Volume Equations for Tree Species from Forest and Trees Outside Forest



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PREFACE

Climate change pose serious threat to the environment and the quality of human life all over the world. Considering this global challenge, the parties to the United Nations Framework Convention on Climate Change (UNFCCC) have undertaken the comprehensive exercise to address the issues of climate change adaptation and mitigation. The significant importance of forests in climate change and global carbon cycle has been proven time and again and is quite evident to policy makers and the scientific community. For this reason, according to the UNFCCC, the signatory nations have to report the state of forest resources and temporal as well as spatial carbon stock inventories.

Measurement of carbon stock is a recognized methodology to monitor the greenhouse gases in the atmosphere. India's strength in measuring its carbon stocks arises from its robust system of monitoring forest cover and carrying out forest inventory on a regular basis. For the second national communication (SNC) to the UNFCCC, the FSI was given the task of conducting Greenhouse gas inventory in Forest Land Remaining Forest Land & Land Converted into Forest Land for the period of 1994 to 2004 under Land Use, Land Use Change and Forestry (LULUCF).

The precise estimates of growing stock largely depend on the availability of accurate volume equations. The book titled 'Volume Equations for Forests of India, Nepal and Bhutan' has been the most reliable source of volume equations in Indian context. With highest contribution from FSI, developing and compiling around 900 volume equations for approximately 270 species was a collaborative effort of FSI, FRI and Karnataka Forest Department. In spite of the commendable job, it is noteworthy to mention here that all these volume equations had been developed for selected forest species.

Unavailability of volume equations for remaining forest species and species from trees outside forest acts as an information gap in precise estimation and assessment of carbon stock at the national level. Therefore, FSI has made an attempt to develop volume equations for 30 tree species each from forest and TOF in this study. I hope the results of this study will provide valuable information to the policy makers, managers, researchers and various other stake holders group to understand and appropriately use the data for sustainable management of forest resources in the country.

Anoop Singh

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All the State Forest Departments have extended full support to FSI teams, in conducting the fieldwork. Help provided to the officials of FSI during the field tours by all the SFDs is gratefully acknowledged.

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ACRONYMS AND ABBREVIATIONS

CASFOS – Central Academy for State Forest Service

COVID-19 – Coronavirus Disease of 2019

DBH – Diameter at Breast Height

DBT – Double Bark Thickness

FGD – Forest Geo-Informatics Division

FRI – Forest Research Institute

FSI – Forest Survey of India

ICFRE – Indian Council of Forestry Research and Education

IGNFA – Indira Gandhi National Forest Academy

INC – Initial National Communication

KFD – Kerala Forest Department

LULUCF - Land Use, Land Use Change and Forestry

LVE – Local Volume Equation

MOEF&CC – Ministry of Environment Forest and Climate Change

NFI – National Forest Inventory

SNC – Second National Communication

TFI – Training and Forest Inventory

TNC – Third National Communication

TOF – Trees Outside Forest

UNFCCC – United Nations Framework Convention on Climate Change

UTs – Union Territories

GLOSSARY

AFFORESTATION	The act or process of establishing a forest especially on land not previously forested.
AGROFORESTRY	It is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence.
ALEXITERIC	A preservative against infectious diseases and also against the effects of venom.
ALLUVIAL	These are soils which consist of earth and sand left behind on land which has been flooded or where a river once flowed.
ANTHELMINTIC	Anthelmintic or antihelminthics are a group of anti-parasitic drugs that expel parasitic worms and other internal parasites from the body by either stunning or killing them and without causing significant damage to the host.
BIOMASS	Forest biomass is organic matter expressed as oven-dry tonnes per unit area: it can be referred to as biomass density when expressed as mass per unit area.
CANOPY	Canopy is the above-ground portion of vegetation in forests consisting of the tops of trees forming a kind of ceiling.
CARBON SEQUESTRATION	It is the long term process of storage of carbon in plants, soil, geological formations and the ocean.
CARMINATIVE	It is an herb or preparation, intended to expelling gas from the stomach or intestines so as to relieve flatulence or abdominal pain or distension.
CORIACEOUS	Leaves with noticeably thick and leathery surfaces are called coriaceous.
DECIDUOUS	Deciduous trees are those that lose all of their leaves for part of the year.
DENDROMETRY	It is the branch of botany that is concerned with the measurement of the various dimensions of trees, such as their diameter, size, shape, age, overall volume, thickness of the bark, etc.
DIAMETER CLASS	Also known as DBH class means any of the intervals into which a range of diameters of tree stems or logs may be divided for classification and utilization.

EVERGREEN	The tree that has leaves throughout the year that are always green and don't fall out.
EXOTIC SPECIES	The species of plants which are non-native to the introduced environment are known as exotic species. Exotic species compete with the native species for resources in an ecosystem.
FOREST MENSURATION	Forest Mensuration is a branch of forestry that deals with the determination of dimensions (e.g. diameter, height, volume etc.), form, age, and increment of single trees, stands or whole woods, either standing or after felling.
FOREST PRODUCTIVITY	The standing forest volume at a given time *t*, *Vt*, which is the cumulative increase of stand volume since the stand was initiated. Forest productivity is generally the basis for evaluating current forest inventory, planning bio-economy and sustainable forest management, and assessing current and future wood supply.
GLABROUS	Glabrous morphological feature is one that is smooth and may be glossy. It has no bristles or hair-like structures such as trichrome.
GLOBOSE	Refers to the trees whose canopy has a shape like a globe.
GREGARIOUS	Growing in groups that are close together but not densely clustered or matted.
GROWING STOCK	The sum (by number or volume) of all the trees growing/living in the forest or a specified part of it.
INDIGENOUS SPECIES	Indigenous species refers to the plants growing natively or naturally in a particular region or environment.
INFLORESCENCE	It is the mode of development and arrangement of flowers on an axis.
INVASIVE SPECIES	The non-native species growing and dispersing easily usually to the detriment of native species and ecosystems. They tend to spread in a quick or aggressive manner.
MONTANE FOREST	Montane Forests in India are characterised by a decrease in temperature with increasing altitude, which causes a change in natural vegetation in mountainous areas. In these forests, coniferous trees such as pine, deodar, silver fir, spruce, and cedar can be found between 1500 and 3000 metres.
POLLARDING	It is a pruning system, involving the removal of the upper branches of a tree, which promotes the growth of a dense head of foliage and branches.
POLYGAMOMONOECIOUS	An individual plant with male, female and perfect flowers on the same plant.
PROTECTED FOREST	An area notified under the provisions of the Indian Forest Act or other State Forest Acts, having limited degree of protection. In protected forest, all activities are permitted unless prohibited.

REFORESTATION	It is the restoration of forests by natural seeding or by the artificial planting of seeds or young trees in areas where forests were removed or destroyed.
REGRESSION	Regression is a statistical measure that defines co-relationship or association of two variables. It describes how an independent variable is associated with the dependent variable.
RESERVED FOREST	An area so constituted under the provisions of the Indian Forest Act or other State Forest Acts, having full degree of protection. In reserved forest, all activities are prohibited unless permitted.
RIVERINE	Refers to the areas, which are on or near the banks of a river.
R-SQUARED	R-squared is a statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable.
SAMPLE SIZE	Sample size refers to the number of participants or observations included in a study. This number is usually represented by n. The size of a sample influences the precision of our estimates and the power of the study to draw conclusions.
STANDARD DEVIATION	Standard deviation measures the dispersion of a dataset relative to its mean and is calculated as the square root of the variance.
STYPTIC	Styptics are a specific type of haemostatic agent that work by contracting tissue to seal injured blood vessels thereby checking the flow of blood from an injury.
SUBTROPICAL	The subtropical zones or subtropics are geographical and climate zones to the north and south of the tropics. Geographically part of the temperate zones of both hemispheres, they cover the middle latitudes from 23°26′10.6″ to approximately 35° north and south.
TOMENTOSE	The leaves, which are covered with a dense layer of short, matted woolly hairs.
TREES OUTSIDE FOREST	It refers to all trees growing outside recorded forest areas irrespective of patch size.
TROPICAL	The tropics are the regions of Earth surrounding the Equator. They are defined in latitude by the Tropic of Cancer in the Northern Hemisphere at 23°26′10.6″ N and the Tropic of Capricorn in the Southern Hemisphere at 23°26′10.6″ S. The tropics are also referred to as the tropical zone and the Torrid Zone.
UNCLASSED FOREST	An area recorded as forest but not included in reserved or protected forest category. Ownership status of such forest varies from state to state.
VOLUME EQUATION	It relates wood volume to stem diameter at breast height and/or to tree height and/or other dendrometric variables.

VOLUME TABLE	It is a tabulated statement of the yield of trees upon the basis of various measurements of diameter and height.
WESTERN GHATS	Also called Sahyadri, north–south-running range of mountains or hills in western India that forms the crest of the western edge of the Deccan plateau parallel to the Malabar Coast of the Arabian Sea. The Western Ghats are a biodiversity hot spot, a biologically rich but threatened region, and a UNESCO World Heritage site.



CHAPTER ONE

INTRODUCTION

1.1 Background

Growing stock is the sum (by number or volume) of all the trees growing/living in the forest or a specific part of it. It constitutes the most important parameter of the forest resources and is an indicator of forest productivity [1]. Historically, forests have been managed to produce timber as a major product and therefore the forest inventories primarily aimed at assessing the growing stock with a focus on sustained yield of timber from forests. Correct assessment of growing stock is very essential for sound forest management. The annual increase in growing stock is harvestable and, more often than not, guides the quantity prescribed for harvesting. For the management purposes, the foresters are often concerned with determining the volume of a large number of trees falling within certain dimensions viz. diameter and height classes. For this purpose, volume tables are used which provide the volume of the trees. The volume tables are based on diameter and/or, height and/or form of the tree. Volume table can be defined as a statement which gives the average volume of trees by girth, diameter, height or form classes in a tabular form. The volume tables are constructed from volume equations.

Growing stock also provides the biomass of forest eco-system and carbon pool and this information has gained much importance in the past few decades because of the role forests play in climate change and global carbon cycle [2]. According to the United Nations Framework Convention on Climate Change (UNFCCC), the signatory nations have to report the state of forest resources and temporal as well as spatial carbon stock inventories [3]. The precise estimates of growing stock largely depend on the availability of accurate volume/allometric equations. The tree allometric equation relates wood volume or that of several tree components to stem diameter at breast height and/or to tree height and/or other dendrometric variables [4].

Types of Volume Equations:

Trees with similar diameter and height even for the same species do not necessarily have the same volume. This is due to the variation in the form of trees caused by natural forces or the pattern of utilisation. Therefore, depending on the applicability, different types of volume equations have been developed and used:

(i) **Local volume equation** – The local volume equations have limited application for a forest or small locality and are based only on diameter at breast height (dbh). The basic assumption involved in preparation of local volume equations is that the trees of same dbh have similar height and form. It may be true as all the three variables; dbh, height and form are the products of the site quality, age and other conditions affecting the growth. A volume equation of this type applied to the sites with similar ecological conditions and productivity values gives true result.

(ii) **Regional volume equation** – It is normally based on two variables such as dbh and height and covers a wide range of distribution of the species in a particular region.

(iii) **General or Standard volume equation** – It is also based on two variables such as dbh and height. It is however, broad based and covers the full distribution of the species over a large area.

1.2 Past studies by Forest Survey of India

Forest survey of India has developed a total of 753 volume equations for 198 species spread throughout India, Bhutan and parts of Nepal. Apart from this, approximately 140 volume equations for about 70 species have been compiled by Forest Research Institute and Karnataka Forest Department in the book on Volume Equations for Forests of India, Nepal and Bhutan [5]. These volume equations are based on a large data collected during the field inventory work and have been developed over a period of around 30 years. The States and Union Territories covered through these studies were Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Gujarat, Goa, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Odisha, Punjab, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal and Andaman and Nicobar Islands.

As both the General and Regional volume equations are based on two variables i.e., diameter and height, few examples of these Volume Equations developed by FSI under this study are given below:

(i) $V = a + bD^2H$

(ii) $V = a + bD + cD^2H$

(iii) $V = a + bD^2 + c(D^2H)^2$

(iv) $V = a + bD + cD^2H + d\ (D^2H)^2$

(v) $V = a + bD + cH + cD^2H$

(vi) $V = a + bD + cD^2 + dD^2H$

(vii) $\log_e V = a + b \log_e D + c \log_e H$

(viii) $V/D^2H = a + bD^2H$

(ix) $V/D^2H = a + bD^2H + c/\ D^2H$

Where V = volume (m^3) under bark

D = diameter at breast height (1.37m) over bark in metre

H = height of tree in metre

'a', 'b', 'c' and 'd' are regression coefficients

Few examples of Local Volume Equations which are based on diameter only are as follows:

(i) $V = a + bD^2$

(ii) $V = a + bD + cD^2$

(iii) $V = a + bD + cD^2 + dD^3$

(iv) $V = a + b\sqrt{D} + cD^2$

(v) $\sqrt{V} = a + bD$

(vi) $\sqrt{V} = a + bD + c\sqrt{D}$

(vii) $V/D^2 = a + b/D^2$

(viii) $V/D^2 = a + b/D + c/D^2$

(ix) $V/D^2 = a + b/D^2 + c/D + dD$

(x) $\text{Log}_e V = a + \log_e D$

Where V = volume (m^3) under bark

D = diameter at breast height (1.37m) over bark in metre

'a', 'b', 'c' and 'd' regression coefficients.

1.3 Objective of the study

In past, the volume equations have been developed by following a destructive approach also known as harvest method wherein the trees have been felled to measure the necessary variables like diameter and height. It is noteworthy to mention that these volume equations have been developed by collecting data from forest areas only which falls in Reserved forest, Protected forest or Unclassed forest. Therefore, to have precise information on carbon stock at national level, developing volume equations for other contributing tree species from forest for which volume equations are yet not available or giving erroneous results, is of utmost importance.

From the last four decades Trees outside forests has taken very significant role for industrial wood production as well as providing other goods and services. It has become imperative to develop volume equations for all significantly contributing such tree species.

Thus, to have precise estimates of volume for important tree species, the study 'Developing volume equations for tree species from forest and TOF' has been undertaken. The project aims to develop local volume equations for 30 important tree species each from forest and TOF following a non-destructive approach.

1.4 Contents of the report

The present report on 'Developing volume equations for tree species from forest and TOF' has been framed in four chapters. A brief description of the chapters has been given below:

Chapter one 'Introduction' provides the background of the study, the past studies conducted by Forest Survey of India related to this field and the different types of derived volume equations. It also focusses on the major objective of this study.

Chapter Two covers 'Methods, Field Study and Analysis'. Initiating with a brief framework of the study, this chapter gives description of the survey and sampling design. It also provides the detailed methodology followed for selection of sites for data collection. This chapter also includes the details of data collection,

processing and analysis so as to arrive at the required results. A sub-section of this chapter named 'Execution of Fieldwork' gives the details of the herculean task of data collection/fieldwork conducted during this study. An overview of the Pan-India fieldwork has been given in the starting followed by detailed information about the five phases in which the field work had been carried out. The data collected from each of the five regions has been presented in the tabular form and bar diagrams. This chapter also showcases the photographs (shown as plates) taken during the data collection process.

Chapter three 'Results and discussions' has been presented in two sections. The first section showcases the developed volume equations for 30 forest tree species and the second section has the developed volume equations for 30 TOF tree species. Both the sections have a brief general description of the tree species followed by the best fit local volume equation developed for each species.

In the fourth chapter 'Conclusion and Future Vision', the gist of the results is presented in tabular format. This chapter also includes the future course of action to be followed to bridge necessary information gaps.

CHAPTER TWO

METHODS, FIELD STUDY AND ANALYSIS

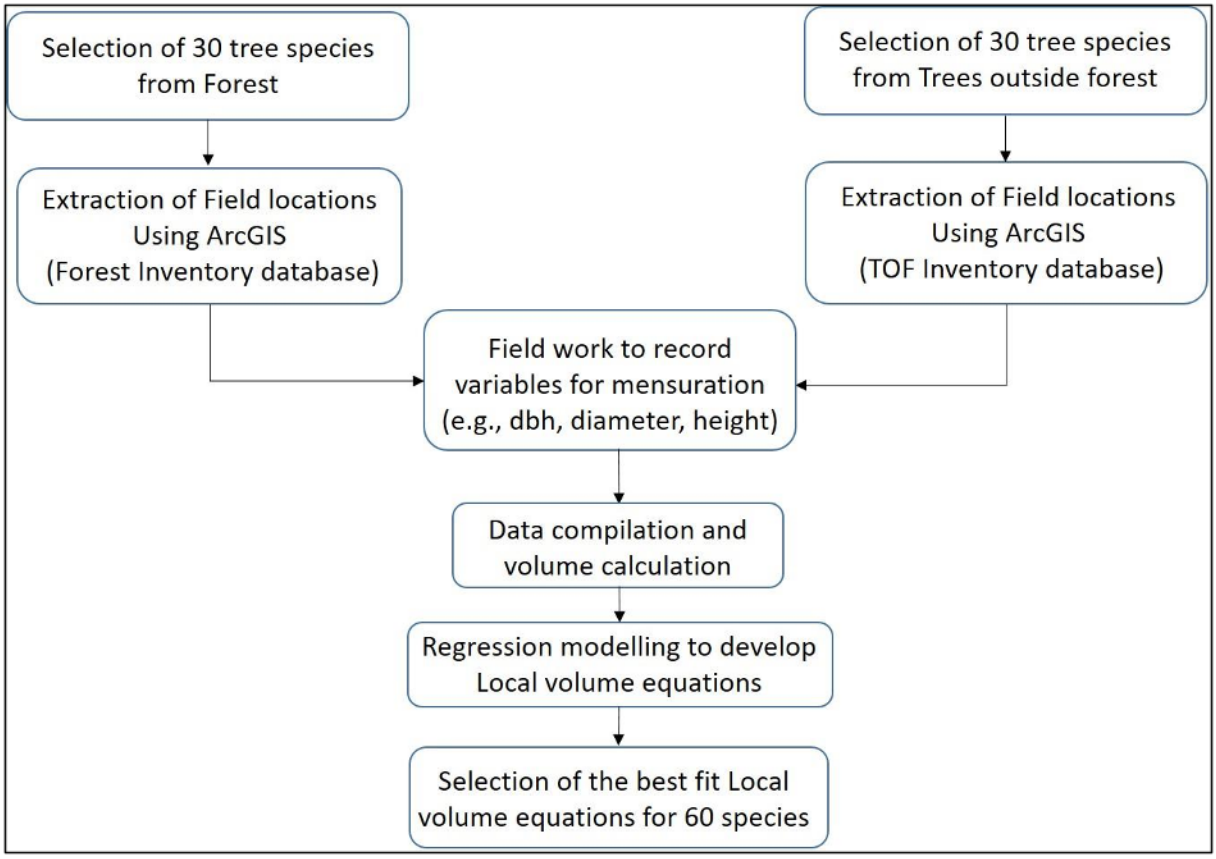
2.1 Methods

2.1.1 Introduction

Harvesting of trees and weighing their parts is the most accurate way of biomass and carbon stock estimation, but due to ban on green felling in India, the non-destructive approach has risen up as an efficient alternative and has been adopted here also. The non-destructive methods of biomass and carbon stock estimation are emphasised because they are less time-consuming and cost-effective than the harvest method [6]. The precise estimation of tree volume and biomass in forest ecosystems is essential for above ground biomass carbon stock assessment. Assessment of carbon sequestration potential in terrestrial ecosystems using regression models is a commonly used approach [7].

2.1.2 Brief Framework of study

Figure 2.1 Flowchart of the Methodology



2.1.3 Selection of tree species:

The foremost requirement to achieve the objective of this project is to identify 30 tree species each in forest and Trees outside forest (TOF) for which Local Volume Equations (LVE) will be developed. The prerequisite of the species selection of forest is that only those species have been selected for which either the Volume equations are non-available or their volume equations are giving imprecise results. In this way, 30 tree species from forest have been selected based on the said criteria. On the other hand, 30 tree species from TOF are selected, those are dominant in terms of their contribution to the volume. The list of selected tree species in forest and TOF has been provided below.

Table 2.1 List of selected species for developing Local Volume Equations

Species in Forest		Species in Trees Outside Forest	
S.no	**Name**	**S.no.**	**Name**
1	*Acacia auriculiformis*	1	*Acacia arabica*
2	*Acacia catechu*	2	*Anacardium occidentale*
3	*Albizia procera*	3	*Artocarpus heterophyllus*
4	*Albizia amara*	4	*Azadirachta indica*
5	*Alnus nepalensis*	5	*Bombax ceiba*
6	*Anogeissus pendula*	6	*Borassus flabelliformis*
7	*Bridelia retusa*	7	*Cocos nucifera*
8	*Buchanania latifolia*	8	*Dalbergia sissoo*
9	*Butea monosperma*	9	*Elaeis guineensis*
10	*Careya arborea*	10	*Butea monosperma*
11	*Cassia siamea*	11	*Ficus benghalensis*
12	*Chloroxylon swietenia*	12	*Ficus racemosa*
13	*Dalbergia paniculata*	13	*Ficus religiosa*
14	*Emblica officinalis*	14	*Grewia oppositifolia*
15	*Hardwickia binata*	15	*Holoptelea integrifolia*
16	*Hevea brasiliensis*	16	*Leucaena leucocephala*
17	*Holarrhena antidysenterica*	17	*Mangifera indica*
18	*Lyonia ovalifolia*	18	*Moringa oleifera*
19	*Macaranga indica*	19	*Morus alba*
20	*Madhuca latifolia*	20	*Phoenix sylvestris*
21	*Mallotus philippinensis*	21	*Pinus kesiya*
22	*Prosopis juliflora*	22	*Pongamia pinnata*
23	*Quercus leucotrichophora*	23	*Populus deltoides*
24	*Rhododendron arboreum*	24	*Prosopis cineraria*
25	*Schima wallichii*	25	*Swietenia mahagoni*
26	*Schleichera oleosa*	26	*Syzygium cumini*
27	*Semecarpus anacardium*	27	*Tamarindus indica*
28	*Terminalia arjuna*	28	*Tectona grandis*
29	*Terminalia paniculata*	29	*Terminalia crenulata*
30	*Xylia xylocarpa*	30	*Zizyphus mauritiana*

2.1.4 Selection of sites for data collection:

The National Forest Inventory database (Forest Survey of India, MoEF&CC) has been used to analyze the distribution of selected species and different diameter classes available for each species at National level. The NFI database has been created by adopting a stratified sampling approach to assess and monitor the country's forest resources. This database contains all the necessary information about each inventoried sample plot in forest and TOF areas.

To cover all 30 selected tree species from TOF, around 13,500 TOF inventory point locations stored as *.csv format, as surveyed during 2016 to 2018, have been incorporated within ArcGIS (ArcMap) to generate geo-spatial point features. The same process has been followed to cover all 30 selected tree species from forest where approximately 4,500 forest inventory point locations have been used to obtain geo-spatial point features.

For each species, the states have been ranked on the basis of percentage distribution of that species on national level. Considering the objective of the project i.e. to develop local volume equations, a district (smallest unit for pan-India) from the State which is ranked first has been chosen to collect field data. The foremost criteria for choosing a particular district is the number of trees and their distribution in different diameter classes in that district for the particular species. Diameter class also known as DBH class means any of the intervals into which a range of diameters of tree stems or logs may be divided for classification and utilization. Based on the DBH value (cm), the trees have been divided in 7 diameter classes which are 10 to 20, 20 to 30, 30 to 40, 40 to 50, 50 to 60, 60 to 70 and 70 plus.

For area sampling situation, sampling intensity is not very relevant but just indicative [8]. Therefore, the optimum sample size i.e. optimum number of trees to be included in the sample which may provide the estimate of population parameter within prescribed limit of error is more important. Determination of optimum sample size is a crucial decision in any sample survey design. The size of sample depends on the variability of main characteristic in the population (say volume/tree), allowable error in the estimate, time and cost factors. Generally, time and cost is not considered in the calculation. It is the variability of the population parameter

(characteristic/attribute) and allowable error that decides the sample size. A general formula for calculation of optimum sample size is given as;

$$n = \frac{t_v{}^2 \left(\frac{CV}{AE}\right)^2}{1 + \frac{1}{N}\left(\frac{CV}{AE}\right)^2}$$

Where,

n = sample size,

CV = Coefficient of variation of the main characteristic/attribute (which can be calculated through past study or pilot survey or using correlated variable.

AE = allowable error (%),

t_v = value of t-statistic with v degrees of freedom and 5% significance level

N = total number of trees in the population

Generally, the N is very-very large in forest resource assessment making denominator approximately one and for that reason and brevity the numerator becomes the formula for sample size calculation.

Scientific studies recommend that a minimum sample size of n=8 is informative given very little variance, but minimum sample size of n≥ 25 is required for more variance [9]. In this study, the calculated sample size for every tree species is fairly above the optimum level. The sample size of forest species and TOF species has been given in the table 2.2 and table 2.3 respectively.

Table 2.2 Sample size of Forest species for selected districts

S.no	Forest Species	District	Sample size (n)
1	*Acacia auriculiformis*	Uttara Kannada	54
2	*Acacia catechu*	Udham Singh Nagar	34
3	*Albizia amara*	Vellore	57
4	Albizia *procera*	Dhalai	55
5	*Alnus nepalensis*	Ukhrul	36
6	*Anogeissus pendula*	Sawai Madhopur	44
7	*Bridelia retusa*	Raipur	36
8	*Buchanania latifolia*	Sundargarh	45
9	*Butea monosperma*	Sawai Madhopur	44
10	*Careya arborea*	North Goa	39
11	*Cassia siamea*	Malkangiri	36
12	*Chloroxylon swietenia*	Chandrapur	54
13	*Dalbergia paniculata*	Kurnool	35
14	*Emblica officinalis*	Chhindwara	33
15	*Hardwickia binata*	Prakasam	46
16	*Hevea brasiliensis*	North Tripura	47
17	*Holarrhena antidysenterica*	West Tripura	41
18	*Lyonia ovalifolia*	Chamoli	44
19	*Macaranga indica*	Mamit	36
20	*Madhuca latifolia*	Sambalpur	43
21	*Mallotus philippinensis*	Udham Singh Nagar	35
22	*Prosopis juliflora*	Patiala	47
23	*Quercus leucotrichophora*	Chamoli	40
24	*Rhododendron arboreum*	Dehradun	39
25	*Schima wallichii*	Jalpaiguri	43
26	*Schleichera oleosa*	South Goa	38
27	*Semecarpus anacardium*	Bilaspur	36
28	*Terminalia arjuna*	Angul	39
29	*Terminalia paniculata*	North Goa	54
30	*Xylia xylocarpa*	Shimoga	39
Total			**1269**

Table 2.3 Sample size of TOF species for selected districts

S.no	TOF Species	District	Sample size (n)
1	*Acacia arabica*	Bikaner	82
2	*Anacardium occidentale*	South Goa	67
3	*Artocarpus heterophyllus*	Udupi	39
4	*Azadirachta indica*	Kachchh	82
5	*Bombax ceiba*	Haridwar	36
6	*Borassus flabelliformis*	Diu	64
7	*Butea monosperma*	Seoni	43
8	*Cocos nucifera*	Diu	76
9	*Dalbergia sissoo*	Firozpur	68
10	*Elaeis guineensis*	East Godavari	74
11	*Ficus benghalensis*	Jalor	37
12	*Ficus racemosa*	Thane	51
13	*Ficus religiosa*	Bharatpur	34
14	*Grewia oppositifolia*	Dehradun	36
15	*Holoptelea integrifolia*	Sabarkantha	54
16	*Leucaena leucocephala*	Surat	45
17	*Mangifera indica*	Haridwar	38
18	*Moringa oleifera*	Janjgir Champa	36
19	*Morus alba*	Udham Singh Nagar	32
20	*Phoenix sylvestris*	Haridwar	41
21	Pinus kesiya	East Khasi Hills	75
22	*Pongamia pinnata*	Sangli	64
23	*Populus deltoides*	Ludhiana	44
24	*Prosopis cineraria*	Jaisalmer	93
25	*Swietenia mahagoni*	Hassan	41
26	*Syzygium cumini*	Mansa	50
27	*Tamarindus indica*	Vellore	53
28	*Tectona grandis*	Narsimhapur	58
29	*Terminalia crenulata*	South Goa	58
30	*Zizyphus mauritiana*	Sirohi	46
Total			**1617**

2.2 FIELD STUDY

2.2.1 Execution of the fieldwork

To efficiently collect the data for 60 tree species, the whole country has been divided in five different regions viz. North Indian region, West Indian region, North-east Indian region, South Indian region and Central Indian region. The fieldwork has been carried out in five phases, each phase covering one particular region of the country.

During the extensive fieldwork, the mensuration data has been collected for a total of 2886 individual trees comprising of 60 tree species. The data collected for 30 tree species from forest comprises of 1269 individual trees whereas the data collected for 30 tree species from trees outside forest comprises of 1617 individual trees.

Forty-eight districts from eighteen States and Union Territories of India have been visited during the extensive fieldwork of approximately 150 days to cover all the 60 tree species.

Table 2.4 State and District-wise details of the fieldwork

S.no.	States and UT's	Districts	No. of species
1	Andhra Pradesh	East Godavari, Kurnool and Prakasam	3
2	Chhattisgarh	Bilaspur, Janjgir Champa and Raipur	3
3	Dadra and Nagar Haveli and Daman and Diu	Diu	2
4	Goa	North Goa and South Goa	5
5	Gujarat	Kachchh, Sabarkantha and Surat	3
6	Karnataka	Uttara Kannada, Udupi, Shimoga and Hassan	4
7	Madhya Pradesh	Chhindwara, Narsimhapur and Seoni	3
8	Maharashtra	Chandrapur, Sangli and Thane	3
9	Manipur	Ukhrul	1
10	Meghalaya	East Khasi hills	1
11	Mizoram	Mamit	1
12	Odisha	Angul, Sambalpur, Sundargarh and Malkangiri	4
13	Punjab	Firozpur, Ludhiana, Mansa and Patiala	4
14	Rajasthan	Bharatpur, Bikaner, Jaisalmer, Jalore, Sawai Madhopur and Sirohi	7
15	Tamil Nadu	Vellore	2
16	Tripura	Dhalai, North Tripura and West Tripura	3
17	Uttarakhand	Chamoli, Dehradun, Haridwar and Udham Singh Nagar	10
18	West Bengal	Jalpaiguri	1
Total	18	48	60

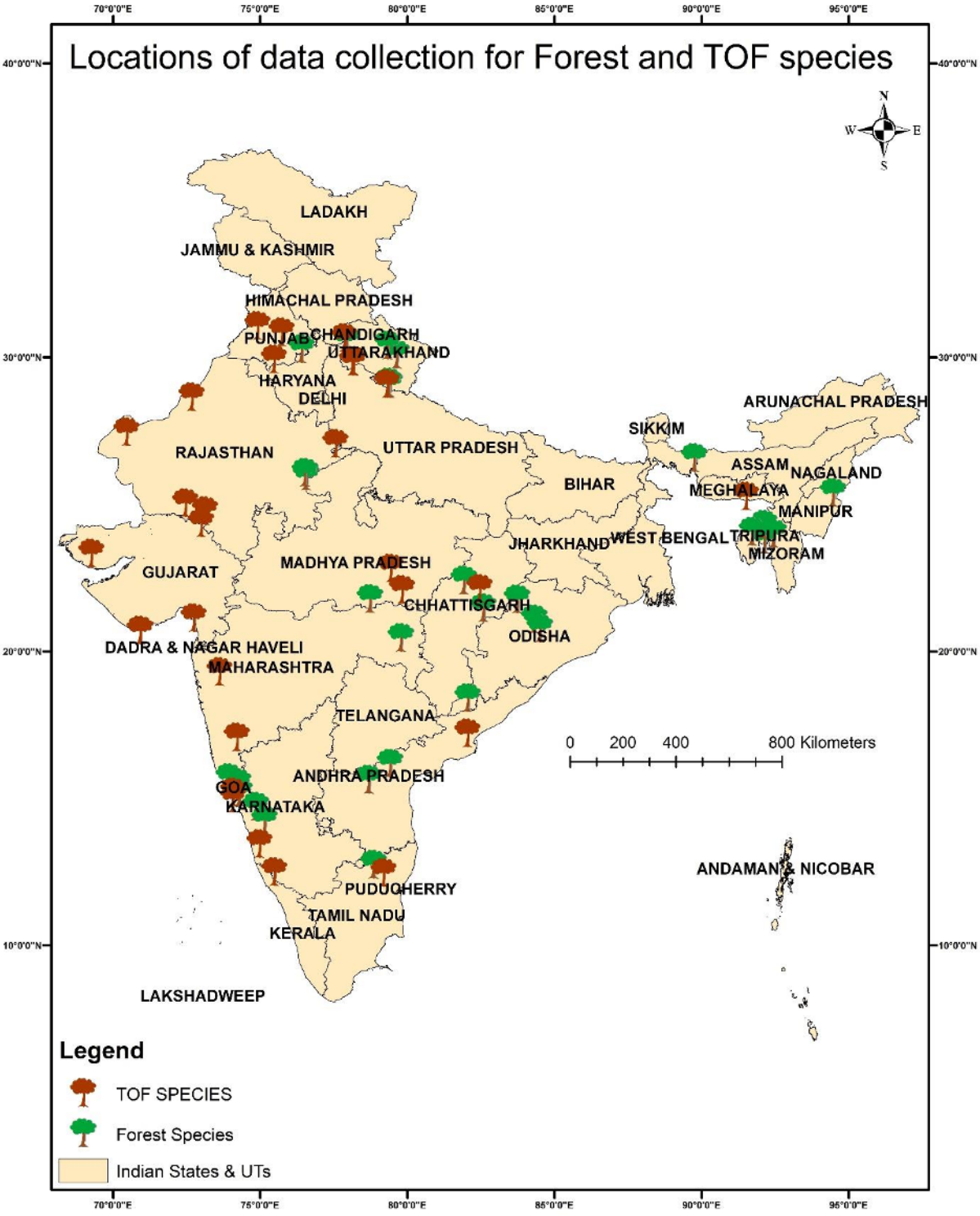


Figure 2.4 Data collection sites for Forest and TOF tree species

2.2.2 Fieldwork in North Indian Region

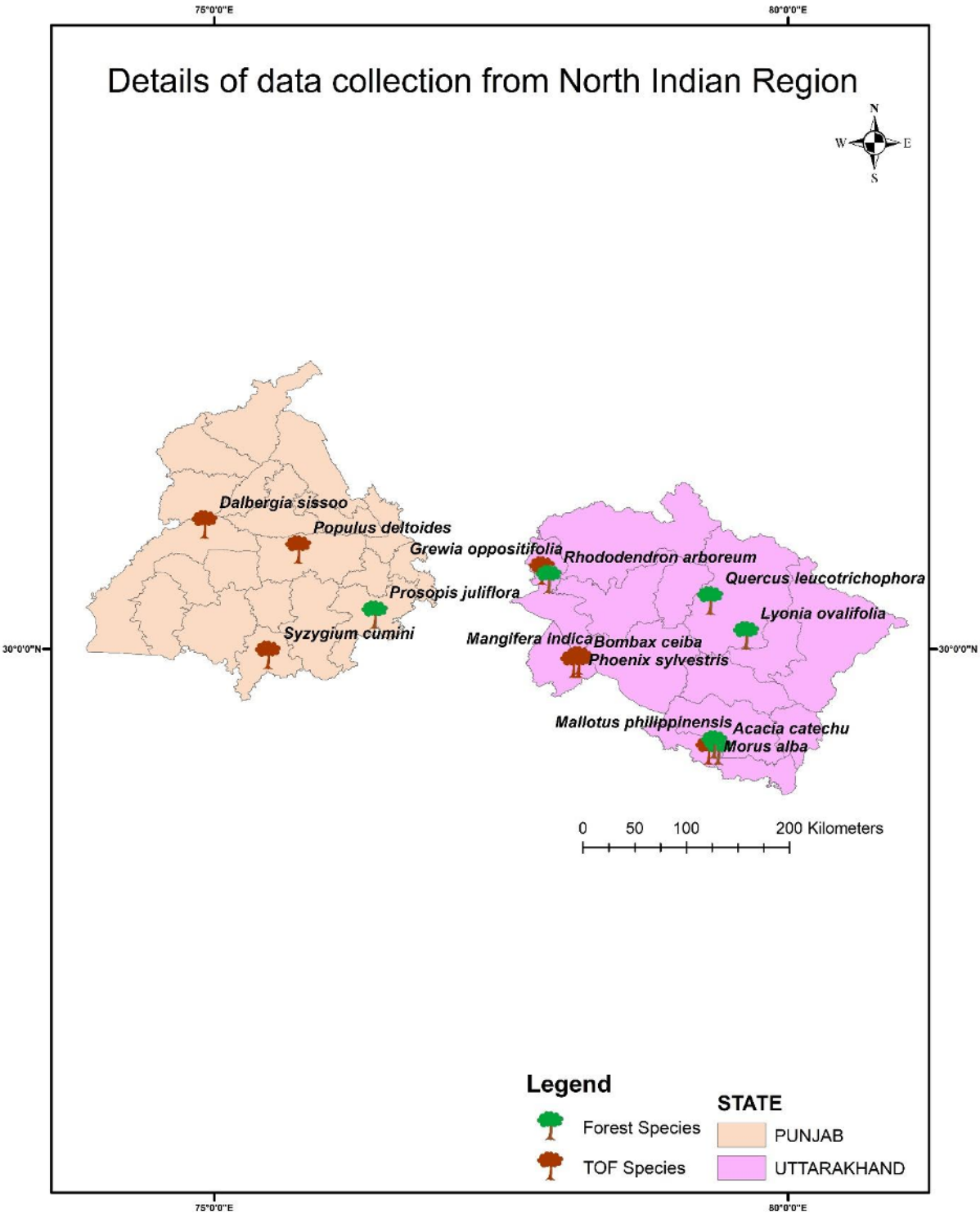


Figure 2.5 Data collection sites for Forest and TOF tree species for North Indian Region

During the first phase of the fieldwork, the two states namely, Uttarakhand and Punjab had been visited from the North Indian region. Measurements from a total of 587 individual trees had been recorded to collect data for 14 tree species which comprise of 8 TOF species and 6 Forest species. The general details like number of trees, number of diameter classes, latitude, longitude etc. for each of the 14 species, covered during the first phase of fieldwork has been given in table 2.5. Based on the number of trees measured for each species in the North Indian region the data can be summarized as:

Minimum – 31

Maximum – 68

Table 2.5 Species-wise details of fieldwork from North Indian region

S.no	Species	District	No. of Dia-class	No. of Trees	Latitude	Longitude	Class
1	*Acacia catechu*	Udham Singh Nagar	5	34	29^0 06' 44.57"	79^0 23' 17.90"	FOREST
2	*Bombax ceiba*	Haridwar	5	36	29^0 52' 04.73"	78^0 10' 25.72"	TOF
3	*Dalbergia sissoo*	Firozpur	5	68	31^0 04' 59.00"	74^0 54' 56.99"	TOF
4	*Grewia oppositifolia*	Dehradun	4	36	30^0 40' 48.75"	77^0 51' 17.55"	TOF
5	*Lyonia ovalifolia*	Chamoli	5	44	30^0 06' 53.63"	79^0 37' 50.56"	FOREST
6	*Mallotus philippinensis*	Udham Singh Nagar	4	35	29^0 09' 54.60"	79^0 21' 12.48"	FOREST
7	*Mangifera indica*	Haridwar	4	38	29^0 53' 52.28"	78^0 10' 27.61"	TOF
8	*Morus alba*	Udham Singh Nagar	3	32	29^0 06' 49.37"	79^0 18' 20.39"	TOF
9	*Phoenix sylvestris*	Haridwar	3	41	29^0 52' 06.67"	78^0 07' 40.11"	TOF
10	*Populus deltoides*	Ludhiana	3	44	30^0 51' 52.99"	75^0 43' 55.99"	TOF
11	*Prosopis juliflora*	Patiala	5	47	30^0 17' 44.99"	76^0 23' 40.99"	FOREST
12	*Quercus leucotrichophora*	Chamoli	4	40	30^0 25' 11.57"	79^0 19' 04.61"	FOREST
13	*Rhododendron arboreum*	Dehradun	4	39	30^0 36' 16.59"	77^0 54' 37.97"	FOREST
14	*Syzygium cumini*	Mansa	5	50	29^0 56' 42.00"	75^0 28' 06.99"	TOF

To understand the distribution of the number of trees in different diameter classes for each species, a bar diagram has been given in figure 2.6. The maximum number of diameter classes i.e., 5 during this fieldwork had been recorded for six species namely, *Acacia catechu*, *Bombax ceiba*, *Dalbergia sissoo*, *Lyonia ovalifolia*, *Prosopis juliflora* and *Syzygium cumini*. On the contrary, the minimum number of diameter

classes i.e., 3 during this fieldwork had been recorded for three species namely, *Morus alba*, *Phoenix sylvestris* and *Populus deltoides*.

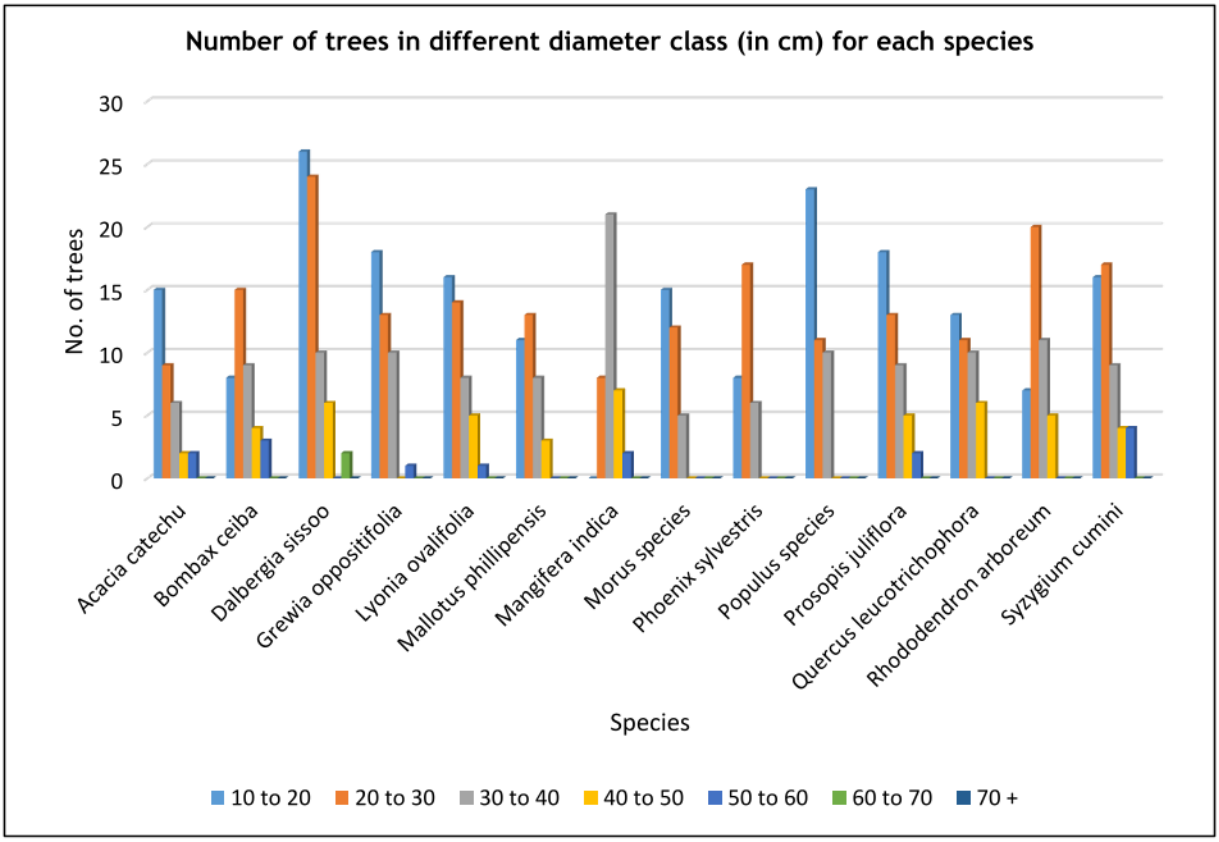


Figure 2.6 Diameter class wise distribution of trees for North Indian Region

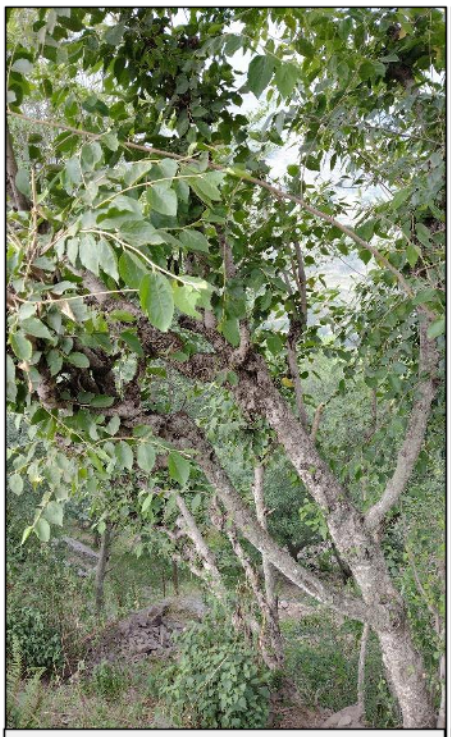


Mallotus philippinensis	*Acacia catechu*	*Lyonia ovalifolia*
Prosopis juliflora	*Dalbergia sissoo*	*Dalbergia sissoo*

Plate 2.1 Data collection during fieldwork in North Indian region



Rhododendron arboreum



Grewia oppositifolia



Lyonia ovalifolia



Phoenix sylvestris



Populus deltoides



Phoenix sylvestris

Plate 2.2 A few species covered during fieldwork in North Indian region

2.2.3 Fieldwork in West Indian Region

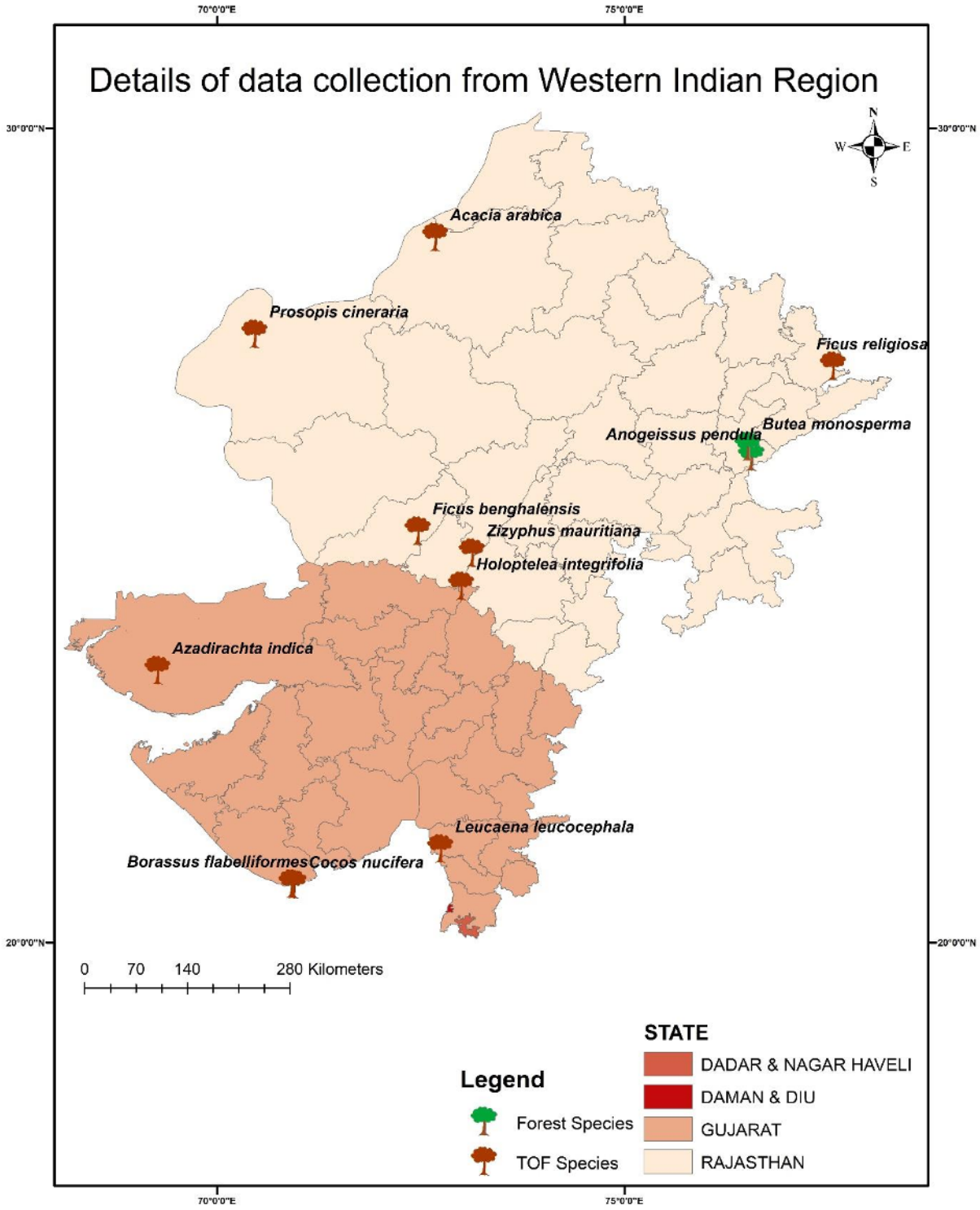


Figure 2.7 Data collection sites for Forest and TOF tree species for West Indian Region

In the second phase of the fieldwork, Rajasthan, Gujarat and Dadra and Nagar Haveli and Daman and Diu had been visited from the West Indian region. During this phase measurements from a total of 697 individual trees had been taken to collect data for 12 tree species which comprise of 10 TOF species and 2 Forest species. The general details like number of trees, number of diameter classes, latitude, longitude etc. for each of the 14 species, covered during the first phase of fieldwork has been given in table 2.6. Based on the number of trees measured for each species in the West Indian region the data can be summarized as:

Minimum – 34

Maximum – 93

Table 2.6 Species-wise details of fieldwork from West Indian region

S.no	Species	District	No. of Dia-class	No. of Trees	Latitude	Longitude	Class
1	*Acacia arabica*	Bikaner	6	82	28^0 39’ 47.99”	72^0 40’ 37.99”	TOF
2	*Anogeissus pendula*	Sawai Madhopur	4	44	25^0 58’ 05.00”	76^0 33’ 06.00”	FOREST
3	*Azadirachta indica*	Kachchh	6	82	23^0 20’ 35.99”	69^0 16’ 08.00”	TOF
4	*Borassus flabelliformes*	Diu	5	64	20^0 43’ 19.99”	70^0 54’ 47.00”	TOF
5	*Butea monosperma*	Sawai Madhopur	7	44	26^0 05’ 36.99”	76^0 30’ 34.99”	FOREST
6	*Cocos nucifera*	Diu	4	76	20^0 42’ 51.00”	70^0 56’ 27.99”	TOF
7	*Ficus benghalensis*	Jalore	7	37	25^0 03’ 19.00”	72^0 27’ 47.00”	TOF
8	*Ficus religiosa*	Bharatpur	6	34	27^0 04’ 46.99”	77^0 33’ 32.00”	TOF
9	*Holoptelea integrifolia*	Sabarkantha	4	54	24^0 22’ 41.99”	72^0 59’ 45.99”	TOF
10	*Leucaena leucocephala*	Surat	4	45	21^0 09’ 09.99”	72^0 44’ 22.99”	TOF
11	*Prosopis cineraria*	Jaisalmer	7	93	27^0 28’ 28.99”	70^0 27’ 41.00”	TOF
12	*Zizyphus mauritiana*	Sirohi	5	46	24^0 47’ 15.00”	73^0 07’ 35.00”	TOF

To understand the distribution of the number of trees in different diameter classes for each species, a bar diagram has been given in figure 2.8. The maximum number of diameter classes i.e., 7 during this fieldwork had been recorded for three species namely, *Butea monosperma*, *Ficus benghalensis* and *Prosopis cineraria*. On the contrary, the minimum number of diameter classes i.e., 4 during this fieldwork had

been recorded for four species namely, *Anogeissus pendula*, *Cocos nucifera*, *Holoptelea integrifolia* and *Leucaena leucocephala*.

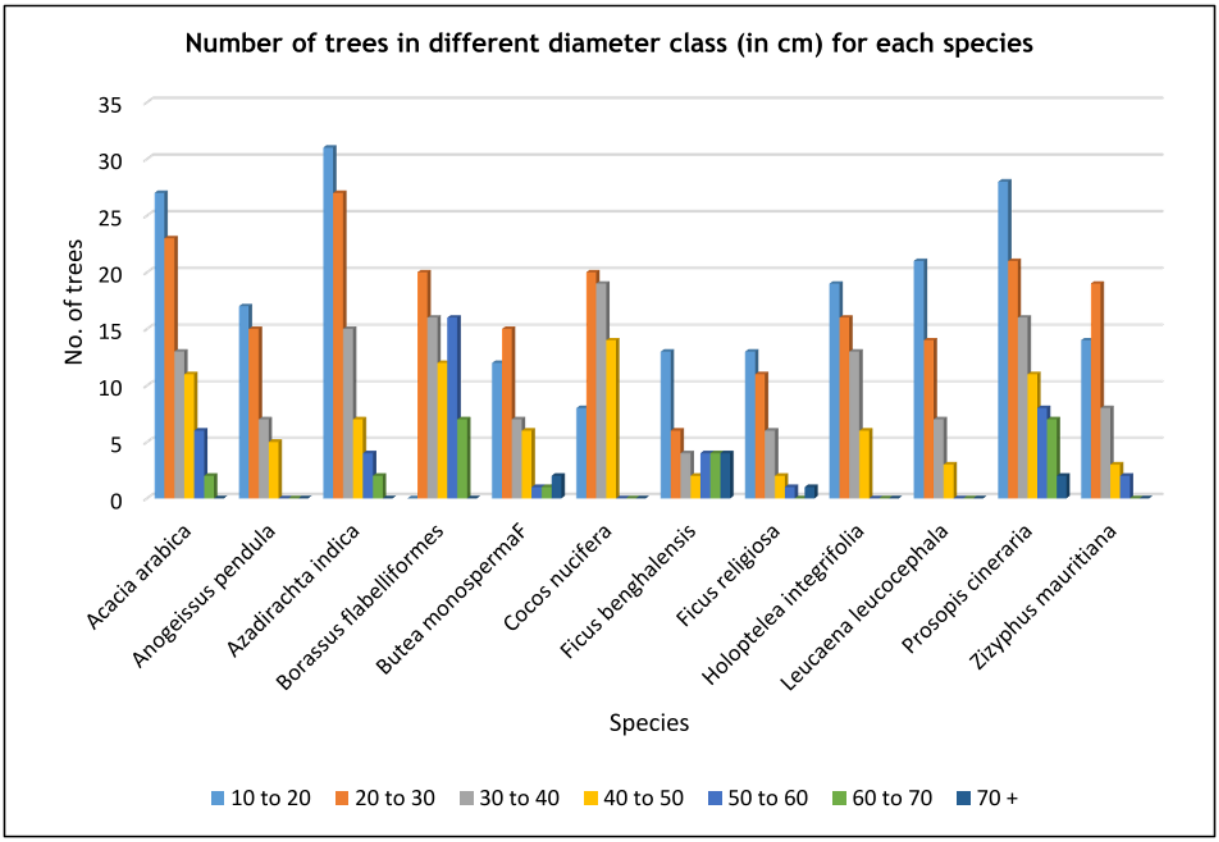


Figure 2.8 Diameter class wise distribution of trees for West Indian Region

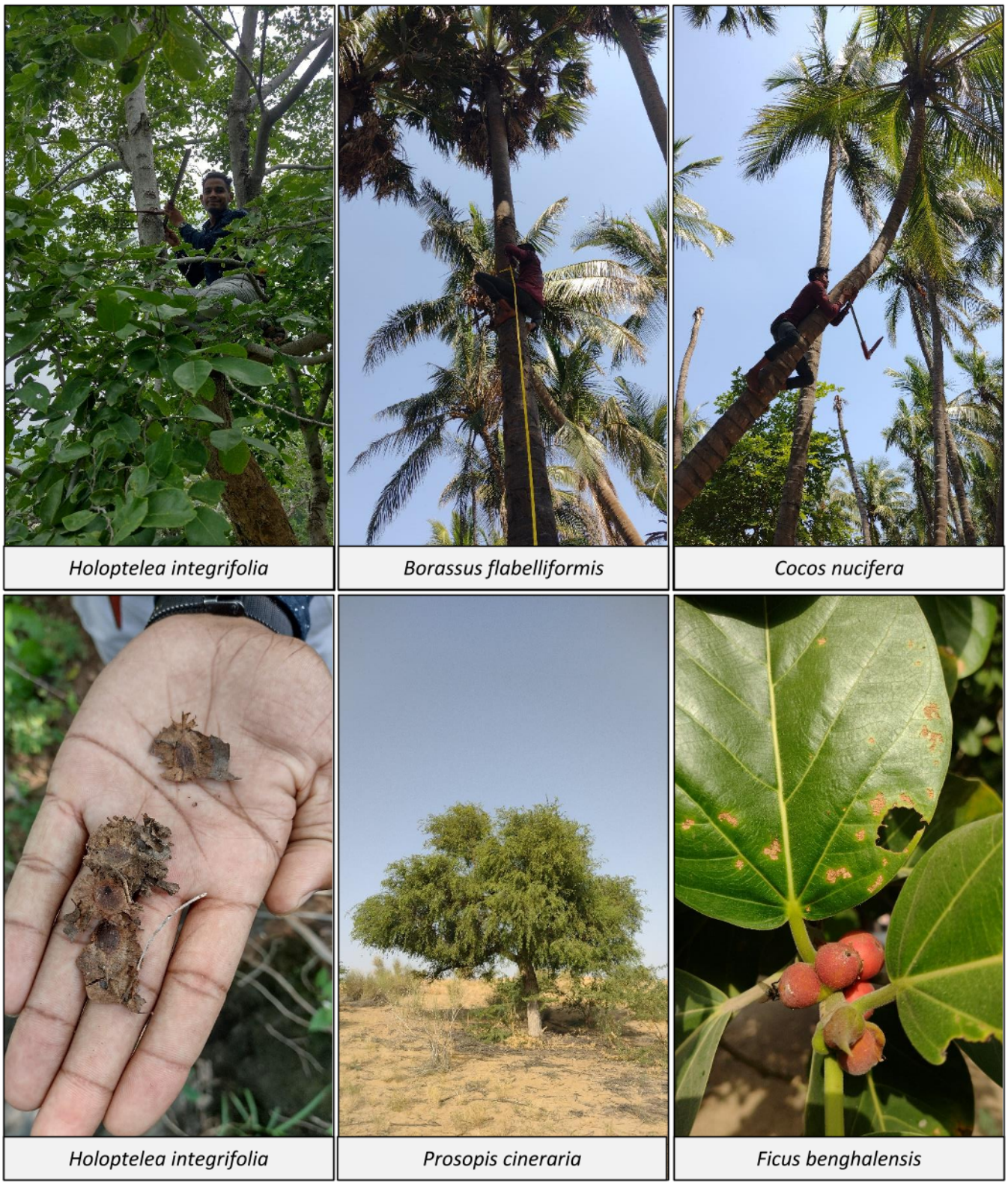


Plate 2.3 Data collection during fieldwork in West Indian region



Butea monosperma



Cocos nucifera



Azadirachta indica



Zizyphus mauritiana



Anogeissus pendula



Cocos nucifera

Plate 2.4 A few species covered during fieldwork in West Indian region

2.2.4 Fieldwork in North-east Indian Region

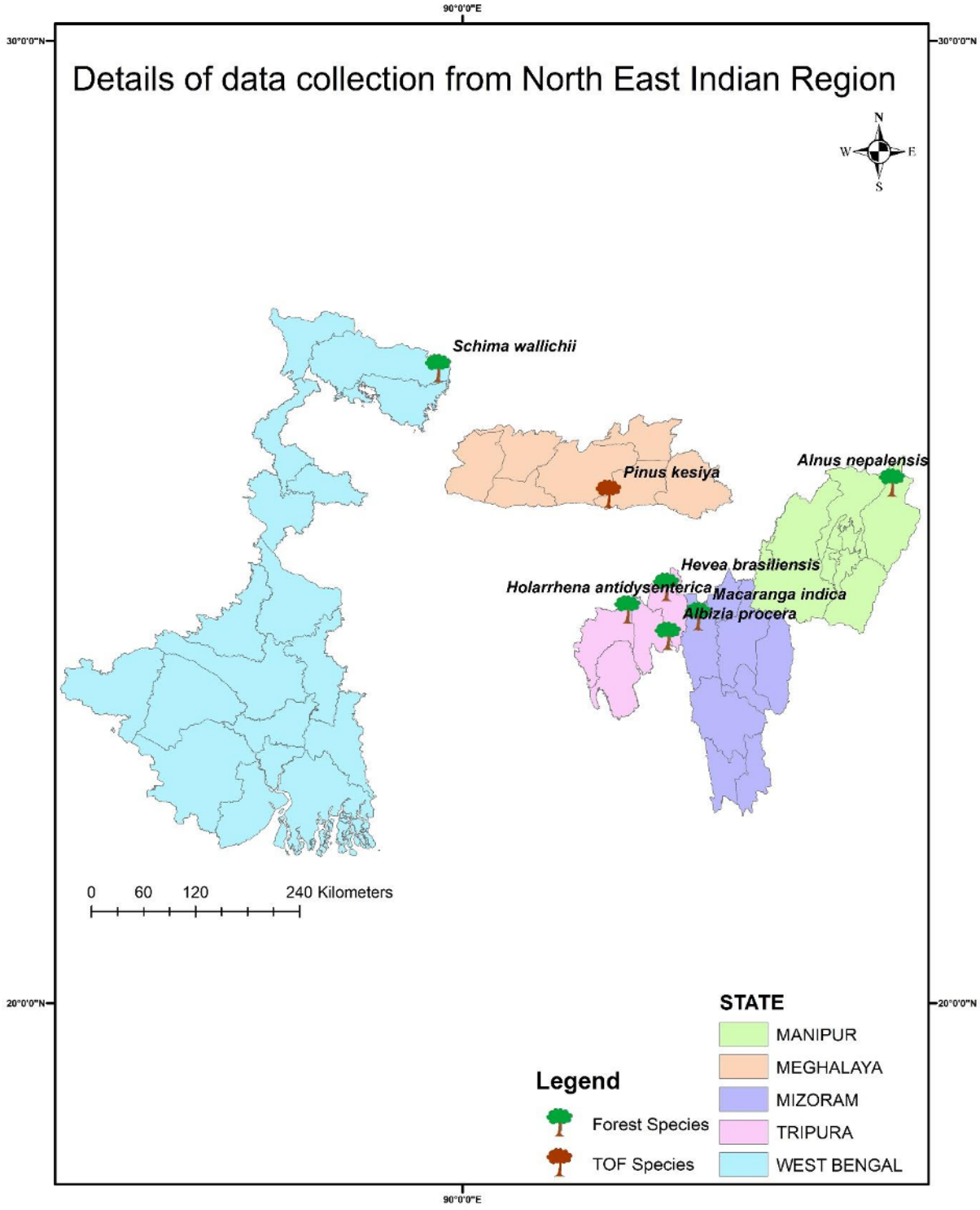


Figure 2.9 Data collection sites for Forest and TOF tree species for North-east Indian Region

**West Bengal is clubbed with the North-east Indian region only for the sake of presentation in a single map.*

During the third phase of the fieldwork, five states namely, Manipur, Meghalaya, Mizoram, Tripura and West Bengal had been visited from the North-east Indian region. During this phase, measurements from a total of 333 individual trees had been taken to collect data for 7 tree species which comprise of 1 TOF species and 6 Forest species. The general details like number of trees, number of diameter classes, latitude, longitude etc. for each of the 7 species, covered during the third phase of fieldwork has been given in table 2.7. Based on the number of trees measured for each species in the North-east Indian region the data can be summarized as:

Minimum – 36

Maximum – 75

Table 2.7 Species-wise details of fieldwork from North-east Indian region

S.no	Species	District	No. of Dia-class	No. of Trees	Latitude	Longitude	Class
1	*Albizia procera*	Dhalai	5	55	23^0 48’ 52.02”	92^0 07’ 43.39”	FOREST
2	*Alnus nepalensis*	Ukhrul	6	36	25^0 24’ 29.92”	94^0 27’ 19.80”	FOREST
3	*Hevea brasiliensis*	North Tripura	3	47	24^0 19’ 26.22”	92^0 06’ 45.50”	FOREST
4	*Holarrhena antidysenterica*	West Tripura	4	41	24^0 05’ 14.92”	91^0 42’ 33.12”	FOREST
5	*Macaranga indica*	Mamit	2	36	24^0 01’ 05.45”	92^0 26’ 28.71”	FOREST
6	*Pinus kesiya*	East khasi hills	7	75	25^0 17’ 25.51”	91^0 30’ 53.68”	TOF
7	*Schima wallichii*	Jalpaiguri	7	43	26^0 35’ 42.32”	89^0 44’ 30.41”	FOREST

To understand the distribution of the number of trees in different diameter classes for each species, a bar diagram has been given in figure 2.10. The maximum number of diameter classes i.e., 7 during this fieldwork had been recorded for two species namely, *Pinus kesiya* and *Schima wallichii*. On the contrary, the minimum number of diameter classes i.e., 2 during this fieldwork had been recorded for one species i.e., *Macaranga indica*.

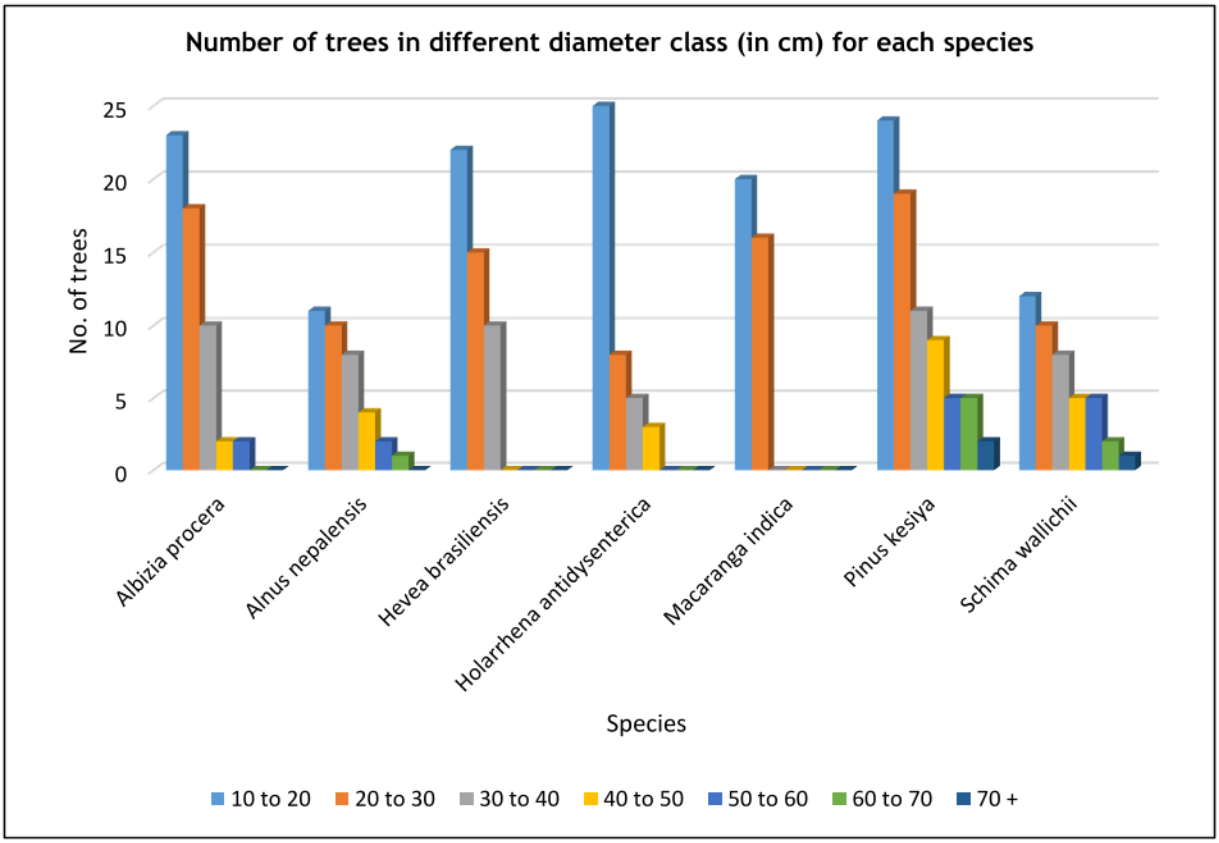


Figure 2.10 Diameter class wise distribution of trees for North-east Indian Region



Pinus kesiya



Albizia procera



Pinus kesiya



Albizia procera



Pinus kesiya



Hevea brasiliensis

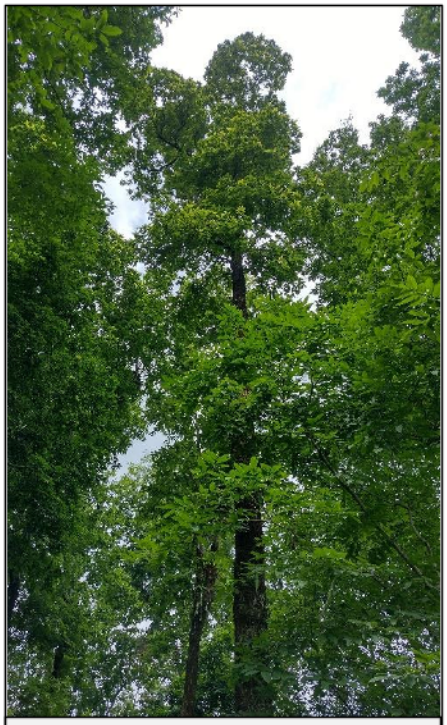
Plate 2.5 Data collection during fieldwork in North-east Indian region



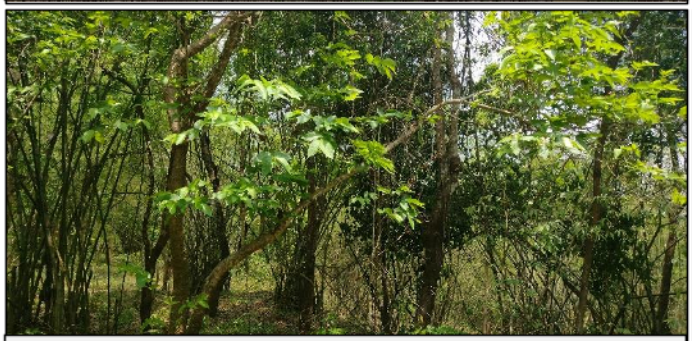
Hevea brasiliensis



Albizia procera



Schima wallichii



Holarrhena antidysenterica



Macaranga indica



Pinus kesiya

Plate 2.6 A few species covered during fieldwork in North-east Indian region

2.2.5 Fieldwork in South Indian Region

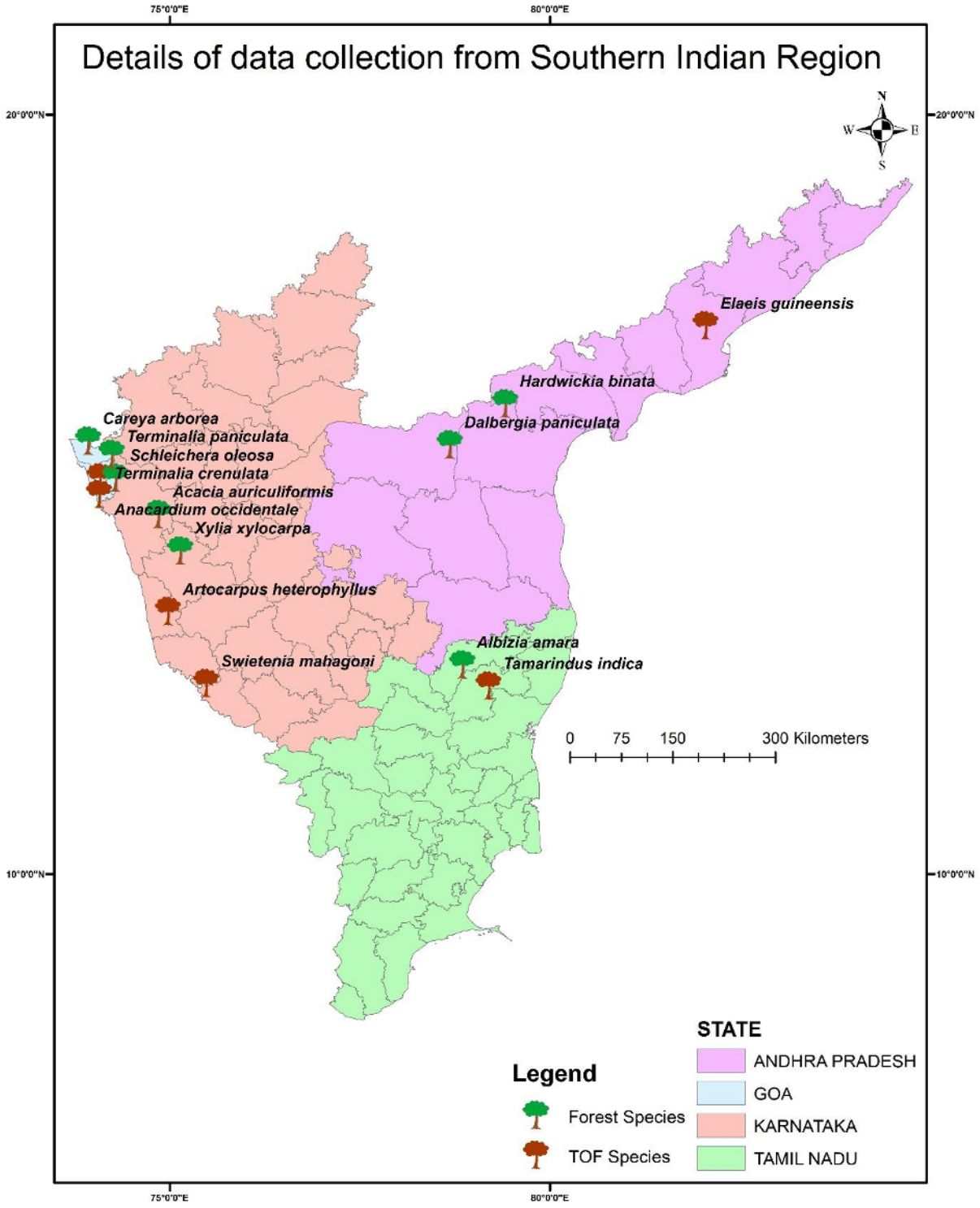


Figure 2.11 Data collection sites for Forest and TOF tree species for South Indian Region

During the fourth phase of the fieldwork, four states namely, Andhra Pradesh, Goa, Karnataka and Tamil Nadu had been visited from the South Indian region. During this phase, measurements from a total of 682 individual trees had been taken to collect data for 14 tree species which comprise of 6 TOF species and 8 Forest species. The general details like number of trees, number of diameter classes, latitude, longitude etc. for each of the 14 species, covered during the fourth phase of fieldwork has been given in table 2.8. Based on the number of trees measured for each species in the South Indian region the data can be summarized as:

Minimum – 35

Maximum – 67

Table 2.8 Species-wise details of fieldwork from South Indian region

S.no	Species	District	No. of Dia-class	No. of Trees	Latitude	Longitude	Class
1	*Acacia auriculiformis*	Uttara Kannada	4	54	14^0 44’ 22.49”	74^0 50’ 37.50”	FOREST
2	*Albizia amara*	Vellore	5	57	12^0 45’ 37.44”	78^0 50’ 37.68”	FOREST
3	*Anacardium occidentale*	South Goa	4	67	15^0 00’ 18.53”	74^0 04’ 22.69”	TOF
4	*Artocarpus heterophyllus*	Udupi	6	39	13^0 15’ 53.25”	74^0 33’ 05.97”	TOF
5	*Careya arborea*	North Goa	4	39	15^0 42’ 19.58”	73^0 55’ 28.67”	FOREST
6	*Dalbergia paniculata*	Kurnool	6	35	15^0 39’ 22.68”	78^0 40’ 37.56”	FOREST
7	*Elaeis guineensis*	East Godavari	4	74	17^0 13’ 36.99”	82^0 02’ 44.59”	TOF
8	*Hardwickia binata*	Prakasam	6	46	16^0 11’ 52.08”	79^0 24’ 21.95”	FOREST
9	*Schleichera oleosa*	South Goa	5	38	15^0 13’ 15.38”	74^0 16’ 53.98”	FOREST
10	*Swietenia mahagoni*	Hassan	7	41	12^0 30’ 53.88”	75^0 28’ 48.13”	TOF
11	*Tamarindus indica*	Vellore	7	53	12^0 28’ 57.20”	79^0 11’ 30.50”	TOF
12	*Terminalia crenulata*	South Goa	6	58	15^0 13’ 23.19”	74^0 04’ 52.34”	TOF
13	*Terminalia paniculata*	North Goa	6	54	15^0 31’ 52.19”	74^0 14’ 06.11”	FOREST
14	*Xylia xylocarpa*	Shimoga	7	39	14^0 15’ 38.00”	75^0 08’ 08.00”	FOREST

To understand the distribution of the number of trees in different diameter classes for each species, a bar diagram has been given in figure 2.12. The maximum number of diameter classes i.e., 7 during this fieldwork had been recorded for three species namely, *Swietenia mahagoni Tamarindus indica* and *Xylia xylocarpa*. On the contrary, the minimum number of diameter classes i.e., 4 during this fieldwork had

been recorded for four species namely, *Acacia auriculiformis*, *Anacardium occidentale*, *Careya arborea* and *Elaeis guineensis*.

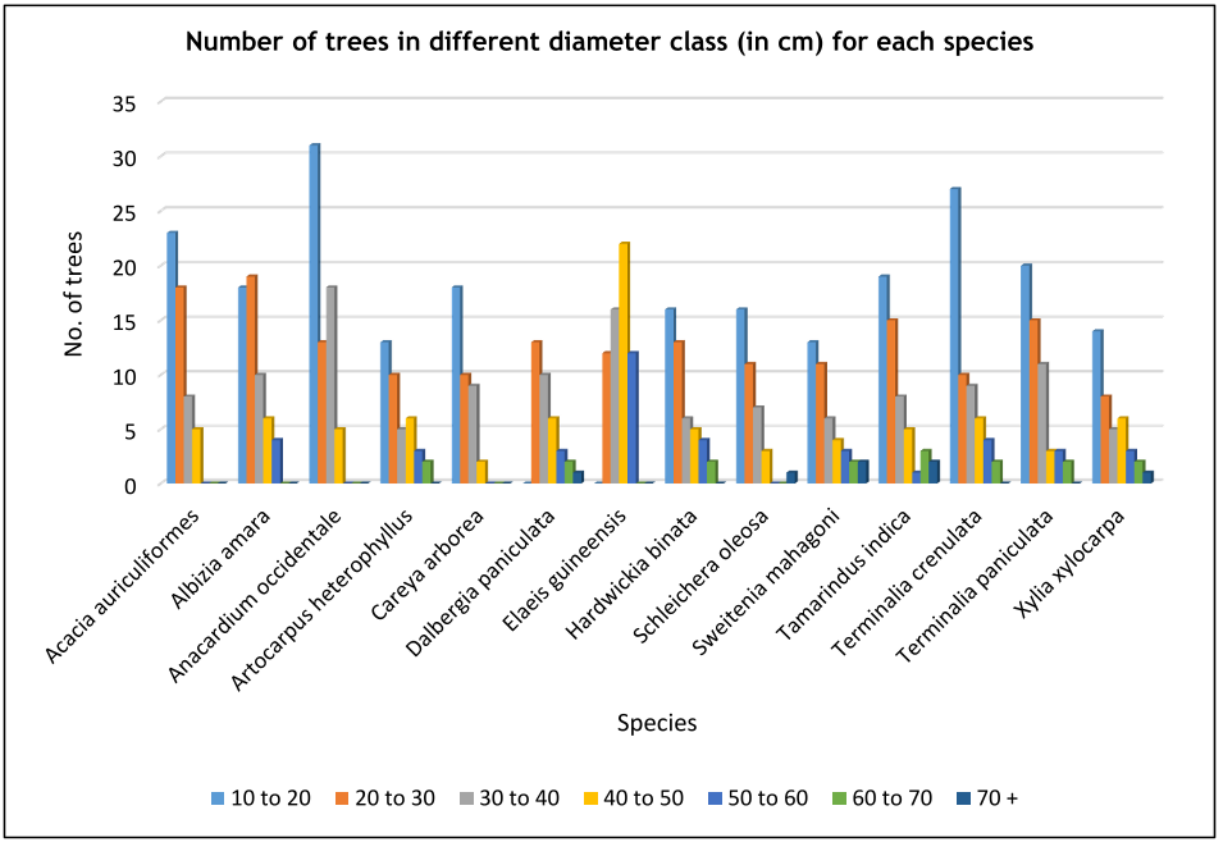
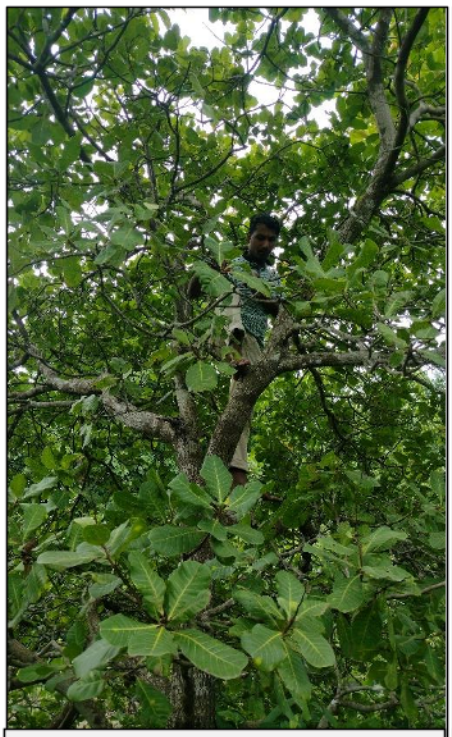


Figure 2.12 Diameter class wise distribution of trees for South Indian Region



Tamarindus indica



Anacardium occidentale



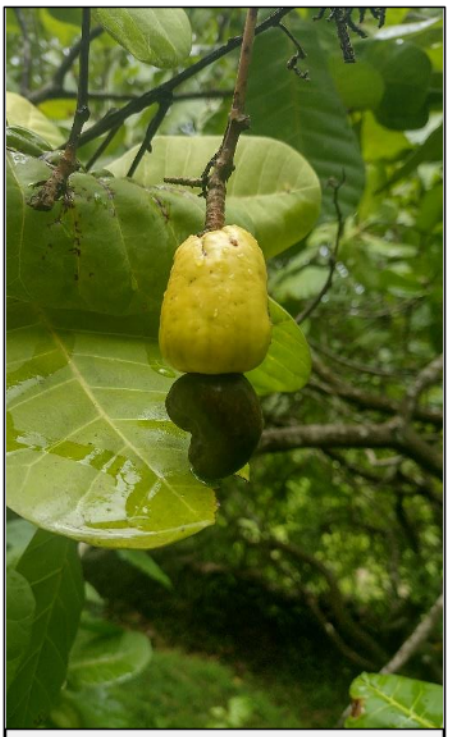
Anacardium occidentale



Artocarpus heterophyllus



Elaeis guineensis



Anacardium occidentale

Plate 2.7 Data collection during fieldwork in South Indian region

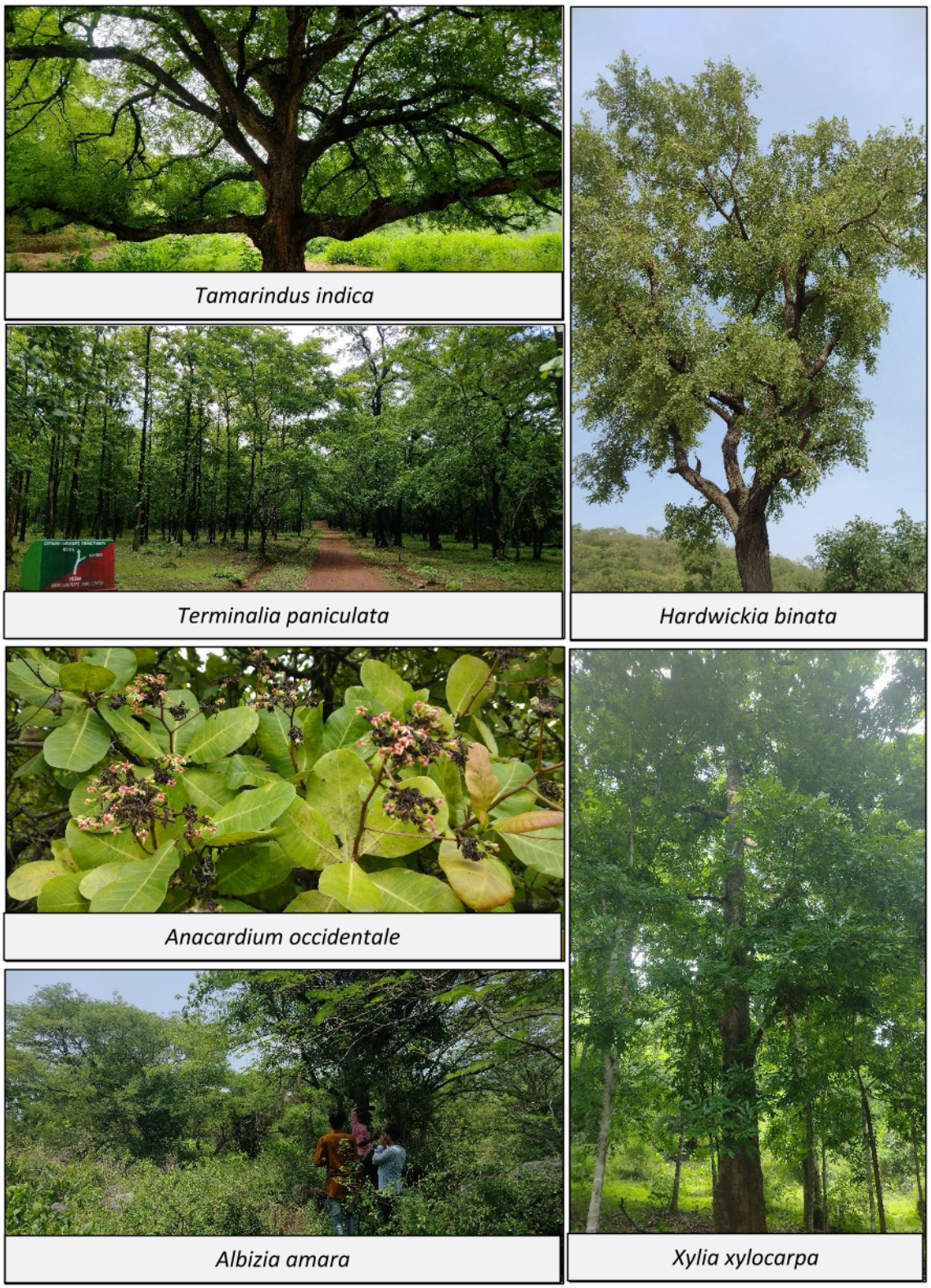


Plate 2.8 A few species covered during fieldwork in South Indian region

2.2.6 Fieldwork in Central Indian Region

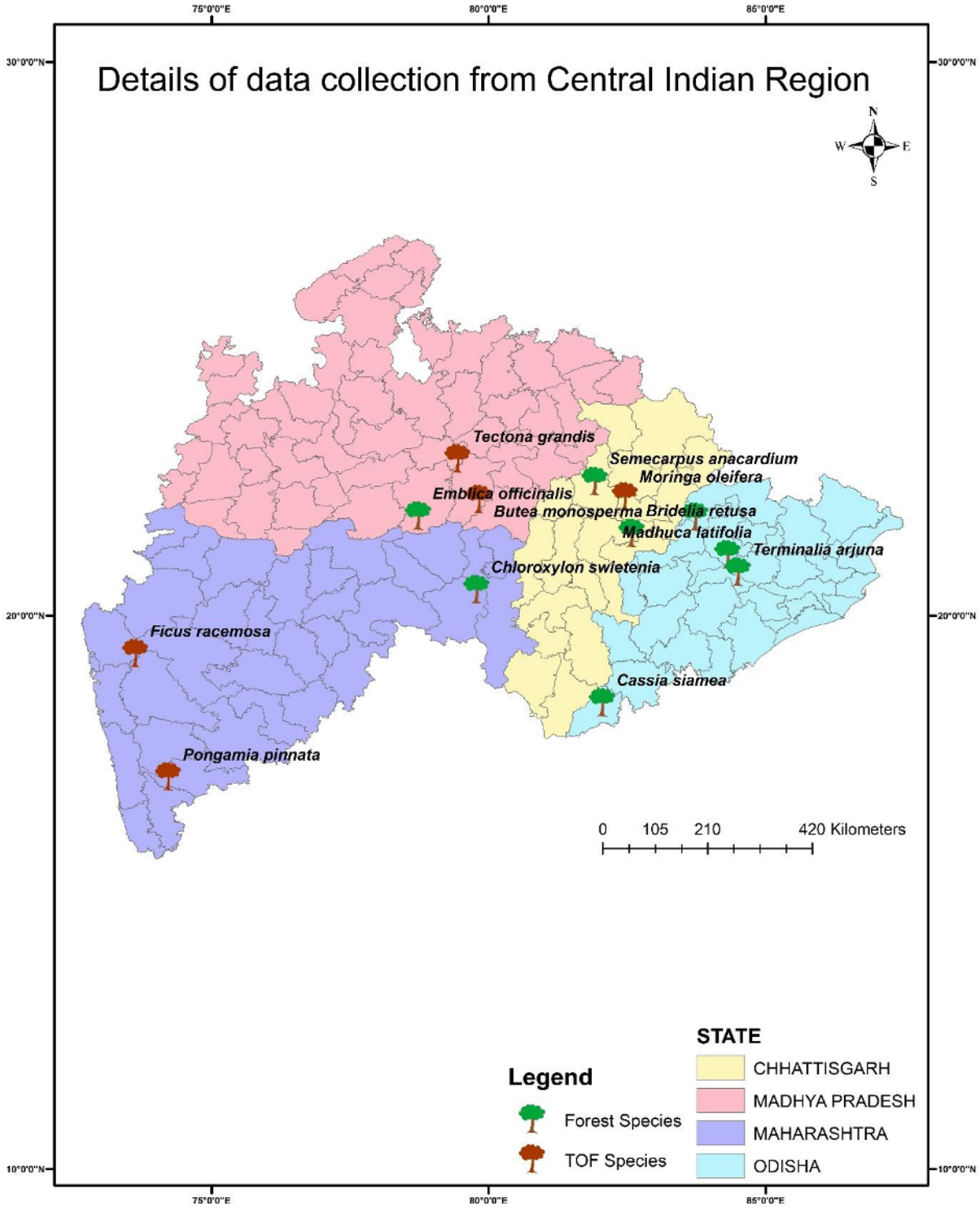


Figure 2.13 Data collection sites for Forest and TOF tree species for Central Indian Region

In the fifth and the last phase of the fieldwork, four states namely, Chhattisgarh, Madhya Pradesh, Maharashtra and Odisha had been visited from the Central Indian region. During this phase, measurements from a total of 574 individual trees had been taken to collect data for 13 tree species which comprise of 5 TOF species and 8 Forest species. The general details like number of trees, number of diameter classes, latitude, longitude etc. for each of the 13 species, covered during the fifth phase of fieldwork has been given in table 2.9. Based on the number of trees measured for each species in the South Indian region the data can be summarized as:

Minimum – 33

Maximum – 64

Table 2.9 Species-wise details of fieldwork from Central Indian region

S.no	Species	District	No. of Dia-class	No. of Trees	Latitude	Longitude	Class
1	*Bridelia retusa*	Raipur	6	36	21^0 29’ 22.56”	82^0 34’ 22.44”	FOREST
2	*Buchanania latifolia*	Sundargarh	3	45	21^0 47’ 13.20”	83^0 43’ 13.08”	FOREST
3	*Butea monosperma*	Seoni	6	43	22^0 06’ 16.99”	79^0 49’ 22.00”	TOF
4	*Cassia siamea*	Malkangiri	4	36	18^0 25’ 48.36”	82^0 02’ 38.04”	FOREST
5	*Chloroxylon swietenia*	Chandrapur	5	54	20^0 28’ 25.61”	79^0 46’ 26.85”	FOREST
6	*Emblica officinalis*	Chhindwara	3	33	21^0 48’ 04.46”	78^0 43’ 11.68”	FOREST
7	*Ficus racemosa*	Thane	6	51	19^0 19’ 09.98”	73^0 37’ 12.00”	TOF
8	*Madhuca latifolia*	Sambalpur	6	43	21^0 06’ 03.35”	84^0 18’ 13.37”	FOREST
9	*Moringa oleifera*	Janjgir Champa	4	36	22^0 08’ 53.01”	82^0 27’ 25.99”	TOF
10	*Pongamia pinnata*	Sangli	7	64	17^0 05’ 27.99”	74^0 12’ 46.00”	TOF
11	*Semecarpus anacardium*	Bilaspur	3	36	22^0 25’ 37.92”	81^0 54’ 23.05”	FOREST
12	*Tectona grandis*	Narsimhapur	6	58	22^0 50’ 14.60”	79^0 26’ 20.40”	TOF
13	*Terminalia arjuna*	Angul	7	39	20^0 47’ 26.88”	84^0 29’ 30.84”	FOREST

To understand the distribution of the number of trees in different diameter classes for each species, a bar diagram has been given in figure 2.14. The maximum number of diameter classes i.e., 7 during this fieldwork had been recorded for two species namely, *Pongamia pinnata* and *Terminalia arjuna*. On the contrary, the minimum number of diameter classes i.e., 3 during this fieldwork had been recorded for three

species namely, *Buchanania latifolia*, *Emblica officinalis* and *Semecarpus anacardium*.

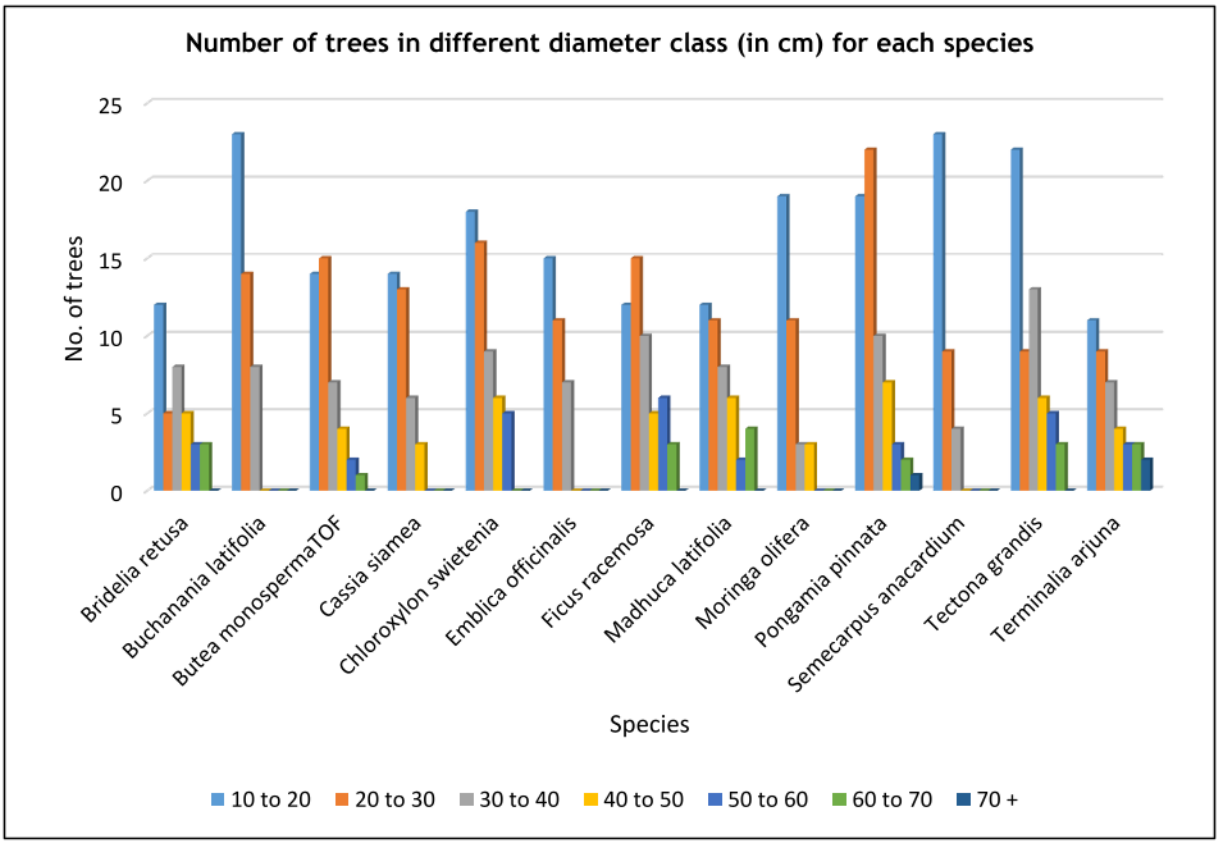


Figure 2.14 Diameter class wise distribution of trees for Central Indian Region



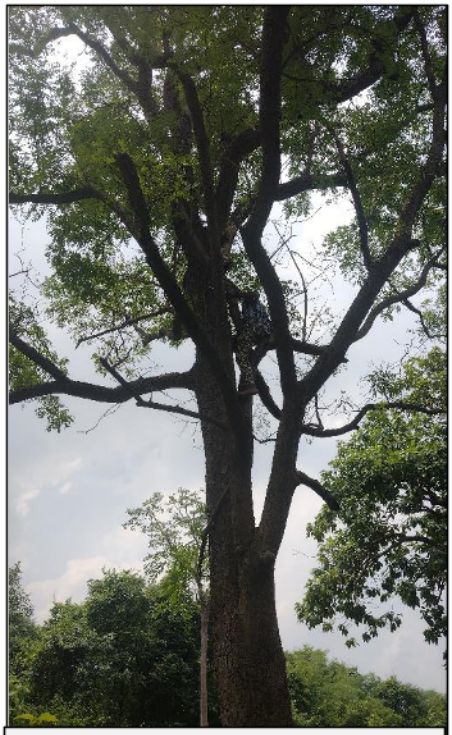
Bridelia retusa



Cassia siamea



Chloroxylon swietenia



Chloroxylon swietenia



Pongamia pinnata



Tectona grandis

Plate 2.9 Data collection during fieldwork in Central Indian region



Pongamia pinnata



Buchanania latifolia



Semecarpus anacardium



Terminalia arjuna



Emblica officinalis



Pongamia pinnata

Plate 2.10 A few species covered during fieldwork in Central Indian region

2.2.7 Data collection

The relevant information pertaining to the location of field site such as geo-coordinates, beat/range, district etc. have been recorded in the field form (Fig2.2). Apart from these, the variables which have been recorded in the field form for data mensuration are as follows:

a. Diameter at breast height (1.37m)
b. Diameter of trunk at 1.5m and after that at every 3m interval up-to 10cm diameter
c. Trunk height (tree height up-to 10cm diameter)
d. Diameter of branches at 1.5m and after that at every 3m interval up-to 5cm diameter [10].
e. Length of all the branches up-to 5cm diameter

All the dendrometric measurements have been taken manually in the field and the measurements for diameter have been recorded over bark.

FIELD FORM

Species Name _____ Date Beat/Range/Village _____ District_____ State

Latitude _____ Longitude_____

	Dbh at 1.37m	Dia. at 1.5m	Dia. at 4.5m	Dia. at 7.5m	Dia. at 10.5m	Dia. at 13.5m	Dia. at 16.5m	Dia. at 19.5m	Dia. at 22.5m	Dia. at 25.5m	Dia. at 28.5m	Dia. at 31.5m	Trunk Height
Trunk													
Branch 1	D.B 1.5m	D.B 4.5m	D.B 7.5m	D.B 10.5m	D.B 13.5m	D.B 16.5m	D.B 19.5m						Branch 1 length
Branch 2	D.B 1.5m	D.B 4.5m	D.B 7.5m	D.B 10.5m	D.B 13.5m	D.B 16.5m	D.B 19.5m						Branch 2 length
Branch 3	D.B 1.5m	D.B 4.5m	D.B 7.5m	D.B 10.5m	D.B 13.5m	D.B 16.5m	D.B 19.5m						Branch 3 length
Branch 4	D.B 1.5m	D.B 4.5m	D.B 7.5m	D.B 10.5m	D.B 13.5m	D.B 16.5m	D.B 19.5m						Branch 4 length
Branch 5	D.B 1.5m	D.B 4.5m	D.B 7.5m	D.B 10.5m	D.B 13.5m	D.B 16.5m	D.B 19.5m						Branch 5 length
Branch 6	D.B 1.5m	D.B 4.5m	D.B 7.5m	D.B 10.5m	D.B 13.5m	D.B 16.5m	D.B 19.5m						Branch 6 length
Branch 7	D.B 1.5m	D.B 4.5m	D.B 7.5m	D.B 10.5m	D.B 13.5m	D.B 16.5m	D.B 19.5m						Branch 7 length

Figure 2.2 Field form for data collection

2.3 ANALYSIS

2.3.1 Data processing and Volume computation

The volume of a part (or frustum) of a second-degree paraboloid is particularly important in forest mensuration because many logs and sections of trees approximate this shape. Several basic formulae are used to measure log volume. When using the formulas which are less common, a mid-length log diameter is required. Bruce (1982) derived a formula using only end diameters and length that was popular in some places in forested countries [11]. These formulas are given below:

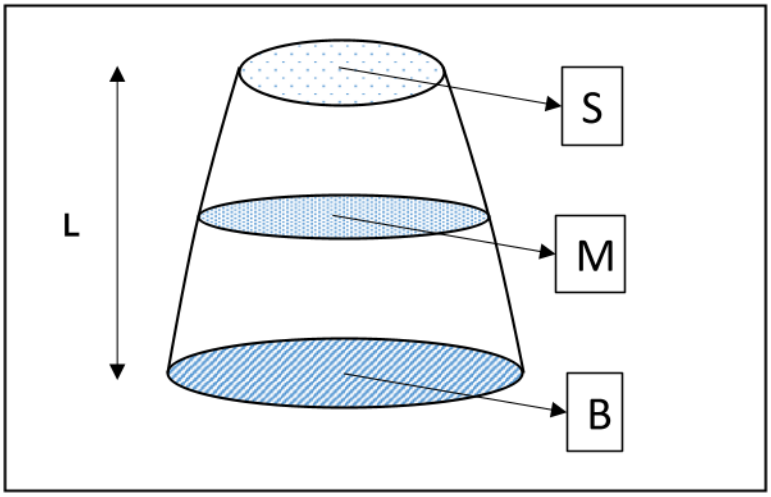


Figure 2.3 Diagrammatic representation of a part of log/section of tree

Huber's formula: $\boldsymbol{V = ML}$

Smalian's formula: $\boldsymbol{V = \frac{B+S}{2} L}$

Newton's formula: $\boldsymbol{V = \frac{B+4M+S}{6} L}$

Bruce's formula: V$= (\mathbf{0.25}\boldsymbol{B} + \mathbf{0.75}\boldsymbol{S})\boldsymbol{L}$

Where, B = cross-sectional area at large end of log; M = cross-sectional area at mid-length of log; S = cross-sectional area at small end of log; L = log length (m).

As the diameter recorded from field is over bark, therefore, to obtain under bark diameter values, the average value of double bark thickness (DBT) has been subtracted from it. The average double bark thickness values for all the 60 tree species have been taken from NFI database. The DBT values obtained from NFI database when compared with the DBT values of some tree species published in scientific papers [12], have been found to be equivalent.

Once the under-bark diameter values have been obtained, the volume of all the logs/sections of each tree have been calculated using Huber's formula. These log volumes are then added up to obtain the total volume of each tree.

2.3.2 Regression modelling to develop volume equations

Regression is a statistical method used to determine the strength and character of the relationship between one dependent variable (usually denoted as Y) and one or more independent variables. The calculated under bark volume (dependent variable) of each tree along-with its respective dbh (independent variable) value has been incorporated in excel file. Then, a combination of various transformed forms of volume and DBH have been applied to perform regression modelling. The different models tried to develop local volume equations under this process are given below:

(i) $V = a_0 + a_1 D$

(ii) $V = a_0 + a_1 D + a_2 D^2$

(iii) $V = a_0 + a_1 D + a_2 D^2 + a_3 \sqrt{D}$

(iv) $V = a_0 + a_2 D^2 + a_3 \sqrt{D}$

(v) $V = a_0 + a_1 D + a_3 \sqrt{D}$

(vi) $V = a_0 + a_2 D^2$

(vii) $\sqrt{V} = a_0 + a_1 D$

(viii) $\sqrt{V} = a_0 + a_1 D + a_2 D^2$

(ix) $\sqrt{V} = a_0 + a_1 D + a_2 D^2 + a_3 \sqrt{D}$

(x) $\sqrt{V} = a_0 + a_2 D^2 + a_3 \sqrt{D}$

(xi) $\sqrt{V} = a_0 + a_1 D + a_3 \sqrt{D}$

(xii) $\sqrt{V} = a_0 + a_2 D^2$

Where, V = volume (m^3) under bark, D = diameter at breast height (1.37m) over bark in metre and 'a_0', 'a_1', 'a_2' and 'a_3' are regression coefficients.

For each model, the different statistical parameters have been considered and analysed carefully to select the best fit model and thereby the local volume equation. These statistical parameters include Adjusted R^2, Standard error, t-testing for regression coefficients, residual analysis and Analysis of variance (ANOVA). The P- value in the ANOVA Table has been used to decide whether the regression is statistically significant or not.

$P \geq 0.05$, absence of evidence against the null hypothesis: data is consistent with the null hypothesis

$0.01 \leq P < 0.05$, sufficient evidence against the null hypothesis: in favour of the alternative

$0.001 \leq P < 0.01$, strong evidence against the null hypothesis: in favour of the alternative

$P < 0.001$, very strong evidence against the null hypothesis: in favour of the alternative

2.3.3 Limitations and constraints

Due to prolonged COVID-19 related travel restrictions across the States, the field work had been excessively hampered. The first phase of the fieldwork had been accomplished only when COVID-19 related restrictions were removed.

During the fieldwork, an attempt had been made to record data from the maximum number of diameter classes available in the field and to reach as closely to the sample size as possible, however it had not been possible to achieve the same for all the species. Depending on the field conditions, for some species, the number of trees and the number of diameter class recorded had been less than the targeted value whereas in some cases, the number of trees and the number of diameter class recorded had been more than the targeted value.

CHAPTER THREE

RESULTS AND DISCUSSION

The data collected from field has been processed and analysed to derive local volume equation for each of the 60 tree species. Every tree has a particular structure that can be represented by its diameter, height and form. Hence, a particular volume equation may be a good fit to one species but not to another. On the other hand, the same species in different geographical areas may have slightly different increments, tree form and branching patterns [13]. Therefore, it is required to carefully consider the applicability of these equations across different regions.

The best fit volume equations along-with the respective **Adjusted R^2 value, Standard error, Sample size (n) and P-value** for each species has been presented below. In all the equations, **V is the volume (in cum) and D is the diameter at breast height (in m)**.

Apart from these statistical parameters, the Diameter/DBH class range is also given with each species. This range is based on the data collected from field and used to develop the local volume equations. In majority of the cases, this range follows the natural growth pattern of the tree species. However, there might be individual trees which lie outside of this given range. Therefore, utmost care should be taken before applying these local volume equations on the trees falling outside the given DBH range.

The volume equations for 30 forest species have been presented in the first section, followed by volume equations for 30 TOF species in the second section.

3.1 Volume Equations for Forest species

(1) *Acacia auriculiformis*

General Description

It is an exotic from Australia which has been planted in a number of states of India such as Bihar, Karnataka, Odisha and West Bengal under various afforestation schemes. It is an evergreen tree. The wood is suitable for paper pulp and for making charcoal. The wood is also used in building construction and for agricultural implements. The tree is also suitable for avenue planting.

Local Volume Equation

$V = 0.2176 - 3.0151D + 13.5937D^2$

n = 54

Adjusted R^2 = 0.9650

Standard error = 0.0807

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(2) *Acacia catechu*

General Description

A thorny deciduous tree with flaky, rough bark and a slender, feathery crown. The bark of Khair is deeply cracked and flaking, and is lifted off the trunk in narrow plates.

Catechin compound in the litter of Khair suppresses the growth of soil microflora and fauna. Catechu (obtained after boiling heartwood) is high in phenolics and used for chewing with betel leaf. Seed is a source of protein, and is used as an ingredient of "paan". Khair has bitter- sweet taste and is an antiseptic and astringent herb. Traditionally grown in living fences, where it helps to exclude livestock and other animals.

Local Volume Equation

$V = 0.1568 + 6.7643D^2 - 0.6378\sqrt{D}$

n = 34

Adjusted R^2 = 0.9913

Standard error = 0.0539

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_2 < 0.001

P value for a_3 < 0.005

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(3) *Albizia amara*

General Description

A middle-sized deciduous tree with a feathery canopy. Native to drier parts of South India. Intolerant of shade, and resistant to drought. The Bark is grey, scaly and grainy.

A nitrogen fixer with green leaves making excellent manure. It is also used as a soil binder to stabilise hills sides. This is an excellent species for reforestation of degraded hilly areas in dry and semi-dry tracts. Finds use in reforestation projects. Some butterflies use it as a larval host plant. The plant has shallow and spreading root system.

Local Volume Equation

$V = 1.4103 + 10.7393D - 7.6634\sqrt{D}$

n = 57

Adjusted R^2 = 0.9398

Standard error = 0.1137

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(4) *Albizia procera*

General Description

This species is seen near roadsides and along riverine open areas. It occurs in moist deciduous forests and in the plains. It is deciduous with leaf fall in the winter months and new leaves appearing in April-May.

This species has been widely cultivated for use in agroforestry, as a nitrogen fixer for soil rehabilitation and improvement, as an ornamental and a shade tree. It is also used as fodder in India, while the bark and leaves are also used as insecticide. It has become an invasive outside its native range.

Local Volume Equation

$V = 1.4035 + 11.0179D - 7.7204\sqrt{D}$

n = 55

Adjusted R^2 = 0.9906

Standard error = 0.0361

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(5) *Alnus nepalensis*

General Description

It is commonly called as Nepalese Alder. It is a large deciduous tree, attaining a height of 24-30 m. This species occurs throughout the Himalaya from the Ravi river in Kashmir to Assam eastwards at 900-2700 m altitude, sometimes lower in Khasi hills and the hills of upper Burma. The wood is pinkish, even grained, soft and suitable for tea-boxes.

Local Volume Equation

$V = 0.9041 + 9.2172D - 5.7697\sqrt{D}$

n = 36

Adjusted R^2 = 0.9867

Standard error = 0.0595

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(6) *Anogeissus pendula*

General Description

It's a deciduous, middle – sized tree with about 10m of height. It is a low maintenance plant, takes less water and survives well in drought prone areas. It is long living tree and can survive for more than 200 years. A unique quality of this tree is its silvery trunk and tiny leaves. The silvery bark turns dark and rough with time.

The trees are valuable for afforesting dry, rocky hills. The leaves are an excellent fodder. The tree yields the Ghatti or Indian Gum which is edible and has been used in sweetmeats and as an emulsifier in the food industry. Its bark is useful in treating dysentery.

Local Volume Equation

$V = 0.1359 - 1.8591D + 9.5348D^2$

n = 44

Adjusted R^2 = 0.9728

Standard error = 0.0573

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 > 0.05

P value for a_1 < 0.005

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(7) *Bridelia retusa*

General Description

It is a moderately sized to large deciduous tree with variable coriaceous leaves. The bark is grey to dark brown, longitudinally cracked. Young trees often have the stems covered with spines. This species occurs throughout the greater part of India and Burma but not in the driest parts of India.

The tree stands moderate but not heavy shade, is frost tender but drought hardy. Wood is grey to olive brown, used for house posts, carts, cart-shafts and agricultural implements. The bark is used for tanning and the leaves are used for cattle fodder.

Local Volume Equation

$$\sqrt{V} = 1.9959 + 19.9898D - 9.4591D^2 - 11.6469\sqrt{D}$$

n = 36

Adjusted R^2 = 0.9889

Standard error = 0.0494

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_1 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(8) *Buchanania latifolia*

General Description

It is a moderate-sized tree, almost evergreen, with a straight trunk. The bark is dark grey or black reddish inside, regularly divided into small rectangular plates, somewhat resembling crocodile hide. This species occurs in deciduous forests throughout the greater part of India and Burma, except in the arid regions of north-western India.

The tree is a moderate light demander, very sensitive to frost and somewhat sensitive to drought. It is not readily browsed. The wood is of poor quality, but the tree is of economic importance for its gum and edible fruits.

Local Volume Equation

$V = 0.1025 - 1.8645D + 10.9625D^2$

n = 45

Adjusted R^2 = 0.9811

Standard error = 0.0332

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 40cm DBH.

(9) *Butea monosperma*

General Description

A medium sized dry season-deciduous tree, growing to 15 m tall. It is a slow growing tree. The plant has lent its name to the town of Palashi, famous for the historic Battle of Plassey fought there. Palash trees are recognised for their vibrant flowers. The bark of the tree is more or less rough with shallow cracks, greyish- brown bark, flaky. Young branches are soft.

Lac insect (among a few sources of sealing wax) dwells in it. This is a mosquito repellent plant. Insects are attracted by the smell and colour of the flower. Eggs that are laid into the liquid within the flower never hatch and the mosquitos that touch the fluid gets killed. Traditional Holi colours were made from its flowers.

Local Volume Equation

$$\sqrt{V} = 1.6007 + 15.6578D - 6.7295D^2 - 9.2184\sqrt{D}$$

n = 44

Adjusted R^2 = 0.9737

Standard error = 0.0632

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.01

P value for a_1 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.005

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(10) *Careya arborea*

General Description

It is a moderate-sized to large deciduous tree with large obovate leaves clustered at the ends of the branches. The bark is dark grey, fissured, red and fibrous inside. The species is found sporadically throughout the greater part of India but not in the driest regions. It is very typical of savannah lands, where owing to its fire-resisting capacity, it is able to survive and regenerate.

The tree stands a fair amount of shade. It is drought hardy, but is subject to damage by browsing. The wood is durable, especially under water and is used for buildings, carts, furniture etc. the bark gives a good rough cordage fibre.

Local Volume Equation

$$\mathbf{V = 0.2697 - 3.7930D + 16.9391D^2}$$

n = 39

Adjusted R^2 = 0.9772

Standard error = 0.0714

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(11) *Cassia siamea*

General Description

It is a moderate sized evergreen tree with a dense crown, probably indigenous to Burma and the southernmost part of Tamil Nadu largely planted for ornamental purpose. The pods ripen towards the end of the hot season. They hang in clusters and give the tree a somewhat untidy appearance. The tree grows fairly rapidly and is easy to cultivate.

Local Volume Equation

$V = 0.3293 - 4.3606D + 17.9828D^2$

n = 36

Adjusted R^2 = 0.9557

Standard error = 0.1125

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(12) *Chloroxylon swietenia*

General Description

It is commonly called Satinwood. It is a moderate sized deciduous tree with a rather short bole and a spreading light feathery crown. The species occurs in the dry deciduous forests in the Indian Peninsula, extending as far north as the Satpuras and Chota Nagpur. It attains comparatively large size on sandy loam.

It is a strong light demander, frost tender and easily damaged by fire. The leaves contain an acrid oil which browsing animals and even goats, find unpalatable and this protects the plants from injury. The tree gives the well-known Satinwood of commercial use for all kinds of ornamental works.

Local Volume Equation

$\sqrt{V} = -0.2303 + 3.3915D$

n = 54

Adjusted R^2 = 0.9784

Standard error = 0.0661

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(13) *Dalbergia paniculata*

General Description

Dalbergia paniculata is a very conspicuous and handsome tree when flowering, which appear very profusely during the months of May and June. It is a large tree with smooth bark and glabrous branches.

The sweet blackish pulp of the seedpod is used as a mild laxative.

Local Volume Equation

$\sqrt{V} = - 0.1373 + 2.7819D$

n = 35

Adjusted R^2 = 0.9518

Standard error = 0.0993

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(14) *Emblica officinalis*

General Description

A medium sized deciduous tree from dry forests with a fluted trunk, fine, feathery foliage and thin, grey bark peeling in small, irregular patches.

Amla is said to correct excessively alkaline soil. The branches are lopped for green manure. The fruit is cooked, baked, preserved and pickled in various ways as a general purpose tonic. Fruit is used to treat jaundice, gastrointestinal disorders, dyspepsia and coughs and is considered diuretic and laxative. Leaves are anti- inflammatory. It is an ingredient in Triphala churan.

Local Volume Equation

$\sqrt{V} = - 0.1737 + 3.0240D$

n = 33

Adjusted R^2 = 0.9675

Standard error = 0.0403

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 40cm DBH.

(15) *Hardwickia binata*

General Description

It is a moderate-sized to large tree, leafless for a short time to nearly evergreen, with drooping slender branchlets. The trees have been much mutilated by pollarding for fodder, manure or bast fibre. This species occurs in the drier parts of the Indian peninsula, extending as far north as the Banda district of Uttar Pradesh.

The wood is perhaps the hardest and heaviest in India. The wood is close grained, very durable. It is used for bridge and house construction, agricultural implements, carts, wheelwork etc. the bast yields a strong fibre largely employed for ropes and the branches are much lopped for manure and cattle fodder.

Local Volume Equation

$$\sqrt{V} = -0.2161 + 2.9509D$$

n = 46

Adjusted R^2 = 0.9856

Standard error = 0.0527

$P < 0.001$

The P value for the coefficients are as follows:

P value for $a_0 < 0.001$

P value for $a_1 < 0.001$

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(16) *Hevea brasiliensis*

General Description

It is commonly called as Rubber Tree which is a deciduous tree, typically 30-40 m tall, though usually 15-25 m tall in cultivation, with a leafy crown. The trunk is cylindrical, but frequently swollen towards the base, and the bark is pale to dark brown with a smooth surface and the inner bark pale brown with abundant white or cream coloured latex. In the wild, trees may grow to over 40 m and live for 100 years, but in plantations they rarely exceed 25 m because growth is reduced by tapping for rubber. Plantation trees are usually replanted after 25-35 years when yields fall to an uneconomic level. The milky latex of Para Rubber Tree is the raw material for natural rubber.

Local Volume Equation

$V = 0.1334 - 2.1584D + 11.2457D^2$

$n = 47$

Adjusted $R^2 = 0.9723$

Standard error = 0.0455

$P < 0.001$

The P value for the coefficients are as follows:

P value for $a_0 < 0.05$

P value for $a_1 < 0.001$

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 40cm DBH.

(17) *Holarrhena antidysenterica*

General Description

It is a small deciduous tree with greyish brown and scaly bark. The tree is important for reclaiming waste lands. This species is distributed throughout India, in deciduous forest and open waste lands. It ascends the outer Himalayan valleys to 1200 m elevation and is abundant in the Sal and mixed deciduous forest of the sub-Himalayan tract.

The tree stands a slight amount of shade but develops best in full light. It is drought hardy but sensitive to frost. The wood is white, soft even grained, used for carving into picture frames and fancy articles. The bark and seed have medicinal value.

Local Volume Equation

$V = 0.3172 - 3.9696D + 15.0557D^2$

n = 41

Adjusted R^2 = 0.9184

Standard error = 0.1134

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.005

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(18) *Lyonia ovalifolia*

General Description

It is a small deciduous tree. The bark is brown, thick, fibrous, exfoliating in long narrow strips, deeply furrowed longitudinally, the furrows often proceeding spirally up the stem. It occurs in the Western Himalayas at an elevation of 1200 m to 2400 m chiefly on grassy slopes. It is also found in Eastern Himalayas descending to 1500 m in the Tista valley and Khasi hills. The tree is fire resistant and not browsed by cattle. The wood is of little value as timber or fuel, but the tree is useful in covering hill slopes.

Local Volume Equation

$$\sqrt{V} = -0.1994 + 2.7286D$$

n = 44

Adjusted R^2 = 0.8481

Standard error = 0.1277

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(19) *Macaranga indica*

General Description

The species is seen growing in the openings of evergreen forests from 300 m to 2000 m. Flowering is in the hot season, while fruiting is in the winter months.

A crimson-coloured resin called "Macaranga gum" is obtained from this plant. Many parts of the plant are used for Ayurveda, folk and Siddha medicine.

Local Volume Equation

$V = 0.2939 + 11.1466D^2 - 1.2100\sqrt{D}$

n = 36

Adjusted R^2 = 0.9826

Standard error = 0.0208

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.01

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 30cm DBH.

(20) *Madhuca latifolia*

General Description

It is a medium sized deciduous tree. The bark is pale grey, smooth and flaking off in large pieces.

The name ‘Madhuca’ refers to the sweet flowers and is derived from the Sanskrit word ‘madhu’ for honey. In many parts of India this is considered to be a very valuable tree because it gives nutritious food for millions of poor people. The flowers are eaten raw. The seeds give ‘mahua butter’ that is used in cooking and in adulterating ghee.

Local Volume Equation

$\sqrt{V} = -0.1808 + 2.8409D$

n = 43

Adjusted R^2 = 0.9831

Standard error = 0.0631

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(21) *Mallotus philippinensis*

General Description

It is a small much branched evergreen tree with a short and often fluted bole. Bark is thin and dark grey. It occurs in the sub-Himalayan tract and outer hills from the Indus eastwards, to nearly 1500 m elevation into West Bengal, Chota Nagpur, Indian peninsula and Burma.

The tree stands a considerable amount of shade. It is frost hardy and drought resistant. The wood is hard and close grained. A dye known as Kamela, used for dyeing silk is obtained from the red glands on the surface of the capsules.

Local Volume Equation

$\sqrt{V} = -0.1120 + 2.4764D$

n = 35

Adjusted R^2 = 0.8541

Standard error = 0.0899

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(22) *Prosopis juliflora*

General Description

A woody, yellow flower bearing tree. This nitrogen-fixing and highly drought and salt tolerant species, rapidly out-competes other vegetation once it spreads. The plant was introduced intentionally to halt further desertification in the Thar Desert, India. It was also introduced to peninsular India as a source of fuel wood.

Local Volume Equation

$$\sqrt{V} = -0.2528 + 3.4327D$$

n = 47

Adjusted R^2 = **0.9349**

Standard error = **0.1026**

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(23) *Quercus leucotrichophora*

General Description

It is commonly called Grey oak or Ban oak. It is a moderate size to large evergreen tree attaining a height of 12-18 m with massive gnarled branches around a rounded crown. The species occurs in Western Himalaya, extending eastward to Nepal, at an elevation of 1200-2400 m, but occasionally descending lower in moist situations. In its younger stages the tree suffers much from goat browsing, and cattle also eat the young shoots, it is also lopped for fodder. The wood is very hard, much used for fuel and charcoal and sometimes used for building and agricultural implements.

Local Volume Equation

$$\sqrt{V} = -0.1522 + 2.6407D$$

n = 40

Adjusted R^2 = 0.8812

Standard error = 0.0926

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(24) *Rhododendron arboreum*

General Description

It is a small evergreen tree, often with a somewhat crooked or gnarled trunk. The bark is soft, easily cut through with a pocket knife. The tree occurs in the Western Himalaya at 1500-2400 m elevation. This species extends to the Eastern Himalaya, where however, it is less common, it is also found in the Khasi hills and the hills of southern India. The wood is of inferior quality, but is used both as timber and as fuel.

Local Volume Equation

$$\sqrt{V} = 0.2404 + 3.7975D^2$$

n = 39

Adjusted R^2 = 0.7131

Standard error = 0.1144

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(25) ***Schima wallichii***

General Description

It occurs in primary lowland forest and montane forests, but often in disturbed open forests. It can grow in a wide elevation range from lowlands to 2400 m or even higher.

It is sometimes used as a shade tree in plantations and planted as a pioneer species in restoration projects and for water conservation in catchments. The wood is valued. The tree is used medicinally, and as a source of tannins and oil. The bark is used as fish poison, antiseptic for wounds, and dyes. Flowers and sap in the stem also have medicinal properties. The wood is used for timber, paper pulp and is a suitable firewood.

Local Volume Equation

$$\sqrt{V} = -0.4319 + 1.7358D^2 + 1.6093\sqrt{D}$$

n = 43

Adjusted R^2 = **0.9877**

Standard error = **0.0509**

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(26) *Schleichera oleosa*

General Description

A large deciduous tree with a broad, shady crown. Apart from seedlings, Kusum trees are naturally produced in forests from root suckers. It has a comparatively short fluted trunk while its bark is grey or pale brown and smooth.

The extended foliage and canopy of Kusum tree provides shade and is suitable for mixed farming with other susceptible economic plants. The tree acts as host for the lac insect, butterflies and moths as well as nectar plant. It is frost and drought hardy and is subject to damage by grazing. Leaves are used as fodder. Both young leaves and shoots are edible.

Local Volume Equation

$\sqrt{V}$ = - 0.2355 + 3.4705D

n = 38

Adjusted R^2 = 0.9932

Standard error = 0.0364

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(27) *Semecarpus anacardium*

General Description

It is commonly called Marking Nut tree. It is a moderate-sized deciduous tree with rough dark brown bark yielding an acrid juice. The tree occurs in the sub-Himalayan tract chiefly in the Sal forests in West Bengal, Assam, Chota Nagpur and throughout the greater part of Indian peninsula and in Bangladesh. The tree is a moderate shade bearer and the seedlings are rather sensitive to frost.

Local Volume Equation

$V = 0.3478 + 11.0475D^2 - 1.3543\sqrt{D}$

n = 36

Adjusted R^2 = 0.9840

Standard error = 0.0343

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 40cm DBH.

(28) *Terminalia arjuna*

General Description

Commonly known as Arjun, it is a large, evergreen tree, with a spreading crown and drooping branches. It grows up to 25 m height, and the bark is grey and smooth. Native to India, the tree attracts lot of attention because of its association with mythology and its many uses.

According to Ayurveda it is alexiteric, styptic, tonic, anthelmintic, and useful in fractures, uclers, heart diseases, biliousness, urinary discharges, asthma, tumours, leucoderma, anaemia, excessive prespiration etc. According to Yunani system of medicine, it is used both externally and internally in gleet and urinary discharges.

Local Volume Equation

$$\sqrt{V} = -0.0868 + 2.7727D$$

n = 39

Adjusted R^2 = 0.9752

Standard error = 0.1208

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 90cm DBH.

(29) *Terminalia paniculata*

General Description

It is a large to very large deciduous tree. The bark is thick, dark brown, rough, with numerous shallow longitudinal and transverse fissures. The lower part of the bole is often much fluted. It occurs in the western region of the Indian peninsula from Maharashtra southwards, and in southern India. It attains its largest dimensions in the deciduous forests of the Western Ghats. It is also found throughout the eastern forests, but here it reaches smaller dimensions. The wood is very hard and is used chiefly for planking, agricultural implements, and canoes. The bark contains much tannin.

Local Volume Equation

$\sqrt{V} = - 0.1713 + 3.1872D$

n = 54

Adjusted R^2 = 0.9765

Standard error = 0.0667

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(30) *Xylia xylocarpa*

General Description

It is a moderate sized to large deciduous tree attaining a height of 18 m. it occurs in the Indian peninsula, extending as far north as Mumbai in the west, Odisha in the east and the Balaghat district of Madhya Pradesh in the centre. It is not found in the dry districts of the Indian peninsula. It is plentiful

throughout the deciduous forests of the Western Ghats. It is a typical gregarious tree often forming nearly pure crops.

The wood is very hard, durable and liable to split in seasoning. It is used for house and bridge construction.

Local Volume Equation

$$\sqrt{V} = -0.0990 + 2.6224D$$

n = 39

Adjusted R^2 = **0.9613**

Standard error = **0.0889**

$P < 0.001$

The P value for the coefficients are as follows:

P value for $a_0 < 0.005$

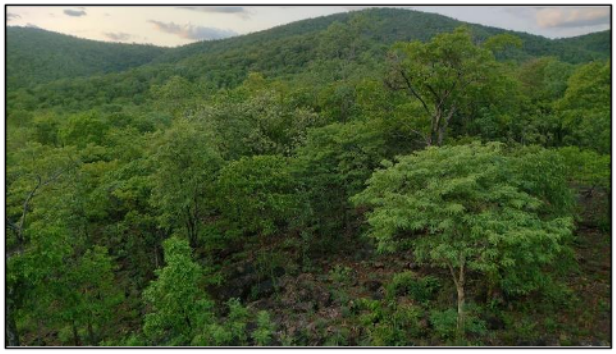
P value for $a_1 < 0.001$

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.









3.2 Volume Equations for TOF species

(1) *Acacia arabica*

General Description

Acacia arabica commonly known as Tomentose Babool, is a very abundant subspecies in India and Pakistan and is also widespread in parts of Africa. It is most often found on alluvial soils that are periodically flooded, sandy-clays and non-saline clay soils. It is resistant to temporary flooding and can grow in waterlogged soils for long periods. Unlike Babool, Tomentose Babool may be thorny when the tree is young, but at maturity the tree has few spines. The characteristic of the tree is densely tomentose, white pods which are deeply constricted between the seeds to make it look like a beaded necklace.

Local Volume Equation

$$V = 0.2006 + 6.8662D^2 - 0.7642\sqrt{D}$$

n = 82

Adjusted R^2 = 0.9928

Standard error = 0.0475

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(2) *Anacardium occidentale*

General Description

The Cashew is a flowering tree, native to north-eastern Brazil, where it is called by its Portuguese name *Caju* (the fruit) or *Cajueiro* (the tree). It is now widely grown in tropical climates for its cashew "nuts" (and cashew apples). It is a small evergreen tree growing to 10-12 m tall, with a short, often irregularly-shaped trunk. The bark is usually grey to dark grey with fine longitudinal fissures. What appears to be the fruit of the cashew tree is an oval or pear-shaped accessory fruit or false fruit that develops from the receptacle of the cashew flower. The true fruit of the cashew tree is a kidney or boxing-glove shaped drupe that grows at the end of the pseudo fruit. The seed is surrounded by a double shell containing a caustic phenolic resin, urushiol, a potent skin irritant toxin also found in the related poison ivy.

Local Volume Equation

$V = 1.4082 + 11.9654D - 8.0664\sqrt{D}$

n = 67

Adjusted R^2 = 0.9681

Standard error = 0.0672

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(3) *Artocarpus heterophyllus*

General Description

A huge tree with milky latex and irregular branching. Bark is dark grey-blackish with numerous reddish lenticels. A common tree in home gardens, also planted along road sides. Preferred for its tasty fruits, green foliage (leaves used for various purposes) and valuable timber.

Local Volume Equation

$$\sqrt{V} = -0.4871 + 2.6345D^2 + 1.8167\sqrt{D}$$

n = 39

Adjusted R^2 = 0.9752

Standard error = 0.0823

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(4) *Azadirachta indica*

General Description

Azadirachta indica commonly called as Neem, is native to India and Burma. It is the state tree of Andhra Pradesh. Neem is a fast growing tree that can reach a height of 15-20 m, rarely to 35-40 m. It is evergreen but under severe drought it may shed most or nearly all of its leaves. The branches are wide spread. The fairly dense crown is roundish or oval and may reach the diameter of 15-20 m in old, free-standing specimens. The trunk is relatively short, straight and may reach a diameter of 1.2 m. The bark is hard, fissured or scaly, and whitish-grey to reddish-brown. But Neem is far more than a tough tree that grows vigorously in difficult sites. Among its many benefits, the one

that is most unusual and immediately practical is the control of farm and household pests.

Local Volume Equation

$$V = 0.3269 + 9.3286D^2 - 1.2430\sqrt{D}$$

n = 82

Adjusted R^2 = **0.9702**

Standard error = **0.1045**

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(5) ***Bombax ceiba***

General Description

A tall deciduous tree with a characteristic branching formation and broad conical head, capable of reaching up to 50m. Its branches grow in tiers radiating from the trunk like ribs of an umbrella. It has an ashy smooth bark. The young trees have conical prickles on lower trunk.

It can be used as a pioneer when restoring native woodland. An oil is obtained from the seeds. Flower buds and calyx are eaten as cooked curry vegetables. It is also used in Ayurveda and folk medicine.

Local Volume Equation

$$V = - 4.64591D + 11.28256D^2 + 1.354514\sqrt{D}$$

n = 33

Adjusted R^2 = 0.987885

Standard error = 0.07562

P < 0.001

The P value for the coefficients are as follows:

P value for a_1 < 0.005

P value for a_2 < 0.001

P value for a_3 < 0.05

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(6) *Borassus flabelliformis*

General Description

Commonly known as Palmyra palm, it is a native of tropical Africa but cultivated and naturalized throughout India. The Palmyra palm is a large tree up to 30m high. The chief product of the Palmyra is the sweet sap (toddy) obtained by tapping the tip of the inflorescence, as is done with the other sugar palms. The toddy ferments naturally within a few hours after sunrise and is locally popular as a beverage.

Traditionally, the Indian 'Nadar' community are the people who make their living from this tree using its wood, fruits, sap, stems, petioles and leaves to process a variety of food products, beverages, furniture, building materials, and handicrafts.

Local Volume Equation

$$V = - 0.4105D + 4.9130D^2$$

n = 64

Adjusted R^2 = 0.9668

Standard error = 0.1031

P < 0.001

The P value for the coefficients are as follows:

P value for a_1 < 0.005

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(7) *Butea monosperma*

General Description

A medium sized dry season-deciduous tree, growing to 15 m tall. It is a slow growing tree. The plant has lent its name to the town of Palashi, famous for the historic Battle of Plassey fought there. Palash trees are recognised for their vibrant flowers. The bark of the tree is more or less rough with shallow cracks, greyish- brown bark, flaky. Young branches are soft. The leaves are usually very leathery and not eaten by cattle.

Lac insect (among a few sources of sealing wax) dwells in it. This is a mosquito repellent plant. Insects are attracted by the smell and colour of the flower. Eggs that are laid into the liquid within the flower never hatch and the mosquitos that touch the fluid gets killed. Traditional Holi colours were made from flowers.

Local Volume Equation

$\sqrt{V}$ = - 0.2182 + 3.0037D

n = 43

Adjusted R^2 = 0.9836

Standard error = 0.0474

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(8) *Cocos nucifera*

General Description

Commonly known as Coconut Palm, it is a member of the palm family. It is the only species in the Genus Cocos, and is a large palm, growing to 30 m tall. Old leaves break away cleanly leaving the trunk smooth. The term coconut refers to the fruit of the coconut palm. The flowers of the coconut palm are polygamomonoecious, with both male and female flowers in the same inflorescence. Flowering occurs continuously, with female flowers producing seeds. Coconut palms are believed to be largely cross-pollinated, although some dwarf varieties are self-pollinating.

Local Volume Equation

$V = 0.0927 - 1.56D + 8.6798D^2$

n = 76

Adjusted R^2 = 0.9691

Standard error = 0.0646

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(9) *Dalbergia sissoo*

General Description

It is commonly called as Sissoo. It is a medium-sized to large, gregarious, deciduous tree with thick grey bark, attaining a height of up to 30 m. it occurs throughout the sub-Himalayan tract and outer Himalayan valleys from Indus to Assam usually up to 900 m but sometimes up to 1500 m elevation. It has been extensively planted along roads and canals, especially in Punjab and Uttar Pradesh and in many other parts of the country.

The species is frost hardy and drought resistant. The tree yields timber for constructional and general utility purposes e.g. in building constructions, boat building, musical instruments and sports equipment. Its wood is an excellent fuel and the leaves are also used as fodder.

Local Volume Equation

$V = 0.1553 - 2.3155D + 11.7116D^2$

n = 68

Adjusted R^2 = 0.9857

Standard error = 0.0755

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(10) *Elaeis guineensis*

General Description

It is commonly known as Palm Oil tree. The tree is generally up to 20 m in height, erect, heavy with ringed trunk. Male and female flowers occur in separate clusters, but on same tree. Male flowers are borne on short furry branches 10-15 cm long, set close to trunk on short stalks. Female flowers and consequently fruits are borne in large clusters of 200-300, close to the trunk on short heavy stalks. Each fruit is plum-like, ovoid-oblong, up to 3.5 cm long and about 2 cm wide, black when ripe, red at base, with thick ivory-white flesh and small cavity in centre. Nuts are encased in a fibrous covering which contains the oil.

Local Volume Equation

$$\sqrt{V} = -0.3072 + 0.947D^2 + 1.6318\sqrt{D}$$

n = 74

Adjusted R^2 = 0.9653

Standard error = 0.0516

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(11) *Ficus benghalensis*

General Description

A large, nearly evergreen, spreading tree with a vast system of prop- roots, it forms the most extensive crown of any plant in the world. Often beginning life on another tree as a strangler, it can grow up to 30 m or taller. It is resistant to drought and mild frost. It produces propagating roots which grow

downwards as aerial roots on the branches that grow downward like lianas. Once these roots reach the ground, they take root and become woody trunks and supportive. The bark is greyish, not rough; exudes milky sap when cut.

The banyan is a fast-growing tree that has been used for soil conservation and as an afforestation species. The figs are eaten by birds, bats and monkeys and as famine food. Its latex is applied to bruises and cracked soles and to relieve rheumatic pains and fevers. An infusion of the bark is drunk as a tonic.

Local Volume Equation

$$\sqrt{V} = -0.1426 + 2.8136D$$

n = 37

Adjusted R^2 = 0.9759

Standard error = 0.1076

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 90cm DBH.

(12) *Ficus racemosa*

General Description

A lovely fig tree with a crooked trunk and a wide, open canopy. This one isn't a "strangler", and it doesn't have any aerial roots. The red, hairy figs grow in small, branching clusters from the trunk or main branches. The bark can be white, yellow, pinkish, silvery gray, or rusty in colour. Smooth at first, but becomes scaly as it ages.

Most parts of the tree are used in traditional healing. An astringent lotion made from the bark is credited with treating deep wounds inflicted by a tiger's claws. The dried leaves are powdered as a cure for bilious afflictions. The figs are carminative and the milky latex is used to treat piles and

diarrhoea. The figs are not often eaten but some forest-dwelling communities seem to relish it. One of the few kinds of wood prescribed in ancient Hindu scriptures for the sacrificial fire. The tree is sacred.

Local Volume Equation

$V = 1.3964 + 12.6253D - 8.3377\sqrt{D}$

n = 51

Adjusted R^2 = 0.9544

Standard error = 0.1857

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_1 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(13) *Ficus religiosa*

General Description

It is commonly known as Peepal. It is a large deciduous tree with a pale stem often appearing fluted on account of the numerous roots which have fused with the stem. A large tree with spreading canopy and with a milky latex. The bark is brown to grey with vertical fissures. The young leaves are frequently pink, change to copper and finally to green.

Peepal is unrivalled for its antiquity and religious significance. No other tree is claimed to have such long life. A grand Peepal tree is a perfect shade tree, and village meetings are often conducted under a Peepal.

Local Volume Equation

$V = 5.06388D^2$

n = 33

Adjusted R^2 = 0.944801

Standard error = 0.144298

P < 0.001

The P value for the coefficients are as follows:

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(14) *Grewia oppositifolia*

General Description

Grewia oppositifolia is commonly known as Bihul or Bhimal. It is a small to medium-sized deciduous tree, 9-12 m in height. Crown is spreading, bole is clear, 3-4 m, and about 1 m diameter. Branches are smooth, pale silvery-brown, bark dark brown, thick and roughish, peeling in small woody scales. Bhimal is found in the Himalayan regions in Pakistan, Nepal and India, usually between 500 m and 2500 m.

Local Volume Equation

$\sqrt{V} = -0.1046 + 2.4041D$

n = 36

Adjusted R^2 = 0.8883

Standard error = 0.0729

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.005

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(15) *Holoptelea integrifolia*

General Description

Commonly known as Indian Elm, it is a large deciduous tree, growing up to 18 m tall. It has grey bark, covered with blisters, peeling in corky scales on old trees. Crushed leaves emit an unpleasant odour.

The bark of Indian Elm is used in rheumatism. Seed and paste of stem bark is used in treating ringworm. Bark and leaves are used for treating oedema, diabetes, leprosy and other skin diseases, intestinal disorders, piles and sprue. Powdered bark when sprinkled on fresh wounds controls bleeding and helps in healing.

Local Volume Equation

$V = 0.3382 + 8.1235D^2 - 1.1968\sqrt{D}$

n = 54

Adjusted R^2 = 0.9573

Standard error = 0.0738

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_2 < 0.001

P value for a_3 < 0.005

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(16) *Leucaena leucocephala*

General Description

A low scrubby tree of tropical and subtropical North America having white flowers tinged with yellow resembling mimosa and long flattened pods. Leaves are like that of tamarind. It is a thorn less shrubby bush or tree often only to 6-8ft but occasionally to 30-60ft. grows very well in arid tropical climates and can become a pest species in such climates. Grows best under full sun, needs little water or care once established. Very fast-growing species which can thrive practically in any soil type.

Local Volume Equation

$V = 0.1060 - 1.7464D + 10.9418D^2$

n = 45

Adjusted R^2 = 0.9872

Standard error = 0.0455

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(17) *Mangifera indica*

General Description

It is commonly known as Mango and is a member of the family Anacardiaceae- notorious for embracing a number of highly poisonous plants. The mango tree

is erect, 10 to 30 m high, with a broad, rounded canopy which may, with age, attain 25 to 30 m in width, or a more upright, oval, relatively slender crown. The bark is greyish black and often peels off in patches. There is great variation in the form, size, colour and quality of the fruits. They may be nearly round, oval, ovoid-oblong, or somewhat kidney-shaped, often with a break at the apex.

Local Volume Equation

$\sqrt{V} = - 0.2087 + 3.0497D$

n = 38

Adjusted R^2 = 0.6909

Standard error = 0.1601

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 > 0.05

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(18) *Moringa oleifera*

General Description

Medium-sized deciduous tree with sparse foliage and fast-growing. The bark is pale brown or silvery-white, corky and furrowed.

Cultivated as one of the world's most useful plants also called the miracle tree. Flowers act as a nectar source for honey bees and butterflies. Because it is fast growing and readily establishes itself in dry areas, it can be extremely useful in creating woodlands. Also provides wind break and shade and support for other climbing creepers. The gum obtained from the stem is used for stomach and bladder ailments. Moringa seeds are effective against skin-

infecting bacteria. Leaves and fruits are an astonishingly rich source of calcium, protein, vitamin B, A, and C.

Local Volume Equation

$V = 1.1412 + 10.8535D - 6.9661\sqrt{D}$

n = 36

Adjusted R^2 = 0.9757

Standard error = 0.0571

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 50cm DBH.

(19) Morus Alba

General Description

A small deciduous tree with a spreading, irregular crown. It is often self-sown and grows untended. Though originally from China, it has been cultivated in India for a long time, and has become naturalised. The bark is dark or medium brown, rough with shallow vertical furrows and gets accentuated with age.

Leaves of mulberry are nutritious fodder. Its fruit is eaten by many birds and animals. Acts as a host plant for butterflies. Fruits have high nutritional value. Mulberries contain alkaloids that helps improve immune system, source of anti-oxidants. Since it is a fast-growing tree, used for reforestation and biological suppression of *Prosopis juliflora*.

Local Volume Equation

$V = 0.6097 + 6.1078D - 3.7368\sqrt{D}$

n = 32

Adjusted R^2 = 0.9509

Standard error = 0.0316

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_1 < 0.001

P value for a_3 < 0.005

This equation is applicable to the trees ranging from 10cm DBH to 40cm DBH.

(20) *Phoenix sylvestris*

General Description

A graceful palm 10-16 m tall with a slender, curving stem and plumose crown. Hardy and adaptable, it is closely related to the true date palm from N African oases. The bark is greyish to black, stepped from the stumps of fallen leaves.

Indicator of high moisture levels in the Ridge areas. Fruit of Khajur has a sweet character, sometimes eaten. Sap can be concentrated into sugar or fermented into alcohol. The juice condenses into palm jaggery on boiling.

Local Volume Equation

$V = - 0.0408 + 5.5395D^2$

n = 41

Adjusted R^2 = 0.8971

Standard error = 0.0481

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.05

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 40cm DBH.

(21) *Pinus kesiya*

General Description

It is a tall evergreen tree attaining a height of 30-45 m. it occurs in the Khasi and Naga hills and in Manipur, Bangladesh and Burma. The branches are more or less whirled, the bark is thick, deeply cracked.

The wood is very resinous, moderately hard, pale brown to red.

Local Volume Equation

$$\sqrt{V} = -0.5394 + 1.9198D^2 + 1.9264\sqrt{D}$$

n = 75

Adjusted R^2 = 0.9829

Standard error = 0.0671

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(22) *Pongamia pinnata*

General Description

It is a fast-growing medium-sized evergreen or briefly deciduous tree with a globose canopy. The bark is smooth and greyish brown.

The seeds, root, bark, leaves and flowers all have various uses in traditional medicine so this is a valuable tree. A reddish oil extracted from the seeds called karanj oil is used to light lamps or as a lubricant for engines.

Local Volume Equation

$$\sqrt{V} = -0.3601 + 4.5249D - 1.3713D^2$$

n = 64

Adjusted R^2 = 0.9774

Standard error = 0.0805

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(23) *Populus deltoides*

General Description

It is commonly known as Poplar. It is a fast-growing species capable of yielding high volume at a relatively low age. Poplar wood is well suited to industries such as matches, pulp and paper, fibre board etc.

Local Volume Equation

$$V = 0.7778 + 7.0180D - 4.5960\sqrt{D}$$

n = 44

Adjusted R^2 = 0.9814

Standard error = 0.0204

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 40cm DBH.

(24) *Prosopis cineraria*

General Description

A thorny deciduous desert tree from the pea family. It is native to arid portions of Western Asia and the Indian Subcontinent. The bark is Ashy and deeply fissured, extremely rough. Cracks are more pronounced in older trees. The twigs are reddish when young.

Hardy, drought resistant and a nitrogen fixer, extremely useful in reforestation of degraded landscapes. The leaves and pods are consumed by livestock and are beneficial forage. The pods are known to prevent protein and mineral deficiency. The dried green pods are used to make a delicious dried vegetable dish.

Local Volume Equation

$$\sqrt{V} = -0.2599 + 2.3011D^2 + 1.1793\sqrt{D}$$

n = 93

Adjusted R^2 = 0.9869

Standard error = 0.0531

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(25) *Swietenia mahagoni*

General Description

It is commonly known as Mahogany. It is a medium-sized semi-evergreen tree which grows up to 30-35 m. The trunk is straight and cylindrical, slightly grooved, with well-developed spurs.

Known for its straight grain and characteristic red brown colour, it polishes and oils very well and can be buffed to a very high shine. An exceptionally durable hardwood, it is the ideal choice for furniture and fittings around the home. Its strength, light weight, resistance to rot, and structural stability made it an ideal timber for ocean-going vessels as well as furniture. Its wood is used to make musical instruments, inlay, boats, caskets, and many other items. Its wood is a popular material for making drums.

Local Volume Equation

$\sqrt{V}$ = - 0.1802 + 3.0598D

n = 41

Adjusted R^2 = 0.9845

Standard error = 0.0647

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_1 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(26) *Syzygium cumini*

General Description

An evergreen tropical tree in the flowering plant family Myrtaceae, and favoured for its fruit, timber, and ornamental value. As a rapidly growing species, it can reach heights of up to 30 m (100 ft.) and can live more than 100 years. Its bark is pale grey brown with dark patches; flaky and rough especially on the lower trunk.

Jamun has dense shade-providing foliage. The fruit is devoured by jackals, civets, etc. and is used in folk medicine to treat diabetes, dysentery, and diseases of the spleen, as a tonic, and to strengthen teeth and gums. Leaves, stem and bark are also used medicinally.

Local Volume Equation

$V = 5.160866D^2$

n = 50

Adjusted R^2 = 0.947031

Standard error = 0.110761

P < 0.001

The P value for the coefficients are as follows:

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.

(27) *Tamarindus indica*

General Description

A large, slow- growing, long- lived deciduous tree with a squat trunk, spreading limbs and a high, shady crown of feathery foliage. It has dark grey, grey- brown, rough bark, having shallow fissures and flaking off in small patches.

The deep roots make it very resistant to storms and suitable for windbreaks. Provides dense shade and inhibits growth of grass. Tamarind's tart fruit is used in curries, chutneys, jams and sauces. Fruit pulp is used to treat fevers, digestive problems and some kinds of poisoning.

Local Volume Equation

$$\sqrt{V} = -0.5193 + 1.5536D^2 + 1.9875\sqrt{D}$$

n = 53

Adjusted R^2 = 0.9792

Standard error = 0.0707

P < 0.001

The P value for the coefficients are as follows:

P value for a_0 < 0.001

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 80cm DBH.

(28) *Tectona grandis*

General Description

It is commonly called as Teak. It is a large deciduous tree with a rounded crown, and under favourable conditions, a tall clean cylindrical bole. The heartwood is dark golden yellow, turning brown with age, oily with a characteristic odour, extremely durable, seasons well and does not warp or split. It is indigenous throughout the greater part of Indian peninsula. It has been planted in many areas outside its natural region.

It is a pronounced light demander, is sensitive to frost and drought and has greater power of resisting fire than the majority of its associates. It is not readily browsed. It is the most important timber tree of India. It is extensively used for ship building, house building, bridge and wharf construction, piles, furniture and cabinet work, general carpentry and for numerous other purposes.

Local Volume Equation

$V = 6.102843D^2 - 0.13475\sqrt{D}$

n = 58

Adjusted R^2 = 0.974965

Standard error = 0.076129

P < 0.001

The P value for the coefficients are as follows:

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(29) *Terminalia crenulata*

General Description

Commonly known as Laurel, it is a large deciduous tree with a long clean bole, spreading branches and heavy crown, attaining a height of 30-35 m. it has a very thick dark-colored bark, deeply cracked longitudinally, resembling very much the back of a crocodile. The tree attains its largest dimensions on deep, rich alluvial soil. It is a common associate of Sal and Teak in their respective zones.

It is a light demander, drought tender, frost resistant and tolerant of waterlogging. It is fairly tolerant to damage by fire and is readily browsed by animals. The timber is used for building and construction works, for making furniture, electric casing, rough carpentry, floorboards and doors. The bark is used for tanning.

Local Volume Equation

$V = 8.168535D^2 - 0.19505\sqrt{D}$

n = 58

Adjusted R^2 = 0.975899

Standard error = 0.083673

P < 0.001

The P value for the coefficients are as follows:

P value for a_2 < 0.001

P value for a_3 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 70cm DBH.

(30) *Zizyphus mauritiana*

General Description

An evergreen smallish spiny tree with a short stem and crooked twisting branches forming a dense spreading crown. Up to 15 m high with trunk 40 cm or more in diameter. The bark is nearly black with wavy ridges and deep vertical burrows. Inner bark is red brown.

The fruit is consumed by both humans and animals. They attract Tussar silkworms and honey bees. Also serves a host plant for several butterfly species of the Lycaenidae family. Fruiting depends on cross pollination by insects attracted by fragrance and nectar of flowers. Plants have extensive root system and can also be used as a living fence. Also serves as a nesting habitat for small birds.

Local Volume Equation

$V = 7.662644D^2$

n = 46

Adjusted R^2 = 0.944956

Standard error = 0.149582

P < 0.001

The P value for the coefficients are as follows:

P value for a_2 < 0.001

This equation is applicable to the trees ranging from 10cm DBH to 60cm DBH.



CHAPTER FOUR

CONCLUSION AND FUTURE VISION

4.1 CONCLUSION

The outcome of this study is the developed local volume equations for each of the 30 tree species in forest and TOF. It is noteworthy to mention here that these equations must be used carefully for the specific districts or area and for the given range of DBH class, otherwise it may result in over-estimation or underestimation of the volume. The local volume equations for forest and TOF species have been given in Table 4.1 and Table 4.2 respectively.

Table 4.1 Local Volume Equations for forest species

Sl. No.	Forest Species	Local volume equation
1	*Acacia auriculiformis*	$V = 0.2176 - 3.0151D + 13.5937D^2$
2	*Acacia catechu*	$V = 0.1568 + 6.7643D^2 - 0.6378\sqrt{D}$
3	*Albizia amara*	$V = 1.4103 + 10.7393D - 7.6634\sqrt{D}$
4	*Albizia procera*	$V = 1.4035 + 11.0179D - 7.7204\sqrt{D}$
5	*Alnus nepalensis*	$V = 0.9041 + 9.2172D - 5.7697\sqrt{D}$
6	*Anogeissus pendula*	$V = 0.1359 - 1.8591D + 9.5348D^2$
7	*Bridelia retusa*	$\sqrt{V} = 1.9959 + 19.9898D - 9.4591D^2 - 11.6469\sqrt{D}$
8	*Buchanania latifolia*	$V = 0.1025 - 1.8645D + 10.9625D^2$
9	*Butea monosperma*	$\sqrt{V} = 1.6007 + 15.6578D - 6.7295D^2 - 9.2184\sqrt{D}$
10	*Careya arborea*	$V = 0.2697 - 3.7930D + 16.9391D^2$
11	*Cassia siamea*	$V = 0.3293 - 4.3606D + 17.9828D^2$
12	*Chloroxylon swietenia*	$\sqrt{V} = - 0.2303 + 3.3915D$
13	*Dalbergia paniculata*	$\sqrt{V} = - 0.1373 + 2.7819D$
14	*Emblica officinalis*	$\sqrt{V} = - 0.1737 + 3.0240D$
15	*Hardwickia binata*	$\sqrt{V} = - 0.2161 + 2.9509D$
16	*Hevea brasiliensis*	$V = 0.1334 - 2.1584D + 11.2457D^2$
17	*Holarrhena antidysenterica*	$V = 0.3172 - 3.9696D + 15.0557D^2$
18	*Lyonia ovalifolia*	$\sqrt{V} = - 0.1994 + 2.7286D$
19	*Macaranga indica*	$V = 0.2939 + 11.1466D^2 - 1.2100\sqrt{D}$
20	*Madhuca indica*	$\sqrt{V} = - 0.1808 + 2.8409D$
21	*Mallotus phillipensis*	$\sqrt{V} = - 0.1120 + 2.4764D$
22	*Prosopis juliflora*	$\sqrt{V} = - 0.2528 + 3.4327D$
23	*Quercus leucotrichophora*	$\sqrt{V} = - 0.1522 + 2.6407D$
24	*Rhododendron arboreum*	$\sqrt{V} = 0.2404 + 3.7975D^2$
25	*Schima wallichii*	$\sqrt{V} = - 0.4319 + 1.7358D^2 + 1.6093\sqrt{D}$
26	*Schleichera oleosa*	$\sqrt{V} = - 0.2355 + 3.4705D$
27	*Semecarpus anacardium*	$V = 0.3478 + 11.0475D^2 - 1.3543\sqrt{D}$
28	*Terminalia arjuna*	$\sqrt{V} = - 0.0868 + 2.7727D$
29	*Terminalia paniculata*	$\sqrt{V} = - 0.1713 + 3.1872D$
30	*Xylia xylocarpa*	$\sqrt{V} = - 0.0990 + 2.6224D$

**Where V is the under bark volume in cubic metre and D is the diameter at breast height (1.37m) in metre.*

Table 4.2 Local Volume Equations for TOF species

Sl. No.	TOF Species	Local volume equation
1	*Acacia arabica*	$V = 0.2006 + 6.8662D^2 - 0.7642\sqrt{D}$
2	*Anacardium occidentale*	$V = 1.4082 + 11.9654D - 8.0664\sqrt{D}$
3	*Artocarpus heterophyllus*	$\sqrt{V} = -0.4871 + 2.6345D^2 + 1.8167\sqrt{D}$
4	*Azadirachta indica*	$V = 0.3269 + 9.3286D^2 - 1.2430\sqrt{D}$
5	*Bombax ceiba*	$V = -4.64591D + 11.28256D^2 + 1.354514\sqrt{D}$
6	*Borassus flabelliformes*	$V = -0.4105D + 4.9130D^2$
7	*Butea monosperma*	$\sqrt{V} = -0.2182 + 3.0037D$
8	*Cocos nucifera*	$V = 0.0927 - 1.56D + 8.6798D^2$
9	*Dalbergia sissoo*	$V = 0.1553 - 2.3155D + 11.7116D^2$
10	*Elaeis guineensis*	$\sqrt{V} = -0.3072 + 0.947D^2 + 1.6318\sqrt{D}$
11	*Ficus benghalensis*	$\sqrt{V} = -0.1426 + 2.8136D$
12	*Ficus racemosa*	$V = 1.3964 + 12.6253D - 8.3377\sqrt{D}$
13	*Ficus religiosa*	$V = 5.06388D^2$
14	*Grewia oppositifolia*	$\sqrt{V} = -0.1046 + 2.4041D$
15	*Holoptelea integrifolia*	$V = 0.3382 + 8.1235D^2 - 1.1968\sqrt{D}$
16	*Leucaena leucocephala*	$V = 0.1060 - 1.7464D + 10.9418D^2$
17	*Mangifera indica*	$\sqrt{V} = -0.2087 + 3.0497D$
18	*Moringa oleifera*	$V = 1.1412 + 10.8535D - 6.9661\sqrt{D}$
19	*Morus alba*	$V = 0.6097 + 6.1078D - 3.7368\sqrt{D}$
20	*Phoenix sylvestris*	$V = -0.0408 + 5.5395D^2$
21	*Pinus kesiya*	$\sqrt{V} = -0.5394 + 1.9198D^2 + 1.9264\sqrt{D}$
22	*Pongamia pinnata*	$\sqrt{V} = -0.3601 + 4.5249D - 1.3713D^2$
23	*Populus deltoides*	$V = 0.7778 + 7.0180D - 4.5960\sqrt{D}$
24	*Prosopis cineraria*	$\sqrt{V} = -0.2599 + 2.3011D^2 + 1.1793\sqrt{D}$
25	*Swietenia mahagony*	$\sqrt{V} = -0.1802 + 3.0598D$
26	*Syzygium cumini*	$V = 5.160866D^2$
27	*Tamarindus indica*	$\sqrt{V} = -0.5193 + 1.5536D^2 + 1.9875\sqrt{D}$
28	*Tectona grandis*	$V = 6.102843D^2 – 0.13475\sqrt{D}$
29	*Terminalia crenulata*	$V = 8.168535D^2 – 0.19505\sqrt{D}$
30	*Zizyphus mauritiana*	$V = 7.662644D^2$

**Where V is the under bark volume in cubic metre and D is the diameter at breast height (1.37m) in metre.*

4.2 FUTURE VISION

The local volume equations developed here are limited to their use for specific area or district. Therefore, to increase the applicability, regional and standard volume equations need to be developed. For this purpose, it is required to collect data for the same species from different locations at state and national level. Manual collection of this data at regional or national level will take too much time and manpower and therefore it is recommended to procure digital instruments which can provide the accurate diameter and height measurements within a short span of time.

Apart from FSI, a few other organizations are working to develop volume equations, however, there are many tree species for which volume equations are not yet available. Including the various State forest departments and other research organizations, a holistic approach can be followed to address this issue. A national level study can be conducted aiming to develop general/standard volume equations for the remaining tree species of India. The results of the proposed study will not only help in bridging the information gaps but also in reflecting the Country's efforts towards precise and accurate estimation of carbon stocks in India.

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Volume equations for tree species from forest and trees outside forest

