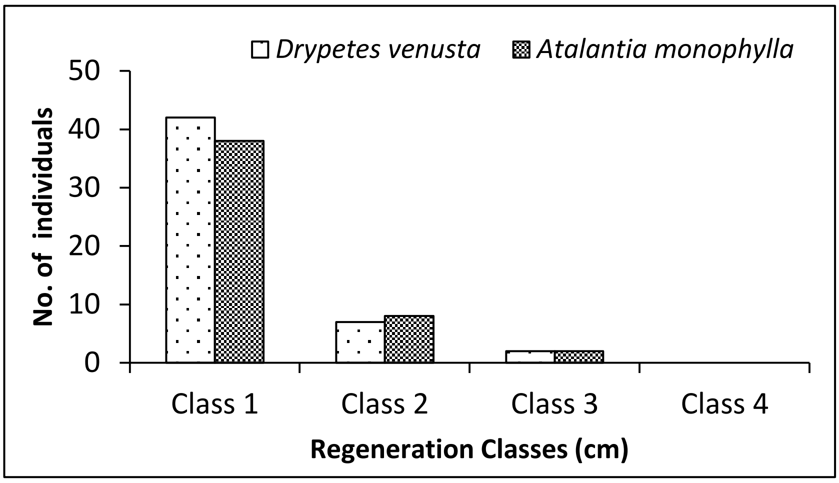


Fig 45. Vegetation structure of Regenerating trees in BWS and PWS of Kodagu district, Karnataka.



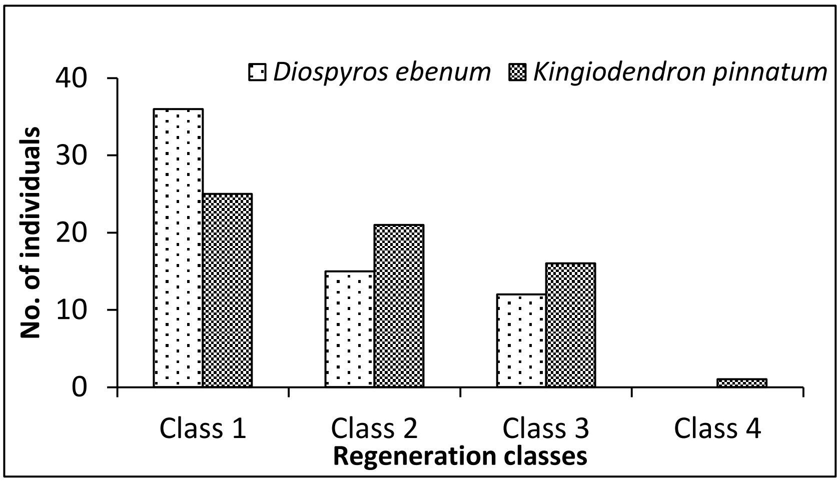


Fig 46: Regeneration pattern of top two Species in a) BWS and b) PWS of Kodagu district,

The growth features and nature of disturbance differs for different species and affects the mechanism of regeneration (Pandey & Shukla, 2003). The high number of regeneration individuals in class 1 can also be attributed to continued process of regeneration initiated from seeds formation, dispersal, germination and establishment (Prasad & Al-Sagheer, 2012). The absence of regenerative individuals in the later stages of growth can be due to a variety of factors such as biotic disturbances (Karthik & Viswanath, 2012), habitat fragmentation, isolation and habitat destruction (Hedge *et al*., 2015), poor seed germination and establishment of seedlings in the forest (Khumbonmayum, 2005). Sapling mortality is the most significant factor determining species turnover and establishment in a forest (Lieberman & Lieberman, 1994) and small saplings are most vulnerable to mortality (Condit *et al*., 1995). The complete absence of regenerative individuals in a forest indicates the constraints for poor regeneration. The absence of regenerative species such as *Ligustrum* *perrottetii*, *Artocarpus hirsutus* in the different classes shows that the regeneration potential is very weak. Seed dispersal is mediated by several biotic and abiotic factors in tropical rain forests and the regeneration of the trees may be taking place at various distances from the mother tree (Kumar *et al*., 2015).

Table 7: Density and Species Richness of Regenerative Species in BWS and PWS of Kodagu district, Karnataka.

		No. of individuals		No. of species	
Sl .No	Elevation	BWS	PWS	BWS	PWS
1.	100	61	-	12	-
2.	200	53	26	11	11
3.	300	35	20	7	4
4.	400	45	23	10	5
5.	500	68	20	10	3
6.	600	52	22	16	5
7.	700	65	25	16	6
8.	800	60	26	14	4
9.	900	21	33	9	5
10.	1000	45	47	8	6
11.	1100	31	16	8	6
12.	1200	24	46	11	7
13.	1300	2	42	2	9
14.	1400	9	39	2	9
15.	1500	-	35	-	5
16.	1600	-	37	-	8
17.	1700	-	22	-	6

The overall reverse ‘J’ shaped population curve of the regeneration classes observed in BWS and PWS was similar to various studies reported from the forests of Northeast India, Western Ghats, Eastern Ghats, Eastern Himalayas and in other parts of the world (Sarkar & Devi, 2014; Bharathi & Prasad, 2015). The density of regenerating individuals is comparable to the evergreen forests of other regions of the Western Ghats (Jayakumar & Nair, 2013; Prasad & Al-Sagheer, 2012). However, regeneration of a species does not account for its adult density (Chauhan *et al*., 2008) and so even though the study shows that there is a high number of regenerative individuals in the study site, not many of them will reach the adult stage and so it is difficult to conclude that the regenerative individuals recorded in this study will reflect in the same way as matured trees in the future.

6.3 Soil Characteristics of BWS and PWS

Soil Types

The soil types in the Western Ghats are red soils, laterites, black soils and humid soils (Subramanyam & Nayar, 1974). The colour of the soil in the forest area of Kodagu consisted of 57.81 % brown coloured soil and 37.50 % of black coloured soil (FSI, 1995). Soils in the evergreen forest of the Western Ghats are mostly sandy loam and sandy soil types as there is less disturbance in these areas (Ramchandra *et al*., 2012b). The soil types in BWS and PWS is deep loamy with varying depths with patches of lateritic or lateritic bright red or yellow colour soil in PWS (GoK, 2008, GoK, 2010). The soil types in the study area was mostly deep, well-drained gravelly clay soils with low available water capacity mostly in the sub-soil and on high hill ranges with steep slopes (Fig 47).

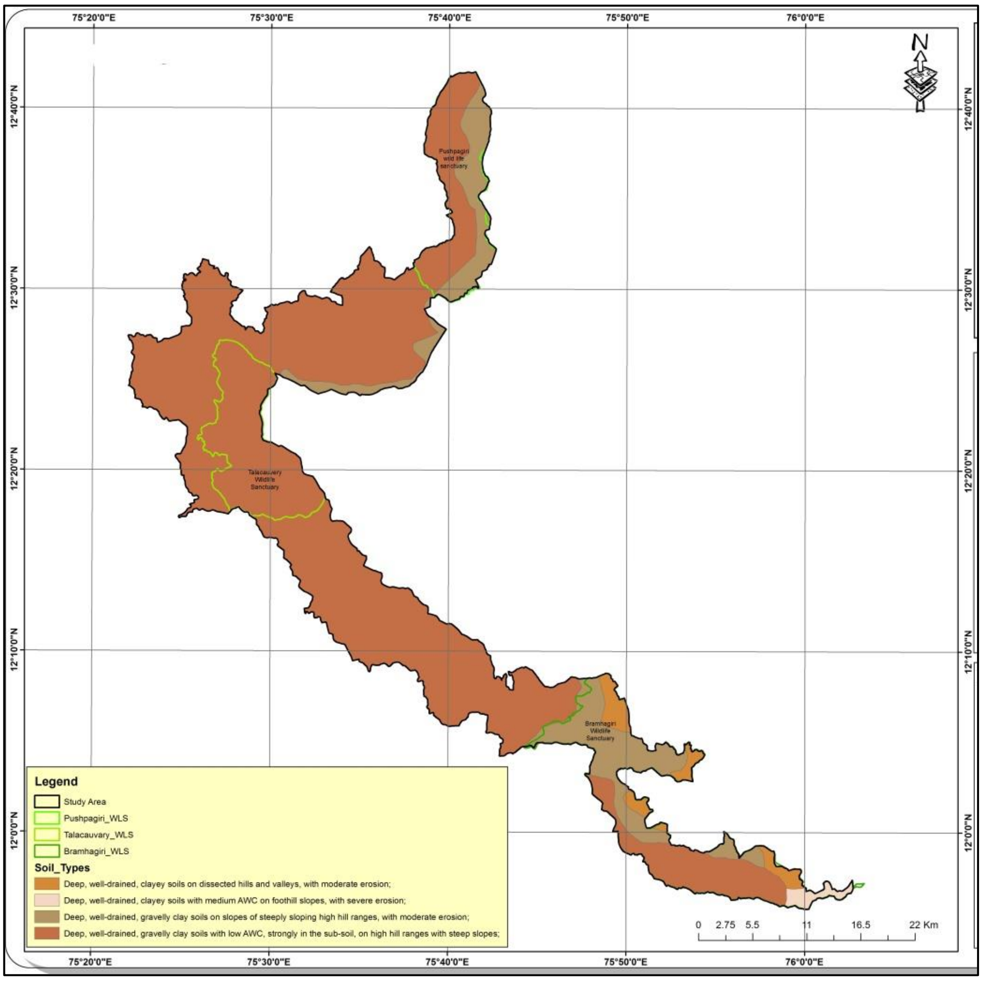


Fig 47: Soil types in Protected Areas and adjoining Reserve Forests of Kodagu district, Karnataka.

pH and Soil Moisture

The pH of the soil in BWS ranged from 5.25 to 7.49 and 4.24 to 6.52 in PWS. The pH of the soil in the elevational gradients in both the sanctuaries indicated that the soils are acidic in nature (Fig 48). The pH of soil in BWS did not follow any specific pattern with elevation whereas the soil in PWS was more acidic in the lower elevations and it decreased higher up the elevations. Studies have shown that the soils in the Western Ghats ranged from mildly acidic to very acidic (Swamy & Proctor, 1994; Ramachandran & Swarupanandan, 2013; Sahu *et al*., 2019).

The soil moisture content along the elevational gradients varied between 5 to 10 % in BWS and 5 to 14% in PWS. The moisture content in the soil did not follow a specific pattern along the elevational gradients. The moisture content was highest at 500 and 1300 m in BWS with 10 % and 800 m site had the least moisture content with 5 % whereas the moisture content in PWS was highest at 1400 m with 14 % followed by 1500 m with 13 % and 400 m site had the least moisture content with 5 % (Fig 49). Overall the moisture content was found to be higher in PWS which may be due to the litter accumulation in the forest bed which retains the moisture in the soil. Also, there was heavy rainfall in the forest of PWS prior to sampling which could have resulted in an increase in the moisture content in the soil. Increased soil moisture content can also be attributed to the vegetation cover which reduces the evaporation rate.

Major Soil Nutrients

The soil organic Carbon content along the elevational gradients varied between 2.4 to 83.16 t/ha in BWS and between 12.12 to 117.36 t/ha in PWS. The average soil carbon in BWS was 35.2 and 59.76 t/ha in PWS respectively. The elevational gradients at 1200 m had the highest organic carbon content with 83.16 t/ha whereas organic content was found to be absent in sites 200 m and 500 m in BWS. The elevational site at 1500 m in PWS had the highest organic carbon content with 117.36 t/ha whereas 900 m site had the least organic carbon content with 12.12 t/ha (Fig 50). The high organic content may be due to the fast decomposition rate of the organic matter and the low organic content can be attributed to the slow decomposition of the organic matter. The high organic content can also be due to the unaltered natural setting with continuous growth of trees and shrubs (Divya *et al*., 2016) The decrease in the soil carbon with the increase in the elevation was also reported in other studies (Sevgi & Tecimen, 2009; Kobler *et al*., 2019). The organic content of 35.2 and 59.76 t/ha in the Protected Areas of Kodagu was found to be much lower than the tropical wet evergreen and semi evergreen forests of the Western Ghats as reported by Singh (1968) whereas it was in the similar range of 161.9 t/ha reported in montane temperate forests (Chabbra *et al*., 2003).

Dense canopy and thick undercover result in increased amount of carbon return in the form of litter and contributes to higher amount organic matter on forest floor. The rapid decomposition of forest litter may also contribute to the high organic content of the soil (Divya *et al*., 2016). Decreased litter input, shifts in abundance of woody and herbaceous vegetation, changes in depth distribution of plant roots, altered soil water and temperature regimes accelerate decomposition and a decrease in net primary productivity (Jackson *et al*., 2000) might have contributed to the loss of SOC in the two elevational gradients. The soil organic carbon is affected by the altitudinal and topographic variation (Parras- Alcantara *et al*., 2015). There is a decrease in the carbon and nitrogen with increasing altitude due to lower decomposition rates due to the decreasing temperature (Shedayi *et al*., 2016). The decrease in vegetation with increasing altitude also results in less accumulation of litter and low input of organic carbon in soils (Sheik *et al*., 2009).

The nitrogen values of the soil samples along the elevational gradients varied between 8.2 mg/kg to 450 mg/Kg in BWS and between 11.4 mg/kg to 394.6 mg/Kg in PWS. The highest Nitrogen content in BWS was found at 300 m elevational site followed by 1400 m with 386 mg/kg at 1400 m. The lowest Nitrogen content was found at 600 m with 8.2 mg/kg. In PWS, the highest Nitrogen content was found at 1600 m elevational site with 394.6 mg/kg followed by 1700 m with 232 mg/kg and the lowest Nitrogen content was found at 700 m with 11.4 mg/kg (Fig 51).

Phosphorus content along the elevational gradients varied between 6.15 mg/kg to 65.56 mg/Kg in BWS and between 12.3 mg/kg to 30.75 mg/Kg in PWS. The highest content in BWS was found at 200 m elevational site with 65.65 mg/kg followed by 200 m with 22.05 mg/kg at 200 m and the lowest was found at 1400 m with 6.15 mg/kg. In PWS, the highest was found at 1500 m elevational site with 30.75 mg/kg followed by 700 m with 30.15 mg/kg at 700 m and the lowest was found at 1700 m with 12.3 mg/kg.

Potassium content of the soil along the elevational gradients varied between 20 mg/kg to 120 mg/Kg in BWS and varied between 10 mg/kg to 100 mg/Kg in PWS. The highest content in BWS was found at 1300 m elevational site with 120 mg/kg followed by 800 m and 900 m with 70 mg/kg each. In PWS, the highest content was found at 900 m elevational site with 100 mg/kg followed by 1400 m with 90 mg/kg each. There was absence of Potassium content in the soils at 100 m and 1400 m in BWS and 300 m, 400 m, 500 m, 1100 m and 1600 m in PWS.

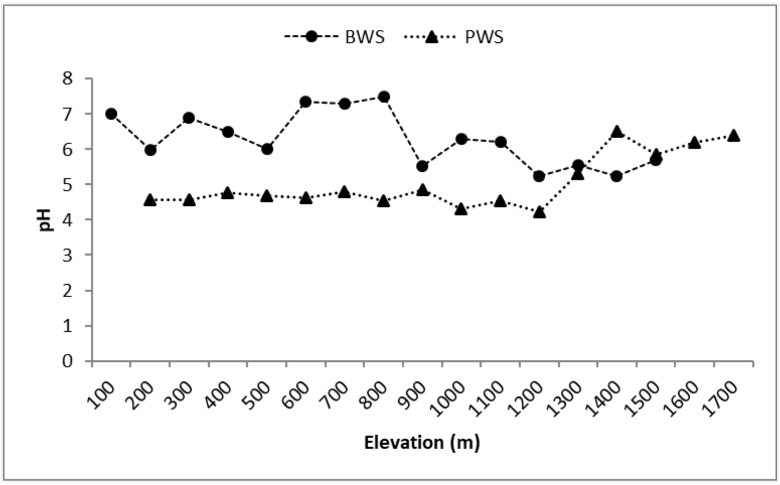


Fig 48. pH of soil across Elevational Gradients in BWS and PWS of Kodagu district, Karnataka.

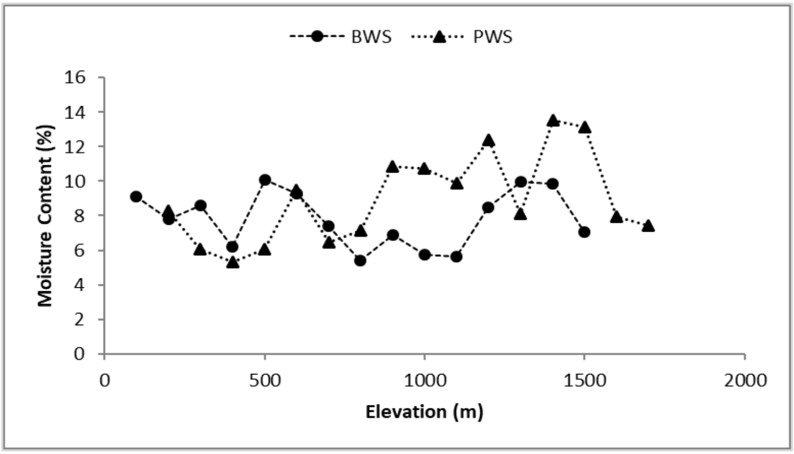


Fig 49. Moisture content of soil across Elevational Gradients in BWS and PWS of Kodagu district, Karnataka.

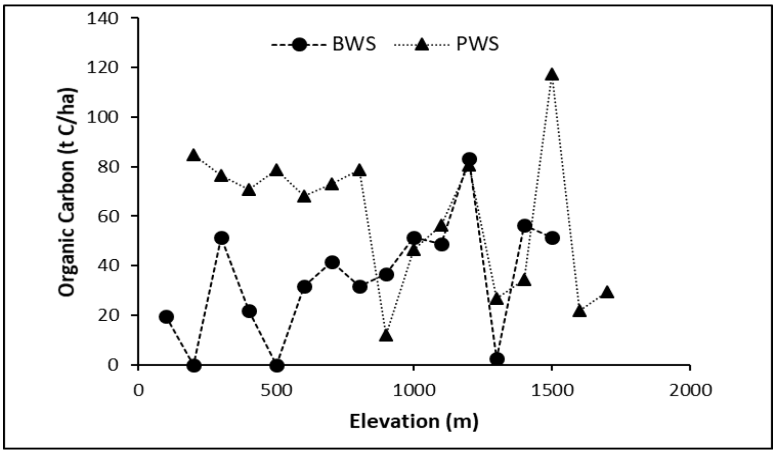
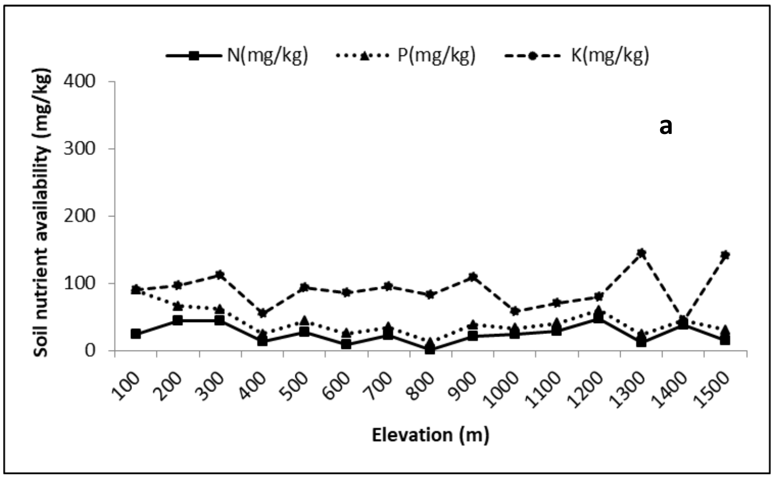


Fig 50. Soil Organic Carbon across Elevational Gradients in BWS and PWS of Kodagu district, Karnataka.



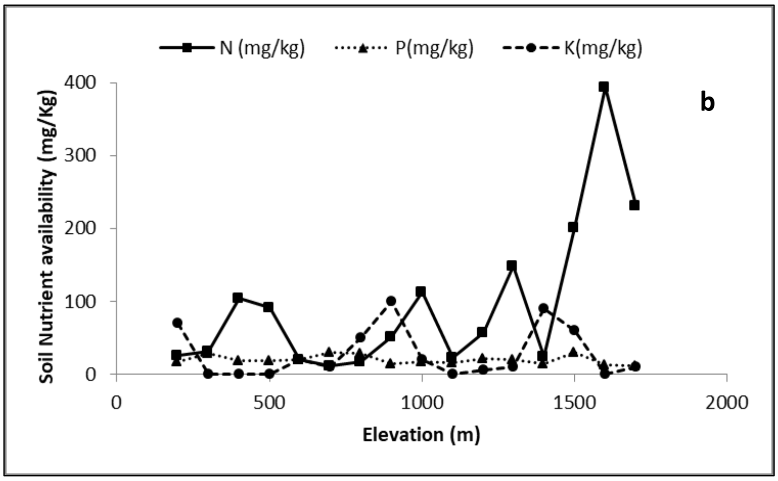


Fig 51. NPK content across Elevational Gradients in BWS (a) and PWS (b) of Kodagu district, Karnataka.

According to the study, the soil nutrients analysed was found to be higher in PWS than in BWS. It can also be because of the high litter content in these forests which contribute to the nutrients in the soil. Herbs and litter supplement nutrients, soil organic carbon and help in maintaining good physical properties of the soil which are essential for growth (Reddy *et al.*, 2012). The low nutrient availability in BWS can be because of different exposure of soils and steepness of the place and decrease in the soil fertility with elevation (FAO, 2015). There was no grassland ecosystem in the study area in PWS compared to BWS which had vast expanse of grassland ecosystem which can also be one of the reasons for the overall low nutrient availability in BWS.

6.4 Carbon Stock across Elevation Ranges

The 15 elevational gradients in BWS and the 16 in PWS was categorized, low (100-500 m), mid (600-1000m) and high (1000-1700 m) elevation ranges. Among the altitudinal ranges classified, carbon stock was recorded maximum for low (426.14±89.36 t/ha), followed by medium (173.42±38.95 t/ha) and high (74.76±34.73 t/ha) range in BWS and it was recorded maximum for medium (170.34±48.52 t/ha) in PWS followed by low (169.40±51.34 t/ha) and high (157.79±77.05 t/ha) elevation range (Fig 52). The carbon stock value varied significantly between the three elevation ranges in BWS (ANOVA:$F=9.19$, $p<0.05$) whereas in PWS, there was not much variation between the carbon stock values (ANOVA:$F=0.01$,$p>0.05$)

The low elevation class of BWS had 49 species with 370 individuals and had higher carbon stock (426.14±89.36 t/ha) than PWS (169.40±51.34 t/ha) with 35 species and 203 individuals. However it may be noted that, lower elevation range in PWS was considered at 200 m and not 100 m as in BWS. The carbon stock of the tree species in low elevation range varied from 0.11 to 520 t/ha and 0.05 to 80.60 t/ha in BWS and PWS respectively. *Hopea parviflora* (520 t/ha) followed by *Dimocarpus longan* (162.25 t/ha) had the highest carbon stock in BWS whereas *Hopea parviflora* (97.58 t/ha) followed by *Messua ferrea* (92.18 t/ha) had the highest carbon stock in PWS. The carbon sequestration potential of the low elevation range was 1563.94±327.98 t/ha in BWS and 621.73±188.44 t/ha in PWS respectively.

The carbon stock of the mid elevation range in BWS (173.42±38.95 t/ha) had higher carbon stock than PWS (170.34±48.52 t/ha). The mid elevation range of BWS had 61 species with

312 individuals and PWS had 54 species with 274 individuals. Carbon stock of trees in the mid elevation range in BWS varied from 0.06 to 125.32 t/ha and 0.12 to 24.26 t/ha in PWS respectively. *Lagerstroemia microcarpa* (125.32 t/ha) followed by *Olea dioica* (78.36 t/ha) had the highest carbon stock in BWS whereas *Hopea canarensis* (117.70 t/ha) followed by *Ficus nervosa* (69.60 t/ha) had the highest Carbon stock in PWS. The carbon sequestration potential of the mid elevation range was 636.46±142.95 t/ha in BWS and 625.15±178.08 t/ha in PWS.

The high elevation range for BWS was up to 1500 m and it was till 1700 m in PWS. The carbon stock was 74.76±34.73 t/ha in BWS and 157.79±77.05 t/ha in PWS. The high elevation range of BWS had 36 species with 202 individuals and PWS had 55 species with 347 individuals. Carbon stock in the high elevation range in BWS varied between 0.07 to 86.11 t/ha and 0.05 to 417.43 t/ha in PWS. *Memecylon randeriana* (86.11 t/ha) followed by *Bischofia javanica* (51.03 t/ha) had the highest Carbon stock in BWS. *Palaquium ellipticum* (417.43 t/ha) followed by *Ficus nervosa* (117.34 t/ha) had the highest carbon stock in PWS. The carbon sequestration potential of the high elevation range was 274.39±127.46 t/ha in BWS and 579.11±282.78 t/ha in PWS.

The carbon stock was found to be higher in low elevation range in BWS but it was found to be higher in the mid elevation range in PWS. The maximum carbon stock in the lower elevation in BWS can be due to the presence of more number of trees whereas the maximum carbon stock in PWS in the mid elevation can be due to more number of trees with larger stem size.

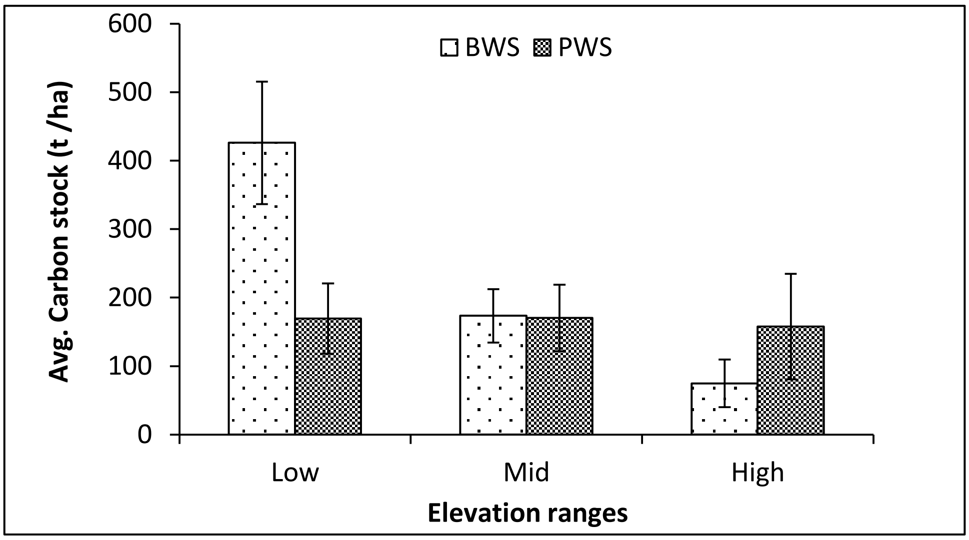


Fig 52. Carbon Stock in Elevational ranges in BWS and PWS of Kodagu District, Karnataka.

Biomass and Carbon Stock

The quantification of carbon stock was carried out in the forests of BWS and PWS using allometric equations for Above Ground Biomass (AGB) and Below Ground Biomass (BGB). The overall biomass of the forests of BWS and PWS was estimated at 381.37±60.94 t/ha. The biomass in BWS was estimated at 449.55±101.67 t/ha and PWS at 329.24±74.01 t/ha respectively. The biomass varied from 31.40 t/ha at 1500 m to 1346.69 t/ha at 100 m in BWS and 10.87 t/ha at 1700 m to 909.72 t/ha at 1200 m across the elevational gradients in PWS.

The total AGB in BWS and PWS was estimated at 161.25±32.90 t/ha. The AGB was estimated at 362.44±83.85 t/ha and 264.67±60.95 t/ha in BWS and PWS respectively. The AGB ranged between 23.54 t/ha at 1500 m and 1113.09 t/ha at 100 m and 7.88 t/ha at 1700 m and 743.79 t/ha at 1100 m across the elevational gradients in BWS and PWS respectively (Fig 53). In BWS, *Hopea parviflora* (866.81 t/ha) contributed the highest AGB whereas *Bridelia retusa* (0.09 t/ha) contributed the lowest AGB and *Ficus nervosa* (78.36 t/ha) contributed the highest AGB whereas *Cinnamomum sulphuratum* (0.06 t/ha) contributed the lowest AGB in PWS.

The AGB of 362.44±83.85 t/ha and 264.67±60.95 t/ha in BWS and PWS respectively is comparable with 324 Mg/ha in the natural forest of Northeast India (Baishya *et al*., 2009), 275.46±96.15 t/ha in the tropical rain forest of Thailand (Terankupisut, 2017) but it is higher than the tropical rain forest of Uttara Kannada district 124.84 ± 29.05 (Bhat & Ravindranath, 2011) and 119.24 t/ha in the montane forest in West Malaysia (Jeyanny *et al*., 2014) and lower than the value of 607.7 Mg/ha in the tropical wet evergreen forest (Rai, 1981), 402.22±83.43 in the Western Himalaya (Bhat *et al*., 2013) and 468 Mg/ha in the tropical semi ever-green forest of Western Ghats of India (Swamy, 1989).

The total BGB in BWS and PWS was estimated at 38.96±7.20 t/ha. The BGB was estimated at 87.12±17.89 t/ha and 64.56±13.09 in BWS and PWS respectively. The BGB ranged between 7.86 t/ha at 1500 m and 236.60 t/ha at 100 m in BWS and between 2.98 t/ha at 1700 m and 170.11 t/ha at 1200 m across the elevational gradients of PWS. *Hopea parviflora* (177.41 t/ha) had the highest value of BGB and *Bridelia retusa* (0.04 t/ha) had the lowest value of BGB in BWS. *Ficus nervosa* (15.10 t/ha) had the highest BGB value and *Cinnamomum sulphuratum* (0.03 t/ha) had the lowest BGB value in PWS.

A total carbon stock of 6006 t and a standing biomass of 12011 t were estimated from 1708 individual trees covering an area of 3.72 ha from the forests of BWS and PWS. The mean carbon stock in each elevation gradient was estimated at 193.73±31.09 t/ha and the standing biomass was estimated at 387.46±62.19 t/ha respectively. The overall carbon stock was found to be higher in BWS than PWS (Fig 54).

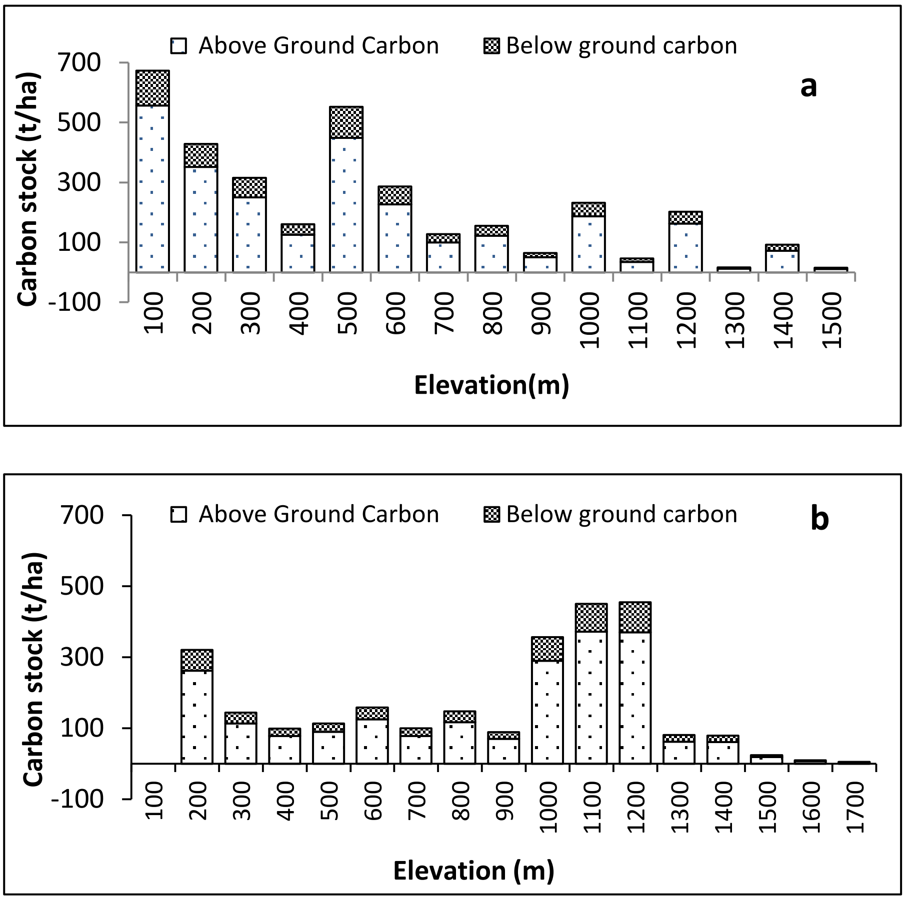


Fig: 53. Above Ground and Below Ground Carbon Stock across Elevational Gradients in BWS (a) and PWS (b) of Kodagu District, Karnataka.

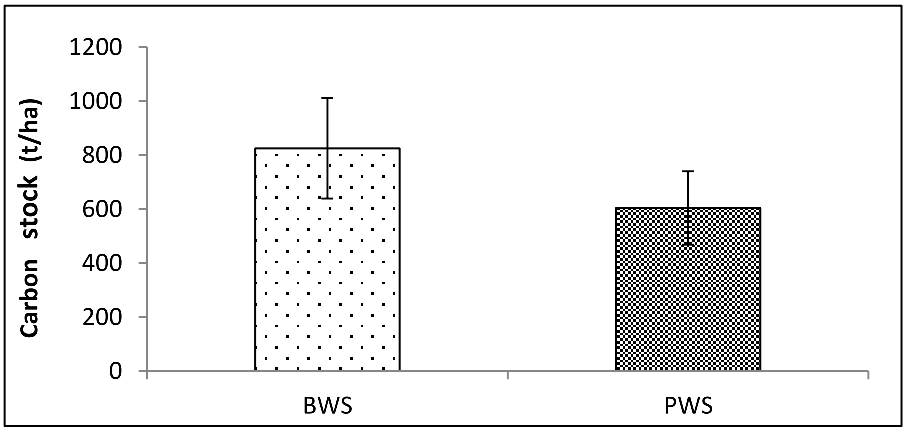


Fig 54. Carbon Stock in BWS and PWS of Kodagu district, Karnataka.

The carbon stock in BWS was estimated at 224.77±50.83 t/ha out of which 181.21±41.92 t/ha contributed to AGC and 43.55±8.94 t/ha contributed to BGC. The minimum carbon stock of 15.68 t/ha was recorded at 1500 m and the maximum carbon stock of 673.33 t/ha was recorded at 100 m in BWS. Whereas in PWS, carbon stock was estimated at 164.62±37.00 t/ha out of which 132.33±30.47 t/ha contributed to AGC and 32.28±6.54 t C/ha contributed to BGC. The minimum carbon stock of 5.43 t/ha was recorded at 1700 m and the maximum carbon stock of 454.85 t/ha was recorded at 1200 m in PWS. There was a strong negative correlation between carbon stocks with elevation in BWS whereas there was a weak correlation between carbon stock with elevation in PWS (Fig 55).

Species and Family Wise Carbon Stock

A total of 94 species was recorded in BWS out of which *Ficus virens* (21.53 t/ha) with two individuals had the highest carbon stock which is due to its large girth size. It was then *Hopea parviflora* (17.40 t/ha) with 30 individuals (Fig 56). *Bridelia retusa* (0.07 t/ha) stored least carbon followed by *Zanthoxylum rhetsa* (0.08 t/ha) with 1 individual each. In PWS, 84 species was recorded and *Ficus nervosa* (46.74 t/ha) with 4 individuals had the highest carbon stock followed by *Hydnocarpus petandra* (31.74 t/ha) with two individuals and *Messua ferrea* (30.73) with three individuals (Fig 57). *Cinnamomum sulphuratum* (0.05 t/ha) followed by *Schefflera wallichiana* (0.07 t/ha) with one individual each had the least carbon stock. The mean carbon stock for each species in BWS was 3.81±0.40 t/ha whereas it was 3.19±0.34 t/ha in PWS.

In both the landscapes, *Ficus* species was found to be the major species which stored more carbon. The carbon stock of 224.77±50.83 t/ha in BWS and 164.62±37.00 t/ha in PWS are comparable with 216.2±26.4 and 206.6±19.9 Mg C/ha from two grassland ecosystems in the Western Ghats (Subashree & Sundarapadian, 2017), but lower than 258.05±53.01 Mg/ha in the Western Himalaya (Bhat *et al*., 2013) and 241.3±37.5 Mg C/ha in the tropical forest of Columbia (Philips *et al*., 2019). The carbon stock decreased with elevation in both BWS and PWS which is similar to the result recorded by Liu & Nan (2018) The variations in the carbon stock may be due to differences in age structure, species composition, storage potential, stage of development and site characteristics (Kumar *et al*., 1998), terrain characteristics, edaphic factors (Subashree & Sundarapandian, 2017), leaf traits, microclimate, edaphic characters (Pragasan, 2016).

The family with the highest biomass was recorded for Melastomaceae (10.70%) in BWS followed by Callophyllaceae (8.32%) whereas Combretaceae (0.18%) followed by Asteraceae (0.24%) had the least biomass in BWS. In PWS, Flacourtiaceae (16.18 %) had the highest biomass followed by Callophyllaceae (15.67%) and the least biomass was recorded for Araliaceae (0.07%) followed by Rutaceae (0.12%) in PWS. The average biomass for each family was 6.88±1.17 t/ha and 10.22±2.41 t/ha in BWS and PWS respectively.

The family Melastomaceae had the highest carbon stock in BWS and contributed to 10.70 % of the carbon stock (14.35 t/ha) (Fig 56) whereas in PWS, Flacourtiaceae had the highest carbon stock and contributed to 16.18 % of the carbon stock (31.74 t/ha) (Fig 56). The average carbon stock for each family was 86.45±20.01 t/ha and 69.31±18.34 t/ha in BWS and PWS respectively.

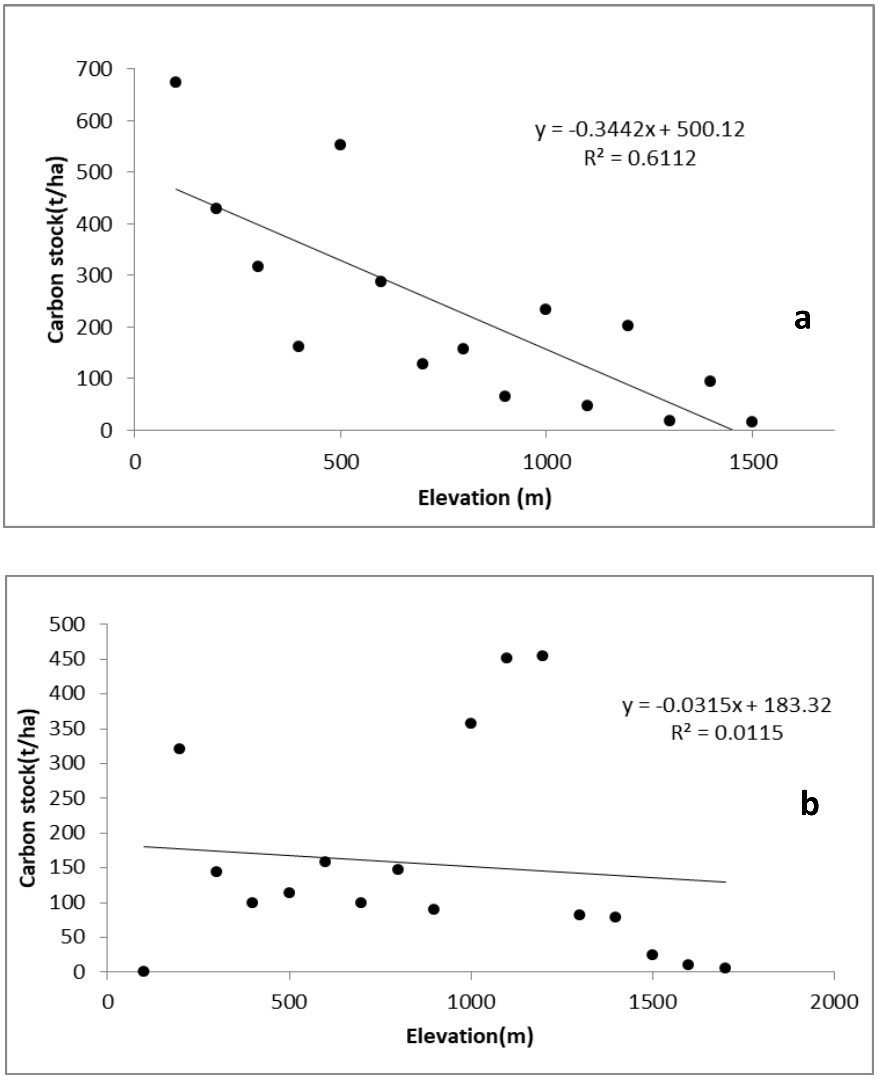
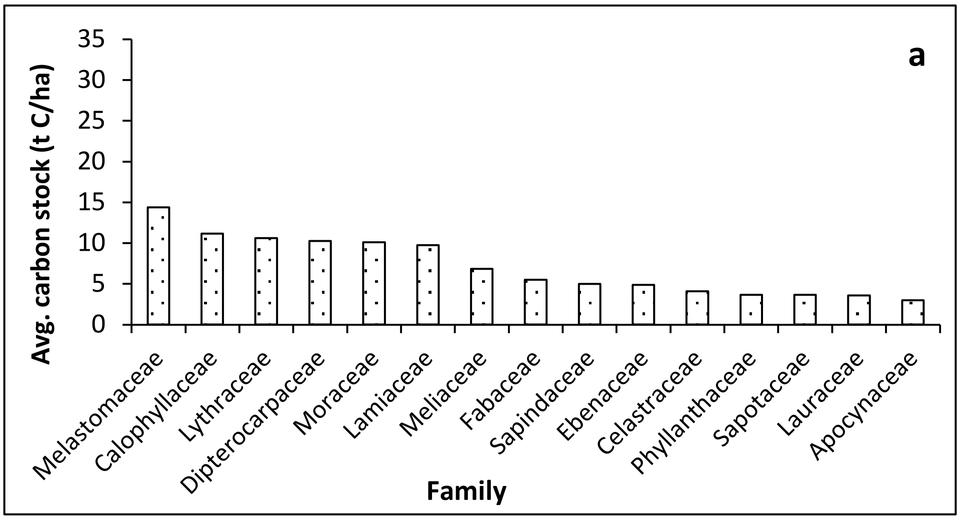


Fig 55. Carbon stock across Elevational Gradients in BWS and PWS of Kodagu district, Karnataka.



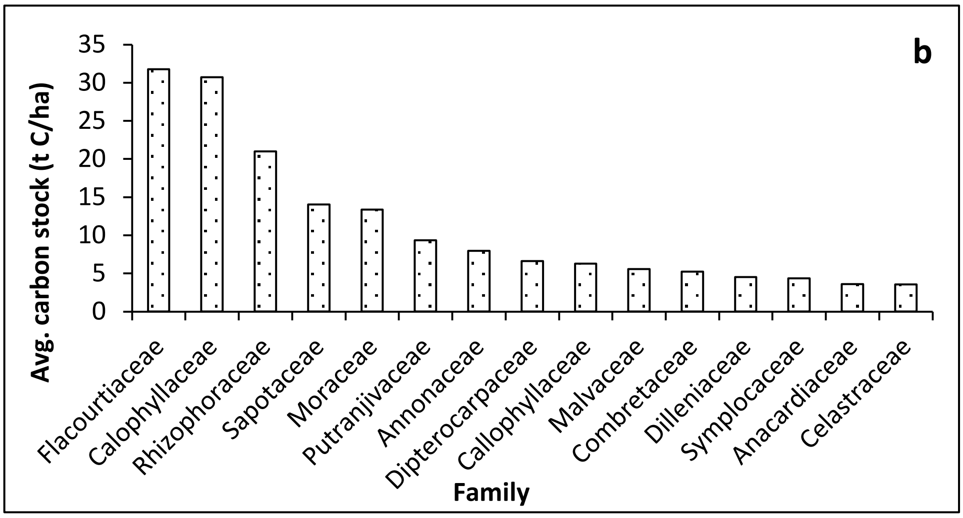
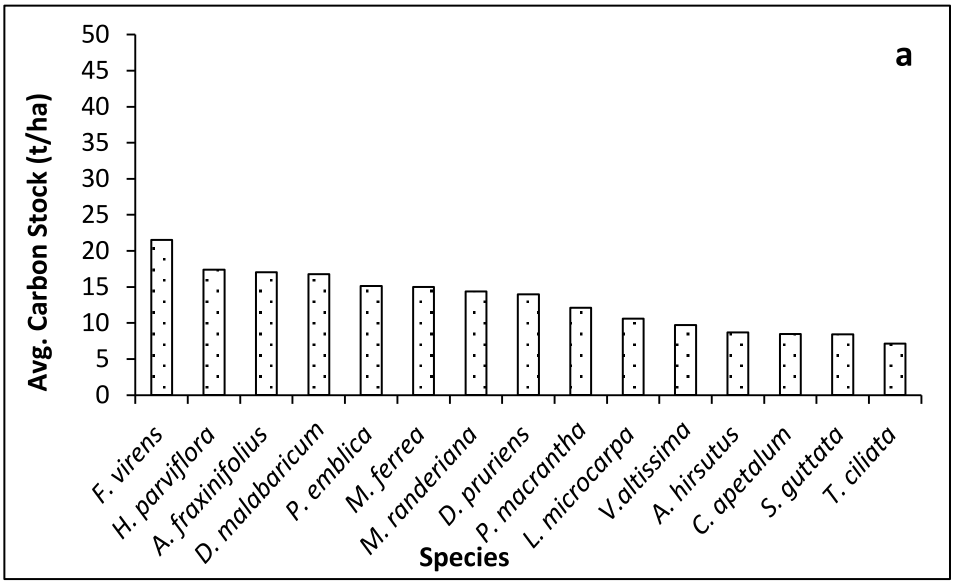


Fig 56. Carbon stock of top fifteen families in BWS (a) and PWS (b) of Kodagu district, Karnataka.



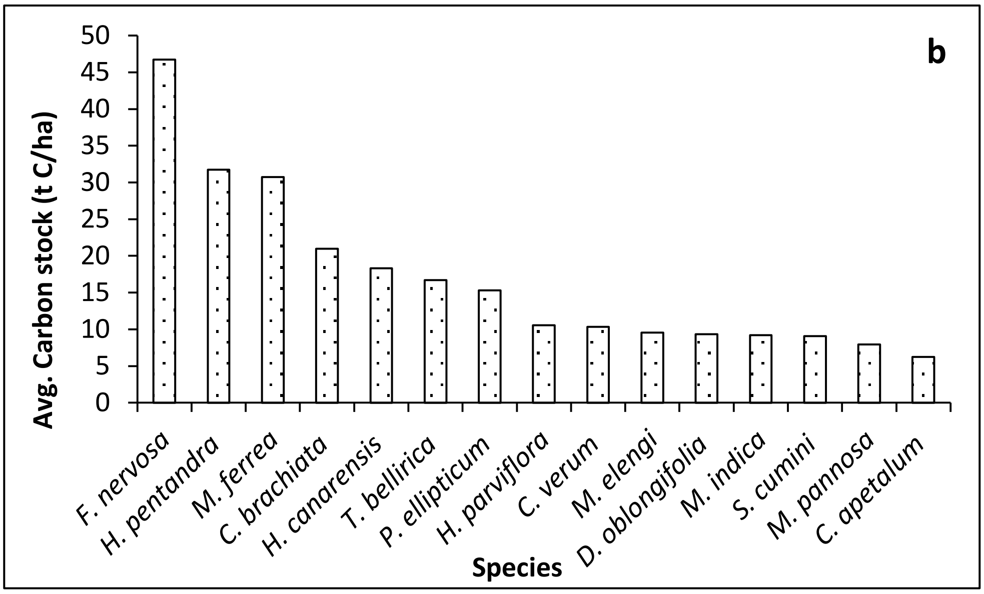


Fig 57. Carbon stock of top fifteen Species in BWS and PWS of Kodagu district, Karnataka.

Carbon Stock according to Girth Size Class

The trees were categorised into ten classes based on their Girth at Breast Height (GBH) viz., 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm, 240-270, 270-300, >300 cm. A significant variation in the distribution of C stock was observed between the ten tree size classes and the maximum C stock was observed for the highest girth class i.e., >300 cm (33.01%) followed by 240-270 cm (8.98 %) in BWS and in PWS, the girth class >300 cm (31.64%) had the highest carbon followed by 120-150 cm (12.05%) (Fig 58). The AGC contributed to 930.35 t/ha and BGC contributed to 27.97 t/ha of the total carbon in the class >300 cm in BWS and in PWS, AGC contributed to 696.18 t/ha and BGC 137.14 t/ha contributed to the total carbon in the class >300m .

The carbon stock of a tree is directly proportional to its stem size and hence total carbon stored in a forest is mostly influenced by the number of trees in larger stem size category rather than total tree density (Pragasan, 2016). The girth class >300 cm contributed the highest in the total carbon stock in both BWS and PWS. A higher proportion of carbon storage in the higher diameter classes in natural forest does indicate the important role of large trees in carbon storage but does not undermine the role of small trees (<60cm) which would enhance the future carbon stock because of their high carbon sequestration potential (Baishya *et al*., 2009).

About 33 % of the biomass was present in > 300 cm GBH trees in the forest of BWS and 32% in the forest of PWS. Even though the number of individuals in 30-60 cm girth class was higher in both BWS and PWS, the carbon stock was greater in >300cm girth class. The contribution of trees to carbon stock was greater in >300 cm girth class trees in both BWS and PWS.

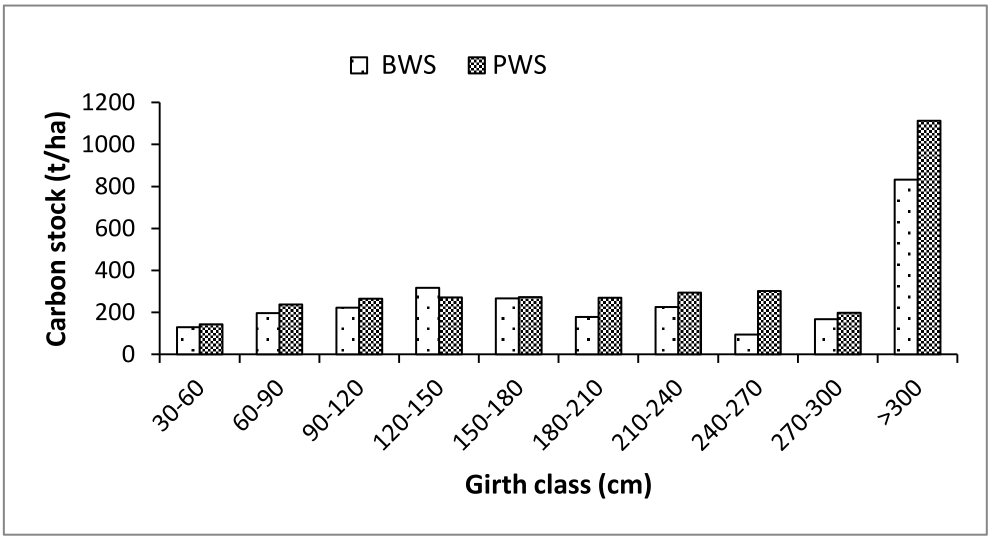


Fig 58. Carbon Stock across Girth Classes in Protected Areas of BWS and PWS of Kodagu District, Karnataka.

Carbon Sequestration

The carbon sequestration potential of the forests of BWS and PWS was estimated at 710.98±114.12 t/ha. The carbon sequestration potential varied among the different elevational gradients and ranged between 57.61 t/ha at 1500 m to 2471.16 t/ha at 100 m in BWS and 19.94 t/ha at 1700 m to 1177.68 t/ha at 200 m in PWS (Fig 59). The mean carbon sequestration potential across the elevational gradients in BWS was 824.93±181.56 t/ha and 604.15±135.81 in PWS. *Ficus virens* (79 t/ha) in BWS and *Ficus nervosa* (171.52 t/ha) in PWS were the species which had the highest carbon sequestration potential. The average carbon sequestration potential for a single species in BWS and PWS was 13.99±1.47 t/ha and 11.73±1.26 respectively. The carbon sequestration potential was found to be higher in BWS than in PWS (Fig. 60).

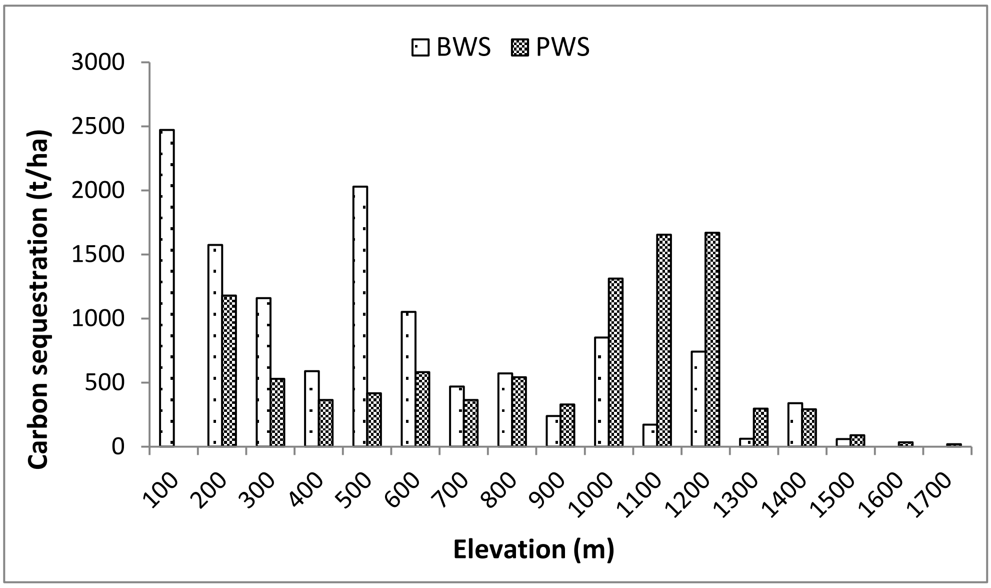


Fig 59. Carbon sequestration across Elevational Gradients of BWS and PWS of Kodagu district, Karnataka.

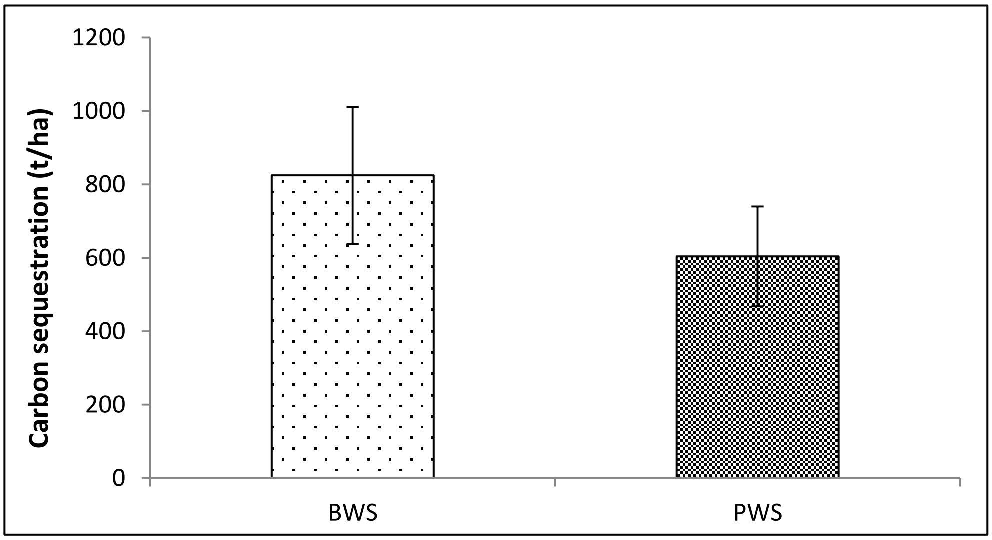


Fig 60. Carbon sequestration in Protected Areas of Kodagu district, Karnataka.

The carbon sequestration potential of the forests of BWS and PWS was recorded at 824.93±181.30 t/ha and 604.15±135.81 respectively which is higher than the evergreen and moist deciduous forests of Kodagu (Hareesh & Nagarajaiah, 2019). Carbon sequestration potential varies on forest type, forest age and size of trees (Terakunpisut *et al*. 2007). The forests of BWS and PWS thus act as carbon sinks and and can assist in the mitigation of climate change.

Chapter - 7

CONCLUSIONS & RECOMMENDATIONS

7.1 Conclusions

The spatio-temporal analysis indicated decrease in land cover and a little increase in areas having habitat with vegetation in the past two decades. The NDVI analysis indicated the same, hence continued efforts are necessary to protect these Protected Areas, Eco-Sensitive Zones and adjoining Reserve Forests. The vegetation across two landscapes showed presence of a diverse flora with maximum species diversity occurring in lower elevations and decreased diversity in higher elevations. However, endemic tree species was found to be more abundant in higher elevations. BWS and PWS have shown relatively healthy regeneration of population, which will help in balancing different species in different strata and girth class. The forest structure and composition of the vegetation changed along the elevational gradients with a decrease in tree height and girth size of the trees with increase in elevation.

The study concludes that elevation plays a major role in vegetation pattern and composition of species. The grassland ecosystem in BWS dominated by *Ageratina adenophora,* an invasive weed spread to a vast area and is a threat for other species. It can also alter the ecological communities of the grasslands and adjoining shola forests. There have also been occurrences of forest fires in the grassland ecosystems, which can also affect the growth of trees as well as other herbs and shrubs. PWS had an abundance of *Strobilanthes kunthiana* along the edge of the forest in the higher elevations which grew tall and suppressed the regeneration of other species. BWS and PWS also showed great potential for carbon sequestration with BWS having higher potential than PWS. These forests thus act as carbon sinks, which is helpful in climate change mitigation.

The green cover in Kodagu district is decreasing with the increase in the expansion for coffee plantations and other commercial activities. Hence Protected Areas are important not only for the conservation of the species but also to regulate climate. Protected Areas are also important as they are the origin of many tributaries. And so without these forests, the livelihood of the people in downstream will be affected. The freshwater from the mountains sustains many natural habitats and contributes to biological diversity. The montane ecosystems are therefore very important for the survival of the species in the Protected Areas. The study also recorded the presence of a large number of endemic species, the habitat of which needs to be protected.

7.2 Recommendations

- The Protected Areas give birth to many rivers such as Kabini, Hemavathi, Harangi, Laxmanthirtha and main Cauvery. These areas need to be protected by undertaking watershed measures such as gully plugging and check dams to enhance the water availability in streams to improve riparian forest, aquatic biodiversity and serve as water source for faunal species in the Sanctuary.
- Shola forests are the tropical evergreen forest patches found in depressions amidst the high altitude grassland. These forests are threatened due to fire and invasive species. Hence, it is proposed to have effective fire prevention measures all along the periphery of important shola forest coming in BWS as top priority. It is therefore suggested to use remote sensing techniques in fire detection and dissemination measures to fire fighter personals to prevent damage.
- The landscapes of these Protected Areas have panoramic view, scenic location with beautiful waterfalls, hillocks, grasslands embedded with sholas which attracts tourist. These Protected Areas have many trekking paths and it will damage the ecology of the area. Hence, eco-tourism should be restricted in fire and monsoon seasons and regulated in other period. Many illegal home-stays in Eco-Sensitive Zones should be restricted and regulated with appropriate ecotourism policy to protect fragile mountain forests.
- These three Protected Areas were declared as UNESCO sites recently. Hence proper coordination is necessary from global to local stakeholders to protect these beautiful landscapes of Western Ghats.
- These three contagious sanctuaries are corridors for Elephants, Tigers and other animals. These big mammals move out of the Protected Areas to coffee plantations in summer in search of food and water creating human wildlife conflict. Hence it is proposed to undertake bamboo plantation on the buffer areas of the adjoining Reserve Forest region to reduce conflicts.

- Our observations in these Protected Areas also reveal that coffee has been introduced upto the fringes of the sanctuary including the Eco-Sensitive Zones and adjoining Reserve Forest. Hence coffee expansion to higher elevation should be restricted to outside Eco-Sensitive Zones of Protected Areas.
- Most of the boundaries of these Protected Areas run along the adjacent agriculture land with scattered settlements. Hence, the forest fringe experiencing grazing and Non-Timber forest products collection need to be regulated to promote regeneration.

REFERENCES

Acharya, B. K., Chettri, B., & Vijayan, L. (2011). Distribution pattern of trees along an elevation gradient of Eastern Himalaya, India. *Acta Oecologica*, 37(4), 329-336.

Ahirwal, J., & Maiti, S. K. (2018). Carbon sequestration and Soil CO_2 flux in reclaimed coal mine lands from India. In Prasad, M.N.V., Favas, P.J. de.C., Maiti, S.K.(Eds.). *Bio-Geotechnologies for Mine Site Rehabilitation*, (pp. 371-392). Elsevier, Netherlands.

Aishan, T., Betz, F., Halik, Ü., Cyffka, B., & Rouzi, A. (2018). Biomass carbon sequestration potential by riparian forest in the Tarim River watershed, Northwest China: Implication for the mitigation of climate change impact. *Forests*, 9 (196), 1-15.

Alexandrov, G. (2008). Climate Change 1: Short-Term Dynamics. In Jorgensen, S.E., & Fath, B. *Encyclopedia of Ecology*. (pp. 588-592). Elsevier, Amsterdam, Netherlands.

Alsaaideh, B., Al-Hanbali, A., & Tateishi, R. (2011). Assessment of land use/cover change and urban expansion of the central part of Jordan using remote sensing and GIS. *Asian Journal of Geoinformatics*, 11(3), 1-9.

Al-Sagheer, N. A., Prasad, A. D., & Prakash, N. A. (2009). Impact of anthropogenic pressures on forest structure and species composition of moist deciduous forest in Thithimathi Range of Western Ghats, India. *International Journal of Applied Agricultural Research*, 4(2), 131-149.

Ambinakudige, S., & Sathish, B. N. (2009). Comparing tree diversity and composition in coffee farms and sacred forests in the Western Ghats of India. *Biodiversity and Conservation*, 18(4), 987-1000.

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

Ashton, P. S. (1992). Species richness in plant communities. In Fiedler, P.L., & Jain, S.K. Conservation biology, (pp. 3-22). Springer, Boston, MA.

Aubert, P. M., Vendé, J., Leroy, M., Boucetta, A., Combaz, D., Ecourtemer, T., Francois. Y., Jehanno, T., Maubourget, S., Michel, E., & Paviot, B.(2012). *Environmental prospective in Kodagu (Kanataka, India): How to enhance biodiversity and watershed resources management?* Working papers. Post Master Programme, International management, nature and society.

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

Bai, Y., Broersma, K., Thompson, D., & Ross, T. J. (2004). Landscape-level dynamics of grassland-forest transitions in British Columbia. *Rangeland Ecology & Management*, 57(1), 66–75.

Baishya, R., Barik, S. K., & Upadhaya, K. (2009). Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India. *Tropical Ecology*, 50(2), 295-304.

Baker, T. R., Phillips, O. L., Malhi, Y., Almeida, S., Arroyo, L., Di Fiore, A., Erwin, T., Killeen, T.J., Laurance, S.G., Laurance,W.F., Lewis,S.L.,Llyod,J., Monteragudo,A.,Neill,D.A.,Patino, S.,Pitman,N.C.A.,Silva,J.N.M., & Martinez, R.V. (2004). Variation in wood density determines spatial patterns in Amazonian forest biomass. *Global Change Biology*, 10(5), 545-562.

Baraloto, C., Molto, Q., Rabaud, S., Hérault, B., Valencia, R., Blanc, L., Fine, P.V.A., & Thompson, J. (2013). Rapid simultaneous estimation of aboveground biomass and tree diversity across Neotropical forests: a comparison of field inventory methods. *Biotropica*, 45(3), 288-298.

Bawa, K. S., Karanth, K. U., Kumar, N. S., Rao, M., Das, A., & Krishnaswamy, J. (2007). *Western Ghats & Sri Lanka biodiversity hotspot*. Critical Ecosystems Partnership Fund, Virginia.

Behera, S. K., Sahu, N., Mishra, A. K., Bargali, S. S., Behera, M. D., & Tuli, R. (2016). Aboveground biomass and carbon stock assessment in Indian tropical deciduous forest and relationship with stand structural attributes. *Ecological Engineering*, 99, 513-524.

Bharathi, S., & Prasad, A. G. D. (2015). Regeneration status of tree composition in the sacred groves of Mercara, Central Western Ghats. *European Journal of Experimental Biology*, *5*(10), 29-40.

Bhat, D. M., & Ravindranath, N. H. (2011). Above-ground standing biomass and carbon stock dynamics under a varied degree of anthropogenic pressure in tropical rain forests of Uttara Kannada District, Western Ghats, India. *Taiwania*, 56(2), 85-96.

Bhat, J.A., Iqbal, K. ,Kumar, M., Negi, A. K., & Todaria, N. P. (2013). Carbon stock of trees along an elevational gradient in temperate forests of Kedarnath Wildlife Sanctuary. *Forest Science and Practice*, 15(2), 137-143.

Bhattarai, K, R., & Vetaas, O, R. (2006). Can Rapoport’s rule explain tree species richness along the Himalayan elevation gradient, Nepal? *Diversity and Distributions*, 12 (4), 373-378.

Bisht, A. S., & Bhat, A.B. (2013). Vegetational structure and plant diversity relation in a sub-alpine region of Garhwal Himalaya, Uttarakhand India. *African Journal of Plant Science*, 7(8), 401-406.

Bounoua, L., Collatz, G. J., Los, S. O., Sellers, P. J., Dazlich, D. A., Tucker, C. J., & Randall, D. A. (2000). Sensitivity of climate to changes in NDVI. *Journal of Climate*, 13(13), 2277-2292.

Bravo F., del Río M., Bravo-Oviedo A., Del Peso C., & Montero G. (2008) Forest Management Strategies and Carbon Sequestration. In: Bravo F., Jandl R., LeMay V., von Gadow K. (eds) *Managing Forest Ecosystems: The Challenge of Climate Change*, 17, 179-194. Springer, Dordrecht, Netherlands.

Brown, S. (1997). *Estimating biomass and biomass change of tropical forests*: a primer. FAO forestry paper 134. Food and Agriculture Organization of the United Nations, Rome.

Brown, S., & Lugo, A. E. (1982). The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica*, 14(3), 161-187.

Bunyan, M., Bardhan, S., Singh, A., & Jose, S. (2015). Effect of topography on the distribution of tropical montane forests fragments: A predictive modelling approach. *Journal of Tropical Forest Science*, 27(1), 30-38.

Cairns, M. A., Brown, S., Helmer, E. H., & Baumgardner, G. A. (1997). Root biomass allocation in the world's upland forests. *Oecologia*, 111(1), 1-11.

CBD. (1992). Article 2. Use of Terms. United Nations. Retrieved from https://www.cbd.int/convention/articles/default.shtml?a=cbd-02

CBD. (2003).Mountain Biological Diversity. Subsidiary Body on Scientific, Technical and Technological Advice 9 Recommendation IX/12. Retrieved from https://www.cbd.int/recommendation/sbstta/?id=7468

Census of India. (2011). Ministry of Home affairs. Government of India. http://censusindia.gov.in/2011-Common/CensusData2011.html

CEPF. (2016). Critical Ecosystem Partnership Fund. https://www.cepf.net/stories/announcing-worlds-36th-biodiversity-hotspot-north-american-coastal-plain

Champion, H. G. (1936). A preliminary survey of forest types of India and Burma. *Indian Forestry Record (NS) Silviculture*, 1(1), (pp.286).

Champion, S. H., & Seth, S. K. (1968). *A revised survey of the forest types of India*. Manager of publications, Delhi.

Chandrashekara, U. M., & Ramakrishnan, P. S. (1994). Vegetation and gap dynamics of a tropical wet evergreen forest in the Western Ghats of Kerala, India. *Journal of Tropical Ecology*, 10(3), 337-354.

Chapin, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., Hobbie, S. E., Mack, M. C., & Diaz, S. (2000). Consequences of changing biodiversity. *Nature*, 405(6783), 234-242.

Chauhan, D. S., Dhanai, C. S., Singh, B., Chauhan, S., Todaria, N. P., & Khalid, M. A. (2008). Regeneration and tree diversity in natural and planted forests in a Terai- Bhabhar forest in Katarniaghat Wildlife Sanctuary, India. *Tropical Ecology*, 49(1), 53-67.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira,T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B., & Yakamura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145(1), 87-99.

Chen, Y., Liu, Z., Rao, X., Wang, X., Liang, C., Lin, Y., Zhou, L., Cai, X., & Fu, S. (2015). Carbon storage and allocation pattern in plant biomass among different forest plantation stands in Guangdong, China. *Forests*, 6(3), 794-808.

Chhabra, A., Palria, S., & Dadhwal, V. K. (2003). Soil organic carbon pool in Indian forests. *Forest Ecology and Management*, 173, 187-199.

Chitale, V.S., Behera, M.D., & Roy, P.S. (2014). Future of endemic flora of Biodiversity hotspots in India. *PLOS One*, 9(12), 1-15.

Condit, R., Hubbell, S. P., & Foster, R. B. (1995). Mortality rates of 205 neotropical tree and shrub species and the impact of a severe drought. *Ecological monographs*, 65(4), 419-439.

Condit, R., Hubbell, S. P., Lafrankie, J.V., Sukumar, R., Manokaran, N., Foster, R.B., & Ashton,P. S. (1996). Species - area and species-individual relationships for tropical trees:A Comparison of three 50-ha plots. *Journal of Ecology*, 84(4), 549-562.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A., & Totterdell, I. J. (2000). Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature*, 408(6809), 184- 187.

Crichton, R. R. (2012). *Biological Inorganic Chemistry: A New Introduction to Molecular Structure and Function* (2rd edition). Academic press.

Curtis, J.T., & McIntosh, R.P. (1950). The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, 31(3), 434- 455.

Daniels, R. R. (1997). Taxonomic uncertainties and conservation assessment of the Western Ghats. *Current Science*, *73*(2), 169-170.

Dar, J. A., & Sundarapandian, S. (2016). Patterns of plant diversity in seven temperate forest types of Western Himalaya, India. *Journal of Asia-Pacific Biodiversity*, 9, 280-292.

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

Dawkins, H. C. (1959). The volume increment of natural tropical high-forest and limitations on its improvements. *Empire Forestry Review*, 38(2), 175-180.

Divya, V., Padmala, D., & Mohanan, C.N. (2016). Soils of Southern Western Ghats (India)-a potential archive of late Holocene Climate records. *International Journal of Scientific and Research Publications*, 6(3), 302-306.

Drisya, J., Kumar, S.D., & Roshni, T. (2018). Spatiotemporal Variability of Soil Moisture and Drought Estimation Using a Distributed Hydrological Model. In Samui, P., Kim, D. & Ghosh, C. (Eds.) *Integrating Disaster Science and Management, Global case studies in mitigation and recovery* (pp. 451-460). Elsevier, Netherlands.

Dyson, F.J. (1977). Can we control the carbon dioxide in the atmosphere? *Energy*, 2(3), 287-291.

Eilu, G., & Obua, J. (2005). Tree condition and natural regeneration in disturbed sites of Bwindi Impenetrable Forest National Park, southwestern Uganda. *Tropical Ecology*, 46(1), 99-101.

FAO. (2003). *Forest and Climate change*. Rome. Instruments related to the United Nations Framework Convention on Climate Change and their potential for sustainable forest management in Africa. Alain Karsenty, Cecile Blanc, Thomas Dufour. CIRAD-Foret, PARIS, France.

FAO. (2010). *Global Forest Resources Assessment*. Food and Agriculture Organization of the United Nations.Rome, Italy.

FAO. (2011). *State of the World's Forest*. Food and Agriculture Organization of the United Nations.

FAO. (2015). Understanding Mountain Soils: *A contribution from mountain areas to the International Year of Soils 2015*, by Romeo, R., Vita, A., Manuelli, S., Zanini, E., Freppaz, M. & Stanchi, S. Rome, Italy.

FAO. (2018). *The State of the World's Forests 2018* - Forest pathways to sustainable development. Rome.

FSI. (1995). *Report on Inventory of Forest resources of Kodagu district (Karnataka)*. Forest Survey of India. Southern Zone. Bangalore. Government of India. Ministry of Environment and forests.

FSI. (2007). *India State of Forest Report. Forest Survey of India*. Ministry of Environment Forest and climate change, Government of India.

FSI. (2017). *India State of Forest Report. Forest Survey of India*. Ministry of Environment Forest and climate change, Government of India.

Fu, C., Hua, X., Li, J., Chang, Z., Pu, Z., & Chen, J. (2006). Elevational patterns of frog species richness and endemic richness in the Hengduan Mountains, China: geometric constraints, area and climate effects. *Ecography*, 29(6), 919-927

Gabriele, B., & Keplin, B. (2005). *Mountain Ecosystems, Studies in Treeline Ecology*. Springer, Berlin Heidelberg, New York.

Gairola, S., Sharma, C. M., Ghildiyal, S. K., & Suyal, S. (2011). Tree species composition and diversity along an altitudinal gradient in moist tropical montane valley slopes of the Garhwal Himalaya, India. *Forest Science and Technology*, 7(3), 91-102.

Gandhi, G. M., Parthiban, S., Thummalu, N., & Christy, A. (2015). NDVI: Vegetation change detection using remote sensing and GIS–a case study of Vellore District. *Procedia Computer Science*, 57, 1199-1210.

Ganesh, T. Ganesan, R. Soubadra, D. M. Davidar, P., & Bawa, K. S. (1996). Assessment of plant biodiversity at a mid-elevation evergreen forest of Kalakad-Mundanthurai Tiger reserve, Western Ghats, India. *Current Science* 71(5), 379-392.

Garcia C., Bhagwat S. A., Ghazoul J., Nath C. D., Nanaya K. M., Kushalappa C. G., Raghuramulu Y., Nasi R., & Vaast P., (2009). Biodiversity Conservation in Agricultural Landscapes: Challenges and Opportunities of Coffee Agroforests in the Western Ghats, India. *Conservation Biology*, 24 (2), 479-488.

Garcia, C., Marie-Vivien, D., Kushalappa, C. G., Chengappa, P. G., & Nanaya, K. M. (2007). Geographical indications and biodiversity in the Western Ghats, India. Can labeling benefit producers and the environment in a mountain agroforestry landscape? *Mountain Research and Development*, 27 (3), 206–210.

Gentry, A. H. (1988). Changes in plant community diversity and floristic composition on environmental and geographical gradients. *Annals of the Missouri botanical garden*, 75(1), 1-34.

Gentry, A. H. (1992). Tropical forest biodiversity: distributional patterns and their conservational significance. *Oikos*, 63(1), 19-28.

George, J., Baby, L., Arickal, A. P., Vattoly, J. D., & Use, L. (2016). Land use/land cover mapping with change detection analysis of Aluva Taluk using remote sensing and GIS. *International Journal of Science, Engineering and Technology*, 4(2), 383-389.

Ghebrezgabher, M. G., Yang, T., Yang, X., Wang, X., & Khan, M. (2016). Extracting and analyzing forest and woodland cover change in Eritrea based on Landsat data using supervised classification. *The Egyptian Journal of Remote Sensing and Space Science*, 19(1), 37-47.

Gibson, P. J., & Power, C. H. (2000). *Introductory remote sensing*: Digital image processing and applications. Routledge publisher, (pp.1- 216).

Giriraj, A., Murthy, M. S. R., Ramesh, B. R., & Dutt, C. B. S. (2009). A method for assessing evergreen habitats using phytodiversity and geospatial techniques in tropical rain forests of Southern Western Ghats (India). *Ecological research*, 24(4), 749-760.

GoI. (1988). *National forest policy*. Government of India. Ministry of Environment and forests, New India.

GoI. (2011). *Methods Manual. Soil testing in India*. Department of Agriculture and Cooperation. Ministry of Agriculture. Government of India. New Delhi. India.

GoI. (2017a). Ministry of Environment, Forest and Climate Change Notification. The Gazette of India. Controller of Publications New Delhi. Retrieved from https://aranya.gov.in/downloads/Talacauvery%20Wildlife%20Sanctuary%20ESZ.pdf

GoI. (2017b). Ministry of Environment, Forest and Climate Change Notification. The Gazette of India. Controller of Publications New Delhi. Retrieved from https://aranya.gov.in/downloads/Brahmagiri%20WIldlife%20Sanctuary%20ESZ.pdf

GoI. (2017c). Ministry of Environment, Forest and Climate Change Notification. The Gazette of India. Controller of Publications New Delhi. Retrieved from https://aranya.gov.in/downloads/Pushpagiri%20Wildlife%20Sanctuary%20ESZ.pdf

GoK. (2008). *Management Plan for Pushpagiri Wildlife Sanctuary*. Plan period 2008-2009 to 2017-2018. Karnataka Forest Department, Government of Karnataka.

GoK. (2008). *Management Plan for Talacauvery Wildlife Sanctuary*. Plan period 2008-2009 to 2017-2018. Karnataka Forest Department, Government of Karnataka.

GoK. (2010). *Management plan for Brahmagiri Wildlife Sanctuary 2011-2016*. Karnataka Forest Department. Government of Karnataka.

Groten, S. M. E. (1993). NDVI—crop monitoring and early yield assessment of Burkina Faso. *International Journal of Remote Sensing*, 14(8), 1495-1515.

Grubb, P.J. (1977). The maintenance of species richness in plant communities: The importance of the regeneration niche. *Biological Reviews*, 52, 107–145.

Grytnes, J. A. (2003). Species-richness patterns of vascular plants along seven altitudinal transects in Norway. *Ecography*, 26(3), 291–300.

Guo, Q., Kelt, D. A., Sun, Z., Liu, H., Hu, L., Ren, H., & Wen J. (2013). Global variation in elevational diversity patterns. *Scientific reports*, 3(3007), 1-7.

Hareesh, T.S. & Nagarajaiah, C. (2019). Effect of vegetation structure and species composition on above ground biomass and carbon in forests of Central Western Ghats, India. *International Journal of current microbiology and applied sciences*, 8(4), 2762-2774.

Hedge, K., Hedge, R., & Ahir, K.C. (2015). Population structure and regeneration status of two threatened NWFP species (*Garcinia gummigutta* and *Myristica dactyloides*) in Northern Western Ghats of Karnataka, India. *Life sciences leaflets*, 61, 42-56.

Hemanjali, A. M., Pramod Kumar, G. R., Somashekar, R. K., & Nagaraja, B. C. (2015). Assessment of forest encroachment in Shimoga district of Western Ghats, India, using remote sensing and GIS. *International Journal of Advanced Technology and Engineering Research*, 5(1), 25-30.

Henle, K., Lindenmayer,D.B., Margules, C.R., Saunders, D.A., & Wissel, C. (2004). Species survival in fragmented landscapes: where are we now? *Biodiversity and Conservation*, 13(1), 1–8.

Herrera-Estrella, A. (2014). Genome-wide approaches toward understanding mycotrophic Trichoderma species. In Gupta, V.K., Schmoll, M., Herrera-Estrella, A., Upadhyay, R.S., Druzhinina, I., & Tuohy, M.G. (Eds). *Biotechnology and Biology of Trichoderma*, 455-464.

Holten, J. I. (1998). Vascular plant species richness in relation to altitudinal and slope gradients in mountain landscapes of central Norway. *The Impacts of Climate Variability on Forests*, 231-239. Springer, Berlin, Heidelberg.

Hunter, M.L, & Yonzon, P. (1993). Altitudinal distributions of birds, mammals, people, forests, and parks in Nepal. *Conservation Biology*, 7(2), 420-423.

Huston, M.A. (1994). *Biological Diversity: Coexistence of Species in Changing Landscapes*, Cambridge University Press, Cambridge, UK.

IMFN. (International Model Forest Network) (2003). Kodagu Forest Model Network. Retrieved from https://imfn.net/regional-networks/kodagu-model-forest/

IPCC. (2001). *Climate Change 2001: Impacts, Adaptation & Vulnerability*: Contribution of Working Group II to the Third Assessment Report of the IPCC. In J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken & K. S. White, (Eds.). (pp. 1-1000).

IPCC. (2006). Chapter 4-Forest land. *IPCC guidelines for National Greenhouse Gas Inventories*. Agriculture, Forestry and Other Land Use.

IPCC. (2007). *Climate Change 2007, Impacts, Adaptations and Vulnerability*. Working Group II contribution to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change.

IPCC. (2014). *Climate Change 2014, Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. IPCC, (pp.151) Geneva, Switzerland.

IUCN. (International Union for Conservation of Nature (2019). https://www.iucn.org/resources/issues-briefs/forests-and-climate-change

Jackson, R. B., Schenk, H. J., Jobbagy, E. G., Canadell, J., Colello, G. D., Dickinson, R. E., ... & Kicklighter, D. W. (2000). Belowground consequences of vegetation change and their treatment in models. *Ecological applications*, 10(2), 470-483.

Jackson, R. B., Sperry, J. S., & Dawson, T. E. (2000). Root water uptake and transport: using physiological processes in global predictions. *Trends in plant science*, 5(11), 482-488.

Jayakumar, R., & Nair, K.K.N. (2013). *Species diversity and tree regeneration patterns in tropical forests of the Western Ghats, India.* ISRN Ecology, Hindawi publishing corporation.

Jeyanny, V., Husni, M. H. A., Rasidah, K. W., Kumar, B. S., Arifin, A., & Hisham, M. K. (2014). Carbon stocks in different carbon pools of a tropical lowland forest and a montane forest with varying topography. *Journal of Tropical Forest Science*, 25(4), 560- 571.

Jin, X. M., Zhang, Y. K., Schaepman, M. E., Clevers, J. G. P. W., & Su, Z. (2008). Impact of elevation and aspect on the spatial distribution of vegetation in the Qilian mountain area with remote sensing data. *International Society for Photogrammetry and Remote Sensing*, 37(B7), 1385-1390.

Jiyuan, L., Mingliang, L., Xiangzheng, D., Dafang, Z., Zengxiang, Z., & Di, L. (2002). The land use and land cover change database and its relative studies in China. *Journal of Geographical Sciences*, 12(3), 275-282.

Joseph, S., Anitha, K., Srivastava, V.K., Reddy, C. S., Thomas, A.P., & Murthy, M.S.R. (2012). Rainfall and Elevation Influence the Local-Scale Distribution of Tree Community in the Southern Region of Western Ghats Biodiversity Hotspot (India). *International Journal of Forestry Research*, 1-10.

Kacholi, D. S. (2014). Analysis of structure and diversity of the kilengwe forest in the Morogoro Region. Tanzania. *International Journal of Biodiversity*, 1-8.

Kadavul, K. & Parthasarathy, N. (1999). Plant biodiversity and conservation of tropical semi-evergreen forest in the SHervarayan hills of Eastern Ghats, India. *Biodiversity and Conservation,* 8(3), 419-437.

Kamruzzaman, M., Ahmed, S., Paul, S., Rahman, M. M., & Osawa, A. (2018). Stand structure and carbon storage in the oligohaline zone of the Sundarbans mangrove forest, Bangladesh. *Forest science and technology*, 14(1), 23-28.

Karnieli, A., Agam, N., Pinker, R. T., Anderson, M., Imhoff, M. L., Gutman, G. G., Panov, N., & Goldberg, A. (2010). Use of NDVI and land surface temperature for drought assessment: Merits and limitations. *Journal of Climate*, 23(3), 618-633.

Karthik, M. L., & Viswanath, S. (2012). Studies on Species Distribution in Tropical Wet Evergreen Forests of Karnataka Using Permanent Preservation Plots (PPPs). ENVIS. *Forestry Bulletin*, 12(2), 78-85.

Kessler, M. (2000). Elevational gradients in species richness and endemism of selected plant groups in the central Bolivian Andes. *Plant ecology*, 149(2), 181-193.

Khan, M. L., Menon, S., & Bawa, K. S. (1997). Effectiveness of the protected area network in biodiversity conservation: a case- study of Meghalaya state. *Biodiversity and Conservation*, 6(6), 853–868.

Khan, S. M., Page, S., Ahmad, H., & Harper, D.M. (2013). Identifying plant species and communities across environmental gradients in the Western Himalayas: Method development and conservation use. *Ecological informatics*, 14, 99-103.

Khan, S. M., Page, S., Ahmad, H., Shaheen, H., & Harper, D. M. (2012). Vegetation dynamics in the Western Himalayas, diversity indices and climate change. *Science Technology and Development*, 31(3), 232-243.

Khumbongmayum, A. D., Khan, M. L., & Tripathi, R. S. (2005). Ethnomedicinal plants in the sacred groves of Manipur. *Indian Journal of Traditional Knowledge*, 4(1), 21-32.

Kishwan, J., Pandey, R., & Dadhwal, V.K. (2007). *India's forest and tree cover: Contribution as a carbon sink*. Technical paper. Indian council of forestry research and education.

Kobler, J., Zehetgruber, B., Dirnböck, T., Jandl, R., Mirtl, M., & Schindlbacher, A. (2019). Effects of aspect and altitude on carbon cycling processes in a temperate mountain forest catchment. *Landscape Ecology*, 34(2), 325-340.

Korner, C. (2000). Why are there global gradients in species richness? Mountains might hold the answer. *Trends in Ecology and Evolution*, 15(12), 513–514.

Kumar, A., Marcot, B. G., & Saxena, A. (2006). Tree species diversity and distribution patterns in tropical forests of Garo Hills. *Current science*, 1370-1381.

Kumar, B.M., George, S.J., Jamaludheen, V., Suresh, T.K. (1998) Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in woodlot and silvi pastoral experiment in Kerala, India. *Forest Ecology and Management*, 112, 145-163.

Kumar, C. N.P., Somashekar, R. K., Nagaraja, B. C., Ramachandra, K., & Shivaprasad, D. (2015). Seed bank estimation and regeneration studies of *Calophyllum apetalum* Willd., from Western Ghats of Karnataka. *Proceedings of the International Academy of Ecology and Environmental Sciences*, *5*(3), 97-103.

Kumar, D. (2011). Monitoring Forest Cover Changes Using Remote Sensing and GIS: A Global Prospective, *Research Journal of Environmental Sciences*, 5(2), 105-123.

Kumar, G. R. P., Hemanjali, A. M., Ravikumar, P., Somashekar, R. K., & Nagaraja, B. C. (2013). Assessing the historical forest Encroachment of Kodagu region of Western Ghats, South India using remote sensing and GIS. *UMI-2013 NRSC/ISRO*, Hyderabad.

Kumar, S., Murti, S. H. K., & George, R. (2014). Application of remote sensing, GIS and GPS for forest management in Andaman and Nicobar Islands, India. *Indian Forester*, 140(2), 107-112.

Kumaraguru, A., Brinda,T., & Satheesh, N. (2016). Diversity of Vegetation in the Tail End of Eastern Ghats, Tiruchirappallli Forest Division, Tamil Nadu, India. *Indian Forester*, 142(4), 324-335.

Kunwar, R. M., & Sharma, S. P. (2004). Quantitative analysis of tree species two community forests of Dolpa district, mid-west Nepal. *Himalayan Journal of Sciences,* 2(3), 23-28.

Kushalappa, C. G., & Bhagwat, S. A. (2001). *Sacred groves: biodiversity, threats and conservation. Forest Genetic Resources: Status, Threats and Conservation Strategies*. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, 21-29.

Kushalappa, C. G., & Raghavendra, S. (2012). Community-linked conservation using Devakad (sacred groves) in the Kodagu Model Forest, India. *The Forestry Chronicle*, 88(3), 266-273.

Kusimi, J. M. (2008). Assessing land use and land cover change in the Wassa West District of Ghana using remote sensing. *GeoJournal*, 71(4), 249-259.

Lieberman, D., Lieberman, M., Peralta, R., & Hartshorn, G,. S. (1996). Tropical forest structure and composition on a large scale altitudinal gradient in Costa Rica. *Journal of Ecology*, 84,137-152.

Lieberman, M. & Lieberman, D. (1994). Patterns of density and dispersion of forest trees. in McDade, L. A., Bawa, K. S., Hespenheide, H. A. & Hartshorn, G. S. (Eds.). (pp. 106-119) *La Selva: ecology and natural history of a tropical rainforest.* University of Chicago Press, Chicago, IL, USA.

Lindsey, R. (2019). *Climate change: Atmospheric carbon dioxide.* NOAA.Climate.gov. Retrieved from,https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

Liu, N., & Nan, H. (2018). Carbon stocks of three secondary coniferous forests along an altitudinal gradient on Loess Plateau in inland China. *PloS ONE*, 13(5), 1-19.

Lomolino, M. V. (2001). Elevation gradients of species-density: historical and prospective views. *Global Ecology and Biogeography*, 10(1), 3-13.

Lugo, A. E., & Brown, S. (1992). Tropical forests as sinks of atmospheric carbon. *Forest Ecology and Management*, 54(1-4), 239-255.

Mallegowda, P., Rengaian, G., Krishnan, J., & Niphadkar, M. (2015). Assessing habitat quality of forest-corridors through NDVI analysis in dry tropical forests of south India: Implications for conservation. *Remote Sensing*, 7(2), 1619-1639.

Mandal, G., & Joshi, S. P. (2014). Analysis of vegetation dynamics and phytodiveristy from three dry deciduous forests of Doon valley, Western Himalaya, India. *Journal of Asia-Pacific Biodiversity*, 7 (3), 292-304.

Manish, K. Pandit, M. K. Telwala, Y. Nautiyal, D.C. Koh, L.P., & Tiwari, S. (2017). Elevational plant species richness patterns and their drivers across non-endemics, endemics and growth forms in the Eastern Himalaya. *Journal of Plant Research*, 130(5), 829-844.

Martínez, M. L., Pérez-Maqueo, O., Vázquez, G., Castillo-Campos, G., García-Franco, J., Mehltreter, K., Equihua, M., & Landgrave, R. (2009). Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. *Forest Ecology and management*, 258(9), 1856-1863.

McCain, C, M., & Grytnes, J, A. (2010). *Elevational Gradients in Species Richness*. In: Encyclopedia of Life Sciences (ELS). John Wiley & Sons, Ltd: Chichester.

Meher-Homji, V.M. (1983). On the Indo-Malaysian and Indo- African elements in India. *Feddes Repertorium*, 94(6), 407-424.

Melkania, N. P. (2009). Carbon sequestration in Indian natural and planted forests. *Indian Forester*, 135(3), 380-392.

Meneses-Tovar, C. L. (2011). NDVI as indicator of degradation. *Unasylva*, 238(62), 39-46.

Meyer, W. B. (1995). Past and present land use and land cover in the USA. *Consequences*, 1(1), 25-33.

Michener, W.K., & Houhoulis, P.F. (1997). Detection of vegetation changes associated with extensive flooding in a forested ecosystem. *Photogrammetric Engineering & Remote Sensing*, 63(12), 1363–1374.

Mir, A. A., Ahmed, P., Bhat, P. A., & Singh, H. (2016). Analyzing Land Use/Land Cover Change Using Remote Sensing and GIS Techniques in Pohru Watershed of Kashmir Valley. *Journal of Research & Development*. 16,104-111.

Misra, R. (1968). *Ecology workbook*. Oxford and IBH Publishing Company, Calcutta.

Mitra, A. (2013). Blue carbon: A hidden treasure in the climate change science. *Journal of Marine Science Research and Development*, 3(2),116.

Mittermeier, R. A., Ganzhorn, J. U., Konstant, W. R., Glander, K., Tattersall, I., Groves, C. P., Rylands, A. B., Hapke, A., Ratsimbazafy, J., Mayor, M. I, Louis, E. E., Rumpler, Y., Schwitzer, C., & Rasolaorison, R.M. (2008). Lemur diversity in Madagascar. *International Journal of Primatology*, 29(6), 1607-1656.

Mori, S. A. Boom, B. M. de Carvalino, A. M., & dos Santos, T. (1983). Ecological importance of Myrtaceae in an Eastern Brazilian Wet Forest. *Biotropica*, 15(1), 68-70.

Morris, E. K., Caruso, T., Buscot, F., Fischer, M., Hancock, C., Maier, T. S., Meiners, T., Muller, C., Obermaier, E., Prati, D., Socher, S. A., Sonnemannn, I., Waschke, N., Wuber, T., Wurst, S., & Riling, M. C. (2014). Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. *Ecology and evolution*, 4(18), 3514-3524.

Munsi, M., Malaviya, S., Oinam, G., & Joshi, P. K. (2010). A landscape approach for quantifying land-use and land-cover change (1976–2006) in middle Himalaya. *Regional Environmental Change*, 10(2), 145-155.

Murthy, K.K.R., & Yoganarasimhan S.N. (1990). *Flora of Coorg* (Kodagu). Karnataka, India. Vismat publishers, Bangalore.

Myers, N., Mittermeier, R. A., Mittermeier, C.G., da Fonseca, G.A.B., & Kent, J.(2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), 853-858.

Naidu, M. T., & Kumar, O. A. (2016). Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India. *Journal of Asia-Pacific Biodiversity*, 9(3), 328-334.

Nayar, T.S., Beegam, A. R., & Sibi, M. (2014). *Flowering Plants of the Western Ghats*, India (Vol 2). Jawaharlal Nehru Tropical Botanic Garden and Research Institute, Palode.

Neginhal, S. G. (2011). *Forest trees of the Western Ghats (includes Eastern Ghats and Deccan Plateau)*. Published by S.G. Neginhal, (pp.1-491). Bangalore.

Niering, W. A. (1987). Vegetation dynamics (succession and climax) in relation to plant community management. *Conservation Biology*, 1(4), 287-295.

NRSC (National Remote Sensing Centre) (2014). Normalized difference vegetation index (NDVVI) products by using ocm2-gac sensor data for Bhuvan noeda. Retrieved from https://www.nrsc.gov.in/sites/default/files/pdf/landproducts/bhuvan_gac_ndvi.pdf.

Olsen, S. R. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*. US Department of Agriculture Circular, 939, 1-19.

Oommen, M, A., & Shanker, K. (2005). Elevational species richness patterns emerge from multiple local mechanisms in Himalayan woody plants. *Ecology*, 86(11), 3039- 3047.

Osuri, A. M., Kumar, V. S., & Sankaran, M. (2014). Altered stand structure and tree allometry reduce carbon storage in evergreen forest fragments in India's Western Ghats. *Forest Ecology and Management*, 329, 375-383.

Othman, M. A., Ash'aari, Z. H., Aris, A. Z., & Ramli, M. F. (2018). Tropical deforestation monitoring using NDVI from MODIS satellite: a case study in Pahang, Malaysia. In IOP Conference Series: *Earth and Environmental Science*, 169, 1-19. IOP Publishing.

Ozcelik, R. (2009). Tree species diversity of natural mixed stands in eastern Black sea and western Mediterranean region of Turkey. *Journal of Environmental Biology*, 30(5), 761-766.

Panda, S. S., Ames, D. P., & Panigrahi, S. (2010). Application of vegetation indices for agricultural crop yield prediction using neural network techniques. *Remote Sensing*, 2(3), 673-696.

Pandey, D. (2012). *Carbon Stocks of World Heritage Forest Sites*. UNESCO World Heritage Centre. www.unesco.org

Pandey, S. K., & Shukla, R. P. (2003). Plant diversity in managed sal (*Shorea robusta* Gaertn.) forests of Gorakhpur, India: species composition, regeneration and conservation. *Biodiversity & Conservation*, *12*(11), 2295-2319.

Parras-Alcántara, L., Lozano-García, B., & Galán-Espejo, A. (2015). Soil organic carbon along an altitudinal gradient in the Despeñaperros Natural Park, southern Spain. *Solid Earth*, 6 (1),125–134.

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

Parthasarathy, N. (2001). Changes in forest composition and structure in three sites of tropical evergreen forest around Sengaltheri, Western Ghats. *Current Science*, 80(3), 389-393.

Parthasarathy, N., Pragasan, L.A., Muthumperumal, C., Raja, S., & Rajkumar, M. (2007). Quantitative assessment of plant diversity, bioresource values and conservation of tropical forests of Southern Eastern Ghats, India. *Proceedings of National seminar on conservation of Eastern Ghats*, 14-18.

Pascal, J. P., & Pelissier, R. (1996). Structure and floristic composition of a tropical evergreen forest in south-west India. *Journal of Tropical Ecology*, 12(2), 191-214.

Pascal, J.P. (1988). *Wet Evergreen Forests of the Western Ghats of India*. Institut Francias De Pondichery, publication du departement d'ecologie-23. (pp.11-309).

Pascal, J.P., & B.R. Ramesh. (1987). A Field Key to the trees and lianas of the Evergreen forests of the Western Ghats. Institut Francias De Pondichery.(pp. 1-220). Pondicherry.

Pearson, T. R., Brown, S. L., & Birdsey, R. A. (2007). *Measurement guidelines for the sequestration of forest carbon*. US Department of Agriculture, Forest Service, Northern Research Station.

Peterson, D., Schreiner, E., & Buckingham, N. (1997). Gradients, Vegetation and Climate: Spatial and Temporal Dynamics in the Olympic Mountains, U.S.A. *Global Ecology and Biogeography Letters*, 6(1), 7-17.

Phillips, J., Ramirez, S., Wayson, C., & Duque, A. (2019). Differences in carbon stocks along an elevational gradient in tropical mountain forests of Colombia. *Biotropica*, 51(4), 490-499.

Pielou, E. C. (1975). *Ecological diversity*. (pp. 165). Wiley, New York.

Pokhriyal, P., Uniyal, P., Chauhan, D.S., & Todaria, N.P. (2010). Regeneration status of tree species in forest of Phakot and Pathri Rao watersheds in Garhwal Himalaya, India. *Current Science*, 98(2), 171-175.

Pragasan, L. A. (2015). Tree carbon stock assessment from the tropical forests of Bodamalai Hills located in India. *Journal of Earth Science & Climatic Change*, 6(10), 1-6.

Pragasan, L. A. (2016). Assessment of carbon stock of tree vegetation in the Kolli Hill forest located in India. *Applied Ecology and Environmental Research*, 14(2), 169-183.

Prasad, A. D., & Al-Sagheer, N. A. (2012). Floristic diversity of regenerated tree species in Dipterocarp forests in Western Ghats of Karnataka, India. *Journal of Environmental Biology*, *33*(4), 791-797.

Premnavi, D., Naidu, M.T., & Venkaiah, M. (2014). Tree species diversity and population structure in the tropical forests of North Central Eastern Ghats, India. *Notulae Scientia Biologicae*, 6(4), 448-453.

Price, M. F., Georg, G., Lalisa, A, D., Thomas, K., D,M., & Rosalaura, R. (Eds.) (2011). *Mountain Forests in a Changing World - Realizing Values, addressing challenges*. Published by FAO/MPS and SDC, Rome.

Raghuramulu, Y. (2006). Diversification in coffee exporting countries. India case study. In P. Greenhalgh, P., Tallontire, A., Davi, J., & Kleih, U. (Eds.) *The potential for diversification in coffee exporting countries*. Natural Resources Institute University of Greenwich, Chatham Kent, United Kingdom.

Rahbek, C. (2005). The role of spatial scale and the perception of large-scale species- richness patterns. *Ecology Letters*, 8(2), 224-239.

Rai, S.N. 1981. *Productivity of Tropical Rain Forests of Karnataka, Ph.D. Thesis*, University of Bombay, India.

Ram, B., & Kolarkar, A. S. (1993). Remote sensing application in monitoring land-use changes in arid Rajasthan. *International Journal of Remote Sensing*, 14(17), 3191-3200.

Ramachandra, T. V., Subash, C. M.D., Joshi, N.V., Sooraj, N. P., Rao, G. R., & Mukri, V. (2012b). *Ecology of sacred Kan forests in Central Western Ghats*. ENVIS technical report, 41.

Ramachandra, T.V., Subhash, C.M.D., Joshi, N.V., Joshi, D., & Kumar, M. (2012a). Soil quality across diverse landscapes in Central Western Ghats, India. Sahyadri Consevation series 16, ENVIS technical report, 42.

Ramachandran, V. S., & Swarupanandan, K. (2013). Structure and floristic composition of old-growth wet evergreen forests of Nelliampathy Hills, Southern Western Ghats. *Journal of Forestry Research*, *24*(1), 37-46.

Ramesh, B. R., & Pascal, J.P. (1997). *Atlas of endemics of the Westerns Ghats (India). Distribution of tree species in the evergreen and semi-evergreen forests*. Institut Francais De Pondichery, Pondicherry.

Ramesh, B.R., Menon, S., & Bawa, K.S. (1997). A vegetation based approach to biodiversity gap analysis in the Agastyamalai region, Western Ghats, India. *Ambio*, 26(8), 529-536.

Rana, C. S., & Gairola, S. (2009). Forest community structure and composition along an elevational gradient of Parshuram Kund area in Lohit district of Arunachal Pradesh, India. *Nature and Science*, 8(1),44-52.

Rao, R. R. (2012). Floristic diversity in Western Ghats: Documentation, conservation and bioprospection- A priority agenda for action. Sahyadri E-News, Western Ghats Biodiversity Information System, Bangalore, Indian Institute of Sciences.

Raunkiaer, C. C. (1934). *The life forms of plants and statistical plant geography*. Clarendon, UK.

Ravindranath, N. H., Somashekhar, B. S., & Gadgil, M. (1997). Carbon flow in Indian forests. *Climatic Change*, 35(3), 297-320.

Rawat, G. S., & Bhainsora, N. S. (1999). Woody vegetation of Shivaliks and outer Himalaya in north western India. *Tropical Ecology*, 40(1), 119-128.

Rawat, J. S., & Kumar, M. (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, 18(1), 77-84.

Rawat, J. S., Biswas, V., & Kumar, M. (2013). Changes in land use/cover using geospatial techniques: A case study of Ramnagar town area, district Nainital, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, 16(1), 111-117.

Reddy, C. S., & Ugle, P. (2008). Tree species diversity and distribution patterns in tropical forest of Eastern Ghats, India: a case study. *Life Science Journal*, 5(4), 87-93.

Reddy, E. N. V., Devakumar, A. S., Charan Kumar, M. E., & Madhusudana, M. K. (2012). Assessment of nutrient turnover and soil fertility of natural forests of Central Western Ghats. *International Journal of Science and Nature*, 3(1), 162-166.

Reed, B. C., Brown, J. F., VanderZee, D., Loveland, T. R., Merchant, J. W., & Ohlen, D. O. (1994). Measuring phenological variability from satellite imagery. *Journal of Vegetation Science*, 5(5), 703-714.

Reeves, D. W. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Research*, 43(1-2), 131-167.

Reyes, G., Brown, S., Chapman, J., & Lugo, A. E. (1992). Wood densities of tropical tree species. General Technical Report. SO-88. USA: United States Department of Agriculture.

Rezende, V, L., de Miranda, P. L.S., Meyer, L., Moreira, C.V., Linhares, F, M., de Oliveira-Filho, A,T., & Eisenlohr,P,V. (2015). Tree species composition and richness along altitudinal gradients as a tool for conservation decisions: the case of Atlantic semi-deciduous forest. *Biodiversity and Conservation*, 24(9), 2149-2163.

Ribichich, A. M., & Protomastro, J. (1998). Woody vegetation structure of xeric forest stands under different edaphic site conditions and disturbance histories in the Biosphere Reserve Parque Costero del Sur, Argentina. *Plant Ecology* 139(2), 189–201.

Rizvi, A.R., Baig, S., Barrow, E., & Kumar, C. (2015). *Synergies between Climate Mitigation and Adaptation in Forest Landscape Restoration*. Gland, Switzerland: IUCN.

Roy, P. S., & Roy, A. (2010). Land use and land cover change in India: Aremote sensing & GIS perspective. *Journal of the Indian Institute of Science*, 90(4), 489-502.

Sahu, S. C., Dhal, N. K., Lal, B. & Mohanty, R. C. (2012). Differences in tree species diversity and soil nutrient status in a tropical sacred forest ecosystem on Niyamgiri hill range, Eastern Ghats, India. *Journal of Mountain Science*, 9(4), 492-500.

Sahu, S. C., Pani, A. K., Mohanta, M. R., & Kumar, J. (2019). Tree species diversity, distribution and soil nutrient status along altitudinal gradients in Saptasajya hill range, Eastern Ghats, India. *Taiwania*, 64(1), 28-38.

Salunkhe, O., Khare, P. K., Kumari, R., & Khan, M. L. (2018). A systematic review on the aboveground biomass and carbon stocks of Indian forest ecosystems. *Ecological processes*, 7(1), 17.

Saravanan, S., Jegankumar, R., Selvaraj, A., Jennifer, J. J., & Parthasarathy, K. S. S. (2019). Utility of landsat data for assessing mangrove degradation in Muthupet Lagoon, South

India. In Ramkumar, M., James, R.A., Menier, D., & Kumarswamy, K. (Eds.). *Coastal Zone Management: Global Perspectives, Regional Processes, Local Issues*. (pp. 471-484). Elsevier,Netherlands.

Sarkar, M., & Devi, A. (2014). Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. *Tropical plant research*, 1(2), 26-36.

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

Saxena, A.K., & Singh, J.S.(1984).Tree population structure of certain Himalayan forest associations and implications concerning their future composition. *Vegetatio*. 58(2),61-69.

Schulze, E. D., Wirth, C., & Heimann, M. (2000). Managing forests after Kyoto. *Science*, 289(5487), 2058-2059.

Sevgi, O., & Tecimen, H. B. (2009). Physical, chemical and pedogenetical properties of soil in relation with altitude at Kazdagi upland black pine forest. Journal of Environmental Biology, 30(3), 349-354.

Shahrokhnia, M. H., & Ahmadi, S. H. (2019). Remotely Sensed Spatial and Temporal Variations of Vegetation Indices Subjected to Rainfall Amount and Distribution Properties. In Pourghasemi, H.R., & Gokceoglu, C. (Eds.). *Spatial Modeling in GIS and R for Earth and Environmental Sciences* (pp. 21-53). Elsevier, Netherlands.

Shanks, R.E., & Norris, F.H. (1950). Microclimate vegetation in a small valley in Eastern Tennessee. *Ecology*, 31(4), 532-539.

Shannon, C.E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, 27 (3), 379–423.

Sharma, C. M. Suyal, S. Gairola, S., & Ghildiyal, S. K. (2009). Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. *Journal of American Science*, 5(5), 19-128.

Shedayi, A. A., Xu, M., Naseer, I., & Khan, B. (2016). Altitudinal gradients of soil and vegetation carbon and nitrogen in a high altitude nature reserve of Karakoram ranges. *Springer Plus, 5*(1), 320.

Sheikh, M. A., Kumar, M., & Bussmann, R. W. (2009). Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon balance and management*, 4(6).

Sheikh, M. A., Kumar, M., Bussman, R. W., & Todaria, N. P. (2011). Forest carbon stocks and fluxes in physiographic zones of India. *Carbon balance and management*, 6(15), 1-10.

Shrestha,T,B., & Joshi,R.M. (1996). *Rare, Endemic and Endangered plants of Nepal*,WWF Nepal Program, Kathmandu, Nepal.(pp.244).

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

Singh, K. P. (1968). Nutrient status of forest soils in humid tropical regions of Western Ghats. *Tropical ecology*, 9, 119-130.

Singh, P., Thakur, J. K., Kumar, S., & Singh, U. C. (2012). Assessment of land use/land cover using geospatial techniques in a semi-arid region of Madhya Pradesh, India. Eds: Thakur, J.K., Singh, S.K., Ramanathan, A., Prasad, M.B.K. & Gossel W. *Geospatial Techniques for Managing Environmental Resources*,152-163. Springer, Dordrecht.

Singh, S., Malik, Z. A., & Sharma, C. M. (2016). Tree species richness, diversity, and regeneration status in different oak (Quercus spp.) dominated forests of Garhwal Himalaya, India. *Journal of Asia-Pacific Biodiversity*, 9(3), 293-300.

Singh, T. P., Singh, S., Roy, P. S., & Rao, B. S. P. (2002). Vegetation mapping and characterization in West Siang District of Arunachal Pradesh, India–a satellite remote sensing-based approach. *Current science*, 83(10), 1221-1230.

Somashekar, R. K., Ravikumar, P., Kumar, C. M., Prakash, K. L., & Nagaraja, B. C. (2009). Burnt area mapping of Bandipur National Park, India using IRS 1C/1D LISS III data. *Journal of the Indian Society of Remote Sensing*, 37(1), 37-50.

Sørensen, T. J. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. I kommission hos E. Munksgaard.

Spehn, E.M., Rudmann-Maurer, K., Körner, C., & Maselli, D. (eds.) (2010). *Mountain Biodiversity and Global Change*. GMBA-DIVERSITAS, Basel.

Sri-Ngernyuang, K., Kanzaki, M., Mizuno, T., Noguchi, H., Teejuntuk, S., Sungpalee, C., Masatoshi, Hara., Yamakura, T., Sahnalu, P., Dhanmanonda, P., & Bunyavejchewin, S. (2003). Habitat differentiation of Lauraceae species in a tropical lower montane forest in northern Thailand. *Ecological Research*, 18(1), 1-14.

Srinivas, V., & Parthasarathy, N. (2000). Comparative analysis of tree diversity and dispersion in the tropical lowland evergreen forest of Agumbe, Central Western Ghats, India. *Tropical Biodiversity*, 7(1), 45-60.

Subashree, K., & Sundarapandian, S. (2017). Biomass and carbon stock assessment in two savannahs of Western Ghats, India. *Taiwania*, 62(3), 272-282.

Subramanyam, K., & Nayar, M. P. (1974). Vegetation and phytogeography of the Western Ghats. In Mani, M.S. (Ed.). *Ecology and biogeography in India* (pp. 178-196). Springer, Dordrecht.

Sukumar, R., Dattaraja, H.S., Suresh, H.S., Radhakrishnan, J., Vasudeva, R., Nirmala, S., & Joshi, N.V. (1992). Long term monitoring of vegetation inn a tropical deciduous forest in Mudumalai, Southern India, *Current Science,* 62(9), 608-616.

Sullivan, M. J., Talbot, J., Lewis, S. L., Phillips, O. L., Qie, L., Begne, S. K., ... & Miles, L. (2017). Diversity and carbon storage across the tropical forest biome. *Scientific Reports*, 7, (39102), 1-12.

Sundarapandian, S. M., & Swamy, P. S. (2000). Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. *Journal of Tropical Forest Science*, 12(1), 104-123.

Sundarapandian, S. M., Amritha, S., Gowsalya, L., Kayathri, P., Thamizharasi, M., Dar, J. A., Srinivas, K. & Gandhi, S. (2013). Estimation of biomass and carbon stock of woody plants in different land-uses. *Forest Research*, 3(1), 1-5.

Sundarapandian, S.M., & Swamy, P.S. (1997). Plant diversity at low-elevation evergreen and moist deciduous forests at Kodayar (Western Ghats). *International Journal of Ecology and Environmental Sciences,* 23, 363-379.

Sundqvist, E., Burruss, R., Fulkner, S., Gleason, R., Harden, J., Kharaka, Y., Tieszen, L., & Waldrop, M. (2008). *Carbon sequestration to mitigate climate change*. United States Geological Survey.

Suratman, M. N. (2012). Tree species diversity and forest stand structure of Pahang National Park, Malaysia. Biodiversity Enrichment in a Diverse world, chapter -18. Intech, open science, open minds.

Swamy, H. R. (1989). *Study of organic productivity, nutrient cycling and small watershed hydrology in natural forests and in monoculture plantations in Chikmagalur District, Karnataka*. Final Report, Sri Jagadguru Chandrasekhara Bharati Memorial College, Sringeri, India.

Swamy, H. R., & Proctor, J. (1994). Rain forests and their soils in the Sringeri area of the Indian Western Ghats. *Global Ecology and Biogeography Letters*, 4(5), 140-154.

Tange, T., Yagi, H., Sasaki, S., Niiyama, K., & Kassim, A. R. (1998). Relationship between topography and soil properties in a hill dipterocarp forest dominated by *Shorea curtisii* at Semangkok Forest Reserve, Peninsular Malaysia. *Journal of Tropical Forest Science*, 10(3), 398-409.

Terakunpisut, J., Gajaseni, N., & Ruankawe, N. (2007). Carbon sequestration potential in aboveground biomass of Thong Pha Phum national forest, Thailand. *Applied ecology and environmental research*, 5(2), 93-102.

Titshall, L. W., O'Connor, T. G., & Morris, C. D. (2000). Effect of long-term exclusion of fire and herbivory on the soils and vegetation of sour grassland. *African Journal of Range and Forage Science*, 17(1-3), 70-80.

Tiwari, M. K., & Saxena, A. (2011). Change detection of land use/landcover pattern in an around Mandideep and Obedullaganj area, using remote sensing and GIS. *International Journal of Technology and Engineering System*, 2(3), 398-402.

Tomar, A. S., & Singh, U. C. (2012). Geomorphological mapping using remote sensing and GIS A tool for land use planning around Shivpuri city, MP, India. IOSR *Journal of Computer Engineering*, 5(1), 28-30.

Toth, S. J., & Prince, A. L. (1949). Estimation of cation-exchange capacity and exchangeable Ca, K, and Na contents of soils by flame photometer techniques. *Soil Science*, 67(6), 439-446.

Trigas, P., Panitsa, M., & Tsiftsis, S. (2013). Elevational Gradient of Vascular Plant Species Richness and Endemism in Crete – The Effect of Post-Isolation Mountain Uplift on a Continental Island System. PLoS ONE 8(3), 1-13.

Tripathi, O. P., & Tripathi, R. S. (2010). Community composition, structure and management of subtropical vegetation of forests in Meghalaya State, northeast India. *International Journal of Biofdiversity Science*, *Ecosystem* Services *& Management*, 6(3-4), 157-163.

Turner, M. G. (1989). Landscape ecology: the effect of pattern on process. *Annual review of ecology and systematics*, 20(1), 171-197.

Udayakumar, M., Manikandan, S., Tamilselvan, B., & Sekar, T. (2016). Estimation of wood density of trees in 10 hectare forest dynamics plot at Pachaimalai, Tamil Nadu. *Scholars Academic Journal of Biosciences*, 4(4A), 348-352.

UNCED, 1992. Earth Summit. Agenda 21. The United Nations Programme of Action from Rio.UnitedNations,NewYork.Retrievedfromhttp://www.un.org/esa/dsd/agenda21/res_agenda21_00.shtml [Accessed 15 May 2015].

UNEP (United Nations Environment Programme). (2001). UNEP Annual report, 1-48. Retrieved from

UNESCO (2015). Western Ghats. Retrieved from https://whc.unesco.org/en/list/1342

UNESCO. (2012). Convention concerning the protection of the world cultural and natural heritage. Decisions adopted by the world heritage committee, 36th session. Saint Petersburg, Russian Federation.

UNESCO. (2019). Retrieved from https://whc.unesco.org/en/statesparties/in

Utkarsh, G. Joshi, N. V. & Gadgil, M. (1998). On the patterns of tree diversity in the Western Ghats of India. *Current Science*, 75(6), 594-603.

Varghese, A. O., & Menon, A.R.R. (1998). Assessment of biodiversity of Peppara Wildlife Sanctuary, Trivandrum District, Kerala. *Journal of Economic and Taxonomic Botany*, 22(3), 609-615.

Vashum, K. T., & Jayakumar, S. (2012). Methods to estimate above-ground biomass and carbon stock in natural forests-a review. *Journal of Ecosystem and Ecography*, 2(4), 1-7.

Vazquez, J.A., & Givnish, T. J. (1998). Altitudinal gradients in tropical forest composition, structure, and diversity in the Sierra de Manantlán. *Journal of Ecology*, 999-1020.

Vetaas, O. R., & Grytnes, J. A. (2002). Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography*, 11(4), 291-301.

Waikhom, S., Yadav, V.G. & Kakadiya,B. (2019). Development of NDVI and LULC map of Surat District using GIS and Remote Sensing. *Global Research and Development Journal for Engineering, Emerging Research and Innovations in Civil Engineering*, 372-276.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29-38.

Waring, R. H., & Running, S. W. (2007). *Forest ecosystems (third edition): Analysis at multiple time and space scales*. Elsevier, USA.

Weier, J. & Herring, D. (2000). *Measuring Vegetation (NDVI & EVI)*. NASA Earth Observatory, WashingtonDC.Retrievedfromhttps://earthobservatory.nasa.gov/features/MeasuringVegetation.

Whitehead, D. (2011). Forests as carbon sinks benefits and consequences. *Tree physiology*, 31(9), 893-902.

Whitford, P. B. 1949. Distribution of woodland plants in relation to succession and clonal growth. *Ecology*, 30(2), 199-208.

Whitmore, T. C. (1998). *An Introduction to Tropical Rain Forests*, Oxford University Press, New York, NY, USA, 2nd edition.

Whittaker, R. H. (1972). Evolution and measurement of species diversity. *Taxon*, 21(2/3), 213-251.

Willig, M. R., & Presley, S. J. (2018). Latitudinal gradients of biodiversity: theory and empirical patterns. DellaSala, D.A, & Goldstein, M.I. (Eds.*) The encyclopedia of the anthropocene*, *3*, (pp.13-19).

Wilson, E. O., & Peter, F.M. (1988). *National forum on Biodiversity: Biodiversity*. National Academy of Sciences, Washington, DC.

World Agroforestry Centre. Tree functional attributes and ecological database. Retrieved from http://db.worldagroforestry.org/, on 10th December, 2016.

Xie, Y. (2008) Remote sensing imagery in vegetation mapping: A review. *Journal of Plant Ecology*, 1(1), 9-23.

Zaitunah, A., Ahmad, A. G., & Safitri, R. A. (2018, March). Normalized Difference Vegetation Index (NDVI) analysis for land cover types using landsat 8 oli in besitang watershed, Indonesia. In IOP Conference Series: *Earth and Environmental Science*, 126(1), 1-9.

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., Miller, R. B., Swenson, N. G., Wiemann, M. C. & Chave, J. (2009). Global wood density database. Retrieved from http://hdl.handle.net/10255/dryad.235, on 20th February, 2017.

Appendix 1: Tree Species across the Elevational Gradients of Brahmagiri Wildlife Sanctuary, Kodagu, Karnataka

			Elevation (m)														
Sl.No	**Name of the species**	**Family**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**
1	*Acrocarpus fraxinifolius* Arn.	Fabaceae	+	+	+	+											
2	*Actinodaphne bourdillonii* Gamble*	Lauraceae							+		+					+	
3	*Aglaia simplicifolia (Bedd.)* Harms*	Meliaceae	+	+	+		+	+	+								
4	*Agrostistachys borneansis* Becc.	Euphorbiaceae						+	+								
5	*Alstonia scholaris* (L.) R. Br.	Apocynaceae		+													
6	*Antiaris toxicaria* (Pers.) Leschen.	Moraceae							+								
7	*Antidesma menasu* (Tul.) Miq. ex Muell.-Arg.	Phyllanthaceae								+							
8	*Aphanamixis polystachya* (Wall.) R. N. Parker	Meliaceae														+	
9	*Aporosa cardiosperma* (Gaertn.) Merr.	Phyllanthaceae									+						
10	*Artocarpus hirsutus* Lam.*	Moraceae					+	+				+					
11	*Atalantia monophylla* (Roxb.) A. DC.	Rutaceae	+		+	+	+										
12	*Baccaurea courtalensis* Muell.-Arg.	Phyllanthaceae	+		+					+							
13	*Bischofia javanica* Blume	Phyllanthaceae	+						+	+		+	+	+			
14	*Bridelia retusa* (L.) A.Juss.	Phyllanthaceae								+							
15	*Calophyllum apetalum* Willd.*	Calophyllaceae		+	+	+	+	+	+								
16	*Canarium strictum* Roxb.	Bursearaceae											+	+			
17	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae			+			+	+								
18	*Caryota urens* L.	Arecaceae										+	+				
19	*Chukrasia tabularis* A. Juss.	Meliaceae										+	+	+			
20	*Cinnamomum riparium* Gamble*	Lauraceae	+	+	+		+	+	+	+							
21	*Cinnamomum sulphuratum* Nees*	Lauraceae									+	+	+		+	+	
22	*Dalbergia latifolia* Roxb.	Fabaceae									+		+				
23	*Dillenia pentagyna* Roxb.	Dilleniaceae				+		+									
24	*Dimocarpus longan* subsp. longan	Sapindaceae	+				+	+	+	+	+	+					
25	Diospyros assimilis Bedd.	Ebenaceae			+												
26	*Diospyros ebenum* J.Koenig ex Retz.	Ebenaceae	+	+	+	+		+	+		+						

27	*Diospyros nilagirica* Bedd.*	Ebenaceae	+			+			+								
28	*Diospyros pruriens* Dalzell*	Ebenaceae		+	+	+											
29	*Diospyros sylvatica* Roxb.	Ebenaceae									+	+	+	+			
30	*Dipterocarpus indicus* Bedd.*	Dipterocarpaceae		+	+	+		+									
31	*Drypetes venusta* (Wight) Pax & K.Hoffm.*	Putranjivaceae	+	+	+												
32	*Dysoxylum malabaricum* Bedd. ex C. DC. *	Meliaceae					+	+					+	+			
33	*Elaeocarpus serratus L.*	Elaeocarpaceae								+						+	
34	*Elaeocarpus tuberculatus* Roxb.	Elaeocarpaceae								+							
35	*Ficus virens W. T. Aiton*	Moraceae								+							
36	*Garcinia gummi-gutta* (L.) Robs.*	Clusiaceae				+			+		+						
37	*Garcinia indica* (Thouars) Choisy.*	Clusiaceae						+			+		+				
38	*Glochidion candolleanum* (Wight & Arn.)Chakrab. & M.Gangop	Euphorbiaceae													+	+	
39	*Glochidion malabaricum* (Müll.Arg.) Bedd.*	Euphorbiaceae													+	+	+
40	*Glycosmis macrocarpa* Wight*	Rutaceae									+						
41	*Harpullia arborea* (Blanco) Radlk.	Sapindaceae	+		+		+		+								
42	*Heynea trijuga* Roxb.	Meliaceae			+	+	+										
43	*Holigarna arnottiana* Wall. ex Hook. f.*	Anacardiaceae		+		+											
44	*Holigarna grahamii* (Wight) Kurz.*	Anacardiaceae										+					
45	*Hopea parviflora* Bedd.*	Dipterocarpaceae	+		+	+	+		+	+							
46	*Hopea ponga* (Dennst.) D.J. Mabberley*	Dipterocarpaceae					+	+	+								
47	*Hopea utilis* (Bedd.) Bole*	Dipterocarpaceae						+									
48	*Humboldtia brunonis* Wall.*	Fabaceae		+		+	+	+		+							
49	*Ixora brachiata* Roxb.*	Rubiaceae					+										
50	*Kingiodendron pinnatum* (DC.)Harms*	Fabaceae		+	+	+											
51	*Knema attenuata* (Hook. fil. & Thoms.) Warb.*	Myristicaceae						+				+	+	+		+	
52	*Lagerstroemia microcarpa* Wight	Lythraceae				+	+	+	+	+	+	+	+	+			
53	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae							+			+		+			
54	*Ligustrum perrottetii* A.DC*	Lauraceae														+	+
55	*Litsea floribunda* (Bl.) Gamble*	Lauraceae				+	+									+	
56	*Litsea spp.*	Lauraceae													+		

57	*Lophopetalum wightianum* Arn.	Celastraceae	+			+	+	+	+	+						
58	*Macaranga indica* Wt.	Euphorbiaceae				+					+	+	+	+		+
59	*Persea macrantha* (Nees) Kosterm.	Lauraceae										+		+		
60	*Mangifera indica* L.	Anacardiaceae			+				+			+				
61	*Meliosma simplicifolia* (Roxb.) Walp. ssp. Simplicifoli	Sabiaceae													+	
62	*Memecylon randeriana* S.M. Almeida & M.R. Almeida*	Melastomaceae											+	+		
63	*Mesua ferrea* L.	Calophyllaceae		+			+	+	+							
64	*Mimusops elengi* L.	Sapotaceae						+		+						
65	*Murraya paniculata* (L.) Jacq.	Rutaceae										+				
66	*Myristica malabarica* Lam.*	Myristicaceae	+	+	+	+	+	+	+							
67	*Nothapodytes nimmoniana* (J. Grah.) D.J. Mabberley*	Stemonuraceae											+		+	+
68	*Nothopegia beddomei* Gamble*	Anacardiaceae											+	+		
69	*Nothopegia travancorica* Bedd. ex Hook. f.*	Anacardiaceae										+				
70	*Nothopegia heyneana* (J. Hk.) Gamble var. heyneana*	Anacardiaceae			+											
71	*Olea dioica* Roxb.	Oleaceae	+		+	+		+	+	+	+	+	+			
72	*Palaquium ellipticum* (Dalzell) Baill.*	Sapotaceae	+		+	+										
73	*Phyllanthus emblica* L.	Phyllanthaceae	+													
74	*Polyalthia fragrans* (Dalzell) Hook. f. & Thomson*	Annonaceae										+				
75	*Psydrax umbellata* (Wight) Bridson	Rubiaceae							+	+						+
76	*Pterygota alata* (Roxb.) R. Br.	Malvaceae	+	+	+											
77	*Sapindus emarginata* Vahl	Sapindaceae										+				
78	*Scolopia crenata* (Wight & Arn.) Clos	Salicaceae				+			+							
79	*Semecarpus auriculata* Bedd.*	Anacardiaceae					+									
80	*Sterculia guttata* Roxb.	Malvaceae	+													
81	*Stereospermum colais* (Buch.-Ham. ex Dillw.) D. L. Mabberley	Bignoniaceae											+	+		
82	*Symplocos cochinchinensis* var laurinia	Symplocaceae														+
83	*Symplocos racemosa* Roxb.	Symplocaceae											+			

84	*Syzygium gardneri* Thw.	Myrtaceae								+			+		+	+	
85	*Syzigium spp.*	Myrtaceae	+		+	+	+				+	+					
86	*Tabernaemontana gamblei* Subramanyam & A.N. Henry*	Apocynaceae									+		+				
87	*Terminalia coriacea* (Roxb.) Wight & Arn.	Combretaceae											+				
88	*Toona ciliata* M. Roem.	Meliaceae					+	+									
89	*Vateria indica* L.*	Dipterocarpaceae					+	+									
90	*Vepris bilocularis* (Wight & Arn.) Engl.*	Rutaceae	+	+	+	+	+	+	+								
91	*Vernonia arborea* Buch.-Ham.	Asteraceae														+	+
92	*Vitex altissima* L.f.	Lamiaceae	+			+	+		+								
93	*Xanthophyllum arnottianum* Wight*	Xanthophyllaceae	+	+	+	+			+								
94	*Zanthoxylum rhetsa* (Roxb.) DC.	Rutaceae											+				

*Endemic Species

Appendix 2: Tree Species across the Elevational Gradients of Pushpagiri Wildlife Sanctuary, Kodagu, Karnataka.

Sl.No	Species name	Family	Elevation (m)															
			200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700
1	*Actinodaphne bourdillonii* Gamble.*	Lauraceae									+	+			+	+		
2	*Aglaia elaeagnoidea* (A. Juss.) Benth.*	Meliaceae									+	+						
3	*Aglaia simplicifolia* (Bedd.) Harms.*	Meliaceae												+	+	+	+	
4	*Agrostistachys borneansis* Becc.	Euphorbiaceae							+	+								
5	*Antidesma menasu* (Tul.) Miq. ex Muell.-Arg.	Phyllanthaceae										+						
6	*Antidesma montanum* Blume.	Phyllanthaceae			+													
7	*Aporosa lindleyana* (Wight) Baill.	Euphorbiaceae	+	+	+	+	+	+										
8	*Archidendron bigeminum* (L.)I.C.Nielsen	Mimosoideae												+	+			
9	*Artocarpus heterophyllus* Lam.	Moraceae									+	+						
10	*Artocarpus hirsutus* Lam.*	Moraceae	+	+		+		+						+	+			
11	*Calophyllum apetalum* Willd.*	Callophyllaceae		+							+							
12	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	+															
13	*Caryota urens* L.	Arecaceae						+				+						
14	*Celtis philippensis wightii* (Planch.) E. Soepadmo	Cannabaceae													+			
15	*Chionanthus mala-elengi* (Dennst.) P.S.Green	Oleaceae	+	+	+		+		+									
16	*Chukrasia tabularis* A. Juss.	Meliaceae										+						
17	*Cinnamomum malabatrum* (Burm. f.) Presl*	Lauraceae	+	+	+	+	+	+					+					
18	*Cinnamomum sulphuratum* Nees*	Lauraceae																+
19	*Cinnamomum verum* J. S. Presl	Lauraceae							+									
20	*Croton laccifer* L.	Euphorbiaceae														+	+	
21	*Cryptocarya wightiana* Thw.	Lauraceae		+	+	+												
22	*Dillenia pentagyna* Roxb.	Dilleniaceae						+										
23	*Dimocarpus longan* subsp. longan	Sapindaceae	+			+	+		+	+	+	+	+		+			
24	*Diospyros assimilis* Bedd.	Ebenaceae									+							
25	*Diospyros ebenum* J.Koenig ex Retz.	Ebenaceae	+	+					+									
26	*Diospyros paniculata* Dalzell*	Ebenaceae									+	+						

27	*Diospyros spp.*	Ebenaceae								+				+	+	+		
28	*Dipterocarpus indicus* Bedd.*	Dipterocarpaceae		+						+			+		+			
29	*Drypetes oblongifolia* (Bedd.) Airy Shaw*	Putranjivaceae						+										
30	*Dysoxylum malabaricum* Bedd. ex C. DC.*	Meliaceae									+	+						
31	*Erythroxylum spp.*	Erythroxylaceae							+									
32	*Ficus nervosa* B.Heyne ex Roth.	Moraceae									+	+		+		+		
33	*Garcinia gummi-gutta* (L.) Robs.*	Clusiaceae									+	+	+	+	+			
34	*Garcinia indica* (Thouars) Choisy.*	Clusiaceae					+	+	+					+	+			
35	*Glochidion ellipticum* Wight	Phyllanthaceae	+		+	+		+	+	+								
36	*Gordonia obtusa* Wall. ex Wight & Arn.*	Theaceae												+			+	
37	*Grewia tiliifolia* Vahl. var. tilifolia	Malvaceae	+															
38	*Holigarna arnottiana* Hook.f. *	Anacardiaceae	+	+	+	+		+	+	+	+		+				+	
39	*Holigarna grahamii* (Wight) Kurz*	Anacardiaceae									+	+						
40	*Hopea canarensis* Hole	Dipterocarpaceae									+	+						
41	*Hopea parviflora* Bedd.*	Dipterocarpaceae	+	+	+										+			
42	*Hopea ponga* (Dennst.) Mabb.*	Dipterocarpaceae		+		+	+	+							+			
43	*Humboldtia brunonis* Wall. *	Fabaceae													+			
44	*Hydnocarpus pentandra* (Buch.-Ham.) Oken*	Flacourtiaceae										+		+				
45	*Ixora brachiata* Roxb.*	Rubiaceae	+		+	+			+	+								
46	*Kingiodendron pinnatum* (DC.)Harms*	Fabaceae	+	+	+	+	+		+									
47	*Knema attenuata* (Hook. fil. & Thoms.) Warb.*	Myristicaceae									+	+						
48	*Ligustrum perrottetii* A.DC.*	Oleaceae											+					
49	*Litsea bourdillonii* Gamble*	Lauraceae														+		
50	*Litsea floribunda* (Bl.) Gamble *	Lauraceae												+	+	+		
51	*Litsea mysorensis* Gamble*	Lauraceae									+			+	+	+	+	+
52	*Lophopetalum wightianum* Arn.	Celastraceae		+	+		+											
53	*Macaranga indica* Wight	Euphorbiaceae			+	+	+	+		+			+			+		
54	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae												+				
55	*Mangifera indica* L.	Anacardiaceae									+							
56	*Meiogyne pannosa* (Dalzell) J. Sinclair*	Annonaceae			+		+	+										

57	*Memecylon umbellatum* Burm. f.	Melastomataceae												+			+	+
58	*Mesua ferrea* L.	Calophyllaceae	+		+													
59	*Mimusops elengi* L.	Sapotaceae			+	+			+			+			+			
60	*Murraya paniculata* (L.) Jacq.	Rutaceae												+				
61	*Myristica dactyloides* Gaertn.	Myristicaceae	+	+	+		+			+	+		+		+			
62	*Myristica malabarica* Lam.*	Myristicaceae	+	+		+			+	+	+	+	+	+				
63	*Neolitsea zeylanica* (Nees & T. Nees) Merr.	Lauraceae														+	+	+
64	*Nothapodytes nimmoniana* (J. Grah.) D.J. Mabberley	Stemonuraceae	+	+	+			+										
65	*Nothopegia beddomei* Gamble	Anacardiaceae									+	+						
66	*Nothopegia travancorica* Bedd. ex Hook. f.*	Anacardiaceae				+			+	+								
67	*Olea dioica Roxb.*	Oleaceae	+	+	+	+	+	+	+	+								
68	*Palaquium ellipticum* (Dalzell) Baill.*	Sapotaceae		+	+				+		+	+	+					
69	*Persea macrantha* (Nees) Kosterm.	Lauraceae	+			+		+			+	+	+	+	+	+	+	
70	*Psychotria spp.*	Rubiaceae														+		
71	*Psydrax umbellata* (Wight)Bridson	Rubiaceae												+				+
72	*Rapanea wightiana* (Wall. ex DC.) Mez	Myrsinaceae												+			+	+
73	*Schefflera spp.*	Araliaceae																+
74	*Schefflera wallichiana* (Wight & Arn.) Harms	Araliaceae						+										
75	*Semecarpus travancorica* Bedd.*	Anacardiaceae		+									+					
76	*Spondias pinnata* (L. f.) Kurz	Anacardiaceae						+								+		
77	*Symplocos cochinchinensis* (Lour.) S.Moore ssp. lauriana (Retz.) Noot.	Symplocaceae										+						
78	*Syzygium cumini* (L.) Skeels	Myrtaceae							+	+								
79	*Syzygium densiflorum* Wall. ex Wt. & Arn.*	Myrtaceae															+	+
80	*Syzygium gardneri* Thw.	Myrtaceae		+		+	+	+	+	+				+		+		
81	*Syzigium spp.*	Myrtaceae													+	+	+	
82	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	+					+		+								
83	*Terminalia travancorensis* Wight & Arn.*	Combretaceae		+		+	+	+										
84	*Vateria Indica* L.*	Dipterocarpaceae					+	+	+		+							
85	*Vitex altissima* L.f.	Lamiaceae	+		+	+	+	+		+								

Annexure 3: Species list of Brahmagiri Wildlife Sanctuary

Sl.No	Name of the species	Family	Total	BA (m^2/ha)	IVI	C t/ha
1	*Acrocarpus fraxinifolius* Arn.	Fabaceae	9	2.27	4.87	153.390
2	*Actinodaphne bourdillonii* Gamble	Lauraceae	3	0.04	1.46	0.445
3	*Aglaia simplicifolia (Bedd.)* Harms	Meliaceae	26	1.94	7.16	106.652
4	*Agrostistachys borneansis* Becc.	Euphorbiaceae	6	0.07	1.48	1.418
5	*Alstonia scholaris* (L.) R. Br.	Apocynaceae	1	0.01	0.48	0.390
6	*Antiaris toxicaria* (Pers.) Leschen.	Moraceae	1	0.08	0.55	1.245
7	*Antidesma menasu* (Tul.) Miq. ex Muell.-Arg.	Phyllanthaceae	4	0.29	1.12	4.954
8	*Aphanamixis polystachya* (Wall.) R. N. Parker	Meliaceae	1	0.03	0.50	0.419
9	*Aporosa cardiosperma* (Gaertn.) Merr.	Phyllanthaceae	1	0.02	0.49	0.195
10	*Artocarpus hirsutus* Lam.	Moraceae	10	2.78	5.17	86.835
11	*Atalantia monophylla* (Roxb.) A. DC.	Rutaceae	17	0.22	3.59	5.602
12	*Baccaurea courtalensis* Muell.-Arg.	Phyllanthaceae	9	0.13	2.23	4.002
13	*Bischofia javanica* Blume	Phyllanthaceae	20	2.85	7.45	106.721
14	*Bridelia retusa* (L.) A.Juss.	Phyllanthaceae	1	0.01	0.48	0.069
15	*Calophyllum apetalum* Willd.	Calophyllaceae	10	1.71	5.11	84.789

16	*Canarium strictum* Roxb.	Bursearaceae	4	0.26	1.45	2.852
17	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	10	0.54	2.79	18.975
18	*Caryota urens* L.	Arecaceae	2	0.09	1.04	1.003
19	*Chukrasia tabularis* A. Juss.	Meliaceae	8	0.82	2.85	30.660
20	*Cinnamomum riparium* Gamble	Lauraceae	12	1.34	5.30	49.904
21	*Cinnamomum sulphuratum* Nees	Lauraceae	18	1.60	5.54	13.214
22	*Dalbergia latifolia* Roxb.	Fabaceae	2	0.25	1.21	8.647
23	*Dillenia pentagyna* Roxb.	Dilleniaceae	2	0.14	1.09	3.334
24	*Dimocarpus longan* subsp. longan	Sapindaceae	32	5.25	11.73	191.064
25	*Diospyros assimilis* Bedd.	Ebenaceae	2	0.06	0.65	3.069
26	*Diospyros ebenum* J.Koenig ex Retz.	Ebenaceae	20	1.18	6.03	53.535
27	*Diospyros nilagirica* Bedd.	Ebenaceae	4	0.20	1.75	6.647
28	*Diospyros pruriens* Dalzell	Ebenaceae	10	2.12	4.47	139.739
29	*Diospyros sylvatica* Roxb.	Ebenaceae	8	0.45	2.82	9.997
30	*Dipterocarpus indicus* Bedd.	Dipterocarpaceae	20	1.56	5.36	70.752
31	*Drypetes venusta* (Wight) Pax & K.Hoffm.	Putranjivaceae	19	0.90	4.18	45.847
32	*Dysoxylum malabaricum* Bedd. ex C. DC.	Meliaceae	10	1.58	4.25	61.087
33	*Elaeocarpus serratus L.*	Elaeocarpaceae	3	0.22	1.30	3.275
34	*Elaeocarpus tuberculatus* Roxb.	Elaeocarpaceae	2	0.10	0.69	1.363
35	*Ficus virens W. T. Aiton*	Moraceae	2	1.58	2.27	43.056
36	*Garcinia gummi-gutta* (L.) Robs.	Clusiaceae	5	0.19	1.84	4.445
37	*Garcinia indica* (Thouars) Choisy.	Clusiaceae	7	0.39	2.28	12.637
38	*Glochidion candolleanum* (Wight & Arn.)Chakrab. & M.Gangop	Euphorbiaceae	7	1.19	2.78	15.691
39	*Glochidion malabaricum* (Müll.Arg.) Bedd.	Euphorbiaceae	8	0.95	3.00	13.666
40	*Glycosmis macrocarpa* Wight	Rutaceae	1	0.02	0.49	0.275
41	*Harpullia arborea* (Blanco) Radlk.	Sapindaceae	8	0.41	2.78	12.356
42	*Heynea trijuga* Roxb.	Meliaceae	5	3.11	4.96	140.792
43	*Holigarna arnottiana* Wall. ex Hook. f.	Anacardiaceae	2	0.12	1.07	3.934
44	*Holigarna grahamii* (Wight) Kurz.	Anacardiaceae	1	0.04	0.52	0.648

45	*Hopea parviflora* Bedd.	Dipterocarpaceae	30	8.55	14.68	522.112
46	*Hopea ponga* (Dennst.) D.J. Mabberley	Dipterocarpaceae	8	0.60	2.62	25.957
47	*Hopea utilis* (Bedd.) Bole	Dipterocarpaceae	1	0.08	0.56	3.783
48	*Humboldtia brunonis* Wall.	Fabaceae	12	0.46	3.64	14.597
49	*Ixora brachiata* Roxb.	Rubiaceae	2	0.02	0.61	0.469
50	*Kingiodendron pinnatum* (DC.)Harms	Fabaceae	24	2.58	6.54	81.835
51	*Knema attenuata* (Hook. fil. & Thoms.) Warb.	Myristicaceae	18	0.41	4.27	14.760
52	*Lagerstroemia microcarpa* Wight	Lythraceae	16	4.79	10.15	169.605
53	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	5	0.47	2.15	8.399
54	*Ligustrum perrottetii* A.DC	Lauraceae	29	2.05	6.19	25.586
55	*Litsea floribunda* (Bl.) Gamble	Lauraceae	11	0.96	3.35	42.461
56	*Litsea spp.*	Lauraceae	4	0.77	1.63	5.759
57	*Lophopetalum wightianum* Arn.	Celastraceae	29	5.57	11.38	118.304
58	*Macaranga indica* Wt.	Euphorbiaceae	10	0.62	3.94	12.251
59	*Persea macrantha* (Nees) Kosterm.	Lauraceae	7	2.50	4.18	84.857
60	*Mangifera indica* L.	Anacardiaceae	4	0.33	1.88	9.542
61	*Meliosma simplicifolia* (Roxb.) Walp. ssp. Simplicifoli	Sabiaceae	7	0.34	1.52	3.439
62	*Memecylon randeriana* S.M. Almeida & M.R. Almeida	Melastomaceae	6	1.99	3.52	86.119
63	*Mesua ferrea* L.	Calophyllaceae	7	1.88	4.24	104.878
64	*Mimusops elengi* L.	Sapotaceae	9	1.14	2.95	17.706
65	*Murraya paniculata* (L.) Jacq.	Rutaceae	1	0.06	0.54	1.772
66	*Myristica malabarica* Lam.	Myristicaceae	28	1.19	6.95	29.988
67	*Nothapodytes nimmoniana* (J. Grah.) D.J. Mabberley	Stemonuraceae	7	0.32	2.21	4.931
68	*Nothopegia beddomei* Gamble	Anacardiaceae	2	0.05	1.00	1.037
69	*Nothopegia travancorica* Bedd. ex Hook. f.	Anacardiaceae	5	0.36	1.31	1.868
70	*Nothopegia heyneana* (J. Hk.) Gamble var. heyneana	Anacardiaceae	5	0.08	1.01	11.506
71	*Olea dioica* Roxb.	Oleaceae	76	3.88	15.96	93.106
72	*Palaquium ellipticum* (Dalzell) Baill.	Sapotaceae	8	2.03	4.15	44.168
73	*Phyllanthus emblica* L.	Phyllanthaceae	1	0.31	0.80	15.100

74	*Polyalthia fragrans* (Dalzell) Hook. f. & Thomson	Annonaceae	2	0.15	0.74	2.440
75	*Psydrax umbellata* (Wight) Bridson	Rubiaceae	7	0.19	2.07	3.490
76	*Pterygota alata* (Roxb.) R. Br.	Malvaceae	11	0.52	2.87	19.617
77	*Sapindus emarginata* Vahl	Sapindaceae	3	0.44	1.17	10.869
78	*Scolopia crenata* (Wight & Arn.) Clos	Salicaceae	4	0.32	1.51	8.174
79	*Semecarpus auriculata* Bedd.	Anacardiaceae	3	0.43	1.15	10.933
80	*Sterculia guttata* Roxb.	Malvaceae	1	0.19	0.68	8.409
81	*Stereospermum colais* (Buch.-Ham. ex Dillw.) D. L. Mabberley	Bignoniaceae	10	0.31	2.18	4.385
82	*Symplocos cochinchinensis* var laurinia	Symplocaceae	2	0.18	0.78	1.629
83	*Symplocos racemosa* Roxb.	Symplocaceae	4	0.16	0.99	1.449
84	*Syzygium gardneri* Thw.	Myrtaceae	12	0.63	3.47	13.206
85	*Syzigium spp.*	Myrtaceae	8	0.78	3.89	31.653
86	*Tabernaemontana gamblei* Subramanyam & A.N. Henry	Apocynaceae	2	0.35	1.32	8.581
87	*Terminalia coriacea* (Roxb.) Wight & Arn.	Combretaceae	4	0.07	0.88	0.956
88	*Toona ciliata* M. Roem.	Meliaceae	2	0.51	1.49	14.272
89	*Vateria indica* L.	Dipterocarpaceae	3	0.37	1.45	12.314
90	*Vepris bilocularis* (Wight & Arn.) Engl.	Rutaceae	50	1.27	9.52	36.294
91	*Vernonia arborea* Buch.-Ham.	Asteraceae	10	0.48	2.36	3.236
92	*Vitex altissima* L.f.	Lamiaceae	9	2.01	4.60	87.522
93	*Xanthophyllum arnottianum* Wight	Xanthophyllaceae	11	0.74	3.83	16.663
94	*Zanthoxylum rhetsa* (Roxb.) DC.	Rutaceae	1	0.01	0.48	0.078

Annexure 4: Species list of Pushpagiri Wildlife Sanctuary

Sl.No	Name of the species	Family	Total	BA (m^2/ha)	IVI	C t/ha
1	*Actinodaphne bourdillonii* Gamble.*	Lauraceae	5	0.11	2.18	3.130
2	*Aglaia elaeagnoidea* (A. Juss.) Benth.*	Meliaceae	7	0.23	1.88	10.140
3	*Aglaia simplicifolia* (Bedd.) Harms.*	Meliaceae	14	0.49	3.79	12.126
4	*Agrostistachys borneansis* Becc.	Euphorbiaceae	3	0.51	1.77	15.544
5	*Antidesma menasu* (Tul.) Miq. ex Muell.-Arg.	Phyllanthaceae	1	0.02	0.50	0.285
6	*Antidesma montanum* Blume.	Phyllanthaceae	1	0.04	0.53	1.033
7	*Aporosa lindleyana* (Wight) Baill.	Euphorbiaceae	14	0.47	4.48	9.680
8	*Archidendron bigeminum* (L.)I.C.Nielsen	Mimosoideae	6	0.33	1.89	5.426
9	*Artocarpus heterophyllus* Lam.	Moraceae	3	0.32	1.52	13.476
10	*Artocarpus hirsutus* Lam.*	Moraceae	11	1.57	5.63	39.636
11	*Calophyllum apetalum* Willd.*	Callophyllaceae	8	0.98	3.03	50.142
12	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	1	0.24	0.81	20.987
13	*Caryota urens* L.	Arecaceae	3	0.26	1.44	5.831
14	*Celtis philippensis wightii* (Planch.) E. Soepadmo	Cannabaceae	2	0.16	0.82	5.295
15	*Chionanthus mala-elengi* (Dennst.) P.S.Green	Oleaceae	21	0.47	4.97	8.989
16	*Chukrasia tabularis* A. Juss.	Meliaceae	1	0.02	0.50	0.240
17	*Cinnamomum malabatrum* (Burm. f.) Presl*	Lauraceae	28	0.74	6.91	17.966
18	*Cinnamomum sulphuratum* Nees*	Lauraceae	1	0.01	0.49	0.048
19	*Cinnamomum verum* J. S. Presl	Lauraceae	1	0.32	0.91	10.343
20	*Croton laccifer* L.	Euphorbiaceae	3	0.04	1.13	0.287
21	*Cryptocarya wightiana* Thw.	Lauraceae	4	0.13	1.73	3.863
22	*Dillenia pentagyna* Roxb.	Dilleniaceae	1	0.17	0.71	4.502
23	*Dimocarpus longan* subsp. longan	Sapindaceae	28	2.31	9.78	77.623
24	*Diospyros assimilis* Bedd.	Ebenaceae	1	0.08	0.59	4.211
25	*Diospyros ebenum* J.Koenig ex Retz.	Ebenaceae	3	0.08	1.54	2.685

26	*Diospyros paniculata* Dalzell*	Ebenaceae	7	0.22	1.86	9.592
27	*Diospyros spp.*	Ebenaceae	10	0.52	3.35	15.397
28	*Dipterocarpus indicus* Bedd.*	Dipterocarpaceae	6	0.57	2.94	15.299
29	*Drypetes oblongifolia* (Bedd.) Airy Shaw*	Putranjivaceae	3	0.53	1.44	28.046
30	*Dysoxylum malabaricum* Bedd. ex C. DC.*	Meliaceae	6	0.13	1.62	3.642
31	*Erythroxylum spp.*	Erythroxylaceae	1	0.02	0.50	0.416
32	*Ficus nervosa* B.Heyne ex Roth.	Moraceae	4	5.43	9.37	186.950
33	*Garcinia gummi-gutta* (L.) Robs.*	Clusiaceae	21	0.78	5.40	18.627
34	*Garcinia indica* (Thouars) Choisy.*	Clusiaceae	6	0.52	3.23	20.879
35	*Glochidion ellipticum* Wight	Phyllanthaceae	10	0.27	3.72	6.238
36	*Gordonia obtusa* Wall. ex Wight & Arn.*	Theaceae	7	0.14	1.76	1.998
37	*Grewia tiliifolia* Vahl. var. tilifolia	Malvaceae	1	0.73	1.47	5.559
38	*Holigarna arnottiana* Hook.f. *	Anacardiaceae	24	4.22	12.27	135.525
39	*Holigarna grahamii* (Wight) Kurz*	Anacardiaceae	4	0.24	1.53	7.942
40	*Hopea canarensis* Hole	Dipterocarpaceae	10	3.26	6.40	183.096
41	*Hopea parviflora* Bedd.*	Dipterocarpaceae	10	1.36	4.51	105.514
42	*Hopea ponga* (Dennst.) Mabb.*	Dipterocarpaceae	25	1.89	7.41	65.060
43	*Humboldtia brunonis* Wall. *	Fabaceae	1	0.02	0.50	0.623
44	*Hydnocarpus pentandra* (Buch.-Ham.) Oken*	Flacourtiaceae	2	2.14	3.89	63.481
45	*Ixora brachiata* Roxb.*	Rubiaceae	23	0.83	5.71	12.798
46	*Kingiodendron pinnatum* (DC.)Harms*	Fabaceae	30	2.33	8.97	88.076
47	*Knema attenuata* (Hook. fil. & Thoms.) Warb.*	Myristicaceae	2	0.06	1.04	5.727
48	*Ligustrum perrottetii* A.DC.*	Oleaceae	9	0.16	1.67	2.990
49	*Litsea bourdillonii* Gamble*	Lauraceae	1	0.06	0.56	0.508
50	*Litsea floribunda* (Bl.) Gamble *	Lauraceae	6	0.39	2.33	23.911
51	*Litsea mysorensis* Gamble*	Lauraceae	35	1.45	8.38	25.586
52	*Lophopetalum wightianum* Arn.	Celastraceae	19	2.69	7.08	67.479
53	*Macaranga indica* Wight	Euphorbiaceae	13	0.54	4.81	8.500
54	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae	11	0.59	2.50	12.904
55	*Mangifera indica* L.	Anacardiaceae	1	0.27	0.84	9.215
56	*Meiogyne pannosa* (Dalzell) J. Sinclair*	Annonaceae	3	0.52	2.14	23.830

57	*Memecylon umbellatum* Burm. f.	Melastomataceae	14	0.28	3.15	5.205
58	*Mesua ferrea* L.	Calophyllaceae	3	1.00	2.45	92.188
59	*Mimusops elengi* L.	Sapotaceae	9	1.45	4.86	85.964
60	*Murraya paniculata* (L.) Jacq.	Rutaceae	2	0.03	0.63	0.475
61	*Myristica dactyloides* Gaertn.	Myristicaceae	32	1.77	9.17	56.157
62	*Myristica malabarica* Lam.*	Myristicaceae	22	1.22	7.56	29.227
63	*Neolitsea zeylanica* (Nees & T. Nees) Merr.	Lauraceae	19	0.46	4.00	4.691
64	*Nothapodytes nimmoniana* (J. Grah.) D.J. Mabberley	Stemonuraceae	8	0.54	3.14	17.239
65	*Nothopegia beddomei* Gamble	Anacardiaceae	3	0.09	1.20	3.521
66	*Nothopegia travancorica* Bedd. ex Hook. f.*	Anacardiaceae	4	0.33	2.01	12.371
67	*Olea dioica Roxb.*	Oleaceae	31	1.40	8.53	44.633
68	*Palaquium ellipticum* (Dalzell) Baill.*	Sapotaceae	31	10.93	20.92	474.452
69	*Persea macrantha* (Nees) Kosterm.	Lauraceae	13	1.02	6.53	26.006
70	*Psychotria spp.*	Rubiaceae	1	0.02	0.50	0.149
71	*Psydrax umbellata* (Wight)Bridson	Rubiaceae	7	0.20	1.84	3.010
72	*Rapanea wightiana* (Wall. ex DC.) Mez	Myrsinaceae	6	0.11	1.95	1.480
73	*Schefflera spp.*	Araliaceae	4	0.11	0.99	0.609
74	*Schefflera wallichiana* (Wight & Arn.) Harms	Araliaceae	1	0.01	0.49	0.071
75	*Semecarpus travancorica* Bedd.*	Anacardiaceae	12	0.67	3.09	12.879
76	*Spondias pinnata* (L. f.) Kurz	Anacardiaceae	3	0.16	1.30	2.075
77	*Symplocos cochinchinensis* (Lour.) S.Moore ssp. lauriana (Retz.) Noot.	Symplocaceae	1	0.11	0.63	4.354
78	*Syzigium spp.*	Myrtaceae	3	0.81	2.19	27.299
79	*Syzygium cumini* (L.) Skeels	Myrtaceae	20	0.51	3.83	4.681
80	*Syzygium densiflorum* Wall. ex Wt. & Arn.*	Myrtaceae	25	2.43	9.22	74.098
81	*Syzygium gardneri* Thw.	Myrtaceae	4	0.04	1.60	0.689
82	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	3	0.84	2.59	50.063
83	*Terminalia travancorensis* Wight & Arn.*	Combretaceae	14	0.78	4.19	38.386
84	*Vateria Indica* L.*	Dipterocarpaceae	10	1.06	4.09	33.348
85	*Vitex altissima* L.f.	Lamiaceae	37	1.43	8.59	49.718

Appendix 5: Regeneration species across Elevational Gradients of Brahamagiri Wildlife Sanctuary, Kodagu, Karnataka

			Elevation(m)														
Sl.No	**Name of the speceis**	**Family**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1100**	**1200**	**1300**	**1400**	**Density**
1	*Acrocarpus fraxinifolius* Arn.	Fabaceae										+					1
2	*Aglaia simplicifolia* (Bedd.) Harms*	Meliaceae	+		+			+									4
3	*Aporosa lindleyanaa (Wight) Baill.*	Euphorbiaceae						+									2
4	*Atalantia monophylla* (Roxb.) A. DC.	Rutaceae	+	+	+	+				+							48
5	*Baccaurea courtalensis* Muell.-Arg.*	Phyllanthaceae	+														1
6	*Calophyllum inophyllum* L.	Calophyllaceae				+											4
7	*Caryota urens* L.	Arecaceae						+	+	+							3
8	*Cinnamommum spp.*	Lauraceae	+								+	+	+	+		+	28
9	*Cinnamomum riparium*	Lauraceae		+	+			+	+	+							21
10	*Coffea arabica* L.	Rubiaceae									+						2
11	*Dalbergia spp.*	Fabaceae												+			1
12	*Dimocarpus longan* subsp. longan	Sapindaceae						+	+	+	+	+	+	+			38
13	*Diospyros ebenum* J.Koenig ex Retz.	Ebenaceae	+	+													8
14	*Diospyros spp.*	Ebenaceae	+	+			+	+	+	+	+			+			57
15	*Dipterocarpus indicus* Bedd.	Dipterocarpaceae		+	+			+									5
16	*Elaeocarpus serratus* L.	Elaeocarpaceae												+			2
17	*Garcinia gummi-gutta* (L.) Robs.	Clusiaceae	+				+					+					3
18	*Glochidion ellipticum* Wight	Euphorbiaceae		+													2
19	*Drypetes venusta* (Wight) Pax & K.Hoffm.	Putranjivaceae	+	+	+	+	+	+									51
20	*Hopea parviflora* Bedd.	Dipterocarpaceae					+										12
21	*Humboldtia brunonis* Wall.	Fabaceae		+					+	+							7
22	*Ixora spp.*	Rubiaceae				+			+								14
23	*Kingiodendron pinnatum* (DC.)Harms	Fabaceae	+	+	+	+	+	+	+	+			+	+			47
24	*Lagerstroemia lanceolata* Wall.	Lythraceae				+											3
25	*Litsea floribunda* (Bl.) Gamble	Lauraceae													+	+	6
26	*Lophopetalum wightianum*	Celastraceae							+								20
27	*Persea Macrantha* (Nees) Kosterm	Lauraceae								+							1
28	*Mangifera indica* L.	Anacardiaceae						+				+					3

29	*Mimusops elengi* L.	Sapotaceae							+	+				+		8
30	*Murraya paniculata* (L.) Jacq.	Rutaceae				+			+	+	+	+	+			14
31	*Myristica malabarica* Lam.	Myristicaceae	+				+		+							8
32	*Nothopegia travancorica* Bedd. ex Hook. f.	Anacardiaceae									+	+	+	+		10
33	*Olea dioica* Roxb.	Oleaceae					+		+	+	+		+			27
34	*Palaquium ellipticum* (Dalzell) Baill.	Sapotaceae	+	+	+	+		+	+							22
35	*Phyllanthus emblica* L.	Phyllanthaceae								+						1
36	*Pittosporum tetraspermum* Wight & Arn.	Pittosporaceae									+	+	+	+		16
37	*Psychotria spp.*	Rubiaceae						+								1
38	*Scolopia crenata* **(**Wight & Arn.*)* Clos	Salicaceae									+					1
39	*Sterculia alata* Roxb.	Malvaceae	+	+		+		+								19
40	*Symplocos cochinchinensis* var laurinia	Symplocaceae					+									2
41	*Syzygium gardneri* Thw.	Myrtaceae							+	+						4
42	*Syzigium spp.*	Myrtaceae						+					+			8
43	*Toona ciliata* M. Roem.	Meliaceae					+							+		5
44	Unknown	-				+	+	+	+							23
45	*Vernonia arborea* Buch.-Ham.	Asteraceae													+	1
46	*Vitex altissima* L.f.	Lamiaceae						+	+	+				+		7

Appendix 6: Regeneration tree species across Elevational Gradients of Pushpagiri Wildlife Sanctuary, Kodagu, Karnataka

Sl.No	Name of the species	Family	Elevation(m)																Density
			200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	
1	*Actinodaphne bourdillonii* Gamble.*	Lauraceae											+	+	+	+	+		20
2	*Chionanthus mala-elengi* (Dennst.) P.S.Green	Oleaceae				+	+												5
3	*Cinnamomum riparium* Gamble	Lauraceae	+		+	+	+	+					+			+			12
4	*Cinnamomum spp.*	Lauraceae																+	3
5	*Cinnamomum sulphuratum* Nees*	Lauraceae												+			+		16
6	*Dimocarpus longan* subsp. longan	Sapindaceae									+	+	+	+	+				43
7	*Diospyros ebenum* J.Koenig ex Retz.	Ebenaceae	+	+	+		+	+	+	+	+	+	+						64
8	*Garcinia gummi-gutta* (L.) Robs.*	Clusiaceae													+				6
9	*Glochidion ellipticum* Wight	Phyllanthaceae	+															+	4
10	*Holigarna arnottiana* Hook.f. *	Anacardiaceae		+	+		+		+	+	+			+	+				43
11	*Hopea parviflora* Bedd.*	Dipterocarpaceae	+	+															3
12	*Hopea ponga* (Dennst.) Mabb.*	Dipterocarpaceae									+	+							7
13	*Ixora brachiata Roxb.**	Rubiaceae										+		+			+		11
14	*Kingiodendron pinnatum* (DC.)Harms*	Fabaceae	+		+	+	+	+	+	+									62
15	*Litsea mysorensis* Gamble*	Lauraceae													+		+	+	27
16	*Memecylon randeriana*	Melastomataceae		+				+						+		+	+		10
17	*Mimusops elengi* L.	Sapotaceae	+					+		+									4
18	*Murraya spp.*	Rutaceae	+								+		+	+					17
19	*Myristica dactyloides* Gaertn.	Myristicaceae	+																1
20	*Myristica malabarica* Lam.*	Myristicaceae											+		+				12
21	*Neolitsea zeylanica* (Nees & T. Nees) Merr.	Lauraceae															+	+	6
22	*Nothopegia spp.*	Anacardiaceae	+		+						+	+		+	+	+			45
23	*Olea dioica* Roxb.	Oleaceae	+																1
24	*Palaquium ellipticum* (Dalzell) Baill.*	Sapotaceae													+				8
25	*Raphanea striata*	Myrsinaceae																+	1
26	*Symplocos cochinchinensis* (Lour.) S.Moore ssp. lauriana (Retz.) Noot.	Symplocaceae										+							1

27	*Syzygium cumini* (L.) Skeels	Myrtaceae		+	+	+							9
28	*Syzygium gardneri* Thw.	Myrtaceae						+	+	+	+	+	36
29	*Terminalia spp.*	Combretaceae					+						1
30	*Vitex altissima* L.f.	Lamiaceae	+										1

PUBLICATIONS

1. Neikha, V., & Nagaraja, B.C. (2019). Tree diversity and Endemism Pattern in Makutta Wildlife Range, Western Ghats, India. *Indian Forester*, 145 (7), 631-636.
2. Neikha, V., & Nagaraja, B.C. (2019). Tree species richness and distribution along an elevational gradient of Brahmagiri Wildlife Sanctuary. Accepted in *Ecology Environment and Conservation*, 25 (3), 255-264.
3. Neikha, V., & Nagaraja, B.C. (2019). Vegetation Composition across Elevational Gradients of Pushpagiri Wildlife Sanctuary in Kodagu, Western Ghats, India. *International Journal of Research in Advent Technology*, 7(2), 676-683.
4. Neikha, V., & Nagaraja, B.C. (2019). Tree species richness across two protected areas in Kodagu, Western Ghats, India. In Nandini, N., Kumar, M., & Nagaraja, B.C (Eds.). *Contemporary Environmental Issues-Concerns and Management*, Bangalore University, Bangalore, pp. 142-149. (Accepted)