“A STUDY ON THE BIOMASS AND CARBON STORAGE IN AN AGE SERIES OF TEAK PLANTATION IN TROPICAL ENVIRONMENT”

M.Sc. (Forestry) THESIS

BY

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2012

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Thesis

Submitted to the

INDIRA GANDHI KRISHI VISHWAVIDYALAYA
RAIPUR

BY

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IN PARTIAL FULFILMENT OF REQUIREMENTS FOR THE DEGREE OF

Master of Science
in
Forestry

Roll No. 12520 I.D. No. 112104034

June, 2012

CERTIFICATE – I

This is to certify that the thesis entitled **"A STUDY ON THE BIOMASS AND CARBON STORAGE IN AN AGE SERIES OF TEAK PLANTATION IN TROPICAL ENVIRONMENT"** submitted in partial fulfilment of the requirements for the degree of **"MASTER OF SCIENCE IN FORESTRY"** of Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **KULESHWAR PRASAD** under my guidance and supervision. The subject of the thesis has been approved by Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published / published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

Date: 29/06/2012

Dr. Lalji Singh
Chairman
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THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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Member	:	Dr. A.K. Singh	----------------------------
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CERTIFICATE – II

This is to certify that the thesis entitled **"A STUDY ON THE BIOMASS AND CARBON STORAGE IN AN AGE SERIES OF TEAK PLANTATION IN TROPICAL ENVIRONMENT"** submitted by **KULESHWAR PRASAD** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur in partial fulfilment of the requirement for the degree of M.Sc. in the Department of Forestry has been approved by external examiner and Student's Advisory Committee after oral examination.

25/09/12

Date. : **EXTERNAL EXAMINER**

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Dean Faculty ________________

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ACKNOWLEDGEMENT

*First of all, I would like to thank and praise almighty "**GOD**" the most beneficent and merciful, for all his love and blessings conferred upon mankind.*

*In the inner core of my heart, I feel great pleasure in expressing my deep sense of gratitude to **Dr. Lalji Singh**, Associate Professor, Department of Forestry and Chairman of my Advisory Committee for his valuable guidance, constant encouragement and constructive criticism throughout the tenure of this investigations and preparation of the manuscript.*

I would like to express my sincere regards and heart felt gratitude to the members of my advisory committee, Dr. S. L. Swamy, Associate Professor, Department of Forestry, Dr. A. K. Singh, Professor and Head, Department of Agricultural Statistics and Social Science (L.), Dr. K. Tedia, Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Raipur for their valuable advises and suggestions for improving this manuscript. Without their kind co-operation it would have not been easy for me to complete this manuscript.

I am highly obliged to teaching staffs of Department of Forestry, Dr. M. N. Naugraiya, Senior Scientist, Miss. V. L. Kog, Assistant Professor for their kind cooperation, suggestions and help rendered during course of this investigation.

With deep and heartfelt respect, I extend my appreciation to Dr. S.K. Patil, Hon'ble Vice Chancellor, Dr. O. P. Kashyap, Dean and Head of Forestry Deparment, College of Agriculture, V.S.Trimurthi, Director Research Services, Dr J.S. Urkurkar, Director Extension Services, Dr. R.B.S. Sengar, Dean Student Welfare and Dr. S.S. Kolhe, Director of Instructions, I.G.K.V., Raipur for providing me the necessary facilities for Research.

I also owe my grateful thanks to all those unmentioned teachers from my schooling life till now who directly or indirectly helped me to reach up to this level.

My cordial thanks goes to my senior, classmates and juniors, Dr. Lekha Ghosh, Mr. V.S. Singh, Mr. Jayant Kasture, Dr. Dhiraj Yadav, Dr. Sajiwan Kumar, Mr. Pratap Rathiya, Smt. Shilpa Chandrawanshi, Mr. Prabhat Ranjan Oraon, Mr. Rajesh A. Alone, Mr. Shailesh Harne, Mr. Manoj Jhariya, Mr. Bhimappa Kittur, Mr. Chaman Negi, Mr. Jitendra Sonkar, Mr. Kedar Yadav, Mr. Khilesh Dindekar, Mr. Ravish sahu, Mr. Manish Dixena, Mr. Thaneshwar, Mr. Mahendra Kaushik, Mr. Khilendra, Mr. Amit, Mr. Ajit, Mr. Pandu, Mr. Malyaj, Mr. Jivraj, Mr. Harish Netam, Mr. Sujeet, Mr. Devendra Pal, Mr. Umesh Paikra, Miss Geeta, Miss Varsha, Bhupendra, Giriraj, Murat, Sarju and Satendra.

*From the core of my heart I express my heartful gratitude to my father Shri **R. K. Sahu** and mother Smt. **Chandrika sahu,** My brother **Yuvraj**, and sisters **Shakun** and other relatives and friends whose filial affection, encouragement, obstinate sacrifice, sincere prayer and love have always been the most vital source of inspiration and raising me to the present position. They have always been beckon of light to me in my endeavor.*

My heartfelt thanks goes to my dearest friends Hareesh, Dhanajay, Tumendra, Lokeshwar, Vinit, Sajal, Bhisham, Yogesh and Tejram whose good wishes, kind co-operation, endless encouragement, affection and blind support has helped me to fulfill my dreams.

Lastly thanks to each and every person soliciting his or her moral wishes for my future.

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LIST OF ABBREVIATIONS

Abbreviations	Description
%	Percent
&	And
<	Less than
=	Equal to
>	More than
≤	Less than equal to
≥	Greater than equal to
^{o}C	Degree centigrade
AGB	Above ground biomass
AGBD	Above ground biomass density
C.G.	Chhattisgarh
CBH	Circumference at breast height
cm	Centimeter
cm^2	Centimeter square
DBH	Diameter at breast height
et al	And others/co-workers
Fig.	Figure
FSI	Forest Survey of India
GBH	Girth at breast height
GIS	Geographical Information System
GOI	Government of India
ha	Hectare
ha^{-1}	Per hectare
i.e.	That is
Ind	Individual
IVI	Importance Value Index
Kg/tree	Kilogram per tree

Abbreviations	Description
Kg ha^{-1}	Kilogram per hectare
Km	Kilometer
m	Meter
m^2	Meter square
MAB	Man and biosphere
Mg	Mega gram = 10^6 gram
Mg ha^{-1}	Mega gram per hectare
Mg $ha^{-1}yr^{-1}$	Mega gram per hectare per year
MoEF	Ministry of Environment and Forest
NE	North East
NPP	Net Primary Productivity
R.B.A.	Relative basal area
R.D.	Relative density
R.F.	Relative frequency
TAGB	Total above ground biomass
TDF	Tropical deciduous forest
t ha^{-1}	Tons per hectare
t $ha^{-1}yr^{-1}$	Tons per hectare per year
UNEP	United Nation Environment Programme
viz.	Namely

LIST OF PLATES

INTRODUCTION

CHAPTER - I

INTRODUCTION

The tropical forests spread over 1376 m ha area worldwide account for 60 % of the global forests (FAO, 2005) and play an important role in global carbon cycle both in terms of carbon flux and the volume of carbon storage. Tropical forests in India cover 56.60 m ha of total geographical area of the country which comes out to be 81.96 % of the actual forest covers of which nearly one third (33.92%) falls in the tropical moist deciduous type and 30.16% falls under dry deciduous forest (FSI, 2009). Tropical forests often referred to as one of the most species diverse ecosystems (Kumar *et al.,* 2006) and most used and threatened ecosystems, especially in India (Shankar, 2001) which contributes around 69% of earth's biological productivity, due to the high rate of carbon and nutrient turnover in soil.

Tropical deciduous forests occur under varied climatic conditions, but essentially with alternate wet and dry period. However, the structure, composition and functioning of deciduous forests undergo changes with the length of wet period, amount of rainfall, latitude, longitude and altitude (Shankar, 2001) and impacts of human and livestock activities. Tropical forests harbour the greatest wealth of biological and genetic diversity on the earth. These biodiversity rich forests have world attention because of the growing awareness of its importance on the one hand and the anticipated massive depletion on the other (Singh, 2002).

Tropical forests are disappearing at alarming rate of 0.8-2.0% per year (May and Stumpf, 2000) due to extraction of timber and other forest produce (Raghubanshi and Tripathi, 2009) and it is argued that continuing biomass extraction activities may thwart the very goal of biodiversity conservation (Schaik *et al.,* 1997). In India, habitat destruction, overexploitation, pollution and species introduction are identified as a major cause of diversity loss (UNEP, 2001).

Tropical forest is one of the richest and complex terrestrial ecosystems, approximately 50% of the world living terrestrial carbon sinks. Tropical forest i.e., moist and dry forest accounts for approximately 60% of global forests (Sharma *et al*., 1992). According to the Holdridge system of life zone classification, dry tropical and sub-tropical forests and woodlands occur in frost free areas where the mean annual biotemperature is higher than 17^0C, mean annual rainfall is 250-2000 mm and the annual ratio of potential evapotranspiration (PET) to precipitation (P) exceeds unity. About 40% of the earth's tropical and subtropical land mass is dominated by open or close forest. Of this, 42% is dry forests, 33% is moist forest and only 25% are wet and rain forest (Holdridge, 1967**).**

Biodiversity is important for human survival and economic well-being and for the function and stability of ecosystem (Singh, 2002). Prior to forest management operations, biodiversity are used to determine the nature and distribution resources of the region being managed. Such diversity inventories are integrated with the timber resources inventories in order that forest management operations can be planned (Rennolls and Laumonier, 2000). In these inventories, quantification of tree species diversity is an important aspect as it provides resources and habitat for many species (Cannon *et al*., 1998). Being a dominant life form, trees are easy to locate precisely and count (Condit *et al*., 1996) and are also relatively better known, taxonomically (Gentry, 1992).

Interest in the role of vegetation in the ecosystem includes dynamic aspects, such as the accumulation and distribution of organic matter, as well as the cycling of minerals and water, and the flow of energy. Biomass quantification is central to all such studies and it is generally defined as the dry weight of organic matter present in a given area of the ecosystem at a particular time. The need to study and monitor the net primary productivity (i.e., the rate of biomass accrual) of different world ecosystems necessitated the establishment, in 1964, of the International Biological Programme (IBP). According to Reichel (1970), one of the objectives of the IBP was to understand, through research and synthesis, the biological basis of productivity and human welfare.

Teak (*Tectona grandis* Linn. f.) belongs to the family verbenaceae, is predominatly tropical or sub-tropical in distribution. The genus *Tectona* and its species *grandis* were first name by Swedish botanist, C. Linnaeus in the year 1781. The genus *Tectona* is represented world over by three species only, namly *Tectona grandis* Linn. f., *Tectona hamilttoniana* Wall. and *Tectona philippinensis* Benth and Hooker. f. In India only *Tectona grandis* is widely distributed. The country has maximum genetic variability of teak with distribution over 8.9 million hectare area.

Teak occurs naturally in parts of India, Myanmar, Lao PDR and Thailand and it is naturalised in Java, where it was probably introduced some 400-600 years ago (Kadambi 1972; White 1991). It has been widely established in plantations as an exotic species for producing high quality poles and timber outside the countries of its natural distribution. Early introductions of teak outside Asia were made in Nigeria, where the first introductions were of Indian origin in 1902 (Horne, 1966) and subsequently were of Burmese origin. Teak planting in what is now eastern Ghana started around 1905

(Kadambi, 1972) and a small plantation of teak was established in the Ivory Coast in 1929 from (plantation) seeds obtained from then Togoland. Teak was introduced to countries of Tropical Africa to supplement local timber supplies because of its excellent timber properties.

Teak is one of the most important and valuable timber species of the world. It has worldwide reputation as paragon among timber trees. It occurs naturally in South and South-East Asia. In 1844 the first successful plantation was raised in Nilambur (Kerala). Teak is a strong light demander and can not withstand in waterloggoing conditions. It thrives best within annual rainfall of 1000-1500 mm. It is gregarious in natural forest and grows up to 1200 m in Western Ghats. Teak wood is moderately hard, extremely durable and is the most important timber of India. The timber is extensively used for bridges, ribs, cabinet work, beams, railway carriages, decorating paneling, carving, ordinance work, general carpentry and ship building.

Fast-growing and high-yielding tree plantations are an increasingly significant source of wood in the tropics. In these areas, improved wood productivity is an important economic goal. *Tectona grandis* has gained a worldwide reputation on account of the attractiveness and durability of its wood. Market demands have prompted the establishment of plantations within and beyond its native countries (Monteuuis and Goh, 1999; Bhat, 2000).

Forests are natural storehouses of biomass and carbon (C). They sequester and store more C than any other terrestrial ecosystem and are an important natural ‘brake’ on climate change. Forests fix, store and emit C by photosynthesis, respiration, decomposition and disturbances through a series of stages in the life cycle from regeneration to harvest. Forest vegetation represents a major pool in the global C cycle and alone contains over 350,000 Tg C.

Biomass constitutes a primary data needed for understanding a number of ecological processes like energy flow, water and nutrient cycling in forest ecosystems (Chaturvedi and Singh, 1987; Tiwari, 1994). The different tree components (branches, roots, twigs and boles) are economically utilized for firewood, particleboard, composite boards, fodder, medicines and many commercial products. Therefore, quantification of total biomass is important as different components play a vital role in structural and functional process of ecosystems.

On the other hand, the estimation of woody biomass is also necessary for determining the status and flux of biological materials in an ecosystem (Anderson, 1970). The quantity of tree biomass per unit land area forms the primary data needed to understand the flow of materials and water through forest ecosystems (Swank and Schreuder, 1974).

In recent time, there has been increasing interest in the quantification of the biomass of forest ecosystems and its potential C fixation. Live tree biomass pool is an important source of uncertainty in C balance from the tropical regions in part due to scarcity of reliable estimates of tree biomass and its variation across landscapes and forest types. It plays an important role in the global C cycle, accounting for a significant fraction of the total C pool and nutrient stocks.

Knowledge of biomass C densities for different forest types is one of the important components for assessing the contribution of forest lands to the global C cycle. A functional relationship between diversity and C storage and sequestration could have important implications for the management of C-sink, not only for reforestation and afforestation-type projects, which are currently supported under international agreements such as the clean development mechanism (CDM) under the Kyoto Protocol, but also for emission reduction projects that focus on forest conservation and management.

Extensive research has already been completed calculating biomass and carbon storage of forests within specific regional parameters. The difference between fixation and loss over an established period of time is used to estimate biomass and carbon stocks among and within large regions (Schroeder *et al*., 1997; Brown and Schroeder, 1999; Mickler *et al.*, 2002; Jenkins *et al.*, 2001).

Forests represent an important carbon store, containing an estimated 638 Gt C (1 Gt =1 billion tonnes) in their ecosystem as a whole, with 283 Gt C in biomass alone (FAO, 2005). Consequently, changes in the forest carbon store have an impact on global climate change. Even potentially small increases in carbon sequestration in forest biomass and soil may help buffer the impact of anthropogenic carbon dioxide (CO_2) emissions, regulating the rate of climate change (Jastrow *et al.*, 2005). Whether or not forests will be able to continue to sequester additional carbon is a key concern as atmospheric CO_2 concentrations continue to rise.

One of the major issues of global carbon concern today is rapidly increasing level of CO_2 (@ 2 ppm yr^{-1}) in the atmosphere and its potential to change the world climate. Elevated levels of CO_2 and other green house gases in the atmosphere have increased global average surface temperature by 0.6 $\pm$ 0.2^0C (IPCC, 1999). The rising CO_2 levels have severe implications on the functioning of physical and biological systems of the world. In order to mitigate this problem, IPCC (1996) have advocated for an increase in the size of the C pool through massive afforestation and reforestation besides maintaining the existing C pools in terrestrial ecosystem. During the last few decades, the rapid land use and land cover change has resulted in large scale carbon degradation in tropical ecosystem. Therefore, suitable land use system that enhances carbon storage is essential for maintaining the carbon balance in the region.

In view of this the present study entitled **"A Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment"** was undertaken with the following major objectives:-

- To study the biomass pattern in age series of teak plantation.
- To study the carbon storage pattern in age series of teak plantation.
- Comparing the biomass and carbon storage potential with natural forests as well as plantations.

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

In this chapter an attempt has been made to review the work done on **"A Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment"**

However, due to paucity of literature on few aspects, the similar types of studies carried in other forest ecosystems are also cited. The literature is broadly reviewed under the following major aspects.

2.1 Biomass pattern

2.2 Carbon storage pattern

2.3 Soil and nutrient

2.1 Biomass pattern

Biomass constitutes a primary data needed for understanding a number of ecological processes like energy flow, water and nutrient cycling in forest ecosystems (Chaturvedi and Singh, 1987; Tiwari, 1994). On the other hand, the estimation of woody biomass is also necessary for determining the storage and flux of biological materials in an ecosystem (Anderson, 1970). The quantity of tree biomass per unit land area forms the primary data needed to understand the flow of materials and water through forest ecosystems (Swank and Schreuder, 1974).

The biomass estimations in forests are conventionally made by the use of species specific allometric equations and component wise viz., stem, branch, foliage and root biomass are estimated in both tree and shrub layer (Misra, 1968; Odum, 1983; Rai, 1984).

In this approach, the availability of species-specific local regression equations is essential for precisely estimating the forest biomass.

Barbhuiya *et al. (*2012) estimated the fine root dynamics in undisturbed and disturbed stands of a tropical wet evergreen forest in northeast India. In the highly disturbed stand, more than 90% of the fine root biomass was recorded in the surface soil layer, whereas in the moderately disturbed and undisturbed stands the proportion averaged 67%. In the undisturbed stand, higher concentrations of fine roots in the surface soil layer were associated with higher nutrient concentrations and moisture retention in the undisturbed stand. Root turnover also decreased with increasing soil depth, root size and intensity of stand disturbance. In the undisturbed, moderately disturbed and highly disturbed stands the annual fine-root turnover was 3181, 1701 and 822 kg ha^{-1} yr^{-1}, respectively. The study revealed that growth and accumulation of fine roots varied with species composition, tree density and basal area.

Cairns *et al. (*2003) estimated the aboveground tree biomass of a dry semi-evergreen forest of Mexico's Yucatan Peninsula and stated that a total of 72 species were found in a 0.5 ha stand with a basal area of 31.3 m^2 ha^{-1} constituting about 225 Mg ha^{-1} of total aboveground tree biomass which was dominated (85%) by the biomass of the large trees.

Cordero and Kanninen (2003) studied aboveground biomass of *Tectona grandis* plantations in Costa Rica. This paper reports the distribution of total aboveground biomass *of Tectona grandis* and its relationship with diameter at breast height (dbh), age and stand density in plantations across Costa Rica. Foliage, branch, stem and total aboveground biomass were highly correlated both with dbh ($r > 0.91$) and with age (r >

0.85). Foliage dry biomass represented between 1 and 6% of the total tree dry biomass, while 5 to 30% corresponded to branches and 70 to 90% to stem dry weight. Per hectare aboveground biomass tended to increase with increasing age class (young, intermediate and mature). Significant relations between crown diameter and aboveground biomass with dbh, age and stand density, useful for the management of stand competition, are the main results of this study.

Konopka (2009) studied the differences in fine root traits between Norway spruce (*Picea abies* [L.] Karst.) and European beech (*Fagus sylvatica* L.) Sequential soil coring was repeatedly implemented in April, June, July, September and October including the soil layers of 0–5, 5–15, 15–25 and 25–35 cm. Spruce had a lower standing stock of fine roots than beech and fine roots of spruce were more superficially distributed than those of beech. Furthermore, he estimated higher seasonal dynamics and also higher turnover of fine roots in spruce than in beech. The production to mortality ratio was higher in beech than in spruce, which was hypothetically explained as the effect of drought episodes that occurred in July and August. The results suggested that the beech root system could resist a physiological stress better than that of spruce. This conclusion was supported by different vertical distributions of fine roots in spruce and beech stands.

Kumar *et al.* (2011) studied the biomass and net primary productivity of different age grouped (5, 10 and 15 year old) *Butea monosperma* forest ecosystems in western India, Rajasthan. The vegetation biomass, forest floor, litter fall and net primary productivity (NPP) of trees and shrubs were estimated and it was found that the tree biomass and net primary productivity increased with increasing age of the forest stand, whereas the herb biomass and net primary productivity decreased significantly ($P < 0.01$)

with increase in the forest age. The biomass of trees increased with age from 183.7 to 298.3 t ha^{-1} while shrub biomass ranged from 4.9 to 6.3 t ha^{-1} and the herb biomass fluctuated from 1.7 to 2.1. The tree layer NPP varied from 17.2 to 29.3 t ha^{-1} yr^{-1} where the NPP of the shrub layer was 0.88 to 1.6 t ha^{-1} yr^{-1}. The productivity of the herb layer ranged from 2.3 to 3.1 t ha^{-1} yr^{-1}. The all values of biomass and NPP of trees, shrubs and herbs were low in 5 year old, moderate in 10 year old and high in 15 year old forest stands. The total forest biomass increased from 190.7 t ha^{-1} in the 5 year old to 306.3 t ha^{-1} 15 year old forest and net primary productivity from 21.1 t ha^{-1} yr^{-1} in the 5 year old to 33.2 t ha^{-1} yr^{-1} in the 15 year old forest.

Kumar *et al.* (2009) studied the quantification of nutrient content in the aboveground biomass of teak plantation in a tropical dry deciduous forest of Udaipur, India. The nutrient contents in the total biomass of teak in the plantation were 165.47 kg/ha N, 20.96 kg/ha P, 35.06 kg/ha K, 49.29 kg/ha Ca, 31.52 kg/ha Mg, 4.27 kg/ha Na, 4.06 kg/ha S and 3.21 kg/ha Cl of the total, 42.93% of the dry matter accounted for crown biomass (leaves, branches, twigs and reproductive parts), which in turn accounts for 60.93% N, 58.63% P, 54.30% K, 51.40% Ca, 62.5% Mg, 53.62% Na, 59.85% S and 60.74% Cl of the aboveground biomass, whereas 57.07% of the dry matter account for trunk biomass (bole bark and bole wood), which in turn accounts for 39.07% N, 41.37% P, 45.70% K, 48.6% Ca, 37.5% Mg, 46.38% Na, 40.15% S and 39.26% Cl.

Lodhiyal *et al.* (1995) studied the dry matter dynamics of an age series of poplar plantations in Central Himalaya. The biomass of plantation, forest floor litter mass, tree litter fall and net primary productivity (NPP) of trees and shrubs increased with increase in plantation age, whereas herb biomass and NPP significantly ($P < 0.01$) decreased with increasing plantation age. The total plantation biomass increased from 84.0 t ha^{-1} in the 5-year-old to 170.0 t ha^{-1} in the 8-year-old plantation and NPP from 16.8 t ha^{-1} yr^{-1} in the 5 and 6-year-old to 21.8 t ha^{-1} yr^{-1} in the 8-year-old plantation. The biomass accumulation ratio (biomass: net production, BAR) for different tree components increased with the increased age of plantation.

Mbaekwe and Mackenzie (2008) studied the use of a best-fit allometric model to estimate aboveground biomass accumulation and distribution in an age series of teak (*Tectona grandis* L.f.) plantations at Gambari Forest Reserve, Oyo State, Nigeria. Biomass accumulation and distribution in four selected plots of an age series (5, 8, 11 and 14 years) of teak plantations were studied. Ten trees per plot (50 m × 50 m) were randomly selected and destructively sampled for the fresh and oven-dry weights of their tree components. The dry weights of the tree components were regressed with their trunk diameters at breast height. The log: log allometric model was used to estimate the biomass. The trends in the biomass accumulation and distribution, as well as those of the mean annual increase in biomass, percentage contribution of the leaf biomass to the overall tree biomass and the undergrowth and litter were discussed. Because of its rapid rate of biomass accumulation compared to species of natural and other timber plantations, the use of teak as an alternative source of timber is justified.

Murali *et al.* (2005) derived biomass estimation equation for tropical deciduous and evergreen forests and developed linear and non–linear regression equations for estimation of biomass of tropical forests along with estimates of goodness of fit and percentage of errors. Basal area and height of trees were found to give high goodness of fit and low percentage of errors for deciduous forests. They found that generally the coefficient of determination (r^2) was low for evergreen forests. The coefficient of determination was high and estimate of error was low for deciduous forests. They concluded that the biomass estimation equations for deciduous forests were precise and therefore useful for field applications.

Nascimento and Laurance (2002) studied the total above ground biomass in central Amazonian rain forests and quantified total above ground dry biomass (TAGB) within 201 ha plots in undisturbed site. TAGB values were very high averaging 397.7 $\pm$ 30.0 t ha^{-1}. The most important component of above ground biomass were large trees (< or $\geq$ 10 cm dbh) which comprised 81.9% of TAGB followed by downed wood debris (7.0%), small trees, saplings and seedlings (< 10 cm dbh; 5.3%), lianas (2.1%), litter (1.9%), snags (1.5%), and stemless palms (0.3%). Among large trees above ground biomass was greatest in intermediate sized (20-50 cm DBH) stems (46.7% of TAGB), with very large (< or $\geq$ 60 cm DBH) trees also containing substantial biomass (13.4% of TAGB). They also found that there were no significant correlations between large tree biomass and that of any other live or dead biomass components.

Prasad *et al.* (2002) studied the biomass burning and related trace gas emission from tropical dry deciduous forests of India. The dominant vegetation type of the study area is tropical dry deciduous along with moist mixed evergreen. Two ground based experiments were carried out to quantify the emission burning practices. Using the DMSP-OLS derived aerial estimates of active fires; the trace gas emissions released from the biomass burning were quantified. The results suggested the emission of 8.2×10^{10} g CO_2, 1.8×10^8 g CO, 6.0×10^6 g N_2O, 3.0×10^6 g NOx and 1.2×10^8 g CH_4 during March 1987. The emissions increased to 1.0×10^{11} g CO_2, 2.3×10^8 g CO, 7.8×10^6 g N_2O, 3.9×10^7

g NOx and 1.6x10^8 g CH_4 over a period of 10 years. The results of the analysis suggest the possible use of monitoring biomass burning events from DMSP-OLS night-time data.

Raizada *et al.* (2007) estimated the biomass production and prediction models for *Acacia nilotica* in salt affected vertisols in Karnataka and they observed that although the plantation is even-aged, there were wide variations in diameter (3.1 to 16 cm) in the entire block and 9.3 to 15.4 cm in the sampled trees. Tree height also varies from 3.5 to 5.1 m, which in turn has influenced above ground biomass. Utilizable biomass (bole + bark + leaf) for firewood ranged from 18.3 to 72.64 kg/tree and total above ground biomass ranged from 26.50 to 100.74 kg/ tree.

Read and Lawrence (2008) stated that the above ground biomass of Calakmul tropical forest ecosystem was 136.42 Mg ha^{-1} in their study recovery of biomass following shifting cultivation in dry tropical forests of the Yucatan, Mexico.

Sharma *et al.* (2002) studied the biomass, net primary productivity, energetics and energy efficiencies in an age series of *Alnus*-cardamom plantations in the eastern Sikkim Himalaya. The impact of stand age (5, 10, 15, 20, 30 and 40 years) on the performance of mixtures of N_2-fixing (*Alnus nepalensis*) and non-N_2-fixing (large cardamom) plants was studied. Large cardamom (*Amomum subulatum*) is the most important perennial cash crop in the region and is cultivated predominantly under *Alnus* trees. Net primary productivity was lowest (7 t ha^{-1} per year) in the 40-year-old stand and was more than three times higher (22 t ha^{-1} per year) in the 15-year-old stand. Agronomic yield of large cardamom peaked between 15 and 20 years of age. Cardamom productivity doubled from the 5 to the 15-year-old stand, and then decreased with plantation age to reach a minimum in the 40-year-old stand. Annual net energy fixation was highest (444 x 10^6 kJ

ha^{-1} per year) in the 15-year-old stand, being 1.4 times that of the 5-year-old stand and 2.9-times that of the 40-year-old stand. Inverse relationships of production efficiency, energy conversion efficiency and energy utilized in N_2-fixation against stand age and a positive relationship between production efficiency and energy conversion efficiency suggest that the younger plantations are more productive.

Singh *et al.* (2009) studied the impact of land use changes on species structure, biomass and carbon storage in tropical deciduous forest and converted forest. They found that the total biomass recorded among the different forest plots was 192.933 Mg ha^{-1} in natural forest followed by 95.64 Mg ha^{-1} in 32 years old converted forest, 85.78 Mg ha^{-1} in 23 years old converted forest and 92.05 Mg ha^{-1} in 15 years old converted forest. The total above ground biomass in different forest plots ranged from 71.94 to 162.91 Mg ha^{-1} with highest in natural forest and lowest in 23 years old converted forest. The below ground biomass varied from 13.97 to 30.02 Mg ha^{-1} with the highest in natural forest and lowest in 23 years old converted forest. Carbon storage was also maximum in natural forest (96.44 Mg ha^{-1}) followed by 32 years old converted forest (47.801 Mg ha^{-1}), 15 years old converted forest (46.25 Mg ha^{-1}) and 23 years old converted forest (42.88 Mg ha^{-1}).

Singh *et al.* (2004) studied biomass and productivity of an age series of three cottonwood clones (*Populus deltoides*) in central Himalayan tarai region, India. Estimates of biomass and net primary productivity of three clones of *Populus deltoides*, namely, IC, D-121 and G-3. Each of the three clones had one young (four years old), one middle age (six years old) and one mature (8 to 10 years) stand. Highest basal area (22.8-24.1 m^2ha^{-1}) was attained by mature stands. Total tree biomass in investigated clones increased from young (32-42 t ha^{-1}) to mature stands (120-170 t ha^{-1}), the lowest and highest biomass being in IC and G-3 clones, respectively. Net primary productivity also revealed similar pattern. At maturity, net productivity was in the order: D-121 (23 t ha^{-1} $year^{-1}$) > G-3 (21 t ha^{-1} $year^{-1}$) > IC (14 t ha^{-1} $year^{-1}$). The ratio of stem to leaf production generally decreased with age from around 2.0 in young stands (D-121 and G-3 clones) to less than 1.0 mature stands. The relationship between biomass and net primary production was very weak.

Swamy *et al.* (2010) studied the biomass, litterfall and net primary productivity (NPP) of tropical evergreen forests of Western Ghats, India and concluded that total stand biomass averaged from 440 to 571 mg ha^{-1}, of which trees contributed 90.2-92.2 % and remaining 8.8-9.8 % contributed by shrubs and herbs. The standing litter ranged from 3.5 to 4.2 Mg ha^{-1} and litter production from 4.0 to 5.7 Mg ha^{-1} yr^{-1}.The average NPP was 23.7 Mg ha^{-1} yr^{-1}, of which 64.7% was contributed by trees, 13.6% by shrubs, 2.7% herbs and 19.1% by litter, Turnover rate and turnover time ranged from 0.93 to 0.95 yr^{-1} and 1.05 to 1.08 yrs, respectively.

Tyagi *et al.* (2009) studied the biomass and productivity in 3, 6 and 9 years old plantation of *Dalbergia sissoo* in sodic lands of Sultanpur district in eastern Utter Pradesh, India. A set of regression equations for biomass production per unit area was also developed to be applied on the regional basis. All the standing trees, in the study area, were measured for their diameter at breast height (DBH) and the entire DBH range was highest in leaves, followed by bark and bole. Major portion of above ground biomass was contributed by bole and the remaining was shared by leaves, twigs, branches and bark. The contribution of leaves, bark and bole to the above ground biomass increased with the increase in age, while twigs and branches showed a reverse trend. Biomass production was positively correlated with age, DBH and height of the trees and the total biomass increased from 388.52 kg/ha in 3 years to 5, 0927.13 kg/ha in 9 years old plantation. In order to predict biomass of the stand on a regional basis, a set of regression equations was derived between easily measurable parameters (DBH and height) and dry weight of different sample tree components (leaves, twigs, branches, bole bark total above ground biomass, root and total biomass).

Upadhyay *et al.* (2009) analyzed that effect of disturbance on standing biomass in a sal mixed forest of Eastern U.P. Three sites selected on the basis of disturbance gradient showed sequential differences in standing biomass. The total biomass of the three forest sites differs significantly from severely disturbed site I to relatively undisturbed site III of which 83% was allocated to above ground parts and 17% to below ground. The understorey contributed about 32% (172 t ha^{-1}) and overstorey layer constituted about 68% (372 t ha^{-1}) to the total biomass.

2.2 Carbon storage pattern

Derwisch *et al.* (2009) studied the estimation and economic evaluation of aboveground carbon storage of *Tectona grandis* plantations in Western Panama. The objectives of study were to measure the carbon (C) storage potential of 1, 2 and 10-years old *Tectona grandis* plantations in the province of Chiriquí, Western Panama and to calculate the monetary value of aboveground C storage if sold as Certified Emission Reduction (CER) carbon credits. The average aboveground C storage ranged from 2.9 Mg C ha^{-1} in the 1-year-old plantations to 40.7 Mg C ha^{-1} in the 10-year-old plantations. Using regression analysis they estimated the potential aboveground C storage of the teak plantation over a 20 year rotation period. The CO_2-storage over this period amounted to

191.1 Mg CO_2 ha^{-1}. The discounted revenues that could be obtained by issuance of carbon credits during a 20 year rotation period were about US $ 460 for temporary CER and US $ 560 for long-term CER, and thus, contribute to a minor extent (1%) to overall revenues, only.

Fonseca *et al.* (2011) studied the carbon accumulation in aboveground and belowground biomass and soil of different age native forest plantations in the humid tropical lowlands of Costa Rica. Carbon fraction in the biomass, mean (± standard deviation), for the different pools varied between 38.5 and 49.7%. Accumulated carbon in the biomass increased with the plantation age, with mean annual increments of 7.1 and 5.3 Mg ha^{-1} $year^{-1}$ for forest plantations of *V. guatemalensis* and *H. alchorneoides*, respectively. At all ages, 66.3% of total biomass was found within the aboveground tree components, while 18.6% was found in structural roots. The soil (0–30 cm) contained 62.2 and 71.5% of the total carbon (biomass plus soil) under *V. guatemalensis* and *H. alchorneoides*, respectively. Mean annual increment for carbon in the soil was 1.7 and 1.3 Mg ha^{-1} $year^{-1}$ in *V. guatemalensis* and *H. alchorneoides*. Allometric equations were constructed to estimate total biomass and carbon in the biomass which had an R^2aj (adjusted R square) greater than 94.5%.

Huifeng and Wage (2008) estimated the changes in forest biomass carbon storage in the South Carolina (SC) Piedmont between 1936 and 2005. They observed that since 1936, the SC Piedmont forests have accumulated 81.84 Tg C due to forest expansion and regrowth, increasing from 57.36 Tg C in 1936 to 139.20 Tg C in 2005. They found that the hardwood and softwood forests accounted for 74% (60.45 Tg C) of carbon accumulations during this period, respectively. It was found that the above ground forest biomass carbon pool represented 80% or 65.17 Tg C of the total carbon accumulation while the below ground fine and coarse roots only accounted for 20% or 16.67 Tg C . It was found that from 1936 through 2005 , forest carbon accumulated at a rate of 1.19 Tg C yr^{-1} , offsetting 5.7 % of CO_2 emission (20.94 Tg C in 2003) of the entire state of South Carolina.

Kaul *et al.* (2010) reported the C storage and sequestration potential of carbon of selected tree species in India. The results indicate that long-term total carbon storage ranges from 101 to 156 Mg C ha^{-1}, with the largest carbon stock in the living biomass of long rotation sal forests (82 Mg C ha^{-1}). The net annual carbon sequestration rates were achieved for fast growing short rotation poplar (8 Mg C $ha^{-1}yr^{-1}$) and Eucalyptus (6 Mg C $ha^{-1}yr^{-1}$) plantations followed by moderate growing teak forests (2 Mg C $ha^{-1}yr^{-1}$) and slow growing long rotation sal forests (1 Mg C $ha^{-1}yr^{-1}$). The carbon stock in soil and products was less sensitive than carbon stock of trees to the change in rotation length. Extending rotation length from the recommended 120 to 150 years increased the average carbon stock of forest ecosystem (trees + soil) by 12%. The net primary productivity was highest (3.7 Mg $ha^{-1}yr^{-1}$) when a 60-year rotation length was applied but decreased with increasing rotation length (e.g., 1.7 Mg $ha^{-1}yr^{-1}$) at 150 years.

Kraenzel *et al.* (2003) measured above and belowground biomass and tissue carbon content of 20-year-old teak trees in four Panamanian plantations to estimate carbon storage potential-level tree carbon storage, which averaged 102 t ha^{-1}. Litter, underground and soil compartment were estimated to accumulation. The estimate of carbon storage in Panamanian harvest-age teak plantations to be 351 t C ha^{-1}. They concluded that teak plantations have appreciable mean carbon storage capacity, much greater than that of the abandoned pasture they were planted on. The compartment of the plantation with the greatest potential for carbon sequestration and carbon storage is the wood biomass (120 t C ha^{-1}).

Miegroet *et al.* (2007) reported that the forest contained on average 403 Mg C ha^{-1} almost half of which stored belowground for a high-elevation red spruce-Fraser fir forest [Picea rubens Sarg./Abies fraseri (Pursh.) poir] in the great smoky Mountains National Parks. Live trees, predominantly spruce, represented a large but highly variable C pool (mean 126 Mg C ha^{-1}, CV = 39%), while dead wood (61 Mg C ha^{-1}), mostly fir, accounted for as much as 15 % of the total ecosystem C. The 10- year mean C sequestration in the living trees was 2700 kg C ha^{-1} $year^{-1,}$ but increased from 2180 kg C ha^{-1} $year^{-1}$ in 1993 – 1998 to 3110 kg C ha^{-1} year $^{-1}$ in 1998 – 2003, especially at higher elevations. Dead wood also increased during that period, releasing on average 1600 kg C ha^{-1} $year^{-1}$. Estimated net soil C efflux ranged between 1000 and 1450 kg C ha^{-1} $year^{-1}$ depending on the calculation of total belowground C allocation. Based on current flux estimated, they concluded that this old-growth system was close to C neutral.

Petsri *et al.* (2007) estimated the aboveground carbon content in mixed deciduous forest and teak plantations. The aboveground carbon content was likely to increase according to age. That is to say, the aboveground carbon content found in the teak plantation trees aged 6, 10, 15, and 23 and 24 years old and in the mixed deciduous forest was 39.51, 40.82, 33.87, 55.23, 41.13 and 71.60 t ha^{-1}, respectively. Furthermore, the density of stands was positively relative to the aboveground carbon content. Namely, the greater the density of tree stands, the greater the aboveground carbon content.

Potvin *et al.* (2004) estimated a case study of carbon pools under three different land-uses in PANAMA. Analysed soil profiles in a grazed pasture and an adjacent 5-year-old teak (*Tectona grandis*) plantation. There were small differences in soil C mass in the top 10 cm of the pasture and the plantation, though analysis of paired profiles suggested larger differences at greater depth. Analysis of the $\delta^{13}C$ signatures in the pasture soils and litter showed that 90% to 95% of the organic matter in the surface 5 cm was derived from C_4 pasture plants, over the 45 years since the pasture was converted from forest. Comparison of the $\delta^{13}C$ signatures in the pasture and teak plantation profiles indicated substantial replacement of C_4 derived organic matter with the dominantly C_3 derived plantation tissues. Organic matter turnover times in the upper 10 cm of the soils ranged from 8 to 34 years and from 11 to 58 years in the upper 30 cm, depending on topographic location. The two ecosystems studied are estimated to be small CO_2 sinks, 92 g C m^{-2} yr^{-1} for the pasture, and 57 g C m^{-2} yr^{-1} for native species plantation in the first year after establishment. The pasture's response to seasonal change was more pronounced, both in term of CO_2 fluxes and in term of herbaceous productivity, than the plantation's response.

Raizada *et al.* (2003) estimated the C flux through litter fall (total and leaf litter fall alone) in forest plantations occurring in four major forest groups in India. Using published studies covering 82 stands and 24 species raised in plantations the annual C flux rates were computed. The C flux rates from leaf litter alone were highest (3.03 Mt C per year) in the montane sub-tropical forests. Results indicate that plantations of short rotation tree species with regular leaf shedding patterns have more C sequestering capacity than species with unimodal or bimodal leaf shedding patterns. Such species could be raised in wastelands for twin purposes biomass production and carbon sequestering.

Ramachandran *et al.* (2007) studied the carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. The total biomass, both above and below ground, was calculated and the total carbon stock was estimated. Likewise, the sequestered soil carbon was also estimated. The biomass carbon was 2.74 Tg and the soil carbon was 3.48 Tg. The lesser soil organic carbon indicates that the forest area is severely affected by degradation due to various need-based forestry practices and anthropogenic disturbances. The need for a carbon databank was addressed in the context of mitigating climatic changes. They suggested that a national-level carbon databank should be envisaged for all types of forest in India so as to study the temporal change and carbon sequestration potential for better management of forests in future.

Ramachandran *et al.* (2007) studied the carbon management in forest floor-an agenda of 21st century in Indian forestry scenario. Degradation of forests is very common in Indian scenario since 1901 to to-date. The reasons are removal of large scale timber species for railway sleepers, ship building charcoal for all kinds of transports, Kumri cultivation in the forest woodlands reforestation of softwoods and miscellaneous species , cattle grazing and human induced fire . The aforementioned problem of degradation led to loss of carbon stock in the standing biomass as well as in soil carbon pool. Such kind of huge loss of carbon pool both in standing biomass and soil had a breakdown in carbon cycle leading to climatic imbalance .

Srivastava and Singh (2007) studied the carbon sequestration and mitigation through conservation approach and they found that the recognition that reforestation and forestation, as well as combating deforestation can not only make a contribution to the local socioeconomic physical conditions and the climate , but the intrinsic part to take along with is preservation of biodiversity which also serves the purpose of acting as a carbon store.

Tangsinmankong *et al.* (2007) studied the carbon stocks in soil of mixed deciduous forest and teak plantation. Results revealed that soil organic carbon from all sites decreased generally with the increasing depth. From the surface soil down to the level of 100 cm. The highest carbon stocks in soil were recorded at the 6-year-old teak plantation followed by the 24 and 15-year-old teak plantations and mixed deciduous forest 157.03, 105.67, 78.78 and 70.96 t C ha^{-1}, respectively. The dissimilarity in soil organic carbon may be due to forest fire, forest management and topography.

Terakunpisut *et al.* (2007) studied the carbon sequestration potential in aboveground biomass of Thong Pha Phum National Forest, Thailand. Tropical rain forest (Ton Mai Yak station) had higher carbon stock than dry evergreen forest (KP 27 station) and mixed deciduous forest (Pong Phu Ron station) as 137.73 ± 48.07, 70.29 ± 7.38 and 48.14 ±16.72 tonne C ha^{-1}, respectively. Habitat variability caused differences of biomass accumulation, species composition and the allometric relationships of forests. In the study area, all forest had a similar pattern of tree size class, with a dominant size class at 4.5-20 cm. The 4.5-20 cm trees potentially provided a greater carbon sequestration in tropical rain forest and dry evergreen forest while the size of > 20- 40 cm gave potentially high carbon sequestration in mixed deciduous forest. Due to the trees have the lowest carbon sequestration but they considerably grow up to the further size classes. Apparently, they will be able to increase more biomass accumulation and store more carbon. They concluded that the greatest carbon sequestration potential is in mixed deciduous forest and followed by tropical rain forest and dry evergreen forest in Thong Pha Phum National Forest. Finally, the appropriate forest ecosystem management can be an alternative solution for carbon dioxide reduction in terms of carbon sink role.

2.3 Soil and nutrient

Kumar *et al.* (2010) studied the tree species diversity and soil nutrient status in three sites of tropical dry deciduous forest of western India. The tree stand density varied from 458-728 individuals ha^{-1} with the average basal area ranging from 5.96 - 19.31 m^2 ha^{-1}. Shannon-Weiner Index (H') ranged from 0.67 - 0.79. The Simpson Index of dominance varied from 0.08 - 0.16, the Margalef's Species Richness Index varied from 21.41 - 23.71, Equitability or evenness index varied from 0.02 - 0.05, the species heterogeneity index varied from 2.53 - 3.61 and β diversity varied from 2.05 - 4.87. Organic carbon ranged from 2.23 - 2.81 %, while concentration of nitrogen fluctuated from 0.16 - 0.21 %, and that of phosphorus varied from 0.021- 0.033 % in all three sites. The C: N ratio ranged from 10.61 - 20.06, whereas C: P ratio fluctuated between 97.9 and 106.2, and N: P ratio ranged from 4.8 -10.0.

Singh and Singh (2002) studied the changes in soil properties and foliage nutrient composition in different age classes of *eucalyptus camaldulensis* plantation. Height and diameter at breast height (dbh) of the stand ranged from 9.2 to 25.7 m and 9.4 to 21.5 cm respectively, depending on the age of the stand. Foliage nutrients were in order of Ca>N>K> Mg > P and differed considerably between different ages. Foliage N and P increased until Y12 and decreased afterwards. Soil organic matter and nitrogen (NH_4-N + NO_3-N) were significantly higher in the 0-15 cm layer compared with the 15-30 cm layer. Soil nutrients were significantly higher in the plantation area compared with the non-planted control plot. Soil pH, PO_4-P, Ca, Mg and K concentrations decreased with stand age whereas SOM, NH_4-N, NO_3-N, Cu, Zn and Mn increased. The study thus suggested that plantations require fertiliser application and/or thinning after 12 years to manage the problem of nutrient depletion.

Singh and Kashyap (2007) studied the variations in soil N-mineralization and nitrification in seasonally dry tropical forest and savanna ecosystems in Vindhyan region, India.The annual N-mineralization and nitrification rates were highest at Hathinala moist forest site having maximum moisture content, organic- C, N and water holding capacity of soil than other study sites. N-mineralization and nitrification rates differ significantly across the sites and seasons. These rates were significantly correlated with soil moisture and mineral-N contents. The result suggested that variations in rates of N-mineralization and nitrification in the dry tropical ecosystems are related to differences in soil moisture content, nutrient status and vegetational cover in combination with other environmental factors.

Singh *et al.* (2011) studied the carbon sequestration potential of Indo-Gangetic agroecosystem soils. The soil texture was loam in the upper soil layers but changed to silt loam as the depth increased. Bulk density increased with soil depth, and had a negative relationship with soil organic C. A significant positive correlation between SOC and clay content was observed. About 69 % of soil carbon in the profile was confined to the upper 40 cm soil layer where C stock ranged from 8.5 to 15.2 t C ha^{-1}. They estimated that the agricultural soils of Indo-Gangetic Plains may contain 12.4 to 22.6 t ha^{-1} of organic C in the top 1 m soil depth. Since agricultural soils contain significantly lower C content than the soils of natural forest ecosystem in the same climate zone, management practices such as residue placement and reduced or no tillage are required to enhance C sequestration.

Tangsinmankong *et al.* (2007) studied the carbon stocks in soil of mixed deciduous forest and teak plantation. Results revealed that soil organic carbon from all sites decreased generally with the increasing depth from the surface soil down to the level of 100 cm. The highest carbon stocks in soil were recorded at the 6-year-old teak plantation followed by the 24 and 15-year-old teak plantations and mixed deciduous forest as 157.03, 105.67, 78.78 and 70.96 t C ha^{-1}, respectively. The dissimilarity of soil organic carbon may be due to forest fire, forest management and topography.

Takahashi *et al.* (2009) studied the soil respiration in different ages of teak plantations in Thailand. Total soil respiration rate was significantly correlated with soil water content in the 0–30 cm layer. The annual amount of CO_2 efflux from the forest floor was estimated to be 1,062–1,154 g C m^{-2} y^{-1} in the teak plantations in 1997. In 1998, annual CO_2 efflux declined to 80% of that in 1997 in the T-Y plot, probably due to low rainfall. They concluded that carbon dynamics in the soil under teak plantations in western Thailand were determined by the soil moisture regime, which is controlled by seasonal rainfall pattern and annual rainfall. Soil respiration in teak plantations had no clear difference between different stand ages.

Yao *et al.* (2010) studied the effects of land use types on soil organic carbon and nitrogen dynamics in Mid-West Côte d'Ivoire. Results showed that total soil organic carbon content decreased significantly (p=0.007) from natural forest to mixed crop systems. The average values were around 2.58 % in natural forest, 1.99 % in multispecies tree plantations, 1.69 %, in teak to 1.48 % in cocoa plantations and 1.29 % in mixed-crop fields. Significantly lower soil pH was observed in cocoa plantations, mixed-crop fields and mixed-tree plantations (5.98, 6.9 and 6.7, respectively), as compared to natural forest and teak plantations (7.3), ($p<0.0001$). Total soil N, organic C and C: N ratios were significantly influenced by land use ($p=0.0012$; 0.007 and 0.0136, respectively). Higher mineralizable C and N levels were observed in natural forest, mixed-tree and teak plantations, with significant differences between main land use types (CMIN, $p=0.0084$; NMIN, <0.0001). The study also shows a highly significant and positive correlation between clay and soil organic C, as well as total N contents ($r^2=0.637$; $p<0.0001$). Land use impact on soil organic C and total N were also significant across the different land use types.

Zhang *et al.* (2007) studied the soil organic carbon in pure rubber and tea-rubber plantations in South-western China. Effects of rubber plantation (RP) and tea-rubber intercropping (TRI) systems on soil organic carbon pools were evaluated by recording changes in soil organic carbon in an age sequence of 12, 20, 26 and 40-year old plantations. Labile organic carbon (LOC) increased in surface soils (0-10 cm) with aging of rubber plantation and tea-rubber intercropping stands. Total organic carbon (TOC) in the soils did not change between stand ages of 12 and 20 years, however it decreased at the 26-year old stand. The TOC increased remarkably in tea-rubber intercropping tea-row soils but remained low in the rubber plantations and tea-rubber intercropping rubber-row soils at the 40-year stand. The study suggests that tea-rubber intercropping tends to sequestrate higher atmospheric carbon in soils than rubber monoculture alone through increased organic carbon pools in the tea-row soils and reduced organic carbon turnover rates in the rubber-row soils.

MATERIALS AND METHODS

CHAPTER-III

MATERIALS AND METHODS

“A Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment” was carried out at Barnawapara wildlife sanctuary, North Raipur Forest Division of Raipur district (Chhattisgarh) during the year 2011-2012. The details of the study site, climate, geology, soils, forest flora, fauna and other features of area along with the methodologies used are described below:

3.1 Study site

The study was conducted in Barnawapara wildlife sanctuary (North Raipur Division) situated in North corner of Raipur district. The geographical location and physiographic features of study area are detailed below.

3.1.1 Geographical location and physiography

The study area is located between 21° 20’ 0” to 21° 25’47” North latitudes and 82° 21’ 17” to 82° 26’ 27” East longitudes. It is situated about 27 km away from Patewa on Raipur-Sambalpur NH No. 6 just on the border of Chhattisgarh. The location of study area is shown in Fig. 3.1 and 3.2.

The general topography of area is undulating due to formation of rockout crop. The area adjoining Nawapara forest village has a number of hillocks scattered all over the area. The slopes of hillocks are moderate to steep. Tilsa pathar is the highest with an approximate altitude of 463 m above m.s.l. The streams and nalas flowing in the area have steep bank rich in alluvial soil and sustain a rich variety of vegetation.

Dry deciduous forest, grasslands, agriculture lands and human habitations surrounds the study area. Most of the villages in study area are categorized as forest

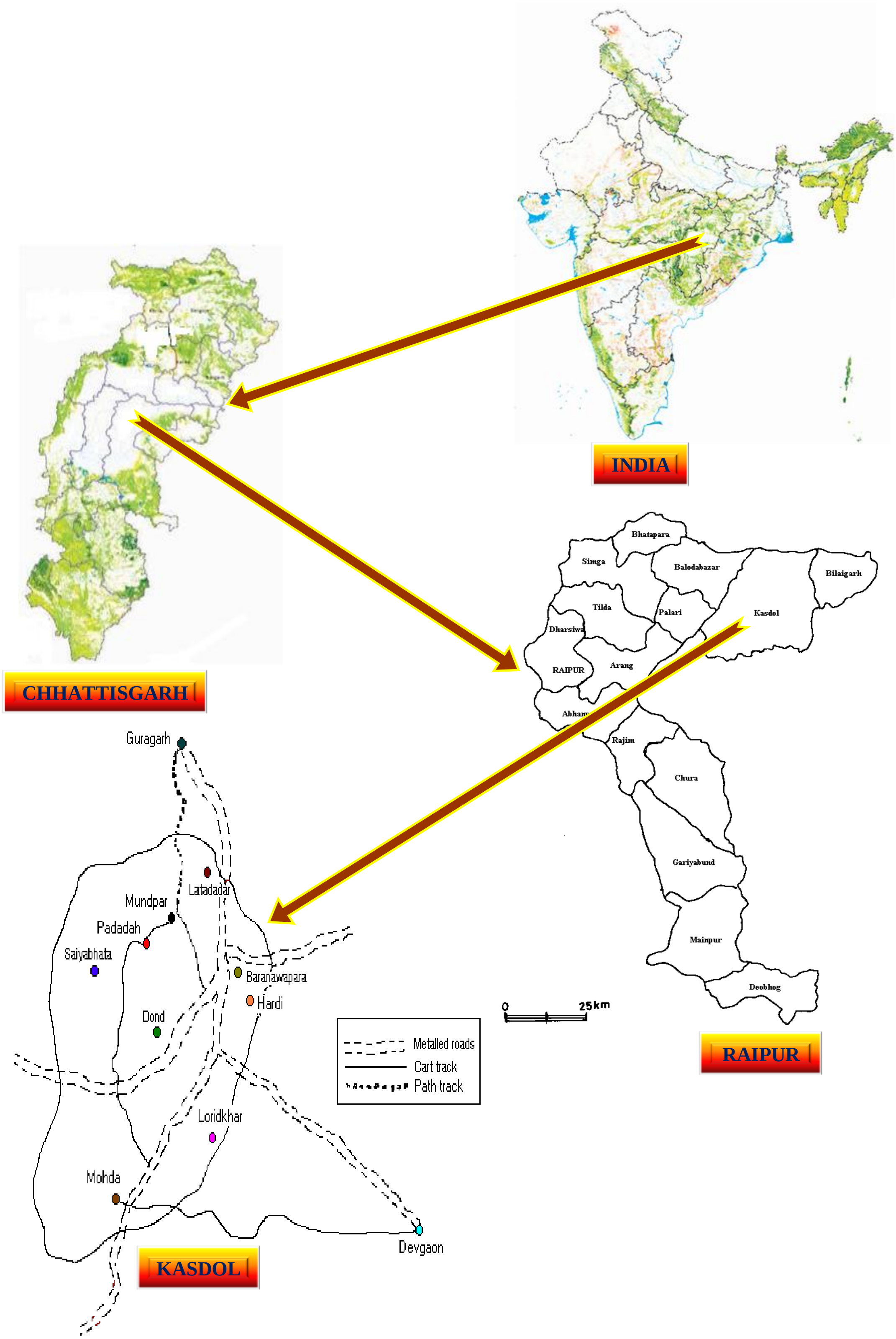

Fig 3.1: Location Map of Study Area

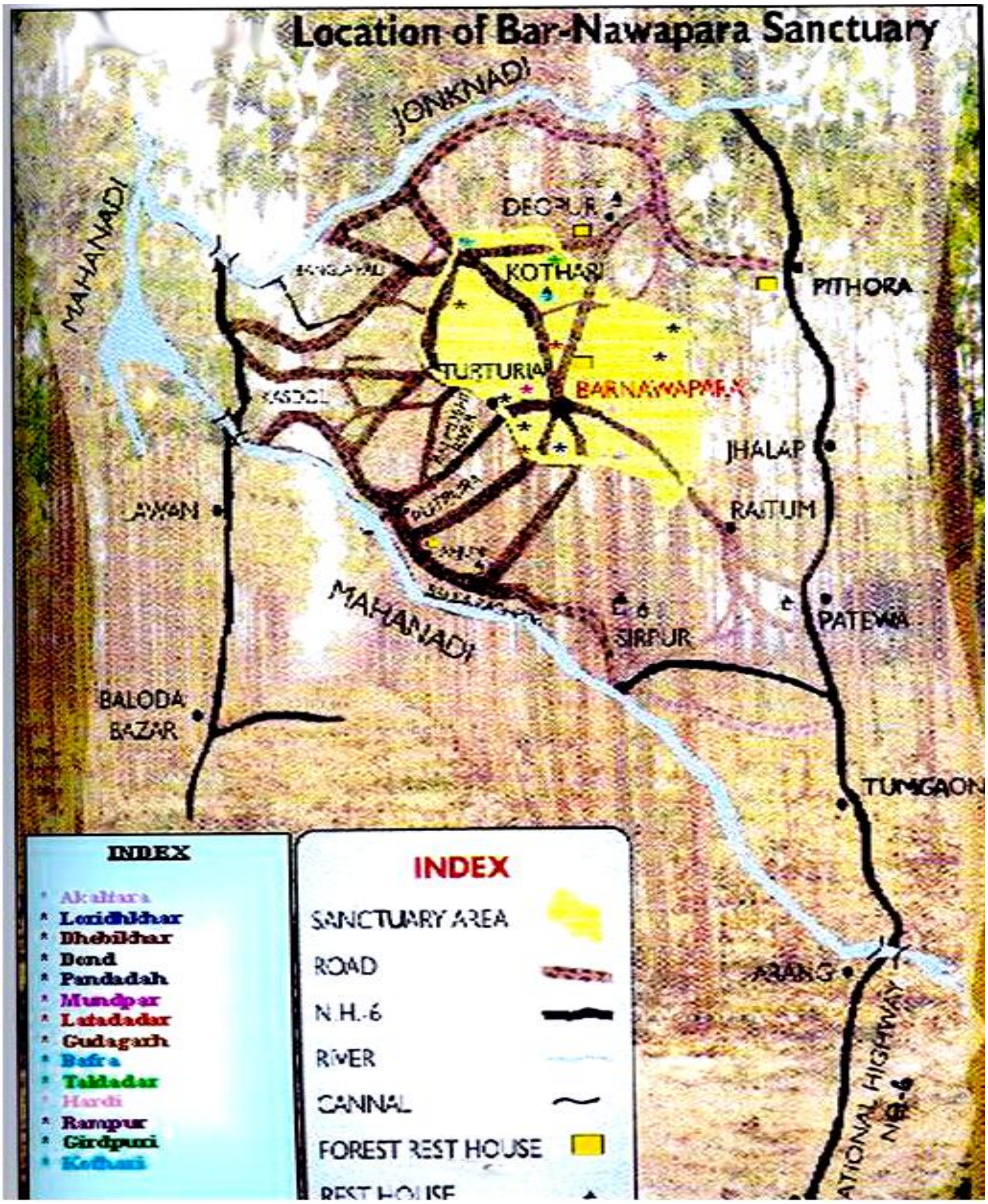

Fig 3.2: Area and Linkages of Barnawapara Wildlife Sanctuary

villages and majorities of them are accessible through kaccha roads, which is motorable only in dry season. Road network is absent in few hilly tracts, which are inaccessible due to steep slopes and dense forest.

3.1.2 Climate

The climate of study area is dry humid tropical comprised of three seasons viz. rainy, winter and summer. The rainy season commences from the middle of June. The winter season, which commences from the beginning of November, lasts till the end of February. The summer commences from the beginning of March. It is quite prolonged and lasts till monsoon sets in.

3.1.3 Rainfall

The average annual rainfall in the study area ranges from 1200-1350 mm. It gradually decreases from south east direction to North West direction. About 80 percent of the rainfall in the study area is received from south west monsoon during June to September. The highest amount of rainfall occurs in July. Number of rainy days varies from 90-100 days.

3.1.4 Temperature

The mean monthly maximum temperature varies from 27.3° C in January to 41.8° C in May and mean monthly minimum temperature ranges from 12.7° C in December to 27.3° C in May. The mean annual maximum and minimum temperatures of study area are 33.1° C and 20.5° C, respectively.

3.1.5 Humidity

Relative humidity of study area increases with the onset of south-west monsoon and it generally becomes more than 80% in July. In the post monsoon and winter season the relative humidity lies between 50-65% in the morning (6:00 to 12:00 hrs.) and 30-40% in the afternoon (12:00 to 16:00 hrs.). Relative humidity is lowest during summer and drops below 30 percent in the afternoon in April and May.

3.1.6 Geology

The Barnawapara sanctuary area has three distinct geological formations viz., Chhattisgarh super group, Late Precambrian and Early Precambrian. Litho logically, the area is divided into seven groups namely Raipur shale and limestone, Khairagarh sandstone, Gunderdehi shale, Cuddapahas charmur limestone, Chandrapur sand grit, Dharwar rocks, Granite and gneiss.

3.1.7 Soils

Soils of Barnawapara area are grouped in to three classes viz., Inceptisols, Alfisols and Vertisols. The Inceptisols are immature soils mostly sandy loam having light texture and shallow to moderate depth. They are low in organic matter and available nutrients, which support mainly grassland and degraded forests, these soils are commonly found in Eastern and Southern aspects. Alfisols occur in midland situation, which are moderately deep and hence have good water holding capacity and bear luxuriant vegetation on the other hand Vertisols are deep clayey soils having good water holding capacity and are supporting rich vegetation. Some of these lands are utilized for cultivation of agricultural crops.

3.1.8 Forest types and flora

Different types of forest vegetation occur in the study area. Northern and Eastern part are covered with luxuriant forests, whereas teak plantations occupy a major area in southern part. In western part, large area is covered by degraded and mixed forest and also with bamboo brakes occasionally found as patches. According to Champion and Seth (1968), the forest of the study area are classified into four major types viz., (1) Southern Tropical Dry Deciduous Teak Forest ($5A/C_{1b}$), (2) Northern Tropical Dry Deciduous Sal Forest ($5B/C_{1c}$), (3) Northern Tropical Mixed Deciduous Sal Forest ($5B/C_2$), (4) Dry Bamboo Brakes ($5/E_9$).

3.2 Experimental details:-

3.2.1 Sampling

A Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment was conducted at Barnawapara wildlife sanctuary. Three sites comprising teak plantation was selected from Barnawapara wildlife sanctuary i.e. 19 years, 23 years and 33 years old teak plantation site (Plates 3.1-3.3).

3.2.2 Method

The stratified random sampling procedure was adopted for characterization of vegetation. The phyto-sociological analysis in each forest plot was carried out by randomly laying sample plots of 10 m × 10 m in size. Randomly 10 sample plots were laid down in each plantation plot. In the center of each 10 m × 10 m quadrat, 2 m × 2 m quadrat area was marked for enumeration of saplings and seedlings. Girth of adult individual was measured at 1.37 m from the ground level (Plate 3.4). Thus, all individual were enumerated by species and the diameters of the individuals were measured.

3.2.3 Phytosociological analysis

The vegetation data were quantitatively analyzed for frequency, density and basal cover (Curtis and McIntosh, 1950). Frequency, density and basal covers were calculated as given below.

$$\text{Frequency (\%)} = \frac{\text{Number of sampling units in which species occurred}}{\text{Total number of sampling units studied}} \times 100$$

$$\text{Density (tree/ha)} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrates studied}} \times 100$$

Basal area (m^2/ha) of trees was calculated as cross sectional area of stem at breast height i.e. at 1.37 m from the ground level. The relative frequency, relative density and relative basal area, were calculated as follows.

$$\text{Relative frequency (RF)} = \frac{\text{Frequency of the individual species}}{\text{Total frequency of all the species}} \times 100$$

$$\text{Relative density (RD)} = \frac{\text{Density of the individual species}}{\text{Total density of all species}} \times 100$$

$$\text{Relative basal area (RBA)} = \frac{\text{Basal area of the individual species}}{\text{Total basal area of all species}} \times 100$$

The Importance Value Index (IVI) was determined as the sum total of relative frequency, relative density and relative basal area (Phillips, 1959).

Importance Value Index (IVI) = RD + RF + RBA

3.2.4 Species diversity analysis

Species diversity on different sites were calculated following Sagar and Singh (1999). Species diversity parameters were determined using basal cover values. Shannon-Wiener information (Shannon and Weaver, 1963) was used for the species diversity:

$$\mathbf{H' = - \sum Pi \log_2 Pi}$$

Where, Pi is the proportion of total stand basal cover represented by the i^{th} species. The working formula given by Smith (1974) was used here

$$H' = 3.3219[\log_{10} N - (\sum Ni \log_{10} Ni/ N)]$$

Where, Ni was the total basal cover of species i and N was the total basal area of all the species. The factor 3.3219 was used to convert the index value to $\log_2$.

Concentration of dominance was measured by Simpson's Index (Simpson, 1949):

$$Cd = \sum (Ni/ N)^2$$

Ni and N were same as described above. Equitability (e) was calculated as suggested by Pielou (1966).

$$e = H' / InS.$$

Where, H′ = Shannon index and S = number of species. Species richness was calculated following Marglef (1958).

$$d = S\text{-}1 / InN.$$

Where, S = total number of species and N = basal area of all species. Beta diversity was calculated according to the formula given by Whittaker (1972).

$$\beta d = Sc/ \overline{S}$$

Where, Sc = total number of species in the three sites and $\overline{S}$ = average number of species per site.

3.2.5 Biomass estimation

For the measurement of tree biomass, allometric equation relating tree circumference to biomass developed earlier by Singh and Mishra (1979) for the dry deciduous forest species were used (Appendix- I). The tree individuals in each quadrat were categorized into different girth classes. The mean CBH (circumference at breast height) value for each species for a girth class was used in the regression equation to get an estimate of biomass (by component) for that girth class. Then this value was multiplied by the density of trees in that girth class. The girth class values were summed to obtain the biomass estimate for each of the quadrats in each site.

The relationship between girth of a tree and dry weight of a component is given by equation:

$$\mathbf{Log\ Y = a + b\ log\ X}$$

Where,

Y = dry weight (kg) of component (bole, branch, leaf and root)

X = girth (cm) at 1.37 m height

a and b = allometric constants.

3.2.6 Forest floor biomass

By using 50 cm × 50 cm randomly placed quadrats (Plate 3.5), forest floor litter was collected and then categorized into different component viz., fresh leaf, wood and partially decayed litter. The collected litter was brought to the laboratory and oven dry weights were determined.

3.2.7 Fine root biomass

The belowground plant material was sampled from 5 monoliths (15 cm × 15 cm × 15 cm, Plate 3.6) on each site. Monoliths were washed with a fine jet of water using 2 mm and 0.5 mm mesh screens. Proportions of live and dead fine roots were estimated on the basis of visual observations such as color, texture etc. Sample were dried at 80ºC to constant weight and weighed. Fine roots were classified into two classes: fine roots < 5 mm diameter and fine roots > 5 mm diameter. Finally each fine root class was converted into live fine root and dead fine roots using live and dead fine roots proportions.

3.2.8 Carbon estimation

Samples of different tree components (bole, branch, foliage, coarse roots) for all species were separately collected from 20-30 trees of all available girth classes on each site. Composite samples of each component of tree were brought to the laboratory and oven dried at 80^{o}C.The oven dried samples were mill ground and stored for chemical analysis.

Carbon concentration was analysed using CHNOS-Auto Analyzer "Elementar Vario EL". The carbon storage for the vegetation components was computed as the sum of the products obtained by multiplying dry weights of components with their mean carbon concentrations. The values for carbon storage in different components were summed to obtain total carbon storage in the vegetations.

3.2.9 Soil analysis

Soil samples were collected from to 0-10 cm and 10-20 cm soil depth on each sites and were analyzed for carbon, nitrogen, phosphorus, potassium. Organic carbon and nitrogen concentration were estimated using CHNOS Auto Analyser. Available phosphorus was determined using spectrophotometer following Jackson, (1958). Available potassium was determined using flame photometer following Jackson, (1958).

3.2.10 Statistical analysis

Survey design: - Stratified random sampling

Analysis: - One way analysis of variance

Strata (site level): -

1) 19 years old teak plantation site.
2) 23 years old teak plantation site.

3) 33 years old teak plantation site.

No. of samples: - 10 quadrats of 10 m × 10 m in size on each site.

Observation and estimation: -

1) Measurement of girth at breast height (GBH) of each tree individuals and saplings in each quadrat.
2) Random collection of 5 soil samples from each site for the analysis of total carbon, total nitrogen, phosphorus and potassium.
3) Measurement of forest floor biomass on each site by taking 5 random samples using the quadrate of 0.25 m^2.
4) Random collection of 5 monoliths (15 × 15 × 15 cm^3) from each site for the estimation of fine root biomass.
5) The biomass, carbon storage, density, basal area and soil were obtained through one way analysis of variance. The significant difference between treatment means for all parameters were tested at $P<0.05$ using least significant difference (Gomez and Gomez, 1984).


Plate 3.1: A view of 19 years old teak plantation


Plate 3.2: A view of 23 years old teak plantation


Plate 3.3: A view of 33 years old teak plantation

Plate 3.4: Measurement of trees in study area

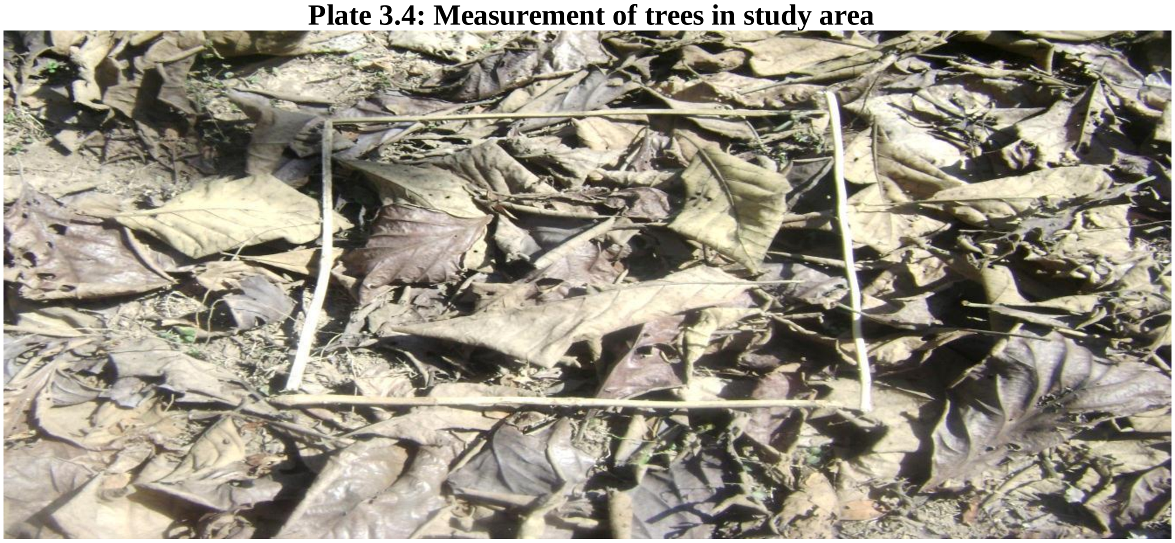

Plate 3.5: Quantification of forest floor biomass in study area

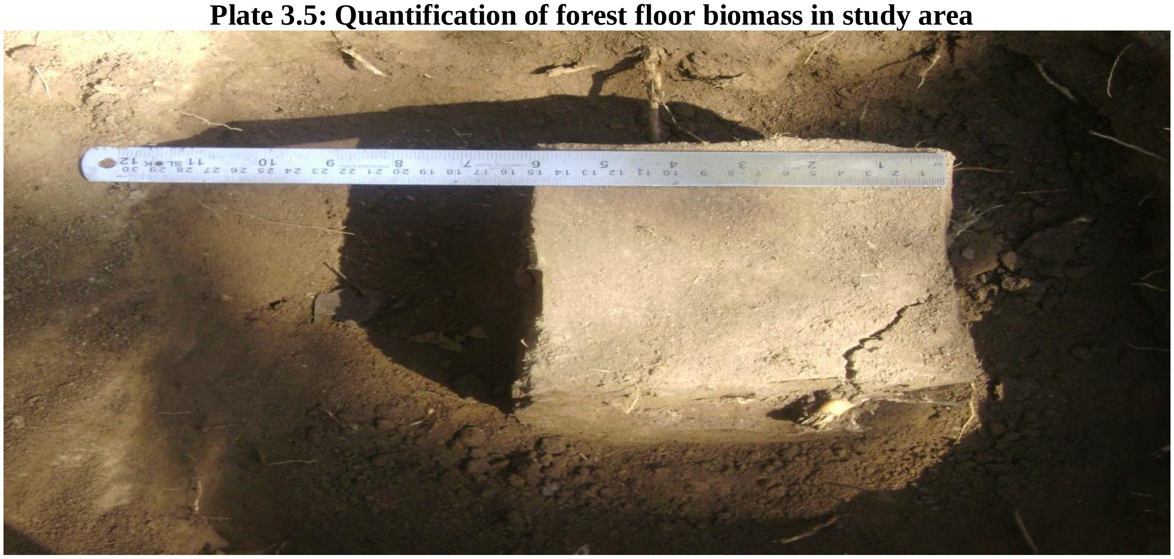

Plate 3.6: Quantification of fine root biomass in study area

RESULTS AND DISCUSSION

CHAPTER-IV

RESULTS AND DISCUSSION

The results on "A Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment." are discussed in this chapter. The findings are presented in three parts to facilitate the interpretation of results in accordance with topics. First part deals with the results on quantification of species structure and species diversity (phytosociological analysis), the second part deals with the results on estimation of biomass pattern and the third part deals with the results on estimation of carbon storage pattern in an age series of teak plantation in tropical environment at Barnawapara wildlife sanctuary. Results on different aspects in each part are described below:-

4.1 Species structure and diversity in an age series of teak plantation

4.1.1 Species structure

The species structure in different age of plantation sites viz., 19 years old teak plantation, 23 years old teak plantation and 33 years old teak plantation is given in Table 4.1-4.3. Analysis of variance indicated that the variation in tree density and tree basal area among the different age of the plantation were significantly different at 5% level of significance.

4.1.1.1 19 years old teak plantation

In the 19 years old teak plantation a total of 1010 trees ha^{-1} representing 4 species were encountered. The overall density of tree layer was 1010 stems ha^{-1} followed by 1500 stems ha^{-1} and 11250 stems ha^{-1} for sapling and seedling, respectively (Fig. 4.1). In tree layer, basal area and density of individual tree species varied from 0.08 m^2 ha^{-1} to 23.23 m^2 ha^{-1} and 10 to 980 stems ha^{-1}, respectively. In sapling layer, basal area and density of individual tree species varied from 0.01 m^2 ha^{-1} to 0.05 m^2 ha-1 and 250 stems ha^{-1}, respectively. The total basal area of tree layer in 19 years old teak plantation was 23.54 m^2 ha^{-1}.

In tree layer, highest tree density was recorded for *Tectona grandis* (980 stems ha^{-1}). Lowest tree density (10 stems ha^{-1}) was recorded for *Cleistanthus collinus, Diospyros melanoxylon* and *Lagerstroemia parviflora* (Table 4.1).

In tree layer, highest basal area was23.23 m^2 ha^{-1} for *Tectona grandis* followed by 0.16 m^2 ha^{-1} for *Diospyros melanoxylon* . Lowest basal area (0.08 m^2 ha^{-1}) was recorded for *Lagerstroemia parviflora* and *Cleistanthus collinus*. In sapling layer, highest basal area was observed for *Tectona grandis* (0.05 m^2 ha^{-1}) followed by *Diospyros melanoxylon* (0.04 m^2 ha^{-1}) and *Lagerstroemia parviflora* (0.04 m^2 ha^{-1}).

In tree layer (Table 4.1) *Tectona grandis* showed highest value of IVI (272.62) followed by *Diospyros melanoxylon* (9.37). In sapling layer (Table 4.2) *Tectona grandis* showed highest value of IVI (59.95) followed by *Diospyros melanoxylon* (53.95) and *Lagerstroemia parviflora* (53.95). In seedling layer (Table 4.3) IVI was highest for *Diospyros melanoxylon* (85.82) followed by *Tectona grandis* (40.59) and *Pterocarpus marsupium* (38.25).

4.1.1.2 23 years old teak plantation

In the 23 years old teak plantation a total of 1380 trees ha^{-1} representing 6 species were encountered. The overall density of tree layer was 1380 stems ha^{-1} followed by 1250 stems ha^{-1} and 7250 stems ha^{-1} for sapling and seedling, respectively (Fig. 4.2). In tree layer, basal area and density of individual tree species varied from 0.10 m^2 ha^{-1} to 39.44 m^2 ha^{-1} and 10 to 1190 stems ha^{-1}, respectively. In sapling layer, basal area and density of individual tree species varied from 0.04 m^2 ha^{-1} to 0.14 m^2 ha^{-1} and 250 to 1000 stems ha^{-1}, respectively. The total basal area of tree layer on 23 years old teak plantation was 41.96 m^2 ha^{-1}.

In tree layer, highest tree density was recorded for *Tectona grandis* (1190 stems ha^{-1}) followed by *Lagerstroemia parviflora* (150). Lowest tree density (10 stems ha^{-1}) was recorded for *Boswelia serrata*, *Buchnania lanzan*, *Diospyros melanoxylon* and S*emecarpus anacardium* (Table 4.1).

In tree layer, highest basal area was observed for *Tectona grandis* (39.44 m^2 ha^{-1}) followed by *Lagerstroemia parviflora* (1.96) and *Buchnania lanzan* (0.18). Lowest basal area (0.10 m^2 ha^{-1}) was recorded for *Diospyros melanoxylon*. In sapling layer, highest basal area was observed for *Lagerstroemia parviflora* (0.14 m^2 ha^{-1}) followed by *Diospyros melanoxylon* (0.04 m^2 ha^{-1}).

In tree layer (Table 4.1) *Tectona grandis* showed highest value of IVI (223.69) followed by *Lagerstroemia parviflora* (54.66) and *Buchnania lanzan* (5.51). In sapling layer (Table 4.2) *Lagerstroemia parviflora* showed highest value of IVI (238.57) followed by *Diospyros melanoxylon* (61.43). In seedling layer (Table 4.3) IVI was highest for *Tectona grandis* (180.26) followed by *Diospyros melanoxylon* (79.91).

4.1.1.3 33 years old teak plantation

In the 33 years old teak plantation a total of 1380 trees ha^{-1} representing 11 species were encountered. The overall density of tree layer was 1380 stems ha^{-1} followed by 1000 stems ha^{-1} and 12000 stems ha^{-1} for sapling and seedling, respectively (Fig.4.3). In tree layer, basal area and density of individual tree species varied from 0.08 m^2 ha^{-1} to 40.47 m^2 ha^{-1} and 10 to 1170 stems ha^{-1}, respectively. In sapling layer, basal area and density of individual tree species varied from 0.02 m^2 ha^{-1} to 0.06 m^2 ha-1 and 250 stems ha^{-1}, respectively. The total basal area of tree layer on 33 years old teak plantation was 44.75 m^2 ha^{-1}.

In tree layer, highest tree density was recorded for *Tectona grandis* (1170 stems ha^{-1}) followed by *Buchnania lanzan* (60 stems ha^{-1}) and *Lagerstroemia parviflora* (40 stems ha^{-1}). Lowest tree density (10 stems ha^{-1}) was recorded for *Bridelia retusa*, *Cassia fistula, Emblica officinalis, Diospyros melanoxylon* and *Lannea coromandelica* (Table 4.1).

In tree layer, highest basal area was observed for *Tectona grandis* (40.47 m^2 ha^{-1}) followed by *Buchnania lanzan* (0.86 m^2 ha^{-1}) and *Lagerstroemia parviflora* (0.66 m^2 ha^{-1}). Lowest basal area (0.08 m^2 ha^{-1}) was recorded for *Diospyros melanoxylon* (0.08 m^2 ha^{-1}). In sapling layer, highest basal area was observed for *Buchnania lanzan* (0.06 m^2 ha^{-1}) followed by *Tectona grandis* (0.04 m^2 ha^{-1}) and *Diospyros melanoxylon* (0.03 m^2 ha^{-1}).

In tree layer (Table 4.1) *Tectona grandis* showed highest value of IVI (209.72) followed by *Buchnania lanzan* (26.95) and *Lagerstroemia parviflora* (14.71). In sapling layer (Table 4.2) *Buchnania lanzan* showed highest value of IVI (90.66) followed by *Tectona grandis* (76.99) and *Diospyros melanoxylon* (68.07). In seedling layer (Table 4.3) IVI was highest for *Diospyros melanoxylon* (69.52) followed by *Tectona grandis* (66.56) and *Holarrhena pubescens* (27.87).

In the present study the tree density in plantation across the age series were ranged from 1010 to 1380 trees ha^{-1} and basal area from 23.54 to 44.75 m^2 ha^{-1} which is resemble with the Singh *et al.* (2004) which reported that the density and basal area of the three Cottonwood clones (*Populus deltoides*) were varied from 400 to 540 trees ha^{-1} and

6.8 to 24.1 m^2 ha^{-1}, respectively. In the present study higher density could be due to the restricted felling or thinning in the wildlife sanctuary area. The finding are also compare with Tyagi *et al.* (2009), where the tree density was 1800 trees ha^{-1} for 3 year, 1967 trees ha^{-1} for 6 year and 1600 trees ha^{-1} for 9 year old *Dalbergia sissoo* plantations (Table 4.4).

Thapa *et al.* (2011) reported 864 trees ha^{-1} tree density for teak plantation and 1110 trees ha^{-1} for sal plantation whereas the sapling density was 1432 trees ha^{-1} and 2880 trees ha^{-1} for teak and sal plantation and seedling density was 12800 seedlings ha^{-1} and 14450 seedlings ha^{-1} for teak and sal plantation, respectively which is in the range of the present study. They have also measured the basal area of teak and sal plantation as 38.32 m^2 ha^{-1} for teak plantation and 93.74 m^2 ha^{-1} for sal plantation, respectively.

According to Cordero and Kanninen (2003) the density of teak plantation varied form 156 trees ha^{-1} to 1600 trees ha^{-1} for 5 to 46 years old teak plantation while in the present study shows the reverse trend in total density in respect to the age series plantation. In contrary to the present findings the reverse trend was also recorded by the Derwisch *et al*. (2009) which reported the higher density in the young plantation and it reduce as the plantation becomes mature or with the increase in the age of the plantation.

Kraenzel *et al*. (2003) found the density of teak plantation in Panama between 566 and 723 trees ha^{-1} which are 43.96% less to the lower limit and 47.61% less to the upper limit of the present estimates. Pande (2005) reported the density of teak forest in disturbed area of Satpura plateau and stated that the density was 690 trees ha^{-1} in site I, 950 trees ha^{-1} in site II, 1630 trees ha^{-1} in site III and 2500 trees ha^{-1} in site IV, respectively.

Table 4.1: Species structure of tree layer at Barnawapara Wildlife Sanctuary

S. No.	Species	19 Years Teak Plantation				23 Years Teak Plantation				33 Years Teak Plantation			
		F (%)	**D (stems/ha)**	**BA (m2/ha)**	**IVI**	**F (%)**	**D (stems/ha)**	**BA (m2/ha)**	**IVI**	**F (%)**	**D (stems/ha)**	**BA (m2/ha)**	**IVI**
1	*Bosweliaserrata*Roxb. exColebr.	-	-	-	-	10	10	0.13	5.38	-	-	-	-
2	*Brideliaretusa*Spreng.	-	-	-	-	-	-	-	-	10	10	0.29	4.81
3	*Buchnanialanzan*Spreng.	-	-	-	-	10	10	0.18	5.51	60	60	0.86	26.95
4	*Cassia fistula* Linn.	-	-	-	-	-	-	-	-	10	10	0.22	4.65
5	*Cleistanthus collinus*	10	10	0.08	9.01	-	-	-	-	10	20	0.59	6.22
6	*Diospyrosmelanoxylon*Roxb.	10	10	0.16	9.37	10	10	0.10	5.32	10	10	0.08	4.34
7	*Emblicaofficinalis*Gaertn.	-	-	-	-	-	-	-	-	10	10	0.50	5.28
8	*Lagerstroemia parviflora*Roxb.	10	10	0.08	9.01	90	150	1.96	54.66	30	40	0.66	14.71
9	*Lanneacoromandelica*Houtt.	-	-	-	-	-	-	-	-	10	10	0.15	4.52
10	*Madhuca indica* J.F. Gmel.	-	-	-	-	-	-	-	-	20	20	0.54	9.55
11	*Semecarpusanacardium*Linn. f.					10	10	0.15	5.44	-	-	-	-
12	*Tectona grandis* Linn. f.	100	980	23.23	272.62	100	1190	39.44	223.69	100	1170	40.47	209.72
13	*Terminaliatomentosa* Roth.	-	-	-	-	-	-	-	-	20	20	0.40	9.23
	Total	130	1010	23.54	300	230	1380	41.96	300	290	1380	44.75	300

*F = Frequency, D = Density, BA = Basal area, IVI = Importance value index

Table 4.2: Species structure of sapling layer at Barnawapara Wildlife Sanctuary

S. No.	Species	19 Years Teak Plantation				23 Years Teak Plantation				33 Years Teak Plantation			
		F (%)	**D (stems/ha)**	**BA (m2/ha)**	**IVI**	**F (%)**	**D (stems/ha)**	**BA (m2/ha)**	**IVI**	**F (%)**	**D (stems/ha)**	**BA (m2/ha)**	**IVI**
1	*Buchnanialanzan*	10	250	0.03	48.71	-	-	-	-	10	250	0.06	90.66
2	*Cassia fistula*	10	250	0.02	42.92	-	-	-	-	-	-	-	-
3	*Cleistanthus collinus*	10	250	0.01	40.53	-	-	-	-	-	-	-	-
4	*Diospyros melanoxylon*	10	250	0.04	53.95	10	250	0.04	61.43	10	250	0.03	68.07
5	*Lagerstroemia parviflora*	10	250	0.04	53.95	40	1000	0.14	238.57	10	250	0.02	64.28
6	*Tectona grandis*	10	250	0.05	59.95	-	-	-	-	10	250	0.04	76.99
	Total	60	1500	0.19	300	50	1250	0.18	300	40	1000	0.14	300

*F = Frequency, D = Density, BA = Basal area, IVI = Importance value index

Table 4.3: Species structure of seedling layer at Barnawapara Wildlife Sanctuary

S. No.	Species	19 Years Teak Plantation				23 Years Teak Plantation				33 Years Teak Plantation			
		F (%)	**D (stems/ha)**	**A**	**IVI**	**F (%)**	**D (stems/ha)**	**A**	**IVI**	**F (%)**	**D (stems/ha)**	**A**	**IVI**
1	*Anogeissus latifolia*	20	750	1.5	24.39	-	-	-	-	-	-	-	-
2	*Azadirachtaindica*	-	-	-	-	-	-	-	-	10	250	1	11.85
3	*Bauhinia racemosa*	-	-	-	-	-	-	-	-	20	500	1	17.50
4	*Boswellia serrata*	-	-	-	-	-	-	-	-	10	250	1	11.85
5	*Buchnanialanzan*	-	-	-	-	-	-	-	-	10	500	2	20.13
6	*Cassia fistula*	-	-	-	-	-	-	-	-	10	250	1	11.85
7	*Cleistanthus collinus*	20	750	1.5	24.39	-	-	-	-	-	-	-	-
8	*Diospyros melanoxylon*	80	4500	2.25	85.82	30	1500	2	79.91	70	3750	2.14	69.52
9	*Grewiatiliaefolia*	10	250	1	12.76	-	-	-	-	30	750	1	23.16
10	*Holarrhenapubescens*		-	-	-	-	-	-	-	20	1000	2	27.87
11	*Kydiacalycina*	20	500	1	18.83	-	-	-	-	-	-	-	-
12	*Lagerstroemia parviflora*	20	750	1.5	24.39	20	500	1	39.84	20	1000	2	27.87
13	*Pterocarpusmarsupium*	30	1500	2	38.25	-	-	-	-	-	-	-	-
14	*Schleicheraoleosa*	10	750	3	30.58	-	-	-	-	10	250	1	11.85
15	*Tectona grandis*	50	1500	1.2	40.59	100	5250	2.1	180.26	70	3500	2	66.56
	Total	260	11250	14.95	300	150	7250	5.1	300	280	12000	16.14	300

*F = Frequency, D = Density, A = Abundance, IVI = Importance value index

Table 4.4: Certain vegetational properties of tropical forest and plantation

Forest/plantation Ecosystems	**Density (stems ha^{-1})**	**Basal cover (m^2 ha^{-1})**	**Number of species Per ha.**	**Source**
Sub-tropical	400-540	6.8 to 24.1	-	Singh *et al.* (2004)
Teak forest	262-395	-	21	Bunyavejchewin (1983), Dhanmanonda and sahunalu (1992)
Pure Sal forest	386-785	12.7-33.2	-	Sharma *et al* (1990)
Sariska Tiger Reserve	1352	131.9	-	Rodgers (1990)
Sal dominated closed forest	1220-1290	25.4-44.65	15-22*	Singh *et al*. (2003)
Sal dominated open forest	390-930	20.05-45.89	11-16*	Singh *et al*. (2003)
Dry Dipterocarp forest	554-789	-	35-37	Visaratana*et al*. (1986)
Mixed deciduous forest	253	-	14	Sahunalu *et al*. (1979), Kiratiprayoon *et al.* (1995)
Seasonally dry tropical forest	484	26.3	-	Sahu *et al.* (2008)
Dry tropical forest	1600-1967	-	-	Tyagi *et al.* (2009)
Dry tropical forest	156-1600			Cordero and Kanninen (2003)
Tropical forest	383-1079	-	-	Derwisch *et al*. (2009)
Tropical forest	566-723	-	-	Kraenzel *et al.* (2003)
Tropical moist deciduous	448-1217	21.43-34.05	31-59	Bhat*et al.* (2000)
Tropical moist deciduous	82-468	6.8-62.2	-	Upadhyay *et al.* (2008)
Tropical dry deciduous	458-728	5.96-19.31	-	Kumar *et al.* (2010)
Tropical dry deciduous	883	18.09	-	Krishnamurthy *et al.* (2010)
Tropical dry deciduous	1010-1380	23.54-44.75	4-11	Present study

*Represents the number of species in 0.1 ha.

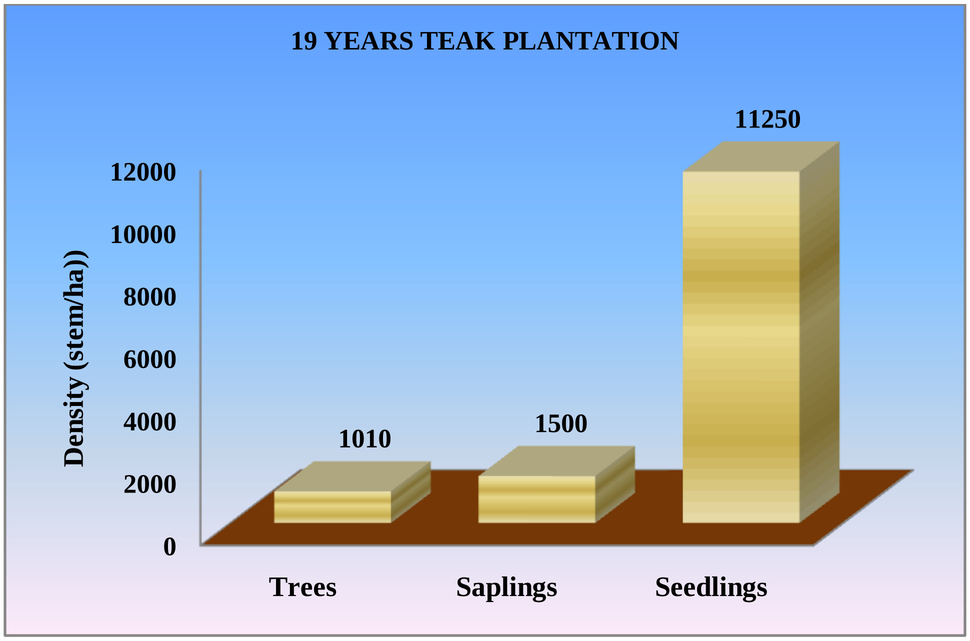

Fig. 4.1: Population structures of tree layer, sapling layer and seedling layer in 19 years old teak plantation.

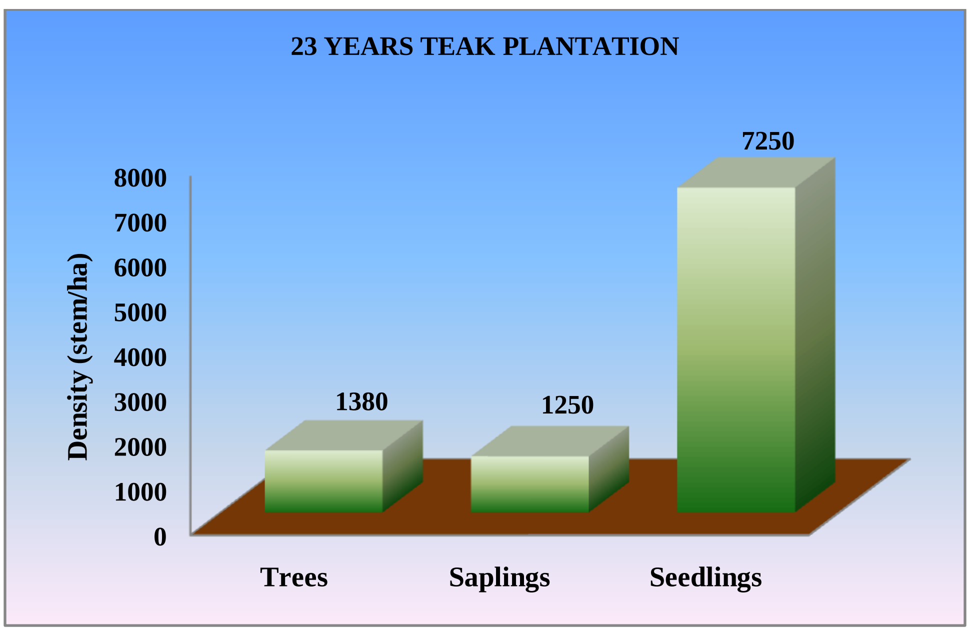

Fig. 4.2: Population structures of tree layer, sapling layer and seedling layer in 23 years oldteak plantation.

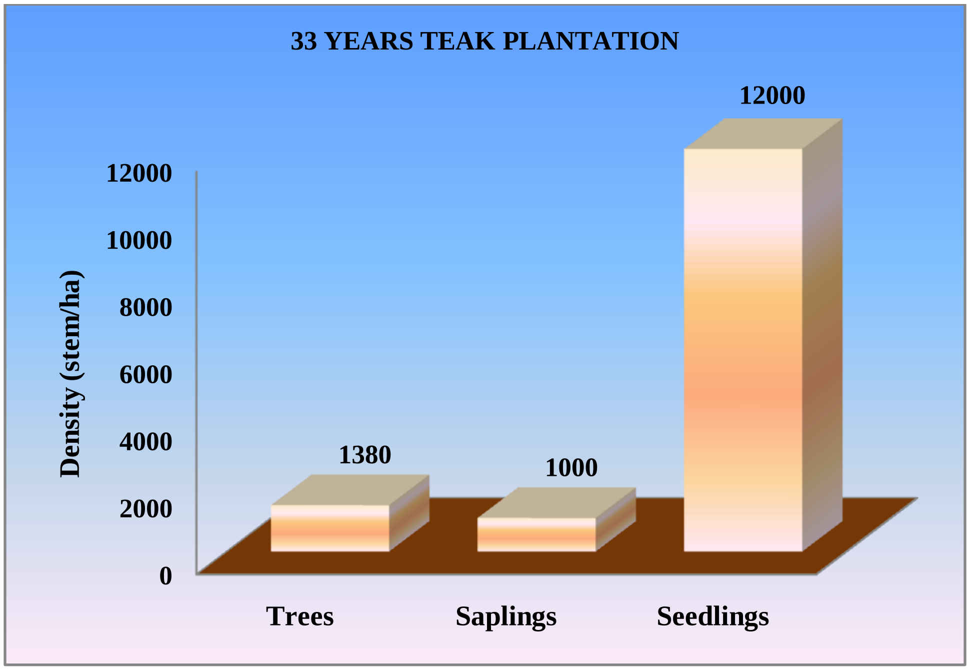

Fig. 4.3: Population structures of tree layer, sapling layer and seedling layer in 33 years oldteak plantation.

4.1.2 Species diversity

Species diversity, the number of species in a community is ecologically important, since it seems to increase as more stable community. The valuations of species diversity on different sites of same locality are not a good sign for better growth of forest of any area. Diversity parameters on different forest site are given in Table 4.5.

4.1.2.1 Species richness (d)

Species richness for tree layer varies from (0.43) for 19 years old teak plantation to (1.38) for 33 years old teak plantation. In tree layer species richness was highest (1.38) on 33 years old teak plantation followed by 23 years old teak plantation (0.69) and lowest on 19 years old teak plantation (0.43). Species richness for seedling layer was highest (1.06) on 33 years old teak plantation followed by 19 years old teak plantation (0.86) and lowest on 23 years old teak plantation (0.23) (Table 4.5). Species richness for sapling layer varies from (0.14) for 23 years old teak plantation to (0.68) for 19 years old teak plantation.

4.1.2.2 Shannon index (H′)

In tree layer Shannon index (H′) value was 0.24 on 19 years old teak plantation, 0.74 on 23 years old teak plantation and 1.07 on 33 years old teak plantation. In sapling layer Shannon index (H′) value was 2.58 on 19 years old teak plantation, 0.72 on 23 years old teak plantation and 2.00 on 33 years old teak plantation. In seedling layer Shannon index (H′) value was 2.67 on 19 years old teak plantation, 1.07 on 23 years old teak plantation and 2.74 on 33 years old teak plantation. On all three sites the species diversity for tree layer was highest on 33 years old teak plantation whereas for sapling layer was highest on 19 years old teak plantation and seedling layer was highest on 33 years old teak plantation.

4.1.2.3 Concentration of dominance (Cd)

In the plantation under study highest Cd value for tree layer was on 19 years old teak plantation followed by 23 years old teak plantation and 33 years old teak plantation. The Cd values for tree layer were 0.94, 0.76 and 0.72, respectively for 19 years old, 23 years old and 33 years old teak plantation. The Cd values for sapling layer were 0.17, 0.68 and 0.25, respectively for 19 years old, 23 years old and 33 years old teak plantation. The Cd values for seedling layer were 0.22, 0.57 and 0. 21, respectively for 19 years old, 23 years old and 33 years old teak plantation (Table 4.5). In the seedling layer Cd value was highest on 23 years old teak plantation followed by 33 years old teak plantation and 19 years old teak plantation.

4.1.2.4 Equitability (e)

Equitability (e) for tree layer was 0.17 for 19 years old teak plantation, 0.41 for 23 years old teak plantation and 0.45 for 33 years old teak plantation; for sapling layer it was 1.44 for 19 years old teak plantation, 1.04 for 23 years old teak plantation and 1.44 for 33 years old teak plantation; while for seedling layer it was 1.21 for 19 years old teak plantation, 0.98 for 23 years old teak plantation and 1.14 for 33 years old teak plantation (Table 4.5). The equitability (e) values for tree layer were highest on 33 years old teak plantation followed by 23 years old teak plantation and lowest at 19 years old teak plantation. For sapling and seedling layer, the values of equitability (e) were highest on 19 years old teak plantation.

4.1.2.5 Beta diversity

Beta diversity for the plantation under study was 3.25, 2.17 and 1.18 (Table 4.5), for tree layer on 19 years old teak plantation, 23 years old teak plantation and 33 years old teak plantation, respectively; for sapling layer, it was 1.00, 3.00 and 1.50 and for seedling layer it was 1.67, 5.00 and 1.36 on 19 years old teak plantation, 23 years old teak plantation and 33 years old teak plantation. Beta diversity for tree layer was highest on 19 years old teak plantation (3.25) followed by 23 years old teak plantation (2.17) and 33 years old teak plantation (1.18). Both sapling and seedling layers were highest on 23 years old teak plantation.

Species richness in a forest depends on climatic, edaphic and biotic factors (Ayappan and Parthasarathy, 1999). The results in present study are similar with the Manhas *et al.* (2011) which stated that the value of Shannon index for teak plantation was 1.16, concentration of dominance was 0.48 and equitability was 0.46. The diversity indices of natural and plantation forest of North India revealed that the Shannon index was 1.19 and 0.62 for natural and plantation forest, species richness was 1.24 and 0.76 for natural and plantation forest, equitability was 0.81 and 0.41 for natural and plantation forest and beta diversity was 1.96 and 1.21 for natural and plantation (Tripathi and Singh, 2009).

Chauhan *et al.* (2010) reported the diversity of natural and planted sal forest of India and stated that the Shannon index was 3.53 for natural sal forest and 3.26 for planted sal forest, whereas the Simpson index was 0.212 for natural sal forest and 0.174 for planted sal forest. The evenness value was 0.0346 for natural sal forest and 0.0354 for planted sal forest of India. The value of Shannon index was lesser in the present study

Table 4.5: Diversity parameters on different sites of teak plantations at Barnawapara Wildlife Sanctuary

Parameters	**Tree Layer**			**Sapling Layer**			**Seedling Layer**		
	19 Years Teak Plantation	23 Years Teak Plantation	33 Years Teak Plantation	19 Years Teak Plantation	23 Years Teak Plantation	33 Years Teak Plantation	19 Years Teak Plantation	23 Years Teak Plantation	33 Years Teak Plantation
Species richness (d)	0.43	0.69	1.38	0.68	0.14	0.43	0.86	0.23	1.06
Shannon index (H')	0.24	0.74	1.07	2.58	0.72	2.00	2.67	1.07	2.74
Concentration of dominance (Cd)	0.94	0.76	0.72	0.17	0.68	0.25	0.22	0.57	0.21
Equitability (e)	0.17	0.41	0.45	1.44	1.04	1.44	1.21	0.98	1.14
Beta diversity (βd)	3.25	2.17	1.18	1	3	1.5	1.67	5	1.36

except the Simpson's index and evenness value. Prasad and Pandey (1992) studied sal and teak forests of Madhya Pradesh and found species diversity varying from 0.32 to 3.76 and concentration of dominance from 0.07 to 0.63 at different distances from habitation in Bilaspur, Mandla, Balaghat and Jabalpur districts of M.P., India which resembled with the value obtained in the present results.

According to the Thapa *et al.* (2011) the values of Shannon index for teak plantation was 1.81, equitability was 0.51 and concentration of dominance was 0.36 whereas in the sal plantation the respective values were 2.93, 0.69 and 0.14 which was found within the range of the present study.

4.2 Estimation of biomass pattern in an age series of teak plantation

4.2.1 Trees biomass

Total biomass in the present study was between 119.37 t $ha^{-1}$and 235.14 t ha^{-1} (Table 4.6). It was highest on 33 years old teak plantation (235.14 t ha^{-1}) followed by 23 years old teak plantation (210.48 t ha^{-1}) and lowest on 19 years old teak plantation (119.37 t ha^{-1}). The total tree biomass increased with age from about 119.37 t ha^{-1} in 19 years old teak plantation to 235.14 t ha^{-1} in 33 years old teak plantation. Total above ground biomass was between 99.08 t ha^{-1} and 197.88 t ha^{-1} and total below ground biomass was between 20.29 t ha^{-1} and 37.26 t ha^{-1}, respectively. Analysis of variance indicated that the variation in biomass among the different age of plantation were significantly different at 5% level of significance.

4.2.1.1 19 years old teak plantation

The total biomass recorded in 19 years old teak plantation (Table 4.6) was 119.37 t ha^{-1}, of which 99.08 t ha^{-1} was above ground and 20.29 t ha^{-1} below ground. The distribution of biomass in the different components was as follows 60.33 t ha^{-1} in bole, 25.53 t ha^{-1} in branch, 13.22 t ha^{-1} in leaf and 20.19 t ha^{-1} in root. The bole, branch, leaf and root biomass constituted 50.54, 21.38, 11.07, and 16.99 %, respectively of the total biomass.

Tectona grandis was major species of the plantation. The total biomass of *Tectona grandis* was 117.49 t ha^{-1} of which 97.53 t ha^{-1} was in above ground part and 19.96 t ha^{-1} in below ground part. The bole, branch, leaf and root biomass of *Tectona grandis* were 59.49 t ha^{-1}, 24.91 t ha^{-1}, 13.13 t ha^{-1} and 19.96 t ha^{-1}, respectively. *Tectona grandis* constituted the highest biomass (117.49 t ha^{-1}) followed by *Diospyros melanoxylon* (0.88 t ha^{-1}) and *Cleistanthus collinus* (0.52 t ha^{-1}) which constituted 98.43, 0.74 and 0.44 % of the total biomass. However, lowest biomass was estimated for *Lagerstroemia parviflora* (0.48 t ha^{-1}).

4.2.1.2 23 years old teak plantation

The total biomass recorded in 23 years old teak plantation (Table 4.6) was 210.48 t ha^{-1} of which 176.22 t ha^{-1} was above ground and 34.25 t ha^{-1} below ground. The distribution of biomass in the different components was 105.57 t ha^{-1} in bole, 48.20 t ha^{-1} in branch, 22.45 t ha^{-1} in leaf and 34.25 t ha^{-1} in root. The bole, branch, leaf and root biomass constituted 50.16, 22.90, 10.67 and 16.27 %, respectively of the total biomass.

Tectona grandis was major species of the plantation. The total biomass of *Tectona grandis* was 119.96 t ha^{-1} of which 165.98 t ha^{-1} was in above ground part and 31.99 t ha^{-1} in below ground part. The bole, branch, leaf and root biomass of *Tectona grandis* were 100.34 t ha^{-1}, 43.90 t ha^{-1}, 21.74 t ha^{-1} and 31.99 t ha^{-1}, respectively. *Tectona grandis* constituted the highest biomass (197.96 t ha^{-1}) followed by

Lagerstroemia parviflora (9.38 t ha^{-1}) and *Boswellia serrata* (0.98 t ha^{-1}) which constituted 94.05, 4.47 and 0.47 % of the total biomass. However, lowest biomass was estimated for *Diospyros melanoxylon* (0.46 t ha^{-1}).

4.2.1.3 33 years old teak plantation

The total biomass measured in 23 years old teak plantation (Table 4.6) was 235.14 t ha^{-1} of which 197.88 t ha^{-1} was above ground and 37.26 t ha^{-1} below ground. The distribution of biomass in the different components was 116.11 t ha^{-1} in bole, 57.86 t ha^{-1} in branch, 23.91 t ha^{-1} in leaf and 37.26 t ha^{-1} in root. The bole, branch, leaf and root biomass constituted 49.38, 24.61, 10.17, and 15.85 %, respectively of the total biomass.

The *Tectona grandis* was major species on this site. The total biomass of *Tectona grandis* was 206.48 t ha^{-1}, of which 173.53 t ha^{-1} was in above ground part and 32.95 t ha^{-1} in below ground part. The bole, branch, leaf and root biomass of *Tectona grandis* was 104.64 t ha^{-1}, 46.33 t ha^{-1}, 22.56 t ha^{-1} and 32.95 t ha^{-1}, respectively. *Tectona grandis* constituted the highest biomass (206.48 t ha^{-1}) followed by *Lagerstroemia parviflora* (4.32 t ha^{-1}) and *Madhuca indica* (4.14 t ha^{-1}) which constituted 87.81, 1.84 and 1.76 %, respectively of the total biomass. However, lowest biomass was estimated for *Diospyros melanoxylon* (0.46 t ha^{-1}).

In the present study the total aboveground biomass was 99.08 t ha^{-1} for 19 years old teak plantation, 176.22 t ha^{-1} for 23 years old teak plantation and 197.88 t ha^{-1} for 33 years old teak plantation. Belowground biomass ranged from 20.29 to 37.26 t ha^{-1} across the different age series. These estimates are comparable with the estimates made by many workers (Table 4.9). Cordero and Kanninen (2003) estimated the aboveground biomass for 16 teak plantations from 10 different sites in Costa Rica and reported that per ha^{-1}

aboveground biomass tended to increase with increasing age class (young, intermediate and mature). Foliage dry biomass varied between 3 and 9 t ha^{-1}, branch biomass between 11 and 54 t ha^{-1}, stem biomass between 70 and 221 t ha^{-1} and total aboveground biomass between 84 and 284 t ha^{-1} for the age series of 8 to 47 years teak plantations. Mbaekwe and Mackenzie (2008) have reported the findings for tropical forest of Nigeria and stated that the total aboveground biomass were 43.33 t ha^{-1} for 5 years old teak plantation, 114.44 t ha^{-1} for 8 years old teak plantation, 114.00 t ha^{-1} for 11 years old teak plantation and 134.27 t ha^{-1} for 14 years old teak plantation. The total bole biomass of present study (60-116 t ha^{-1}) was also comparable with Mbaekwe and Mackenzie (2008).

Kandya (1974) reported 63% of the biomass storage in the stem, 31.9% in the branches and the remaining in the foliage in a 20 years old teak growing in Sagar. Per hectare total aboveground biomass currently found for teak plantations under study is similar to that reported by Negi *et al.* (1990) in Tripura (138 t ha^{-1} at 20 years), but lower than the values found by Ola-Adams (1993) in South-Western Nigeria (378 t ha^{-1} at 18 years) plantation. Kumar *et al.* (2011) also reported the tree biomass in three different aged *Butea* forest ecosystems in Western India, of different age group (5, 10 and 15 years old) and stated that the biomass of trees increased with age from 183.7 to 298.3 t ha^{-1}. The all values of biomass of trees were low in 5 years old, moderate in 10 years old and high in 15 years old forest stands. The total forest biomass increased from 190.7 t ha^{-1} in the 5 years old to 306.3 t ha^{-1} 15 years old forest. A similar trend was also found in present study.

Lodhiyal *et al.* (1995) observed the biomass of plantation increased with increase in age series of plantation. The total biomass increased from 84.0 t ha^{-1} in the 5 years old to 170.0 t ha^{-1} in the 8 years old plantation. The biomass accumulations for different tree components were also increased with the age of plantation increase. This result also supports the findings made by Singh *et al.* (2009) according to this the total biomass recorded different forest sites was 192.933 Mg ha^{-1} in natural forest followed by 95.64 Mg ha^{-1} in 32 years old converted forest, 85.78 Mg ha^{-1} in 23 years old converted forest and 92.05 Mg ha^{-1} in 15 years old converted forest. The total above ground biomass in different forest plots ranged from 71.94 to 162.91 Mg ha^{-1} with highest in natural forest and lowest in 23 years old converted forest. The below ground biomass varied from 13.97 to 30.02 Mg ha^{-1} with the highest in natural forest and lowest in 23 years old converted forest.

Singh *et al.* (2004) studied biomass and productivity of an age series of three cottonwood clones (*Populus deltoides*) in central Himalayan, India. The three clones had one young (four years old), one middle age (six years old) and one mature (8 to 10 years) stand. Total tree biomass in investigated clones increased from young (32-42 t ha^{-1}) to mature stands (120-170 t ha^{-1}), the lowest and highest biomass being in IC and G-3 clones. Similar trends were also recorded in present study. Biomass estimation studies were conducted in 3, 6 and 9 years old plantation of *Dalbergia sissoo* by Tyagi *et al.* (2009). Major portion of above ground biomass was contributed by bole and the remaining was shared by leaves, twigs, branches and bark. The contribution of leaves, bark and bole to the above ground biomass increased with the increase in age, biomass production was positively correlated with age.

Table 4.6: Biomass (t ha^{-1}) of different tree components in age series of teak plantation at Barnawapara Wildlife Sanctuary

		19 Years Teak Plantation					23 Years Teak Plantation					33 Years Teak Plantation				
S. No.	**Species**	Bole	Branch	Leaf	Root	**Total**	Bole	Branch	Leaf	Root	**Total**	Bole	Branch	Leaf	Root	**Total**
1	*Boswelliaserrata*Roxb. exColebr.	-	-	-	-	-	0.41	0.38	0.05	0.15	0.98	-	-	-	-	-
2	*Brideliaretusa*Spreng.	-	-	-	-	-	-	-	-	-	-	0.95	1.11	0.10	0.35	2.51
3	*Buchnanialanzan*Spreng.	-	-	-	-	-	0.35	0.21	0.05	0.11	0.72	1.98	1.25	0.29	0.61	4.12
4	*Cassia fistula* Linn.	-	-	-	-	-	-	-	-	-	-	0.64	0.68	0.07	0.24	1.64
5	*Cleistanthuscollinus*Roxb.	0.23	0.18	0.03	0.09	0.52	-	-	-	-	-	1.59	1.79	0.17	0.60	4.14
6	*Diospyrosmelanoxylon*Roxb.	0.40	0.28	0.04	0.15	0.88	0.22	0.13	0.02	0.09	0.46	0.22	0.13	0.02	0.09	0.46
7	*Emblicaofficinalis*Gaertn.	-	-	-	-	-	-	-	-	-	-	1.20	1.58	0.11	0.41	3.30
8	*Lagerstroemia parviflora*Roxb.	0.20	0.16	0.03	0.09	0.48	3.86	3.21	0.55	1.76	9.38	1.72	1.54	0.23	0.83	4.32
9	*Lanneacoromandelica*Houtt.	-	-	-	-	-	-	-	-	-	-	0.41	0.38	0.05	0.15	0.98
10	*Madhuca indica* J.F. Gmel.	-	-	-	-	-	-	-	-	-	-	1.59	1.79	0.17	0.60	4.14
11	*Semecarpusanacardium*Linn. f.	-	-	-	-	-	0.41	0.38	0.05	0.15	0.98	-	-	-	-	-
12	*Tectona grandis* Linn. f.	59.49	24.91	13.13	19.96	117.49	100.34	43.90	21.74	31.99	197.96	104.64	46.33	22.56	32.95	206.48
13	*Terminaliatomentosa* Roth.	-	-	-	-	-	-	-	-	-	-	1.17	1.29	0.13	0.44	3.03
	Total	60.33	25.53	13.22	20.29	**119.37**	105.57	48.20	22.45	34.25	**210.48**	116.11	57.86	23.91	37.26	**235.14**

Distribution pattern of biomass on different age of plantation sites:

Although the young individuals belonging to seedlings and saplings classes. The seedlings dominated the entire three sites in terms of density. The total biomass accumulation was greater in the middle girth class in an age series of teak plantation (Fig 4.4).

In 19 years old teak plantation total biomass accumulation was greater in the middle girth class followed by higher girth class while it was minimum in lower girth classes (Fig 4.5). About 59.80 per cent biomass accumulation was in the girth class ≥50-70 cm, 21.04 per cent in girth class ≥70-90 cm and 19.13 per cent in girth class ≥30-50 cm. In 23 years old teak plantation total biomass accumulation was greater in the middle girth class followed by higher girth class while it was minimum in lower girth classes (Fig 4.6). In 33 years old teak plantation total biomass accumulation was greater in the middle girth followed by higher girth class while it was minimum in lower girth classes (Fig 4.7).

4.2.2 Forest floor biomass

Total forest floor biomass in the present study was between 2.19 t ha^{-1} and 2.66 t ha^{-1}. The forest floor biomass was highest on 33 years old teak plantation (2.66 t ha^{-1}) followed by 23 years old teak plantation (2.31 t ha^{-1}) and lowest on 19 years old teak plantation (2.19 t ha^{-1}; Fig. 4.8). The forest floor biomass increased with the age of the teak plantation. Analysis of variance indicated that the variation in forest floor litter biomass due to age of plantation (site) was non-significantly different at 5% level of significance.

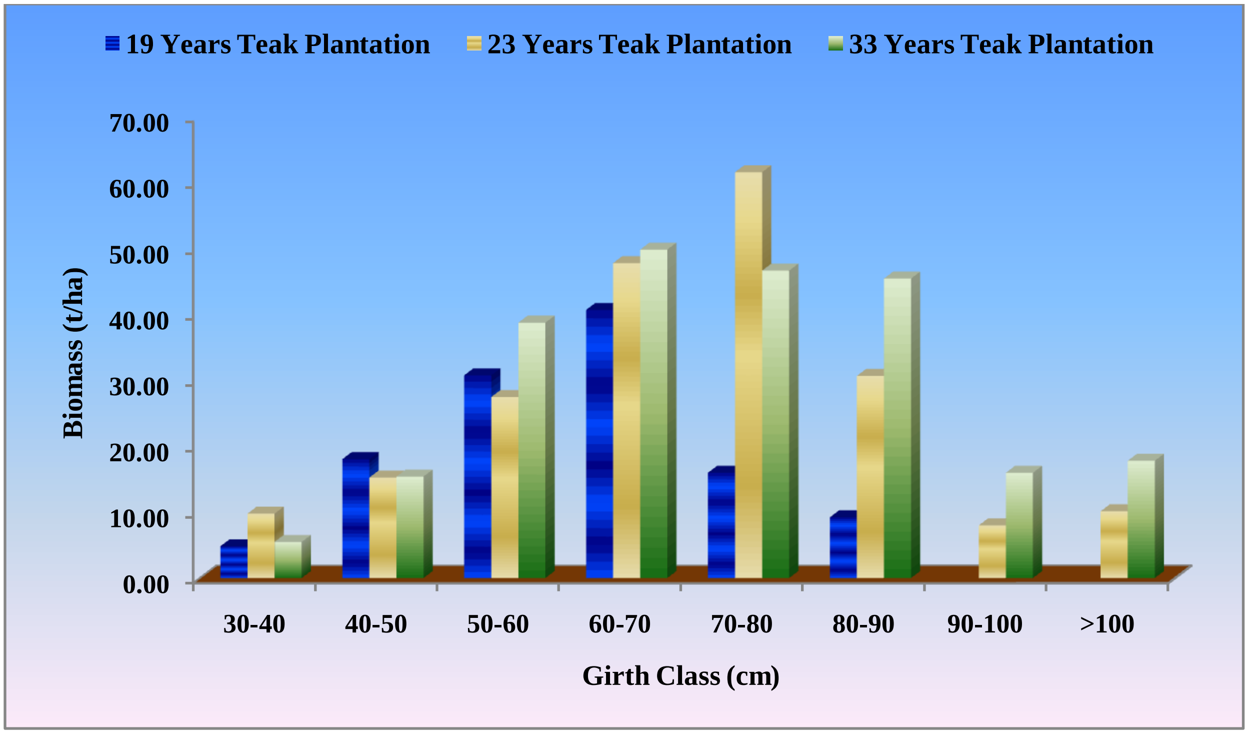

Fig. 4.4: Distribution pattern of biomass along the girth classes in an age series of teak plantation.

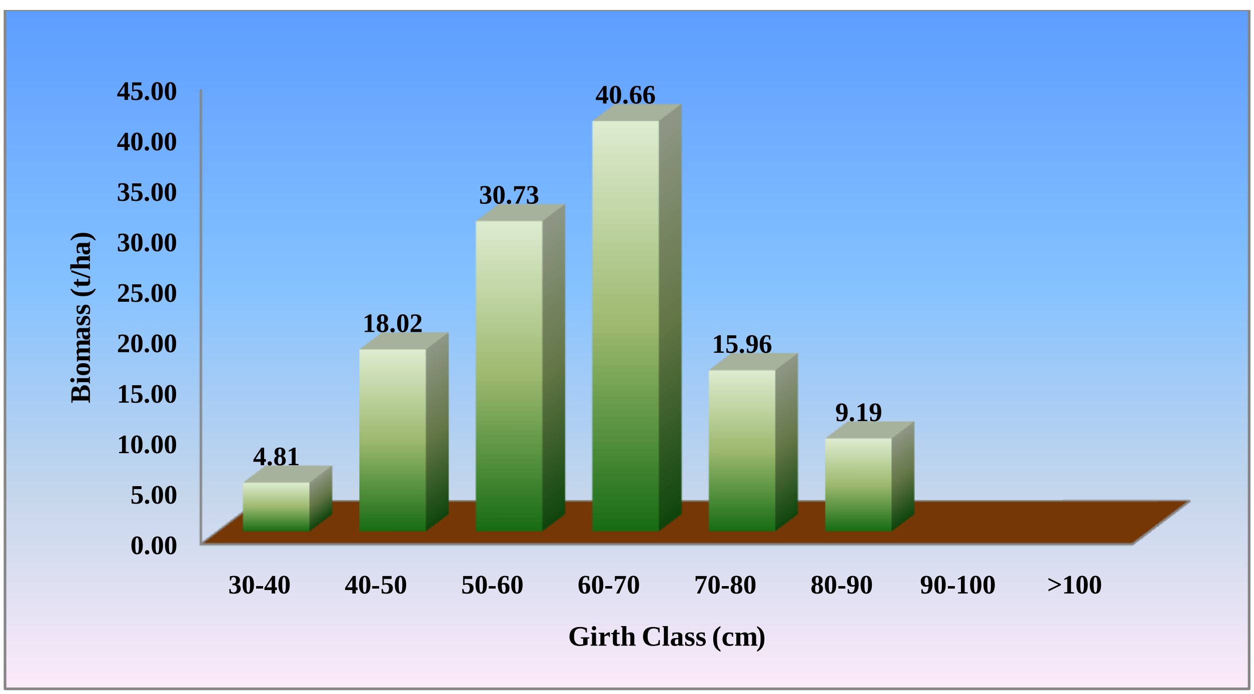

Fig. 4.5: Distribution pattern of biomass along the girth classes in 19 years old teak plantation.

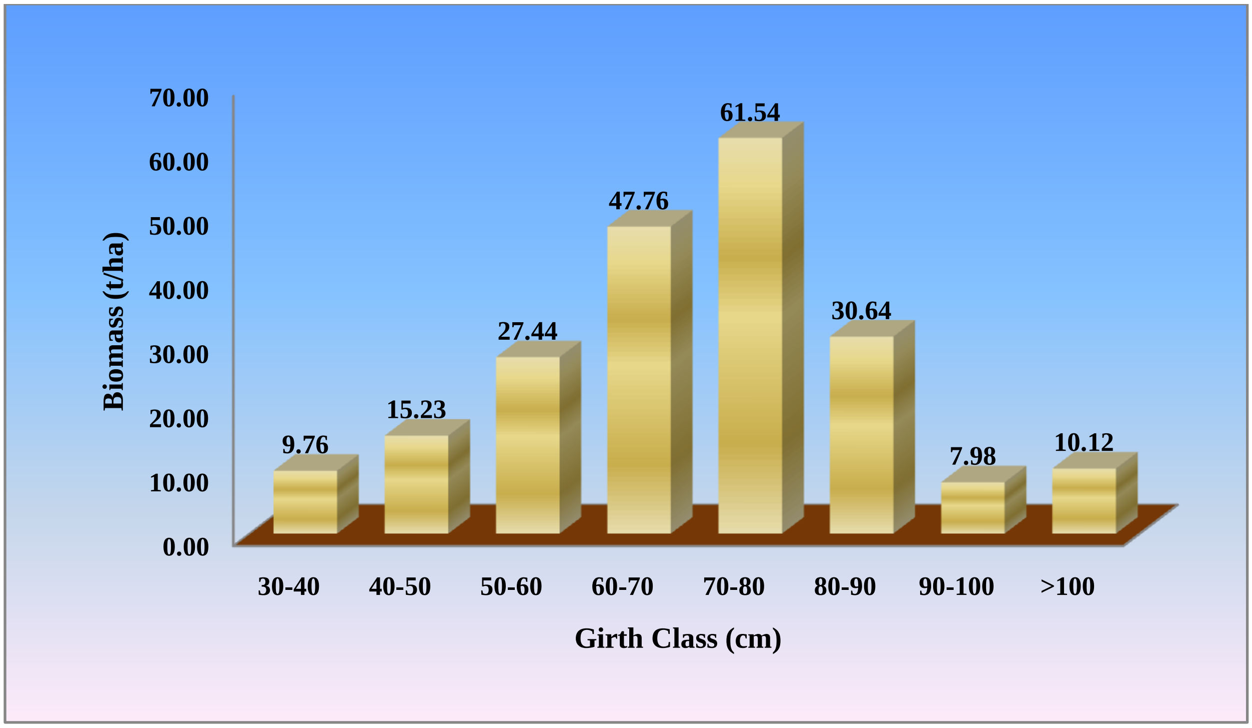

Fig. 4.6: Distribution pattern of biomass along the girth classes in 23 years oldteak plantation.

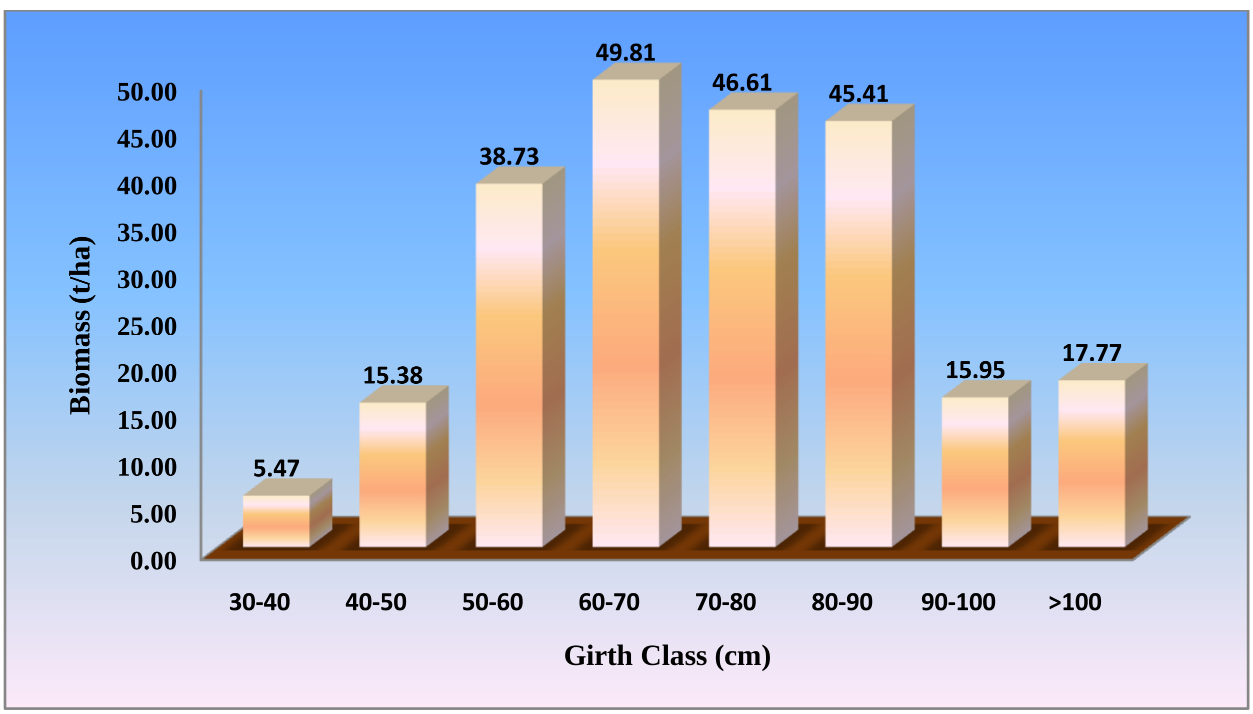

Fig. 4.7: Distribution pattern of biomass along the girth classes in 33 years oldteak plantation.

4.2.2.1 19 years old teak plantation

The total forest floor biomass was 2.19 t ha^{-1} on this site (Table 4.7). The distribution of biomass in the different components was 0.90 t ha^{-1} in fresh leaf litter, 0.67 t ha^{-1} in wood litter and 0.62 t ha^{-1} in decayed litter (Fig. 4.9). The fresh leaf litter, wood litter and decayed litter constituted 41.10, 30.59 and 28.31%, respectively of the total forest floor biomass.

4.2.2.2 23 years old teak plantation

The total forest floor biomass was 2.31 t ha^{-1} on this site (Table 4.7). The distribution of biomass in the different components was 1.35 t ha^{-1} in fresh leaf litter, 0.51 t ha^{-1} in wood litter and 0.45 t ha^{-1} in decayed litter (Fig. 4.9). The fresh leaf litter, wood litter and decayed litter constituted about 58.44, 22.08 and 19.48%, respectively of the total forest floor biomass.

4.2.2.3 33 years old teak plantation

The total forest floor biomass was 2.66 t ha^{-1} on this site (Table 4.7). The distribution of biomass in the different components was 0.87 t ha^{-1} in fresh leaf litter, 1.18 t ha^{-1} in wood litter and 0.61 t ha^{-1} in decayed litter (Fig. 4.9). The fresh leaf litter, wood litter and decayed litter constituted 32.71, 44.36 and 22.93%, respectively of the total forest floor biomass.

Lodhiyal *et al.* (1995) found the increasing trend in forest floor litter mass of poplar plantations in Central Himalaya. Present study were also supported by Kumar *et al*. (2011).The total forest floor biomass was 4.04 t ha^{-1} for 5 years age plantation, 4.92 t ha^{-1} for 10 years age plantation and 5.1 t ha^{-1} for 15 years age plantation in the study of Kumar *et al*. (2011).

4.2.3 Fine root biomass

Total fine root biomass in the present study was between 4.80 t ha^{-1} and 9.81 t ha^{-1} (Table 4.8). The fine root biomass value was highest on 19 years old teak plantation (9.81 t ha^{-1}) followed by 23 years old teak plantation (7.75 t ha^{-1}) and lowest on 33 years old teak plantation (4.80 t ha^{-1}). The fine root biomass decreases with age of the teak plantation. Analysis of variance indicated that the variation in fine root biomass due to age of plantation (site) were non-significantly different at 5% level of significance.

Lodhiyal *et al.* (1995) observed the fine roots biomass as 1.2 t ha^{-1} for 5 years age plantation, 1.2 t ha^{-1} for 6 years age plantation, 1.1 t ha^{-1} for 7 years age plantations and 1.0 t ha^{-1} for 8 years age plantations, similar trend were also observed in present study which revealed that the fine root biomass was remain higher in young plantation than the mature ones. Fine root biomass in present study was found to be higher than the findings made by Kumar *et al.* (2011).

Vanninen and Makela (1999) observed that the fine root biomass of pine stand differing in age was the lower than the present findings in different age series of the plantations. Barbhuiya *et al. (*2012) estimated the fine root dynamics in undisturbed and disturbed stands of a tropical wet evergreen forest in India and stated that in the highly disturbed stand; more than 90 % of the fine root biomass was recorded in the surface soil layer, whereas in the moderately disturbed and undisturbed stands the proportion averaged 67%. Root turnover also decreased with increasing soil depth, root size and intensity of stand disturbance. In the undisturbed, moderately disturbed and highly disturbed stands the annual fine-root turnover was 3181, 1701 and 822 kg ha^{-1} yr^{-1}, respectively. The study revealed that growth and accumulation of fine roots varied with

Table 4.7: Forest floor biomass (t/ha) in various components in an age series of teak plantation at Barnawapara Wildlife Sanctuary

Forest Floor Biomass	**19 Years Teak Plantation**	**23 Years Teak Plantation**	**33 Years Teak Plantation**
Fresh leaf litter	0.90	1.35	0.87
Decayed litter	0.62	0.45	0.61
Wood litter	0.67	0.51	1.18
Total	2.19	2.31	2.66

Table 4.8: Fine root biomass (t/ha) in an age series of teak plantation at Barnawapara Wildlife Sanctuary

Plantation	**Fine Root Biomass**				**Total**
	Thickness < 5mm		**Thickness > 5mm**		
	Live	Dead	Live	Dead	
19 Years Teak Plantation	2.67	4.28	2.86	-	9.81
23 Years Teak Plantation	1.55	2.22	3.98	-	7.75
33 Years Teak Plantation	1.28	2.49	0.98	0.05	4.80

Table 4.9: Comparative account of stand biomass (t ha^{-1}) of certain tropical forests and plantations of the world

Forest type	Location	Stand biomass			Source
		Aboveground	Belowground	Total	
Tropical lower montane Rain	New Guinea	310	39	349	Edward and Grabb (1977)
Tropical wet	Cambodia	322	60	382	Hozum*et al.* (1969)
Tropical wet evergreen	India	-	-	440-588	Swamy *et al.* (2010)
Tropical Rain	Ghana	233	54	287	Greenland and Kowal (1960)
	Wisconsin, USA	1-358	-	-	Zheng*et al*. (2004)
	Thailand	167	-	-	Clark *et al*.(2001)
Tropical montane wet	Venezuela	347	73	420	Brun (1976)
Tropical Moist	Brazil Amazonia	377	104	481	Klinge and Herrera (1978)
	Ivory Coast	151.5	29	180.5	Clark *et al*. (2001)
	Calakmul, Campeche	116.37	-	-	Navar (2011)
	La Pila, S.L.P.	173.25	-	-	Navar (2011)
	Chuchupe, S.L.P.	167.43	-	-	Navar (2011)
	Chamela, Jalisco	136.42	-	-	Read & Lawrence (2008)
Tropical Plantations	Puerto Rica	-	-	0.4-506	Lugo *et al.* (1988)
Tropical premontane Moist	Papua-New Guinea	286	46	332	Enright (1979)
	Zaire	320	51	371	Freson*et al*. (1974)
	Ivory Coast	431	24	455	Huttel and Bernhard-Reversat (1975)
Sub-tropical lower montane wet	Jamaica	279	65	344	Tanner (1980)
Sub-tropical wet	Eleverde Puerto Rico	237	116	353	Crow (1980)
	Global pattern	228	89	317	Jordan (1971a)
Sub-tropical Moist	India	67.4-134.3	-	83.6-170	Lodhiyal *et al*.(1995)
	India	26.68-109.86	14.75-38.06	41.43-132.26	Sharma *et al*.(2002)
Sub-tropical Dry	India	28	12	40	Vyas*et al*. (1977)
	Puerto Rico Guanica	53	45	98	Murphy and Lugo (1986a)
Tropical Dry	Global pattern	3-273	10-45	78-320	Murphy and Lugo (1986b)
	India	67.4	-	-	Haripriya (2000)
	India	71.94-162.91	13.97-30.02	85.78-192.93	Singh *et al*. (2009)
	India	28.12-85.26	9.01-15.62	37.12-100.88	Pande (2005)
	India	83-87	13-17	183.7-298.3	Kumar *et al*. (2011)
	Puerto Rica	84.8	-	-	Clark *et al*. (2001)
	Nigeria	49.22-141.29			Mbaekwe and Mackenzie (2008)
	Chamela, Jalisco	47.74			Jaramillo *et al*. (2003)
	Mexico	126	17.1	143.1	Jaramillo *et al*. (2003)
	West Africa	29.88	-	-	Thenkabail*et al*.(2004)
	Baja California Sur	40.06	-	-	Navar (2011)
	Vado Hondo, Sinaloa	47.81	-	-	Navar (2011)
	Tiniaquis, Sinaloa	58.15	-	-	Navar (2011)
	Morelos	14.13	-	-	Navar (2011)
	India	99.08-197.87	20.29-37.26	119.37-235.14	Present study

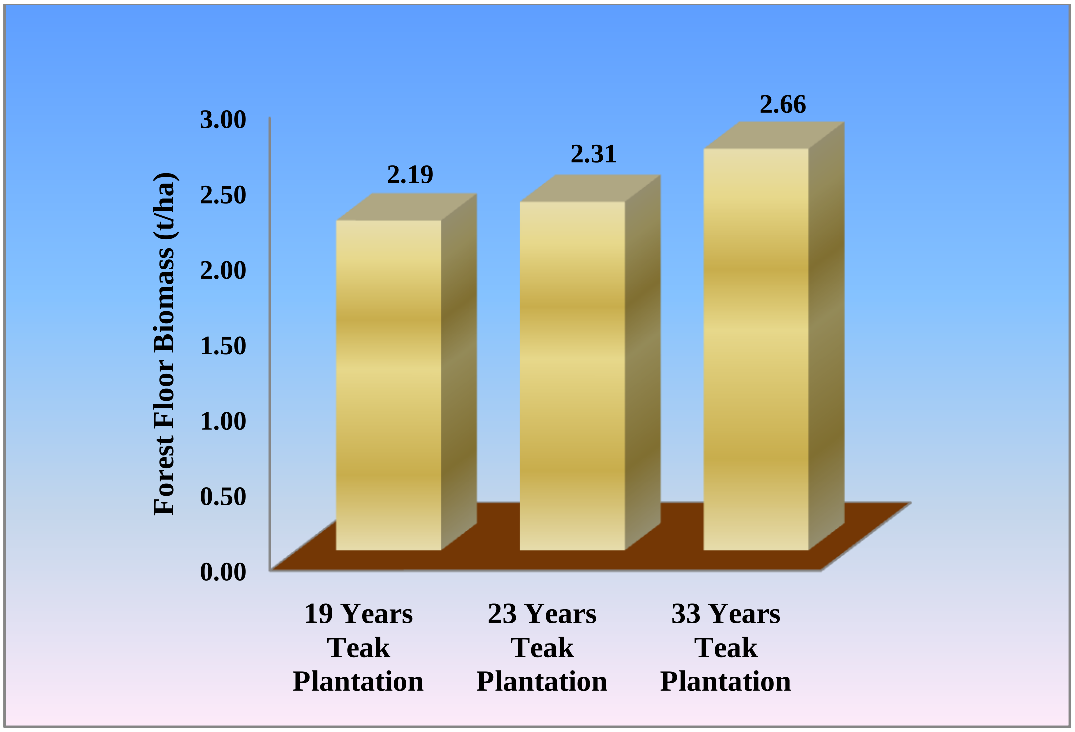

Fig. 4.8: Distribution pattern of forest floor biomass on different sites.

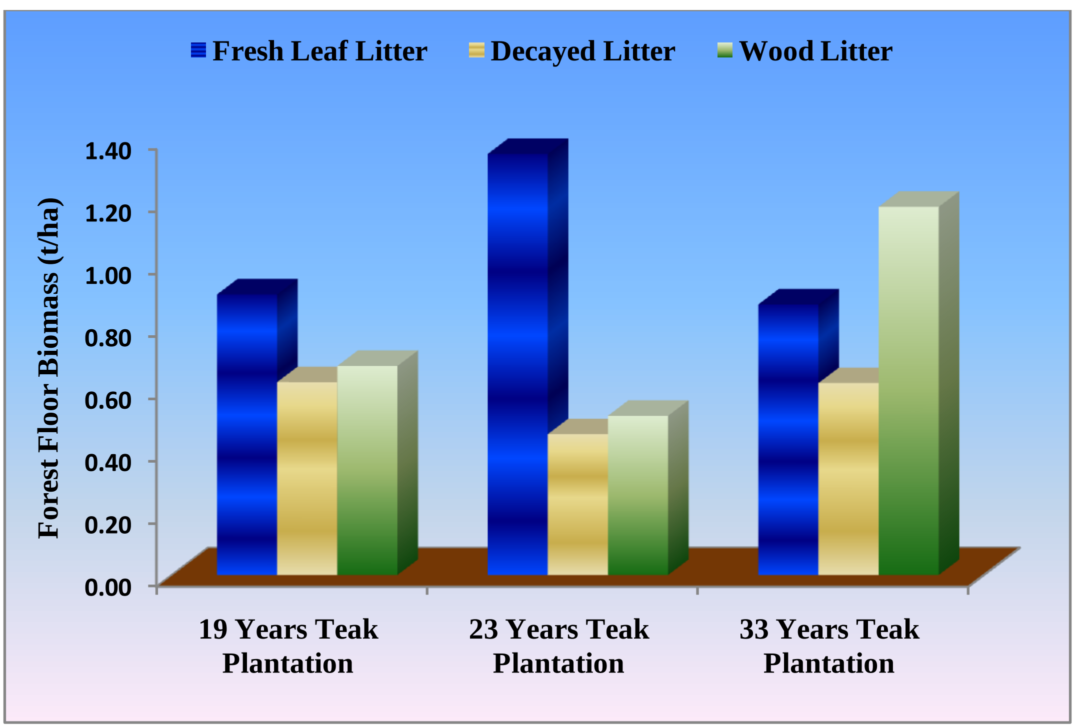

Fig. 4.9: Distribution pattern of various componentsof forest floor biomass on different sites.

species composition, tree density and basal area. These estimates were three times lower than the present findings of fine root biomass.

4.3 Estimation of carbon storage pattern in an age series of teak plantation

The carbon concentration (Table 4.10) in bole, branch, leaf and coarse roots were 43.50 %, 45.67 %, 46.67 % and 35.73%, respectively. The total carbon (C) in trees varied from 51.32 - 101.40 t ha^{-1} (Table 4.11). The total C increased with age of the plantation from about 51.32 t ha^{-1} in 19 years old teak plantation to 101.40 t ha^{-1} in 33 years old teak plantation. Quantity of C in aboveground and belowground portion in trees on different plantation was between 44.07 - 88.09 t ha^{-1} and 7.25 - 13.31 t ha^{-1}, respectively. In different components of trees on the three plantations the quantity of C varied from 26.24 - 50.51t ha^{-1} in bole, 11.66 - 26.42 t ha^{-1} in branch, 6.17 - 11.16 t ha^{-1} in leaf and 7.25 - 13.31 t ha^{-1} in root. The relative contribution of C by aboveground and belowground components in the total C storage was 85.87 - 86.87 % and 13.13 – 14.13 %, respectively. Analysis of variance indicated that the variation in C among the different age of plantation were significantly different at 5% level of significance.

4.3.1 19 years old teak plantation

The total carbon estimated in 19 years old teak plantation (Table 4.11) was 51.32 t ha^{-1}, of which 44.07 t ha^{-1} was above ground and 7.25 t ha^{-1} below ground. The distribution of carbon in the different components was 26.24 t ha^{-1} in bole, 11.66 t ha^{-1} in branch, 6.17 t ha^{-1} in leaf and 7.25 t ha^{-1} in root. The bole, branch, leaf and root constituted 51.13, 22.72, 12.02 and 14.13 per cent, respectively of the total carbon. Among the individual species *Tectona grandis* constituted the highest carbon (50.51 t ha^{-1}) followed by *Diospyros melanoxylon* (0.38 t ha^{-1}) and *Cleistanthus collinus* (0.23 t ha^{-1})

Table 4.10: Carbon concentration in different components of tree

Components	**Carbon %**
Bole	43.50
Branch	45.67
Foliage	46.67
Coarse roots	35.73

Table 4.11: Carbon (t ha^{-1})storage pattern at Barnawapara Wildlife Sanctuary

		19 Years Teak Plantation					**23 Years Teak Plantation**					**33 Years Teak Plantation**				
S. No.	**Species**	Bole	Branch	Leaf	Root	**Total**	Bole	Branch	Leaf	Root	**Total**	Bole	Branch	Leaf	Root	**Total**
1	*Boswelliaserrata*Roxb. exColebr.	-	-	-	-	-	0.18	0.17	0.02	0.05	0.43	-	-	-	-	-
2	*Bridelicaretusa*Spreng.	-	-	-	-	-	-	-	-	-	-	0.41	0.51	0.05	0.13	1.09
3	*Buchnanialanzan*Spreng.	-	-	-	-	-	0.15	0.10	0.02	0.04	0.31	0.86	0.57	0.14	0.22	1.78
4	*Cassia fistula* Linn.	-	-	-	-	-	-	-	-	-	-	0.28	0.31	0.03	0.09	0.71
5	*Cleistanthuscollinus*Roxb.	0.10	0.08	0.01	0.03	0.23	-	-	-	-	-	0.69	0.82	0.08	0.21	1.80
6	*Diospyrosmelanoxylon*Roxb.	0.18	0.13	0.02	0.06	0.38	0.10	0.06	0.01	0.03	0.20	0.10	0.06	0.01	0.03	0.20
7	*Emblicaofficinalis*Gaertn.	-	-	-	-	-	-	-	-	-	-	0.52	0.72	0.05	0.15	1.44
8	*Lagerstroemia parviflora*Roxb.	0.09	0.07	0.01	0.03	0.21	1.68	1.47	0.26	0.63	4.03	0.75	0.70	0.11	0.30	1.85
9	*Lanneacoromandelica*Houtt.	-	-	-	-	-	-	-	-	-	-	0.18	0.17	0.02	0.05	0.43
10	*Madhucaindica* J.F. Gmel.	-	-	-	-	-	-	-	-	-	-	0.69	0.82	0.08	0.21	1.80
11	*Semecarpusanacardium* Linn. f.	-	-	-	-	-	0.18	0.17	0.02	0.05	0.43	-	-	-	-	-
12	*Tectona grandis* Linn. f.	25.88	11.38	6.13	7.13	50.51	43.65	20.05	10.14	11.43	85.27	45.52	21.16	10.53	11.77	88.98
13	*Terminaliatomentosa* Roth.	-	-	-	-	-	-	-	-	-	-	0.51	0.59	0.06	0.16	1.32
	Total	26.24	11.66	6.17	7.25	**51.32**	45.92	22.01	10.48	12.24	**90.66**	50.51	26.42	11.16	13.31	**101.40**

which constituted 98.42, 0.74 and 0.49 per cent of the total carbon. However, lowest carbon was estimated for *Lagerstroemia parviflora* (0.21 t ha^{-1}).

4.3.2 23 years old teak plantation

The total carbon estimated in 23 years old teak plantation (Table 4.11) was 90.66 t ha^{-1}, of which 78.41 t ha^{-1} was above ground and 12.24 t ha^{-1} below ground. The distribution of carbon in the different components was 45.92 t ha^{-1} in bole, 22.01 t ha^{-1} in branch, 10.48 t ha^{-1} in leaf and 12.24 t ha^{-1} in root. The bole, branch, leaf and root carbon constituted 50.65, 24.28, 11.55 and 13.50 per cent, respectively of the total carbon. Among the individual species *Tectona grandis* constituted the highest carbon (85.27 t ha^{-1}) followed by *Lagerstroemia parviflora* (4.03 t ha^{-1}) and *Boswellia serrata* (0.43 t ha^{-1}) which constituted 94.05, 4.45 and 0.47 per cent of the total carbon. However, lowest carbon was measured for *Diospyros melanoxylon* (0.20 t ha^{-1}).

4.3.3 33 years old teak plantation

The total carbon estimated in 33 years old teak plantation (Table 4.11) was 101.40 t ha^{-1} of which 88.09 t ha^{-1} was above ground and 13.31 t ha^{-1} below ground. The distribution of carbon in the different components was 50.51 t ha^{-1} in bole, 26.42 t ha^{-1} in branch, 11.16 t ha^{-1} in leaf and 13.31 t ha^{-1} in root. The bole, branch, leaf and root carbon constituted 49.81, 26.06, 11.00 and 13.13 per cent, respectively of the total carbon. Among the individual species *Tectona grandis* constituted the highest carbon (88.98 t ha^{-1}) followed by *Lagerstroemia parviflora* (1.85 t ha^{-1}) and *Cleistanthus collinus* (1.80 t ha^{-1}) which constituted 87.75, 1.82, and 1.78 per cent of the total carbon. However, lowest carbon was measured for *Diospyros melanoxylon* (0.20 t ha^{-1}).

The present estimates of carbon storage pattern in age series of teak plantation were resembled with the Kraenzel *et al.* (2003) and other estimates (Table 4.12). They have reported that the carbon storage of harvest age teak (*Tectona grandis*), Panama, of 20 years old teak plantation trees in four sites. The aboveground tree carbon storage varied from 86.8 t C ha^{-1} to 122.2 t C ha^{-1}, whereas the total tree carbon storage were ranged between 99.8 t C ha^{-1} to 140.6 t C ha^{-1}, respectively.

Petsri *et al.* (2007) estimated the aboveground carbon content in mixed deciduous forest and teak plantations. The aboveground carbon content was likely to increase according to age. That is to say, the aboveground carbon content found in the teak plantation trees aged 6, 10, 15, and 23 and 24 years old and in the mixed deciduous forest was 29.76, 33.84, 29.38, 49.72, 37.58 and 60.06 t ha^{-1}, respectively. Furthermore, the density of stands was positively related to the aboveground carbon content. Namely, the greater the density of tree stands, the greater the aboveground carbon content. Similar trend were also found in present study but the total carbon was slightly higher and increasing as the age of plantation increasing. According to the Singh *et al.* (2009), the carbon storage was maximum in natural forest (96.44 Mg ha^{-1}) followed by 32 years old converted forest (47.801 Mg ha^{-1}), 15 years old converted forest (46.25 Mg ha^{-1}) and 23 years old converted forest (42.88 Mg ha^{-1}). In the present study the total carbon storage pattern is much higher i.e. 52.85% for 33 years teak plantation and 52.70% for 23 years teak plantation, respectively.

Derwisch *et al.* (2009) evaluated the aboveground carbon storage of *Tectona grandis* in Western Panama, of 1, 2 and 10-years old plantations. The average aboveground C storage ranged from 2.9 Mg C ha^{-1} in the 1 year old plantations to 40.7

Table 4.12: Comparative account of carbon storage (t ha^{-1}) in certain tropical forests and plantations of the world

Forest type	**Location**	**Carbon storage**	**Source**
Tropical humid forest		3.2-27.5	Shepherd and Montagnini (2001)
Subtropical moist forest	Australia	498	Keith *et al.* (2008)
Tropical forest		180 (aboveground)	Jaramillo *et al.* (2003)
	Panama	99.8-140.6	Kraenzel *et al.*(2003)
	Global pattern	46-183	Brown and Lugo (1982)
	Thailand	126	Gajaseni (2000)
	Australia	111-248	Keith *et al.* (2008)
	Thailand	15.97	Viriyabuncha*et al.*(2002)
	Thailand	29.38-60.06	Petsri*et al.*(2007)
	India	33.7 (aboveground)	Haripriya (2000)
	Thailand	48.14-137 (aboveground)	Terakunpisut *et al.*(2007)
	India	42.88-96.44	Singh *et al*. (2009)
	India	51.32-101.40	Present study

Mg C ha^{-1} in the 10 years old plantations. The CO_2 storage over this period amounted to 191.1 Mg CO_2 ha^{-1}, the projected carbon storage were twice higher than the present carbon estimates for 23 years old teak plantation (90.66 t ha^{-1}). In the present study the carbon storage pattern were increasing towards the age series of the teak plantation. Similar findings were also made by Fonseca *et al.* (2011) which stated that accumulation of carbon and the biomass increased with the plantation age.

Distribution pattern of carbon in an age series of teak plantation

Distribution pattern of carbon across the girth classes also followed the similar pattern as was the case with biomass distribution. It was negligible in young individuals belonging to seedlings and saplings classes and highest storage was observed in middle girth classes in an age series of teak plantation (Fig. 4.10-4.13).

4.4 Soil properties in age series of teak plantation

The chemical properties of soil across the age of plantation sites viz., 19 years old teak plantation, 23 years old teak plantation and 33 years old teak plantation is given in Table 4.13. Analysis of variance indicated the variation in total nitrogen and total cabon among the different age of plantation were significantly different at 5% level of significance. Available phosphorus and available potassium were not significantly different at 5% level of significance.

Total nitrogen observed under soil in age series of teak plantation ranged from 0.083 to 0.143% for surface soil (0-10 cm) and 0.064 to 0.091% for lower layer soil (10-20 cm). Among the plantations, the 23 years old teak plantation contained maximum nitrogen content at both the soil depth as compare to the other plantations.

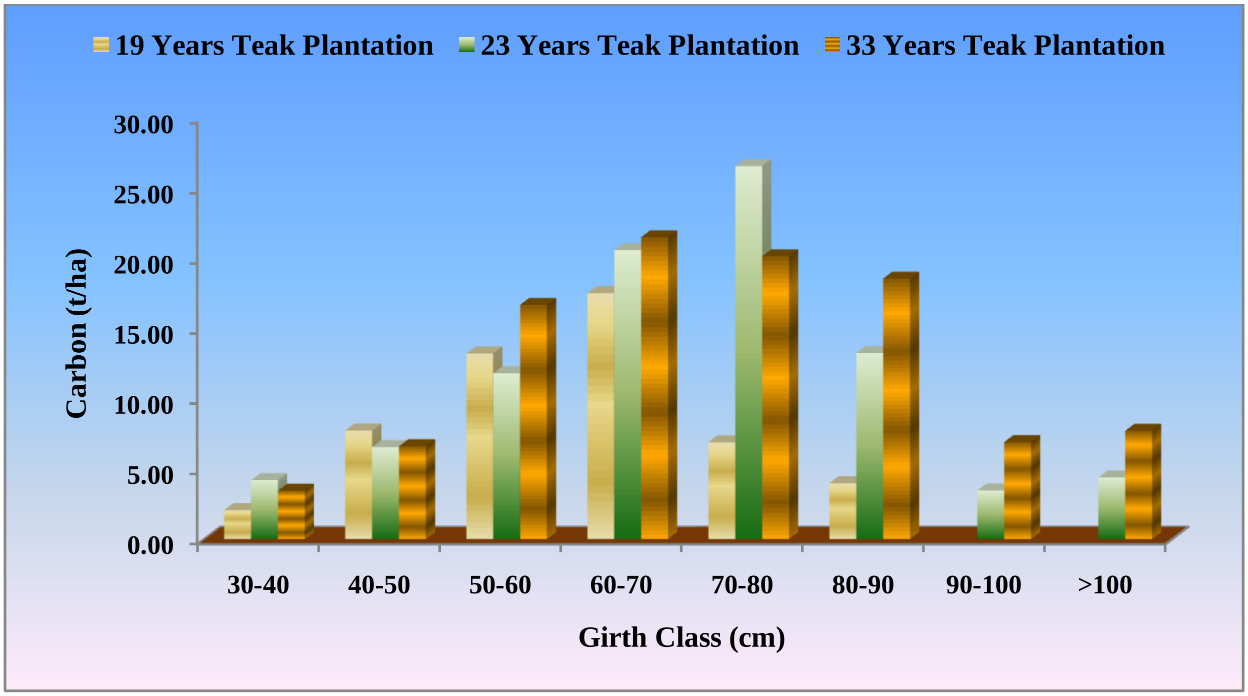

Fig. 4.10: Distribution pattern of carbon along the girth classes in age series of teak plantation.

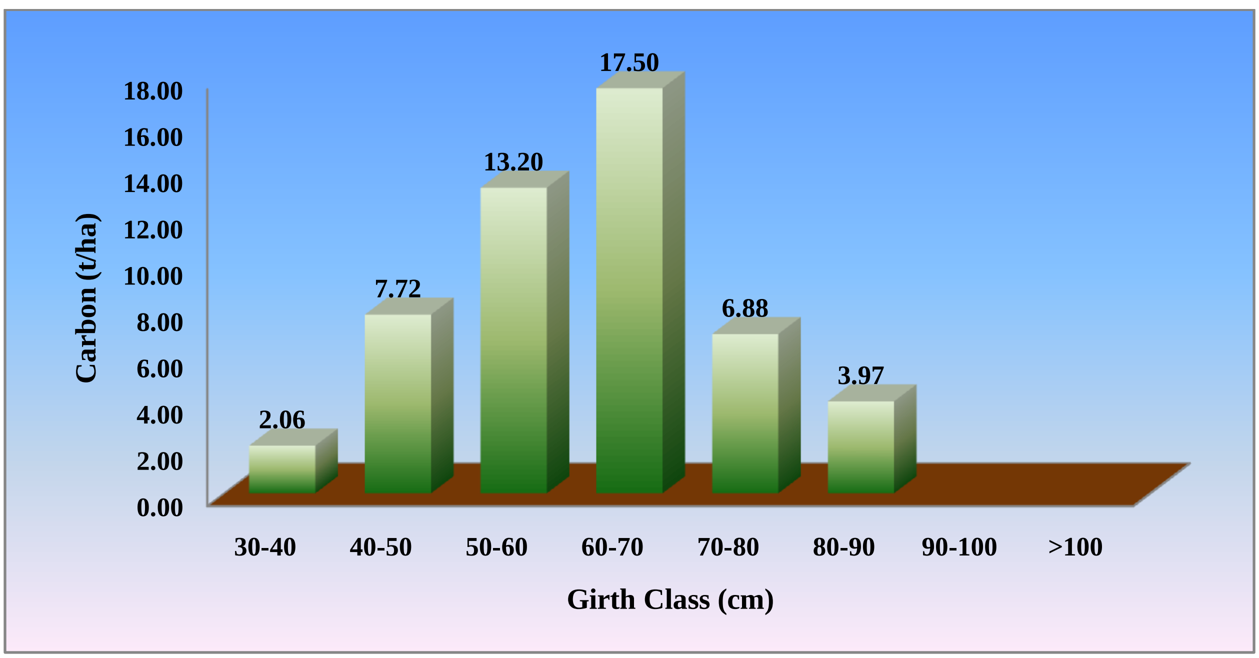

Fig. 4.11: Distribution pattern of carbon along the girth classes in 19 years oldteak plantation.

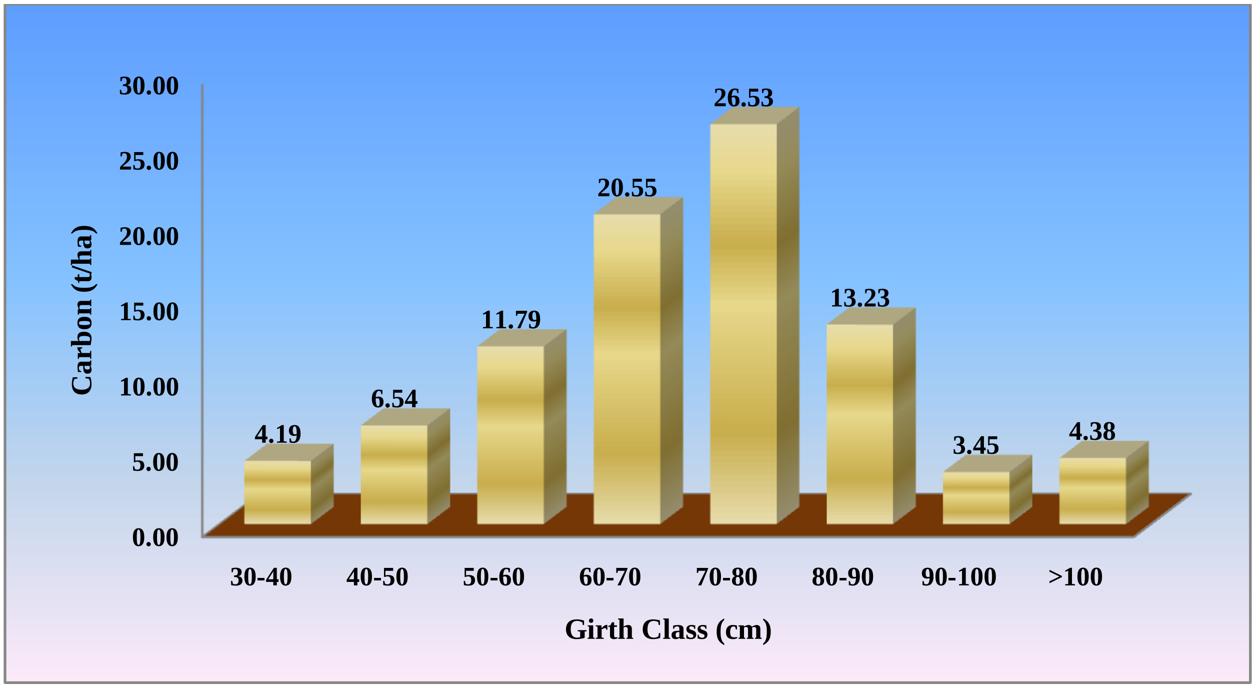

Fig. 4.12: Distribution pattern of carbon along the girth classes in 23 years oldteak plantation.

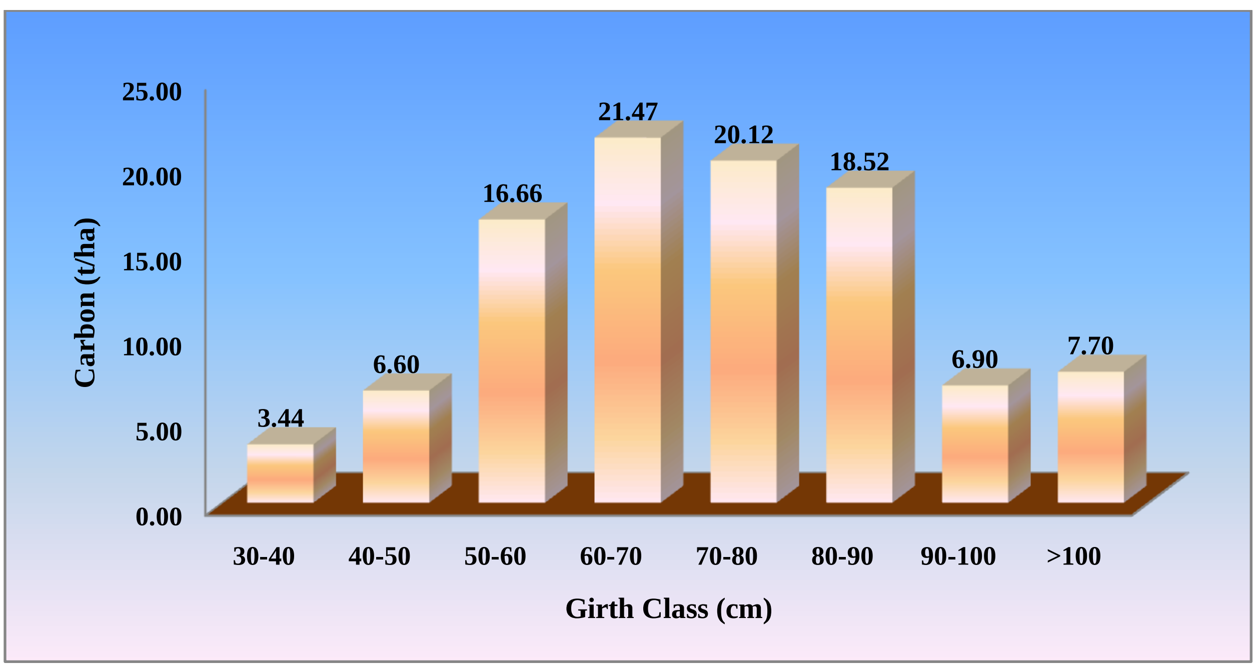

Fig. 4.13: Distribution pattern of carbon along the girth classes in 33 years oldteak plantation.

Table 4.13: Chemical properties of soil in an age series of teak plantation at Barnawapara Wildlife Sanctuary

Chemical Properties of Soil	**19 Years Teak Plantation**		**23 Years Teak Plantation**		**33 Years Teak Plantation**	
	0-10	**10-20**	**0-10**	**10-20**	**0-10**	**10-20**
Total N %	0.104	0.064	0.143	0.091	0.083	0.079
Total C %	1.129	0.703	1.736	1.312	1.124	1.084
Available P (kg/ha)	8.55	12.04	11.88	15.72	13.74	12.06
Available K (kg/ha)	314.07	335.48	382.21	266.47	292.95	249.54

Total carbon observed under soil in age series of teak plantation were ranged from 1.124 to 1.736% for surface soil sample (0-10 cm) and 0.703 to 1.312% for lower layer soil sample (10-20 cm). Among the plantations, the 23 years old teak plantation contained maximum carbon content at both the soil depth as compare to the other plantations.

The concentration of available phosphorus (0-20 cm) under the 19 years old teak plantation and 33 years old teak plantation varied from 8.55 to 12.04 kg ha^{-1} and 13.74 to 12.06 kg ha^{-1}, respectively (Table 4.13). The availability of phosphorus (0-20 cm) in the soil of 23 years old teak plantation was found to be higher as 11.88 to 15.72 kg ha^{-1} than the other plantations. Whereas, it was recorded minimum in the 19 years old teak plantation.

The result of available potassium for the soil (0-20 cm) were 314.07 to 335.48 kg ha^{-1}, 382.21 to 266.47 kg ha^{-1} and 292.95 to 249.54 kg ha^{-1} under 19 years old teak plantation, 23 years old teak plantation and 33 years old teak plantation, respectively. In all the study sites the potassium content was low in 33 years old teak plantation while it was higher under the soil of 23 years old teak plantation.

In general, most microbial activity occurs in the upper soil layers (0-20 cm) as soil at this depth is more nutritious and porous. Burke (1989) suggested that nutrient accumulation is a dynamic ecosystem property and is influenced by slowly changing landscape pattern in semi-arid ecosystem; nutrient dynamics are closely linked to seasonal variation in temperature and moisture. Moreover, the higher values of mineral N, inorganic P and soil physical properties close to trees could be attributed to higher amount of organic matter inputs through litter fall, root mortality and herbaceous biomass**.** Singh *et al*. (2000) reported that temporal variation in soil organic carbon, increased soil organic carbon and coincided with the periods of litter production. Subsequent to deforestation, decomposition rates of organic matter, both on the soil surface and within the top soil layers, are enhanced, rendering the system vulnerable to leakage of nutrients.

Singh and Singh (2002) have reported the soil nutrients were significantly higher in the plantation area compared with the non-planted control plot. Soil pH, PO_4-P, Ca, Mg and K concentrations decreased with stand age whereas SOM, NH_4-N, NO_3-N, Cu, Zn and Mn increased, reverse trend was noticed in the present study. Kumar *et al.* (2010) have reported organic carbon between 2.23 - 2.81 %, while concentration of nitrogen from 0.16 - 0.21 %, and that of phosphorus from 0.021- 0.033 % in all three sites, which is compared with the present findings. Tangsinmankong *et al.* (2007) studied the carbon stocks in soil of mixed deciduous forest and teak plantation. Results revealed that soil organic carbon from all sites decreased generally with the increasing depth from the surface soil to the lower layer soil. Similar observations were observed the present study. Contrary to this they also showed the highest carbon stocks in soils of 6 years old teak plantation followed by the 24 and 15 years old teak plantations and mixed deciduous forest i.e., 157.03, 105.67, 78.78 and 70.96 t C ha^{-1} respectively. The dissimilarity of soil organic carbon may be due to forest fire, forest management and topography.

Takahashi *et al.* (2009) studied the soil respiration in different ages of teak plantations in Thailand. They concluded that carbon dynamics in the soil under teak plantations were determined by the soil moisture regime, which is controlled by seasonal rainfall pattern and annual rainfall. Soil respiration in teak plantations had no clear difference between different stand ages. Chauhan *et al.* (2010) reported the soil organic carbon in natural forest as 2.2% and 1.5% in plantation forest whereas the available phosphorus was 10.7 kg ha^{-1} and 8.4 kg ha^{-1} for both natural and plantation forest. They reported the value of N as 209.2 kg ha^{-1} for natural forest and 170 kg ha^{-1} for plantation forest whereas the available K was 331 kg ha^{-1} for natural forest and 294.5 kg ha^{-1} for plantation forest. The values were found within the range for the present findings.

SUMMARY, CONCLUSION AND SUGGESTION FOR FUTURE RESEARCH WORK

CHAPTER-V

SUMMARY CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

“A Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment” was carried out in teak plantation at Barnawapara wildlife sanctuary situated in North-Eastern corner of Raipur district which is located between $21^0$20’0” to $21^0$25’47” North latitudes and $82^0$21’17 to $82^0$26’27” East longitudes having an area of 244.66 km^2 during the year 2011-2012.

The species structure, species diversity, biomass and carbon storage pattern in age series of teak plantation was measured by randomly placing quadrats of 10 m × 10 m in size at three plantation sites. Randomly 10 quadrats were laid down on each plantation sites. In each quadrat GBH (girth at breast height) of each tree individuals were measured. In the center of each 10 m × 10 m quadrat, 2 m × 2 m quadrat area was marked for enumeration of saplings and seedlings. The structural analysis was done by quantifying frequency, density and basal area. Subsequently, relative frequency, relative density, relative basal area and IVI were computed using frequency, density and basal area. The diversity parameters viz., Shannon index, Simpson’s Index, equitability, species richness and beta diversity were calculated for each plantation sites. Biomass for each forest sites was estimated using allometric equations based on the relationship between girth of a tree and dry weight of component. The carbon storage for the vegetation components was computed as the sum of the products obtained by multiplying dry weights of components with their mean carbon concentrations. The salient findings on “A

Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment" are summarized below:

Species structure

19 years old teak plantation

- In 19 years old teak plantation *Tectona grandis* emerged as dominant plant species.
- Maximum density was observed for *Tectona grandis* (980 stems ha^{-1}) followed by *Cleistanthus collinus* (10 stems ha^{-1}) and *Diospyros melanoxylon* (10 stems ha^{-1}).
- Maximum basal cover was observed for *Tectona grandis* (23.23 m^2 ha^{-1}) followed by *Diospyros melanoxylon* (0.16 m^2 ha^{-1}).
- Lowest basal cover (0.08 m^2 ha^{-1}) was measured for *Lagerstroemia parviflora* and *Cleistanthus collinus*.
- Basal area and density of individual tree species varied from 0.08 m^2 ha^{-1} to 23.23 m^2 ha^{-1} and 10 to 980 stems ha^{-1}, respectively.
- Highest IVI was calculated for *Tectona grandis* (272.62) followed by *Diospyros melanoxylon* (9.37).
- The total density and basal area in 19 years old teak plantation was 1010 trees ha^{-1} and 23.54 m^2 ha^{-1}.

23 years old teak plantation

- In 23 years old teak plantation also *Tectona grandis* again emerged as dominant plant species and *Lagerstroemia parviflora* as co-dominant plant species.
- Maximum density was observed for *Tectona grandis* (1190 stems ha^{-1}) followed by *Lagerstroemia parviflora* (150).

- Lowest tree density (10 stems ha^{-1}) was recorded for *Boswelia serrata*, *Buchnania lanzan*, *Diospyros melanoxylon* and S*emecarpus anacardium.*
- Maximum basal cover was observed for *Tectona grandis* (39.44 m^2 ha^{-1}) followed by *Lagerstroemia parviflora* (1.96) and *Buchnania lanzan* (0.18).
- Basal area and density of individual tree species varied from 0.10 m^2 ha^{-1} to 39.44 m^2 ha^{-1} and 10 to 1190 stems ha^{-1}, respectively.
- Highest value of IVI was calculated for *Tectona grandis* (223.69) followed by *Lagerstroemia parviflora* (54.66) and *Buchnania lanzan* (5.51).
- The total density and basal area of 23 years old teak plantation was 1380 trees ha^{-1} and 41.96 m^2 ha^{-1}.

33 years old teak plantation

- In 33 years old teak plantation *Tectona grandis* emerged as dominant plant species and *Buchnania lanzan* as co-dominant plant.
- Maximum density was observed for *Tectona grandis* (1170 stems ha^{-1}) followed by *Buchnania lanzan* (60 stems ha^{-1}) and *Lagerstroemia parviflora* (40 stems ha^{-1}).
- Maximum basal cover was observed for *Tectona grandis* (40.47 m^2 ha^{-1}) followed by *Buchnania lanzan* (0.86 m^2 ha^{-1}) and *Lagerstroemia parviflora* (0.66 m^2 ha^{-1}).
- Basal area and density of individual tree species varied from 0.08 m^2 ha^{-1} to 40.47 m^2 ha^{-1} and 10 to 1170 stems ha^{-1}, respectively.
- Highest IVI was recorded for *Tectona grandis* (209.72) followed by *Buchnania lanzan* (26.95) and *Lagerstroemia parviflora* (14.71).

- The total density and basal area of 33 years old teak plantation was 1380 trees ha^{-1} and 44.75 m^2 ha^{-1}.

Species diversity

- Species richness on study sites various plantations ranged from 0.43 to 1.38 and recorded highest on 33 years old teak plantation (1.38) and lowest on 19 years old teak plantation (1.38).
- Shannon index in plantations under study ranged between 0.24 to 1.07. It was highest on 33 years old teak plantation (1.07) and lowest on 19 years old teak plantation (0.24).
- Concentration of dominance ranged between 0.72 and 0.94 and highest in 19 years old teak plantation (0.94) and lowest in 33 years old teak plantation (0.72).
- Equitability (e) values ranged from 0.17 to 0.45, respectively in plantations under study and were highest on 33 years old teak plantation and lowest on 19 years old teak plantation.
- Beta diversity values in various plantations ranged from 1.18 to 3.25 and were highest on 19 years old teak plantation (3.25) and lowest on 33 years old teak plantation (1.18).

Biomass

19 years old teak plantation

- The total biomass recorded in 19 years old teak plantation was 119.37 t ha^{-1} of which 99.08 t ha^{-1} was above ground and 20.29 t ha^{-1} below ground.

- *Tectona grandis* was major species of the plantation site. The total biomass of *Tectona grandis* was 117.49 t ha^{-1}, of which 97.53 t ha^{-1} was in above ground part and 19.96 t ha^{-1} in below ground part.
- The distribution of biomass in the different components was 60.33 t ha^{-1} in bole, 25.53 t ha^{-1} in branch, 13.22 t ha^{-1} in leaf and 20.29 t ha^{-1} in root.
- The bole, branch, leaf and root constituted 50.54, 21.38, 11.07, and 16.99 per cent of the total biomass, respectively.
- The total forest floor biomass was 2.19 t ha^{-1}.
- The distribution of litter biomass in the different components was 0.90 t ha^{-1} in fresh leaf litter, 0.67 t ha^{-1} in wood litter and 0.62 t ha^{-1} in decayed litter.
- The total fine root biomass estimated was 9.81 t ha^{-1}.

23 years old teak plantation

- The total above ground biomass and below ground biomass in 23 years old teak plantation was 176.22 t ha^{-1} and 34.25 t ha^{-1}, respectively and total biomass of the site was 210.48 t ha^{-1}.
- The *Tectona grandis* constituted the highest biomass (197.96 t ha^{-1}) followed by *Lagerstroemia parviflora* (9.38 t ha^{-1}) and *Boswellia serrata* (0.98 t ha^{-1}).
- The distribution of biomass in the different components was 105.57 t ha^{-1} in bole, 48.20 t ha^{-1} in branch, 22.45 t ha^{-1} in leaf and 34.25 t ha^{-1} in root.
- The bole, branch, leaf and root biomass constituted 50.16, 22.90, 10.67 and 16.27 per cent, respectively of the total biomass.
- The total forest floor biomass was 2.31 t ha^{-1}.

- The fresh leaf litter, wood litter and decayed litter constituted 58.44, 22.08 and 19.48 per cent, respectively of the total forest floor biomass.
- The total fine root biomass was 7.75 t ha^{-1}.

33 years old teak plantation

- The total biomass recorded in 33 years old teak plantation was 235.14 t ha^{-1} of which 197.88 t ha^{-1} was above ground and 37.26 t ha^{-1} below ground biomass.
- *Tectona grandis* was major species of the plantation site. The total biomass of *Tectona grandis* was 206.48 t ha^{-1} of which 173.53 t ha^{-1} was in above ground part and 32.95 t ha^{-1} in below ground part.
- The distribution of biomass in the different components was as 116.11 t ha^{-1} in bole, 57.86 t ha^{-1} in branch, 23.91 t ha^{-1} in leaf and 37.26 t ha^{-1} in root.
- The bole, branch, leaf and root biomass constituted 49.38, 24.61, 10.17, and 15.85 %, respectively of the total biomass.
- The total forest floor biomass was 2.66 t ha^{-1}.
- The distribution of litter biomass in the different components was 0.87 t ha^{-1} in fresh leaf litter, 1.18 t ha^{-1} in wood litter and 0.61 t ha^{-1} in decayed litter.
- The total fine root biomass estimated was 4.80 t ha^{-1}.

Carbon storage

19 years old teak plantation

- The total carbon measured in 19 years old teak plantation was 51.32 t ha^{-1} of which 44.07 t ha^{-1} was above ground and 7.25 t ha^{-1} below ground.
- Highest carbon was stored in bole (26.24 t ha^{-1}) followed by branch (11.66 t ha^{-1}) and root (7.25 t ha^{-1}).

- Lowest carbon was stored in leaf (6.17 t ha^{-1}).
- The bole, branch, leaf and root carbon constituted 51.13, 22.72, 12.02 and 14.13 per cent, respectively of the total carbon.

23 years old teak plantation

- The total carbon estimated for 23 years old teak plantation was 90.66 t ha^{-1} of which 78.41 t ha^{-1} was above ground and 12.24 t ha^{-1} below ground.
- Highest carbon was stored in bole (45.92 t ha^{-1}) followed by branch (22.01 t ha^{-1}) and root (12.24 t ha^{-1}).
- Lowest carbon was stored by leaf (10.48 t ha^{-1}).
- The bole, branch, leaf and root carbon constituted 50.65, 24.28, 11.55 and 13.50 per cent, respectively of the total carbon.

33 years old teak plantation

- The total carbon recorded in 33 years old teak plantation was 101.40 t ha^{-1} of which 88.09 t ha^{-1} was above ground and 13.31 t ha^{-1} below ground.
- Highest carbon was stored in bole (50.51 t ha^{-1}) followed by branch (26.42 t ha^{-1}) and root (13.31 t ha^{-1}).
- Lowest carbon was stored in leaf (11.16 t ha^{-1}).
- The bole, branch, leaf and root carbon constituted 49.81, 26.06, 11.00 and 13.13 per cent, respectively of the total carbon.

Soil properties

- Total carbon observed under soil in age series of teak plantation ranged from 1.124 to 1.736% for surface soil (0-10 cm) and 0.703 to 1.312% for lower soil layer (10-20 cm).

- The 23 years old teak plantation contained maximum nitrogen content as compare to the other sites. It ranged from 0.083 to 0.143% for surface soil (0-10 cm) and 0.064 to 0.091% for lower soil layer (10-20 cm) on all the three sites.
- The concentration of available phosphorus (0-20 cm) was 8.55 to 12.04 kg ha^{-1} in 19 years old teak plantation, 11.88 to 15.72 kg ha^{-1} in 23 years old teak plantation and 13.74 to 12.06 kg ha^{-1} in 33 years old teak plantation.
- The available potassium for 0-20 cm soil depth was 314.07 to 335.48 kg ha^{-1}, 382.21 to 266.47 kg ha^{-1} and 292.95 to 249.54 kg ha^{-1} respectively, under 19 years old teak plantation, 23 years old teak plantation and 33 years old teak plantation.

Conclusion and suggestions for future work

Tropical forests occur under varied climatic conditions, but essentially with alternate wet and dry period. However, the structure, composition and functioning of deciduous forests undergo changes with the length of wet period, amount of rainfall, latitude, longitude and altitude and impacts of human and livestock activities. Tropical forests harbour the greatest wealth of biological and genetic diversity on the earth. These biodiversity rich forests have world attention because of the growing awareness of its importance on the one hand and the anticipated massive depletion on the other.

Fast-growing and high-yielding tree plantations are increasingly significant source of wood in the tropics. In these areas, improved wood productivity is an important economic goal. *Tectona grandis* has gained a worldwide reputation on account of the attractiveness and durability of its wood. Market demands have prompted the establishment of plantations within and beyond its native countries. Total dry matter production is a function of tree density, age and growth performance of plants.

The present study reveals that the age series in the teak plantation had significantly influenced structure, diversity, regeneration, composition, biomass and carbon storage status of sub-humid tropics. Based on the age series study, the biomass and carbon increased steadily with respect to the increase in the age, dbh and height of the plantation as the biomass is generally associated with the age and size of the trees. Biomass of the individual tree components also increased with the increase in the age of the plantation. The per cent contribution of different tree components to the total biomass was found to vary with the age of the plantation.

The practices that minimally disturb, replace or maintain the original structure of tropical forests tend to be those that are most likely to be sustainable in the long-term. However, the long-term sustainability of these forests will depend heavily on forest planning, monitoring and adaptive management strategies to ensure the successful maintenance of the ecosystem services. Due attention has been focused on teak plantation in recent years by NGOs, private companies, forest department and individuals. It is suggested that technical developments in tree breeding and in the option of reduced rotation lengths may enhance returns, but considerable research is essential on many aspects of teak plantation silviculture, management and utilization. In particular further investigation is needed into the differences in timber properties that may exist between short-rotation plantation grown and teak from natural or other long rotation stands, including the effects of provenance and site on growth rates and wood quality. Further research is needed into such aspects as the effects on growth and wood quality of pruning, the effects on the site of growing teak in mixed vegetation.

But above all, considerable uncertainty exists regarding the basic information needed to plan future teak plantation programmes. There is lack of reliable information on yields and costs but especially on future markets and prices for plantation grown teak wood for the calculation of returns. Such information is required not only to give investors a reliable indication of the likely return on investment, but also for policy decisions related to the payment of different kinds and rates of incentive for teak plantation establishment.

ABSTRACT

"A STUDY ON THE BIOMASS AND CARBON STORAGE IN AN AGE SERIES OF TEAK PLANTATION IN TROPICAL ENVIRONMENT"

By

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ABSTRACT

The present study was conducted to investigate "A Study on the Biomass and Carbon Storage in an Age Series of Teak Plantation in Tropical Environment" at Barnawapara Wildlife Sanctuary in Raipur district of Chhattisgarh during the year 2011-2012. The study was conducted in three different age of plantation in tropical environment. Forest structure was determined using phytosociological observations. Biomass for each plantation site was estimated using allometric equations based on the relationship between girth of tree and dry weight of the components (bole, branch, leaf and root). The carbon storage for the vegetation components was computed as the sum of the products obtained by multiplying dry weights of components with their mean carbon concentrations.

A total of 13 species of 9 families were encountered. Tree stand density varied from 1010-1380 stems ha^{-1} with basal area ranging from 23.54 to 44.75 m^2 ha^{-1}. Species diversity index varied between 0.24 for 19 years old teak plantation to 1.07 for 33 years old teak plantation, Simpson index of diversity ranged between 0.72 and 0.94. The Margalef ´s index of richness varied from 0.43-1.38, Equitability index varied from 0.17 to 0.45 and β diversity varied from 1.18 to 3.25.

The total biomass (t ha^{-1}) recorded in age series of teak plantation was between 119.37 t $ha^{-1}$and 235.14 t ha^{-1}, and it was highest in 33 years old teak plantation (235.14 t ha^{-1}) followed by 23 years old teak plantation (210.48 t ha^{-1}) and lowest in 19 years old teak plantation (119.37 t ha^{-1}). The total above ground biomass in different age of plantation ranged from 99.08 to 197.88 t ha^{-1} with highest in 33 years old teak plantation and lowest in 19 years old teak plantation. The below ground biomass in different plantation sites varied from 20.29 to 37.26 t ha^{-1} and it was highest in 33 years old teak plantation and lowest in 19 years old teak plantation. The total tree biomass increased with age of the plantation.

The total carbon (t ha^{-1}) recorded among the different age of plantation sites was maximum in 33 years old teak plantation (101.40) followed by 23 years old teak

plantation (90.66), and 19 years old teak plantation (51.32). The higher proportion of above ground carbon was allocated in bole followed by branch and root in different age of plantation. The above ground carbon in different age of plantation ranged between 44.07 to 88.09 t ha^{-1} with highest in 33 years old teak plantation and lowest in 19 years old teak plantation. The below ground carbon in different plantation varied from 7.25 to 13.31 t ha^{-1} and it was highest in 33 years old teak plantation and lowest in 19 years old teak plantation. The total forest floor biomass in the present findings was between 2.19 t ha^{-1} and 2.66 t ha^{-1}. It was highest on 33 years old teak plantation (2.66 t ha^{-1}) followed by 23 years old teak plantation (2.31 t ha^{-1}) and lowest on 19 years old teak plantation (2.19 t ha^{-1}). The fine root biomass values varied between 4.80 t ha^{-1} and 9.81 t $ha^{-1}$and it was decrease with age of the teak plantation.

Total carbon observed under soil in age series of teak plantation ranged from 1.124 to 1.736% for surface soil (0-10 cm) and 0.703 to 1.312% for lower soil layer (10-20 cm). The 23 years old teak plantation contained maximum nitrogen content as compare to the other sites. It ranged from 0.083 to 0.143% for surface soil (0-10 cm) and 0.064 to 0.091% for lower soil layer (10-20 cm) in all three sites. The concentration of available phosphorus (0-20 cm) was 8.55 to 12.04 kg ha^{-1} in 19 years old teak plantation, 11.88 to 15.72 kg ha^{-1} in 23 years old teak plantation and 13.74 to 12.06 kg ha^{-1} in 33 years old teak plantation. The available potassium for the soil depth 0-20 cm were 314.07 to 335.48 kg ha^{-1}, 382.21 to 266.47 kg ha^{-1} and 292.95 to 249.54 kg ha^{-1} under 19 years old teak plantation, 23 years old teak plantation and 33 years old teak plantation, respectively.

From these studies, it is evident that the biomass and carbon increased steadily with respect to the increase in the age, dbh and height of the plantation as the biomass is generally associated with the age and size of the trees. Biomass of the individual tree components also increased with the increase in the age of the plantation.

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APPENDIX

APPENDIX

Appendix-I: Allometric relationship between the log dry weight (kg) of different components (Y) on log girth (X, cm) for trees in natural forests (Based on Singh, K.P. and Misra , R. 1979). All equations are of the form Log Y = a+ b log X.

Species	component	Correlation coefficient r	intercept log a	slope b	Standard error of estimate (SEE)	Standard error of b (SE of b)
Anogeissus latifolia (n=23)	Bole	0.9977	-1.8132	2.0630	0.0346	0.0304
	Branch	0.9970	-2.4915	2.6983	0.0523	0.0460
	Leaf	0.9798	-3.2713	2.4708	0.1251	0.1100
	Root	0.9938	-2.3785	2.2849	0.0635	0.0558
	Total	0.9979	-1.8287	2.4177	0.0391	0.0344
Diospyros melanoxylon (n=21)	Bole	0.9961	-2.3639	2.4012	0.0498	0.0486
	Branch	0.9941	-3.7528	3.1466	0.0805	0.0785
	Leaf	0.9678	-2.7088	1.9890	0.1217	0.1186
	Root	0.9923	-2.5205	2.2442	0.0659	0.0643
	Total	0.9988	-2.2359	2.5331	0.0289	0.0282
Buchanania lanzan (n=24)	Bole	0.9957	-2.3043	2.3252	0.0567	0.0459
	Branch	0.9929	-4.6363	3.6077	0.1140	0.0923
	Leaf	0.9858	-2.9857	2.2339	0.1000	0.0810
	Root	0.9976	-2.6984	2.2529	0.0413	0.0334
	Total	0.9952	-2.4411	2.6143	0.0679	0.0549
Pterocarpus marsupium (n=21)	Bole	0.9937	-2.1871	2.3169	0.0632	0.0597
	Branch	0.9936	-3.3958	2.9497	0.0814	0.0769
	Leaf	0.9916	-2.3706	1.7609	0.0558	0.0527
	Root	0.9754	-2.9550	2.4184	0.1326	0.1253
	Total	0.9969	-2.1540	2.4860	0.0474	0.0448
Phyllanthus emblica (n=21)	Bole	0.9970	-2.2675	2.3179	0.0436	0.0415
	Branch	0.9914	-3.1576	2.8571	0.0910	0.0867
	Leaf	0.9910	-2.2645	1.7667	0.0574	0.0547
	Root	0.9964	-2.1898	2.0283	0.0417	0.0397
	Total	0.9987	-2.0281	2.4227	0.0297	0.0283
Flaourtia ramontchi (n=15)	Bole	0.9850	-2.0747	2.2774	0.0818	0.1106
	Branch	0.9939	-2.7468	2.7141	0.0617	0.0833
	Leaf	0.9902	-2.6635	2.0118	0.0583	0.0788
	Root	0.9898	-2.5309	2.2709	0.0671	0.0907
	Total	0.9940	-1.9179	2.4300	0.0548	0.0740

Species	component	Correlation coefficient r	intercept log a	slope b	Standard error of estimate (SEE)	Standard error of b (SE of b)
Lagerstroemia parviflora (n=18)	Bole	0.9957	-2.2277	2.2908	0.0492	0.0534
	Branch	0.9898	-2.9451	2.6849	0.0888	0.0964
	Leaf	0.9853	-2.7657	2.0988	0.0840	0.0911
	Root	0.9920	-3.0475	2.5876	0.0758	0.0822
	Total	0.9965	-2.0908	2.4470	0.0472	0.0512
Saccupetalum tomentosum (n=24)	Bole	0.9933	-2.4161	2.5060	0.0657	0.0810
	Branch	0.9937	-3.9360	3.2905	0.0838	0.1033
	Leaf	0.9936	-2.7398	2.0922	0.0536	0.0660
	Root	0.9957	-3.1304	2.6249	0.0549	0.0676
	Total	0.9972	-2.4028	2.6826	0.0456	0.0561
Ggrewia tiliaelfolia (n=18)	Bole	0.9925	-2.4946	2.4910	0.0723	0.0768
	Branch	0.9661	-2.7396	2.6410	0.1660	0.1764
	Leaf	0.9910	-2.3512	1.8503	0.0590	0.0626
	Root	0.9977	-2.6802	2.3433	0.0371	0.0394
	Total	0.9893	-2.0260	2.4495	0.0852	0.0905
Eriolaena hookeriana (n=12)	Bole	0.9932	-2.8174	2.7104	0.0579	0.1004
	Branch	0.9880	-3.4809	3.1303	0.0893	0.1548
	Leaf	0.9927	-2.3127	1.7989	0.0400	0.0693
	Root	0.9855	-2.8021	2.4096	0.0758	0.1314
	Total	0.9969	-2.4665	2.7390	0.0395	0.0685
Acacia catechu (n=12)	Bole	0.9938	-2.0973	2.3131	0.0508	0.0819
	Branch	0.9906	-3.1626	2.9565	0.0800	0.1290
	Leaf	0.9822	-2.2882	1.6889	0.0634	0.1022
	Root	0.9920	-2.1735	2.0756	0.0518	0.0835
	Total	0.9949	-1.9235	2.4333	0.0482	0.0777
‘Other species’(Total of all species) (n=200)	Bole	0.9874	-2.1725	2.2880	0.0842	0.0260
	Branch	0.9569	-3.2888	2.9420	0.2051	0.0635
	Leaf	0.9678	-2.6977	2.0403	0.1219	0.0377
	Root	0.9697	-2.0645	2.2913	0.1327	0.0410
	Total	0.9844	-2.0854	2.4750	0.1015	0.0314
Tectona grandis (n=15)	Bole	0.9950	-2.3687	2.3636	0.0520	
	Branch	0.9900	-3.2713	2.6579	0.0850	
	Leaf	0.9960	-2.8054	2.2401	0.0430	
	Root	0.9540	-2.2276	2.0172	0.1450	
	Total	0.9940	-1.9663	2.3001	0.0560	

n = no. of trees felled.