LIGHT USE EFFICIENCY AND PRODUCTIVITY ESTIMATION IN FORESTS OF PANNA NATIONAL PARK, PANNA DISTRICT, MP – A REMOTE SENSING AND GIS APPROACH

Thesis submitted to the Andhra University in partial fulfilment of the requirements for the award of Master of Technology in Remote Sensing and Geographic Information System.

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CERTIFICATE

This is to certify that Mr. Saurabh Varma has carried out the pilot project titled " Light Use Efficiency and Productivity Estimation in the Forests of Panna National Park, Panna District, MP – A Remote Sensing and GIS Approach" for the partial fulfillment for the award of Master of Technology (M.Tech.) in Remote Sensing and Geographic Information System, by Andhra University. The project presented here in this report is an original work of the candidate and has been carried out in Forestry and Ecology Division under the guidance of Dr. Sarnam Singh, at Indian Institute of Remote Sensing, Dehradun, India.

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ACKNOWLEDGEMENT

It takes a lot of good people to make a good project. If this proves to be a good project, which I hope it will, credits are due to many.

First of all I would like to express my gratitude and sincere thanks to Dr. V.K.Dadhwal, Dean IIRS, for giving me an opportunity to undertake the M.Tech. programme at IIRS. I am grateful to him for his timely guidance and full cooperation regarding the use of institute's laboratory facilities.

I owe special debt of gratitude to my supervisor, Dr. Sarnam Singh, for his close guidance, supervision and generosity all through the project.

I pay equal debt of gratitude to Dr. S.P.S.Kushwaha, Head of the Forestry and Ecology Division, for providing invariable support and facilities.

Gratitude is paid to Director, NRSA for providing a seven month Student Research Assistantship, during the project tenure.

I am greatly thankful to Dr. M.C.Porwal, Dr. I.J.Singh, Dr. D.N.Pant, Dr. K.K.Das, faculty members of Forestry and Ecology Division, for their constant encouragement and valuable suggestions.

I am very much grateful to the officials of M.P. Forest Department, particularly PCCF Wildlife, MP for granting permission to work in Panna National Park and Field Director, Mr. Krishnamurthy Panna National Park, Deputy Field Director, Mr. A.K.Nagar, Panna National Park, DFO South Panna

District, and Mr. Ajay Pataria, Range Officer, Hinouta Range, Panna National Park, for their cooperation and logistic support during the fieldwork.

It seems appropriate to acknowledge Research Fellows, Mr. Subrata Nandy, Ms.Uttara Pandey, Deepak Kushwaha, Mr. Ranjit Kumar and Arun Kr. Thakur for helping me in completing the project in time. Respectful thanks are also paid to Dr. Manish Kale, Mr. Subroto Paul, Mr. Gaurav Srivastava and Mr. M.L.Srivastava for time to time help during the project duration.

Above all, special mention cannot be omitted regarding my class mate especially Ms. Smita Majumdar who was all along with me in the field and laboratory for constant help. I also thank Ms. Aditi Sarkar, Ms. Vidya A., Ms. Nidhi Mishra, Tushar Zanje, Rahul Patil, Hurishikesh Chavan, Gautam Gosh and Prashant Patil for extensive perseverance they have shown all along the duration of the project.

Last but not the least I would like to acknowledge the love affection and support of my mother, father and family members during the project tenure.

Saurabh Varma

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Chapter 1

Introduction

Photosynthesis is the cornerstone of life and the starting point for community metabolism. The bulk of Earth's living mantle is green plants and only a small fraction of life is animal life (Whittaker 1975). Terrestrial ecosystem stores large quantities of carbon and play an important role in controlling the concentration of carbon dioxide in the atmosphere. The carbon balance of vegetation and ecosystem governs the productivity of the biosphere and the impact of ecosystem on the earth system. Studies related to plant productivity thus play a crucial role in the carbon cycle and has links with the greenhouse effect and global climate change.

Carbon dioxide is the most common form of carbon in the atmosphere, and it is the primary source of carbon in organic matter. At present the mean mole fraction of carbon dioxide (CO_2) in the atmosphere is 365 parts per million. However, this value of CO_2 is increasing at the rate of 2.4% per year due to combustion of fossil fuel, cement production and vast scale of deforestation. In order to neutralize this increase, people and governments have started looking at the green cover of the earth and agreeing on a common platform of 'Population Plateaus and Clean - Green Technologies'. In the recent conference on global climate change at Bali, Indonesia, December, 2007, the UN's Intergovernmental Panel on Climate Change (IPCC) has recommended a cut in carbon emissions of 25 to 40 percent in the advanced industrial countries by 2020 and a total world emissions reduction of 50 percent by 2050 (Patrick O'Connor 2007).

Highly productive forests grow quickly and produce large amount of biomass in a short period of time. Forest productivity is the rate of accumulation of forest dry matter per unit area per unit time. It is commonly expressed as Net

Primary Productivity (NPP). NPP includes the biomass accumulation of all plants, stems, leaves, roots and reproductive structures, and it includes litter fall, root sloughing and plant biomass consumed by herbivory and plant and animal decomposers. NPP is expressed in terms of dry matter accumulation per square meter per year (gm^{-2} $year^{-1}$) or dry mass per hectare per year ($Mgha^{-1}$ $year^{-1}$). The below ground component of the NPP is difficult to measure and hence aboveground component is mostly measured as Aboveground Net Primary Productivity (ANPP). Forest productivity can be depicted and defined as a logistic curve of production as a function of time. Just after forest establishment, when light, water and nutrient resources are in ample supply, biomass increases exponentially until a point of time when the resources are fully exploited by the forest.

Net Primary Production (NPP) is a useful measure of the metabolism of an ecosystem and the potential of the vegetation to produce food and fiber for human use. Gross Primary Production (GPP) is a measure of the total amount of dry matter (Biomass) made by the plants in photosynthesis along with the respiratory loss. Net Ecosystem Production (NEP) is the net carbon accumulation by an ecosystem and is the difference between carbon inputs from GPP and different avenues of carbon loss: respiration, leaching and disturbances.

Global terrestrial NPP is estimated to be $110\sim120\times10^9$ tones dry weight per year (Begon *et al*. 1996) (Table 1.1 and Fig.1.1). Production of this energy is not uniformly distributed across the globe. In forest biomes there is a trend of increasing productivity from boreal, to temperate, to tropical regions (Schlesinger 1997). This latitudinal change suggests that temperature and radiation are the main limiting factors; other factors include the availability of water, essential mineral nutrients, soil and canopy cover. Pattern of biomass allocation credits tropical forests for about half of the earth's total plant biomass, although they cover only 13% of the ice free land area. Other forests contribute an additional 30% to the global biomass (Saugier *et al*. 2001). Non-forest biomes account for less than 20% of the total plant biomass and the crops account for just 1% of terrestrial biomass.

Table 1.1 Estimates of Area, Biomass and NPP of Tropical Savannas and Grasslands[1]. (Source: House & Hall, Productivity of Tropical Savannas and Grassland, 2001)

Source	Vegetation Type	Area (Mkm^2)	Biomass (Pg DM)	Biomass ($kgDM\ m^{-2}$)	NPP ($PgDMyr^{-1}$)	NPP ($gDMm^{-2}\ yr^{-1}$)
Whittaker & Likens (1973,1975)	Savannas (includes tropical grasslands)	15	60	4(0.2-15)	13.5	900 (200-2000)
Atjay *et al*	Dry Savanna thorn forest	3.50	52.5	15	4.55	1300
	Low tree/shrub savanna	6.00	45	7.5	12.60	2100
	Dry thorny shrub	7.00	35	5.0	8.40	1200
	Grass dominated savanna	6.00	13.2	2.2	13.80	2300
	Total	**22.50**	**145.7**	**6.5**	**39.35**	**1749**
Olson *et al.* (1983)	Tropical dry forest and woodland (32)	4.7	73.3	15.6	6.00	1271
	Tropical savanna & woodland (43)	6.7	44.9	6.7	7.33	1091
	Succulent & thorn woods (59)	4.0	35.6	8.9	3.56	889
	Semi-arid woodland or low forest (48)	0.9	11.1	11.1	0.89	977
	Warm or hot shrub & grasslands (41)	17.3	50.2	2.9	15.56	899
	Total (Temperate & tropical)	**37.3**	**247.1**	**6.6**	**36.22**	**972**
Scholes &Hall (1996)	Drought-deciduous woodlands	4.6	34.4	8.3	5.2	1263
	Savanna	6.7	15.1	2.5	8.6	1426
	Succulents & thorn woods	3.9	1.4	2.5	2.7	856
	Eucalyptus and *Acacia* woodlands	0.9	7.8	2.5	0.4	733
	Total (tropical)	**16.1**	**58.7**	**3.6**	**16.9**	**1216**
House and Hall (2001)	Tropical dry forest & woodlands	4.7	64.7	13.7	6.0	1263
	Tropical savanna & woodland	6.7	31.8	4.7	9.6	1426
	Succulents and thorn woods	4.0	23.4	5.8	3.4	856
	Semi- arid woodland or low forest	0.9	6.3	7.0	0.7	733
	Warm or hot shrub & grassland	11.2	32.4	2.9	10.1	899
	Total (tropical)	**27.6**	**158.5**	**5.75**	**29.7**	**1078**

[1] DM, Dry Matter; $Mg=10^{16}$ g; $Pg=10^{15}$

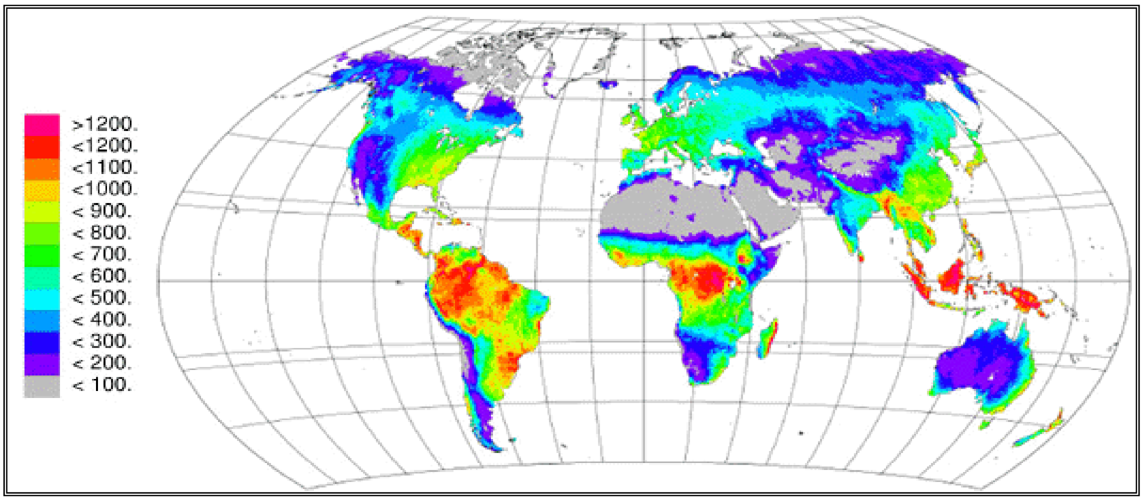

Figure. 1.1: Annual net primary production (gCm^{-2}year^{-1}) estimated as the average of all model estimates. **(Source: GAIM 1993-1997 Report)**

1.1 Measuring the Forest Productivity

Historically available forest productivity data from multiple harvest of standing stock provide the best and most direct measure of forest productivity. Foresters estimated forest productivity by measuring the rate of growth, or the volume accumulation of live, standing, aboveground woody biomass contained within the stems of desired tree. The most accurate way to measure NPP is to measure the net photosynthetic rates of tissues, then deducing the respiratory rate form non-photosynthetic tissues and extrapolating the results to the community level.

At community level, NPP is calculated by the harvest technique. The harvest technique is based on the harvesting all plants from a sample plot and is appropriate for simple communities of short lived plants e.g., grasslands. Since for some annuals, biomass and net production are nearly the same hence sequential harvest of all plant parts during the growing season, provides the net productivity data. Forest and shrub land productivity techniques are based on more complex measurements of growth of different tissues in trees and other plants. The method relies on forest inventory based Fig. 1.2, allometric equations that relate plant growth to plant size.

Recent trends rely on remote sensing method where both optical and microwave data sets are used to generate models aided by various physiological, environmental and metrological data to estimate net primary productivity. Air borne sensors are also used to determine the productivity, where sensor input and subsequent regression of factors such as Leaf Area Index (LAI) and Absorbed Photosynthetically Active Radiation (APAR) is used. LAI shows relation to NPP (Reiners, 1988) however, the relationship is not linear throughout the year. The product of LAI and stand height is an expression of biomass (Mickler and Fox, 1998).

Many investigators have used the gas exchange technique to measure the flux of carbon dioxide within a community. A method for measuring the whole community gas exchange involves measuring the day time depletion and night time accumulation of carbon dioxide in different strata of community. This technique is called Eddy-correlation method and has been applied to a variety of forest and grassland ecosystems (Maselli, 2006), Fig. 1.3.

Fig. 1.2: Inventory based method

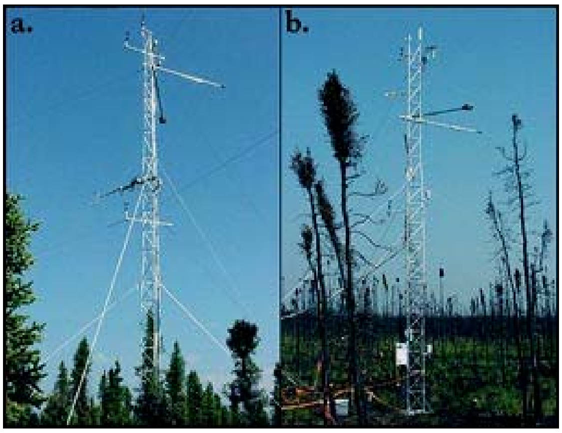

Fig. 1.3: CO_2 estimating Flux tower

Remote sensing of primary productivity is based on the differential absorption of the light by chlorophyll and other leaf pigments. The method is good for large scale NPP calculation. In the present study Production Efficiency Model (PEM), is being used to calculate NPP making use of forest inventory data, photosynthetic rates, Absorbed Photosynthetically Active Radiation (APAR) and remote sensing images. These inputs will be utilized to extrapolate productivity to the regional level. The model assumes that the productivity is a function of light intercepted by the leaves. APAR is one of the best representatives of vegetation parameters as it shows the vegetation dynamics in tropical dry deciduous forests in terms of radiation change. Measurement of APAR by the canopy can be then empirically related with dry matter production over a time (Monteith, 1972). Photosynthetically Active Radiation (PAR) and Photosynthetic Efficiency (PE) are the main model inputs. The study was carried out in Panna National Park, Panna which lies in Madhya Pradesh, Central India.

1.2 Environmental control of Net Primary Productivity

Plant productivity is affected by factors (Zelitch, 1971) like:

i) The soil and the soil water, nutrient availability and carbon dioxide release during soil respiration;

ii) The properties of leaves such as age, size, shape and angle, their stomatal numbers and behavior, response of the mesophyll to irradiance, reflectance and transmission properties;

iii) The architecture of the stand including the total leaf area that covers a unit area of soil;

iv) Ambient climatic factors such as air temperature, wind speed, carbon dioxide concentration, relative humidity, angle of the sun and whether the irradiation is direct or diffused;

v) Duration of photosynthesis and efficiency of carbon dioxide assimilation.

1.3 Modeling Approach to NPP estimation

Terrestrial biosphere productivity is basically governed by the amount of incident radiation and the climatic conditions. Precipitation and temperature are the two major climatic parameters that govern the absorption of the photosynthetically active radiation (PAR) and its conversion into the dry matter, i.e. net primary productivity. A large number of complex models have been developed to account for the ecophysiological and biophysical processes which govern the spatial and temporal features of NPP. The major plant processes involved includes photosynthesis, growth and maintenance respiration, evapotranspiration, uptake and release of nitrogen, allocation of photosynthethates to different parts of the plant, litter production decomposition and phenological development. Some models focus on elaborate mechanistic relationships as stomatal conductance for water, CO_2 fluxes and net nitrogen mineralization for the nitrogen cycle while others rely on simple empirical relationships or satellite observations to derive important features e.g. canopy characteristics or phenology. A comprehensive list of models estimating productivity worldwide is depicted in Table 1.2.

Models like CASA, CENTURY and HRBM relate NPP directly to vegetation characteristics and environmental variables such as temperature, precipitation, available soil nitrogen or other fertility factors, whereas other models estimated NPP as the difference between modeled Gross Primary Productivity (GPP) and Autotrophic Respiration. In this case the environmental variables influenced GPP and RA instead of NPP. All of the above mentioned models can be grouped into three categories:

- The first group of models required satellite data to determine the temporal behavior of the tree canopy. These models could be used to examine the effect of climatic variability on NPP.

Table 1.2 List of NPP estimating models, modeling team and their references

(Source: GAIM 1993-1997 Report)

Model	Full Name	Host Institution	Key references
BIOME3		Department of Ecology, Lund University Sweden	Haxeltine & Prentice 1996 Haxeltine *et al*. 1996
BIOME - BG	Biome BioGeochemical Cycles Model	School of Forestry, University of Montana, Missoula, MT, USA	Running & Hunt 1993
CARAIB 2.1	Carbon Assimilation in the Biosphere Model	Laboratory of Planetary and Atmospheric Physics, Liege University, Liege, Belgium	Warnant *et al*. 1994; Nemry *et al*. 1996
CASA	Camegie Ames Standford Approach Model	Camegie Institute of Washington, Stanford, CA, USA	Potter *et al*. 1993 Field *et al*. 1995
CENTURY 40		University of Colorado, Fort Collins, Colorado, USA	Parton *et al*. 1993
DOLY		Department of Plant and Animal Sciences, Sheffield University, Sheffield, UK ; Department of Environmental Sciences, University of Virginia, Charlottesville, VA, USA	Woodward *et al*. 1995
FBM 2.2	Frankfurt Biosphere Model	Department of Theoretical and Physical Chemistry, Johann-Wolfgang-Goethe University, Frankfurt Main, Germany	Kindermann et al. , Lodeke *et al*. 1994, Kohlmaier *et al* in press
GLOPEM	Global Production Efficiency Model	Department of Geography, University of Maryland, MD, USA	Prince 1991, Prince & Goward 1995
HRBM 3.0	High Resolution Biosphere Model	Department of Plant Ecology, Justus-Liebig- University, Gieben, Germany	Esser *et al*. 1994
HYBRID 3.0		Institute of Terrestrial Ecology, Edinburgh, Scotland, UK	Friend 1995 Friend *et al*. 1997
KGBM	Kergoat Global Biosphere Model	Laboratory of Terrestrial Ecology, Toulouse, France	Kergoat in press
PLAI 0.2	Potsdam Land Atmosphere Interaction Model	Potsdam Institute for Climate Impact Research, Potsdam, Germany	Plochl & Cramer 1995a, Plochl & Cramer 1995b
SDBM	Simple Diagnostic Biosphere Model	Max-Planck Institute of Meteorology, Hamburg, Germany	Knorr & Heimann 1995
SIB 2	Simple Interactive Biosphere Model	NASA/Goddard Space Flight Center, Greenbelt, MD, USA	Sellers *et al*. 1996 ab Randall *et al*. 1996
SILVAN 2.2	Simulating Land Vegetation And NPP Model	Max-Planck Institute of Meteorology, Hamburg, Germany	Kaduk & Heimann 1996
TEM 4.0	Terrestrial Ecosystem Model	University of Alaska, Fairbanks, AK,USA; The Ecosystems Center, MBL, Woods Hole, MA, USA	Mc Guire *et al*. 1995 Mc Guire *et al*.
TURC	Terrestrial Uptake and release of Carbon	Carnegic Institute of Washington, Stanford University, Stanford, CA, USA	Ruimy *et al*. 1996

- The second group stimulates the biogeochemical fluxes on the basis of soil and climate characteristics and uses spatially explicit vegetation database.
- The third group of models exhibit changes in both ecosystem structure (distribution and phenology) and function (biogeochemistry).

1.4 Role of Remote Sensing in Forest Productivity Estimation

The Earth is constantly under observation from dozens of satellites orbiting the planet and collecting data. They are engaged in something called "remote sensing”: the act of obtaining information about an object without being in direct contact with it. Weather report is one familiar application of this data /information-gathering techniques. The satellite images, as well as the actual predictions are obtained through remote sensing of the Earth. The satellites don't gather the information themselves; they simply orbit the Earth and provide platforms from which the sensors can observe large areas of the surface and collect data on the earth surface phenomenon. Airplanes also provide platforms for remote sensing, and some sensors operate from land.

Forest is an important global resource that human population depends on for wood, air quality, recreation and many other uses. They also serve as habitats for millions of plant and animal species. Both commercial and non-commercial forestry utilize a particularly diverse range of remote sensing applications. Traditionally, obtaining information about forests was achieved by sending a team of scientists into forest to physically sample small areas of that forest. The scientists then had to extrapolate the data and apply the findings to the entire forest. Using remote sensing, foresters can get more accurate and cost-effective information, and can directly observe as large an area as necessary. Due to the versatility and scale of remote sensing, it is invaluable in all stages of forest management. The forester's task begins with growing healthy forests. Remote sensing is a useful tool for assessment of environmental conditions, either in an existing forest or prior to planting a new one. The composition and viability of a forest may be determined using a combination of Remote Sensing and Geographic Information System (GIS).

Remote sensing technology has immense potential for continuously monitoring and analyzing vegetated areas at different spatial and temporal resolutions (Richards 1993). This best implies to the forest ecosystem because it shows dynamic nature with change in season, area and human interaction (Odum 1971). Due to its wide coverage area, satellite data provide the opportunity to detect several vegetation parameters like species, density or the green biomass. Goward and Dye (1987) has shown that satellite derived integrated vegetation index shows direct relationship with above ground phytomass and productivity. Vegetation canopy reflectance models coupled with remote sensing data has been successful in estimating the foliage, woody biomass and productivity (Roy 1989). Roy and Shirish (1996) estimated per unit biomass values for each plot using satellite derived vegetation index and then extrapolated the data to the entire homogenous forest area. SAR (Synthetic Aperture Radar) a non optical method of remote sensing provides great opportunity for species-wise forest stratification specifically in areas with perpetual cloud cover. The sensitivity of SAR data to optical data is more and it is more responsive to moisture, cloud, temperature, girth, biomass, branch architecture, and canopy density. Moreover SAR data is endowed with more information content such as multi–polarization data and capacity to penetrate more in the forest canopies. These attributes have given SAR data an upper edge to the optical data. SAR data derived backscatter in the L and P band shows better correlation or high sensitivity to studies related to biomass as compared to the bands such as X, C, S which has less penetration power (Ranson and Sun 1992).

1.5 Hypothesis

1. Whether Remote Sensing is amenable to vegetation cover type mapping?
2. Whether Remote Sensing can be used to estimate biomass and NPP?
3. What is the relationship among parameters, (APAR) Absorbed Photosynthetically Active Radiation, NDVI, (LUE) Light Use Efficiency, Biomass and NPP?

4. Whether carbon sequestration differs with respect to the forest types?

1.6 Objectives

The major objective of the project is to estimate two time (2004 and 2007) Above-ground Woody Biomass (AWB) and then to calculate the Aboveground Net Primary Productivity (ANPP) of the Panna National Park, Panna district (litter and roots not considered). Effort has also being made to study the carbon sequestration potential of different forest types. An attempt to calculate the forest type-wise bole turnover rate and turn over time for an element will also be made. The main objectives are as follows:

- Vegetation cover type mapping using multi season LISS III data.
- Estimation of Aboveground Woody Biomass (AWB), Aboveground Net Primary Productivity (ANPP) of different forest types.
- Establish relationship between IPAR, NDVI, Light Use Efficiency (LUE) and Biomass and Productivity.
- Carbon Sequestration potential of forests within the Panna National Park.

1.7 Application of Remote Sensing and GIS in Forestry and Ecology

Forest as a major source of energy was focused sometimes in the year 1973, when oil crisis emerged worldwide. Remote sensing was a major tool to collect urgently needed data related to monitoring changes in forest cover, assessing land use and forest land degradation, evaluating the productivity of the land and providing information not only for forest inventory but also for direct inputs to forest management and strategic planning. Some of the major applications apart from biomass and productivity studies, where remote sensing and geographic information system has played vita role are:

a) **Biodiversity Characterization:** The topic basically deals with the biological richness mapping of an area. This gives an idea about identifying the gap areas, species habitat relationship and helps in biodiversity conservation on a priority basis. Biodiversity characterization further deals with the preparation and integration of field collected forest and ecological data and there by providing these data a spatial domain. Thus remote sensing in combination with geospatial modeling with GIS and GPS technique provides a platform for landscape characterization. Roy *et al*. 2002 demonstrated biodiversity characterization at the landscape level and defined various conservation strategies to it.

b) **Forest Cover Mapping:** Remote sensing has been tremendously used for preparing national forest cover map. Forest Survey of India started using satellite data from 1983. The assessment is done every two years and the findings are published in the form of State of Forest Report (SFR). The latest in this series is the SFR – 2005 published in 2008. The forests here are categorized into dense, medium dense, open and scrub. Mangroves find a distinct position in the classification scheme. The data here is not just restricted to the national level rather it has details regarding forest cover on a district basis. The latest State of Forest Report-2005, presents the total forest cover of India to be 677,088 km^2 and this constitutes 20.60 percent of the geographic area of the country. Of this 1.66% (54,569 km^2) is very dense forest, 10.12% (332,647 km^2) is moderately dense forest while, 289,872 km^2 or 8.82% is open forest. The rest is scrub, 38,475 km^2 (1.17%), SFR, Forest Survey of India (2005).

c) **Change Detection Analysis:** The most fundamental data on landscape changes arises from observations of the state of a landscape at two time periods. This gives a preview regarding the physical changes going on the ground. Such studies are more helpful in monitoring; mining reclamation sites, study fast and major deforested areas and predict the outcome of forest plantation efforts. Srivastava *et al*. assessed large scale deforestation in Sonitpur district of Assam, India using change detection technique.

d) **Forest Fire:** Forests are often at risk of being destroyed by forest fires. Remote sensing can be used in efforts to reduce the risk and minimize damage if a fire occurs. Weather information, such as measurements of precipitation and temperature, allows foresters to calculate risk assessments and isolate the areas most susceptible to fire. Those areas can be closely monitored by satellites, such as Advanced Very High Resolution Radiometer (AVHRR) and Satellite Pour l'Observation de la Terra (SPOT). Images from these satellites are readily available and small fires show up on them almost immediately. Remote sensing contributes to fire-fighting efforts, as well. Data on wind direction and speed, and the dryness of surrounding areas can help predict the directions and speed at which a fire spreads. With this information, firefighters can be dispatched with maximum effectiveness and safety, and fires can be put out before they cause much damage. Radar and thermal sensing allow for constant observation of fires, unaffected by clouds, smoke, or other conditions that hinder aerial observation. Porwal et al. 1997 used spatial modeling to assign weights to different parameters like fuel availability, elevation, slope, aspect and accessibility to generate a fire risk model which gave a cumulative fire risk index, Fig (1.4 and1.5) .

Fig. 1.4: Forest Fire

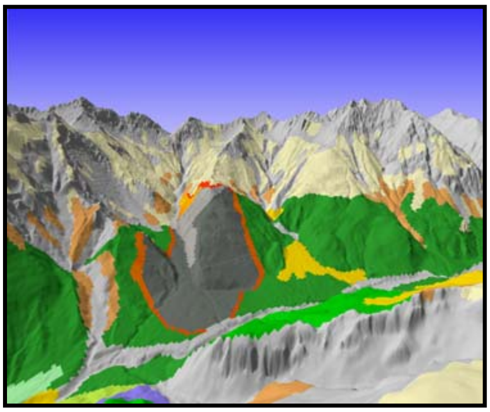

Fig. 1.5: Modeling Fire spread

e) **Forest Management:** During every stage of forest management, foresters can use remote sensing data to estimate future urban spread and population growth. Then, forest management can be planned taking into account the future needs of settlements. Urban planning data can also be applied to the management of urban forestry, to create inventories of trees in parks and on streets. The logical extension of commercial forestry is logging, and the nature of the industry requires long-term planning for cutting and re-growth. The accurate data from aerial photography and satellite images are used for planning and monitoring of these activities. Satellite remote sensing has played key role in providing information with respect to forest cover, vegetation type and their changes at global, regional, national or micro level studies (Roy *et al*. 1987, Unni *et al*. 1985, Porwal and Pant, 1986).

f) **Habitat Suitability Analysis:** This technique incorporates both remote sensing and GIS modeling for resource management and using the concept of habitat suitability index. Based on habitat evaluation procedure, a model for any species can be designed taking into consideration different variables found significant enough to affect the habitat of a species. In India, Roy *et al*. (1995), Porwal *et al*. (1996) and Kushwaha *et al*. (2000, 2001) have used remote sensing and geospatial modeling to evaluate the habitats for single horned Indian Rhino, *Rhinoceros unicornis* and sambar, *Cervus unicolor*. Alfred *et al*. (2000) did habitat suitability analysis of Chinkara, *Gazella bennetti* in Rajasthan using remote sensing and GIS approach.

Chapter 2

Literature Review

Forest can act both as source and sink for atmospheric carbon dioxide. A large number of studies are in progress in this regard. The rate of afforestation in India is one of the highest among tropical countries and it is because of that India has maintained approximately 64 million ha of forest cover for the last decade. In the Indian context 86% of the forest area falls broadly into tropical forest of which 53% is dry deciduous, 37% is moist deciduous and the rest is wet evergreen, (Kaul and Sharma, 1971). These forests have high carbon credits and hence regular attempts are made to understand the role of terrestrial ecosystem in these areas and especially studies related to forest biomass and productivity using ecological and remote sensing methods.

Exhaustive work has been done for biomass related studies using conventional ecological methods. Singh and Yadava (1974), found seasonal variation in the composition, plant biomass and net primary productivity (NPP) for a, tropical grassland within the campus of Kurushetra University. A major finding, within this report was that net primary productivity was more directed towards above ground biomass increase during the rainy season and below ground biomass increase during the dry season.

Pandey and Singh (1992), examined the effects of rainfall amount, rainfall distribution and grazing intensity on the NPP and herbivory for a dry tropical savannah. The total herbaceous and woody NPP ranged from 11.9 to 19.1 t/ha/yr. This value is in tune to the native tropical dry deciduous forest, except that the production of herbaceous species is 61% lower in the forest. Garkoti 2007, described the biomass and productivity of maple (*Acer cappadocium*) forest occurring at an altitude of 2,750m in the West Central Himalayas. Total vegetation biomass was estimated to be 308.3 t/ha, of which the tree layer contributed the most, followed by shrubs and herbs. NPP of the total vegetation was estimated to be 19.5t/ha/yr. The production efficiency of leaves was marked higher as compared to those of the low altitude forest of the region.

Annual productivity of bamboo species *Dendrocalamus strictus* was found to be in the range of (1.8 – 7.7) t/ha/yr; Tripathi and Singh (1994). Lodhiyal and Lodhiyal (2002), illustrated biomass and NPP in different age groups shisham (*Dalbergia sissoo*) forest planted after clearing up of sal (*Shorea robusta*) tree species in Bhabbar (a nutrient poor and low water table site) adjacent to the foothills in Kumaun of Central Himalayas. The total biomass and NPP ranged from 52 t/ha for 5years age group to 118.1 t/ha for 15 year age group and 11.4 t/ha/yr for 5 years to 14.8 t/ha/yr for 15 years respectively.

Ground based remote sensing is widely being used to estimate the biomass and productivity of forests and thus correlating it with the biophysical parameters of vegetation. Use of remote sensing is cost effective and less time consuming procedure where data through remote sensing is visually and digitally interpreted through certain ground checks and maps are prepared simultaneously. Spectral characteristics of vegetation especially in the range of 630nm to 690nm show high degree of regression significance between spectral reflectance and six canopy variables, Tucker, 1977. The 740nm to 1000nm region of electromagnetic radiation is best suited for spectral estimation of moderate to high density biomass, chlorophyll or leaf water content, Tucker, 1977. The basic concept behind this is that different objects behave differently in different wavelengths of electromagnetic radiation. Interaction of radiation with plant leaves is extremely complex. Gates, 1965, studied the spectral characteristics of leaf reflection, transmission and adsorption. Roy et al. 1986, studied spectral properties of grassland and developed some relationship with biomass. The quantification of biomass is required as the primary inventory data to understand pool changes and productivity of the forests. Further, biomass and productivity information is also important for studies related to the climate change. The annual forest productivity of India has increased from 0.7 m^3 /ha in 1985 to 1.37 m^3 /ha in 1995, Lal and Singh, 2000. Increase in the annual productivity is directly linked to an increase in the forest biomass and higher carbon sequestration potential.

Geographically referenced NPP and their corresponding seasonal fluctuations are vital to understanding of both the functioning of living ecosystems and their subsequent feedbacks to the environment. Biospheric flux models relate geographically to the specific and comprehensive estimates of temperature, water availability and Photosynthetically Active Radiation (PAR), as well as their season changes to some or all of the basic processes of photosynthesis, growth and maintenance respiration, water and nitrogen fluxes, allocation of photosynthetates in the plants and production and decomposition of litter. Productivity is a keystone variable for the sustainability of human use of the biosphere through agriculture and forestry.

Terrestrial NPP has been derived from satellite image derived vegetation indices, by estimating the amount of absorbed photosynthetically active radiation (APAR), Hunt, 1994. Sensors on-board such as Advanced Very High Resolution Radiometer (AVHRR) have been used extensively to demonstrate the role of forest eco-system on the global carbon budget. Goward et. al. (1985) and Tucker et. al. (1986) showed vegetation indices, such as Normalized Vegetation Difference Vegetation Index (NDVI = (NIR-R)/ (NIR+R)) are related to net primary productivity (NPP, gm^{-2} $year^{-1}$ or t ha^{-1} yr^{-1}). Satellites receive an integrated spectral response of target object within a specified spectral width. The satellite images which we receive are in the form of digital numbers, which does not depict properly the physical units such as radiance, reflectance or temperature. Therefore studies which rely more on remote sensing images to quantify ground surface characteristics such as leaf area index, biomass and net primary productivity, require the digital images to be converted into target reflectance, Mehul *et al*., 2002. Zhang and He **(**2005) demonstrated atmospheric correction as an important step in the process of land surface reflectance retrieval for IRS P6 LISS 3 images. Computation of at sensor solar exoatmospheric irradiance for IRS P6 sensors were obtained from Data Quality Evaluation, Data Processing Area, Hyderabad.

Monteith (1972, 1977) was of the view that net primary productivity under non-stressed condition is linearly related to the amount of absorbed photosynthetically active radiation (APAR, MJm^{-2}). Later on Kumar and Monteith 1981, reveled how the fraction of PAR absorbed relates to the ratio of red reflectance to the near infrared reflectance. Later on Asrar et al. 1984, related the NDVI to the fraction of PAR absorbed and thus NPP was calculated using the equation; NPP = $\varepsilon \sum (APAR)$ or $\varepsilon \sum(NDVI \times APAR)$, where $\sum (APAR)$ is the annual sum of APAR and ε is the PAR conversion efficiency (gMJ^{-1}). Kale, Singh and Roy 2002, developed methods to correlate the biomass with the girth and height. Component wise biomass equation was developed, which was used to get the biomass values at the patch level. Kale et al. 2002, used Production Efficiency Model to estimate the NPP at the patch level, which takes into consideration the Intercepted Photosynthetically Active Radiation (IPAR) and Photosynthetic Efficiency in Shivpuri district of Madhya Pradesh. Xianfeng et al. 2005, stimulated China's terrestrial NPP using carbon – water coupled process model based on remote sensing and explored the temporal and spatial variation in NPP and its reaction to the environmental factors. Tickle et al. 2001, assessed forest productivity at local scales across a native eucalyptus forest using process based model called 3PG-SPATIAL, they used GIS, by creating spatial layers of climate and soils to predict forest growth and compared it with the ground based plot data. Maselli et al. 2005, tested procedures to use remote sensing and ancillary data to assess large scale patterns of forest productivity in Italy. They used of C-Fix model which is based primarily on relationship between photosynthetically active radiation absorbed by the plant canopy and relevant Gross Primary Productivity (GPP). Mathematical modeling with ECOSYS to generate net ecosystem productivity of boreal forests under drought and climate change was done by Grant et al. 2006, Raddi et al. estimated radiation use efficiency and radiation absorbed by the green canopy to predict the forest productivity from remote sensing, they used Photochemical Reflectance Index as it has a defined functional basis because of good relation between non-photochemical quenching of the absorbed radiation and the de-epoxydation state of xanthophylls pigment, (Muller, Li & Niyogi, 2001). Maselli and Chiesi 2005 developed and tested different integration procedures for producing Normalized Difference Vegetation Index with high spatial and temporal resolutions. Output images were then compared on per pixel basis to the higher spatial resolution Landsat TM/ETM $^{+}$ data. The NDVI temporal profile were transformed into Fractional of Absorbed Photosynthetically Active Radiation (FPAR) estimates, which were combined with combined with standard meteorological data (radiation) data to compute the Gross Primary Productivity (GPP).

Productivity of the terrestrial biosphere is mainly controlled by the amount of incident radiation and the climatic conditions under which plants are able to carry out photosynthesis and then distribute the photosynthetates to various components of the tree like, roots, bole, stem, leaves, flowers and fruits. Precipitation and temperature are the two main driving forces that guide the absorption of Photosynthetically Active Radiation and its conversion into the dry matter. The pioneer NPP MIAMI model by Lieth 1975 used an empirical regression equation to show relationship between annual NPP and mean annual temperature and precipitation. A large range of complex models have been developed to account for the ecophysiological and biophysical processes which determine the spatial and temporal features of NPP. Some models focus more on detailed mechanistic relationship while others rely on the empirical relationship or satellite imagery in order to derive important plant features like canopy characteristics and phenology.

Two basic approaches were followed to calculate NPP. Some models (eg., CASA, CENTURY and HRBM) related NPP directly to the vegetation characteristics and environmental variables or indicators such as temperature, precipitation available soil nitrogen or other factors which enhances the fertility. Other models estimated NPP as the difference between two processes which were modeled separately: gross primary productivity - the total uptake of carbon from the atmosphere by plants), and autotrophic respiration (RA) the release of carbon to the atmosphere by the plant respiration. At Postdam 1995 NPP inter-comparison conference, three model groups were identified.

The first group of models required satellite data to determine the temporal nature of photosynthetically active canopy content. These models can be used to examine the effect of climate variability on NPP, but such models are constrained due to dependency on the satellite data archive. The second group of models stimulates the biogeochemical fluxes on the basis of soil and climate features along with the spatially available vegetation data sets. Many of these models examine the influence of the climate change Melillo et al. 1993. However, these models simply describe the functional changes within a particular vegetation type. The third group of models, stimulates changes in both ecosystem structure i.e. vegetation distribution, phenology and function.

All the models for NPP estimation are climate driven and hence have the data requirements for moisture and temperature which are mostly gridded at 0.5° longitude and latitude. Stimulations were done at 0.5° resolution by all the models except GLO-PEM and SIB2 to be compared at the Postdam Conference. Models requiring satellite data used a uniform globally available Advanced Very High Resolution Radiometer (AVHRR) to analyze seasonal changes in FPAR Meeson et al. 1995; Sellers et al. 1994. The seasonal FPAR was derived from FASIR-NDVI. To analyze stimulated phenology, two main categories of global NPP models were considered: 1) models driven by satellite data to estimate the temporal variations of the fraction of Absorbed Photosynthetically Active Radiation and 2) models that stimulate the temporal behavior of the canopy, i.e., changes in the leaf area index. Thus, the importance of the radiative activity of the canopy is recognized for carbon assimilation. The seasonal absorption of APAR as well as the relationships between absorbed radiation and photosynthesis was examined to find the differences among predicted NPP.

Fifteen out of seventeen global models compared at the Postdam 1995 conference uses solar radiation as a driver of plant production. For each model, the fraction of light absorbed by the plant canopy was estimated by converting the incident global radiation into photosynthetically active radiation (PAR), and using a constant ratio of 0.48 MJ PAR Mc Cree 1972. The relationship between NPP and its component, APAR and Light Use Efficiency (LUE), were examined at three spatial level i.e. grid level, zonal level and global level. For the grid cell level analysis, the values of NPP versus APAR and LUE were plotted for each model over all grid cells of common area. This gave an insight into the intra-model relationships or the relationships between NPP and its components within the models. Thus the inter model relationship has shown good agreement between the present generation of models over many wide features, despite the fact that the models were widely developed with different objectives and model inputs.

Chapter 3

Study Area

3.1 Introduction

Panna National Park lies in the north-central part of Madhya Pradesh, situated in the Vindhyan Range and spreads over Panna and Chattarpur districts. It received the status of a National Park in the year 1981 and in 1994 it was declared as a Project Tiger Reserve by the Government of India. Panna National Park encompasses 542.67 km^2 of area under its jurisdiction and lies within the geocoordinate of 79˚45' to 80˚09' East longitude and 24˚27' to 24˚46' North latitude. In the present study Panna National Park lying within Panna district has been taken which covers an area of 350 km^2.

The park covers area of the former Gangua Wildlife Sanctuary established in 1975. The sanctuary comprises of territorial forests of the present North and South Panna Forest Division to which a portion of the adjoining Chattarpur forest division was added later. The reserved forests of the park in Panna district and some protected forests on Chattarpur side were the game hunting preserves of the erstwhile rulers of Panna, Chattarpur and Bijawar princely states in the past.

Ken River traverses through the park and offers some of the most spectacular scenes to the visitors while it meanders for some 55 km through the park. The terrain of the reserve is characterized by extensive plateaus and deep gorges. The landscape is mildly undulating with height of hills ranging from 200-500 meters. Series of undulating hills and plateaus rise on the other side of Ken River in Chattarpur district. The location of the National Park is also important because it is situated at a point where the continuity of the forest belt, which starts from Cape Comorin in the south, is broken and beyond this the great Gangetic plains begin. This area is also the northern most tip of the natural teak forests and the eastern most tip of the natural Kardhai (*Anogeissus pendula*) forests. The climate of this region is tropical. Summers are too hot and uncomfortable, though this is the time when one has the maximum chances of encountering the exclusive wildlife of this park (Fig. 3.1, 3.2).

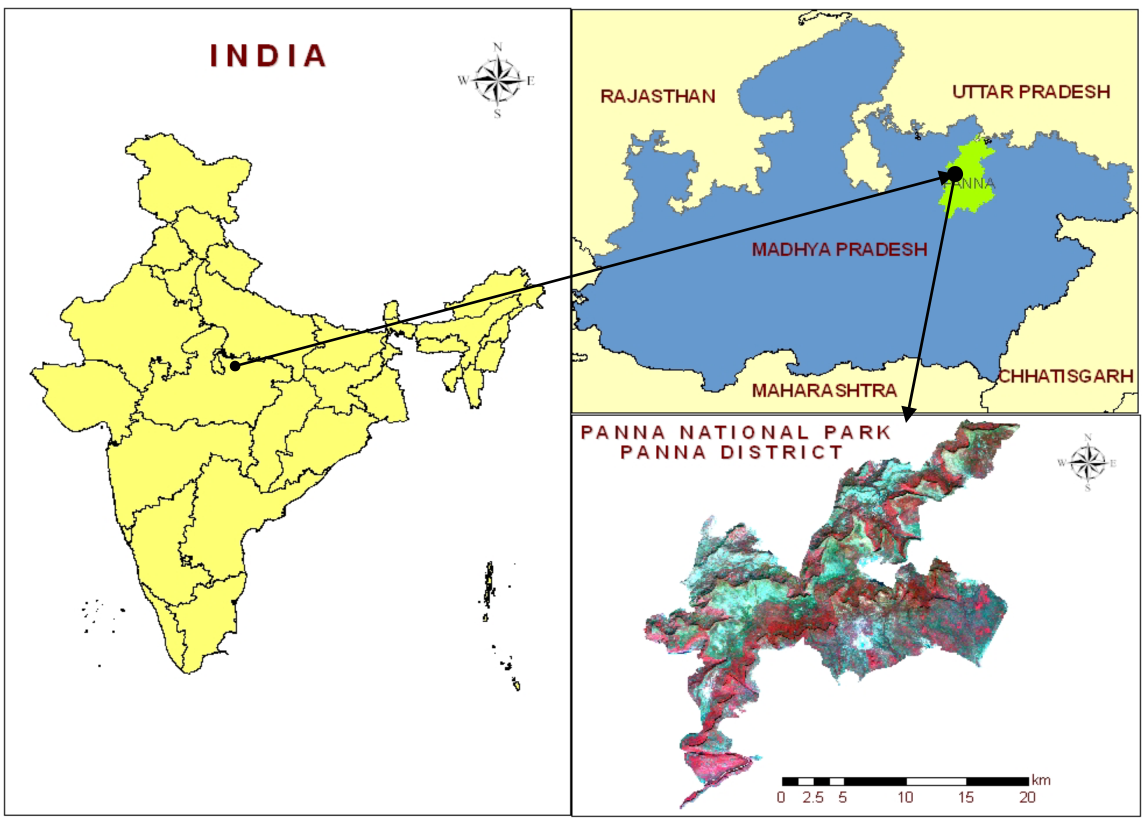

Fig. 3.1 Location map of study area

3.2 Geology

The protected area which has bench topography can broadly be divided into three distinct tablelands on Panna side: the upper Talgaon Plateau, the middle Hinouta plateau and the Ken valley. This has given rise to a large numbers of gorges, cliffs and overhangs. Large numbers of caves and rock shelters are also spread all over the area.

The Vindhyan sandstone acts as a good source for aquifer recharge in the area. The soils are of three types. Majority of the area is covered by the lateritic soil. These are well spread in the Panna, Hinouta and Chandranagar ranges. Black cotton soil is restricted to some depressions and in the vicinity of water bodies in three ranges. The third type of soil includes the most productive loamy soil, formed due to the disintegration of the Vindhyan conglomerate near the Madla and Hinouta ranges.

Fig. 3.2. Different facets of Panna National Park

3.3 Drainage

Ken river traverses the park and acts as a boundary between Panna and Chattarpur districts. Along with this there are number of ephemeral drains that meet river Ken and then drain into Yamuna.

3.4 Climate

The climate is broadly divided into three distinct seasons: the hot summer extending from middle of February to middle of June; the rainy season extends from middle June to September and the winter from November to middle February. The month of October witnesses the transition from the rainy to the cold weather. Average annual rainfall around Panna is about 1200 mm. No meteorological station is situated within the park boundaries; only a rain gauge of U.P. Government, Irrigation Department is located at the Gangua dam to record rainfall data on a regular basis. Temperature remains at its peak during the months of May and June and it remains on average above 35°C. December and January are the coldest months where the mercury dips to 5-6°C or below.

3.5 Wildlife

Panna National Park is endowed with rich faunal wealth. Tiger is the top carnivore found in the park followed by Leopard and Hyena. A large number of herbivores graze through the park and its adjacent areas. The best known area from the point of view of animal distribution is Madla and Hinouta Ranges. Open and peripheral plateaus of these ranges have good populations of Chinkara and Nilgai. Sloth Bear and pig are also frequently found near the ridges. Other animals include Jackals and Langoors. Sambar is generally found in dense sloppy areas to ecotones between forest and plateau grasslands. Chousinghas and Cheetals are met in woody grassy areas, mostly away from habitation. Mugger and Ghariyal can be easily seen in many parts of Ken River, Fig. 3.3.



Chousinghas **Nilgai (Male)** **Spotted Deer**



Leopard **Tiger** **Peacock**

Fig. 3.3: Wildlife sighted at Panna National Park, Panna District.

3.6 Vegetation

Vegetation of the Panna Park is a dry deciduous, its chief tree species being teak (dry), Kardahi, Khair, Salai, common bamboo, a host of Euphorbia species etc. There are long but narrow flat terraces separated with higher or lower ones with hilly slopes, varying in gradient from gentle to steep or precipitous slopes/vertical climb. Flats or the table lands generally have open forest with different varieties of grasses; whereas good forest often with bamboo is found on the slopes. Certain plant species are conspicuous in their distribution in particular areas like Kardahi and Salai.

3.6.1 Biogeographic Classification

Panna National Park with its north-central location in Madhya Pradesh forms part of the Indo-Malayan Realm floristically. The following forest types are encountered in the park (Champion and Seth, 1968) Plate 1 and 2.

1. Southern Tropical Dry Deciduous Dry Teak Forest – 5 A/C_1 b
2. Northern Tropical Dry Deciduous Mixed Forest – 5 B/C_2
3. Dry Deciduous Scrub Forest - $5/S_1$
4. Boswellia Forest – $5/E_2$
5. Dry Bamboo Brakes – $5/E_9$
6. *Anogeissus pendula* Forest – $5/E_1$

Dry Teak Forest occurs on trap, shale, granites, gneisses and sandstones. The growth is good in the Ken valley where the soil is sandy loam and the water table is high. Low water table on the plateaus favors stunted and sparse growth of tree species. Percentage of teak varies from 65% to 25%, depending upon the site quality. The associated tree species are Dhaora (*Anogeissus latifolia)*, Saja (*Terminalia tomentosa*), Tendu (*Dyospyros melanoxylon*), Lendia (*Lagerstromia parviflora*), Amla (*Emblica officianalis*), Tinsa (*Ougenia ooginensis*), Bija Sal (*Pterocarpus marsupium*), Moyen (*Lannea coromendelica*), Salai (*Boswellia serrata*), etc. The second-storey consists of Achar (*Buchnania lanzan*), Katai (*Gardenia latifolia*), Bel (*Aegle marmelos*), Amaltas (*Cassia fistula*), Khair (*Acacia catechu*), and under-wood species Dudhi (*Holorrhena pubescens*), Ghont (*Ziziphus xylopyra*) etc.

Dry mixed forests occur mainly on sandstones, shales and laterites where soils are fairly deep, sandy and red loam. These forests are more prone to fires and have been subjected to heavy cattle grazing during the past. The main tree species include Saja, Seja, Tendu, Mahua, Haldu, Rohan, Kaima, Moyen, Ghont, Salai, Jamun, Kusum and some teak trees.

Riverine Forest (October-2007)

Riverine Forest viewed from top

Grassland (June-2007)

Grassland (October-2007)

Savannah

Moist Mixed Deciduous Forest

PALTE – 1: Different Forest types in Panna National Park, Panna District

Anogeissus Forest (June – 2007)

Anogeissus Forest (October – 2007)

Boswellia Forest (October-2007)

Acacia Forest (October – 2007)

Teak Forest (October-2007)

Teak Forest (June-2007)

PLATE – 2: Different Forest types in the Panna National Park, Panna District.

Dry Scrub Forest is the degradation stage of teak and mixed forests and is found within areas adjacent to villages and cultivation. Retrogression due to heavy felling, clearance of land for agricultural purpose, heavy cattle grazing and browsing and frequent forest fires during the summers is frequently seen. Most of the tree species are stunted and sparsely grown. Grasses here are more prominent as they attain good height and density. Palash (*Butea monosperma*) is more common in these areas.

Boswellia forest occurs on dry upper plateaus of hills having dry shallow and stony soils. Pure *Boswellia* patches occur on the ridges of Talgaon and Kawar beats. The main tree associates includes, Kaima, Moyan, Saja, Dhoban, Tendu, Tinsa, Amla, Rohan, Ghont, Dudhi, Papra, Amaltas, and Achar.

Dry Bamboo Brakes are represented by *Dendrocalamus strictus* which occurs in the under storey of teak and mixed forest. It occurs on the slopes of hills, in the upper reaches of nalas and occasionally along the bank of streams.

Anogeissus pendula forest occurs mainly in a long strip of small width in the undulating foot hills from Pipartola to Gangua dam along the Ken river on both the banks. Teak intrudes in some patches to break up the strip but their growth is not significant enough. Anogeissus grows in a gregarious form and with almost full crown density.

Grasslands occur in the centre part of the park. The grasses are tall and basically includes *Heteropogon* sp., Golden grass etc. Savannah grassland has interspersed species of *Ziziphus*, *Acacia catechu* and Teak.

Chapter 4

Materials and Method

In the present work, multi-date and multi-season LISS III data of IRS P6 Resourcesat 1 has been used, Table 4.1. The spatial resolution of the sensor is 23.5 m which can be up scaled to 0.1 ha for studies related to vegetation and its physical and physiological processes. LISS III has green (0.52-0.60) µm, red (0.63-0.69) µm, near infra-red (0.76-0.90) µm and short wave infrared (SWIR) (1.55-1.75) µm bands respectively. The swath is 141km and the temporal resolution is 24 days.

Table 4.1: Data used in the present study.

IRS-P6 SENSOR	DATE-MONTH-YEAR	PATH	ROW
LISS III	04-11-2003	99	54
LISS III	28-11-2004	99	54
LISS III	07-09-2006	99	54
LISS III	25-10-2006	99	54
LISS III	18-11-2006	99	54
LISS III	12-12-2006	99	54
LISS III	05-01-2007	99	54
LISS III	03-02-2007	99	54
LISS III	18-03-2007	99	54
LISS III	11-04-2007	99	54

4.1. Ancillary Data

The ancillary data used in the project includes:

- Survey of India topographic sheets 63D2 and 54P14 at 1:50,000 scale.
- Forest Management Plan of the Panna National Park.

- Forest Survey of India Volumetric equation for the tree species occurring in the study area.
- Literature: Indian Woods, volume (I-VI) for specific gravity of tree species.
- Computed at sensor Solar Exoatmospheric Irradiance and Rayleigh Optical thickness for IRS-P6 Sensors, Data Quality Evaluation, Data Processing Area, National Remote sensing Agency, Hyderabad.

4.2 Instruments Used

The instruments used in the present study are:

a) Leaf Chamber Infra red Gas Analyzer
b) Ceptometer
c) Global Positioning System (GPS) for locating the geo-coordinates of the sample plots and Magnetic compass for laying the plots.
d) Hypsometer

4.2.1 Leaf Chamber Infra-red Gas Analyzer (LCi)

LCi is a portable microprocessor controlled system for carbon dioxide and water vapour exchange measurements. The system is equipped with newly developed miniaturized infrared gas analysis (IRGA) sensors, housed in a conditioned air chamber. The purpose of the instrument is to measure the environment of a leaf contained in the jaws of the chamber, and to calculate the photosynthetic activity of the leaf.

The instrument comprises a main console containing a large Liquid Crystal Display (LCD) (Fig.4.2 and 4.3) , a 5-button keypad and a microprocessor controlled operating system with signal conditioning, air supply unit and PC (Personal Computer) card data storage. A Leaf Chamber (LC) is connected to the Console by an umbilical cord. The main consol supplies air with a relatively stable carbon dioxide concentration at a controlled flow rate to the leaf chamber.

The CO_2 and H_2O concentration are measured, and the air is directed over both surfaces of the leaf. The discharged air leaving the chamber is analyzed and its CO_2 content and H_2O content are determined, Fig. 4.4. From the known air flow rate and differences in the gas concentration, the assimilation and transpiration rates are calculated and updated every second with a complete analysis cycle taking about 20 seconds depending on the flow rate used.

Fig. 4.1: Teak leaf being analyzed by LCi

Fig. 4.2: LCi instrument getting initialized

Fig. 4.3: Consol LCD with readings

Fig.4.4: LCi readings being taken in the forest

The system also measures leaf temperature, chamber air temperature, PAR (Photosynthetically Active Radiation), and atmospheric pressure. The PAR at the leaf and the radiant energy balance of the leaf are calculated.

Measured and calculated data are displayed on the large Liquid Crystal Display (LCD) on the front panel of the console. The display has three pages, which can be scrolled through using the "page" key. The data can either be logged on a PCMCIA type-1 memory card or sent directly to a "dumb" terminal via the RS232 serial link connector.

The LC*i* uses the principal of Non Dispersive Infrared (NDIR) for the CO_2 measurement. This relies on the fact that CO_2 absorbs energy in the infrared region in a proportion related to the concentration of the gas. The gas sample to be measured is passed through a tube (or cell). A source of infrared is directed down the cell which is gold plated to maximize the intensity of the source. A solid state detector at the receiving end of the cell measures the amplitude of the infrared signal, which will be reduced if CO_2 is present in the gas sample. A thin film filter (TFF), with a pass band of 4.24μm, is fitted in front of the detector to narrow the bandwidth being measured to one which includes a strong absorption band for CO_2. The reference (gas into the chamber) and analysis (gas from the chamber) gases are alternated with 'zero' gas during a measurement cycle which typically lasts 16-20 seconds. The 'zero' gas is generated by passing the air through soda lime, which removes all of the CO_2. The cycle time allows for the cell to re-fill, and is automatically adjusted to suit the current flow rate, if requested by the user. This arrangement provides measurement of the CO_2 content in both the reference and the analysis gases, while eliminating much of the drift due to temperature change etc.

4.2.2 Ceptometer

The instrument is battery-operated linear PAR ceptometer, used to measure light interception in plant canopies. It consists of an integrated Microprocessor - driven data-logger and probe. The probe contains 80 independent sensors, spaced 1cm apart. The photo-sensors measure PAR (Photosynthetically Active Radiation) in the 400-700nm waveband with the unit of micromoles per meter square per second ($\mu mol\ m^{-2}\ s^{-1}$). PAR (photosynthetically active radiation) represents the portion of the spectrum which plants use for photosynthesis. Under a plant canopy, radiation levels can vary from full sun to almost zero over the space of a few centimeters. Therefore, reliable measurement of PAR requires many samples at different locations under the canopy. Intercepted PAR (IPAR) data can be used for determining important parameters of canopy structure and for the calculation of LAI.

4.2.3 Global Positioning System (GPS)

Garmin 12 channel GPS was used in the present study to locate the geo-coordinates of the field plots. GPS was basically designed by U.S. Department of Defense as a global radio navigation system for military purposes, but later on it was made public to the whole world for civilian purposes. Working of the GPS is based on a constellation of 24 high altitude satellites. These satellites are arranged in such a way that they provide 24 hours of non stop navigation.

4.2.4 Hypsometer

Blume Leiss Hypsometer was used in the field to measure the height of tree species. It measures the height of the tree with accuracy taking into consideration the trigonometric principles. The theory of height measurement of trees is based on the following mathematical principle:

I. Geometric principles based on the relations of similar sides of similar triangle.
II. Trigonometric principles based on the relations existing between the sides and trigonometric function of a right angled triangle. This function says that if an angle other than the right angle is known, the relation between the sides of a triangle can be ascertained.

4.3 Sampling Strategy

The sampling technique to be used in forest inventory varies from the objective of the study to the kind of forest and geography of the area. A sampling scheme basically comprises of determining the size of the sampling units, number of sampling units to be used, distribution of sampling units over the entire area and the statistical procedure adopted for analyzing the data.

In the present study, size of the sampling unit was determined using the standard species area curve method, where square quadrat of small area were laid in the study area and occurrences of the number of species in that area were recorded. The quadrate size was increased and simultaneously the number of species occurring was recorded. Initially as we increased the plot size, the number of species recorded increased but after some size it stops increasing and the curve flattens. At this point a perpendicular to the x-axis represented the quadrate area at which the sampling should be performed. The standard quadrat area attained was (31.61×31.61) m^2 or 0.1ha for sampling of the tree species, Fig. 4.5. Apart from this another reason to take 0.1 ha of plot size is that it

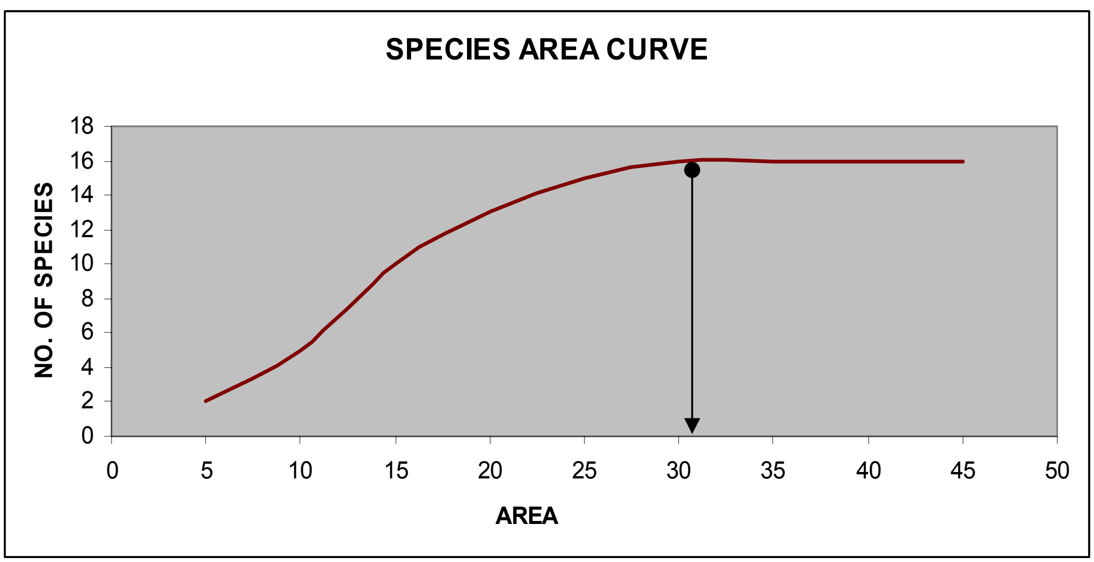

Fig. 4.5: Species area curve.

is the standard uniformly followed by the Forest Survey of India (FSI), State Forest Departments and in national level projects like the Biodiversity Characterization at Landscape Level Using Satellite Remote Sensing and GIS by Department of Space and Department of Biotechnology, Government of India. Further, 0.1 ha sample size is justified from the fact that the pixel size of IRS - P6 LISS III sensor is 23.5 m which can be up-scaled to 31.61 m for better analysis.

Stratified random sampling technique was implied to lay the sample plots on the ground. In this process, the study area was first stratified into forest type wise and their sampling units were selected based on probability proportionate to the size. Sampling was done at an intensity of 0.01% of the total area considering the limited time frame, intensive and exhaustive field covering various microclimatic variations.

Forest inventory data collected in the year 2004 by a working team at IIRS Dehradun was used as the time one data set and it recorded the geo-coordinates of the sample plots and names, height and girth of tree species occurring within the plots. Time two observations were made after a gap of three years in 2007 on the same sample plots and the increase or decrease in the number of tree species was accounted. Altered tree height and diameter at breast height of all trees falling within the sample plots were recorded. Time two observations included three regular fortnightly field visits to the Panna National Park in the months of June, October and November - December. June month was used to note the tree height and girth where as October and November – December field visits were made to take the LCi and Ceptometer readings in the field.

4.4 Method

The present study mainly aims at estimation of terrestrial (above ground) woody biomass of the Panna National Park for the year 2004 and 2007 (a gap of three years) respectively and there by estimating the Net Primary Productivity (NPP). APAR of the forest cover was estimated on ground by using the Ceptometer instrument. Biomass and NPP are important parameters for carbon pool estimation. Apart from this carbon sequestration potential of different forest types present in the area will also be analyzed on the basis of readings being collected. A gist of overall methodology adopted in the project is given in the below flowchart.

The methodology Fig. 4.6, can be broadly grouped into two parts, one dealing with the extensive ground data collection and the other dealing with the remote sensing parameters. Using Geographic Information System (GIS) and statistical approach, data from forest inventory and remote sensing were integrated to generate an aboveground forest biomass and productivity maps for the study area.

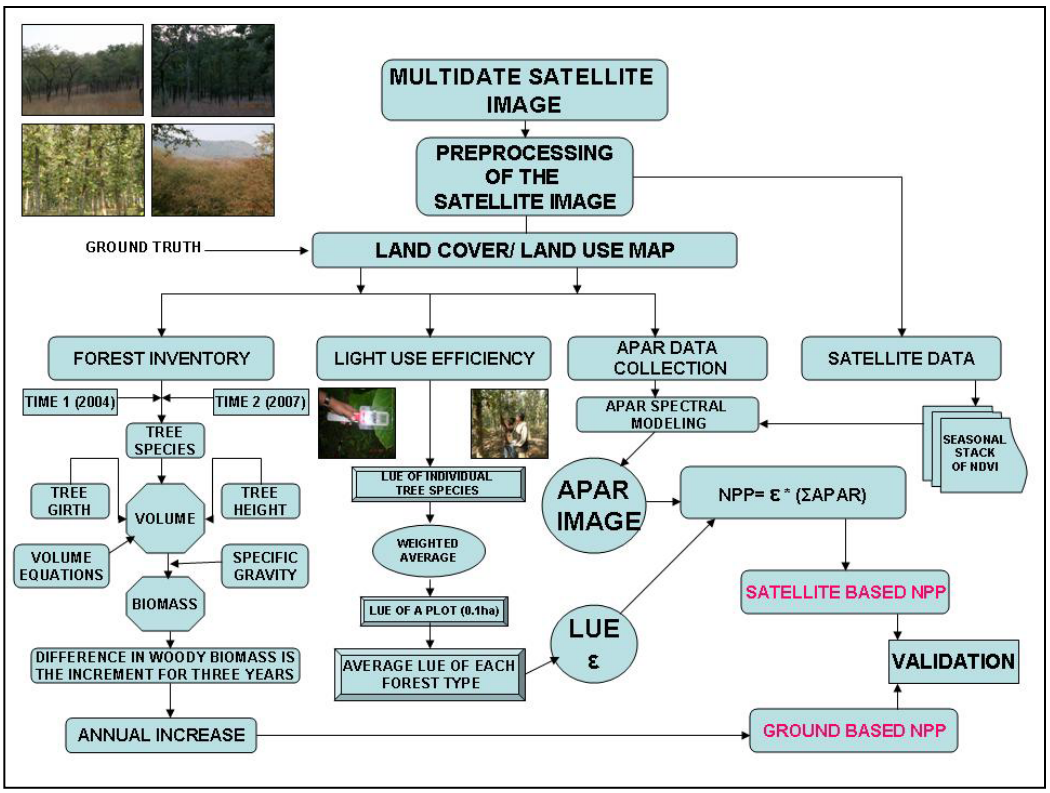

Fig. 4.6: Methodology adopted in the project.

4.4.1 Ground Data Collection

In the present study, ground data collection is broadly grouped into three major heads namely;

- ❖ Forest inventory data collection and ground data analysis.
- ❖ Tree species wise Light Use Efficiency (LUE) collection through LCi instrument and up scaling it to different forest types.
- ❖ Sample plot wise APAR value collection.

4.4.2 Forest Inventory

After finalizing the sampling strategy forest inventory work was taken up for the time-2 data collection in the field. The permanent plots laid in the year 2004 was revisited in June 2007 to record the change in tree girth and tree height and also note the physical condition of the plots. For each plot, the permanent markings were redone, Fig.4.7 and 4.8 and all the tree species lying within the plot were counted and their height and diameter at breast height were measured with the help of Blume Leiss Hypsometer and steel tapes. Apart from this GPS reading, local name of the tree species, slope, biotic and abiotic interferences were also noted. These data were documented into Microsoft Excel workbook for further calculation and analysis. The volumetric equations (Appendix-I) within the standard Forest Survey of India (FSI) book was used to attain the volume of each tree lying in a sample plot. This volume equation book takes into account the tree height and tree diameter (dbh) to calculate the tree volume of each tree. Volume thus obtained was multiplied with tree species particular specific gravity, to get the biomass of each individual tree within a plot. Specific gravity was referred from Indian Woods, volume (I-VI); this book lists the specific gravity of tree species (arranged family wise) based on the area and eco-climatic-zone (Appendix-II).

Fig. 4.7: Plots being marked

Fig. 4.8: Training field assistants

The biomass values of all trees were summed up to get the total plot wise biomass. Similarly, plot wise biomass was calculated for all the plots in the study area. The value attained is the aboveground woody biomass of the tree species. All sample plots were clubbed into different forest types and their average plot biomass was multiplied with the corresponding area to generate the forest type wise biomass map of the study area.

4.4.3 Primary Productivity Estimation

As discussed, primary production refers to all or any part of the energy fixed by the plants possessing chlorophyll. Productivity refers to the rate of production on a unit area basis. The total amount of solar energy converted into chemical energy by green plants is called Gross Primary Productivity (GPP). A certain amount of GPP is utilized by the plants for their maintenance and the remainder is called net primary productivity (NPP), which appears as the new plant biomass. The basic steps involved in Net Primary Productivity estimation at the ground level is well explained in Fig. 4.9.

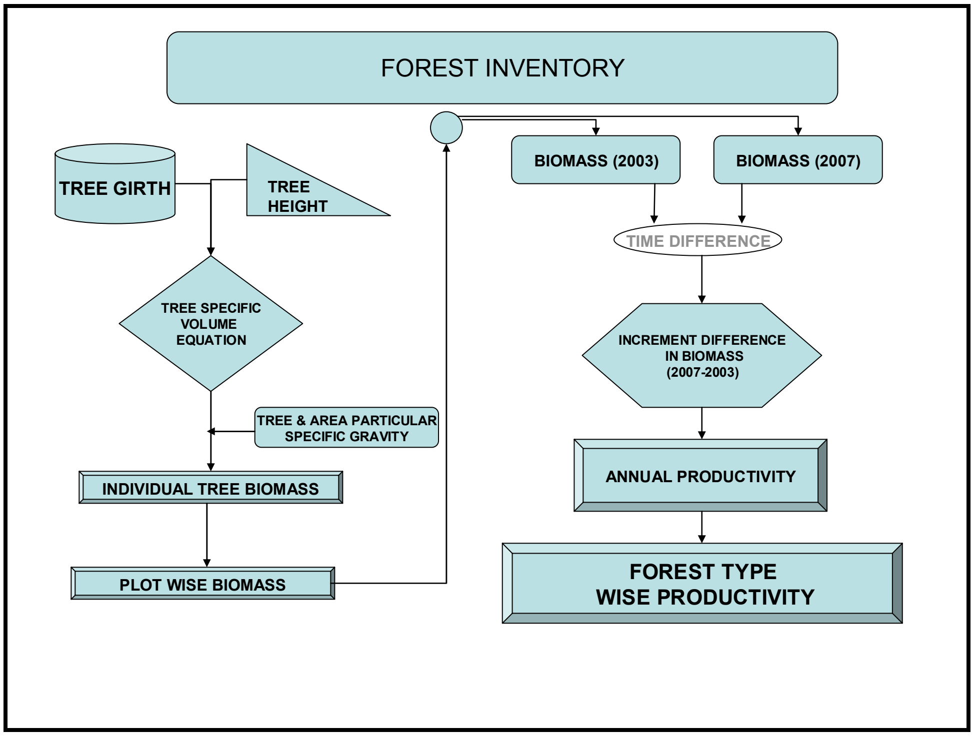

Fig. 4.9: Forest inventory methodology

Plot wise biomass of for the year 2004 and 2007 were calculated through ground based technique and the net increment/decrement in biomass (biomass value in 2004 is subtracted from biomass value for the year 2007) was noted for each plot for a given area and time. The unit for NPP is (t/ha/year) or (gm/m^2/year). This value was further averaged out according to the forest type wise, to give the annual woody increment or the NPP of the sampled area. In order to validate the ground based method and to reduce the load, expense and the effort put into the ground based method of forest inventory technique, remote sensing and GIS has come into play. This new technique requires less time and effort in the field, is more cost effective and can handle more and more data sets simultaneously at a very fast rate.

4.4.4 Light Use Efficiency

Light Use Efficiency (LUE), photosynthetic efficiency, radiation use efficiency or energy conversion efficiency is the ratio of output carbon dioxide to input Photosynthetically Active Radiation (PAR) energy. The total PAR is available during the growing season. Three field trips were made to collect ground observations. Data for CO_2 uptake measurements during the growing period (October, November) and dry season (June) was made in the field using the Leaf Chamber Infrared Gas Analyzer (LCi). Best time to take the observations is from 09:00hrs to 11:00hrs in the morning (post monsoon season). Species-wise LUE observations for each plot were made. Before taking the observations, the machine was stabilized by making the Δ c (difference in carbon dioxide) constant. A leaf was put in the chamber and the difference in carbon dioxide released and PAR falling on the same leaf was noted to generate the LUE value for that particular leaf. Observation on 6-10 leaves at different height, orientation (N, S, E, W) and light conditions for a particular tree species in a plot were made and documented. Thus all together, all species occurring in a plot were covered by this technique. Later on weighted average for all species within a plot was used to integrate the LUE values at the plot level. The LUE value obtained forest wise, was used in the Production Efficiency Model to know the Net Primary Production of the study area since LUE provides link between light harvested by the tree species and the efficiency of use of the energy in assimilation of the carbon. The steps are enumerated in Fig. 4.10.

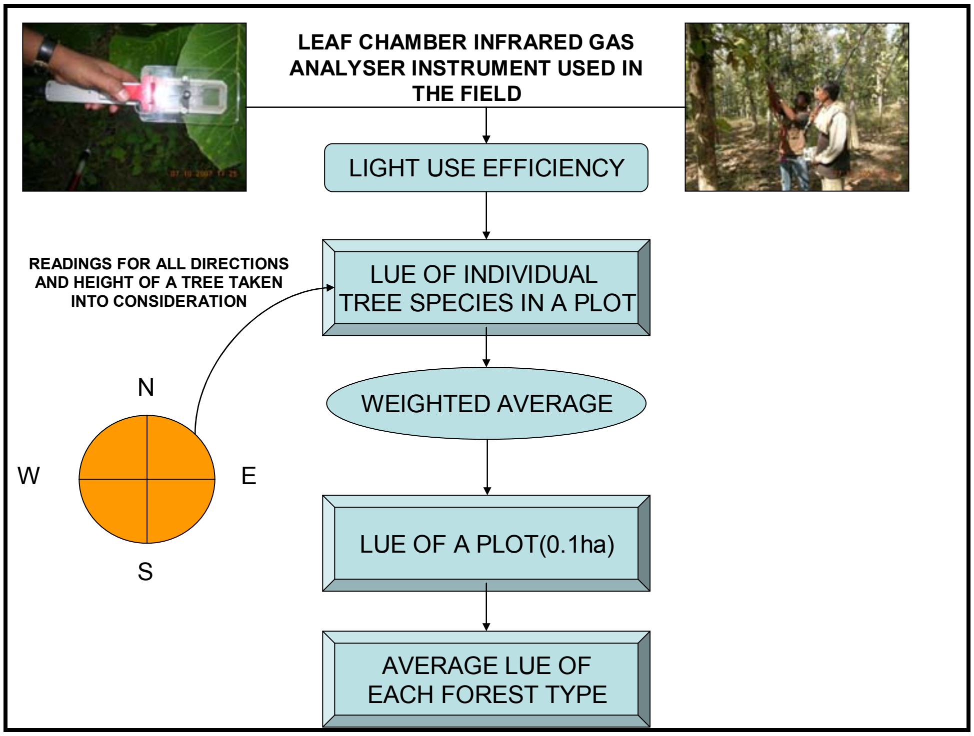

Fig. 4.10: Light Use Efficiency calculations for each forest type.

4.4.5 Absorbed Photosynthetically Active Radiation

The instrument used in the field to make observations for this purpose was Decagon's Ceptometer. This instrument measures electromagnetic radiation in the range of (0.4 -0.7 µm), which is the most active zone for vegetation features. The instrument is kept below the canopy and light reaching the ground is measured. The light (direct, diffused or transmitted) reaching on the ground is based on the canopy density and sun angle. Thus it was possible to find the Absorbed Photosynthetically Active Radiation (APAR) from the incident or the total PAR. PAR observation was made on monthly basis for the month of June, October and November (year 2007, for both the seasons) in all the permanent plots. However, reading for the senescent month of June, 2007 was not taken into consideration because of total defoliation of the leaves. Accurate measurement of PAR inside the plant canopy is a challenging task as it requires perfection in the placement of the instrument for taking the readings. Readings were taken moving diagonally in the plot and the all the readings were averaged out to achieve a single figure. It was made sure that the readings were taken on bright sunny day so as to avoid diffused light effect. Since, canopy of the study area is not very high the probability of receiving diffused light is minimized. Mathematically APAR can be represented by the following equation:

$$APAR = (I_0 + R_c) - (T_c + R_s)$$

Where, APAR = Incident PAR absorbed by the canopy,

I_0 = Incident PAR flux density,

R_c = PAR reflected from the canopy,

T_c = PAR transmitted through the canopy,

and, R_s= PAR reflected from the soil.

Since finding of R_c and R_s is difficult in forested ecosystem, APAR is denoted as the difference between Incident PAR flux density and PAR transmitted through the canopy. Incident PAR was measured in open area outside the forested area followed by the measurement of Transmitted PAR within the plot by moving diagonally in the sample plot. APAR show seasonal variation mainly due to;

I. Seasonal movement of the earth around the sun which causes the change in solar zenith angle.
II. Change in plant phenology i.e. shedding of the leaves during the senescent period and full foliage during the growing period.

4.5 Remote Sensing Data Processing

4.5.1. Radiometric Correction

Both time one (2004) and time two (2006-2007) data received underwent a systematic approach of image processing. This involved raw data import into*.img format suitable for ERDAS IMAGINE software. This imported image underwent radiometric correction followed by geometric correction. The radiometry was corrected using the dark pixel subtraction method. This technique assumes that there is a high probability of at least a few pixels within the image which should be black, i.e. with zero reflectance. However, because of atmospheric scattering, the image system records a non-zero DN value at the supposedly dark shadowed pixel location. This represents the DN value that must be subtracted from the image to remove the first order scattering component, Fig. 4.11.

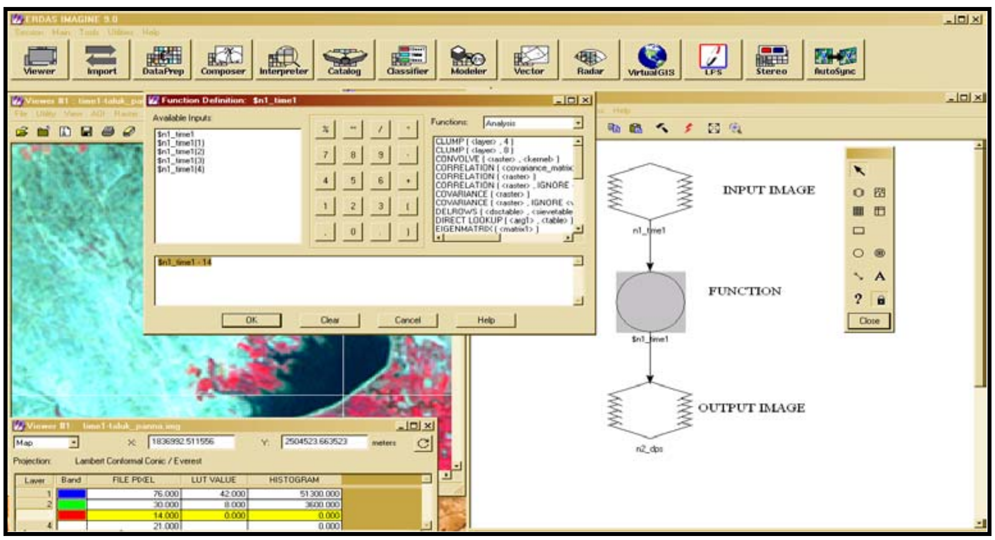

Fig. 4.11: Dark Pixel Subtraction of the image using Spatial Modeler.

Apart from this, conversion of digital numbers to ground reflectance in the solar radiation wavebands (0.4 - 3.0 μm) was achieved through radiometric conversions and atmospheric corrections. This requires the knowledge of solar exoatmospheric extra terrestrial irradiance for each wave band. Methodology adopted for the conversion of image DN value into image reflectance value was adopted according to the above given flowchart. The two basic steps include the conversion of the DN image into radiance image and this is followed by its conversion into target reflectance value image. Every raw image contains a CD information file along with P6 Super word file attached to it. This word file contains a formula and values for the conversion of the DN numbers into radiance for IRS-P6

LISS III. The formula used above is as such; RADIANCE IMAGE = {DN/ Grey $_{max}$ × (L_{max} – L_{min}) +L_{min} } where; DN is the Band wise image, Grey $_{Max}$ is 255 for corrected products and L_{max} and L_{min} values were obtained from the Leader file attached to the raw image CD. The radiance image has a unit of ($mW/cm^2/str/micrometer$), Fig. 4.14.

The radiance image obtained was later converted into reflectance image using the formula; REFLECTANCE IMAGE = [$\pi \times L \times d^2 / E_{0\,Sun} \times \cos\theta$] where, L is the band wise radiance image, d is the earth sun distance in astronomical units on the day the satellite image was taken by the sensor, $E_{0\,Sun}$ is the band wise Extra Terrestrial Solar Irradiation values and θ is the Zenith Angle which changes according to the day, time and planimetry positions. Generation of the cos θ map in itself requires a lot of inputs as the standard formula to derive a cos theta map is, $\cos\theta = \sin(\varnothing) \times \sin(\delta) + \cos(\varnothing) \times \cos(\delta) \times \cos(\omega)$ where; Ø is the Latitude map of the area, δ is the Solar Declination Angle which is converted into radians and ω is the Hour Angle Map generated using the formula; $\omega = 15\,(LAT-12) \times (\pi/180)$; unit are in Radians where again LAT is the Local Apparent Time Map, (LAT) = UTC+4 ×[(Lc/60)+(Et/60)], and UTC is the Universal Time, L_c is the Longitude Map and E_t is the standard equation of time for all the months in a year and it also has a standard graph. Methodology is demonstrated in Fig. 4.15.

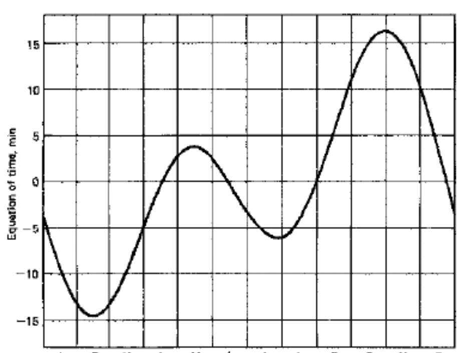

Fig. 4.12: Standard Equation of time in minutes as a function of time of year.
Source: Iqbal (1983)

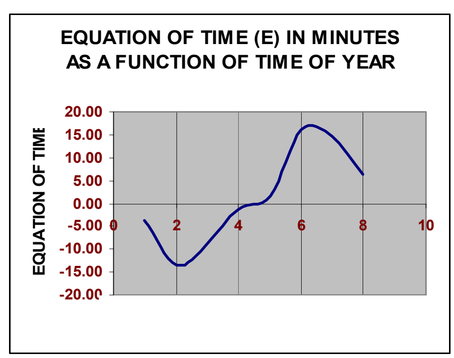

Fig. 4.13: Equation of time derived in the present study. They are in tune to the standard graph (values for the month May, June, July and August not used).

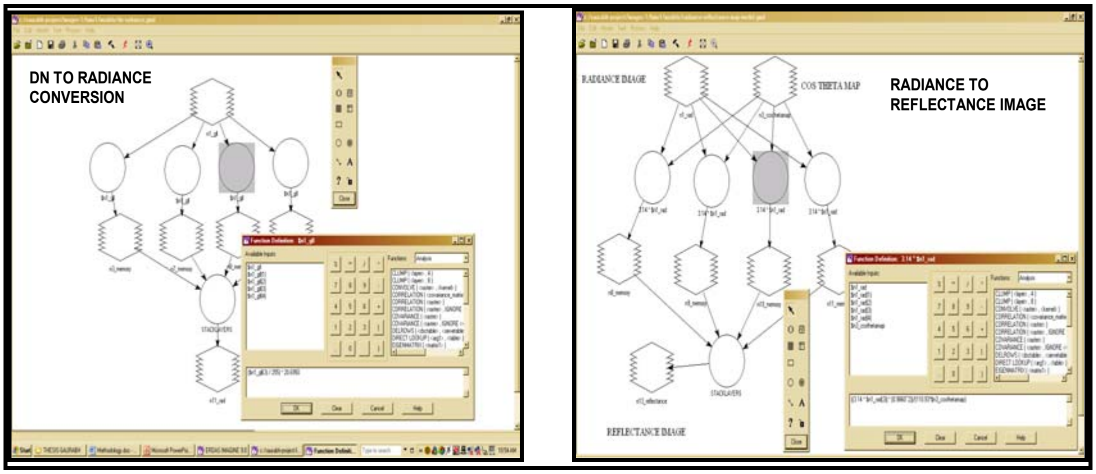

Fig. 4.14: DN to Radiance conversion and Radiance to Reflectance conversion using Spatial Modeler.

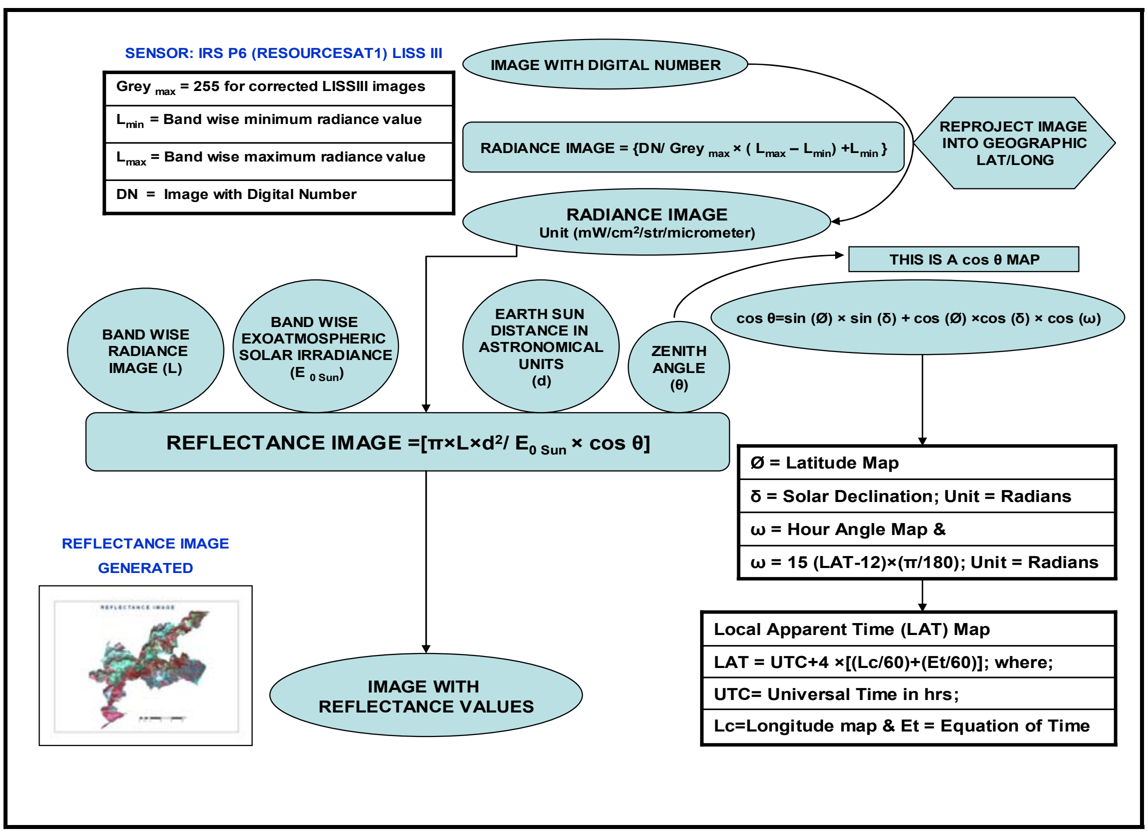

Fig. 4.15: Methodology adopted to convert DN value into reflectance value.

4.5.2. Geometric Correction

The radiometrically corrected raw image underwent image registration and georefrencing. Registration is the process, of making an image conform to another image. A map system is not necessarily involved in this process, where as georefrencing refers to the process of assigning map coordinates to the image data. In the present study one of the scene (January, 2007) was registered using Survey of India toposheets. Rest of the scenes underwent image to image registration using the January scene as the reference image and nearest neighbour with first order polynomial equation as the resampling technique. During resampling the pixel size was maintained at 25 m. The image registration was carried out with the following projection details:

Projection :	**Lambert Conformal Conic**
Spheroid :	**Everest**
Datum :	**Undefined**

Once the images are geo-referenced, vector layer of the Panna National Park boundary digitized was overlaid on the scenes and desired study area was clipped from the whole scene of LISS III.

4.6. Image Classification

Multispectral image classification is the process of sorting pixels into a finite number of individual classes or categories, based upon their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criterion. This process is also called as image segmentation. Two basic schemes adopted for image classification are unsupervised and supervised classification. Both are digital forms of image classification where spectral information contained within different bands of the image are utilized to group the pixels into similar spectral clusters.

In supervised classification, the analyst identifies in the imagery homogeneous representative samples of the different surface cover types of interest. These samples are referred to as training sites. The selection of the training site is based upon the analyst's familiarity with the geographical area and the knowledge of the terrain and features present there. The numerical information in all spectral bands for the pixels comprising these areas is used to train the computer to recognize spectrally similar areas for each class. The computer uses a special program or algorithm (of which there are several variations), to determine the numerical signatures for each training class. Once the computer has determined the signatures for each class, each pixel in the image is compared to these signatures and labeled as the class it most closely resembles digitally.

Unsupervised classification in essence reverses the supervised classification process. Spectral classes are grouped first, based solely on the numerical information in the data, and are then matched by the analyst to information classes (if possible). Programs, called clustering algorithms, are used to determine the natural (statistical) groupings or structures in the data. Usually the analyst specifies how many groups or clusters are to be looked for in the data. In addition to specifying the desired number of classes, the analyst may also specify parameters related to the separation distance among the clusters and the variation within each cluster. The final result of this iterative clustering process may result in some clusters that the analyst will want to subsequently combine, or clusters that should be broken down further - each of these requiring a further application of the clustering algorithm. Thus, unsupervised classification is not completely without human intervention. However, it does not start with a pre-determined set of classes as in a supervised classification.

In the present study unsupervised method of digital image classification was performed on multi season satellite data (both growing and senescent phase) with 500 clusters to extract maximum features on the ground with high spectral variability. The algorithm behind this classification scheme is Iterative Self Organizing Data Analysis Technique (ISODATA) clustering. ISODATA is iterative as it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. Self-Organizing refers to the way in which it locates clusters with minimum user input. The ISODATA method uses minimum spectral distance to assign a cluster for each candidate pixel. The process begins with a specified number of arbitrary cluster means or the means of existing signatures, and then it processes repetitively, so that those means shift to the means of the clusters in the data. Because the ISODATA method is iterative, it is not biased to the top of the data file.

4.6.1. ISODATA Clustering Parameters

To perform ISODATA clustering, one has to specify:

- N - The maximum number of clusters to be considered. Since each cluster is the basis for a class, this number becomes the maximum number of classes to be formed. The ISODATA process begins by determining N arbitrary cluster means. Some clusters with too few pixels can be eliminated, leaving less than N clusters.
- T - A convergence threshold, which is the maximum percentage of pixels whose class values are allowed to be unchanged between iterations.
- M - The maximum number of iterations to be performed.

4.6.2. Accuracy Assessment

Accuracy assessment is a general term for comparing the classification to geographical data set that is assumed to be true, in order to determine the accuracy of the classification procedure. In the present study, few ground truth points were considered to be true and were used as reference points to develop the accuracy report, since practically it is not possible to ground truth all the pixels lying in a classified image. It is this relationship between the remote sensing derived classification map and the reference test information, which is summarized as error matrix. An error matrix is a square array of numbers laid out in rows and columns, that expresses the number of sample units assigned to a particular category relative to the actual category as verified in the field. The columns basically represent the reference data, while the row indicates the classified map generated. This way of error report generation is very effective as it clearly describes individual categories error of inclusion (commission error) or User's accuracy and error of exclusion (omission error) or Producer's accuracy.

Apart from this Kappa Statistics of the classification was also performed to attain the measure of agreement for the classification and to incorporate the off diagonal elements as a product of row and column marginal, which is not considered in the over all accuracy assessment of the classified image.

4.7 Modeling NPP

The present study focuses on the Production Efficiency Model (PEM) to establish the net increase in the woody biomass of the Panna National Park within a gap of three years, i.e. 2007 and 2004. The most important model input is APAR, since it is best representative of vegetation parameter as it shows the vegetation dynamics in tropical dry deciduous forests in terms of radiation change. Inclusion of Light Use efficiency (LUE) or Radiation use efficiency (RUE) gives the model a more reliable touch since each species in a plot will be taken into account. A weighted average is generated to estimate the light conversion efficiency, which is further scaled up to forest type wise light use efficiency.

Monteith (1977) showed that crop productivity is linearly proportional to intercepted solar radiation and this has been confirmed for a number of tree strands (e.g., Linder, 1985; Wang *et al*., 1991; Runyon *et al*., 1994). Utilizing the Monteith relationship, empirical models have been developed to compute the plant productivity from intercepted solar radiation to provide the regional estimates of NPP directly (Ruimy *et al*., 1994; Landsberg *et al*., 1996) i.e., NPP as a function of Light use Efficiency and Absorbed Photosynthetically Active Radiation as; $NPP = \varepsilon \times \sum APAR$ (Monteith 1977).

Multi date satellite data for the growing and the senescent season was taken into consideration and different NDVI image forms like month wise NDVI, Average NDVI and $\sum$ NDVI image was generated for the study area. The best R^2 value was used and its equation was utilized for the generation of APAR map of the study area. This APAR map generated was a direct input for the PEM where, LUE for different forest type was the other. The product of these two maps yielded estimates of NPP for the forest region.

Later on a comparative study was performed on the results we received both through direct ground based technique and remote sensing based technique. All these studies show that NPP is a long term cumulative net flux of carbon in vegetation, and is difficult to measure directly at any scale. NPP estimates must therefore rely on indirect measurements combined with models that relate these measurements to the overall flux.

4.8 Estimating Turn Over rate and Turn Over Time

Measuring the rate at which biomass of a given component is replaced is helpful to the scientific community. The rate of substitution of a component or a substance from a system is referred to as the turnover rate. Mathematically turnover rate is the ratio of production to biomass (P/B). The most dynamic components of the ecosystem have a faster turnover rate. In the present study, turnover rate of boles for different forest types have been calculated. Studies related to the turnover rate yields turnover time, which is the reciprocal of turnover rate and an indicator of residence time or transit time of a given element in a component. By residence time one refers to the time a given amount of substance remains in a designated compartment (tree trunk, leaves and root) of a given substance. Studies related to turnover rate (P/B) ratio indicates that for phytoplankton's the P/B ratio varies from 20 – 40 and their turnover time from 0.05 – 0.025 years or (9 – 10) days. High P/B ratio indicates great energy availability to the herbivores. Low turnover rate or P/B ratio indicates extensive development of the supporting tissues in the forest, thereby meaning greater longevity and larger accumulation of the biomass.

Chapter 5

Results and Discussion

5.1 Vegetation Cover Type and Land Use Classification

Multi date and multi season satellite data were used to generate a vegetation cover type and land use classification map of the Panna National Park, Panna district. This approach of image classification helped in retrieving maximum features on the ground in the best possible manner. All together, five hundred clusters were taken for unsupervised image classification, of which seventeen classes have been identified, Fig. 5.1. Moist Mixed Deciduous forest covers maximum area of 101.65 km^2, followed by 76.39 km^2 by Dry Mixed Deciduous forest. Moist Teak forest and Dry Teak forest cover 36.14 km^2 and 31.49 km^2 respectively. *Anogeissus*, *Acacia* and *Boswellia* forest covers 15.12 km^2, 13.99 km^2 and 6.05 km^2 of the Panna National Park respectively (Table 5.1). Degraded forest covers nearly 18.4 km^2 of the area due to biotic pressure from the villages inside the park, Fig. 5.2. The other major classes include Riverine forest along the rocky seasonal streams, mostly covered by *Terminalia arjuna*, Acacia Savannah, Grassland, Scrub land, occupied by the alien weed *Lantana camara* along the road sides and along the fringes of the villages within the park. Apart form this other land use classes found within the park includes, settlements in the form of villages, agriculture/ fallow land and water bodies in the form of river, check dam for seasonal streams and artificial ponds.

The bench topography of Panna National Park harbors, both dry and moist teak forests. The chief tree species are Teak, Kardahi, Khair, Salai and a host of *Euphorbia* species. The flat terraces separated with high or low slopes, varying in gradient from gentle to steep or precipitous slopes. Flat table tops generally have open forest with different variety of grasses, where as slopes are generally covered with moist teak forest and bamboo brakes. Certain tree species like *Boswellia* and *Anogeissus* occur in certain edaphic conditions.

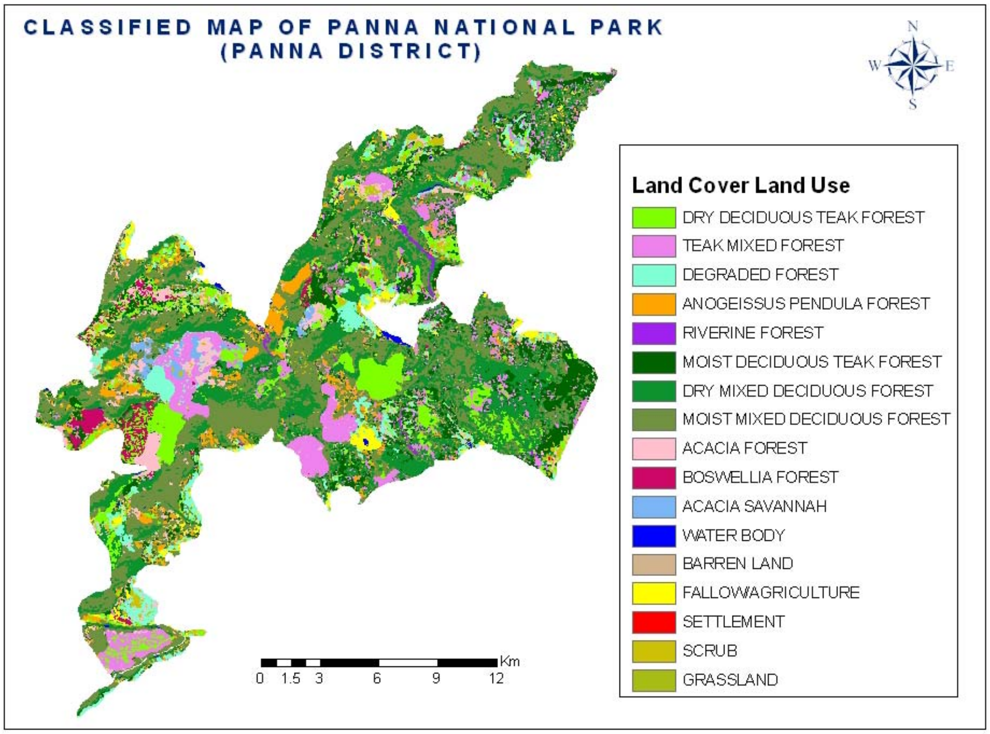

Fig. 5.1: Classified map of Panna National Park, Panna District.

Table 5.1: Area distribution of Land Cover Land Use classes

Land Cover Land Use Classes	Area(km^2)	Percentage
Moist Mixed Deciduous Forest	101.65	28.97
Dry Mixed Deciduous Forest	76.39	21.77
Moist Deciduous Teak Forest	36.14	10.30
Teak Mixed Forest	32.61	9.30
Dry Deciduous Teak Forest	31.49	8.98
Degraded Forest	18.44	5.25
Anogeissus Pendula Forest	15.13	4.31
Acacia Forest	14.00	3.99
Fallow/Agriculture	8.72	2.49
Boswellia Forest	6.06	1.73
Scrub	4.43	1.26
Acacia Savannah	2.99	0.85
Riverine Forest	1.18	0.34
Water Body	1.11	0.32
Grassland	0.21	0.06
Barren Land	0.18	0.05
Settlement	0.13	0.04

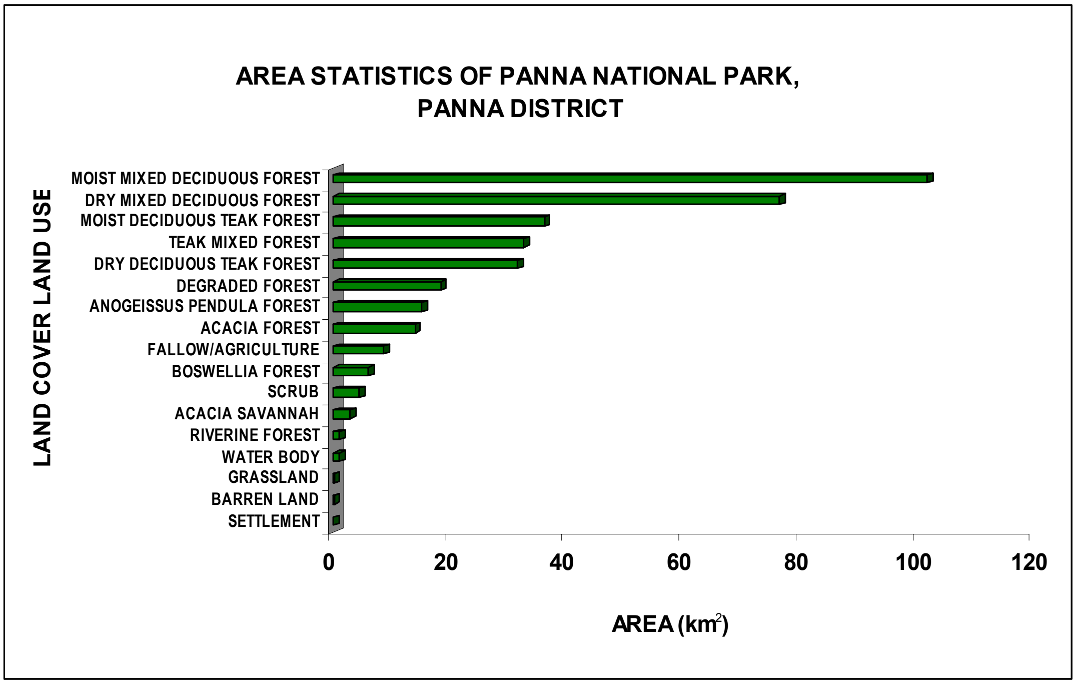

Fig. 5.2: Graph depicting area statistics of Panna National Park, Panna District.

5.2 Accuracy Assessment of the classified image

Accuracy assessment is basically performed by comparing the two source of information (Jensen, 1996) one being the remote sensing derived classification data and the other being the reference data. In this study, unsupervised classification approach has been performed on stacked multi season data to generate a classified map. The reference information is the sample plots along with some ground control points taken during the field work.

The relationship between these two yields an error matrix which is used to calculate the overall accuracy of the classification. In this study, the overall accuracy achieved was 82.35%. The table given below (Table no. 5.2) explains forest type wise User and Producer's accuracy achieved. Along with this Kappa statistics of the classified image was generated where the Kappa Coefficient for the image classified was 0.7981.

Table 5.2: Classification accuracy assessment report

Class	Reference	Classified	Number	Producers	Users
Name	Totals	Totals	Correct	Accuracy	Accuracy
Moist Deciduous Teak Forest	3	3	2	66.67%	66.67%
Teak Mixed Forest	3	3	2	66.67%	66.67%
Dry Deciduous Teak Forest	7	5	5	71.43%	100.00%
Degraded Forest	4	4	3	75.00%	75.00%
Dry Mixed Deciduous Forest	9	9	8	88.89%	88.89%
Acacia Forest	1	1	1	100.00%	100.00%
Anogeissus Pendula Forest	1	1	1	100.00%	100.00%
Boswellia Forest	1	1	1	100.00%	100.00%
Moist Mixed Deciduous Forest	3	5	3	100.00%	60.00%
Riverine Forest	1	1	1	100.00%	100.00%
Totals	34	34	28		
Overall Accuracy = 82.35 %					

5.3 Biomass Estimation for the year 2004

Plot details of all the 34 plots were entered in the digital database and calculation of volume and biomass was done. In a plot individual tree height, girth at breast height, and tree specific volume equations were used to calculate the volume of individual trees. This volume was further multiplied with specific gravity of tree species to get the biomass of an individual tree. Later, the plot data on biomass was summed up to generate a plot biomass for the above ground tree part (mainly tree trunk and branches up till 10 cm diameter). Readings for the year 2004 showed variation from 114.48 t/ha in Riverine forest to 2.03 t/ha in the open scrub land of the Panna National Park. High biomass was reported from Riverine forest due to the presence of *Terminalia arjuna* tree which are huge and have an average girth of two meters, Table 5.3.

Table 5.3: Plot details for the year 2004, Panna National Park, Panna District

PLOT NO.	FOREST TYPE	Biomass (t/0.1ha) (2004)	Biomass (t/ha) 2004
1	Dry Deciduous Teak Forest	1.78	17.77
2	Dry Deciduous Teak Forest	1.07	10.66
3	Teak Mixed Forest	2.07	20.71
4	Teak Mixed Forest	3.07	30.74
5	Degraded Forest	1.46	14.58
6	Scrub	0.20	2.03
7	Anogeissus pendula Forest	4.19	41.89
8	Riverine Forest	11.45	114.48
9	Anogeissus pendula Forest	2.47	24.66
10	Teak Mixed Forest	5.04	50.41
11	Dry Deciduous Teak Forest	2.49	24.91
12	Moist Deciduous Teak Forest	1.65	16.55
13	Dry Mixed Deciduous Forest	2.25	22.48
14	Moist Mixed Deciduous Forest	3.57	35.73
15	Teak Mixed Forest	2.59	25.89
16	Moist Mixed Deciduous Forest	1.68	16.79
17	Dry Deciduous Teak Forest	1.31	13.15
18	Dry Mixed Deciduous Forest	2.49	24.91
19	Dry Mixed Deciduous Forest	4.89	48.90
20	Moist Mixed Deciduous Forest	4.64	46.40
21	Teak Mixed Forest	1.36	13.62
22	Dry Deciduous Teak Forest	2.71	27.06
23	Dry Deciduous Teak Forest	1.75	17.48
24	Acacia Forest	1.62	16.22
25	Dry Mixed Deciduous Forest	2.49	24.94
26	Dry Mixed Deciduous Forest	3.52	35.25
27	Moist Deciduous Teak Forest	3.70	37.02
28	Moist Deciduous Teak Forest	5.06	50.62
29	Dry Mixed Deciduous Forest	1.28	12.81
30	Dry Mixed Deciduous Forest	3.80	37.98
31	Teak Mixed Forest	3.72	37.16
32	Boswellia Forest	3.57	35.75
33	Acacia Forest	1.15	11.49
34	Degraded Forest	0.88	8.84

5.4 Biomass estimation for the year 2007

Plots sampled in the year 2004 (March-April) were revisited after a gap of three years in June, 2007. All the 34 plots were marked well for easy identification during consecutive field studies in the month of October and November - December, Table. 5.4.

Table 5.4: Plot details for the year 2007, Panna National Park, Panna District

PLOT NO.	FOREST TYPE	Biomass (t/0.1ha) (2007)	Biomass (t/ha) (2007)
1	Dry Deciduous Teak Forest	2.36	23.63
2	Dry Deciduous Teak Forest	1.46	14.55
3	Teak Mixed Forest	4.19	41.89
4	Teak Mixed Forest	4.95	49.51
5	Degraded Forest	1.76	17.59
6	Scrub	0.29	2.90
7	Anogeissus pendula Forest	4.46	44.56
8	Riverine Forest	12.40	123.95
9	Anogeissus pendula Forest	2.63	26.32
10	Teak Mixed Forest	5.54	55.38
11	Dry Deciduous Teak Forest	3.10	30.99
12	Moist Deciduous Teak Forest	1.94	19.40
13	Dry Mixed Deciduous Forest	2.95	29.46
14	Moist Mixed Deciduous Forest	2.80	27.96
15	Teak Mixed Forest	2.99	29.94
16	Moist Mixed Deciduous Forest	3.30	33.01
17	Dry Deciduous Teak Forest	1.32	13.21
18	Dry Mixed Deciduous Forest	2.78	27.85
19	Dry Mixed Deciduous Forest	7.26	72.61
20	Moist Mixed Deciduous Forest	5.24	52.42
21	Teak Mixed Forest	2.03	20.26
22	Dry Deciduous Teak Forest	3.45	34.49
23	Dry Deciduous Teak Forest	2.25	22.53
24	Acacia Forest	2.85	28.51
25	Dry Mixed Deciduous Forest	2.71	27.09
26	Dry Mixed Deciduous Forest	4.21	42.11
27	Moist Deciduous Teak Forest	3.81	38.06
28	Moist Deciduous Teak Forest	5.13	51.31
29	Dry Mixed Deciduous Forest	1.65	16.46
30	Dry Mixed Deciduous Forest	6.57	65.65
31	Teak Mixed Forest	4.90	48.99
32	Boswellia Forest	3.79	37.91
33	Acacia Forest	2.21	22.06
34	Degraded Forest	1.69	16.95

Among all the plots, Riverine forest showed the maximum above ground biomass of 123.95 t/ha, whereas, scrub had a biomass of 2.90 t/ha. All 34 sample plots were then brought under ten major forest types; Moist Teak forest, Moist Mixed Deciduous forest, Dry Deciduous Teak forest, Teak Mixed forest, *Boswellia* forest, *Acacia* forest, *Anogeissus pendula* forest, Riverine forest, Degraded forest and the Scrub. Readings for the year 2007, revealed an increase in the biomass of the tree species. This increase in the biomass can be attributed to the fact that the area is a protected area and is devoid of high anthropogenic disturbances as compared to the non protected forest areas.

On the basis of above observations for time one and time two, all the 34 plots were clubbed to generate average forest type wise biomass, Table 5.5. These values were multiplied with the area covered by each of these forest types to generate biomass map of the Panna National Park for the year 2004 and 2007 respectively, Fig. 5.3.

Table 5.5: Forest type - wise average biomass for the year 2004 and 2007.

Sl. No.	FOREST TYPE	Average Biomass (t/ha) 2004	Average Biomass (t/ha) 2007
1	Acacia Forest	13.85	25.28
2	Anogeissus pendula Forest	33.27	35.44
3	Boswellia Forest	35.75	37.96
4	Degraded Forest	11.71	17.27
5	Dry Deciduous Teak Forest	21.29	29.30
6	Dry Mixed Deciduous Forest	28.21	35.93
7	Moist Deciduous Teak Forest	34.73	36.26
8	Moist Mixed Deciduous Forest	32.97	41.13
9	Riverine	114.48	123.95
10	Scrub	2.03	2.90
11	Teak Mixed Forest	29.76	41.00

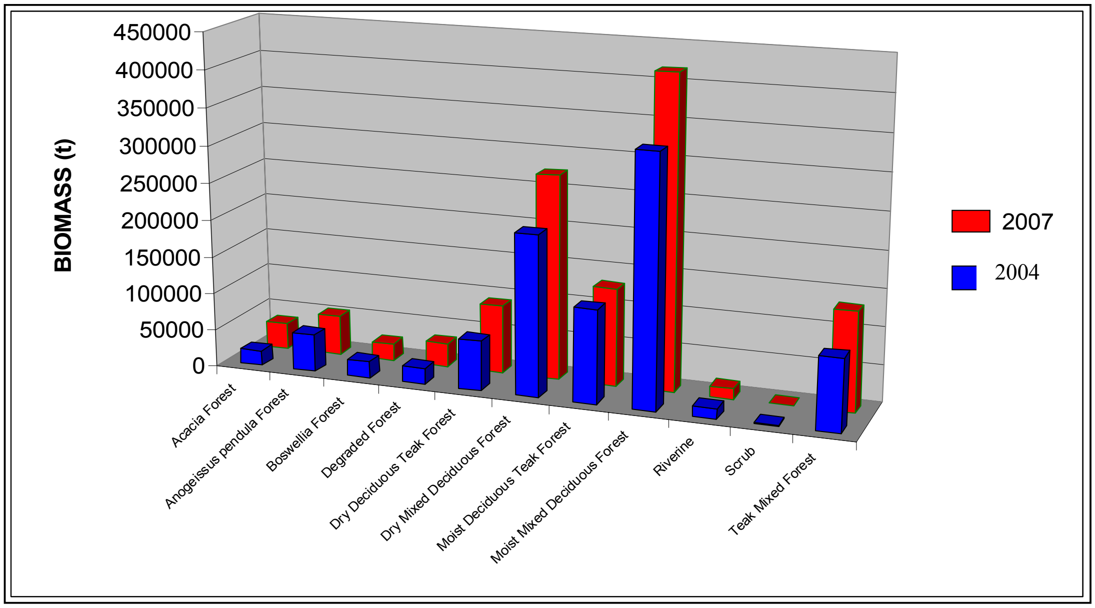

Fig. 5.3: Total Forest above ground biomass for the year 2007 and 2004, in Panna National Park

Table 5.6: Forest type wise total biomass of Panna National Park.

Sl. No.	FOREST TYPE	Total Biomass 2004 (t)	Total Biomass 2007 (t)
1	Acacia Forest	19386.30	35385.71
2	Anogeissus pendula Forest	50334.86	53610.00
3	Boswellia Forest	21645.88	22988.42
4	Degraded Forest	21587.18	31836.67
5	Dry Deciduous Teak Forest	67037.42	92261.59
6	Dry Mixed Deciduous Forest	215540.09	274478.22
7	Moist Deciduous Teak Forest	125517.70	131042.63
8	Moist Mixed Deciduous Forest	335193.79	418112.58
9	Riverine	13523.42	14641.63
10	Scrub	898.21	1285.18
11	Teak Mixed Forest	97043.50	133701.16
	TOTAL	967708.36(t)	1209343.80(t)

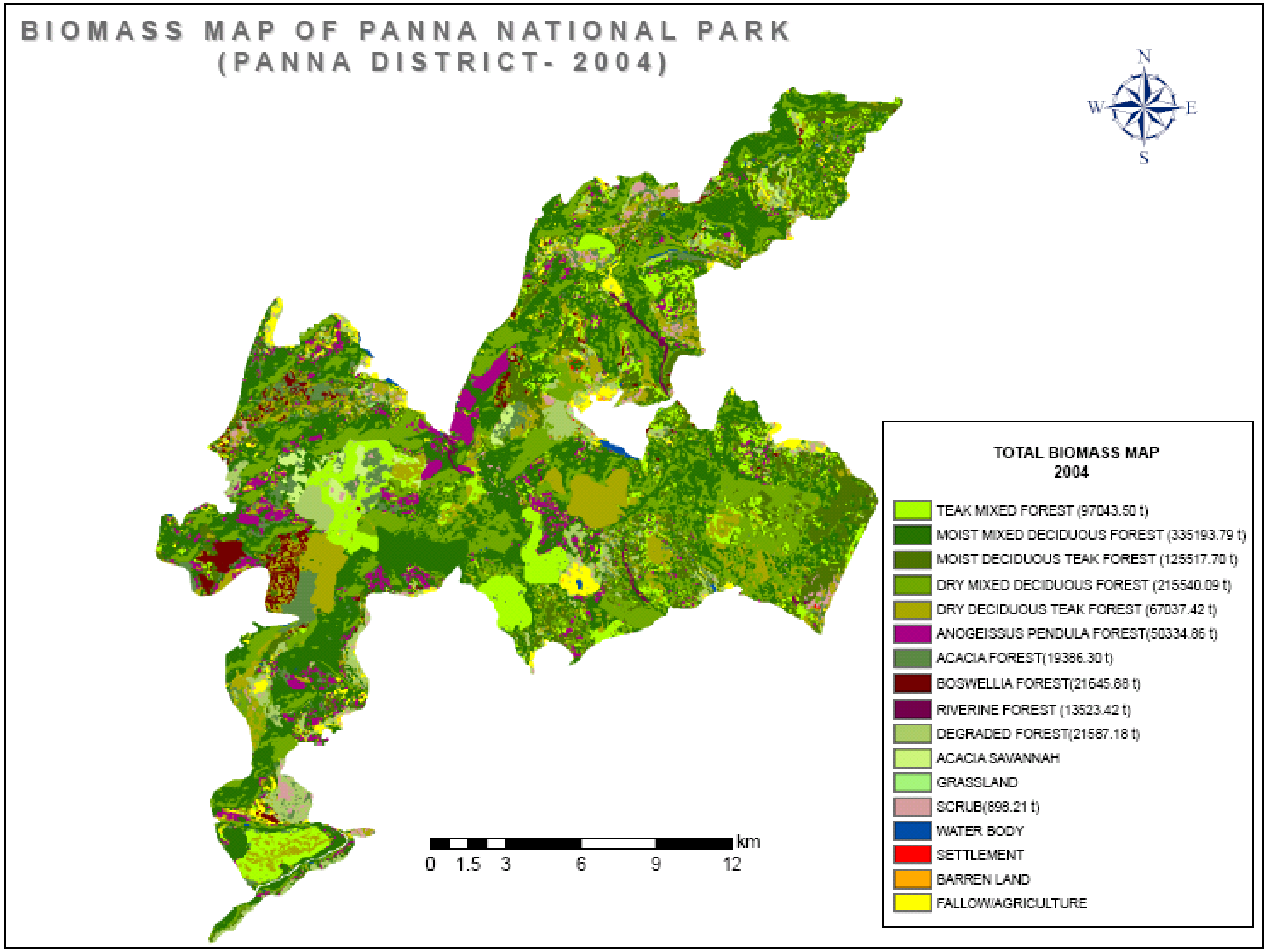

Fig. 5.4 : Biomass Map of Panna National Park, Panna District – 2004

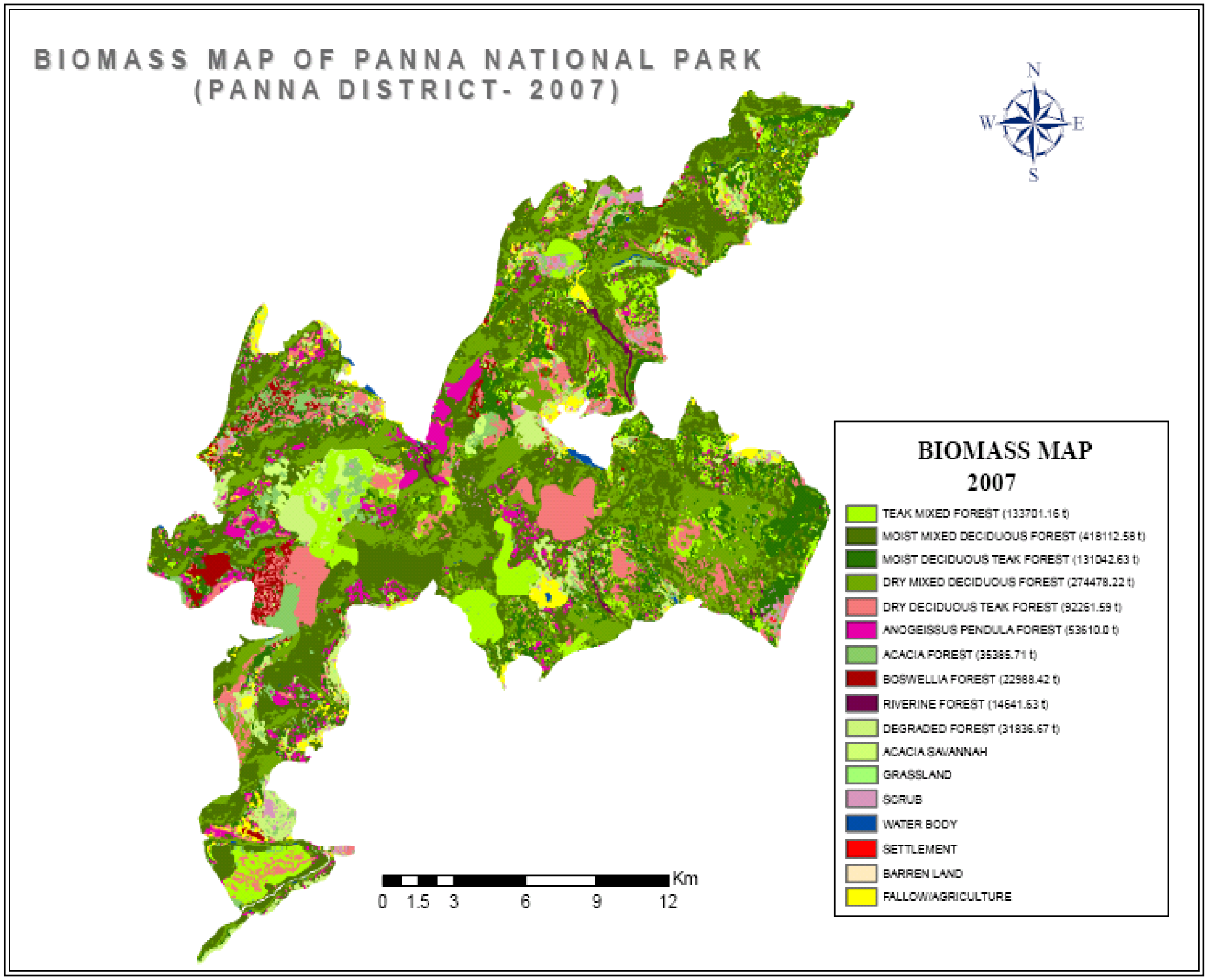

Fig. 5.5 : Biomass Map of Panna National Park, Panna District - 2007

The total biomass recorded in the year 2004 was 967708.36 tons (t), of which Moist Mixed Deciduous forest had maximum biomass of 335193.79t followed by Dry Mixed Deciduous forest at 215540.09t.Teak Mixed and Dry Deciduous Teak forest reported, 97043.50t and 67037.40t of woody biomass. *Acacia*, *Anogeissus* and *Boswellia* forest reported 19386.30t, 50334.86t and 21645.88t respectively. Although Riverine forest covered an area of 1.18km^2 only within the park, its biomass content was as high as 13523.42t, Table 5.6.

Similarly, the total woody biomass recorded in Panna National Park, Panna district, for the year 2007 was 1209343.80t. Here again Moist Mixed Deciduous forest had the maximum biomass of 418112.58t followed by 274487.22t in Dry Mixed Deciduous forest. Further, 133701.16t and 92261.59t of biomass has been found in Teak Mixed forest and Dry Deciduous forest. *Acacia*, *Anogeissus* and *Boswellia* forest recorded 35385.71t, 53610.0t and 22988.42t of woody biomass for the year 2007. Riverine forest shows a comparatively less increase in biomass; this may be due to the fact that the trees found there are almost matured enough to show any considerable growth in a span of three years.

5.5 Remote Sensing Derived Predicted Biomass Map

Remote sensing based satellite image provides vital clue in studies related to the physical properties of vegetation like biomass and non-physical quantity like productivity and annual woody increment. In the present study, multi – season satellite image of IRS P6 LISS III, for the year 2007 was used to generate Normalized Difference Vegetation Index map (NDVI). This NDVI map was generated by converting the digital number of the image into target reflectance. Later on the ground based biomass values were correlated with the satellite derived NDVI image and using spectral modeling a biomass map of the study area was generated. The coefficient of determination (R^2) between NDVI image points and the ground based biomass value was 0.7603 (number of samples was

33), and a linear equation derived through this was; $y = 9.5763x - 1.9866$, Fig. 5.6. Equation thus attained was used to generate biomass map of the study area. In the above equation, gradient, constants and NDVI image as 'x' was used generate the biomass map of the study area using Spatial Modeler of ERDAS Imagine.

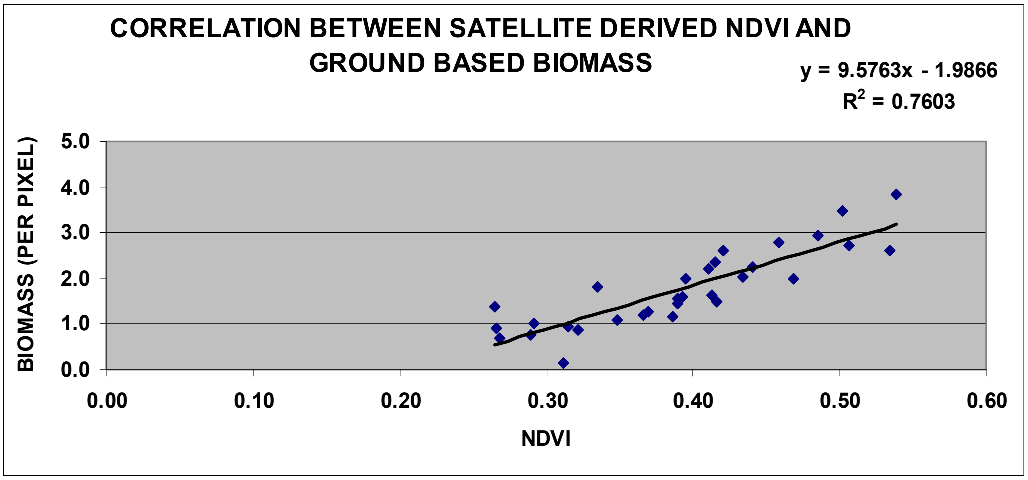

Fig. 5.6: Graph showing correlation between satellite derived NDVI image and ground based biomass calibrated to pixel size.

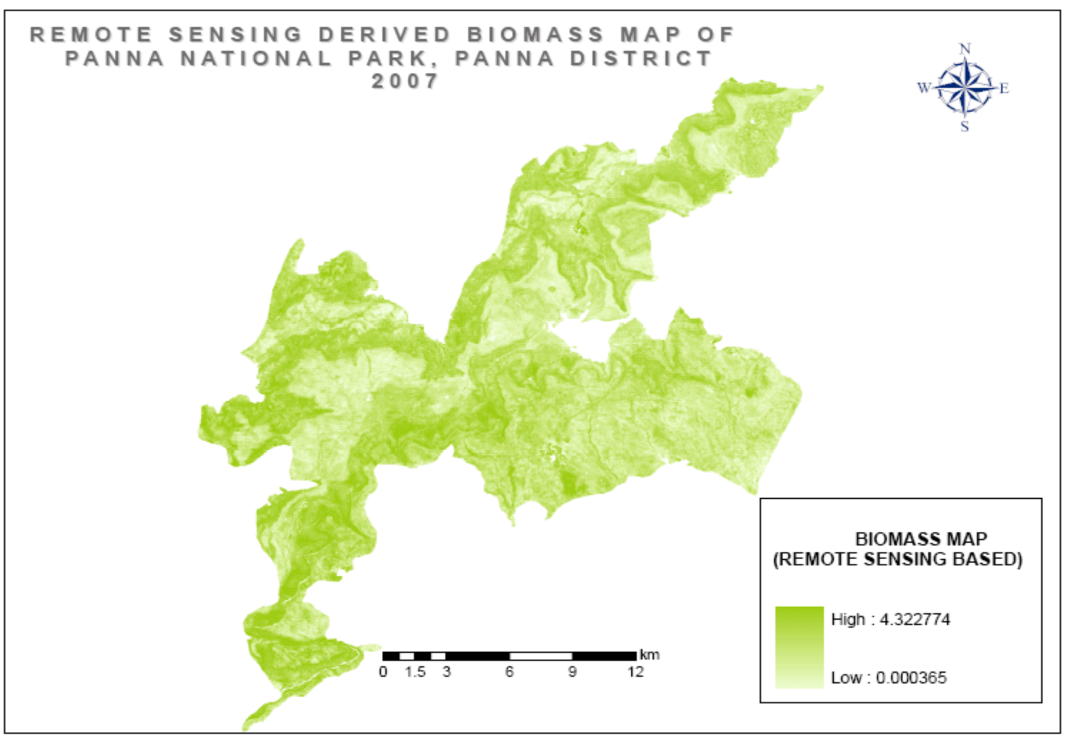

Fig. 5.7: Remote sensing and spectral modeling based Biomass map of Panna National Park, Panna District.

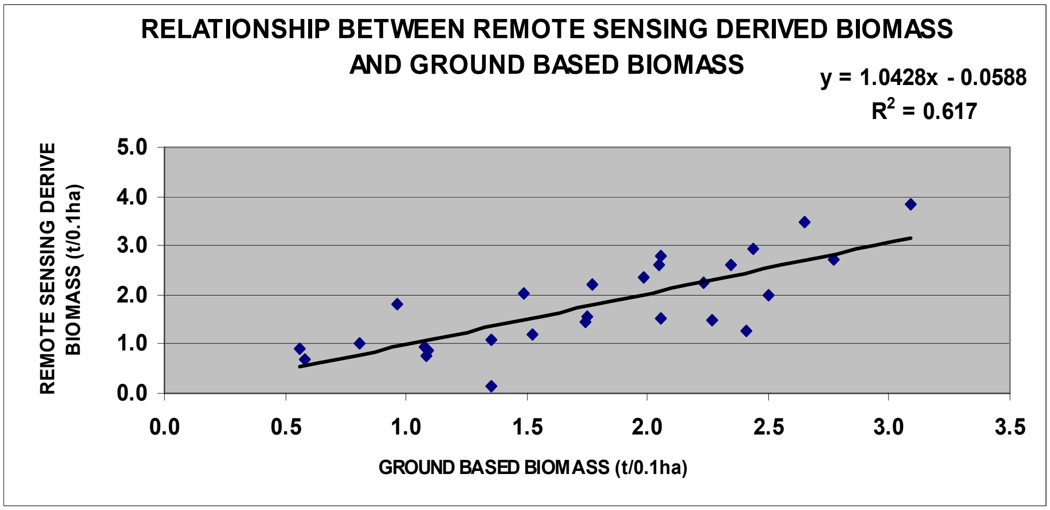

Fig. 5.8: Graph showing relationship between remote sensing derived biomass and ground based biomass (n=27).

The Biomass map generated through remote sensing was validated using the ground results. The biomass map ranged from 4.32 tons per pixel size to 0.000365 tons per pixel size (25×25 m), whereas the ground based result showed a range of 4.8 tons per pixel size to 0.15368 tons per pixel size, Fig. 5.7. The correlation between both these data showed a linear relationship with a R^2 value of 0.617, (n=27), Fig. 5.8.

5.6 Carbon Estimation

Studies related to growing stock and biomass have reveled that biomass has a direct relationship with the amount of carbon present in it. Westlake, 1963 had reported that there is 47% carbon present in the dry biomass. According to the Inter– Governmental Panel on Climate Change (IPCC, 1995), the total amount of carbon present in the biomass is about 45%. Following the Westlake's estimation, the average carbon content of different forest type was calculated for the year 2004 and 2007. This is reproduced in the table number 5.7.

Table 5.7: Forest type - wise average Carbon content (t C/ha)

Sl. No.	FOREST TYPE	Carbon (t C/ha) 2004	Carbon (t C/ha) 2007
1	Acacia Forest	6.51	11.88
2	Anogeissus pendula Forest	15.64	16.65
3	Boswellia Forest	16.80	17.84
4	Degraded Forest	5.50	8.12
5	Dry Deciduous Teak Forest	10.00	13.77
6	Dry Mixed Deciduous Forest	13.26	16.89
7	Moist Deciduous Teak Forest	16.32	17.04
8	Moist Mixed Deciduous Forest	15.50	19.33
9	Riverine	53.81	58.26
10	Scrub	0.95	1.36
11	Teak Mixed Forest	13.99	19.27

The table 5.7 shows that Riverine forest has the highest carbon content of 58.26 and 53.81 tons per hectare for the year 2007 and 2004 respectively. Scrub areas had the lowest carbon content of 1.36 and 0.95 t C/ha. Teak Mixed forest and Moist Mixed Deciduous Forest recorded 19.27 and 17.04 t C/ha for the year 2007 and 13.99 and 16.32 t C/ha for the year 2004. *Boswellia*, *Anogeissus pendula* and *Acacia* forest recorded 17.84, 16.65 and 11.88 t C/ha for the year 2007 and 16.80, 15.64 and 6.51 t C/ha for the year 2004 respectively.

Apart from this the area covered by each of these forest types in the Panna National Park was used to calculate the total amount of carbon present in different forest types, Table 5.8 and Fig. 5.9 and carbon maps for 2004 and 2007 was prepared, Fig. 5.10 and 5.11, respectively.

Table 5.8: Total Carbon present in different forest type of the Panna National Park

Sl. No.	FOREST TYPE	Carbon 2007 (t)C	Carbon 2004 (t)C
1	Acacia Forest	16631.28	9111.56
2	Anogeissus pendula Forest	25196.70	23657.39
3	Boswellia Forest	10804.56	10173.56
4	Degraded Forest	14963.23	10145.98
5	Dry Deciduous Teak Forest	43362.95	31507.59
6	Dry Mixed Deciduous Forest	129004.77	101303.84
7	Moist Deciduous Teak Forest	61590.04	58993.32
8	Moist Mixed Deciduous Forest	196512.91	157541.08
9	Riverine	6881.56	6356.01
10	Scrub	604.04	422.16
11	Teak Mixed Forest	62839.55	45610.44

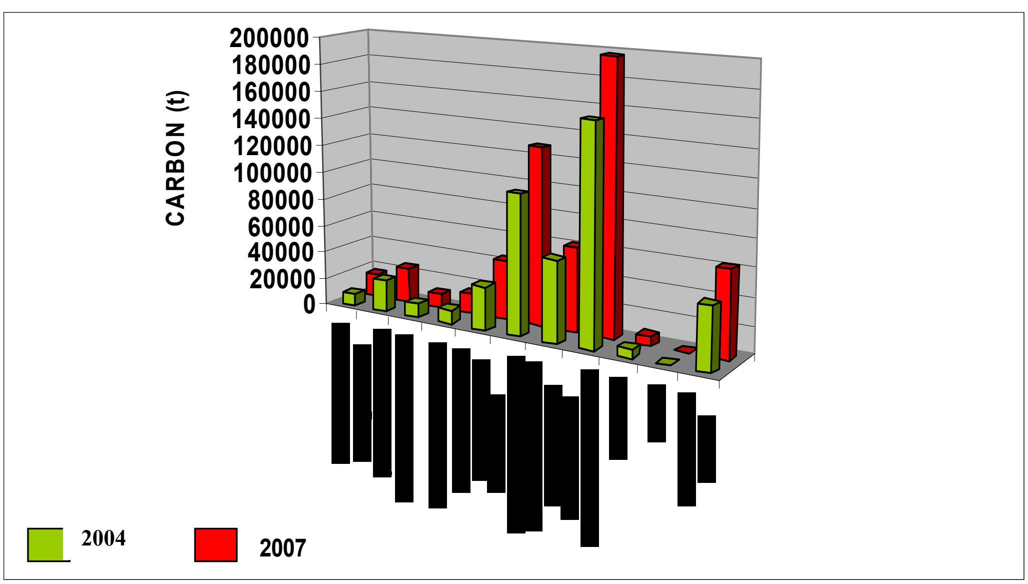

Fig. 5.9: Forest type wise total carbon content in Panna National Park for the year 2004 and 2007 respectively.

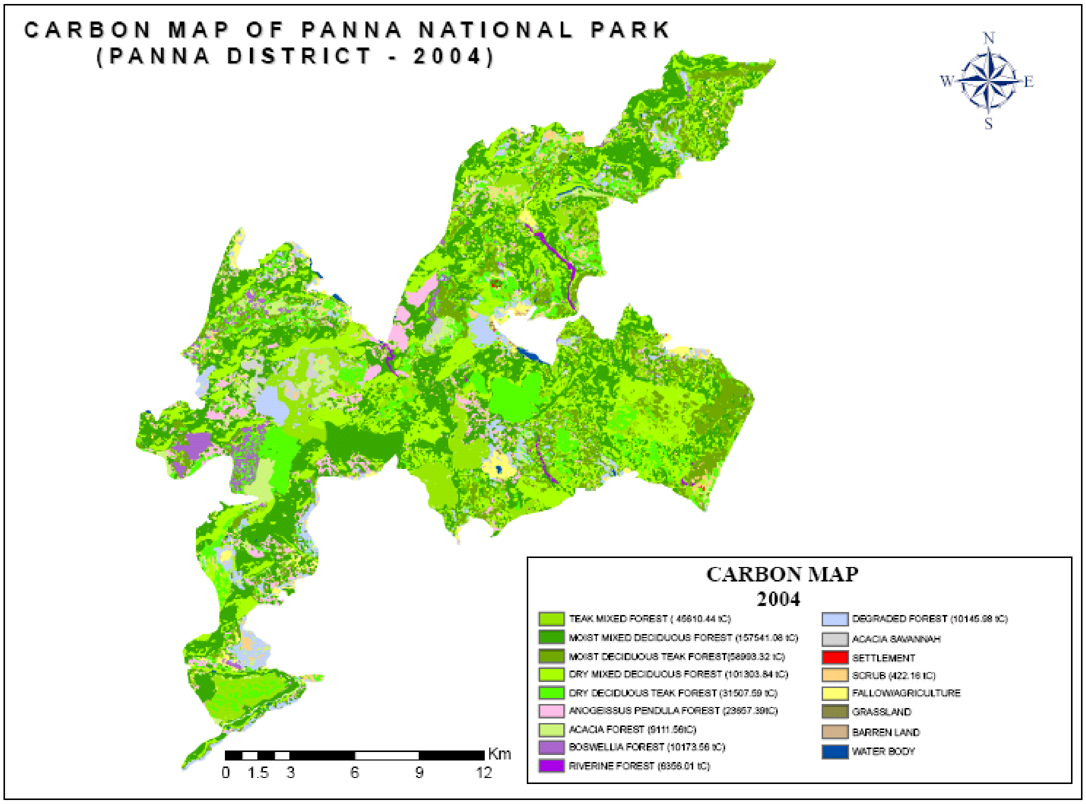

Fig. 5.10: Forest Carbon Map of Panna National, 2004.

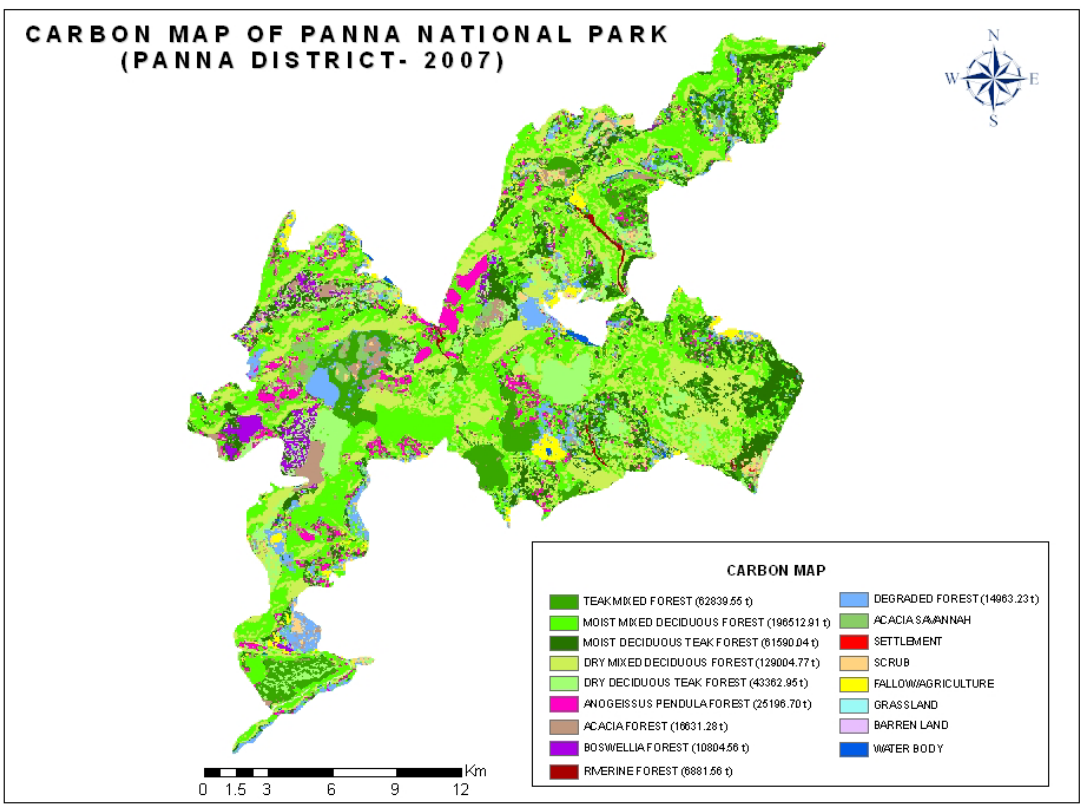

Fig. 5.11: Forest Carbon Map of Panna National, 2007.

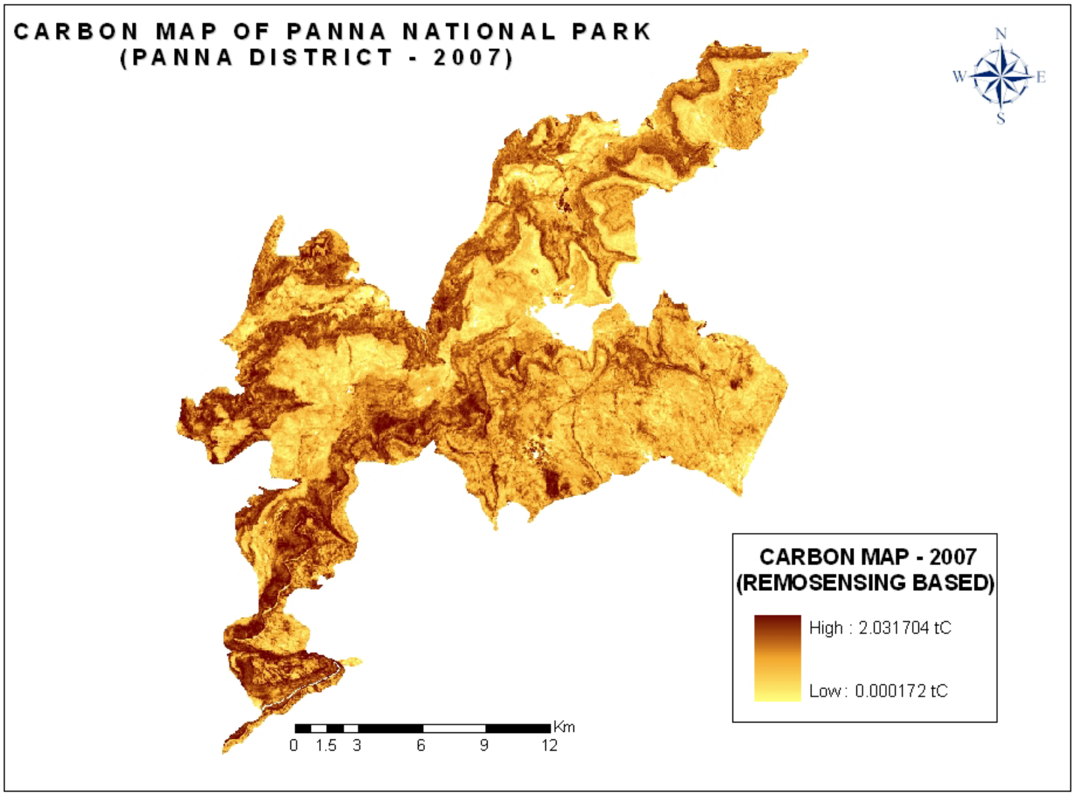

Fig. 5.12: Forest Carbon Map of Panna National Park, based on Remote Sensing data

5.7 Remote sensing based Predicted Carbon Map

The biomass map produced above through remote sensing was used to generate a carbon map of the park. As already mentioned carbon constitutes about 47% of biomass (Westlake, 1963), hence this information was used to further calculate the carbon content of Panna National Park. The above given map depicts the carbon content present in different areas of the Panna National Park. It ranges from 2.031 t C $ha^{-1}year^{-1}$ to 0.000172 t C $ha^{-1}year^{-1}$, Fig. 5.12. The high carbon contained area includes the Moist Mixed deciduous forest, Dry Mixed Deciduous Forest, Dry Teak Forest of the park.

5.8 Carbon Sequestration

Carbon sequestration on an annual basis for the Panna National Park was made by subtracting the average forest type-wise carbon content for the year 2004 with average forest type carbon content for the year 2007 and dividing the result with the gap period of three years. The result obtained is shown in the table no. 5.9.

Table 5.9: Forest type wise annual carbon sequestration in tons

Sl.No.	FOREST TYPE	CARBON SEQUESTRATION (tC/year)
1	Acacia Forest	2442
2	Anogeissus pendula Forest	513
3	Boswellia Forest	210
4	Degraded Forest	1606
5	Dry Deciduous Teak Forest	3952
6	Dry Mixed Deciduous Forest	9234
7	Moist Deciduous Teak Forest	866
8	Moist Mixed Deciduous Forest	12991
9	Riverine	175
10	Scrub	61
11	Teak Mixed Forest	5743

From the above table it is clear that Moist Mixed Deciduous forest can sequester maximum 12991 tons of carbon annually followed by 9234 tons of carbon by Dry Mixed Deciduous forest. Teak Mixed forest and Dry Deciduous forest will be able to sequester 5743 tons and 3952 tons of carbon on an annual basis respectively. Thus the total amount of carbon sequestered by the Panna National Park will amount to 37792 tons of carbon annually.

5.9 Ground Based Productivity Estimation

Plot-wise biomass values obtained for all the 34 plots in the field for the year 2004 and 2007 was used to calculate the net increase in the woody biomass of tree species lying within the plots. Later on these plots were regrouped according to their forest types to get the increased woody biomass for each forest type in the study area. The increase noted was for a time period of three years;

hence annual productivity of the trees was calculated taking into account the time factor. Unit of productivity thus obtained is t ha^{-1} $year^{-1}$, Table 5.10 and Fig. 5.13.

Table 5.10: Forest type wise average productivity of Panna National Park

FOREST TYPES	PRODUCTIVITY (t $ha^{-1}year^{-1}$)
Acacia Forest	3.81
Anogeissus pendula Forest	0.72
Boswellia Forest	0.74
Degraded Forest	1.85
Dry Mixed Deciduous Forest	2.57
Dry Teak Forest	1.85
Moist Mixed Deciduous Forest	2.72
Moist Teak Forest	0.51
Riverine Forest	3.16
Teak Mixed Forest	3.75
Scrub	0.29

Net Primary Productivity obtained for different forest types ranges from 0.29t $ha^{-1}year^{-1}$ to 3.81t $ha^{-1}year^{-1}$. Kale *et al*. 2002 reported above ground productivity in the range of (1.77 – 8.98) t $ha^{-1}year^{-1}$ for Shivpuri district, in Central India. Scrub recorded the least productivity of 0.29t $ha^{-1}year^{-1}$ whereas Acacia forest recorded the highest productivity of 3.8106 t $ha^{-1}year^{-1}$ followed by 3.75 t $ha^{-1}year^{-1}$ by Teak mixed forest. *Boswellia* and *Anogeissus* forest recorded a productivity of 0.7390 t $ha^{-1}year^{-1}$ and 0.72t $ha^{-1}year^{-1}$. Dry Teak forest, Dry Mixed Deciduous forest and Moist Mixed forest recorded productivity of 1.85, 2.57 and 2.72 t $ha^{-1}year^{-1}$.

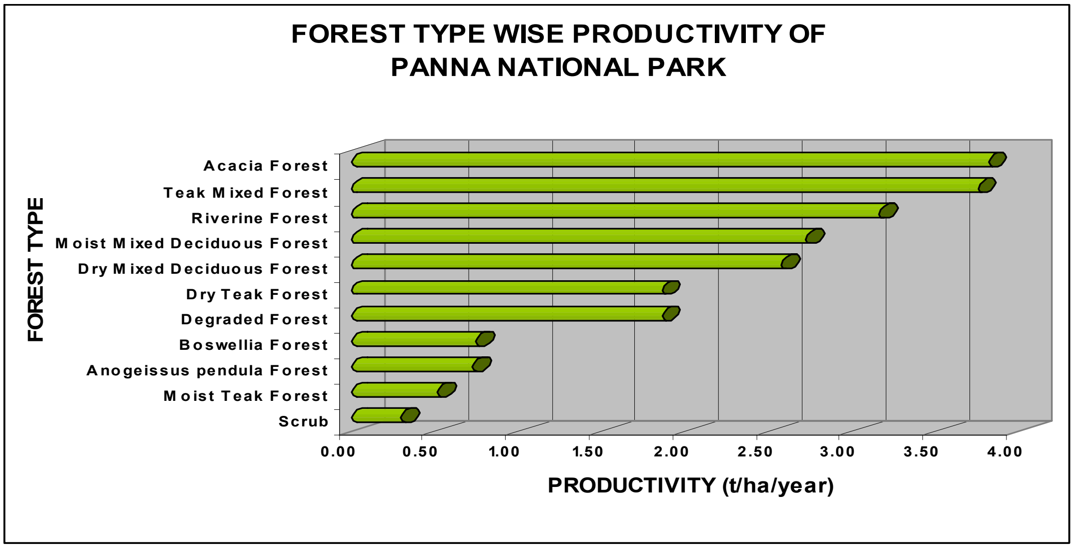

Fig. 5.13: Bar graph showing forest type – wise productivity of Panna National Park, Panna District

The productivity of *Acacia* forest is the highest; this is due to the fact that the rate of biomass accumulation and nutrient accumulation is reported to be high (Kumar *et al*. 1998). Apart from this, Acacia forest lies on the table tops where there is least disturbance and has the better soil and adequate water availability for its optimum growth. Teak Mixed forest, Moist Mixed Deciduous forest and Dry Mixed Deciduous forest shows net primary productivity in the range of (3.75 – 2.57) t $ha^{-1}year^{-1}$ where as; the *Anogeissus pendula* forest and *Boswellia* forest showed productivity in the range of (0.72 – 0.74) t $ha^{-1}year^{-1}$.

5.10 Forest Productivity Estimation Using Spectral Modeling and Production Efficiency Model (Monteith Model)

Forest productivity estimation using remote sensing data and Monteith model (1972) can be broadly classified into three major groups, such as:

1. Absorbed Photosynthetically Active Radiation (APAR) estimation.
2. Light Use Efficiency estimation based on forest types.
3. NPP estimation using Monteith's Production Efficiency Model (1972).

5.10.1 Absorbed Photosynthetically Active Radiation (APAR) estimation

APAR is an important parameter in determining the productivity while using Production Efficiency Model. In this model it has been demonstrated that productivity is a function of APAR and Light use efficiency of vegetated matter. Further, APAR depends upon the presence/absence of leaves and can be directly related to the amount of leaves present or absent in tree species. This means that during the growing season (July-November) when the amount of leaves are more and the leaves are intact, the APAR value is high whereas, during the senescent period the APAR value or the solar radiation intercepted by the leaves is low due to falling of the leaves. APAR can be expressed as μ mol $m^{-2}s^{-1}$.

Table 5.11: Forest type wise APAR readings collected in the field.

FOREST TYPE	OCTOBER	NOVEMBER	∑APAR
Anogeissus pendula Forest	480	307	787
Acacia Forest	773	599	1372
Degraded Forest	810	782	1592
Dry Deciduous Teak Forest	907	545	1452
Riverine Forest	1074	740	1814
Moist Teak Forest	1142	970	2112
Teak Mixed Forest	1178	1009	2187
Dry Deciduous Teak Forest	1181	1104	2285
Boswellia Forest	1192	950	2142
Teak Forest	1207	1038	2245
Dry Deciduous Teak Forest	1221	798	2019
Dry Mixed Deciduous Forest	1260	1176	2436
Moist Teak Forest	1380	740	2120
Moist Mixed Deciduous Forest	1419	1304	2723
Teak Mixed Forest	1748	1486	3234

In the study, APAR values collected in the ground showed variation from 787µ mol $m^{-2}s^{-1}$ to 3234µ mol $m^{-2}s^{-1}$ in different forest types, Table 5.11. Teak Mixed forest and Moist Mixed Deciduous forest showed maximum summed up APAR i.e., 3234 µ mol $m^{-2}s^{-1}$ and 2723µ mol $m^{-2}s^{-1}$ in the month of October and November due to high foliage density in the forest. *Anogeissus pendula* forest and Acacia forest showed least APAR values 787 µ mol $m^{-2}s^{-1}$ and 1372 µ mol $m^{-2}s^{-1}$ due to their sparse canopy and leaf structure. Monthly variation in the APAR values can be easily seen in the month of October and November. In Madhya Pradesh, the study area lies in the Northern dry deciduous part of Central India. Here, the forest is very dynamic and the phenology of the trees changes to a significant level fortnightly. This can be reflected in the data collected from the field Table 5.11 and Fig. 5.14 where, the APAR value is more in the month of October as compared to November. This is due to the fact that November is assumed to be a prelude to winters and the trees start defoliating.

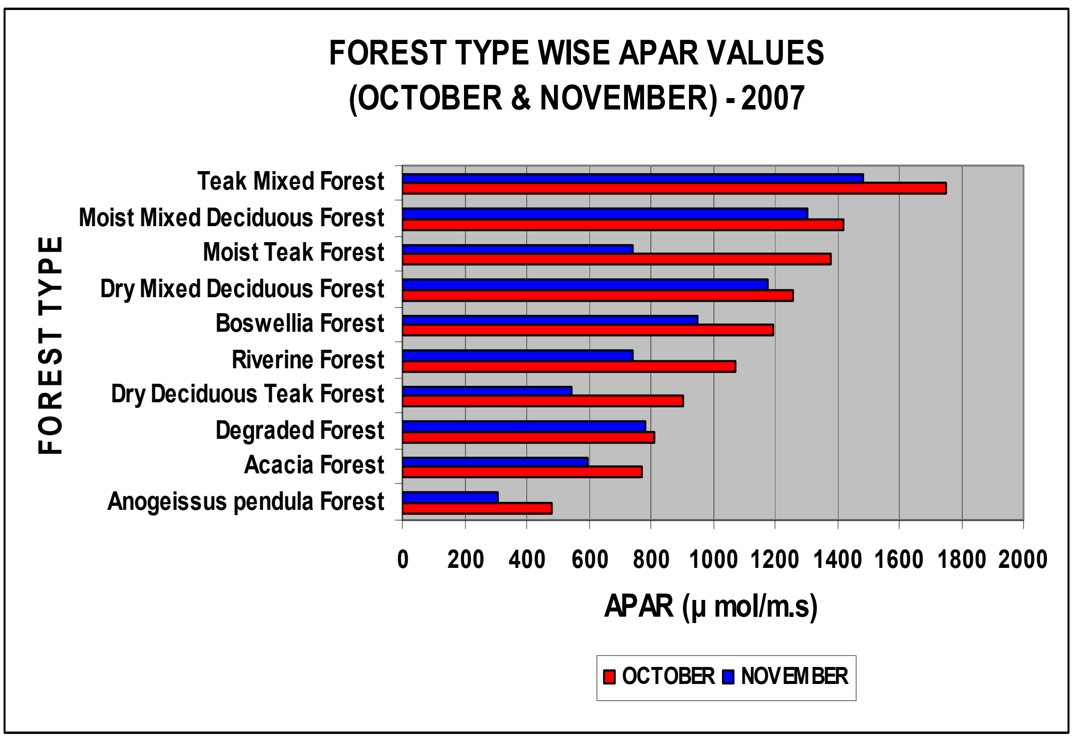

Fig. 5.14: Forest type wise APAR values for the month of October & November

In order to estimate the APAR using remote sensing image, statistical analysis was performed to see the correlation between satellites derived Normalized Difference Vegetation Index (NDVI) and ground based APAR values. NDVI values acts as a function of vegetation dynamism. A higher value of NDVI indicates vegetation to be in good physical shape and with good foliage cover.

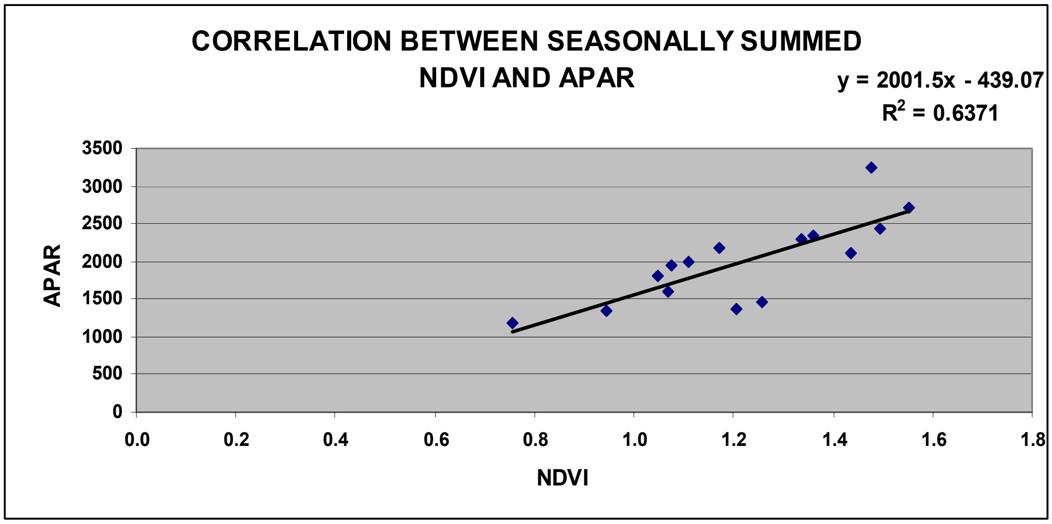

Fig. 5.15: Correlation between Remote Sensing derived ∑NDVI and ground based ∑ Absorbed Photosynthetically Active Radiation.

In the present study, correlation was established between monthly NDVI image and monthly APAR values collected in the field. However, the correlation was not significant enough, Table 5.12. The correlation between seasonally summed NDVI and APAR yielded a plausible correlation with a R^2 value of 0.6371. The linear equation thus obtained was; y = 2001.5x – 439.07, Fig. 5.15 which was further used to generate an APAR map with the help of up ∑NDVI image.

Table 5.12: Correlation analysis between APAR and NDVI

Sl. No.	Parameter 1	Parameter 2	Coefficient of Determination (R^2)
1	APAR (October)	NDVI (October)	0.2516
2	APAR (November)	NDVI (November)	0.2201
3	APAR (∑Oct-Nov)	NDVI (∑Oct-Nov)	0.6371

The APAR map obtained using spectral modeling was later on used as an input for calculating the net primary productivity of the study area using Production Efficiency Model. The APAR values of the map were grouped into

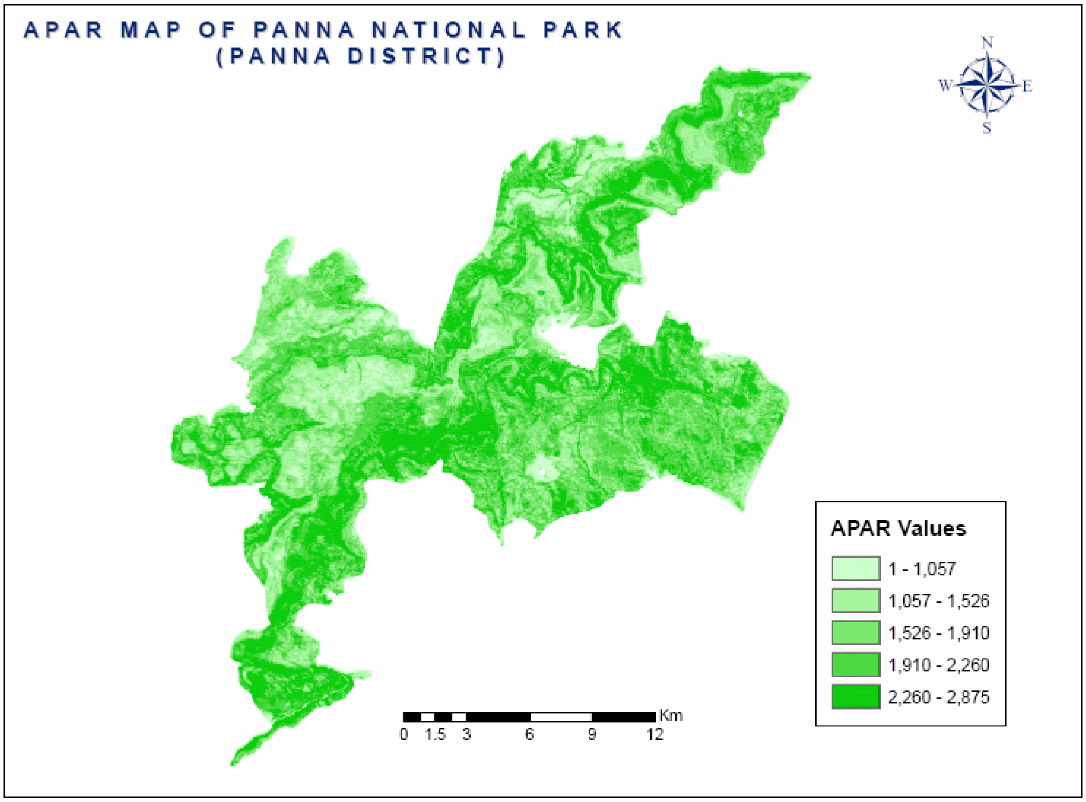

Fig. 5.16: Remote sensing derived APAR map of Panna National Park.

five classes; (1) 2260 – 2875 μ mol $m^{-2}s^{-1}$, (2) 1910 – 2260 μ mol $m^{-2}s^{-1}$, (3) 1526 – 1910 μ mol $m^{-2}s^{-1}$, (4) 1057 – 1526 μ mol $m^{-2}s^{-1}$ and (5) 1 – 1057 μ mol $m^{-2}s^{-1}$, Fig. 5.16. Forested area showed high APAR values as compared to the non forested area because in the forest the trees are present in close canopy with full foliage during the growing period. The remote sensing derived APAR image is in tune to the APAR values collected in the field. High APAR value means more absorption of incoming solar radiation, indicating high density of tree species. High tree species density is an indicator of better moisture availability, topography and good edaphic conditions.

5.10.2 Light Use Efficiency Estimation

Light Use Efficiency (LUE) or Radiation Use Efficiency (RUE) in principle is a ratio between carbon dioxide utilized in the process of photosynthesis to the amount of Photosynthetically Active Radiation (PAR) falling on the leaf. The basis of LUE based PAR model lies in the complex relationship between solar energy incident on vegetation canopy and the production of dry matter.

In the present study, observations for LUE have been estimated using the Leaf Chamber Infrared Gas Analyzer (LCi) instrument. In the field, species-wise LUE estimation was made at each plot. Within each plot first an enumeration of all tree species was made. Later on readings for all species present in that plot was made. While covering a species, readings from all directions and height of the tree was taken into consideration so as to incorporate the whole of the tree. This gave a realistic and scientific approach of taking the readings. Individual species database was further up scaled to plot wise taking into consideration the weighted average of tree species for each plot. Later on forest type wise light use efficiency values were generated.

The LUE values for the month of October were on a higher side as compared to the light use efficiency for November month. This is so because the tree leaves cover maximum area and reach optimal maturity during October and thus the rate of utilizing the solar electromagnetic radiation for the process of photosynthesis is the maximum. During the month of October the LUE values ranged from 0.0423 to 0.0948 µmole m^{-2} sec^{-1} whereas it ranged from 0.0024 to 0.0598 µmole m^{-2} sec^{-1} in the month of November. This change is mainly due to regular phenological changes occurring in the forest. Most of the tree species especially in Dry teak forest the leaves are completely dried up and the leaves start shedding. Boswellia forest shows a drastic change in their LUE because in the month of November and December the leaves were hardly seen in the forest.

Acacia forest shows comparatively high LUE, this may be attributed to the fact that in *Acacia*, the leaves are pinnate compound and the leaflets occur in succession along the rachis thus covering a greater leaf margin as compared to a simple leaf. More over they inhabit harsh environmental places, hence their leaf anatomical setup is more efficient by providing high stomatal index as compared to other trees occurring in study area. Further in the month of October, Moist Mixed and Teak Mixed Deciduous and Riverine forest showed a LUE value of 0.0948, 0.0831, and 0.0846 µmole m^{-2} sec^{-1} respectively. Plot wise values of light use efficiency for individual tree species was summed up and their average weighted mean was taken for each forest type into consideration to attain final forest type wise light use efficiency, Table 5.13.

Table 5.13: Forest type wise weighted LUE

FOREST TYPE	Weighted LUE
Acacia Forest	0.1689
Anogeissus Forest	0.0374
Boswellia Forest	0.0651
Dry Mixed Deciduous Forest	0.0971
Moist Deciduous Teak Forest	0.0245
Moist Mixed Deciduous Forest	0.0948
Riverine Forest	0.1131
Dry Deciduous Teak Forest	0.0619
Teak Mixed Forest	0.1440

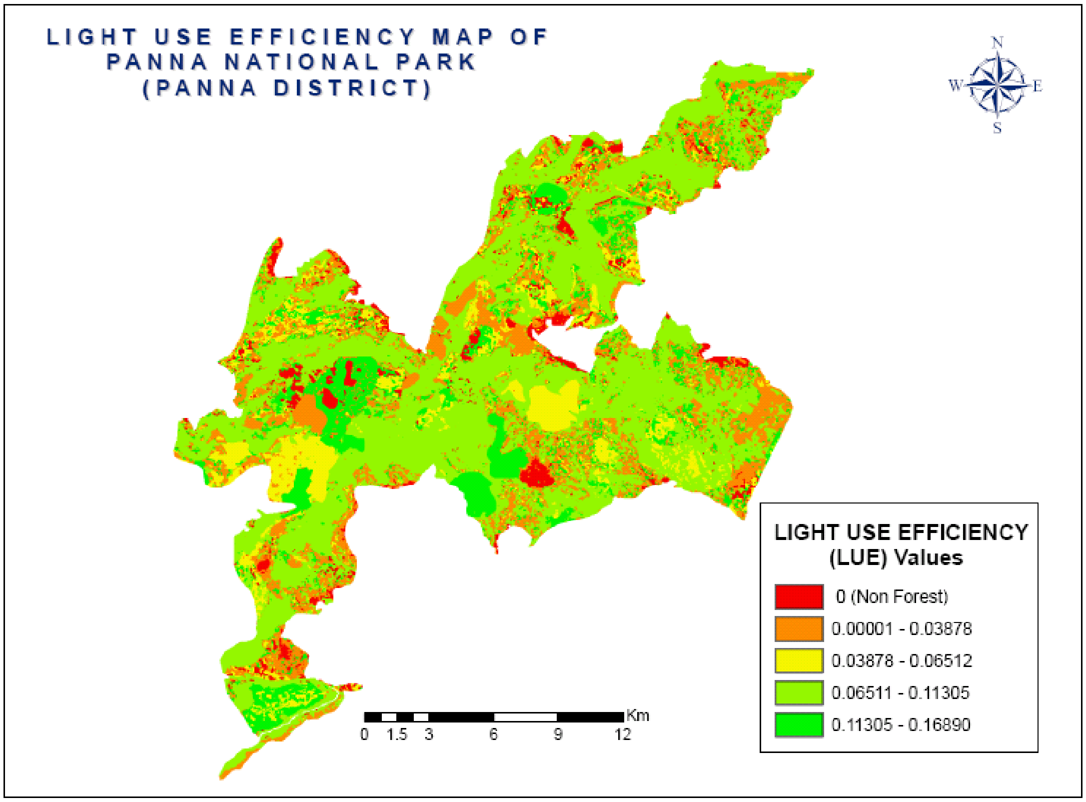

Fig. 5.17: Light Use Efficiency map of Panna National Park, for the month of October and November, 2007.

The Light use Efficiency map obtained was grouped into five major classes of which one class was considered as Non-forest. The other classes includes; (1) 0.11305 – 0.1689 µmole m^{-2} sec^{-1}, (2) 0.6511 – 0.11305 µmole m^{-2} sec^{-1} (3) 0.3878 – 0.06512 µmole m^{-2} sec^{-1} and (4) .00001 – 0.03878 µmole m^{-2} sec^{-1} respectively, Fig. 5.17. The results obtained are in agreement to the results obtained for a similar type of tropical dry deciduous forest by Kale and Roy, 2005. They reported the light use efficiency in the range of 0.02 µmole m^{-2} to 0.08 µmole m^{-2} for different forest types during the growing season. The study shows that light use efficiency is low during the senescent period because most of the trees shed their leaves and high temperature act as a limiting factor for photosynthesis efficiency of tree species especially in the dry deciduous belt of Central India.

5.10.3 NPP estimation

Data received through remote sensing technique and ground based field work was integrated in the Monteith's Production Efficiency Model to generate the NPP map of the Panna National Park, Panna District. Monteith (1972), estimated NPP as a direct product of absorbed PAR and light use efficiency in crop fields. The same methodology is adopted here to estimate the APAR and species wise photosynthetic efficiency of trees. Production Efficiency Model approach to quantify the net primary productivity is unique in the sense that it uses satellite data to measure both APAR and environmental variables that effect the consumption of APAR in primary productivity.

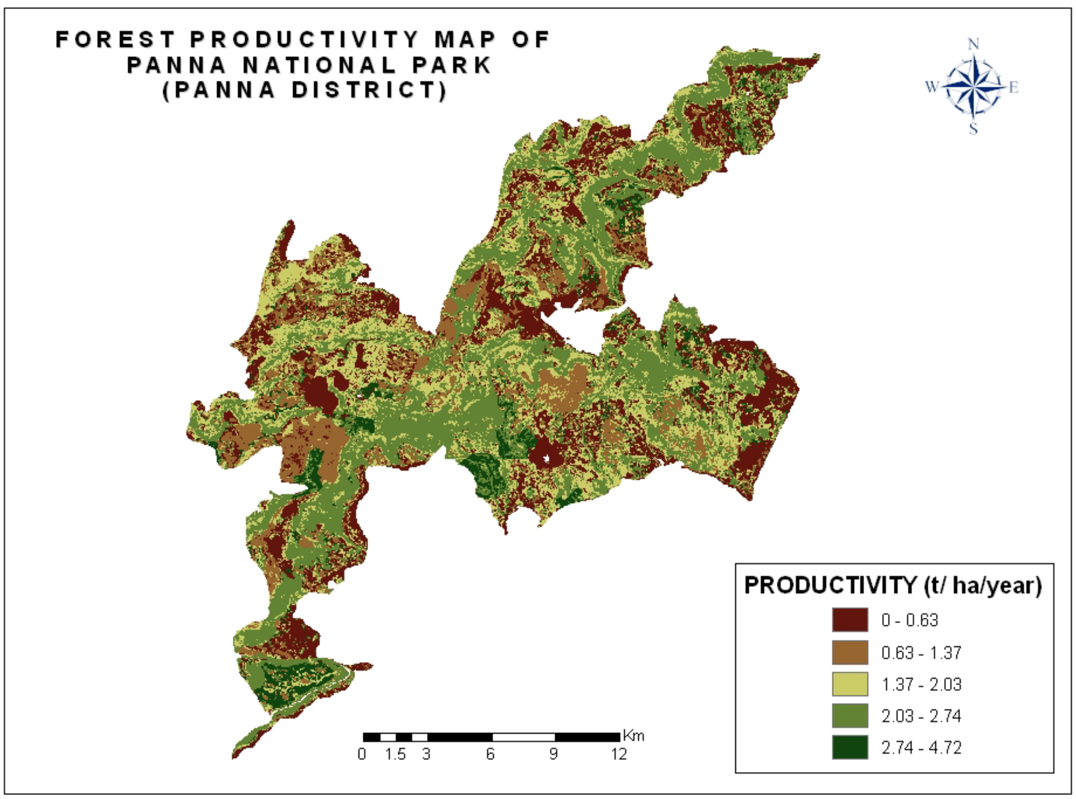

Fig. 5.18: Forest Productivity Map of Panna National Park, Panna District

The use of satellite measurements gives global, repetitive, spatially contiguous and time specific observations of actual vegetation conditions. APAR used in the model draws much of the attention because it is the most realistic parameter representing the vegetations dynamic nature in a tropical dry deciduous forest in terms of changing solar radiation. Forest type wise light use efficiency on the other hand is a comprehensive physiological parameter since for a plot; each species occurring into the plot was taken into consideration. The productivity map yielded from crossing the APAR and the LUE map ranged from 0 (Non-forest) to 4.72 t $ha^{-1}year^{-1}$ for the forested area, Fig 5.18. Highly productive areas included southern part of the park where it is found that least human interference with the vegetation occurs. The productivity map was classified into five classes; the highest productive zone ranged from 2.74 to 4.72 t $ha^{-1}year^{-1}$. These basically included the Acacia forests and the Moist Mixed Teak forest.

5.10.4 Validation of Remote Sensing Derived Forest Productivity Map

Remote sensing based forest productivity values were compared with the ground collected productivity values, in order to validate the models output. The given Table 5.14, shows the variation in the value.

Table 5.14: Comparative account of ground based and remote sensing based productivity values in the Panna National Park, Panna District.

Forest Type	Ground Based Productivity (t $ha^{-1}year^{-1}$)	Remote Sensing based Productivity (t $ha^{-1}year^{-1}$)
Acacia Forest	3.8106	2.3173
Anogeissus pendula Forest	0.7216	0.8766
Boswellia Forest	0.7390	0.7671
Degraded Forest	1.8531	0.3544
Dry Mixed Deciduous Forest	2.5717	2.3644
Dry Teak Forest	1.8531	0.8991
Moist Mixed Deciduous Forest	2.7190	2.5800
Moist Teak Forest	0.5096	0.4905
Riverine	3.1554	2.0507
Teak Mixed Forest	3.7466	3.9034

A correlation analysis was performed between the ground based forest productivity values and remote sensing derived productivity. The coefficient of determination value (R^2) attained was 0.7071, where n=10, Fig. 5.19.

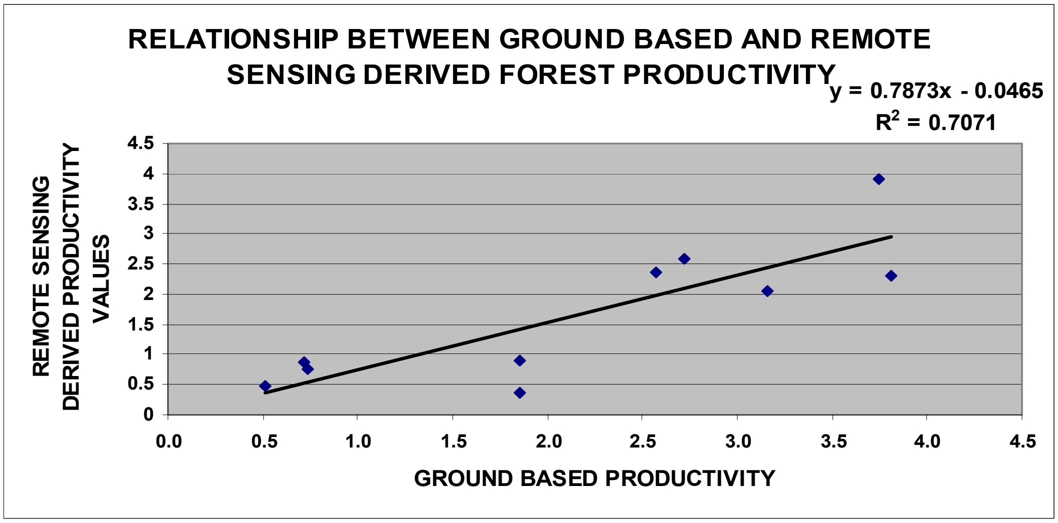

Fig. 5.19: Correlation between ground based and remote sensing derived forest productivity values, (t/ha/year).

Within the forest types; remote sensing based productivity ranged from 3.9034 t $ha^{-1}year^{-1}$ in Teak Mixed forest to 0.3544 t $ha^{-1}year^{-1}$ in the degraded forest. Moist Mixed Deciduous Forest and Dry Mixed Deciduous forest ranged from 2.58t $ha^{-1}year^{-1}$ to 2.3644t $ha^{-1}year^{-1}$ respectively. Acacia forest recorded 2.3173t $ha^{-1}year^{-1}$, whereas *Anogeissus pendula* and *Boswellia* forest recorded 0.8766 t $ha^{-1}year^{-1}$ and 0.7671 t $ha^{-1}year^{-1}$. While comparing the values with ground based productivity values, some deviation was noticed in the Acacia forest, Degraded forest, Dry Teak forest and Riverine forest. Acacia forest showed a deviation in productivity values from 3.8106 t $ha^{-1}year^{-1}$ to 2.3173t $ha^{-1}year^{-1}$ this may be due to the fact that Acacia forest basically has a low to medium density distribution, thus adding more components of the soil rather than vegetation in the reflectance image which we receive. Similar reasons also stand for the Degraded forest where the tree density is very less. Dry Teak forest had variations because in the month of November its leaves had completely dried out and the spectral reflectance received from such non green feature got under estimated in the remote sensing driven model. Riverine plot was the most unique among all plots because it covered a narrow strip of vegetation along the dry or water fed streams. The rest of the area was mostly covered with big boulders, pebbles and gravel. These features on the ground gave a collective reflectance for the pixel concerned, where the amount of non vegetated area was more as compared to the vegetated ones.

The remote sensing and ground based productivity values were compared with Light Use Efficiency to develop a relation between photosynthetic efficiency and vegetation productivity. The coefficient of determination R^2 ranged from 0.7263 for remote sensing derived forest productivity to 0.7966 for ground derived productivity values, (Fig. 5.20 and 5.21). This clearly shows that light use efficiency is linearly related to productivity of the vegetated matter; hence its inclusion in the production efficiency model was justified.

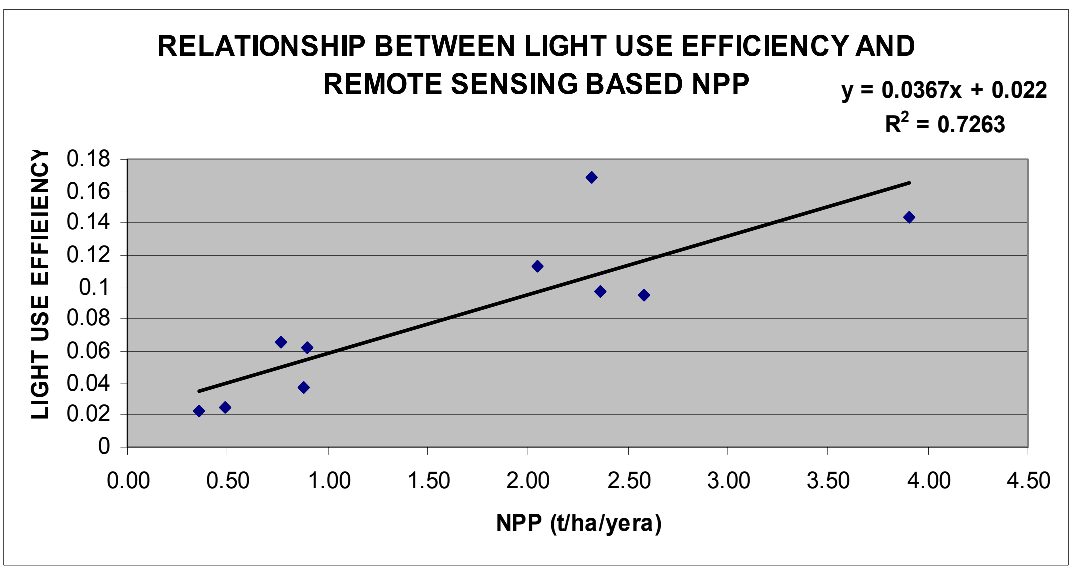

Fig. 5.20: Correlation between Light Use Efficiency and Remote Sensing derived NPP.

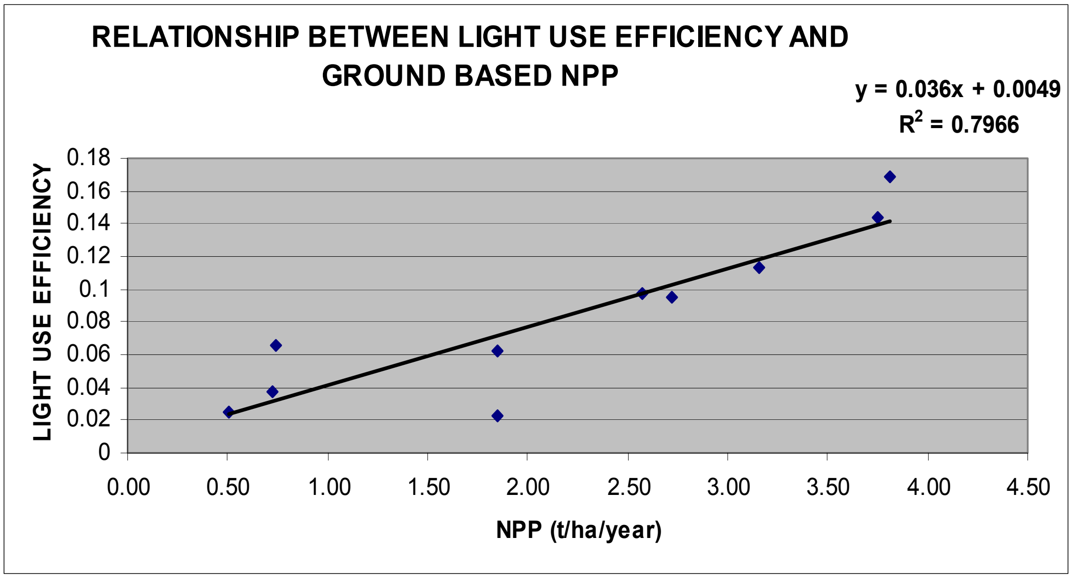

Fig. 5.21: Correlation between Light Use Efficiency and Ground based NPP.

5.11. Validation of plot biomass using Basal Area of Time 1 and Time 2

Biomass estimated in different plots for two-time periods (2004 and 2007) was checked for its changes at plot level. A scatter plot was generated between the basal area of time1 and time2. It is observed that there was increase in the basal area in the three years time period in thirty plots, lying above the threshold line (Fig. 5.22). However, four plot-values of basal area lay below the zero intercept line. This may be attributed to the fact that either trees have been removed, died or there was an error in locating the exact plot at time 2 due to inherent error in GPS.

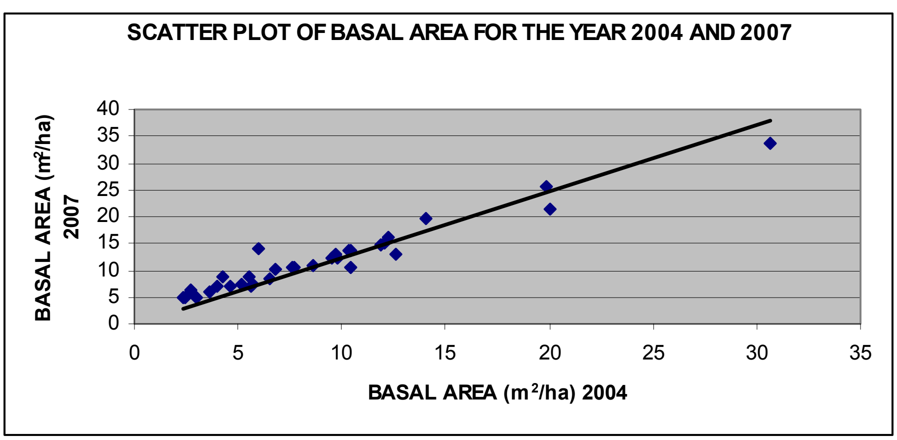

Fig. 5.22: Scatter plot showing Basal area of 2004 against basal area of 2007.

5.12 Forest Type wise Bole Turnover Rate and Turnover Time

Plant biomass accumulation by the forest ecosystem is the maximum as compared to the marine or fresh water ecosystem (Whittaker and Likens 1975). In the present study the rate at which biomass gets accumulated in the bole/trunk of trees occurring in the dry deciduous forests of Central India has been assessed. This study also gives an insight into the rate at which biomass of a given component is replaced. The rate of replacement of any component of a system is referred to as turnover rate. Odum (1971) has defined turnover rate as the ratio of output relative to input of a component and can be expressed as rate fraction or as turnover time.

Turnover time can be best defined as the reciprocal of turnover rate. Turnover time basically denotes the residence time of a substance or the time a given substance will remain in a systems component say trunk, leaves or roots. Turnover rate can thus be defined as the ratio of net primary production to biomass or (P/B) ratio. Table 5.15, gives an idea about turnover rate.

Table 5.15: Average biomass, productivity and turnover rate in different forest types of Panna National Park, Panna District.

Sl. No.	Forest Type	Biomass (t/ha) (B)	Productivity (t ha^{-1} $year^{-1}$) (P)	Turn Over rate (P/B)
1	Acacia Forest	25.28	3.81	0.151
2	Anogeissus pendula Forest	35.44	0.72	0.020
3	Boswellia Forest	37.96	0.74	0.019
4	Degraded Forest	17.27	1.85	0.107
5	Dry Deciduous Teak Forest	29.30	1.85	0.063
6	Dry Mixed Deciduous Forest	35.93	2.57	0.072
7	Moist Deciduous Teak Forest	36.26	0.51	0.014
8	Moist Mixed Deciduous Forest	41.13	2.72	0.066
9	Riverine	123.95	3.16	0.025
10	Scrub	2.90	0.29	0.100
11	Teak Mixed Forest	41.00	3.75	0.091

The importance of studying the turnover rate and turnover time in different forest types is due to the fact that such type of study gives an insight as to how much time the carbon sequestered by these forest types will remain trapped in the ecosystem and what remedial measures can be adopted to increase the residence time carbon within these forest types. Moreover, if we come to know about the turnover rate of bole and branches for a Dry Deciduous Teak forest which is 0.063 (i.e., 6.3% per year) we can say that the above ground biomass (woody) in such type of forest will get replaced at the rate of 6.3% per year and the turnover time for this forest is 15.8 years. Thus a high P/B ratio is indicative of the fact that the turnover rate is high or the replacement of a component on an annual basis is fast so its turnover time is short as compared to those whose P/B ratio is less. This study also tries to analyze the forest type wise turnover time or the time period in years a substance will be trapped inside a component (trunk) of the trees belonging to the Park. The following table 5.16 gives an idea about the turnover time for different forest types

Table 5.16: Turnover rate and turnover time for different Forest types in Panna National Park, Panna District.

Sl. No.	FOREST TYPE	Turn Over rate (P/B)	Turnover Time(year) (1/Turnover Rate)
1	Acacia Forest	0.151	6.6
2	Anogeissus pendula Forest	0.020	49.1
3	Boswellia Forest	0.019	51.4
4	Degraded Forest	0.107	9.3
5	Dry Deciduous Teak Forest	0.063	15.8
6	Dry Mixed Deciduous Forest	0.072	14.0
7	Moist Deciduous Teak Forest	0.014	71.2
8	Moist Mixed Deciduous Forest	0.066	15.1
9	Riverine	0.025	39.3
10	Scrub	0.100	10.0
11	Teak Mixed Forest	0.091	10.9

occurring in the Panna National Park, Panna district. Moist Deciduous Teak forest turnover time period calculated is 71 years. This is followed by *Boswellia* forest 51.4 years, *Anogeissus* forest 49.1 years and Riverine forest 39.3 years respectively. Residence time for a component in *Acacia* forest is 6.6 years, whereas the scrub and the degraded forest will be able to hold a substance within their trunk for a period of 10 years and 9.3 years respectively. This is because the turnover rate of *Acacia* forest is 0.151, i.e., 15.1% of woody above ground biomass will get replaced on an annual basis as compared to that of Scrub (10.1% per year) and Degraded forest (10.7% per year). Moist deciduous Teak forest has the slowest pace for replacing its above ground woody biomass i.e., at the rate of 1.4% per year.

Chapter 6

Conclusion

The probability of attaining fast and vast estimates of forest above ground net primary productivity is motivating scientific community for scientific and practical purposes. Aboveground woody biomass and net primary productivity has a major share in the forest carbon budget and thus it can be utilized by the forest managers for a better understanding and management of their natural resources. Use of high spectral and spatial satellite data for long period of time in a dry deciduous area of Central India where forest phenology changes rapidly is a major achievement. In this context, remote sensing derived Normalized Difference Vegetation Index (NDVI) images and their temporal datasets are very useful in studies related to forest biomass and productivity estimation. Production Efficiency model (PEM) considers the physiological processes and hence are better than models based on only physical parameters. Spatial distribution of above ground productivity in a forest area can be determined by exploiting the availability of seasonal absorbed photosynthetically active radiation and light use efficiency. The relative simplicity of the Production Efficiency Model allows its application to wider areas, relying on remote sensing, ancillary data and forest inventory. Satellite data sets can be utilized in conjunction with the absorbed photosynthetically active radiation and light use efficiency using Production Efficiency Model to calculate the above ground forest productivity. In the present study two approaches have been used. The results obtained in PEM are in conformity to the ground collected data.

Using medium resolution satellite data for image classification on a regional basis provides a good accuracy. In the present context multi season satellite data was used to achieve classification accuracy of 82.35%. Output maps like the biomass, carbon, APAR, LUE and productivity provides a spatial overview of their distribution in a specific area and time period. This can further help in forest management plans and decision making for the future and studies related to the climate change.

The study also emphasizes on the amount of carbon sequestered on an annual basis in the Panna National Park. It deals with the carbon sequestration potential of different forest types. Such studies provide an insight as to which forest type has more potential to sequester carbon from the atmosphere. In the present study, Moist Mixed Deciduous forest sequester maximum amount of carbon from the atmosphere on an annual basis (12991 tC/year), followed by the Dry Mixed Deciduous forest and Teak Mixed forest, i.e., (9234 and 5743 tC/year). Such data will provide an insight for prioritizing forests for conservation and management strategies and their role as carbon sinks. Studies related to carbon sequestration are gaining relevance due to the increasing pressure and concern raised upon our environment. Forests are acknowledged to be a major terrestrial sink of carbon in the world. Ever increasing human population and desire to achieve better standards of life is taking a heavy toll of our environment. To meet the ever growing demand, we not only need to sustain our forests wealth rather we all should look forward to a massive afforestation drive in the country in the coming future. This will not just be for an environmental reason rather we can encash these green patches for attaining carbon credit in the global market from the developed countries and their by adding to our national exchequer.

Using biomass and productivity values for different forest types in Panna National Park, an attempt has also been made to calculate the turnover rate (ratio between productivity and biomass) and turnover time or residence time. Residence time is an indicator how long an element stays in a component of a system. In the present study, amount of carbon sequestered annually and the residence time of carbon for different forest type gives an idea about the future role and amount of carbon that will be sequestered by these forest types. Turnover time also gives an idea about the replacement time of above ground biomass for different forest types in the dry deciduous forest belt of Central India.

It may be concluded and emphasized here that remote sensing has come to stay, and its usability in managing our forests on a sustainable basis cannot be overemphasized. Conservation and restoration processes especially with regard to renewable natural resources, like forest is essential to contribute towards environmental stability. For achieving this near real time information some system is absolutely necessary. It is, therefore suggested that at country level all state forest departments should soon get to know more about modern, cost effective and time saving technique of remote sensing and GIS, so that our forest management practices could keep pace peoples growing demands.

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APPENDIX- I

Volumetric Equation of tree species occurring in the study area:

- *Acacia catechu* (L. f.) Willd. = $0.21612-4.16597D+24.50948D^2 - 29.6773(D^3)$
- *Acacia leucophloea* (Roxb.) Willd. = $(-0.00142+2.61911D-0.54703\sqrt{D})^2$
- *Acacia nilotica* (L.) Willd. ex Delile = $(-0.00142+2.61911D-0.54703\sqrt{D})^2$
- *Acacia pennata* (L.) Willd. = $(-0.00142+2.61911D-0.54703\sqrt{D})^2$
- *Aegle marmelos* (L.) Corr. = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr. = $-(0.012484/(D^2)*H + 0.424503 - 0.009419(D^2)*H)* (D^2)*H$
- *Anogeissus pendula* Edgew. = $(0.00085/(D^2)-0.35165/D+4.77386- 0.90585D)*D^2$
- *Bauhinia vahlii* Wt. & Arn. = $-0.04262+6.09491(D^2)$
- *Bauhinia variegata* L. = $-0.04262+6.09491(D^2)$
- *Bombax ceiba* L. = $0.076+0.228(D^2)*H$
- *Boswellia serrata* Roxb. ex Colebr. = $(-0.1503+2.79425*D)^2$
- *Bridelia retusa* (L.) Spreng. = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Buchanania lanzan* Spreng. = $0.017+0.381(D^2)*H$
- *Butea monosperma* (Lam.) Taub. = $-0.07803+1.70258D- 9.16180(D^2) + 33.91455(D^3)$
- *Cassia fistula* L. = $0.066+0.287(D^2)*H$
- *Cassine glauca* (Rottb.) O. Kuntze = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Cochlospermum religiosum* (L.) Alston = $0.005183+0.245578(D^2)*H$
- *Dalbergia paniculata* Roxb. = $(0.76896+7.31777D-4.01953\sqrt{D})^2$
- *Diospyros melanoxylon* Roxb. = $0.042+0.246(D^2)*H$
- *Euphorbia royaleana* Boiss. = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Flacourtia indica* (Burm. f.) Merr. = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Gardenia latifolia* Ait. = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Grewia tiliifolia* Vahl. = $-0.057+0.292 (D^2)*H$
- *Lagerstroemia parviflora* Roxb. = $(0.002565/(D^2)*H+0.489814-0.00552(D^2)*H$
- *Lannea coromandelica* (Houtt.) Merr. = $-0.057+0.292 (D^2)*H$
- *Madhuca longifolia* (Koenig) Macbr. Var. latifolia (Roxb.) Chev. = $-0.014+0.275(D^2)*H$

- *Miliusa tomentosa* (Roxb.) Sinc. = $(1.67477+14.8374*D-9.43386\sqrt{D})^2$
- *Mitragyna parvifolia* (Roxb.) Korth. = $(0.099768/(D^2)-1.744274/D+10.086934)*D^2$
- *Narangi crenulata* (Roxb.) Nicols. = $0.17553-0.71434\sqrt{D}+7.94663(D*D)$
- *Nyctanthes arbor- tristis* L. = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Ougeinia oogeinsis* (Roxb.) Hochr. = √-0.469152+1.403410D+1.42555√D)^2
- *Phyllanthus emblica* L. = $-0.038+0.344(D^2)*H$
- *Pterocarpus marsupium* (Jacq.) Weight = $\square 0.175068+4.598243*D-1.500562\sqrt{D})^2$
- *Schleichera oleosa* (Lour.) Oken. = $0.010-0.912D+11.396(D^2)$
- *Soymida febrifuga* (Roxb.) A. Juss. = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$
- *Sterculia urens* Roxb. = $0.0023/(D^2)*H+0.34018)*(D^2)*H$
- *Tectona grandis* L.f. = $0.008690+0.323051(D^2)*H$
- *Terminalia alata* Heyne ex Roth. = $(0.41071+5.51319D-2.59952\sqrt{D})^2$
- *Terminalia bellirica* (Gaertn.) Roxb. = $-0.005564+0.365874(D^2)*H$
- *Ziziphus mauritiana* Lam. = $0.027354+4.663714(D^2)$
- *Ziziphus oenoplia* (L.) Mill. = $0.027354+4.663714(D^2)$
- *Ziziphus xylopyrus* (Retz.) Willd. = $-0.002557+0.260114(D^2)*H$
- General Equation = $0.17553-0.71434\sqrt{D}+7.94663(D^2)$

Source: Volume Equations of India, Nepal and Bhutan, (1996), Forest Survey of India.

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APPENDIX- II

Specific gravity of tree species occurring in the study area

BOTANICAL NAMES	SPECIFIC GRAVITY
Acacia catechu (L. f.) Willd.	0.86
Acacia leucophloea (Roxb.) Willd.	0.82
Acacia nilotica (L.) Willd. ex Delile	0.85
Acacia pennata (L.) Willd.	0.85
Aegle marmelos (L.) Corr.	0.75
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill.	0.92
Anogeissus pendula Edgew.	1.01
Antidesma acidum Retz.	0.62
Bauhinia vahlii Wt. & Arn.	0.66
Bauhinia variegata L.	0.66
Bombax ceiba L.	0.37
Boswellia serrata Roxb. ex Colebr.	0.57
Bridelia retusa (L.) Spreng.	0.64
Buchanania lanzan Spreng.	0.47
Butea monosperma (Lam.) Taub.	0.44
Cassia fistula L.	0.81
Dalbergia paniculata Roxb.	0.60
Diospyros melanoxylon Roxb.	0.44
Erythrina suberosa Roxb.	0.30
Euphorbia royaleana Boiss.	0.50
Feronia limonia(L.) Swingle	0.78
Flacourtia indica (Burm. f.) Merr.	0.77
Gardenia latifolia Ait.	0.74
Grewia tiliifolia Vahl	0.76
Holarrhena pubescens (Buch.-Ham.) Wall. ex G. Don	0.60

Helicteres isora L.	0.56
Hymenedictyon orixense (Roxb.) Mabb.	0.45
Lagerstroemia parviflora Roxb.	0.78
Lannea coromandelica (Houtt.) Merr.	0.54
Madhuca longifolia (Koenig) Macbr. Var. latifolia (Roxb.) Chev.	0.96
Manilkara hexandra (Roxb.) Dubard	1.09
Miliusa tomentosa (Roxb.) Sinc.	0.84
Mitragyna parvifolia (Roxb.) Korth.	0.68
Narangi crenulata (Roxb.) Nicols.	0.50
Nyctanthes arbor- tristis L.	0.79
Ougeinia oogeinsis (Roxb.) Hochr.	0.87
Phyllanthus emblica L.	0.77
Pterocarpus marsupium Roxb.	0.80
Schleichera oleosa (Lour.) Oken	1.03
Semicarpus anacardium	0.57
Soymida febrifuga (Roxb.) A. Juss.	1.10
Sterculia urens Roxb.	0.57
Syzigium cumini	0.76
Tectona grandis L.f.	0.64
Terminalia alata Heyne ex Roth	0.85
Terminalia arjuna (Roxb .ex DC.) Wight & Arnott.	0.78
Terminalia bellirica (Gaertn.) Roxb.	0.69
Ziziphus mauritiana Lam.	0.56
Ziziphus nummularia	0.70
Ziziphus oenoplia (L.) Mill.	0.65
Ziziphus rugosa	0.61
Ziziphus xylopyrus (Retz.) Willd.	0.78

Source: Indian Woods, Volume I – VI, FRI, Publications

APPENDIX- III

Common names of tree species occurring in the Panna National Park

COMMON NAMES	BOTANICAL NAMES
Achar	*Buchnania lanzan* Spreng.
Amaltas	*Cassia fistula* L.
Ambla	*Phyllanthus emblica* L.
Arjun	*Terminalia arjuna* (Roxb .ex DC.) Wight & Arnott.
Bel	*Aegle marmelos* (L.) Correa
Bhelsena	*Narangi crenulata* (Roxb.) Nicols.
Bija Sal	*Pterocarpus marsupium* Roxb.
Borar	*Grewia elastica* Vahl
Dhaman	*Grewia tiliifolia* Vahl
Dhawa	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill.
Dudhi	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G. Don
Ghont	*Ziziphus xylopyrus* (Retz.) Willd.
Gunja	*Lannea coromandelica* (Houtt.) Merr.
Harshringar	*Nyctanthes arbor- tristis* L.
Jamrasi	*Cassine glauca* (Rottb.) O. Kuntze
Kachnar	*Bauhinia variegata* L.
Kaitha	*Feronia limonia*(L.) Swingle
Kardahi	*Anogeissus pendulai* Edgew
Karhar	*Gardenia latifolia* Ait.
Kari	*Miliusa tomentosa* (Roxb.) Sinc.
Katai	*Flacourtia indica* (Burm. f.) Merr.
Kathbar	*Ficus sp.*
Keima	*Mitragyna parvifolia* (Roxb.) Korth.

Cont..

Kerwara	*Cassia fistula* L.
Khair	*Acacia catechu* (L. f.) Willd.
Kosam	*Schleichera oleosa* (Lour.) Oken
Kullu	*Sterculia urens* Roxb.
Mahua	*Madhuca longifolia* (Koenig) Macbr. Var. latifolia (Roxb.) Chev.
Makoi	*Ziziphus oenoplia* (L.) Mill.
Neem	*Azhadirachta indica* A. Juss.
Palash	*Butea monosperma* (Lam.) Taub.
Reunja	*Acacia leucophloea* (Roxb.) Willd.
Rohini	*Soymida febrifuga* (Roxb.) A. Juss.
Saguan	*Tectona grandis* L.f.
Sagun	*Tectona grandis* L.f.
Saj	*Terminalia alata* Heyne ex Roth
Salai	*Boswellia serrata* Roxb. ex Colebr.
Seja	*Lagerstroemia parviflora* Roxb.
Semul	*Bombax ceiba* L.
Syamar	*Bombax ceiba* L.
Tendu	*Diospyros melanoxylon* Roxb.
Thua	*Euphorbia sp.*

APPENDIX- IV

GPS Location of the Plots

Plot. Id.	Latitude	Longitude
1	24˚ 37’ 23.8’’	80˚ 00’ 19.1’’
2	24˚ 37’ 18.1’’	80˚ 00’ 58.9’’
3	24˚ 36’ 30.5’’	80˚ 00’ 27.5’’
4	24˚ 34’ 13.9’’	80˚ 01’ 36.8’’
5	24˚ 34’ 02.4’’	80˚ 00’ 31.8’’
6	24˚ 33’ 23.3’’	80˚ 00’ 15.2’’
7	24˚ 38’ 30.6’’	79˚ 57’ 19.8’’
8	24˚ 38’ 22.9’’	79˚ 57’ 38.8’’
9	24˚ 36’ 51.5’’	79˚ 54’ 18.0’’
10	24˚ 39’ 59.7’’	79˚ 58’ 22.7’’
11	24˚ 39’ 19.1’’	80˚ 02’ 52.2’’
12	24˚ 39’ 16.9’’	80˚ 02’ 46.8’’
13	24˚ 38’ 10.4’’	80˚ 00’ 05.0’’
14	24˚ 37’ 58.3’’	79˚ 59’ 02.6’’
15	24˚ 36’ 16.7’’	79˚57’ 38.4’’
16	24˚ 35’ 57.3’’	79˚57’ 23.7’’
17	24˚ 36’ 42.3’’	79˚57’ 37.2’’
18	24˚ 36’ 25.2’’	79˚ 56’ 58.7’’
19	24˚ 36’ 25.6’’	79˚ 56’ 14.5’’
20	24˚ 36’ 16.3’’	79˚ 56’ 02.8’’
21	24˚ 35’ 56.4’’	79˚ 55’ 26.3’’
22	24˚ 35’ 37.7’’	79˚ 55’ 01.0’’
23	24˚ 34’ 51.9’’	79˚54’ 40.5’’
24	24˚36’51.5’’	79˚54’ 18.0’’
25	24˚36’31.6’’	79˚55’ 50.7’’
26	24˚33’59.6’’	79˚54’ 09.5’’
27	24˚33’47.0’’	79˚53’ 37.9’’
28	24˚ 32’53.4’’	79˚ 53’ 42.3’’
29	24˚ 38’33.3’’	80˚ 00’ 54.3’’
30	24˚ 42’03.7’’	79˚ 59’ 29.4’’
31	24˚ 35’51.5’’	79˚ 53’ 07.1’’
32	24˚ 35’42.4’’	79˚ 51’ 59.5’’
33	24˚ 35’ 31.2’’	79˚ 51’ 21.3’’
34	24˚ 36’ 51.6’’	79˚ 54’ 18.1’’

GARMIN GPS – WGS 84