

**“REGENERATION STATUS, SPECIES DIVERSITY,
BIOMASS AND CARBON STORAGE PATTERN IN
NATURAL AND PLANTATION FORESTS OF SUB-
HUMID TROPICS IN BARNAWAPARA WILDLIFE
SANCTUARY”**

M.Sc. (Forestry) THESIS

BY

CHAMAN LAL

DEPARTMENT OF FORESTRY
COLLEGE OF AGRICULTURE
INDIRA GANDHI KRISHI VISHWAVIDYALAYA
RAIPUR (C.G.) 492006

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Thesis

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**INDIRA GANDHI KRISHI VISHWAVIDYALAYA
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BY

CHAMAN LAL

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THE DEGREE OF**

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in

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CERTIFICATE – I

This is to certify that the thesis entitled “**REGENERATION STATUS, SPECIES DIVERSITY, BIOMASS AND CARBON STORAGE PATTERN IN NATURAL AND PLANTATION FORESTS OF SUB-HUMID TROPICS IN BARNAWAPARA WILDLIFE SANCTUARY**” 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 **CHAMAN LAL** 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:

(Lalji Singh)

Chairman

Advisory Committee

THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE

Chairman: Dr. Lalji Singh -----

Member: Dr. S.S. Bargali -----

Member: Dr. S.L. Swamy -----

Member: Dr. R.R. Saxena -----

Member: Dr. R.N. Singh -----

CERTIFICATE – II

This is to certify that the thesis entitled **“REGENERATION STATUS, SPECIES DIVERSITY, BIOMASS AND CARBON STORAGE PATTERN IN NATURAL AND PLANTATION FORESTS OF SUB-HUMID TROPICS IN BARNAWAPARA WILDLIFE SANCTUARY”** submitted by **CHAMAN LAL** 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.

Date. :

External Examiner

Major Advisor

Head of the Department/Section

Dean Faculty

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Department of Forestry
College of agriculture,
I.G.K.V., Raipur (C.G.)
Date: _____

(CHAMAN LAL)

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LIST OF ABBREVIATIONS

<i>Abbreviations</i>	<i>Description</i>
%	Percent
&	And
<	Less Than
=	equal to
>	More Than
≤	less than equal to
≥	greater than equal to
°C	degree centigrade
AGB	Above ground biomass
BGB	Below ground biomass
C.G.	Chhattisgarh
CBH	Circumference at breast height
cm	centimeter
DBH	Diameter at breast height
<i>et al</i>	And Others/co-workers
Fig.	Figure
GBH	Girth at Breast Height
GIS	Geographical Information System
ha	hectare
ha ⁻¹	per hectare
t ha ⁻¹	tons per hectare
ht	Height
i.e.	that is
viz.	namely
e.g.	for example
m ha	million hectare

<i>Abbreviations</i>	<i>Description</i>
Kg ha ⁻¹	kilogram per hectare
m	meter
MAB	Man and Biosphere
C	Carbon
N	Nitrogen
P	Phosphorus
CO ₂	Carbon dioxide
Mg	mega gram = 10 ⁶ gram
MoEF	ministry of Environment and Foest
R.B.A.	Relative Basal Area
R.D.	Relative Density
R.F.	Relative Frequency
IVI	Importance Value Index
FSI	Forest Survey of India
UNEP	United Nation Environment Programme
IPCC	Inter-governmental Panel on Climate Change
FAO	Food and Agricultural Organization
N. H.	National Highway
amsl	above mean sea level
NPP	Net Primary Productivity
M.P.	Madhya Pradesh
NE	North East
TAGB	Total above ground dry biomass
Mt	Metric ton
MPT's	Multi purpose tree species

CHAPTER-I

INTRODUCTION

Tropical forests are characterized by high species richness, standing biomass and productivity (Jordan, 1983) and their diversity has attracted much attention in recent years (Sahu *et al.* 2008; Sagar *et al.* 2003). In most developing countries, including India, even protected forests experience extensive anthropogenic disturbance due to grazing, extraction of fuelwood and collection of non-wood forest products which contribute to the livelihood of forest dwelling populations (Singh *et al.* 1997; Hegde & Enters 2000; Pattanayak *et al.* 2003). The degree of anthropogenic disturbance may differ in different parts of a conservation area (Kolongo *et al.* 2006) and it is argued that continuing biomass extraction activities may thwart the very goal of biodiversity conservation (van Schaik *et al.* 1997). Sheil (1999) suggested that disturbance of a suitable intensity can potentially increase species richness in old-growth communities in concordance with intermediate disturbance hypothesis. Others, however, argue that disturbance does not increase diversity in old-growth forests (Phillips *et al.* 1997).

The tropical forest covers 1376 m ha worldwide which covers 60 per cent of the land area (FAO, 2005) and play an important role in biomass accumulation and CO₂ sequestration. Tropical forest in India covers 56.60 m ha, of which 20.84 m ha falls under dry deciduous forest (FSI, 2009). Regeneration status and species diversity in natural and plantation forest of the tropical dry deciduous forest being carried out for the purpose which solves either these forests are in progression or in retrogression.

In recent years interest in tropical forest has been simulated, in part, by the alarming rate at which they are being modified or completely destroyed and partly because of their vast store of carbon and the potential effects of their disruption on the

world's carbon balance (Murphy and Lugo, 1986a). Global models of the C, N, P and S cycles (Bolin *et al.* 1983) have led to useful insights into global level problems such as increasing atmospheric concentrations of gases of C and N, ozone degradation in the stratosphere and acid precipitation.

According to Kaul and Sharma (1971) 86% of the forests area of India is under tropical forests, of which 37% is of the moist deciduous type, 53% is dry deciduous and the rest is wet evergreen or semievergreen. Tropical deciduous forests occur under varied climatic conditions, but essentially with alternate wet and dry period. The structure and composition of deciduous forests change with the length of wet period, amount of rainfall, latitude, longitude and altitude.

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).

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 tree components like bole, branch, leaves and roots are economically utilized for fodder, firewood, timber, pulp and paper, plywood, composite wood, medicinal and other uses. Therefore quantification

of total biomass is important as different component play a vital role in structural and functional process of ecosystems.

Trees play a vital role in mitigating the diverse effect of environmental degradation and increasing concentration of CO₂ in the atmosphere and also in its consequence on climate change. It promotes the search for suitable method to sequester the carbon into soil and plant biomass. Tree based land use practice could be one among the viable alternative to store atmospheric CO₂ due to its cost effectiveness, high potential rate of carbon uptake and associated environmental as well as social benefits (Costa, 1996).

One of the major issues of global carbon concern today is rapidly increasing level of CO₂ @ 2 ppm per year in atmosphere and its potential to change the world climate. Elevated levels of CO₂ and other green house gases in the atmosphere have increased global average surface temperature by $0.6 \pm 0.2^{\circ}\text{C}$ (IPCC, 1999). The rising CO₂ 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 carbon 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.

India's per capita low forest area of 695 m² result in a large gap between supply and demand for forest products. India has 2.5 per cent of the world's land area and 1.8 per cent of the global forest area, but supports 15.6 per cent of the world's human population and 14 per cent of the livestock population. It has a large rural

population of 700 million with a high population density of 2.57 persons/ha and 4.26 livestock/ha of forestland. This large population depends on forest for the supply of fuel wood, raw materials for rural handicrafts and industries, among other products. They are potentially very important also for their environmental functions including soil and water conservation, flood control and carbon storage.

In recent years, a complex array of social, economic and political changes have altered human demands on forests. These changing demands have had devastating impact on forest status and integrity. The destruction of the world's tropical forests, which are disappearing at an alarming rate, is one of today's most urgent global environment issues.

There is an alarming threat to life supporting systems on planet earth due to rapid declining of diversity and complexity of living organisms. The problem is serious, especially in tropical regions, where the 14 hot spots (endangered zones) out of 25 in the world are identified by the biologists. Biodiversity is intimately interconnected with the long-term health and vigour of the biosphere as an indicator of global environment but also as a regulator of ecosystem functioning. Therefore, conservation of biodiversity at different levels is necessary.

In view of this the present study entitled "Regeneration Status, Species Diversity, Biomass and Carbon storage pattern in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary" was undertaken. The study was carried out with the following major objectives:-

1. To study the regeneration status and species diversity pattern between plantation and natural forest.
2. To study the biomass and carbon storage pattern between plantation and natural forest.

CHAPTER-II

REVIEW OF LITERATURE

In this chapter an attempt has been made to review the work done on **“Regeneration Status, Species Diversity, Biomass and Carbon storage pattern in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary”**. 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 Regeneration and Species Diversity.

2.2 Biomass and Carbon Storage Pattern.

2.1 Regeneration and Species Diversity.

Regeneration of any species is confined to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographic distribution (Grubb, 1977). The population structure of a species in a forest can convey its regeneration behaviour (Saxena and Singh, 1984). The population structure, characterized by the presence of sufficient population of seedlings, saplings and adults, indicates successful regeneration of forest species, and presence of saplings under the canopies of adult trees also indicates the future composition of a community (Austin, 1977). Regeneration status of trees can be predicted by the age structure of their population. Regeneration of a particular species is poor if seedlings and saplings are much less than the mature trees (Khan *et al.* 1987; Vablen *et al.* 1979; Tripathi and Khan, 2007). Chauhan *et al.* (2005) have compared the regeneration, diversity status and general community attributes in natural and plantation forest in Terai-Bhabhar forests of Katarniaghat Wildlife Sanctuary.

Forest resources are renewable only because they can regenerate. The regeneration dynamics or pace, at which older trees of a forest are replaced by younger ones in time and space, is determined by the regeneration potential of the component tree species and the factors that influence the actual regeneration. The study of regeneration of forest trees has important implications for the management of natural forests, and is one of the thrust area of forestry.

Tree regeneration can be predicted by the structure of their populations (Khan *et al.* 1987). The presence of sufficient numbers of seedlings, saplings and young trees in a given population indicates successful regeneration (Khan *et al.* 1987). A sustained regeneration and growth of all species in the presence of older plants is required for the growth of any plant community (Taylor and Zisheng 1988). Information on forest composition, effects of biotic and abiotic pressure, type of species surviving and the extent of biomass removal can help in rejuvenation of depleting forest through refinement of silvicultural practices, which must also be compatible with community involvement (Sundriyal *et al.* 1994; Murali and Setty, 2001).

The structural and functional processes have to be quantified for thoroughly understanding the vegetation dynamics. The structural analysis of vegetation entail the floristic composition, stand density, basal area, vertical stratification and community types, while diversity provides information on species richness, distribution and rate of change in species composition. Both structure and diversity of vegetation have strong functional role in controlling ecosystem process like biomass, production, cycling of water and nutrients (Gower *et al.* 1992).

According to Champion and Seth (1968) the forests of Chhattisgarh have been broadly categorized under tropical moist deciduous forest, tropical dry deciduous

forest and montane sub tropical forest that have been further divided into sub categories and are grouped into 3 groups.

I. In group 3. Tropical Moist Deciduous Forests:

- (1) 3B/C1c Slightly moist teak forests
- (2) 3C/C2c Moist peninsular sal forest
- (3) 3C/C3 Moist mixed deciduous forest

II. In group 5. Tropical Dry Deciduous Forest:

- (1) 5B/C1c Dry peninsular sal forest
- (2) SB/C2 Northern dry mixed deciduous forest

III. In group 8. Montane Subtropical Forest:

- (1) 8A/C3 Central Indian sub tropical hill Forest

Chhattisgarh is third densely forested state of the country after M. P. and Arunachal Pradesh since it has 41.33 per cent of forest cover of its total area which is more than 33 per cent of forest cover as recommended by National Forest policy. The state is well known in the country for its sal forests, which occupy nearly 36 per cent of total forest cover. Teak forests are also abundant but mainly in western and southern parts of the state (Kumar *et al.*, 2003). In Chhattisgarh, so far only four species are endemic e.g. *Staurogyne perpusilla* (Henry and Balakr), *Maytenus bailadillana* (Narayan and Mooney) Raju and Babu, *Eriocaulon rajendrababui* Ansari & Balakr and *E. raipurensis* K.K. Khanna, V. Mudgal and Anand Kumar. An analysis has pointed out that about 480 taxa are rare in the state (Kumar *et al.*, 2003).

India is recognized as one of the world's top 12 mega diversity nation (Myers, 1988). Their richness in biodiversity is due to immense variety of climatic and altitudinal conditions coupled with varied ecological habitats. The country has over 1,15,000 species of plants and animals. Among flora, the country can boast of 45,000

species which accounts for 15 per cent of the known world plants. Of the 15,000 species of flowering plant 35 per cent are endemic and located in 26 endemic centers. Among the Monocotyledons, out of 588 genera occurring in the country, 22 are strictly endemic.

Singh and Singh (1981) reported the diversity of trees and shrubs in the fenced as 1173 and 132 tree ha⁻¹ and unfenced as 936 and 554 tree ha⁻¹ in tropical dry deciduous forests. Tree density and total basal area in an equatorial forest ecosystem in Kongolo islands Zaire ranged from 440 to 553 tree/ha and 10000 to 45000 cm²/ha respectively (Mosang, 1991), Pandey (2001) reported density and dominance (cm²/ha) as 690-1630 and 95643-155480 for closed canopy tropical dry deciduous teak forests of Satpura plateau.

Jha and Singh (1990) analysed the dry tropical forests of India and recognized five predominant plant communities. The environmental relationships of these community types were analysed through discriminate analysis. The study showed the importance of soil texture in determining the distribution of these communities.

Singh and Singh (1991) studied the species composition and diversity index in mixed dry deciduous forests of Vindhyan region. The basal cover of vegetation varied from 3.8 to 10.4 m² ha⁻¹ for trees and 3.1 to 7.8 m² ha⁻¹ for shrubs. Shannon and Weiner index and concentration of dominance ranged between 1.93 to 2.18 and 0.18 to 0.38, respectively. The beta diversity was 3.1. Topographic factors modify the microclimate and edaphic conditions of a site and responsible for determining the status of vegetation in a given habitat (Cook *et al.* 1989). Kusum Latha and Bisht (1991) reported that phytosociological characters differ among aspect and position even in the same vegetation type. They observed 0.22 to 0.58 concentration of

dominance in oak forests and from 0.21 to 0.26 in chirpine forests in different aspects of Himalayas.

Prasad and Pandey (1992) reported species diversity ranging from 0.32 to 3.76 and concentration of dominance from 0.07 to 0.63 at different distances from habitation in sal and teak forest in four districts of Madhya Pradesh, India. The forest with in 0.5 km radius of habitation recorded lower diversity and dominance compared to forest with in 5 km radius of habitation.

Verghese and Menon (1998) conducted studies in south moist mixed deciduous forests of Agasthyamalai region of Kerala, India through quadrat sampling method. The stand density, species density and basal area of these forests were 535 trees/ha, 12 species per 0.1 ha and 26.57 /ha, respectively. Shannon index of these forests was 1.89, while evenness index was 0.73. *Terminalia paniculata*, *Pterocarpus marsupium* and *Careya arborea* were found as dominant plant association.

Pande (1999) compared the vegetation of sal forest of Doon valley and relate the magnitude of disturbance with quantification of vegetation, their resource apportionment and the regeneration of sal. The whole area is divided into five sites as per their disturbance magnitude. Total basal area ($\text{cm}^2/100 \text{ m}^2$) ranged between 2324-3775 for trees, 74-354 for shrubs and 1.28-30 for herbs. The distribution patterns for most of the species at different sites were random, where as some species of younger stand showed contagious/clumped pattern of distribution. The range of diversity index (Shannon Wiener index) was 0.89-2.31 for trees, 0.87-1.99 for shrubs and 0.64-2.34 for herbs. Diversity index was invariably higher for herbs followed by shrubs and trees. The tree diversity was higher for least disturbed sites (2.31). Where as shrubs and herb density followed reverse trend. Maximum turnover of tree species was

recorded between site I and III (5) and lowest at site II & V (0.25). The range for turnover of shrub layer was 0.60 (site II & IV) – 3.33 (site I & III) while herbs were ranged between 1.8 (site I-V) to 6.5 (site IV & V). He noticed that not only disturbance and stand age affect the sal regeneration due to invasion of new competitors at seedling and sampling stage but the compactness of stand due to old and big trees also reduce it by increasing moisture status of soil at the moist areas.

Ipor *et al.* (2002) investigated the floristic composition of mixed Dipterocarp forest of Mahua crockar Range National park. The species composition was moderately diverse. It has a total of 44 species where importance value of tree species revealed that *Duabanga molukana* (24.54), *Kalma ashtonii* (14.87), *Agathis lanecolata* (12.68), *Lithrocarpus cantleyannur* (12.3) and *Litsea ochracea* (9.9) were dominant species and *Shorea maxwelliana*, *Alseodaphne inignis*, *Litsa resinsa*, *Litsea Malchilifolar* and *Alseodephne foxiana* were found to be endangered.

Pande *et al.* (2002) studied the vegetation composition, species diversity, distribution pattern and other parameters of vegetation analysis along population structure and regeneration of some tree species in Western Himalayan forests of Chakrata forest division (Uttaranchal). The density for tree species (plant 100 m⁻²) was 4.51-6.64, for shrubs was 23.56-41.62 and for herbaceous species was 7280-11920, while the range for total basal cover was 0.332-0.938 (m² 100 m⁻²) for trees; 9.50-18.81 cm²/100 m² for shrubs and 235-323 cm²/100 m² for herbaceous species. The maximum diversity of trees was 12 (species richness) and minimum up to 1 for trees, 9-14 for shrubs, 20-23 for herbs. Concentration of dominance (Cd) shows reverse trend to diversity and it was 0.1201 for trees 0.13-0.15 for shrubs and 0.1 to 0.13 for herbs. Diversity index varies from 0 to 2.25 for trees, 1.53 to 2.31 for shrubs and 2.41 to 2.69 for herbs. Beta diversity between 2 sites of forests shows 4 and 11

for trees, 1.25 and 3.67 for shrubs, 3.8 and 1.2 for herbs. Tropical forests indicate higher diversity as calculated by Knight (1975) for young stand ($H' = 5.06$) and for old stand ($H' = 5.4$). Sukumaran (2005) studied the floristic composition of sacred groves where he recorded 33 plant species from 251 genera belonging to 110 families. In which 108 belonging to angiosperms and two to gymnosperms. Forest was rich with 139 species of trees, 95 shrubs, 79 herbs and 16 lianas and climbers. 54 species are listed rare, endemic and threatened.

Shi and Singh (2002) assessed the status of worlds remaining closed forest population distribution and protected areas in global biodiversity hot spots. According to them the worlds remaining closed forests were about 2.87 billion hectares, which occupies about 21.9 per cent of the land area of the world. The high human population pressure in the hot spots exists in 10.7 per cent of closed forests. The four hot spots with the most elevated risk as assessed by human population pressure were in the Western Ghats, Srilanka, Polynesia and Micronesia, Philippines and Caribbean hot spots.

Negi and Nautiyal (2005) studied the phytosociological characteristics of Thalke Dhar Reserve forest of Central Himalayas. A total of 53 species (13 species of tree, 24 species of shrubs and 16 species of herbs) were recorded. The tree density were 1010-1230 stems ha^{-1} in different compartment. Total basal covers of tree species ranged from 49.39 m^2/ha to 64.74 m^2/ha across compartment. Density of sapling ranges between 690-770 saplings/ha. The value of diversity ranges from 2.156 to 2.323, 2.53 to 2.67, 2.39 to 3.20 and 3.32 to 3.94 for trees saplings, seedlings and shrubs, respectively. The value of beta diversity was 1.42, 1.32, 1.16 and 1.30 for trees, saplings, seedlings and shrub layer, respectively.

In several temperate forests the value of total basal cover and density were 0.15-0.6 m²/100m² and 3.2-20.8 tree/100 m², respectively (Saxena and Singh 1982, Singh *et al.*, 1997). The same ranges from 0.11-0.68 m²/100m² and from 5.5-18 trees/100m² for tropical forests (Visalakshi 1995, Parthasarathy *et al.* 1992). The diversity values reported in temperate forest were between 1.16-3.4 by many workers.

Khanduri *et al.* (2002) conducted study on forest composition and socio economic status of villages of Garhwal Himalayas. The rate of exploitation of forest resources was verified by vegetation analysis where no regeneration has been recorded from all the adjacent forests for the selected villages. The total basal cover of all the species was 76.47 m²/ha as highest and lowest as 46.94 m²/ha. The values of diversity vary from 0.33-2.95. The values recorded for concentration of dominance were 0.14 to 0.56. It is apparent that the diversity increased with increased in species richness. The concentration of dominance value for oak forest from Kumaun Himalaya was reported as 0.11-0.93 in the tree layer (Tiwari and Singh, 1985).

Pande (2005) studied the ecological status of vegetation in Satpura plateau, M.P. Total density for tree layer ranged between 46.93-387.5 tree ha⁻¹, 114 to 714.95 for shrubs and 15905 to 102078 plant ha⁻¹ for herbs layer. Whereas the range for dominance was 9570 to 217333 cm²/ha for trees, 2912 to 32462 cm²/ha for shrubs and 1304 to 218468 cm²/ha for herbs.

Shannon Wiener diversity indices are generally higher for tropical forests, that ranges between 0.81-4.1 for the Indian sub continent (Singh *et al.*, 1984, Parthasarathy *et al.*, 1992, Visalakshi, 1995, Pande 1999, 2001). Vishalakshi (1995) reported Shannon Wiener diversity between 0.83 and 2.43 for Marakkanam reserve forest in south India. The value reported by (Bisht, 1989, Parthasarathy *et al.* 1992; Visalakshi, 1995) for tropical evergreen forests were significantly higher than those

of the Satpura Plateau between 1.19-1.98 for tree and 1.19-1.89 for shrubs. The values of concentration of dominance (Cd) for tropical forest lie within the range of 0.21 to 0.92.

Tripathi (2004) studied the distribution and community characteristics in subtropical pine forests of Meghalaya. Altogether 174 species belonging to 139 genera and 77 families were recorded in different altitudes. The species richness (7.69), diversity (4.13) and evenness (0.26) of the three life forms (tree, shrub, herbs) were maximum on the high elevation stand and minimum on the low-elevation stand. Species diversity in the stand was positively correlated ($r = 0.92$, $P = 0.001$) with annual rainfall and negatively ($r = -0.93$, $p = 0.001$) related to the temperature. The dominance of pine was positively correlated ($r = 0.89$, $p = 0.001$) with temperature but negatively correlated ($r = -0.89$, $P = 0.01$) with mean annual rainfall. The tree density varied between 810 and 1050 stem ha^{-1} and basal covers from 28.9 to 37.4 $\text{m}^2 \text{ha}^{-1}$.

Density of trees and their regeneration in the forest are largely dependent on the response of the seedling and saplings to the forest microenvironment and interactive influence of an array of biotic and abiotic factors (Umashankar, 2001, Mishra *et al.*, 2003).

Shankar (2001) studied floristic composition, regeneration and conservation of sal dominated forest in Eastern Himalaya and found that diverse sal forest continually experiences anthropogenic interference by the inhabitants on fringes. Rare species that contribute maximum to the tree diversity are at high risk of local extinction. Pokhriyal *et al.* (2010) studied the two watersheds of Uttarakhand region for regeneration pattern and they concluded that both the forests were regenerating well, although the regeneration was better in Phakot watershed as compared to Pathri Rao

watershed. Kumar *et al.* (2010) studied species diversity and soil nutrient status in tropical dry deciduous forests of western India and found the tree density varied from 458 - 728 stems ha⁻¹ with average basal area ranging from 5.96 - 19.31 m² ha⁻¹. Shannon-Weiner Index ranged from 0.67 - 0.79. The Concentration of Dominance varied from 0.08-0.16, the Species Richness Index ranged between 21.41 - 23.71, Equitability Index ranged between 0.02- 0.05 and Beta Diversity ranged between 2.02 - 4.87.

2.2 Biomass and Carbon Storage Pattern

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 (Mishra, 1968: Odum, 1983: Rai, 1984). In this approach, the availability of species-specific local regression equations is essential for precisely estimating the forest biomass.

Pande *et al.* (1986) studied the biomass production and distribution of nutrients in moist deciduous forests in Goa and found that the dominant species were *Terminalia tomentosa* in the upper storey and under storey and *Careya arborea* and *Lannea grandis* in the under storey and reported that as much as 92% of the total biomass was contributed by *Terminalia tomentosa* with only 8% by the other two species.

Castellanos *et al.* (1991) studied the root biomass of dry deciduous tropical forest in Mexico and found that the above and below ground biomass of trees, shrubs and lianas was 73.6 t ha⁻¹ and 31 t ha⁻¹, respectively. A root: shoot biomass ratio of 0.42 was calculated.

Hall and Uhling (1991) estimated the biomass density of forest in South and South east Asia using the volume estimates and biomass comparison factors derived from Brown *et al.* (1989). Their biomass estimates for India ranged from 116 Mg ha⁻¹

for undisturbed forest for 60-80 years and 35, 66 and 84 Mg ha⁻¹ for logged, unproductive and managed forests respectively. However, these estimates were only made from 9 percent of forest area and no information was given in relation to forest types and species composition.

Singh and Singh (1991) studied the species composition, plant biomass and diversity index in mixed dry deciduous forests of Vindhyan region. They found that the standing biomass of vegetation averaged 66.98 t ha⁻¹ with 46.70 t ha⁻¹ in tree layer, 13.97 t ha⁻¹ in the fine roots. A total of 83 per cent vegetation carbon was stored in above ground plant parts, while the above ground NPP was responsible for 72 per cent of the total carbon input into the system.

Mishra *et al.* (1998) studied the biomass status of two sites- a biotically disturbed site (BD) and an undisturbed site (UD) of mixed dry deciduous forest of Shiwalik hill in Haryana. The total basal area was 7.9 m² ha⁻¹ in BD and 9.7 m² ha⁻¹ in UD. Three important tree species *Anogeissus latifolia*, *Acacia catechu*, and *Terminalia tomentosa* accounted for 88% of total tree density in BD and 66% in UD. Total above ground tree biomass was 22.05 t ha⁻¹ in BD and 31.19 t ha⁻¹ in UD, indicating a significant difference.

Haripriya (2000) estimated the above ground biomass density and carbon storage in biomass of major forest strata (21) of India from data collected from 1,70,000 sampling units distributed all over the country in 1993. Biomass densities ranged from 14 to 210 Mg ha⁻¹ with a mean of 67.4 Mg ha⁻¹, which equals around 34 Mg ha⁻¹.

Tian *et al.* (2000) studied the climatic and biotic controls on annual carbon storage in Amazonian ecosystem. They found that the total carbon storage in the Amazon Basin in 1980 was estimated to be 127.6 Pg C, with about 94.3 Pg C in

vegetation and 33.3 Pg C in the reactive pool of soil organic carbon. About 83% of the total carbon storage occurred in tropical evergreen forests. Results show that the strength of inter annual variations in net carbon storage in such undisturbed ecosystems in the Amazon Basin varies from a carbon source of 0.2 Pg C per year to a carbon sink of 0.7 Pg C per year. The analysis also suggest that proper scaling of site-specific and sub-annual measurements of carbon fluxes to produce Amazon Basin-wide flux estimates must take into account seasonal and spatial variations in net carbon storage.

Nascimento and Laurance (2002) studied 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 $397.7 \pm 30.0 \text{ t ha}^{-1}$. The most important component of above ground biomass were large trees ($< \text{ or } \geq 10 \text{ cm dbh}$) which comprised 81.9% of TAGB followed by downed wood debris (7.0%), small trees, saplings and seedlings ($< 10 \text{ cm dbh}$; 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 ($< \text{ or } \geq 60 \text{ cm DBH}$) 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.

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.

Murali *et al.* (2005) studied 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 estimate equations for deciduous forests were precise and therefore useful for field applications.

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.

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 .

Raizada *et al.* (2007) Studied the Biomass production and prediction models for *Acacia nilotica* in salt affected verticals in Karnataka and they observed that although the plantation is even-aged, there are 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.

Baisya *et al.*, (2009) studied above ground biomass distribution and carbon storage in different DBH and compared between natural semi evergreen forest and sal plantation in the humid tropics of NE India. They found that the above ground biomass in natural forest was higher in the trees having DBH > 60 cm as compared to plantation forests. The highest carbon storage in natural and plantation forest was found in 60 – 80 cm and 40 – 60 cm class, respectively.

CHAPTER-III

MATERIALS AND METHODS

The study on **“Regeneration Status, Species Diversity, Biomass and Carbon storage pattern in natural and plantation forest”** was carried out at Barnawapara wildlife sanctuary, North Raipur Forest Division of Raipur district (Chhattisgarh) during the year 2009-2010. The details of the study site, climate, geology, soils, flora, fauna and other features of study area 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 given below.

3.1.1 Geographical location and physiography

The study area is located between 21° 20' 00" to 21° 25' 47" North latitudes and 82° 21' 17" to 82° 26' 27" East longitudes. It is situated about 17 km away from Patewa on Raipur-Sambalpur NH No. 6 just on the border of Chhattisgarh. The location of study area, important places and road network are depicted in Figs. 3.1 and 3.2.

The general topography of area is undulating due to formation of rockout crop. Tilsa pathar is the highest with an approximate altitude of 463 m amsl. 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

villages and majorities of them are accessible through kachcha 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 consist of three seasons viz. rainy, winter and summer. The rainy season commences from about 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 August. 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 ranges 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 area has three distinct geological formations viz. Chhattisgarh super group, Late Precambrian and Early Precambrians. Lithologically the area is divided into seven groups namely Raipur Shale and limestone, Khairagarh sandstone, Gunderdehi Shale, Cuddapahas charmua limestone, Chandrapur sand stone grit, Dharwar rocks, Granite and genesis.

3.1.7 Soils

Soils of study area are Inceptisols. The Inceptisols are immature soils mostly sandy loams having light texture and shallow to moderate depth. They are low in organic matter and available nutrients, which support mainly grasslands and degraded forests. These soils are commonly found in the Eastern and Southern aspects.

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/C₂), (4) Dry Bamboo Brakes (5/E₉).

3.2 Experimental details:-

3.2.1 Sampling /Ground Inventory

The study on Regeneration Status, Species Diversity, Biomass and Carbon storage pattern in natural and plantation forest was conducted at Barnawapara wildlife sanctuary. Three sites comprising two natural forest (one closed forest and one open forest) and one teak plantation forest were selected from Barnawapara wildlife sanctuary.

3.2.2 Method

Regeneration status, species composition and diversity of tree species of both i.e. natural forest and teak plantation were studied during 2009–2010. Phytosociological studies were carried out using quadrat method. The quadrats were laid down in stratified random manner. To study the regeneration pattern and species composition 10 m × 10 m square quadrats were laid down on forest floor. Inside 10 m x 10 m quadrat, 2 m x 2 m quadrats were laid down for the enumeration of seedling and saplings. For tree, sapling and seedling species, a total of 10 quadrats were laid down on each site. Species area curve was used to determine minimal sample area which is based on quantitative variation of the vegetation terms of species number (Muellor-Dombios and Ellenberg, 1974). The adequacy of sample size was estimated by stopping sampling at the point at which additional quadrats did not significantly affect the mean of species. In each 10 m × 10 m quadrat, individuals as having >30 cm CBH (circumference at breast height, i.e. 1.37 m above the ground) were considered trees and were measured species-wise. Individuals having <10 cm circumference were considered as seedlings, and those having the intermediate position with respect to these circumferences were considered as saplings (Singh *et al.* 2006). The density of seedlings and saplings is considered as an indicator of the

regeneration potential. From the field data, phytosociological parameters of sapling and seedling were calculated following Mishra (1968).

The status of regeneration of species was determined based on population size of seedlings and saplings (Shankar 2001). The status of sampled species was assessed based on one time phytosociological data in the following categories. (a) good, if seedlings > saplings > adult; (b) fair, if seedlings > saplings ≤ adults; (c) poor, if a species survives in only sapling stage, but not as seedlings (though saplings may be less, more or equal to adults); (d) none, if a species is absent both in sapling and seedling stages, but present in adults; and (e) new, if a species has no adults, but only saplings and/or seedlings.

3.2.3 Phytosociological analysis

The vegetation data in each forest plot was quantitatively analyzed for frequency, density and basal cover following Curtis and McIntosh, 1950. Following expressions were used for the calculations of frequency, density and basal covers.

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

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

Basal area of trees was calculated as cross sectional area of stem at breast height i. e. at 1.37m from the ground level. The relative frequency, relative density and relative basal area, were calculated following equations.

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

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

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

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

$$\text{Importance Value Index (IVI)} = \text{RD} + \text{RF} + \text{RBA}$$

3.2.4 Plant diversity analysis

Plant diversity in different forest plot was quantified by following diversity indices.

a) Shannon Index (Shannon and Weaver, 1963) was used for the species diversity

The working formula given by Smith (1974) was used here

$$H' = 3.3219 \left[\log_{10} N - \left\{ \frac{\sum N_i \log_{10} N_i}{N} \right\} \right]$$

Where,

N_i 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 $\log_2$.

b) Concentration of dominance was measured by Simpson Index

(Simpson, 1949)

$$Cd = \sum \left[\frac{N_i}{N} \right]^2$$

Where,

N_i = the total basal cover of species i

N = the total basal area of all the species

c) **Equitability (e)** was calculated as suggested by Pielou (1966)

$$e = \frac{H'}{\ln S}$$

Where,

H' = Shannon index

S = the number of species.

d) **Species richness** was calculated following Marglef, 1958.

$$D = \frac{S-1}{\ln N}$$

Where,

S = total number of species,

N = basal area of all species

e) **Beta diversity** was calculated following Whittaker, 1972.

$$Bd = \frac{Sc}{\bar{s}}$$

Where,

Sc = total number of species in all sites and

$\bar{s}$ = average number of species per site.

These indices were calculated following Sagar and Singh (1999).

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 GBH (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 quadrates 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 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°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.

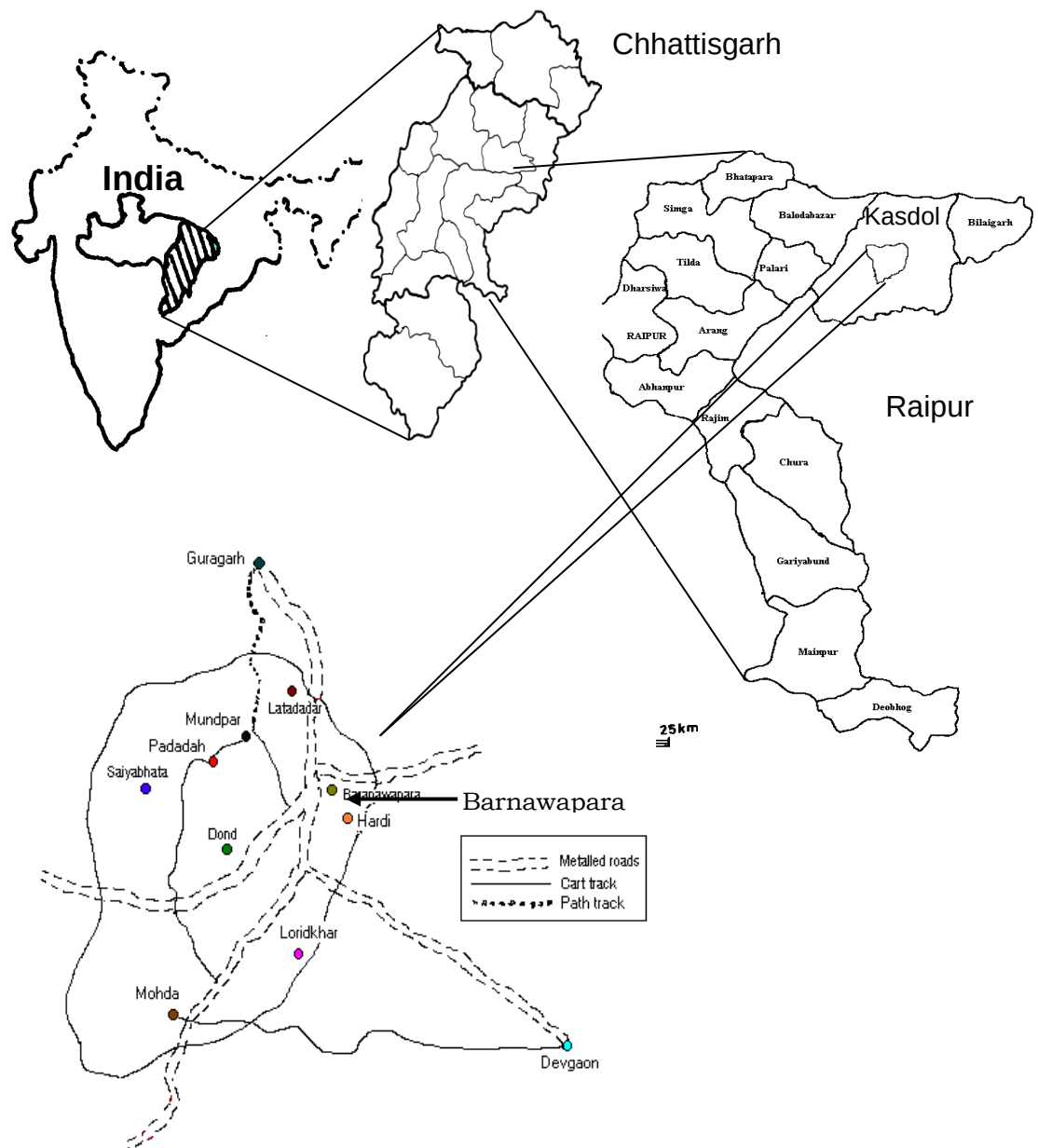


Fig 3.1: Location Map of Study area

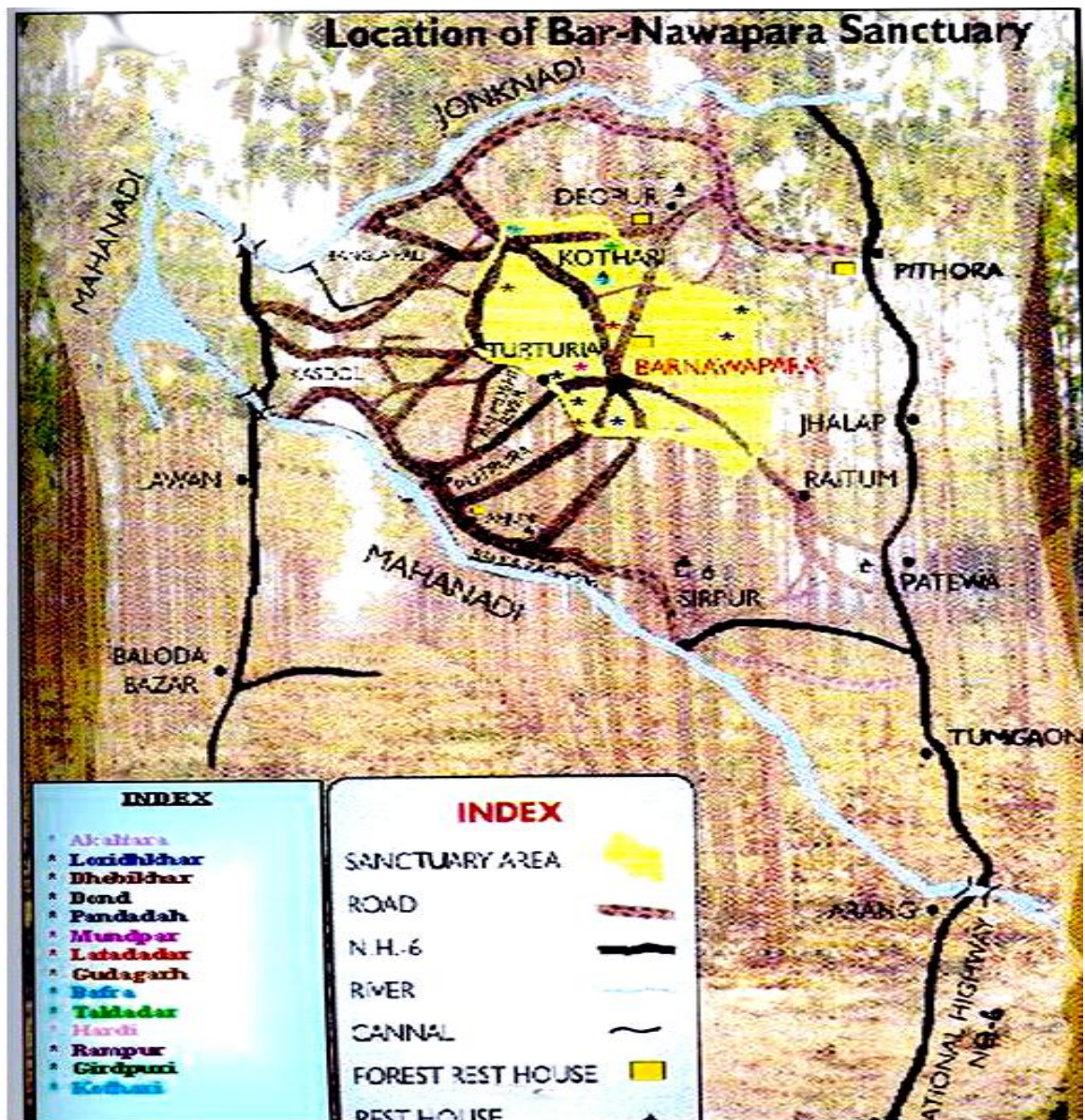


Fig 3.2: Area and Linkages of Barnawapara Wildlife Sanctuary

CHAPTER-IV

RESULTS AND DISCUSSION

The results on “Regeneration Status, Species Diversity, Biomass and Carbon storage pattern in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary” are discussed in this chapter. The findings are presented in two parts to facilitate the interpretation of results in accordance with topics. First part deals with the results on quantification of species composition and species diversity (phytosociological analysis) and the second part deals with the results on estimation of biomass and carbon storage in various forest sites of tropical deciduous forest of Barnawapara wildlife sanctuary. Results on different aspects in each part are described below-:

4.1 Species composition

In the present study among all the sites a total 33 species and 17 families were observed. The most diverse families were Leguminaceae (7), Euphorbiaceae (4), Anacardiaceae (3), Rubiaceae (3) and Combretaceae (2). The family Leguminaceae represented highest individual followed by Euphorbiaceae, Anacardiaceae and Rubiaceae.

4.2 Regeneration status:

Seedling density: The renewal of the tree crop by natural means in the form of crop is the indication of the health of site, recruitment and establishment of regenerating plants of tree species. The density of seedlings (Table 4.1) was found to be 960 stems/ha at closed natural forest, 400 stems/ha at open natural forest and 340 stems/ha at teak plantation forest.

Density/ basal area of sapling: Similarly density of sapling (Table 4.1) was found to be 220 stems/ha at closed natural forest, 90 stems/ha at open natural forest and 40

stems/ha at teak plantation forest. The basal area of sapling layer was 0.816, 0.252 and 0.163 m²/ ha at closed natural forest, opens natural forest and plantation forest, respectively.

The status of regeneration of species was determined based on population size of seedlings and saplings. Good regeneration, i.e., if particular species is present in seedling > sapling > tree; fair regeneration, i.e., if species is present in seedling > sapling < tree; poor regeneration, i.e., if a species survives only in sapling stage, but not as seedling; if species is present only in adult form it is considered as not regenerating. A species is considered as not abundant if the species has no tree representatives, but only sapling and/or seedlings.

The tree density in closed forest, open forest and teak plantation varied greatly and it was highest in Teak plantation (990 stems ha⁻¹) followed by closed forest (950 stems/ha) and lowest in open forest (520 stems ha⁻¹). The sapling density of closed forest was highest followed by open forest (90 stems ha⁻¹) and lowest in teak plantation (40 stems ha⁻¹). Seedling density too was highest in closed forest (960 stems/ha) followed by open forest (400 stems ha⁻¹) and lowest in teak plantations (340 stems/ha) Figure 4.1

The highest tree density in closed forest was recorded for *Cleistanthus collinus* (330 stems/ha) followed *Lagerstroemia parviflora* (130 stems ha⁻¹). The highest tree density in open forest was recorded for *Garuga pinnata* (80 stems/ha) followed *Grewia tiliaefolia* (70 stems ha⁻¹). Whereas on teak plantation, the highest tree density was recorded for *Tectona grandis* (920 stems ha⁻¹) followed by *Cleistanthus collinus* and *Lagerstroemia parviflora* 30 stems ha⁻¹ (Table 4.1).

A total of 20 tree species, 6 saplings and 13 seedlings were found in closed forest site. The highest density for seedling was recorded for *Diospyros melanoxylon*

(580 stems ha⁻¹) followed by *Cleistanthus collinus* (90 stems ha⁻¹). The lowest seedling density (10 stems ha⁻¹) was recorded for *Madhuca indica*, *Ougeinia oojeinensis* and *Pterocarpus marsupium*. The highest sapling density (110 stems ha⁻¹) was recorded for *Cleistanthus collinus* followed by *Bauhania racemosa* and *Diospyros melanoxylon* (30 stems ha⁻¹). The lowest sapling density was represented by *Madhuca indica* (10 stems ha⁻¹) (Table 1).

A total of 14 species of trees, 12 of seedlings and 5 of saplings were found in open forest. The maximum seedling density (70 stems ha⁻¹) was recorded for *Bombax ceiba* and *Grewia tiliaefolia* which is followed by *Terminalia tomentosa* (40 stems ha⁻¹). The lowest seedling density (10 stems ha⁻¹) was recorded for *Anogeissus latifolia* and *Lagerstroemia parviflora*. The highest sapling density (30 stems ha⁻¹) was recorded for *Acacia catechu* followed by *Chloroxylon sweitenia* and *Grewia tiliaefolia* (20 stems ha⁻¹). The lowest sapling density (10 stems ha⁻¹) was represented by *Cleistanthus collinus* and *Gardinia recemofera* (Table 4.1).

A total of 4 tree species, 1 sapling and 5 seedlings were found in teak plantation site. The highest density for seedling was recorded for *Lagerstroemia parviflora* (180 stems/ha) followed by *Tectona grandis* (90 stems ha⁻¹). The lowest seedling density (10 stems ha⁻¹) was recorded for *Flacourtia remontchi*. The only sapling found in the site was of *Lagerstroemia parviflora*. (Table 4.1).

The three life stages (seedlings, saplings and trees) for different species suggested their possible future status in the forest. The density vs girth relationship between density and girth of the tree, sapling and seedling species of closed forest, open forest and teak plantation show consistent decrease from seedling to sapling stage (from <10 cm to 20–30 cm), while from sapling to trees increased in density was observed. This could be related to more biotic pressure on sapling population for

the use as fuel wood and fodder. Thus, all the three forest sites were regenerating, although regeneration was higher in closed forest (Figure 4.1).

The diameter distribution of trees has often been used to represent the population structure of forests (Saxena and Singh 1984; Khan *et al.* 1987a). In all the three forest sites studied girth curve showed individuals with small girth class (<10 cm) were high but those with girth class (10–30 cm) were less in number. Further, individuals with medium girth class (30–60 cm) increased (Figure 4.2-4.4). In a study conducted elsewhere the proportion of large diameter individuals was greater than small diameter individuals in the tree population in undisturbed stand while in the disturbed stand the proportion of young individuals was more (Khan *et al.* 1987b).

In closed forest site out of 20 tree species, two species, viz. *Cleistanthus collinus* and *Diospyros melanoxylon* showed good regeneration as all these species having good number of seedlings and saplings, one species recorded fair, eight species poor regeneration and three were not abundant. Eleven species, viz. *Antidesma acidum*, *Buchanania lanzan*, *Bauhania racemosa*, *Bombax ceiba*, *Careya arboria*, *Emblia officinalis*, *Garuga pinnata*, *Mitragyna parviflora*, *Semecarpus anacardium*, and *Terminalia tomentosa* were not regenerating. It might be due to thick litter accumulation which reduced seed germination of most canopy species (Janzen, 1970; Singh and Singh, 1992).

In open forest site, out of 14 tree species, none of the species showed good regeneration and only one species showed fair and 6 species recorded poor regeneration viz., *Anogeissu latifolia*, *Acacia catechu*, *Bombax ceiba*, *Lagerstroemia parviflora*, *Terminalia tomentosa* and *T. arjuna*, while 5 species were not found to be regenerating, viz., *Bridelia retusa*, *Cassia fistula*, *Chloroxylon sweitenia*, *Boswellia serrata*, *Zizyphus xylocarpa*, (Table 4.1).

In teak plantation site, out of 4 tree species, *Lagerstroemia parviflora* showed good regeneration and one species showed fair regeneration. Two species (*Buchanania lanzan* and *Cleistanthus collinus*) on this site were not found to be regenerating and three species were categorized as not abundant (Table 4.1). The population size of the species that lack either seedlings or saplings may decline in the coming years. The forest stands characterized by the abundance of only adults of the species or absence or very low population of seedlings and saplings are expected to face local extinction (Dalling *et al*, 1998). Densities of seedlings are influenced by the densities of large trees (Rao *et al.*, 1990). The density girth class distribution of tree species of closed forest showed decline in density from seedlings (small diameter class) to saplings (higher diameter class) however, there was a further increase population from low girth class(10-30cm) to high girth class (30-60) but the density of trees further declined in preceding girth classes. It shows that smaller diameter class individuals were high in number and only a small fraction of the seedlings and saplings classes survived to the larger tree classes (Figure 4.2-4.4). A study on density–diameter distribution of woody species in the four sacred groves showed the highest stand density in the lowest girth class (30–60 cm; Kennedy *et al.*, 1991).

In general all the three site did not show good regenerating, however closed forest site was comparatively better regenerating because of high density of seedlings and saplings in closed forest. Chauhan *et al.* (2005) found the species showing 32.5 % good regeneration, 19.8 % fair, 24.6 % poor and 11.1 % did not show regeneration out of 126 species in natural and planted forest in a Terai-Bhabhar forest in Kalarnaighat Wildlife Sanctuary, India.

All the forest site comes under a protected area and lopping is not allowed within the sanctuary and thus the forest having good canopy cover might have

affected the survival of seedlings under good tree canopy due to the absence of light. It has been recorded that regeneration of species is affected by fire (Sukumar *et al.*, 1997; Murthy *et al.*, 2002) grazing, light (Teketay, 97), canopy density, soil moisture, soil nutrients and anthropogenic pressure. Regeneration of a species is dependent on internal forest process and exogenic disturbance (Barker and Kirk Patrick, 1994). In the present study, eleven species in closed forest, six species in open forest and two species in teak plantation were not regenerating so it should be given emphasis in further research.

Change in density and basal area of both seedling and saplings shows that prevailing biotic factors such as exploitation of forest to meet daily requirements of fuel wood, wood for agricultural implements and house construction for preparation of boundaries along the houses and farm land, unregulated grazing by domestic cattle are the key determinants of structure and function of the forest. These factors in the absence of any viable alternatives defy all regulatory measures. As a result the forests get degraded year after year without any hope of rejuvenation without exclusion of these pressures. Variation in vegetation attributes such as IVI, tree density, basal area and distribution of the tree species at different sites in the forest indicate the complex plant succession resulting from varying degree of pressures at different sites.

4.3 Quantification of species composition and species diversity in various forest plots

4.3.1 Species composition of closed natural forest

In closed natural forest a total of 950 trees ha⁻¹ representing 20 species and 12 families were encountered. The Euphorbiaceae family was represented by 41 individuals followed by Combristaceae, Leguminaceae 13 species each. It is evident from the data presented in the Table 4.2. that *Cleistanthus collinus* was the most

dominant tree followed by *Terminalia tomentosa* and *Lagerstroemia parviflora*. Highest density (stems ha⁻¹) was recorded for *Cleistanthus collinus* (330) followed by *Lagerstroemia parviflora* (130), *Terminalia tomentosa* (120). Lowest density was recorded for *Buchanania lanzan*, *Pterocarpus marsupium* and *Embllica officinalis* (10 individuals of each). Total basal area of this site was 47.3 m² ha⁻¹. Highest basal area (m² ha⁻¹) was observed for *Terminalia tomentosa* (9.40) followed by *Madhuca indica* (7.86) and *Lagerstroemia parviflora* (7.05). Lowest basal area (m² ha⁻¹) was observed in case of *Semecarpus anacardium* (0.12). Basal area and density of individual tree species varied from 0.12 to 9.40 m² ha⁻¹ and 10 to 330 stems ha⁻¹, respectively. *Cleistanthus collinus* showed highest value of IVI (57.70) followed by *Terminalia tomentosa* (47.10) and *Lagerstroemia parviflora* (32.92).

4.3.2 Species composition of open natural forest

In the open forest a total of 520 trees ha⁻¹ representing 14 species and 12 families were encountered. The Combristaceae family was represented by 12 individuals followed by, Burseraceae (8), Tiliaceae (7). It is evident from the data presented in the Table 4.2 that *Boswelvia serrata* was the most dominant tree layer followed by *Garuga pinnata* and *Terminalia tomentosa*. Highest density (stems ha⁻¹) was recorded for *Garuga pinnata* (80) followed by *Grewia tiliefolia* (70), *Terminalia tomentosa* (60). Lowest density was recorded in case of *Cassia fistula*, *Terminalia arjuna* and *Lagerstroemia parviflora* (10 for each). Total basal area of this site was 21.50 m² ha⁻¹. Highest basal area (m² ha⁻¹) was observed for *Boswelvia serrata* (5.54) followed by *Terminalia tomentosa* (3.84) and *Bombax ceiba* (2.43). Lowest basal area was observed in case of *Cassia fistula* (0.07), *Bridelia retusa* (0.10) and *Lagerstroemia parviflora* (0.12). Basal area and density of individual tree species varied from 0.07 to 5.54 m² ha⁻¹ and 10 to 80 stems ha⁻¹, respectively. *Boswelvia*

serrata showed highest value of IVI (43.97) followed by *Garuga pinnata* (41.93) and *Terminalia tomentosa* (37.28).

4.3.3 Species composition of Teak plantation

In the plantation forest of teak a total of 990 trees ha^{-1} representing 4 species and 4 families were encountered. It is evident from the data presented in the Table 4.2 that *Tectona grandis* was the most dominant tree layer followed by *Cleistanthus collinus* and *Lagerstroemia parviflora*. Highest density (stems ha^{-1}) was recorded for *Tectona grandis* (920) followed by *Cleistanthus collinus* (30) and *Lagerstroemia parviflora* (30). Lowest density was recorded in case of *Buchanania lanzan* (10). The total basal area in teak plantation site was $28.03 \text{ m}^2 \text{ ha}^{-1}$. Highest basal area ($\text{m}^2 \text{ ha}^{-1}$) was observed for *Tectona grandis* (27.30) followed by *Lagerstroemia parviflora* (0.30) and *Cleistanthus collinus* (0.24). Lowest basal area was observed for case *Buchanania lanzan* (0.08). Basal area and density of individual tree species varied from 0.08 to $27.30 \text{ m}^2 \text{ ha}^{-1}$ and 10 to 920 stems ha^{-1} . *Tectona grandis* showed highest value of IVI (257.17) followed by *Cleistanthus collinus* (22.64) and least for *Buchanania lanzan* (7.55).

Tree basal cover in the present study varied from 21.50 to $47.30 \text{ m}^2 \text{ ha}^{-1}$ for various forest plots. These basal cover values were higher than the values reported for several dry tropical forest communities in Western India reported by Kumar *et al.*, (2010) with average basal area ranging from 5.96 - $19.31 \text{ m}^2 \text{ ha}^{-1}$, Vindhyan region reported by Jha and Singh (1990) between 6.58 and $23.21 \text{ m}^2 \text{ ha}^{-1}$ and from 3.80 to $10.36 \text{ m}^2 \text{ ha}^{-1}$ by Singh and Singh (1991). The total tree basal cover in the present study, ranged between 21.50 to $47.30 \text{ m}^2 \text{ ha}^{-1}$. These values compare with 17 to $40 \text{ m}^2 \text{ ha}^{-1}$ for dry tropical forest and 20 to $75 \text{ m}^2 \text{ ha}^{-1}$ for wet forest (Murphy and Lugo, 1986a). Basal cover in a Puerto Rican sub-tropical dry forest was $19.8 \text{ m}^2 \text{ ha}^{-1}$

(Murphy and Lugo, 1986b). In the present study, tree density ranged between 520 to 990 for the various forest plots in tropical deciduous forest. Compared to the present study the density of forest in Thailand, of dry *Dipterocarp* forest, was 554 to 789 (Visaratana *et al.*, 1986); of mixed deciduous forest was 253 (Sahunalu *et al.*, 1979), of teak forest was 262 to 395 (Bunyavejchewin, 1983; Dhanmanonda and Sahunalu, 1992) and of tropical rain forest was 818 to 1540 (Kiratiprayoon, 1986).

Tree density in tropical dry deciduous forests of Western India ranged between 458 - 728 stems ha^{-1} (Kumar *et al.*, (2010) and in the Vindhyan region ranges between 294 to 627 stems ha^{-1} for several dry tropical forest communities (Singh and Singh, 1991; Jha and Singh, 1990). The forest canopy was three storied in the present forest. The dry tropical forest usually has 1-3 and the wet tropical forest has three or more canopy strata (Murphy and Lugo, 1986a). Density and basal cover values in the present study area are compared in Table 4.3 with the forest of Vindhyan hills and other tropical forests studied elsewhere. In general the above values are comparable to the several tropical forests. However, Rodgers (1990) reported a very high value of basal cover ($131 \text{ m}^2 \text{ ha}^{-1}$) for the forests of Sariska Tiger Reserve.

Changes in density and basal area of trees in different forest plots shows that prevailing biotic factors such as exploitation of forests to meet daily requirements of fuel wood, wood for agricultural implements and house hold construction, for preparation of boundaries along the houses and farm land, unregulated grazing by domestic cattle are the key determinants of structure and function of the forest. These factors in the absence of any viable alternatives defy all regulatory measures. As a result the forest goes on degrading year after year without any hope of rejuvenation without exclusion of these pressures. Variation in vegetation attributes such as IVI, tree density, basal area and distribution of tree species at different sites in the forest

indicate the complex plant succession resulting from varying degree of pressures at different sites.

4.3.4 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 (H') at different sites of same locality is not a good sign for better growth of forest of any area. In natural and plantation forest species diversity (H') was observed to be variable from site to site in the study area of Bharnawapara wildlife sanctuary. Diversity parameters on different forest site is given in Table 4.4. Species diversity (H') was 3.35 at closed natural forest, 3.08 at open natural forest and 0.19 at plantation forest of *Tectona grandis*, respectively exhibiting decreasing trend in diversity due to conversion of forest to plantation.

4.3.5 Concentration of dominance (Cd)

In the forest under study highest Cd value for tree layer was highest at plantation forest of *Tectona grandis* followed by open natural forest and closed natural forest. The Cd values were 0.95, 0.14 and 0.12, respectively for closed forest, open forest and teak plantation (Table 4.4).

4.3.6 Equitability (e)

Equitability (e) values were 1.12 for closed natural forest, 1.17 for open natural forest, 2.39 for plantation forest of teak (Table 4.4).

4.3.7 Species richness (d)

Species richness was highest (4.93) in closed natural forest followed by open natural forest (4.32) and lowest in plantation forest of teak 0.90 (Table 4.4).

4.3.8 Beta diversity

Beta diversity for the forest under study was 3.16, 5.77 and 3.03 (Table 4.4), for tree layer at closed natural forest, open natural forest and plantation forest of *Tectona grandis*, respectively.

Results of diversity parameter revealed that the Shannon index values in different forest types ranged from 0.19 to 3.35, Cd value from 0.12 to 0.95 and beta diversity from 3.01 to 5.77. The diversity parameters of these forest are comparable with the diversity indices reported in different tropical forests (Singh and Singh, 1991).

The Shannon index values of dry tropical forests in study area were comparatively lower than those reported by Singh *et al.* (1984) and Swamy *et al.* (2010) for other tropical forests of India. Singh *et al.* (1984) reported Shannon index value between 3.4 to 4.8 for tropical rain forests of Silent valley in Western Ghats, India. Similarly, Swamy *et al.* (2010) reported 1.49 to 3.67 Shannon index values for tropical evergreen forests of Karnataka, India. The lower diversity of dry tropical ecosystem in this study is attributed to sharing of large proportion of resources to only few species, while in tropical evergreen forests more number of species efficiently shared the resources. Therefore, the higher diversity was found in those forests. It is also evident from the results that Shannon index values were higher than concentration of dominance for different site of forest. The inverse relationship was found between Shannon index and Simpson index. These results are in agreement with earlier findings of Singh and Singh (1991) and Kumar *et al.* (2010).

Among different forest types, the mixed forest showed higher diversity and lower dominance, while teak forest showed poor diversity and higher concentration of dominance. The higher diversity in mixed forest is attributed to the presence of higher number of species (20), while the higher concentration of dominance in plantation forest of *Tectona grandis* were attributed to higher relative proportion of *Tectona*

grandis in these forest types compared to other species. The beta diversity was found to be highest for mixed forests and lowest for plantation forest of *Tectona grandis*, shows that higher rate of species turnover in former type compared other forest type. The higher beta diversity represents the higher niche diversification in natural forests compared to plantation forests. The results also showed that disturbance significantly influenced the basal area, tree density and species diversity, concentration of dominance and beta diversity in the forest.

4.4 Quantification of biomass and carbon storage at various forest plots

4.4.1 Biomass of various forest plots

Total biomass in the present study was between 134.99 t ha⁻¹ and 473.60 t ha⁻¹, and it was highest on closed natural forest (473.60 t ha⁻¹) followed by open natural forest (217.59 t ha⁻¹) and lowest on teak plantation. (134.99 t ha⁻¹). Analysis of variance indicated that the variation in biomass due to site were significantly different ($p > 0.01$).

4.4.2 Closed natural forest

The total biomass estimated for closed natural forest (Table 4.5) was 473.60 t ha⁻¹ of which 414.26 t ha⁻¹ was above ground and 59.34 t ha⁻¹ below ground. The distribution of biomass in the different components was 151.78 t ha⁻¹ in bole, 248.81 t ha⁻¹ in branch, 13.87 t ha⁻¹ in leaf and 59.34 t ha⁻¹ in root. The bole, branch, leaf and root constituted 32.00, 52.53, 2.92 and 12.53 per cent, respectively of the total biomass. Among the individual species *Madhuca indica* constituted the highest biomass (114.11) followed by *Terminalia tomentosa* (99.91) and *Lagerstroemia parviflora* (52.64), which contributed 24.09, 21.09 and 11.11 per cent of the total biomass.

4.4.3 Open natural forest

The total biomass estimated for open natural forest (Table 4.5) was 217.59 t ha⁻¹ of which 190.55 t ha⁻¹ was above ground and 27.04 t ha⁻¹ below ground. The distribution of biomass in the different components was 67.55 t ha⁻¹ in bole, 115.99 t ha⁻¹ in branch, 7.01 t ha⁻¹ in leaf and 27.04 t ha⁻¹ in root. The bole, branch, leaf and root biomass constituted 31.04, 53.30, 3.22 and 12.42 per cent, respectively of the total biomass. Among the individual species *Boswellia serrata* constituted the highest biomass (60.88) followed by *Terminalia tomentosa* (37.31) and *Anogeissus latifolia* (25.51) which constituted 27.97, 17.14, and 11.72 per cent of the total biomass.

4.4.4 Teak plantation

The total biomass estimated for teak plantation (Table 4.5) was 134.99 t ha⁻¹ of which 112.73 t ha⁻¹ was above ground and 22.26 t ha⁻¹ below ground. The distribution of biomass in the different components was 68.13 t ha⁻¹ in bole, 29.88 t ha⁻¹ in branch, 14.72 t ha⁻¹ in leaf and 22.26 t ha⁻¹ in root. The bole, branch, leaf and root biomass constituted 50.47, 22.13, 10.90 and 16.49 per cent, respectively of the total biomass. Among the individual species *Tectona grandis* constituted the highest biomass (131.25) followed by *Lagerstroemia parviflora* (1.84) and *Cleistanthus collinus* (1.54) which constituted 97.22, 1.36 and 1.14 per cent of the total biomass.

The above values are comparable with the estimates made by many workers (Murphy and Lugo, 1986; Singh and Singh, 1991; Haripriya, 2000; Swamy et al. 2010). The comparative account of biomass of important tropical forests is compared in Table 4.6. Singh and Mishra (1979) reported 77 Mg ha⁻¹ and Singh and Singh (1991) reported 42-78 Mg ha⁻¹ biomass in dry tropical forests of U.P., India. Roy and Ravan (1996) estimated the biomass of tropical dry deciduous forests of Madhav National Park, Madhya Pradesh, India. Total biomass of the different forest

communities ranged from 7.42 to 52.41 t ha⁻¹. Hall and Uhling (1991) estimated the biomass density of forests in South and South East Asia using the volume estimates and biomass expansion factors derived from Brown *et al.* (1989). Their biomass estimates for India ranged from 116 Mg ha⁻¹ for forest undisturbed for 60-80 years and 35, 66 and 84 Mg ha⁻¹ for logged, unproductive and managed forests, respectively. However, the present estimates were comparable to Murphy and Lugo (1986), where they reported 30 to 276 Mg ha⁻¹ above ground biomass for variety of dry tropical forests of the world. Tiwari (1994) reported average total above ground biomass in different forest types of Rajaji National Park, Dehradun, India between 52.36 t ha⁻¹ (Plantations) and 371.08 t ha⁻¹ (Sal forest).

Distribution pattern of biomass in natural and plantation forests:

Although the young individuals belonging to seedlings and saplings classes dominated all the three site in terms of density the total biomass accumulation was greater in the >100 cm girth class in natural forest sites while it was maximum in middle girth classes in teak plantation (Figures 4.5-4.7).

4.4.5 Carbon concentration:

The carbon concentration (Table 4.7) in bole, branch, leaf and coarse roots were 43.50 %, 45.67 %, 46.67 % and 35.73, respectively.

4.4.6 Carbon storage of various forest plots

The total carbon at different sites of Bharnawapara wildlife sanctuary is given the Table 4.8. Analysis of variance indicated that the variation in carbon due to site were significantly different ($p > 0.01$).

4.4.7 Closed natural forest

The total carbon estimated for closed natural forest was 208.22 t ha⁻¹ of which 187.08 t C ha⁻¹ was above ground and 21.14 t C ha⁻¹ below ground. The distribution of carbon in the different components was 66.63 t ha⁻¹ in bole, 113.54 t ha⁻¹ in branch, 6.91 t ha⁻¹ in leaf and 21.14 t ha⁻¹ in root. The bole, branch, leaf and root constituted 31.94, 54.52, 3.31 and 10.15 per cent, respectively of the total carbon. Among the individual species *Madhuca indica* constituted the highest carbon (50.34) followed by *Terminalia tomentosa* (43.47) and *Lagerstroemia parviflora* (22.54) which constituted 24.17, 21.01 and 10.84 per cent of the total carbon.

4.4.8 Open natural forest

The total carbon estimated for open natural forest was 95.11 t ha⁻¹ of which 85.60 t C ha⁻¹ was above ground and 9.59 t C ha⁻¹ below ground. The distribution of carbon in the different components was 29.33 t ha⁻¹ in bole, 52.91 t ha⁻¹ in branch, 3.24 t ha⁻¹ in leaf and 9.59 t ha⁻¹ in root. The bole, branch, leaf and root constituted 30.84, 55.63, 3.04 and 10.08 per cent, respectively of the total carbon. Among the individual species *Boswellia serrata* constituted the highest carbon (26.73) followed by *Terminalia tomentosa* (16.33) and *Anogeissus latifolia* (11.20) which constituted 28.10, 17.17 and 11.77 per cent of the total carbon.

4.4.9 Plantation forest of Teak

The total carbon estimated for plantation forest of teak was 58.06 t ha⁻¹ of which 50.11 t C ha⁻¹ was above ground and 7.95 t C ha⁻¹ below ground. The distribution of carbon in the different components was 29.62 t ha⁻¹ in bole, 13.63 t ha⁻¹ in branch, 6.86 t ha⁻¹ in leaf and 7.95 t ha⁻¹ in root. The bole, branch, leaf and root constituted 51.01, 23.47, 11.81 and 13.69 per cent, respectively of the total carbon. Among the individual species *Tectona grandis* constituted the highest carbon (56.48)

followed by *Lagerstroemia parviflora* (0.78) and *Cleistanthus collinus* (0.66) which constituted 97.27, 1.34 and 1.13 per cent of the total carbon.

Distribution pattern of carbon in natural and plantation forests:

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 girth class >100 cm in natural forest. In teak plantation carbon storage was maximum in middle girth classes (Figs 4.8-4.10).

CHAPTER-V

SUMMARY CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

The study on **“Regeneration Status, Species Diversity, Biomass and Carbon storage pattern in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary”** was carried out in various forest plots of Barnawapara wildlife sanctuary situated in North-Eastern corner of Raipur district which is located between 21⁰20'00" to 21⁰25'47" North latitudes and 82⁰21'17" to 82⁰26'27" East longitudes having an area of 244.66 km² during the year 2009-2010.

The species composition, species diversity, biomass and carbon storage of different forest plots was measured by randomly placing quadrats of 10 m x 10 m at various sites. Randomly 10 quadrats were laid down in each forest plot. In each quadrat GBH (girth at breast height) of each adult individual (≥ 30 cm gbh) were measured. In the center of each 10 m x 10 m quadrat, 2 m x 2 m quadrat area was marked for enumeration of sapling and seedling. The structural analysis was done by determining primary variables (frequency, density, and basal area). Subsequently secondary variables (relative frequency, relative density, relative basal area and IVI) were computed from primary data. The diversity parameters viz., Shannon Index, Simpson's Index, equitability, species richness and beta diversity were also calculated for each forest plot. Biomass for each forest plot was estimated using allometric equations based on the relationship between girth of a tree and dry weight of component. The salient findings on regeneration status, species diversity, biomass and carbon storage pattern in natural and plantation forest in sub-humid tropics are summarized below:

Regeneration Status

The density of seedlings was found to be 960 ha⁻¹ of 13 species at closed natural forest, 400 ha⁻¹ of 14 species at open natural forest and 340/ha of 5 species at plantation forest of *Tectona grandis* in Barnawapara wildlife sanctuary. Similarly density of sapling (Table 4.1) was found to be 220 ha⁻¹ of 13 species at closed natural forest, 90 ha⁻¹ of 14 species at open natural forest and 40 ha⁻¹ of 5 species at teak plantation in the same study site.

From the study it is found that the forest is poor in regeneration for most of the species although, few species like *Diospyros melanoxylon* in closed natural forest and *Lagerstroemia parviflora* in teak plantation showing good regeneration.

Species composition

Closed Natural Forest

- In closed natural forest *Cleistanthus collinus* was recognized as dominant plant species and *Terminalia tomentosa* as co-dominant.
- Maximum density was observed for *Cleistanthus collinus* (330 stems ha⁻¹) followed by *Lagerstroemia parviflora* (130 stems ha⁻¹) and *Terminalia tomentosa* (120 stems ha⁻¹).
- Maximum basal cover was observed for *Terminalia tomentosa* (9.40 m² ha⁻¹) followed by *Madhuca indica* (7.86 m² ha⁻¹) and *Lagerstroemia parviflora* (7.05 m² ha⁻¹).
- Basal area and density of individual tree species varied respectively, between 0.12 to 9.41 m² ha⁻¹ and 10 to 330 stems ha⁻¹.
- Highest IVI value was observed for *Cleistanthus collinus* (57.70) followed by *Terminalia tomentosa* (47.10) and *Lagerstroemia parviflora* (36.92).

- The total density and basal area of natural forest was 950 trees ha⁻¹ and 47.30 m² ha⁻¹.

Open Natural Forest

- In open natural forest *Boswellia serrata* was recognized as dominant plant species and *Garuga pinnata* as co-dominant.
- Maximum density was observed for *Garuga pinnata* (80 stems ha⁻¹) followed by *Grewia tiliaefolia* (70 stems ha⁻¹) and *Terminalia tomentosa* (60 stems ha⁻¹).
- Maximum basal cover was observed for *Boswellia serrata* (5.53 m² ha⁻¹) followed by *Terminalia tomentosa* (3.84 m² ha⁻¹) and *Bombax ceiba* (2.43 m² ha⁻¹).
- Basal area and density of individual tree species varied respectively, between 0.10 to 3.84 m ha⁻¹ and 10 to 80 stems ha⁻¹.
- Highest IVI value was observed for *Boswellia serrata* (43.97) followed by *Garuga pinnata* (41.93) and *Terminalia tomentosa* (37.28).
- The total density and basal area of closed forest was 520 trees ha⁻¹ and 21.50 m² ha⁻¹.

Teak Plantation

- In teak plantation forest *Tectona grandis* emerged as dominant plant species and *Cleistanthus collinus* as co-dominant.
- Maximum density was observed for *Tectona grandis* (920 stems ha⁻¹) followed by *Cleistanthus collinus* (30 stems ha⁻¹) and *Lagerstroemia parviflora* (30 stems ha⁻¹).

- Maximum basal cover was observed for *Tectona grandis* (27.30 m² ha⁻¹) followed by *Lagerstroemia parviflora* (0.30 m² ha⁻¹) and *Cleistanthus collinus* (0.24 m² ha⁻¹).
- Basal area and density of individual tree species varied between 0.08 m² ha⁻¹ to 27.30 m² ha⁻¹ and 10 to 920 stems ha⁻¹.
- Highest IVI value was recorded for *Tectona grandis* (257.17) followed by *Cleistanthus collinus* (22.64) and *Lagerstroemia parviflora* (16.64).
- The total density and basal area of teak plantation was 990 trees ha⁻¹ and 28.03 m² ha⁻¹.

Species diversity

- Shannon index in forest plots under study ranged between 0.19 to 3.35. It was highest in closed natural forest (3.35) and lowest in teak plantation (0.19).
- Equitability (e) values ranged from 1.12 to 2.39, respectively in various forest plots and was highest in teak plantation and lowest in closed natural forest.
- Species richness in various forest plots ranged from 0.90 to 4.93 and recorded highest in closed natural forest (4.93) and lowest in teak plantation (0.90).
- Beta diversity values in various forest plots ranged from 3.03 to 5.77 and was highest in open natural forest (5.77) and lowest in teak plantation (3.03).
- Concentration of dominance ranged between 1.12 to 2.39, being highest in teak plantation (2.39) and lowest in closed natural forest (1.12).

Biomass

Closed Natural Forest

The total biomass recorded in natural forest was 473.60 t ha⁻¹, of which 414.26 t ha⁻¹ was above ground and 59.34 t ha⁻¹ below ground biomass.

- Highest biomass was constituted by branch (248.81 t ha⁻¹) followed by bole (151.78 t ha⁻¹) and root (59.34 t ha⁻¹).
- Lowest biomass was constituted by leaf (13.87 t ha⁻¹).
- The bole, branch, leaf and root biomass constituted 32.00, 52.53, 2.92 and 12.53 per cent, respectively of the total biomass.

Open natural forest

- The total biomass recorded in open natural forest was 217.59 t ha⁻¹ of which 190.55 t ha⁻¹ was above ground and 27.04 t ha⁻¹ below ground biomass.
- Highest biomass was constituted by branch (115.99 t ha⁻¹) followed by bole (67.55 t ha⁻¹) and root (27.04 t ha⁻¹).
- Lowest biomass was constituted by leaf (7.01 t ha⁻¹).
- The bole, branch, leaf and root biomass constituted 31.04, 53.30, 3.22 and 12.42 per cent, respectively of the total biomass.

Teak plantation

- The total biomass recorded in teak plantation was 134.99 t ha⁻¹ of which 112.73 t ha⁻¹ was above ground and 22.26 t ha⁻¹ below ground biomass.
- Highest biomass was constituted by bole (68.13 t ha⁻¹) followed by branch (29.88 t ha⁻¹) and root (22.26 t ha⁻¹).
- Lowest biomass was constituted by leaf (14.72 t ha⁻¹).
- The bole, branch, leaf and root biomass constituted respectively, 50.47, 22.13, 10.90 and 16.49 per cent of the total biomass.

Carbon storage

Closed Natural Forest

- The total carbon estimated for closed natural forest was 208.22 t ha⁻¹ of which 187.08 t C ha⁻¹ was above ground and 21.14 t C ha⁻¹ below ground biomass.

- Highest carbon was constituted by branch (113.54 t ha^{-1}) followed by bole (66.63 t ha^{-1}) and root (21.14 t ha^{-1}).
- Lowest carbon constituted by leaf (6.91 t ha^{-1}).
- The bole, branch, leaf and root carbon constituted respectively, 31.99, 54.52, 3.31 and 10.82 per cent of the total carbon storage.

Open natural forest

- The total carbon estimated for open natural forest was 95.11 t ha^{-1} of which $85.60 \text{ t C ha}^{-1}$ was above ground and 9.59 t C ha^{-1} below ground biomass.
- Highest carbon was constituted by branch (52.91 t ha^{-1}) followed by bole (29.53 t ha^{-1}) and root (9.59 t ha^{-1}).
- Lowest carbon constituted by leaf (3.24 t ha^{-1}).
- The bole, branch, leaf and root carbon constituted respectively, 30.84, 55.84, 3.04 and 10.08 per cent of the total carbon storage.

Teak plantation

- The total carbon estimated for teak plantation was 58.06 t ha^{-1} of which $50.11 \text{ t C ha}^{-1}$ was above ground and 7.95 t C ha^{-1} below ground biomass.
- Highest carbon was constituted by bole (29.62 t ha^{-1}) followed by branch (13.63 t ha^{-1}) and root (7.95 t ha^{-1}).
- Lowest carbon constituted by leaf (6.86 t ha^{-1}).
- The bole, branch, leaf and root carbon constituted respectively 51.01, 23.47, 11.81 and 13.69 per cent of the total carbon storage.

The present study reveals that the disturbance created in the forest had significantly influenced the regeneration, species composition, diversity, biomass and carbon storage status of sub-humid tropics. It reflects that tropical deciduous forest of Chhattisgarh are ecologically rich as compared to other tropical forests of the country

in terms of composition and diversity. The increasing biotic interferences are degrading these forests and resulting in poor regeneration, density, basal area and diversity. The study recommends adopting intensive conservation measures especially in degraded areas of the forests.

Perennial grasses, hardy trees and shrubs should be planted on deep slopes to reduce surface runoff, control soil erosion and stabilize the degraded slopes. In order to encourage and improve regeneration in forests, the temporary closure needs to be made at least for a period of 5 to 10 years. The silvipastoral system should be developed in open natural grassland by planting MPT's and other palatable grasses to protect the forest area from over grazing and browsing. The rotational grazing practices should be adopted in regenerating grasslands.

It is also suggested to practice alternate system of land management/agri-silvicultural practices in marginal, degraded and agricultural lands, which are actually underutilized. These strategies will help in reducing the biotic pressure and also restoring and conserving the fragile tropical deciduous forests of Chhattisgarh.

**“Regeneration Status, Species Diversity, Biomass and Carbon Storage Pattern in
Natural and Plantation Forests of Sub-humid Tropics in Barnawapara wildlife
sanctuary”**

by

CHAMAN LAL

ABSTRACT

The present work aimed to study the regeneration status, species diversity, biomass and carbon storage pattern in natural and plantation forests of sub-humid tropics in Barnawapara Wildlife Sanctuary during 2009-2010. Biomass for each site was estimated using allometric equations based on the relationship between girth of tree and dry weight of the component (bole, branch, leaf, root). Trees in the sampling quadrats in each forest were enumerated for their GBH. A total of 33 species of 17 families were encountered. Regeneration status in all the study sites are dissimilar. Although closed natural forest was regenerating well with *Diospyros melanoxylon* and *Cleistanthus collinus*.

Tree stand density varied from 520-990 stems ha⁻¹ with average basal area ranging from 21.50 to 47.30 m² ha⁻¹. Species diversity index varied between 0.19 for plantation forest to 3.35 for closed natural forest, Simpson index of dominance ranged between 0.12- 0.95. The Margalef's Species Richness Index varied from 0.90-4.93, equitability index varied from 1.12-2.39 and β diversity varied from 3.03-5.77. Total biomass (t ha⁻¹) recorded was maximum in closed natural forest (473.60) followed by open natural forest (217.59) and teak plantation (134.99). In natural forest maximum biomass was accumulated in higher girth classes while in plantation forest biomass accumulation was higher in middle girth classes. Carbon storage has same pattern as that biomass accumulation at all sites.

From these studies it is evident that natural forest has an edge over plantation forest in terms of regeneration, species diversity, dominance, richness, biomass accumulation and carbon storage. Efforts are needed to conserve the natural forest for their diversity and existence. They are supplemented with plantation forests to lower the biotic pressure.

Date:
Place: Raipur

Dr. Lalji Singh
Chairman,
Advisory committee

REFERENCES

- Austin, M. P. 1977. Use of ordination and other multivariate descriptive methods to study succession. *Vegetatio*, 3: 165-175.
- Baisya, R., Barik, S. K. and Upadhaya, K. 2009. Distribution Pattern of above ground biomass in natural and plantation forests of humid tropics in NE-India. *Tropical Ecology*, 50(2): 295-304.
- Barker, P. C. J. and Kirk Patrick, J. B. 1994. *Phyllocladus asplenifolius*: variability in the population structure of the regeneration niche and dispersion pattern in Tasmanian forest. *Aust. J. Bot.*, 42 : 163-190.
- Bisht, A. P. S. 1989. Microsite mosaic and under canopy vegetation dynamics of Sal communities in East and West Dehradun forest division. D. Phil. Thesis, Garhwal University, Srinagar (Garhwal) India. 187 pp.
- Bolin, B. 1983. C N P and S cycles: Major reservoirs and fluxes. The carbon cycle. In: Bolin B, Cook RB (eds) The major biogeochemical cycles and their interactions. Wiley, Chichester, pp. 41– 45.
- Brown, S., Gillespie, A. J. R. and Lugo, A. E. 1989. Biomass estimation methods for tropical forests with application to forest inventory data. *Forest Science*, 35:881-902.
- Brun, R. 1976. Methodik und Ergebnisse Zur Biomassenbestimmung eines Nebewald- Okosystems in den Venezolanischen Anden. pp. 490-499. In: proc. Div. I . 16th IUFRO World Congress, Oslo, Norway.
- Brunig, E. F., Herrera, F., Heuvelod, J., Jordan, C., Klinge, H. and Medina, E. 1979. The international Amazon MAB rainforest ecosystem pilot project at San Carlos de Rio Negro: Review of developments since the 1st International workshop. pp. 47-66. In: S. Adiosoemanto and E.F.

- Brunig (eds.) Trans. 2nd Int. MAB-IUFRO workshop, Tropical Rain Forest Ecosystem Research, Special Report no. 2. Hamburg-Reinbeck, Germany.
- Bunyavejchewin, S. 1983. Analysis of the tropical dry deciduous forest of Thailand, Characteristics of dominance-type. *Nat. His. Bull. Siam Soc.*, 31(2): 109-122.
- Cannon, C. H., Peart, D. R. and Leighton, M. 1998. Tree species diversity in commercially
- Castellanos, J., Mass, M. and Kummerow, J. 1991. Root biomass of a dry deciduous tropical forest in Mexico. *Plant and Soil*, 131: 2, 225-228; 13 ref.
- Champion, H. G. and Seth, S. K. 1968. A revised Survey of the Forest Types of India. Government of India Publication New Delhi.
- Chaturvedi, O. P. and Singh, J. S. 1987. The structure and function of pine forest in central Himalaya. Dry matter dynamics. *Annals of botany*, 60: 237-252.
- Chauhan, D. S., Dhanai, C. S., Singh, B., Chauhan, S., Todaria N. P. and Khalid, M. A. 2005. Regeneration and tree diversity in natural and planted forests in a Terai-Bhabhar forest in Katarniaghat Wildlife Sanctuary, India. *Tropical Ecology*, 49(1): 53-67, 2008
- Condit, R., Hubbell, S. P., Lafrankie, J. V., Sukumar, R., Manokaran, N., Foster, R. B. and Ashton, P. S. 1996. Species area and species individual relationships for tropical trees: a comparison of three 50-ha plots. *Journal of Ecology*, 84: 549-562.

- Cook, E. A., Jerson, L. R. and Graham, R. L. 1989. Estimating forest productivity with thematic mapper and bio-geographical data. *Remote Sensing of Environment*, 28: 131-141.
- Costa, P. M. 1996. Tropical forestry practices for carbon sequestration-review and case study from SE Asia. *Ambio*, 25: 279-283.
- Crow, T. R. 1980. A rain forest chronicle: A 30 year record of change in structure and composition at El Verde, Puerto Rico. *Biotropica*, 12: 42-55.
- Curtis, J. T. and McIntosh, R. P. 1950. The interrelations of certain analytic and Synthetic phytosociological characters. *Ecology*, 31: 434-455.
- Dalling, J. W., Hubble, S. P. and Silvera, K. 1998. Seedling establishment and gap partitioning among tropical pioneer trees. *J. Ecol.*, 86: 674-689.
- Dhanmanonda, P. and Sahunalu, P. 1992. Research on natural teak forests. In: Teak conference: 50th Anniversary of the Huay Tak Teak Plantation in Lampang, Royal Forest Department, Bangkok, Thailand. Pp. 15-55.
- Drew, W. B., Akornkoae, S. and Kaitpraneet, W. 1978. An assessment of productivity in successional stages from abandoned swidden (Rai) to dry evergreen forest in northeastern Thailand. Forest Res. Bull. 56. Fac. For., Kasetsart Univ., Bangkok, Thailand. pp. 31.
- Edwards, P. J. and Grubb, P. J. 1977. Studies of mineral cycling in a montane rain forest in New Guinea. I. The distribution of organic matter in the vegetation and soil. *J. Ecol.*, 65: 943-969.
- Enright, N. J. 1979. Litter production and nutrient partitioning in rain forest near Bulolo, Papua New Guinea. *Malaysian Forester*, 42: 202-207.

- FAO, 2005. Global Forest Resources Assessment. Progress towards sustainable forest management. FAO Forests Paper. 147. Rome.
- Folster, H., De las Salas, G. and Khanna, P. 1976. A tropical evergreen forest site with perched water table, Magdalena Valley, Colombia, biomass and bioelement inventory of primary and secondary vegetation. *Oecol. Plant.*, 11: 297-320.
- Freson, R., Goffinet, G. and Malaisse, F. 1974. Ecological effects of the regressive succession Muhulu-Mimbo-Savannah in Upper-Shaba (Zaire). pp. 365-371. In: Proc. 1st Int. cong. Ecol. The Hague, Pudoc, Wageningen, Netherlands.
- Gentry, A. H. 1992. Tropical forest biodiversity: distributional patterns and their conservational significance. *Oikos*, 63: 19-28.
- Golley, F. B., McGinnis, J. T., Clements, R. G., Child, G. I. and Duever, M. J. 1975. Mineral cycling in a Tropical Moist Forest Ecosystem. University of Georgia Press, Athens, U.S.A. pp. 248.
- Gower, S. T., Vogt, K. A. and Grier, C. C. 1992. Carbon dynamics of rocky mountain Douglas fir: Influence of water and nutrient availability. *Ecological monographs*, 62(1): 43-65.
- Greenland, D. J. and Kowal, J. M. L. 1960. Nutrient content of the moist tropical forest in Ghana. *Plant Soil*, 12: 154-174.
- Grubb, P. J. 1977. The maintenance of species richness in plant communities. The importance of the regeneration niche. *Biological Review*. 52: 107-145.
- Hall, C. A. S. and Uhlig, J. 1991. Refining estimates of carbon released from Tropical land use change. *Canadian Journal of Forest Research*, 21: 118-131.

- Haripriya, G. S. 2000. Estimates of biomass in Indian forests. *Biomass and Bioenergy*, 19(250): 245-258.
- Hegde, R. and Enters, T. 2000. Forest products and household economy: a case study from Mudumalai Wildlife Sanctuary, Southern India. *Environmental Conservation*, 27: 250-259.
- Hozumi, K., Yoda, K., Kokawa, S. and Kira, T. 1969. Production ecology of tropical rain forests in SW Cambodia. I. Plant biomass. *Nature Life South East Asia*, 6: 1-54.
- Huttel, C. H. and Bernhard-Reversat, F. 1975. Recherches sur l' ecosysteme de la foret subequatoriale de base Cote-D' Ivoire. Cycle de las matiere organi que. *Terre Vie* 29: 203-228.
- IPCC, 1996. Impacts, adaptations and mitigation of climate change: Scientific technical analysis contributions of working group II to IInd assessment report of intergovernmental panel on climate change edited by Watson, R.T., Zingowera, M.C., Moss, R.H. (eds.) *Cambridge Univ. Press New York*, NY USA, 880 pp.
- IPCC, 1999. Inter Governmental panel on climate change – Report on land use change and forestry. Watson, R., Noble, L., Bolin, B., Ravindranath, N.H., (eds.). *Government Publishing Service, Canberra, Australia*, pp.79.
- Ipor, I., Hamsawi, S. and Cheksum, T. 2002. Floristic composition of forest formation at Mahua, crocker range National park, sabah *ASEAN Review of Biodiversity and Environmental Conservation (ARBEC)*.
- Janzen, D. H. 1970. Herbivores and the number of tree species in tropical forest. *American Naturalist*, 104: 501–528.

- Jha, C. S. and Singh, J. S. 1990. Composition and dynamics of dry tropical forest in relation to soil texture. *J. Veg. Sci.*, 1: 609-614.
- Jordan, C. F. 1971a. Productivity of a tropical forest and its relation to a world pattern of energy storage. *J. Ecol.*, 59: 127-142.
- Jordan, C. F. 1983. Productivity of tropical rain forest ecosystems and the implications for their use as future wood and energy sources. In: Golley, F.B. (ed.) *Ecosystems of the world. Tropical rain forest ecosystems*, pp. 117-136.
- Jung, G. 1969. Cycles biogéochimiques dans UN écosystème de région tropicale sèche *Acacia albidia* (Del.) sol ferrugineux tropical peu lessive (Dior). (Note préliminaire). *Oecol. Plant*, 4: 195-210.
- Kaul, O. N. and Sharma, D. C. 1971. Forest types statistics. *Indian Forester*, 97: 432-436.
- Kennedy, D. N. and Swaine, M. D. 1991. Germination and growth of colonising species in disturbance and recovery. Royal Society, London. pp. 357-367.
- Khan, M. L., Rai, J. P. N. and Tripathi, R.S. 1987. Population structure of some tree species in disturbed and protected sub-tropical forests of North East India. *Acta Oecologica: Oecologia Applicata* 8: 247-255.
- Khan, M., Rai, J. P. N. and Tripathi, R. S. 1987a. Population structure of some tree species in disturbed and protected subtropical forests of northern India. *Acta Ecol.*, 8: 247-255.
- Khan, M., Rai, J. P. N. and Tripathi, R. S. 1987b. Regeneration and survival of tree seedlings and sprout in tropical deciduous and subtropical forest of Meghalaya, India. *Forest Ecol. Manage.*, 14: 293-304.

- Khanduri, U. P., Sharma, C. M., Ghildiyal, S. K. and Puspwan, K. S. 2002. Forest composition in relation to socio economic status of people at three high altitudinal villages of a part of Garhwal Himalayas. *Indian Forester* 128(12): 1335.
- Kiratiprayoon, S. 1986. Comparative Study on the Structure of the Rattan Bearing Tropical Rain Forest. M.Sc. Thesis, Kasetsart University.
- Kiratiprayoon, S., Luangiam, J., Damrongthai, P. and Tarumatsawas, M. 1995. Species diversity of the second growth at Nago Demonstration Forest, Lampang Province. pp. 237-245. In: T.J.B. Boyle and B. Boontawe (eds.) *Measuring and Monitoring Biodiversity in Tropical and Temperate Forests*. Centre for International Forestry Research, Bogor, Indonesia.
- Klinge, H. and Herrera, R. 1978. Biomass studies in Amazon caatinga forest in southern Venezuela. I. Standing crop of composite root mass in selected stands. *Trop. Ecol.*, 19: 93-110.
- Knight, N., Kumar, A., Ram, J. and Tiwari, A. 2001. Plant diversity assessment in relation to disturbance in mid elevation forest of central Himalaya, India. *Tropical Ecology*, 42: 83-95.
- Kolongo, T. S. D., Decocq, G., Yao, C. Y. A., Blom, E. C. and Van Rompaey, R. S. A. R. 2006. Plant species diversity in the southern part of the Tai National Park (Côte d'Ivoire). *Biodiversity and Conservation*, 15: 2123-2142.
- Kumar, A., Khanna, K. K. and Jha, A. K. 2003. Forest types of Chhattisgarh. *Indian Journal of Forestry* 26(4): 401-405.

- Latha, K. and Bisht, N. S. 1991. Quantitative analysis and regeneration potential of moist temperature forest in Garhwal Himalayas. *Indian Journal of Forestry*, 14(2): 98-106.
- Lugo, A. E., Brown, S. and Chapman, J. 1988. An analytical review of production rates and stemwood biomass of tropical forest plantations. *Forest Ecology and Management* 23: 179-200.
- Nirmal Kumar, J. I., Kumar, R. N., Kumar, R. B. and Sajish, P. R. 2010. Tree species diversity and soil nutrient status in three sites of tropical dry deciduous forest of western India. *Tropical Ecology* 51(2): 273-279.
- Margalef, D. R. 1958. Information theory in Ecology. *Gen. Syst.*, 3: 36-71.
- Mishra, R. 1968. Ecology Work Book Oxford and IBH Publishing Co., Calcutta, pp. 244.
- Mishra, R., Bankhwal, D. P., Pacholi, R. K. and Singh, V. P. 1998. Biomass status of mixed dry deciduous forest of Shiwalik hills in Haryana. *Indian Forester* 124(5): 287-291.
- Mishra, B. P., Tripathi, R. S., Tripathi, O. P. and Pandey, H. N. 2003. Effect of disturbance on regeneration of 4 dominant and economically important woody species in a broad leaved subtropical humid forest of Meghalaya north east India. *Curr. Sci.*, 84: 1449-1453.
- Mosango, M. 1991. Contribution le-u de botanique biogeochemigude L. ecosystem forest en region equatorial (Lie Kongola, aire). *Belgian J. Bot.*, 124: 167-94.
- Muellor-Dombois, D. and Ellenberg, H. 1974. Aims and Methods of Vegetation Ecology,
John Wiley & Sons, New York.

- Muller, D. and Nielsen, J. 1965. Production brute, pertes par respiration et production nette dans la forest ombrophile tropicale. Det Forstlige Forsogsvaesen I Denmark 29: 69-160.
- Murali, K. S. and Setty, R. S. 2001: Effect of weed Lantana camara and Chromelina odorata growth on the species diversity, regeneration stem density of tree and shrub layer in BRT sanctuary. *Current Science*, 80: 675-678.
- Murali, K. S, Bhat, D. M. and Ravindranath, N. H. 2005. Biomass estimation equations for tropical deciduous and evergreen forests. *International Journal of Agricultural Resources, Governance and Ecology*, 4(1): 81-92.
- Murphy, P. G. 1986. Ecology of tropical dry forests. *Annual review of ecology and systematics*, 17: 67-88.
- Murphy, P. G. and Lugo, A. E. 1986a. Ecology of tropical dry forest. *Annual Review of Ecology and Systematics*, 17: 67-88.
- Murphy, P. G. and Lugo, A. E. 1986b. Structure and biomass of a subtropical dry forest in Puerto Rico. *Biotropica*, 18: 89-96.
- Murthi, I. K., Murali, K. S., Hegde, G. T. Bhat, P. R. and Ravindranath, N. H. 2002. A comparative analysis of regeneration in natural forest and joint forest management plantations in Uttara Kannada Dist., Western Ghats. *Curr. Sci.*, 83: 1358-1364.
- Myers, N. 1988. Threatened biota's, 'Hot spots' in tropical forests. *The Environmentalist* 8: 187-208.
- Nascimento, H. E. M. and Laurance, W. F. 2002. Total aboveground biomass in central Amazonian rainforests: a landscape-scale study. *Forest Ecology and Management* 168(1/3): 311-321.

- Negi, C. S. and Nautiyal, S. 2005. Phytosociological studies of a traditional reserve forest -Thalke Dhar, Pithoragarh, Central Himalayas. *Indian Forester* 13(4): 535.
- Odum, H.T. 1970. Summary: an emerging view of the ecological system at El Verde. pp. I-191 to I-289. In: H.T. Odum and R.F. Pigeon (eds.) A Tropical Rain Forest, Division of Technical Information, U.S. atomic Energy Commission, Oak Ridge, Tennessee, U.A.
- Odum, E.P. 1983. Basic Ecology. Saunders College Publishing, Holt Saunders Japan, 613
- Ogawa, H., Yoda, K., Ogino, K. and Kira, T. 1965. Comparative ecological studies on three main types of forest vegetation in Thailand. II. Plant biomass. *Nature Life S.E. Asia*. 4: 49-80.
- Pande, M. C., Tandon, V. N. and Negi, M. 1986. Biomass production and distribution of nutrients in moist deciduous forests in Goa. *Van Vigyan*, 24: 3-4, 83-85; 2 ref.
- Pande, P. K. 1999. Comparative vegetation analysis and Sal regeneration in relation to their disturbance magnitude in some Sal forests. *Trop. Ecol.* 40(1): 51-61.
- Pande, P. K. 2001. Structure of tropical dry deciduous teak forest of Satpura plateau (India) with special emphasis on regeneration and disturbances. *Journal of Tropical Forest Science*, 13: 329-343.
- Pande, P. K. 2005. Ecological assessment of vegetation in JFM adapted village forest in Satpura plateau, M.P. *Indian Forester*, 131(1): 97.
- Pande, P. K., Negi, J. D. S. and Sharma, S. L. 2002. Plant species diversity composition. Gradient analysis and regeneration behaviour of some

tree species in a moist temperate Western Himalayan forest ecosystem.
Indian Forester, 128(8): 869-885.

Parthasarathy, N., Kinhal, U. and Praveen Kumar, L. 1992. Plant species diversity and human impact in tropical wet evergreen forests of South Western Ghats. Indo French workshop on tropical forest system: Natural functioning and Anthropogenic impact, French Institute, Pondicherry, pp.165-176.

Pattanayak, S., Sills, E. O., Mehta, A. D. and Kramer, R. A. 2003. Local uses of parks: uncovering patterns of household production from forests of Siberut, Indonesia. *Conservation and Society*, 1: 209-222.

Philips, E. A. 1959. Methods of vegetation study. Henry Holt and Co., London. pp. 105.

Phillips, O. L., Hall, P., Gentry, A. H., Sawyer, S. A. & Vasquez, R. 1997. Species richness, tropical forest dynamics and sampling: response to Sheil. *Oikos*, 79: 183-190.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, 13: 131-144.

Pokhriyal, P., Uniyal, P., Chauhan, D. S. and Todaria, N. P. 2010. Regeneartion status of

tree species in forests of Phakot and Pathri rao watersheds in Gharwal Himalayas. *Current Science*, 98(2): 171- 175.

Prasad R. and Pandey, R. K. 1992. An observation on plant diversity of Sal and teak forest in relation to intensity of biotic impact of various distances from habitation in Madhya Pradesh, A case study. *Journal of Tropical Forestry*, 8(1): 62-83.

- Proctor, J., Anderson, J. M., Chai, P. and Vallack, H. W. 1983b. Ecological studies in four contrasting low land rain forests in Gunung Mulu National Park, Sarawak. I. Forest environment, structure and floristics. *J. Ecol.*, 71: 237-260.
- Rai, S. N. 1984. Bole, branch, current year twig, leaf and root biomass production in Tropical rain (Wet evergreen) forests of Western Ghats of Karnataka. *Indian Forester*, 110(9): 901-913.
- Rai, S. N. and Proctor, J. 1986b. Ecological studies on four rain forests in Karnataka, India. II . Litterfall. *J. Ecol.*, 74: 455-463.
- Rao, P., Barik, S. K., Pandey, H. N. and Tripathi, R. S. 1990 Community composition and population structure in a sub-tropical broad leaved forest along a disturbance gradient. *Vegetio*, 88: 151-162.
- Raizada, A., Parandiyal, A. K., Ghosh, B. N. 2003. Estimation of carbon flux through litter fall in forest plantations of India. *Indian Forester*, 129(7): 881-894.
- Raizada, A. Ramamohan, Rao, M. S., Nambiar, K. T. N. Padmaiah, M. 2007. Biomass production and prediction models for Acacia in salt affected vertisols in Karnataka. *Indian Journal of Forestry*, pp. 239-246.
- Ramachandran, A., Jayakumar, S., Mohamed Harron, A. R., Bhaskaran, A. 2007. carbon management in forest floor - An agenda of 21st century in *Indian Forestry Scenario*. pp. 25-37.
- Rennolls, K. and Laumonier, Y. 2000. Species diversity structure analysis at two sites in the tropical rain forest of Sumatra. *Journal of Tropical Ecology*, 16: 253-270.

- Rodgers, W. A. 1990. A preliminary ecological survey of Algal spring Sariska Tiger Reserve, Rajasthan. *Journal of Bombay Natural History Society*, 87: 201-209.
- Sagar, R. and Singh, J. S. 1999. Species diversity and its measurement. *The Botanica* 49: 9-16.
- Sagar, R., Raghubanshi, A. S. and Singh, J. S. 2003. Tree species composition, dispersion and diversity along disturbance gradient in a dry tropical forest region of India. *For. Ecol. Manage.*, 186: 61- 71.
- Sahu, P. K., Sagar, R. and Singh, J. S. 2008. Tropical forest structure and diversity in relation to altitude and disturbance in a Biosphere Reserve in central India. *Applied Vegetation Science*, 11: 461–470.
- Sahunlu, P., Chamrenpruk, M., Puriyakorn, B., Dhanmanonda, P., Suwannapin, W. and Prachaiya, B. 1979. Structure of three forest types in the Prom Basin, Chaiyaphum province. *Forest Research Bulletin No. 63*, Faculty of Forestry, Kasetsart University (in Thai).
- Saxena, A. K. and Singh, J. S. 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetatio*, 50: 3-32.
- Saxena, A. K. and Singh, J. S. 1984. Tree population structure of certain Himalayan forest association and implications concerning their future composition. *Vegetatio*, 58: 61-69.

- Shankar, U. 2001. A case of high tree diversity in a sal (*Shorea robusta*)- dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. *Current Science*, 81(7): 776-786.
- Shannon, C. E. and Weaver, W. 1963. The mathematical Theory of Communication. University of Illinois Press, Urbana USA. pp. 117.
- Sheil, D. 1999. Tropical forest diversity, environmental change and species augmentation: after intermediate disturbance hypothesis. *Journal of Vegetation Science*, 10: 851-860.
- Shi, H. and Singh, A. 2002. An assessment of biodiversity hotspots using Remote Sensing and GIS. *Journal of Indian Society of Remote Sensing*, 30(1&2): 105-112.
- Singh, K. P. and Misra, R. 1979. Structure and Functioning of Natural, Modified and Silvicultural Ecosystems of Eastern Uttar Pradesh. Final Technical Report (1975-1978). MAB research project. Banaras Hindu University, India.
- Singh, K. P., and Singh, R. P. 1981. Seasonal variation in biomass and energy of small root in tropical dry deciduous forests, Varanasi, India. *Oakes*, 37: 88-92.
- Singh, J.S., Singh, S.P., Saxena, A.K. and Rawat, Y.S. 1984. The forest vegetation of Silent valley, India. Tropical Rainforest. *The Leed symposium*, pp.25-52.
- Singh, L. and Singh, J. S. 1991. Species structure, dry matter dynamics and carbon flux of a dry tropical forest in India. *Annals of Botany*, 68: 263-273.
- Singh, J. S. and Singh, S. P. 1992. Forest of Himalaya. *Structure and Functioning and Impact of Man*, Gyanodya Prakashan, Nainital.

- Singh, J. S. 2002. The biodiversity crisis: a multifaceted review. *Current Science*, 82: 638-647.
- Singh, S. P., Rawat, Y. S. and Garkoti, S. C. 1997. Failure of brown oak (*Quercus semicarpifolia*) to regenerate in the Central Himalaya: a case of environmental semi-surprise. *Current Science*, 73: 371-374.
- Simpson, E. H. 1949. Measurement of diversity. *Nature*, 168: 688.
- Smith, R.L. 1974. *Ecology and Field Biology*. Harpar and Row Publication, New York. pp. 850.
- Srivastava, R. K. and Singh, B. 2007. Carbon sequestration and mitigation through conservation approach. *Indian Journal of Forestry*, pp. 475-483.
- State of Forest Report. 2009. Forest Survey of India (MoEF, GOI) Dehradun.
- Sukumar, Suresh, H. S., Dattaraja, H. S. and Joshi, N. V. 1997. Forest Biodiversity Research, Monitoring and Modelling: Conceptual Background and Old World Case Studies, (eds Dallmeier, F. and Comiskey, J. A.), Parthenon Publishing, 1: 529-540.
- Sukumaran, S. 2005. The floristic composition of sacred groves a functional tool to analyze the mini forest ecosystem. *Indian Forester*, 131(6): 773.
- Sundriyal, R. C., Sharma, E., Rai, L. K. and Rai, S. C. 1994. Tree structure regeneration and woody biomass removal in a subtropical forest of Mamlay watershed in Sikkim Himalaya. *Vegetatio*, 113: 53-63.
- Swamy, S. L., Dutt, C. B. S., Murthy, M. S. R., Mishra, A. and Bargali, S. S. 2010. Floristics and dry matter dynamics of tropical wet evergreen forests of Western Ghats, India. *Current Science*, 99(3): 253-264.
- Tanner, E. V. J. 1980. Studies on the biomass and productivity in a series of montane rain forest in Jamaica. *J. Ecol.*, 68: 573-588.

- Taylor, A. H. and Zisheng, Q. 1988. Regeneration patterns in old Growth *Abies-betula* forest in the Wolong natural reserve, Sichuan, China. *J. of Ecol.*, 76: 1204-1218.
- Teketay, D. 1997. Seedling population and regeneration of woody species in dry Afromontane forests of Ethiopia. *Forest Ecol. Manage.*, 98: 149-165.
- Tian, H., Melillo, J. M., Kicklighter, D. W., Mehuire, A. D., Helfrich, J., Moore, B. and Varasmarty, C.J. 2000. Climatic and biotic controls on annual carbon storage in Amazonian ecosystem. *Global Ecology and Biogeography*, 9(4): 315-335.
- Tiwari, A. K. 1994. Mapping forest biomass through digital processing of IRS-1A data. *International Journal of Remote Sensing*, 15(9): 1849-1866.
- Tiwari, J. C. and Singh, S. P. 1985. Analysis of woody vegetation in mixed oak forest of Kumaun Himalayas. *Proc. Indian Nat. Sci. Academy*, 51(b): 232-247.
- Tripathi, O. P., Pandey, H. N. and Tripathi, R. S. 2004. Distribution, community characteristics and tree population structure of sub tropical pine forest of Meghalaya, Northeast India. *International J. of Ecology and Envi. Sci.*, 30: 207-214.
- Tripathi, R. S. and Khan, M. L. 2007. Regeneration dynamics of natural forests- A review. *Proc. Indian Natl. Sci. Acad.*, 73: 167-195.
- van Schaik, C. P., Terborgh, J. and Dugelby, B. 1997. The silent crisis: the state of rain forest nature preserves. In: Kramer, R. van Schaik, C. & Johnson, J.(eds.) *Last stand: protected areas and the defense of tropical biodiversity*, pp. 64-89.

- Vablen, T. T., Ashton, D. H. and Schlsgel, F. J. 1979. Tree regeneration strategies in lowland Nothofagus dominated forest in south-central Chile. *J. Biogeogr.*, 6: 329-340.
- Verghese, A. O . and Menon, A. R. R. 1998. Vegetation characteristics of southern secondary moist mixed deciduous forests of Agasthyamalai region of Kerala. *Indian Journal of Forestry*, 21(4): 639-644.
- Visalakshi, K. 1995. Vegetation analysis of two tropical dry evergreen forests in South India. *Trop. Ecol.*, 36(1): 117-127
- Visaratana, T., Pitprecha, K., Kiratiprayoon, S., Kampan, T. and Higuchi, K. 1986. Structural characteristics and species composition of dry Dipterocarp forest at Salak Phra Wildlife Sanctuary. Technical Paper No. 10 Forest Ecology Section, FRd (in Thai).
- Vyas, L. N., Garg, R. K. and Vyas N. L. 1977. Stand structure and aboveground biomass in dry deciduous forests of Aravalli Hills at Udaipur (Rajasthan), India. *Biologia* (Bratislava) 32: 265-270.
- Whitaker, R. H. 1972. Evolution and measurement of species diversity. *Taxon*, 21: 213-251.

Table 4.1 : Floristic composition and regeneration status on different sites

		Closed natural forest				Open natural forest				Teak Plantation			
Sr.No.	Species	Tree (stems/ /ha)	Sapling (stems/ ha)	Seedling (stems/ha)	Status	Tree (stems/ ha)	Sapling (stems/ ha)	Seedling (stems/ha)	Status	Tree (stems/ ha)	Sapling (stems/ ha)	Seedling (stems/ ha)	Status
1	<i>Anogeissus latifolia</i>	-	-	30	Not abundant	50	-	10	Poor regeneration	-	-	-	
2	<i>Antidesma acidum</i>	20	-	-	No regeneration	-	-	-		-	-	-	
3	<i>Acacia catechu</i>	-	-	-		30	30	20	Poor regeneration	-	-	-	
4	<i>Bridelia retusa</i>	50	-	40	Poor regeneration	10	-	-	No regeneration	-	-	-	
5	<i>Buchanania lanzan</i>	10	-	-	No regeneration	-	-	-		10	-	-	No regeneration
6	<i>Bauhania racemosa</i>	30	30	-	No regeneration	-	-	-		-	-	-	
7	<i>Boswelvia serrata</i>	-	-	-		40	-	-	No regeneration	-	-	-	
8	<i>Bombax ceiba</i>	10	-	-	No regeneration	20	-	70	Poor regeneration	-	-	-	
9	<i>Cleistanthus collinus</i>	330	110	90	Good regeneration	40	10	10		30	-	-	No regeneration
10	<i>Careya arboria</i>	20	-	-	No regeneration	-	-	-		-	-	-	
11	<i>Cassia fistula</i>	-	-	50	Not abundant	10	-	-	No regeneration	-	-	-	
12	<i>Chloroxylon sweitenia</i>	-	20	-	Poor regeneration	30	20	-	No regeneration	-	-	-	
13	<i>Diospyros melanoxylon</i>	60	30	580	Good regeneration	-	-	30	Not abundant	-	-	40	Not abundant
14	<i>Dalbergia paniculata</i>	10	-	30	Poor regeneration	-	-	-		-	-	-	
15	<i>Emblica officinalis</i>	10	-	-	No regeneration	-	-	-		-	-	-	
16	<i>Flacourtia remontchi</i>	-	-	-		-	-	-		-	-	10	Not abundant
17	<i>Grewia Tiliaefolia</i>	10	-	10	Poor regeneration	70	20	70	Fair regeneration	-	-	-	
18	<i>Gardinia recemofera</i>	-	-	-		-	10	20		-	-	-	
19	<i>Garuga pinnata</i>	40	-	-	No regeneration	80	-	-		-	-	-	
20	<i>Holarrhena pubescens</i>	-	-	-		-	-	20	Not abundant	-	-	20	Not abundant
21	<i>Hymenodactyon excelsium</i>	-	-	50	Not abundant	-	-	-		-	-	-	
22	<i>Lannea coromendelica</i>	-	-	-		-	-	-		-	-	-	
23	<i>Lagerstroemia parviflora</i>	130	20	20	Fair regeneration	20	-	10	Poor regeneration	30	40	180	Good regeneration
24	<i>Madhuca indica</i>	30	10	10	Poor regeneration	-	-	-		-	-	-	
25	<i>Mitragyna parviflora</i>	20	-	-	No regeneration	-	-	-		-	-	-	
26	<i>Ougeinia oojeinensis</i>	20	-	10	Poor regeneration	-	-	-		-	-	-	
27	<i>Pterocarpus marsupium</i>	10	-	10	Poor regeneration	-	-	20	Not abundant	-	-	-	
28	<i>Semecarpus anacardium</i>	10	-	-	No regeneration	-	-	-		-	-	-	
29	<i>Tectona Grandis</i>	-	-	-		-	-	-		920	-	90	Fair regeneration
30	<i>Terminalia tomentosa</i>	120	-	-	No regeneration	60	-	40	Poor regeneration	-	-	-	
31	<i>Terminalia arjuna</i>	-	-	-		10	-	30	Poor regeneration	-	-	-	
32	<i>Terminalia chebula</i>	10	-	30	Poor regeneration	-	-	-		-	-	-	
33	<i>Zizyphus xylocarpa</i>	-	-	-		50	-	-	No regeneration	-	-	-	
Total		950	220	960		520	90	400		990	40	340	

Table 4.2: Species Structure of tree layer at Baranawapara Wildlife Sanctuary

Sr. No.	Species	Closed natural forest				Open natural forest				Plantation forest			
		F (%)	D (stems/ ha)	BA (m ² /ha)	IVI	F (%)	D (stems/ha)	BA (m ² /ha)	IVI	F (%)	D (stems/ha)	BA (m ² /ha)	IVI
1	<i>Anogeissus latifolia</i> Roxb. ex DC.	-	-	-	-	50	50	1.83	31.27	-	-	-	-
2	<i>Antidesma acidum</i> Roth.	20	20	0.1881	6.67	-	-	-	-	-	-	-	-
3	<i>Acacia catechu</i> (L.f.) Willd.	-	-	-	-	20	30	0.18	11.86	-	-	-	-
4	<i>Bridelia retusa</i> (L.) Spreng.	30	50	2.5422	16.89	10	10	0.10	5.04	-	-	-	-
5	<i>Buchnanania lanzan</i> Spreng.	10	10	0.1370	3.43	-	-	-	-	10	10	0.0810	7.55
6	<i>Bauhinia racemosa</i> Lam.	10	30	0.4718	6.24	-	-	-	-	-	-	-	-
7	<i>Boswelvia serrata</i> Roxb. ex Colebr.	-	-	-	-	40	40	5.54	43.97	-	-	-	-
8	<i>Bombax ceiba</i> Linn.	10	10	0.5748	4.35	20	20	2.43	20.41	-	-	-	-
9	<i>Cleistanthus collinus</i> (Roxb.) Benth & Hook.	60	330	4.9515	57.70	20	40	0.98	17.53	30	30	0.2415	22.64
10	<i>Careya arborea</i> Roxb.	30	40	0.3793	11.26	-	-	-	-	-	-	-	-
11	<i>Cassia fistula</i> Linn.	-	-	-	-	10	10	0.07	4.89	-	-	-	-
12	<i>Chloroxylon swietenia</i> DC.	-	-	-	-	20	30	1.55	18.26	-	-	-	-
13	<i>Diospyros melanoxylon</i> Roxb.	50	60	5.5309	28.42	-	-	-	-	-	-	-	-
14	<i>Dalbergia paniculata</i> Roxb.	10	10	1.8067	6.96	-	-	-	-	-	-	-	-
15	<i>Embllica officinalis</i> Gaertn.	10	10	0.2676	3.70	-	-	-	-	-	-	-	-
16	<i>Grewia tiliaefolia</i> Vahl	10	10	0.1640	3.48	50	70	0.77	30.23	-	-	-	-
17	<i>Garuga pinnata</i> Roxb.	20	20	1.3920	9.21	60	80	2.31	41.93	-	-	-	-
18	<i>Lagerstroemia parviflora</i> Roxb.	40	130	7.0502	36.92	10	20	0.12	7.06	20	30	0.3098	16.64
19	<i>Madhuca indica</i> J.F. Gmel.	30	30	7.8651	26.03	-	-	-	-	-	-	-	-
20	<i>Mitragyna parviflora</i> (Roxb.) Korth	20	20	1.1453	8.69	-	-	-	-	-	-	-	-
21	<i>Ougeinia oojeinensis</i> (Roxb). Hochr.	20	20	2.4846	11.52	-	-	-	-	-	-	-	-
22	<i>Pterocarpus marsupium</i> Roxb.	10	10	0.6851	4.58	-	-	-	-	-	-	-	-
23	<i>Semecarpus anacardium</i> Linn. f.	10	10	0.1216	3.39	-	-	-	-	-	-	-	-
24	<i>Tectona grandis</i> Linn. f.	-	-	-	-	-	-	-	-	100	920	27.30	253.17
25	<i>Terminalia arjuna</i> (Roxb. ex DC.) Wright & Arnott	-	-	-	-	10	10	0.84	8.48	-	-	-	-
26	<i>Terminalia chebula</i> Retz.	10	10	0.1410	3.43	-	-	-	-	-	-	-	-
27	<i>Terminalia tomentosa</i> (Roxb. ex DC.) Wright & Arnott	70	120	9.4077	47.10	30	60	3.84	37.28	-	-	-	-
28	<i>Zizyphus xylocarpa</i> (Retz.) Willd.	-	-	-	-	30	50	0.92	21.77	-	-	-	-
Total		480	950	47.30	300	380	520	21.50	300	160	990	28.03	300

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

Table 4.3 : Certain vegetational properties of tropical forest

Forest Ecosystems	Density (stem ha⁻¹)	Basal cover (m² /ha⁻¹)	Number of species per ha.	Source
Mixed deciduous forest	294-559	6.6-23.2	-	Jha and Singh (1990)
<i>Boswellia-Acacia</i> forest	342-627	3.8-10.4	-	Singh and Singh (1991)
Sariska Tigar Reserve	1352	131.9	-	Rodgers (1990)
Dry Dipterocarp forest	554-789	-	35-37	Visaratana <i>et al.</i> (1986)
Mixed deciduous forest	253	-	14	Sahunalu <i>et al.</i> (1979), Kiratiprayoon <i>et al.</i> (1995)
Teak forest	262-395	-	21	Bunyavejchewin (1983), Dhanmanonda and Sahunalu (1992)
Tropical rain forest	818-1540	-	61-109	Kiratiprayoon (1986)
Tropical wet evergreen	263-438	29.0-41.8	28-38	Swamy <i>et al.</i> (2010)
Tropical Dry Deciduous forest	520-990	21.50-47.30	-	Present study

*Represents the number of species in 0.1 ha.

Table 4.5: Biomass (t ha⁻¹) of different tree component at Baranawapara Wildlife Sanctuary

S. No.	Species	Closed natural forest					Open natural forest					Plantation forest				
		Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
1	<i>Anogeissus latifolia</i> Roxb. ex DC.	-	-	-	-	-	4.90	16.14	0.99	3.48	25.51	-	-	-	-	-
2	<i>Antidesma acidum</i> Roth.	0.46	0.34	0.04	0.18	1.02	-	-	-	-	-	-	-	-	-	-
3	<i>Acacia catechu</i> (L.f.) Willd.	-	-	-	-	-	0.86	0.73	0.10	0.32	2.01	-	-	-	-	-
4	<i>Bridelia retusa</i> Spreng.	7.64	11.12	0.75	2.86	22.37	0.23	0.17	0.02	0.09	0.51	-	-	-	-	-
5	<i>Buchnanania lanzan</i> Spreng.	0.34	0.21	0.05	0.10	0.70	-	-	-	-	-	0.19	0.08	0.03	0.06	0.36
6	<i>Bauhinia racemosa</i> Lam.	1.45	1.42	0.16	0.54	3.57	-	-	-	-	-	-	-	-	-	-
7	<i>Boswellia serrata</i> Roxb. ex Colebr.	-	-	-	-	-	18.24	34.17	1.62	6.85	60.88	-	-	-	-	-
8	<i>Bombax ceiba</i> Linn.	1.74	2.44	0.17	0.65	5.00	7.70	13.53	0.70	2.89	24.82	-	-	-	-	-
9	<i>Cleistanthus collinus</i> Roxb.	12.95	12.99	1.47	4.85	32.26	2.94	3.27	0.31	1.10	7.62	0.68	0.53	0.08	0.25	1.54
10	<i>Careya arborea</i> Roxb.	1.17	1.28	0.12	0.44	3.01	-	-	-	-	-	-	-	-	-	-
11	<i>Cassia fistula</i> Linn.	-	-	-	-	-	0.23	0.17	0.02	0.09	0.51	-	-	-	-	-
12	<i>Chloroxylon sweitenia</i> DC.	-	-	-	-	-	5.09	8.44	0.48	1.91	15.92	-	-	-	-	-
13	<i>Diospyros melanoxylon</i> Roxb.	21.15	34.07	1.28	6.84	63.34	-	-	-	-	-	-	-	-	-	-
14	<i>Dalbergia paniculata</i> Roxb.	6.90	14.29	0.59	2.59	24.37	-	-	-	-	-	-	-	-	-	-
15	<i>Embllica officinalis</i> Gaertn.	0.58	0.65	0.06	0.21	1.50	-	-	-	-	-	-	-	-	-	-
16	<i>Grewia tiliaefolia</i> Vahl.	0.42	0.42	0.05	0.15	1.04	1.76	1.73	0.24	0.67	4.40	-	-	-	-	-
17	<i>Garuga pinnata</i> Roxb.	1.05	1.05	.11	0.39	2.60	7.89	10.23	0.81	2.96	21.89	-	-	-	-	-
18	<i>Lagerstroemia parviflora</i> Roxb.	18.58	21.06	2.27	10.73	52.64	0.56	0.47	0.08	0.25	1.36	0.77	0.62	0.11	0.34	1.84
19	<i>Madhuca indica</i> J.F. Gmel.	30.16	70.14	2.47	11.34	114.11	-	-	-	-	-	-	-	-	-	-
20	<i>Mitragyna parviflora</i> (Roxb.) Korth	3.45	5.22	0.33	1.30	10.30	-	-	-	-	-	-	-	-	-	-
21	<i>Ougeinia oojeinensis</i> Roxb.	8.51	15.45	0.76	3.20	27.92	-	-	-	-	-	-	-	-	-	-
22	<i>Pterocarpus marsupium</i> Roxb	2.48	2.74	0.12	0.44	3.01	-	-	-	-	-	-	-	-	-	-
23	<i>Semecarpus anacardium</i> Linn. f.	0.23	0.17	0.02	0.09	0.51	-	-	-	-	-	-	-	-	-	-
24	<i>Tectona grandis</i> Linn. f.	-	-	-	-	-	-	-	-	-	-	66.55	28.65	14.50	21.16	131.25
25	<i>Terminalia arjuna</i> (Roxb. ex DC.) Wright & Arnott	-	-	-	-	-	2.83	4.54	0.26	1.06	8.69	-	-	-	-	-
26	<i>Terminalia chebula</i> Retz.	0.64	0.67	0.07	0.24	1.62	-	-	-	-	-	-	-	-	-	-
27	<i>Terminalia tomentosa</i> Roth.	31.88	53.08	2.98	11.97	99.91	11.87	19.88	1.11	4.45	37.31	-	-	-	-	-
28	<i>Zizyphus xylocarpa</i> (Retz.) Willd.	-	-	-	-	-	2.45	2.52	0.27	0.92	6.16	-	-	-	-	-
Total		151.78	248.81	13.87	59.34	473.60	67.55	115.99	7.01	27.04	217.59	68.13	29.88	14.72	22.26	134.99

Table 4.8: Carbon (t ha⁻¹) storage pattern at Baranawapara Wildlife Sanctuary

S. No.	Species	Closed natural forest					Open natural forest					Plantation forest				
		Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
1	<i>Anogeissus latifolia</i> Roxb. ex DC.	-	-	-	-	-	2.13	7.37	0.46	1.24	11.20	-	-	-	-	-
2	<i>Antidesma acidum</i> Roth.	0.20	0.14	0.02	0.06	0.42	-	-	-	-	-	-	-	-	-	-
3	<i>Acacia catechu</i> (L.f.) Willd.	-	-	-	-	-	0.37	0.33	0.05	0.11	0.86	-	-	-	-	-
4	<i>Bridelia retusa</i> Spreng.	3.32	5.07	0.35	1.02	9.76	0.10	0.07	0.01	0.03	0.21	-	-	-	-	-
5	<i>Buchnanania lanzan</i> Spreng.	0.15	0.09	0.02	0.03	0.29	-	-	-	-	-	0.08	0.03	0.01	0.02	0.14
6	<i>Bauhinia racemosa</i> Lam.	0.63	0.65	0.07	0.19	1.54	-	-	-	-	-	-	-	-	-	-
7	<i>Boswellia serrata</i> Roxb. ex Colebr.	-	-	-	-	-	7.93	15.60	0.75	2.45	26.73	-	-	-	-	-
8	<i>Bombax ceiba</i> Linn.	0.75	1.11	0.08	0.23	2.17	3.34	6.17	0.32	1.03	10.86	-	-	-	-	-
9	<i>Cleistanthus collinus</i> Roxb.	5.89	5.93	0.68	1.73	14.23	1.27	1.49	0.14	0.39	3.29	0.29	0.24	0.04	0.09	0.66
10	<i>Careya arborea</i> Roxb.	0.51	0.58	0.06	0.16	1.31	-	-	-	-	-	-	-	-	-	-
11	<i>Cassia fistula</i> Linn.	-	-	-	-	-	0.10	0.07	0.01	0.03	0.21	-	-	-	-	-
12	<i>Chloroxylon sweitenia</i> DC.	-	-	-	-	-	2.21	3.85	0.22	0.68	6.96	-	-	-	-	-
13	<i>Diospyros melanoxylon</i> Roxb.	9.20	15.55	0.59	2.44	27.78	-	-	-	-	-	-	-	-	-	-
14	<i>Dalbergia paniculata</i> Roxb.	3.14	6.52	0.27	0.92	10.85	-	-	-	-	-	-	-	-	-	-
15	<i>Emblica officinalis</i> Gaertn.	0.25	0.29	0.03	0.07	0.64	-	-	-	-	-	-	-	-	-	-
16	<i>Grewia tiliaefolia</i> Vahl.	0.19	0.19	0.02	0.05	0.45	0.76	0.79	0.11	0.24	1.90	-	-	-	-	-
17	<i>Garuga pinnata</i> Roxb.	0.45	0.48	0.52	0.14	1.59	3.43	4.67	0.37	1.05	9.52	-	-	-	-	-
18	<i>Lagerstroemia parviflora</i> Roxb.	8.08	9.62	1.06	3.83	22.59	0.24	0.21	0.04	0.09	0.58	0.33	0.28	0.05	0.12	0.87
19	<i>Madhuca indica</i> J.F. Gmel.	13.11	32.03	1.15	4.05	50.34	-	-	-	-	-	-	-	-	-	-
20	<i>Mitragyna parviflora</i> (Roxb.) Korth	1.57	2.38	0.15	0.46	4.56	-	-	-	-	-	-	-	-	-	-
21	<i>Ougeinia oojeinensis</i> (Roxb). Hochr.	3.87	7.05	0.35	1.14	14.41	-	-	-	-	-	-	-	-	-	-
22	<i>Pterocarpus marsupium</i> Roxb.	1.07	1.25	0.06	0.24	2.62	-	-	-	-	-	-	-	-	-	-
23	<i>Semecarpus anacardium</i> Linn. f.	0.10	0.07	0.01	0.03	0.21	-	-	-	-	-	-	-	-	-	-
24	<i>Tectona grandis</i> Linn. f.	-	-	-	-	-	-	-	-	-	-	28.92	13.08	6.76	7.72	56.48
25	<i>Terminalia arjuna</i> (Roxb. ex DC.) Wright & Arnott	-	-	-	-	-	1.23	2.07	0.12	0.38	3.80	-	-	-	-	-
26	<i>Terminalia chebula</i> Retz.	0.29	0.30	0.03	0.08	0.70	-	-	-	-	-	-	-	-	-	-
27	<i>Terminalia tomentosa</i> Roth.	13.86	24.24	1.39	4.27	43.76	5.16	9.07	0.52	1.58	16.33	-	-	-	-	-
28	<i>Zizyphus xylocarpa</i> (Retz.) Willd.	-	-	-	-	-	1.06	1.15	0.12	0.33	2.66	-	-	-	-	-
Total		66.63	113.54	6.91	21.14	208.22	29.33	52.91	3.24	9.59	95.11	29.62	13.63	6.86	7.95	58.06

Table 4. 6: Comparative account of stand biomass of certain tropical forests of the world (t ha⁻¹)

Forests	Location	Stand biomass			Source
		Above ground	Below ground	Total	
Tropical lower montane Rain	New Guinea	310	39	349	Edward and Grabb (1977)
Tropical wet	Cambodia	322	60	382	Hozum <i>et al.</i> (1969)
Tropical wet	Global pattern	213-1173	11-135	269-1186	Murphy and Lugo (1986b)
Tropical Rain	Sarawak			210-650	Proctor <i>et al.</i> (1983b)
	India	420-649	14-20	434-669	Rai and Proctor (1986a)
	Thailand	295-371	31-33	326-404	Ogawa <i>et al.</i> (1965)
	Ghana	233	54	287	Greenland and Kowal (1960)
Tropical montane wet	Venezuela	347	73	420	Brun (1976)
Tropical Moist	San Carlos	340	56	396	Bruning <i>et al.</i> (1979)
		326	55	381	Folster <i>et al.</i> (1976)
	Global	316	11	327	Golley <i>et al.</i> (1975)
	Brazil Amazonia	377	104	481	Klinge and Herrera (1978)
	Ivory Coast	243	48	291	Muller and Nielson (1965)
Tropical Plantations	Puerto Rica	-	-	0.4-506	Lugo <i>et al.</i> (1988)
Tropical premontane Moist	Papua-New Guinea	286	46	332	Enright (1979)
	Zaire	320	51	371	Freson <i>et al.</i> (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)
		198	73	271	Odum (1970)
Sub-tropical Moist	Thailand	253	10	263	Drew <i>et al.</i> (1978)
Sub-tropical Dry	Senegal	82	58	140	Jung (1969)
	Thailand	69	10	79	Ogawa <i>et al.</i> (1965)
	India	28	12	40	Vyas <i>et al.</i> (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	77	20	97	Singh and Mishra (1979)
	India	42-78	9-16	53-94	Singh and Singh (1991)
	India	112.73-414.26	22.26-59.34	134.99-473.60	Present study

Table 4.4: Diversity parameters of various forest plots

Natural Parameters	Closed natural forest	Open natural forest	Teak plantation forest
Species richness (d)	4.93	4.23	0.90
Shannon index (H')	3.35	3.08	0.19
Concentration of dominance (Cd)	0.12	0.14	0.95
Equitability (e)	1.12	1.17	2.39
Beta diversity (Bd)	3.16	5.77	3.03

Table 4.7: Carbon concentration in different components of tree

Components	C
Bole	43.50
Branch	45.67
Foliage	46.67
Coarse roots	35.73

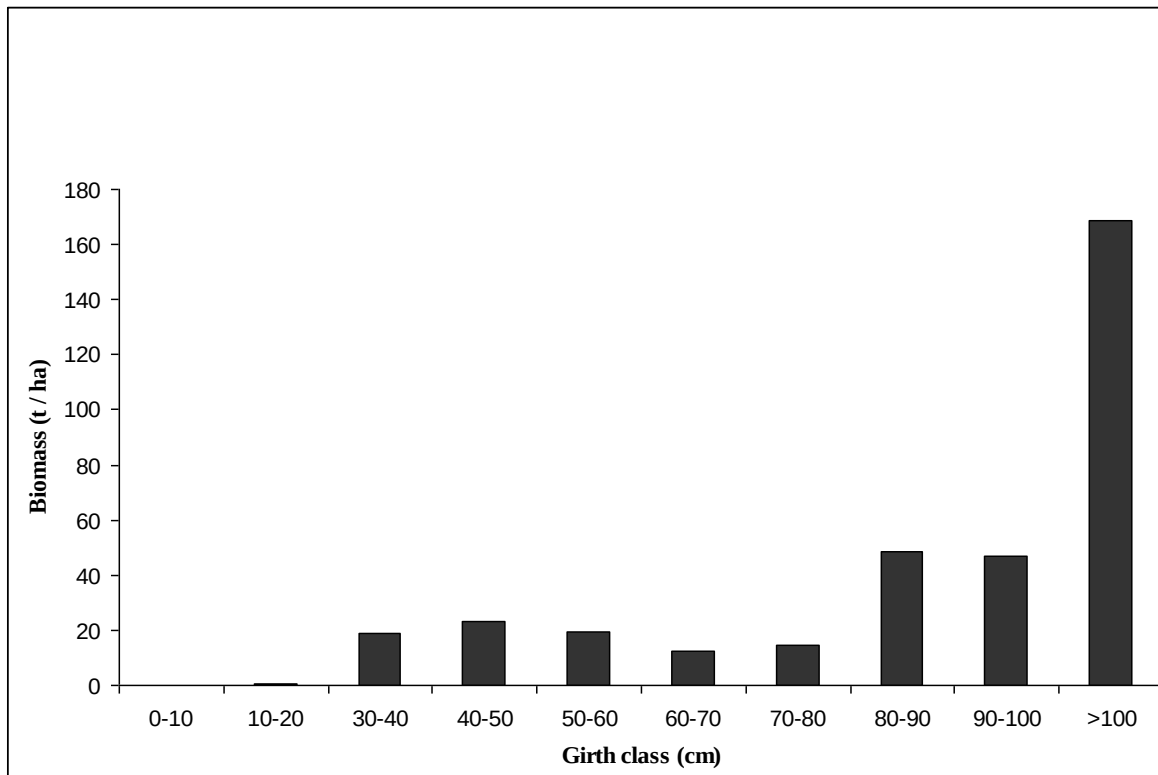


Fig. 4.5: Distribution pattern of biomass along the girth classes in closed forest site.

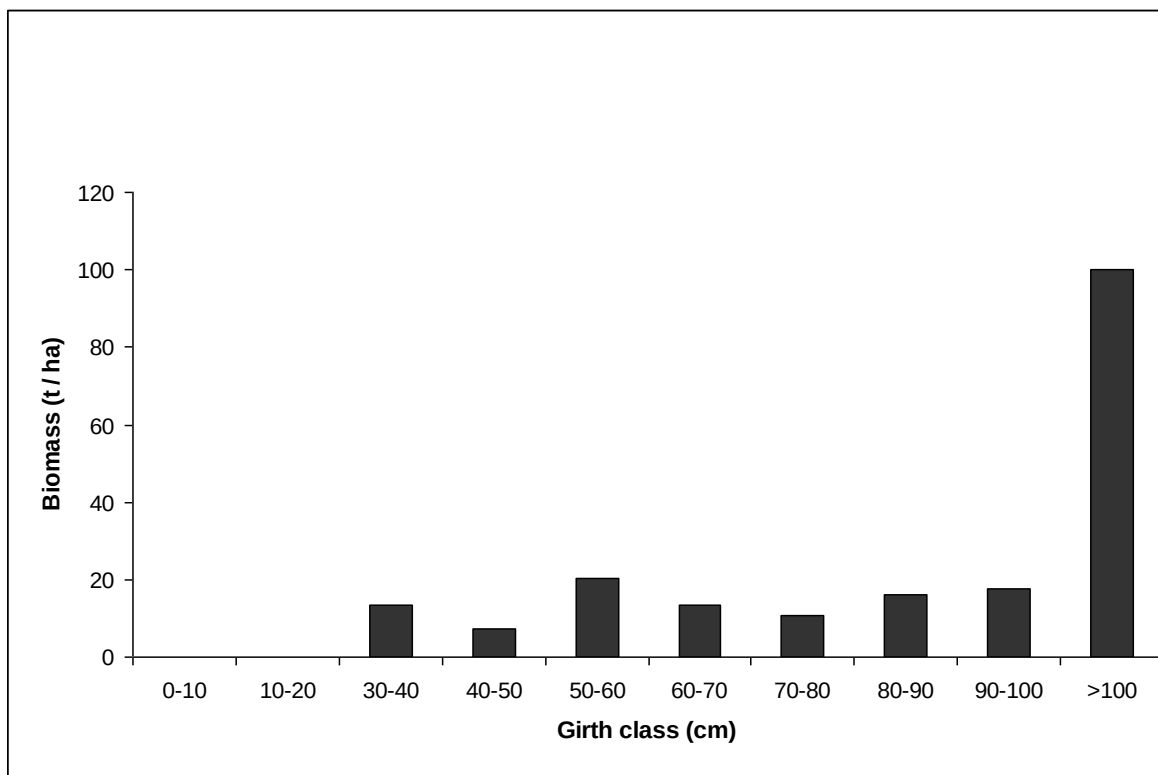


Fig. 4.6 Distribution pattern of biomass along the girth classes in open forest site.

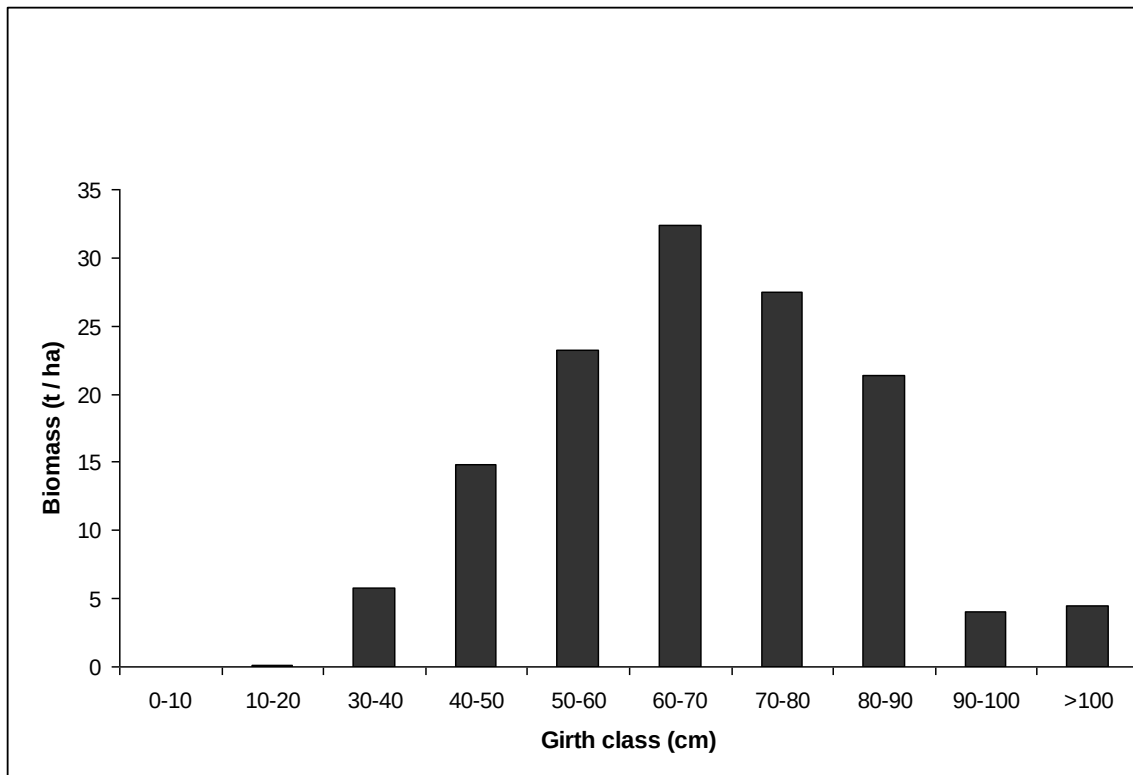


Fig. 4.7: Distribution pattern of biomass along the girth classes in teak plantation site.

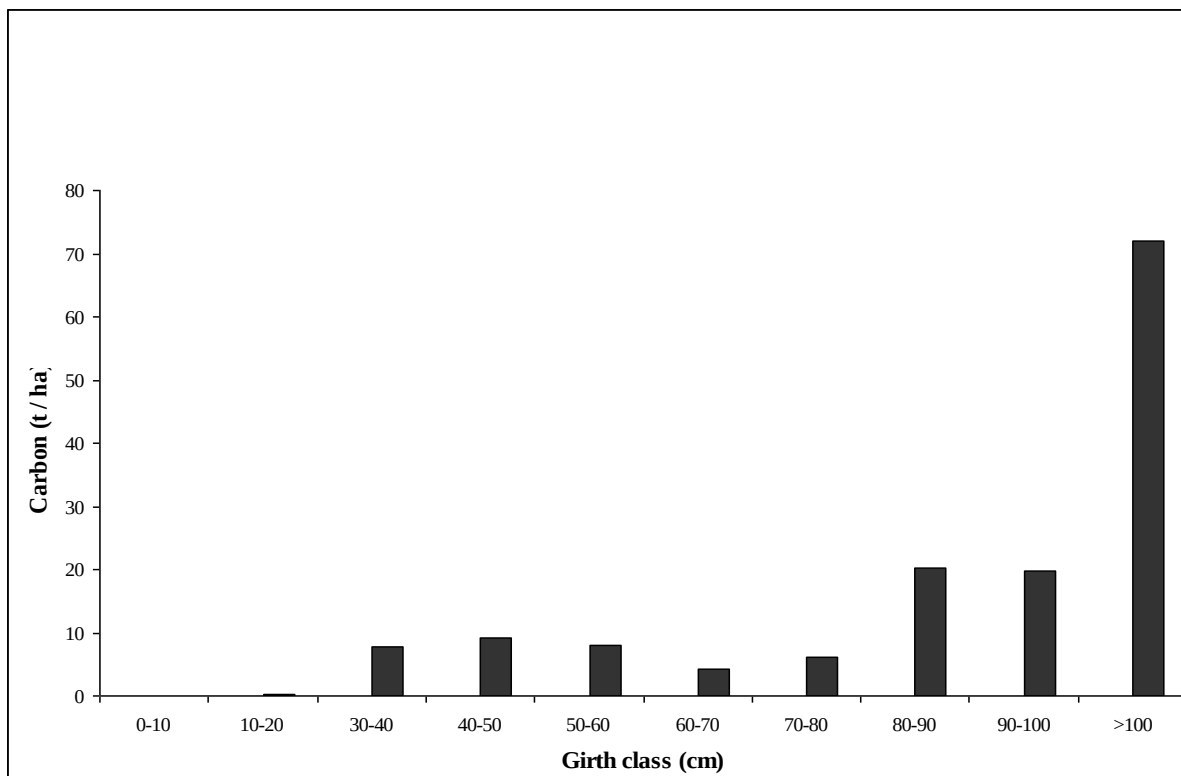


Fig. 4.8: Distribution pattern of carbon along the girth classes in closed forest site.

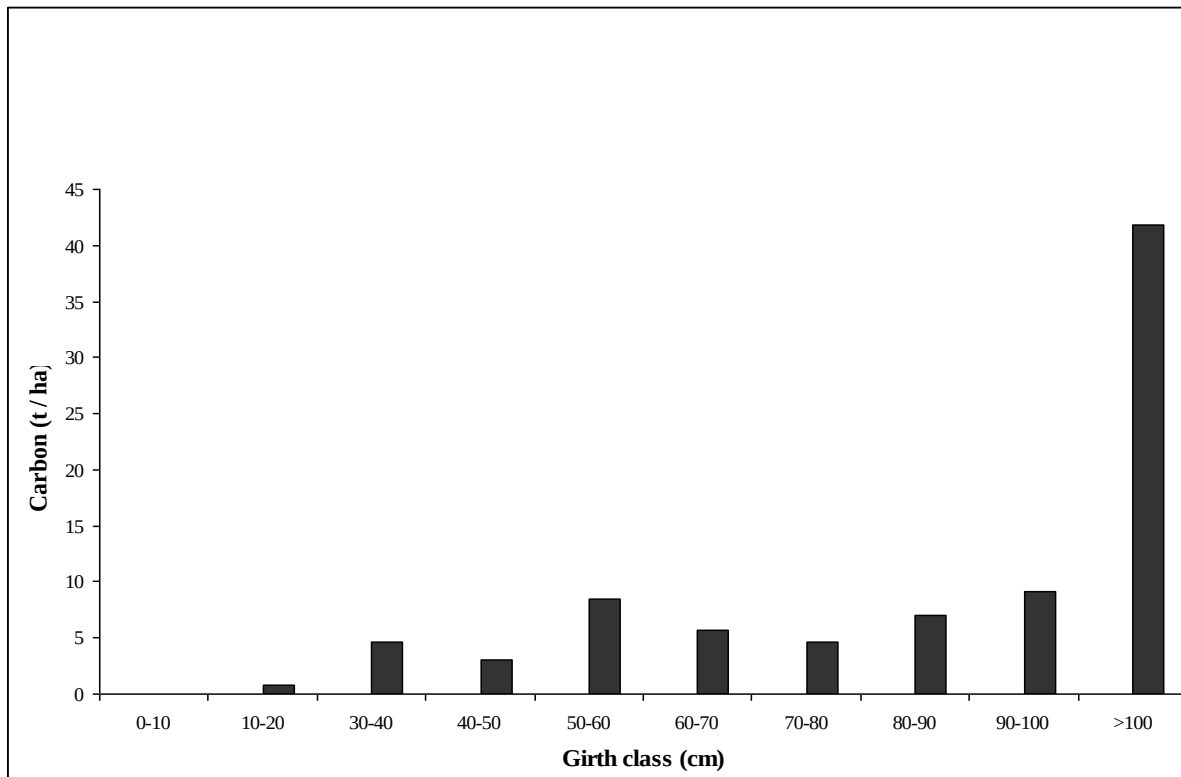


Fig. 4.9: Distribution pattern of carbon along the girth classes in open forest site.

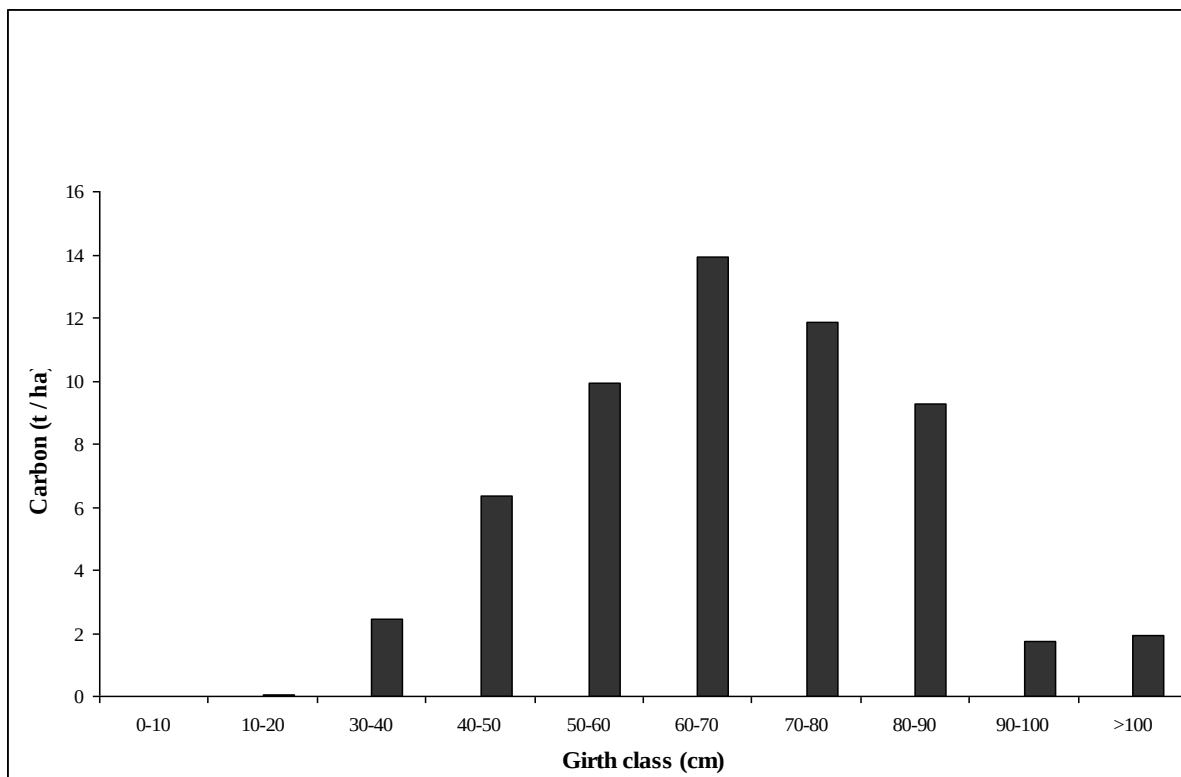


Fig. 4.10: Distribution pattern of carbon along the girth classes in teak plantation site.



Fig. 4.1: Relationship between density of seedling, sapling and trees with mean girth.

Girth classes (cm) are: 1 = ≤ 10 ; 2 = $> 10 - \leq 30$; 3 = $> 30 - \leq 60$; 4 = $> 60 - \leq 90$; 5 = $> 90 - \leq 120$; 6 = > 120

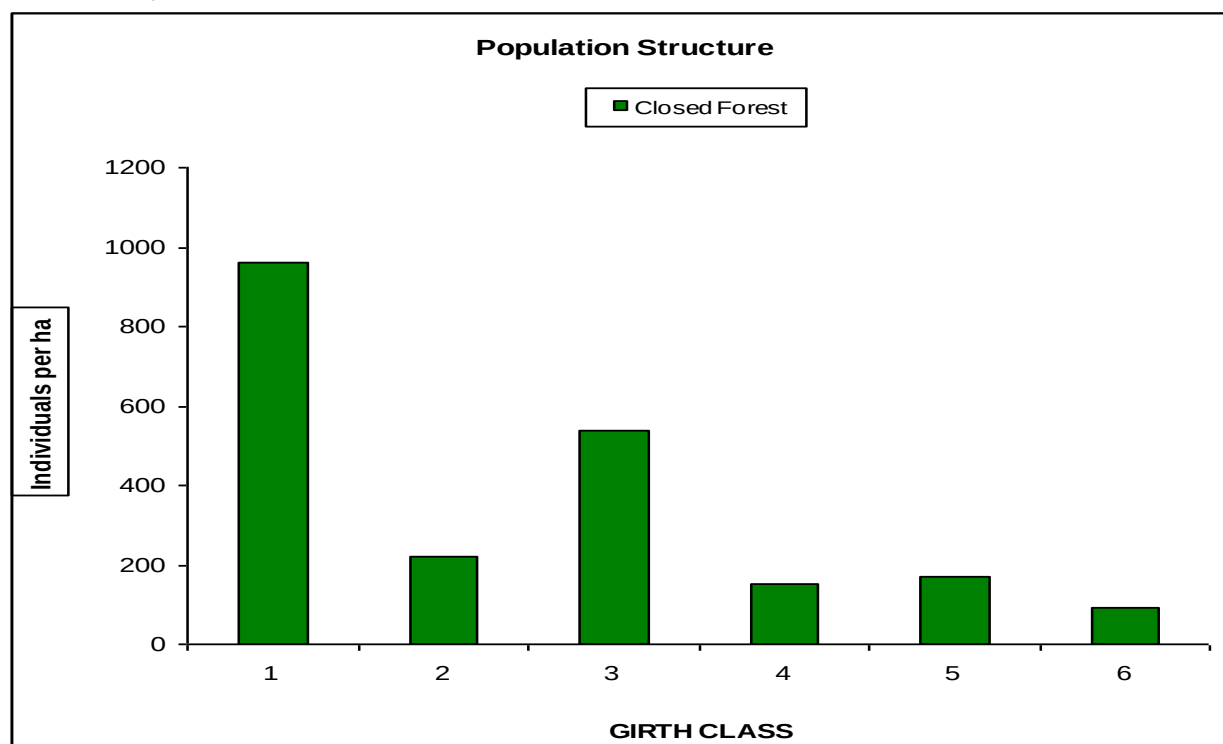


Fig. 4.2: Relationship between density of seedling, sapling and trees with mean girth on closed forest site. Girth classes (cm) are: 1 = ≤ 10 ; 2 = $> 10 - \leq 30$; 3 = $> 30 - \leq 60$; 4 = $> 60 - \leq 90$; 5 = $> 90 - \leq 120$; 6 = > 120

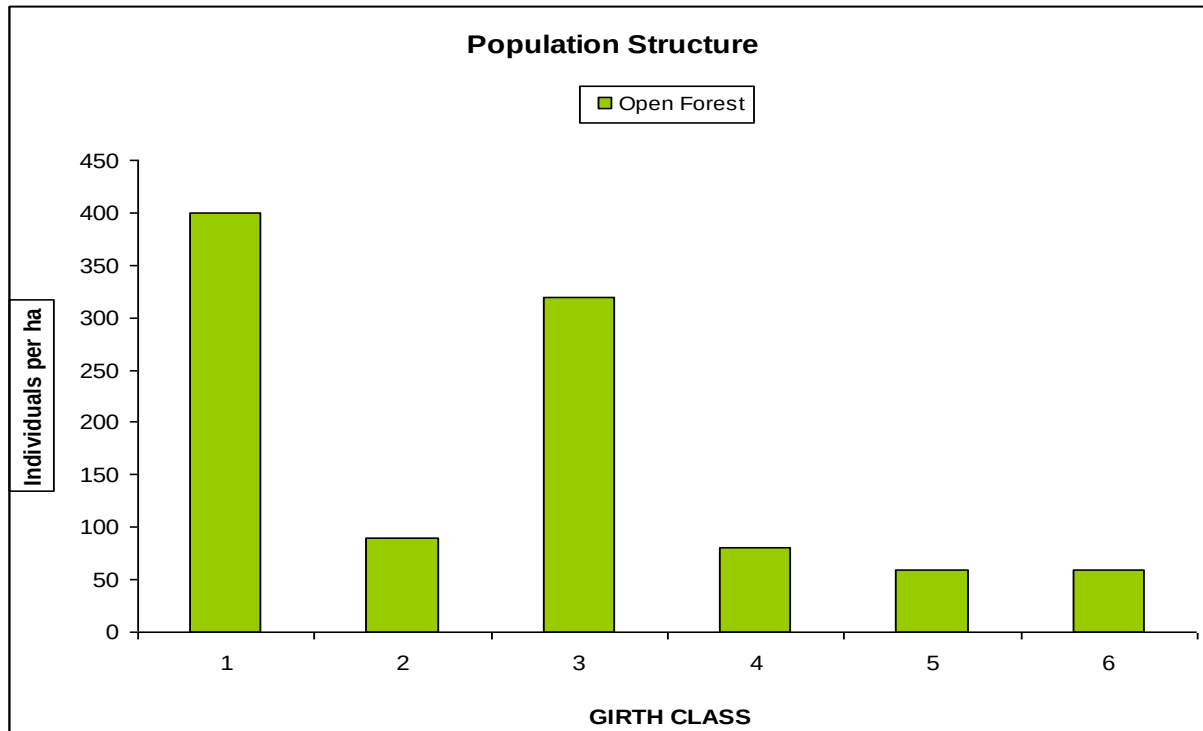


Fig. 4.3: Relationship between density of seedling, sapling and trees with mean girth on open forest site. Girth classes (cm) are: 1 = ≤ 10 ; 2 = $> 10 - \leq 30$; 3 = $> 30 - \leq 60$; 4 = $> 60 - \leq 90$; 5 = $> 90 - \leq 120$; 6 = > 120



Fig. 4.4: Relationship between density of seedling, sapling and trees with mean girth on teak plantation site. Girth classes (cm) are: 1 = ≤ 10 ; 2 = $> 10 - \leq 30$; 3 = $> 30 - \leq 60$; 4 = $> 60 - \leq 90$; 5 = $> 90 - \leq 120$; 6 = > 120