A STUDY ON VEGETATION ECOLOGY IN PENCH TIGER RESERVE, MADHYA PRADESH WITH REFERENCE TO GAUR (*Bos gaurus*), USING REMOTE SENSING AND GIS TECHNIQUES

Dissertation submitted to Saurashtra University, Rajkot, Gujarat, for the award of the Degree of Doctor of Philosophy in Wildlife Science

Submitted by:

Gopala Areendran

Under the supervision of:

Dr. K. Sankar

Wildlife Institute of India
Dehradun

October 2007

10th October 2007

CERTIFICATE

This is to certify that the thesis titled **"A study on vegetation ecology in Pench Tiger Reserve, Madhya Pradesh with reference to Gaur *(Bos gaurus)*, using Remote Sensing and GIS Techniques"** submitted for the award of degree of **Doctor of Philosophy** in **Wildlife Science** to Saurashtra University, Rajkot, is a record of original and independent research work carried out by **Mr. G. Areendran** under my guidance. No part of this thesis has been submitted in part or full to any other University/Institution for the award of any degree and it fulfils all the requirements laid down by Saurashtra University.

Dr. K. Sankar
Ph. D. Supervisor
Professor & Research Coordinator
Wildlife Institute of India

Acknowledgements

This thesis completion was possible only due to the extensive support and co-operation provided to me by various institutions and individuals. I thank the Wildlife Institute of India, Madhya Pradesh State Forest Department, Central Ministry of Environment & Forests, Pench Tiger Reserve authorities and World Wide Fund-India for the permission, facilitation and logistic support.

I am greatly indebted to Dr. K.Sankar, my Ph. D. supervisor and the investigator of the project, for his guidance, encouragement and support all through. He brought me back to the academic line and ensured thesis completion.

Many thanks to Mr. Qamar Quereshi for the much needed technical inputs and encouragements. I also thank K. Ramesh for helping me in various ways to complete the thesis, and for putting up with me. Khalid Pasha was a great company during the days in the field and was indeed a great experience in working with him in the project.

I am thankful to Mr. P.R. Sinha, Director of WII, the former Directors, Mr. S.K. Mukherjee, and Mr. V.B. Sawarkar for the encouragement and extending unconditional institutional support.

I am grateful to Mr. R.D. Sharma (PCCF), Mr. P.K. Mishra (Addl. PCCF), Mr. R.C. Sharma (Ex. Field Director, PTR), Mr. R.G. Soni (Field Director, PTR), Mr. L.K. Chaudhary (Deputy Director, PTR) and Mr. Dwivedi (Ex. Deputy Director & Ecodevelopment Officer, PTR) for their support provided throughout the course of work.

Mr. Suhas Kumar (then CF, Bhopal) deserves special thanks for his ideas and encouragement, which led to Pench Tiger Reserve, Madhya Pradesh for studying gaur ecology. Special thanks to Dr. P.K. Malik, Prof. Peshin and Dr. A.B.Srivastav for their expertise and wonderful job in radio collaring of gaur. Mr Sanjay Mukharia, Mr. S.K.S. Chauhan, Mr. Shahbaz Ahmed, Mr. C.K. Patil, Dr. Hassan and Mr. Asim Srivastava were helpful in providing the logistics for the field work during the initial period. Mr. Ahlawat (CF), Mr. R.P. Singh (DFO), Mr. Divendra Singh (DFO) & Mr. Kaushalendra Singh (DFO), of the Seoni Territorial Division and their staff are thanked for the support extended during field work. Mr. Shree Bhagvan (CF), Mr. S.B. Banubakode (DCF), Mr. N.D. Choudhary (DCF), Mr. Kotkar, Sh S.S.Notey, Mr. P.B. Kottewar (RFO's) and the field staff of Pench Tiger Reserve, Maharashtra for Showing keen interest and cooperation in this project. Mr. Jagdish Chandra, Mr. Sharma and Mr. Panwar, (ACFs, PTR), Mr. A. Aggarwal, Mr. Dundwae, Mr. Sharma and Mr. Amulaya (RFOs, PTR), Mr. N. Tewari and Mr. Sharma (Range Assistants, Karmajhiri), Mr. Soni and Mr. Tewari, (Forest Guards, PTR), and other field and office staff at the office of the Field

Director, PTR, Seoni, are thanked for their help and co-operation extended during the fieldwork.

Mr. P.K. Sen (Ex-Director Project Tiger) and Dr. Rajesh Gopal (Director Project Tiger) are thanked for showing keen interest in the research.

Mr. Sanjay Deshpandey, Bhabiji, and Shivali, Mr. Altaf Ahmed, Mr.Shirish Katekar and Mr..Rajashekar & their families at Nagpur are thanked for the kind hospitality and support provided for our research team. Mr. Amrit Pal Singh is thanked for giving us useful tips on photography during his visits to Pench. Gurhan Lal, Guddu, Beeran, Mehatlal and Late Phoolbansa, our field assistants, are thanked for sharing their knowledge of field craft, providing with tasty cuisine in the field and making our arduous field work a smooth one. Dr. Patle, Veteranary doctor at Kurai is thanked for providing us with valuable information on livestock diseases. At Kawasa, I thank Mr. Parashar and Mr. Pramod Kumar, Managers of Maharashtra Bank for their personal interest shown in the project and also for managing project bank accounts. I thank the Forest Department wireless staff at Kawasa RFO's office, and the Staff at Kawasa Post Office.

At the Wildlife Institute of India, I am grateful to Dr. A.J.T.Johnsingh, former Dean, Dr.G.S.Rawat, Dr.Y.V.Jhala, Dr.Ravi Chellam, Dr. S. Sathyakumar and Dr.S.P.Goyal are thanked for the useful discussions. I also thank Mr. Gyanesh Chhibber for helping me with the Saurashtra University procedures. I thank Dr. S.A. Hussain and Dr. V.P. Uniyal for extending the hostel facility, especially during the thesis writing stage. I also thank the Members of Research Advisory Committee of WII; Dr. V.B. Mathur, Dr. K. Sankar, Dr. P.K. Mathur, Dr. Y.V. Jhala, and Mr. Anil Bhardwaj. I also thank Dr. A.K.Gupta (ex-registrar), Dr. S.P.Singh (ex-registrar), Mr..D.V.S.Khati (ex-registrar), Dr.Sushant Choudhury (ex-registrar), Mr. Sanjay Shrivastava and Dr.Karthikeyan Vasudevan for their support and cooperation. Mr. S.S. Oberoi, Mr. M.D.Gupta, Smt. Baljeet Kaur, Mr. Kharak Singh, and Mr. Dubey are thanked for handling the financial matters and Mr. M.P. Aggarwal for the secretarial assistance. Mr.Rajesh Thapa, Dr. Navneet Gupta, Dr. Manoj Aggarwal and Dr. Panna Lal are acknowledged for their help in GIS. Mr. V. Sukumar and Mr. Leknath Sharma at the computer section are thanked for their assistance in computer related works. Dr. Rakesh Singh, Mr. Ajay Sharma and Mr. Rakesh Sundrial are thanked for their assistance in laboratory for the project related sample analysis. Mr. Vinod Thakur, laboratory technician assisted us in gaur radio collaring operation in Pench. Mr. M.M. Babu & Mr. Saklani are thanked for identifying the plant samples collected from Pench. Dr. Madan S. Rana, Mr. Y.S. Verma, Mr. Madan Uniyal, Mr. Kishan Singh, Mr. B.S. Chauhan, Smt. Sunita Agarwal, Smt. Shashi Uniyal and Mr. Mahesh Gosh are thanked for their ever-willing assistance to us in the library. Mr Virendra Sharma is acknowledged for facilitating the DTP work. Mr. Birendra Kumar and Mr. Vijay Prasad, Chitra Pal Singh are thanked for the risographic related work. Mr. Shyam Lal is acknowledged for providing assistance in various project-related matters.

My special thanks are due to Jayapal, Bhaskar and Sayanthan who also did research works on various other aspects in Pench. They were not only great company in the field, but also contributed to data collection during crucial stages.

I also thank my friends and colleagues Christy Williams, T.R.K.Yoganand, M.N.Ishwar, Bivash Pandav, Suresh Kumar, Harish Kumar, Rajkumar, Sanjay Uniyal, Anjali, Reema, Manisha, Diwakar Sharma, Neel, K. Sivakumar, Justus, Wesley, Priya, Ashish David, Ambica (especially for helping me with FRAGSTATS software), Meera, Karthik Shankar, Ambika, Padma, Roopali, Meena, Jatinder, Gopi G.V., Gopi Sundar, Kashmira, Sushma and Anupama. I wish to thank the entire WWF fraternity, especially Mr Ravi Singh, Dr. Sejal Worah, Dr. Prakash Rao, and my efficient staff at IGCMC viz., Krishna Raj, Rajeev Kumar, Sandeep, Ms. Dinni and others.

I like to place on record that the thesis would have not seen its light, but for the unending love and support from my family members. The emotional influence from my mother, father, brother, sister and Shivani was incredible. My mother-in-law and father-in-law deserve appreciable mention for the lasting support and for patiently sharing my burden. Thanks to Rosy and Manjit for being great inspiration and motivation. Looking back the whole process, my wife Livleen and son Arnav have been rock solid behind me during the whole time, endured my problems, and motivated me by their love and support all along. They truly reinvigorated the sense of purpose in life and the need for completing my thesis.

(G. Areendran)

Contents

List of Maps

List of Figures

List of Tables

List of Appendices

Executive Summary

A study on vegetation ecology with reference to Gaur (*Bos gaurus*) using remote sensing and Geographic Information System (GIS) in Pench Tiger Reserve (PTR) Madhya Pradesh was conducted from February 1996 to September 2000. The Tiger Reserve is located between 77° 55' W to 79° 35' E & 21° 08' S to 22° 00' N and lies in the southwestern region of the state of Madhya Pradesh. The Tiger Reserve comprises of the Sanctuary and the National Park of the same name, and buffer zone covering an area of 757.85 sq. km.

The PTR lies in the southern lower reaches of Satpura Hill ranges. The terrain is gently undulating and criss-crossed by small streams and nullahs; most of these are seasonal. The hills have gradual to steep slopes with almost flat tops. Climatically the area has three distinct seasons. The summer, lasting from March to June, monsoon (July to August) and winter (October to February).

According to Champion and Seth (1968), the vegetation of the PTR
comprises of

I. South Indian Tropical Moist deciduous-

- 3 BC 1 C. Slightly moist teak forests.

II. Southern Tropical Dry Deciduous Teak bearing Forest:

- 5A/C1b Dry teak forests

5A/C3 Southern dry mixed deciduous forests

The PTR offers a unique opportunity for research into the aspects of both the ecology and the management of gaur populations and their habitats. This is due to, both, the diverse pattern of habitat, as a result of rich floral composition and varied topology, and gaur populations that can readily be seen almost throughout the year. In Madhya Pradesh alone, the gaur population is found in 10 districts and they are geographically isolated from one another.

The main objectives of the study were:

- To study vegetation communities, composition, species distribution, abundance and richness in Pench Tiger Reserve, Madhya Pradesh.
- To map vegetation types and quantify landscape characteristics in PTR, Madhya Pradesh.
- To evaluate the available habitat and predict distribution areas of Gaur in PTR, Madhya Pradesh.

Vegetation types were identified for stratified random sampling. Circular plots of 10 m (0.01 ha) were laid randomly within each vegetation type for measuring vegetation structure and composition. Species circumference at breast height (CBH, 1.37 m above ground), height of the individual species, crown cover and GPS location of the plot were noted down. Nested within a radius of 10 m, a plot of 5 m radius was considered for the shrub and herb layer evaluation. Four 0.5 meter quadrats were laid within the plot at each major direction (North, South, East, West) for collecting information on ground cover such as litter, grass, etc. Individuals of the shrub and herb species encountered were noted down. The size and the number of sampling units were determined by species area curve and running mean method respectively.

Individuals with CBH < 20 m were treated as trees, > 20 cm were categorized as saplings, and seedlings.

Data collected from the field were analyzed for tree and shrub species density, frequency, dominance, and abundance. The relative values of frequency, dominance, and abundance and density were used for determining Importance Value Index (IVI).

The Indian Remote Sensing (IRS) LISS III P6 data was procured from NRSA Hyderabad for Pench Tiger Reserve (PTR) and its surrounding areas. The data received was in two scenes (Path & Row 99-57 & 100-57) with spatial resolution of 23.5 m^2. In addition, Landsat MSS (1977) and Landsat ETM+ (2001) were downloaded in the GeoTIFF format from the Global Land Cover Facility (GLCF) on the geoportal -http://glcfapp.umiacs.umd.edu.

Topographical maps of 1:50 000 scales were obtained from Survey of India covering the entire park and surrounding areas. The total area of PTR to be mapped covers the following toposheets: 55 O/2, O/5, O/6, O/9, and 55 K/13 and K/14. The toposheet was scanned and later converted in to digital format for digitization. **S**cenes were geometrically rectified and projected to Universal Transverse Mercator (UTM) projection using 50 ground control points (GCP'S) from the georeferenced SOI.

Both unsupervised and supervised clustering was used for classifying vegetation types. Classification was performed using maximum likelihood classifier as it has been proven very efficient in vegetation mapping. Change detection of vegetation cover was done using the Landsat 1977 image and landsat ETM + 2001 image. Analysis on landscape configuration including fragmentation status was carried out using FRAGSATS software version 3.3 (McGarigal et al. 2002**)**.

I had attempted to model the habitat suitability and predict distribution of Gaur in Pench National Park based on Ecological niche factor analysis (ENFA) using Biomapper software Different variables (Aspect, Cover change, Drainage, Elevation, Food dentity, Ground cover, Slope, Vegetation type, Vegetation index) were used in the model to predict the suitable habitat and distribution of Gaur.

Nine vegetation associations were identified from the Twinspan result. *Viz*. Pure *Tectona grandis*, *Tectona grandis* associated with *Lagerstromia purviflora*, *Tectona grandis* with *Diospyros melanoxylon*, - *Ougenia oogenesis* - *Dalbergia latifolia*-*Anogeisus latifolia* association, *Tectona grandis* with *Grewia taeliafolia* - *Miliusa velutina*, *Dendrocalamus strictus* community, *Butea monosperma– Zizyphus xylopora* association, *Termanalia tomentosa* - *Anogeisus latifolia* - *Chlroxylon swietnia* association, *Boswellia serrata*-*Embellica officinalis*- *Lannea corromendalica* association, and pure *Clistansthus collinus* community. A total of 49 families with 218 species of plant species were recorded from the sampling plots. There was significance difference observed in shrub species richness and diversity amongst the three management units, in PTR. There was a significance difference observed in the tree species richness amongst the management units (Seoni, Chindwara, Sanctuary) P= (.001), though the tree density amongst the units did not show any significant difference. The the shrub richness and density clearly showed significance difference P= (.001) amongst the three management units of the Tiger Reserve.

The vegetation map derived from the satellite imagery using Remote Sensing technique in Pench Tiger Reserve broadly categorized the vegetation cover into three major types of forest, i.e. Teak dominant, Teak Mixed, and Dry Mixed Deciduous. It was observed from the spatial distribution of each vegetation type, the Teak dominant type was occupying the major extent (46.6 %) of the park. Mixed forest type was the lowest in the distribution covering 87 km^2 and occupying 10 % of the total area.

Teak dominant forest had the largest patch Index with 5.5%, while the mixed dry deciduous forest had the smallest patch size with an Index with 0.1 %. The total number of patches varied from 7154 to 30970 among the classes of the landscape. Mixed dry deciduous (MDD) forest had the maximum number of patches, while Butea woodland had the minimum number of patches in the entire landscape. In terms of patch density, mixed dry deciduous had the maximum patch density (PD) with 14.5 patches per sqkm. The forest loss was very prominent in the buffer areas and Chindwara portion of the National Park. There was a conspicuous increase in the forest cover within the National Park and Sanctuary, and areas close to southwest portion adjoining the reservoir.

Initial observations, made an assumption that food plant density and ground cover and teak mixed forest type were the driving factors for gaur distribution, but the factors responsible for the suitable habitat were found to be gentle slope, mid elevation range (450 to 550 msl), and the water availability. The suitable habitat available for the gaur was eventually used by livestock also which in turn contributed to the fact that gaur had to restrict their movement only to the eastern portion of the reserve.

Five domestic elephants (2 male, 2 female & 1 calf) were brought into PTR by the Park management Authorities during the year 1999, in order cater to the tourism needs and for the anti-poaching patrolling. During summer, more than 95% trees and shrubs remain leafless and the ground layer is yellow-brown in colour. It is expected that for the available browse in summer, including bamboo, the competition between gaur and the domestic elephants will be much higher. If the present browsing pressure of elephants on these bamboo patches continues, it will lead in to depletion of food recourses for gaur in the coming years. It is suggested that the park authorities should initiate a short-term study covering all the major seasons, in order to understand the level of competition between domestic elephants and gaur for the available recourses in Pench.

The fires are more frequent in Pench during the months of February to June. During the summer, the dry litter on the forest floor and the other dry vegetation makes Pench more prone to fires. It is observed during the present study, gaur completely avoided burnt areas. It is suggested that in high fire risk areas, regular patrolling is required during summers to prevent fire occurrences.

Past records in the country indicate that populations of gaur have succumbed to epidemics of foot and mouth disease (FMD), rinderpest and anthrax in many areas of distribution. This is largely due to the fact that gaur has little immunity to some cattle diseases. The reserve authorities with the help of local veterinary hospitals conduct vaccination programme for the domestic cattle in some villages located around PTR. This service needs to be extended to all the 99 villages located in and around PTR. The Pench Tiger Reserve shares its boundary with South Seoni Territorial Forests

Division on the north and north-eastern side. These areas are important seasonal movement routes for gaur during summer. The forest cover in these three areas is very similar and is managed as different administrative units by the Madhya Pradesh Forest Department (South Seoni Territorial Forest Division and Pench Tiger Reserve) and Maharashtra Forest Department (Maharashtra Pench Tiger Reserve). Inter state coordination between Maharashtra and Madhya Pradesh Sates in managing the `Greater Pench Conservation Unit' (GPCU) is the need of the hour. It is suggested that the Rookahard Territorial Forest Division, currently managed by the South Seoni Forest Division, should be included in the Pench Tiger Reserve in order to make is as a single administrative unit for effective management and conservation of large mammals.

The Central Indian Highlands harbor approximately one fourth of the present gaur population surviving in the country. But the exact status of the present thriving populations and the condition of their habitat is not known. The suggested survey on the `status of gaur in Central Indian Highlands' will provide a comparative analysis of the sites in which long term ecological studies on gaur should be conducted, important corridor used by gaur populations, help in understanding the distributional patterns of gaur in areas with similar habitats as well as of dissimilar floristic composition.

Chapter 1

Introduction

1.1 Vegetation ecology

Seasonally dry tropical forests have a wide global distribution and coverage. Nearly 42% of tropical forests around the world are composed of seasonal dry plant communities. (Murphy and Lugo, 1986). However, most scientific efforts regarding conservation status of tropical vegetation have focused on the current and future loss of tropical rain forests, and less focused on seasonally dry forests (Mooney et al. 1995). Degradation of these seasonal forests is similar to or higher than that of tropical rain forest. As a result there is small fraction of the dry forests remains intact (Janzen, 1988). Despite these isolated reports, quantitative assessments of their conservation situation remain extremely scarce, in comparison to the situation for tropical rain forests.

It is the developing countries that harbour the most diverse and rich natural resources, the tropical forests, due to which the degradation and disruption of these habitats is faster as compared to the other forest. Unlike temperate forest species, which are far less abundant, tropical forests species have specialized ecological requirements.

There is enormous conservation interest in long term changes in vegetation cover arising from habitat conversion and fragmentation. (Anderson et al. 1997). In forest, variation in species composition or structure often results from past disturbance. (White, 1979, Veblen, 1989). Disturbance is partly responsible for spatial mosaics in vegetation and is a dynamic process. The structural characteristics of the vegetation cover and their spatial distribution are the most important among the various parameters. Also increasing pressure on land has resulted in rapid changes in such natural areas. Thus understanding green vegetation cover is required in many studies of global and local change monitoring. These studies are fundamental to understand the ecology in the region.

1.2 Forests of Central India and Pench Tiger Reserve

According to Champion and Seth (1968), the forests of Central Indian Highlands are classified into five major groups and seven subgroups, as following:

I. Tropical Semi-evergreen Forests
   - Northern tropical semi-evergreen forests

II. Tropical Moist Deciduous Forests
   - South Indian moist deciduous forests
   - North Indian moist deciduous forests

III. Tropical Dry Deciduous Forests
   - Southern tropical dry deciduous forests
   - Northern tropical dry deciduous forests

IV. Tropical Thorn Forests
   - Southern tropical thorn forests

V. Subtropical Broadleaved Hill Forests
   - Southern subtropical broadleaved hill forests

Pench Tiger Reserve vegetation types can be described under the following groups.

I. South Indian Tropical Moist deciduous-

- 3 BC 1 C. Slightly moist teak forests.

II. Southern Tropical Dry Deciduous Teak bearing Forest:

- 5A/C1b Dry teak forests
- 5A/C3 Southern dry mixed deciduous forests.

1.3 Gaur (*Bos gaurus*) description

Gaur (*Bos g. gaurus)* is the tallest living oxen (Brander), and the second heaviest (Krishnan 1972). Gaur bulls weigh 600-1000kg and stand 1.6 to 1.9m at shoulder whereas cows are about 10 cm shorter and weigh about one fourth less than the males. One of the most striking features among gaur is the muscular ridge upon its shoulders, which slopes down to the middle of the back where it ends in an abrupt dip. This is often referred to as the dorsal ridge and is the result of the extension of the dorsal vertebrae. Both sexes have horns, in the males especially are larger at base with more outward swath and the curving at the tips is less. There is high bulging forehead ridge between the horns. The average spread / length of horn is 80-100 cm. The distance between tips of horns may be up to 120 cm. The colour of the eyes is brown. Gaurs are known to have acute sense of smell and good hearing but the visual senses are relatively less developed.

The old males have two prominent skin folds (dewlap), one small at the chin and the other hanging below throat. At the time of the birth the newly born calf is light golden yellow, which slowly changes colour with the age. The younger bulls and females have brown pelage but the older males are almost jet black. The forehead is ashy and both hind and fore legs are white or slightly yellowish colour up to the knees, forming stockings.

Gaur is a gregarious animal. The group structure is very fluid and dynamic. The group size may range from 2-16 animals or, sometimes more than 20 animals. A group usually consists of cows and few calves, one to two adult bulls and sub adults. Younger bulls may sometime join to form a bachelor herd. Old males are generally solitary in nature and only join the herds during the rut. Adult cows generally lead the herd. Cows and young usually stay in-groups. The strongest bond is of mother and the calf.

Gaur is a generalist feeder but prefers to browse in dry season and predominantly graze in monsoon. Their diet chiefly includes shoots and foliage of trees, shrubs and, buds, fruits like of *Diospyros melanoxylon* and *Aegale marmalos*, tender seeds of bamboo, herbs, grasses and bark of trees like *Adina cordifolia* and Tectona *grandis*. They visit salt licks periodically. Being an obligatory drinker, gaur needs water every day and may visit water bodies twice a day during the hottest periods. During the hot hours of the day gaur retire to the shelter under thick tree cover and ruminate. Feeding is more predominant during the early morning and evening hours. On an average they feed for 15-18 hours a day. Gaurs by nature are shy animals. The bulls rarely fight and exhibit their massive body in form of lateral display. They snort and give *phoo* calls when alert. During the rut the males produce rutting calls with very high pitch and can be herd at long distances. The bulls exhibit flehmen, an up curled lip movement, when approaching a cow in heat. The time of mating season or rut varies across its distribution ranges but has definite peaks. But some individuals do breed throughout the year. In central India the peak rutting period is from March-May. Cows give birth to a single calf after a gestation period of eight to nine months. Twins may be very rare. The cow moves away from the herd before giving birth and remains with the calf for a few days before rejoining again into the herd. The newly born calf becomes active after a few hours of birth and stays with the mother. For almost 5-8 months the young suckles milk from mother and then switches over to green feed. The natural predator of gaur is tiger (*Panthera tigris*) and leopard (*Panthera pardus*) is known to predate on calves and yearlings of gaur.

1.3.1 Evolutionary history of gaur

Gaur belongs to the family Bovidae, whose evolution dates back to Lower Miocene period, almost 20 million years ago (Gentry 1992, Vrba 1985). The oldest fossils are known as late as the beginning of the Upper lignite era (Grzimek 1972). Since then the bovids have undergone a rapid radiation, unparalleled in other groups of large mammals (Hedges 1997). The family Bovidae, in addition to cattle and buffaloes, includes. This family, also consisting of antelopes, sheep and goats, dominates the Old World and is well represented in Asia. As far as the diversification of the Bovids is concerned they are one of the most diverse groups amongst the mammals. There are more than 125 extant species in almost 50 genera and approximately 300 extinct species. This diversification has posed a great problem in bovid systematics (Hedges 1997) and thus considered as most troublesome groups of mammals to classify (Simpson 1945).

Gaur (*Bos gaurus*) along with wild cattle represents the group of wild oxen. The original home of the wild oxen is Asia and most of the present surviving species are confined to this continent (Grzimek 1972). Most of the species of wild oxen could successfully survive only in Asia and Africa. In contrast, European and North American wild oxen were almost exterminated from the wild and presently few that have survived are present in protected areas and zoological gardens (Grzimek 1972). There are 9 species and 21 subspecies of wild oxen in the world belonging to four genera. These include the Asiatic buffalo, African buffalo, true cattle and bison. All these members are a part of the family Bovidae, which contains all artiodactyls ungulates possessing non-deciduous horns mounted on bony cores. The horns are always present in males but may be less developed or absent in the females of many species. The genus *Bos*, to which gaur also belongs is distributed in Europe and Central Asia (Eisenberg 1981).

PTR offers a unique opportunity for research into the aspects of both the ecology and the management of gaur populations and their habitats. This is due to, both, the diverse pattern of habitat, as a result of rich floral composition and varied topology, and gaur populations that can readily be seen almost throughout the year. Though the exact status is unclear, Central India supposedly harbors approximately one fourth of the present gaur (*Bos gaurus*) population surviving in the country. In Madhya Pradesh alone, the gaur population is found in 10 districts and they are geographically isolated from one another.

1.4. Vegetation and large mammal interaction

The animal-habitat relationship is very intricate and depends upon a number of abiotic and biotic factors which may also vary considerably from one ecosystem to another. Abiotic factors include climate, geography, geology, altitude, and spatio-temporal availability of water, whereas biotic factors include vegetation, wild animals and other biotic factors such as domestic stock, man and his activities. Activities such as hunting, predation, starvation, and disease, as decimating factors, and the extreme environmental conditions which affects wildlife by influencing them (Leopold 1933). Some of the important factors which plays important role in the ecological interactions between wild animals and vegetation are discussed here in this study.

1.5 Use of Remote sensing and Geographical information systems techniques in the study

Remote sensing techniques have emerged as one of the most appropriate technologies to accomplish information on vegetation characteristics. Remotely sensed estimates of regional variation in biodiversity can be useful in analyzing diversity patterns, monitoring changes, and aiding in conservation efforts. This technique can be used for mapping a variety of ecosystem patterns and process correlated with vegetation types. The advancement and improvement of these techniques in the recent years had made possible of quantifying the structural changes more precise and accurately. In the present study remote sensing and GIS techniques has been applied extensively to study the vegetation community, structure s and their quantification. Potential gaur habitat was predicted using the spatial information derived from using the techniques.

1.6 Objectives of the study

The main objectives of the study are :

- To study vegetation communities, composition, species distribution, abundance and richness in Pench Tiger Reserve, Madhya Pradesh.
- To map vegetation types and quantify landscape characteristics in PTR, Madhya Pradesh.
- To evaluate the available habitat and predict the suitable gaur habitat available in PTR.

1.7 Organization of the thesis

This Thesis is composed of five chapters. First chapters deals with the general introduction to the vegetation ecology, description on the central India vegetation, details of the study animal and objective of the study. The chapter 2 deals with the description of the study area in details such as topography, soils, geology, geomorphology, climate, drainage, flora and fauna. The chapter 3 deals with the assessment vegetation communities, their composition, species diversity, abundance and richness in the study area. The chapter 4 describes the mapping and quantification of the vegetation communities using the remote sensing and GIS techniques. Chapter 5 discusses the model predicting suitable gaur habitat surface available in the Pench Tiger Reserve. The chapter 6 discusses the conservation of gaur in Pench Tiger Reserve.

Chapter 2

Study Area

2.1 Introduction

Pench Tiger Reserve (PTR) (77° 55' W to 79° 35' E & 21° 08' S to 22° 00' N), lies in the southwestern region of the state of Madhya Pradesh (Map – 1 & 2**).** The Tiger Reserve comprises of the Sanctuary and the National Park of the same name, covering an area of 757.85 sq. km (Map 4). Pench Tiger Reserve is located 98 km. north of Nagpur (Maharashtra) and 12 km. from Khawasa (Madhya Pradesh) on the National Highway No. 7.

2.2 History and management units

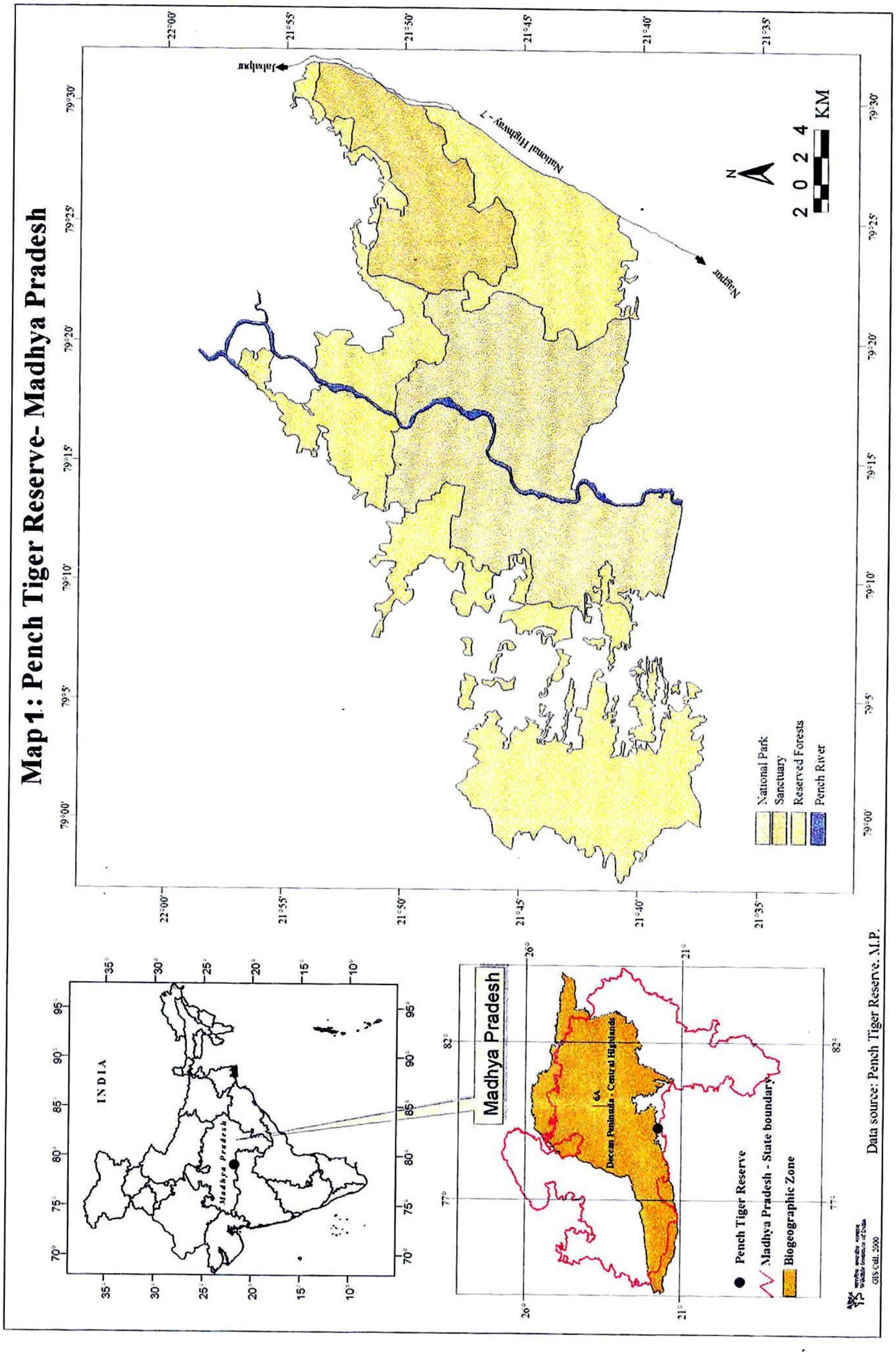
This part of Central India has been a major attraction for naturalists as well as sport hunters. Descriptions of its natural wealth and richness appear in the writings dating back to the 14th Century. Ain-I-A-Akbari and the references available on Deogarh Kingdom of the sixteenth century also give passing remarks on the wildlife of this area respectively. (Forsyth 1889, Sterndale 1887, Brander 1923) have given a good detailed account of the distribution of the flora, fauna and the local inhabitants of Central Indian Highlands and this tract. The well known work of Kipling "The Jungle Book" too revolves around this tract of Satpura.

In 1862, Col. Pearson, the Officer-in-Charge of the Armed Police stationed at Seoni was appointed as the first Conservator of Forests of Sagar and Harda, which included the forests of Seoni and Chindwara. In 1863, the first Inspector General of forests India, Dr. Brandis, toured the area and laid down the policies for these forests. In 1929 these forests were declared as Reserve Forests. Hunting permits were given up to 1970-71. In 1949-50, 49 tigers were shot in the area. Forsyth (1871) shot many small and big mammals from this area.

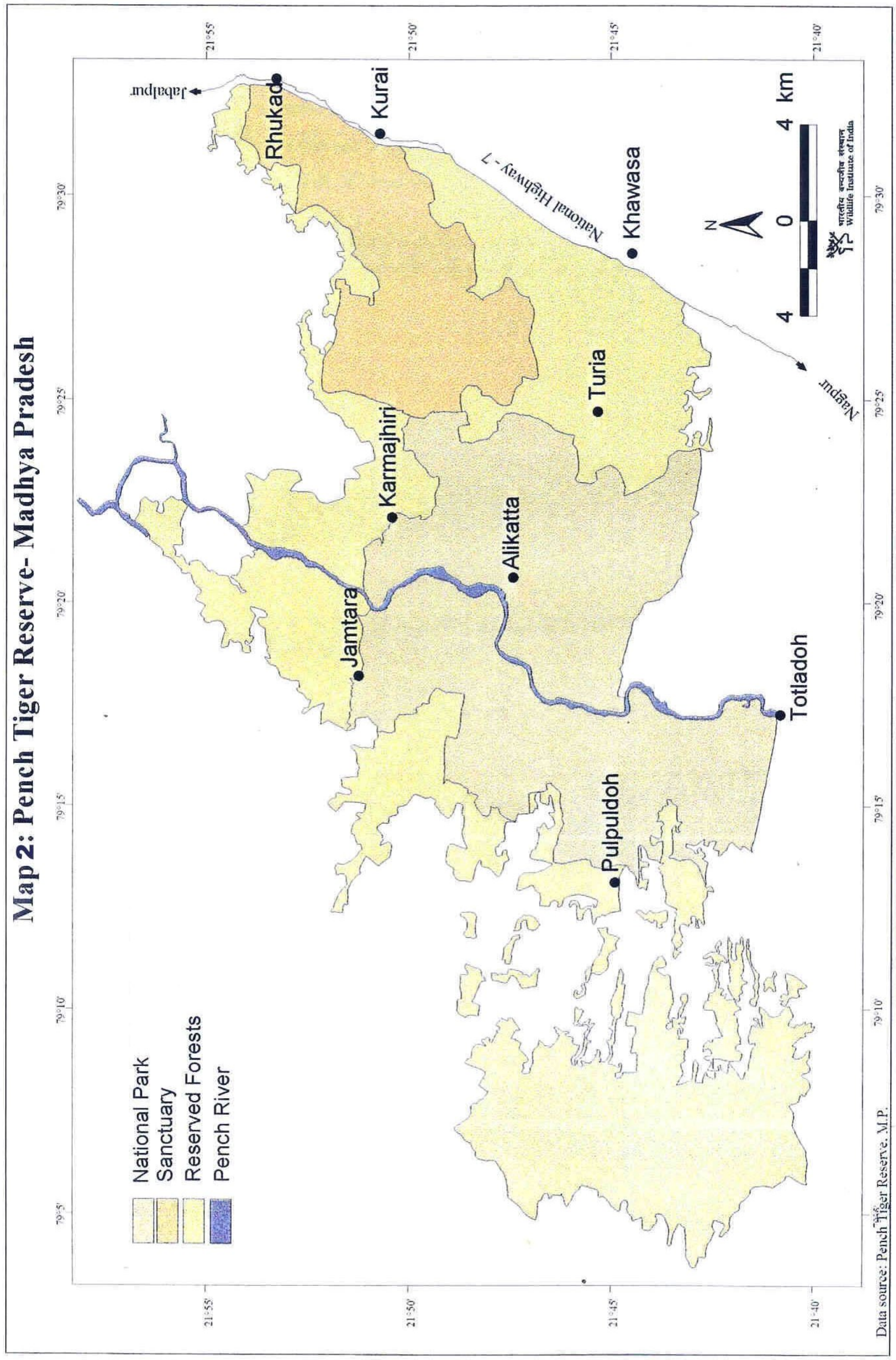
In 1977 an area of 449.39 sq. km. was notified as the Pench Game Sanctuary; vide Madhya Pradesh State Forest Department Memo No. F/15/77-10(3) Bhopal, dated 30.09.1977. In March 1983, the Government of Madhya Pradesh notified its intention to constitute an area of 292.85 sq. km. as Pench National Park, to be carved out of the pre-existing Pench Sanctuary area vide notification No. 15/5/82-10(2) Bhopal dated 01.03.1983 (3). The present Pench Tiger Reserve was included into the stream of the Tiger Reserves in 1992. This was then the 19th Tiger Reserve of India.

The Pench River, from which the reserve derives the name, flows through the center of the park dividing it into the west Chindwara and the east Seoni block. The total area of the National Park is 292.85-sq. km. out of which 145.24 sq. km. lies in Seoni District and the rest in Chindwara District.

On the southern end of the river stands a dam. The dam was constructed on the Pench river under the Pench Hydro-electric Power Project in 1987, which resulted in the submergence of 74 sq. km. of the forested area, of which 54 sq. km. lies in PTR (Madhya Pradesh State) and rest in the State of Maharashtra. The dam marks the State boundary of the two states. The dam has been built for the generation of electricity and irrigation facility for both the States of Madhya Pradesh and Maharashtra.



Map1: Pench Tiger Reserve- Madhya Pradesh


Map 2: Pench Tiger Reserve- Madhya Pradesh
National Park
Sanctuary
Reserved Forests
Pench River
Jabalpur
Rhukad
Kurai
National Highway - 7
Khawasa
Turia
Nagpur
Karmajhiri
Alikatta
Jamtara
Totladoh
Pulpuldoh
4 0 4 km
N
Wildlife Institute of India
Data source: Pench Tiger Reserve, M.P.

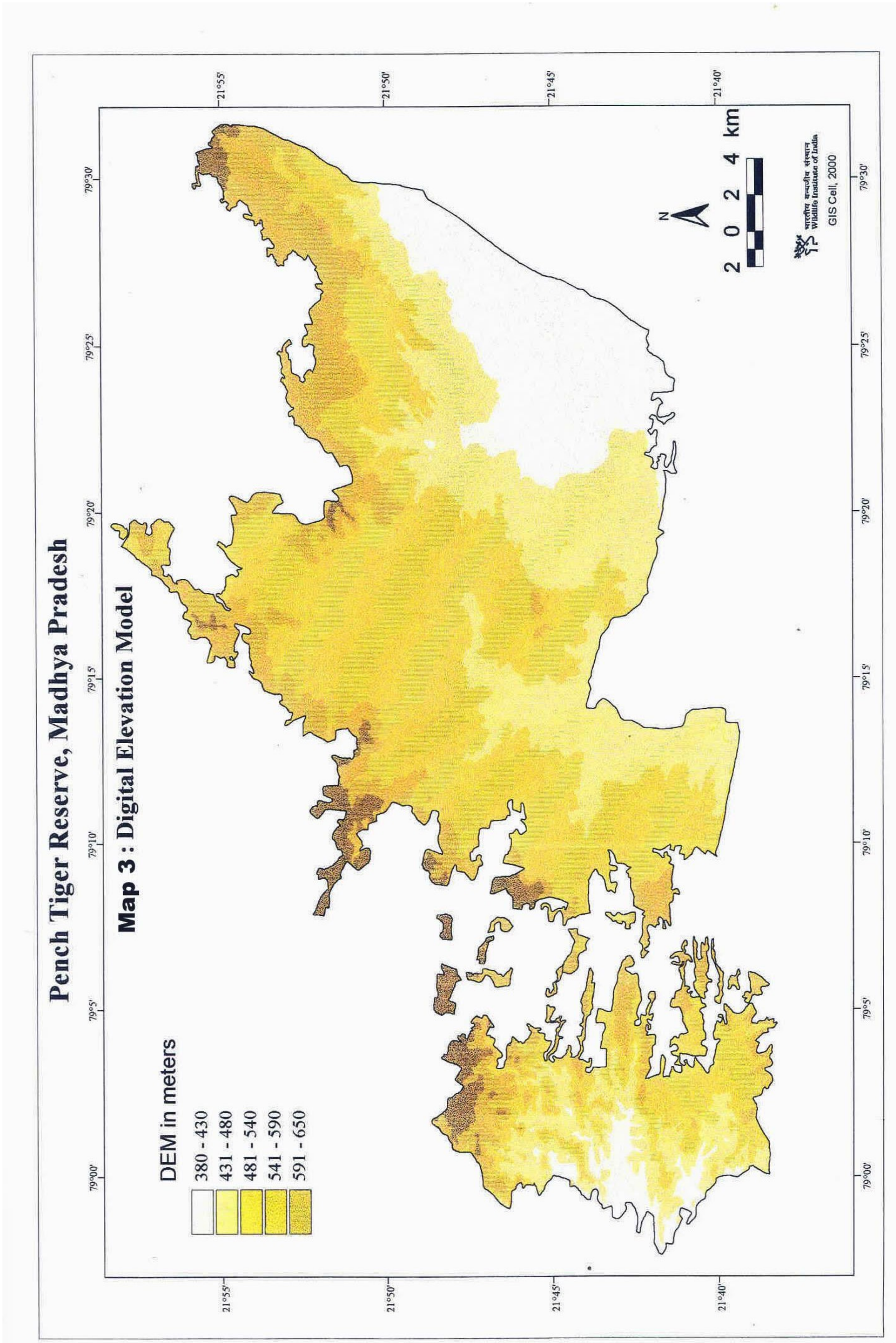
Pench forests have been the key place in the natural history of central India in general and for wildlife in particular. Famous naturalist captain J. Forsyth , A.A.D. Brander and Rudyard kipling also presented a vivid account of this area in their books “Highlands of central India” “Wild animals in central India” and “Jungle book” respectively.

2.3 Physical attributes

2.3.1 Topography

PTR lies in the southern lower reaches of Satpura Hill ranges. The terrain is gently undulating and criss-crossed by small streams and nullahs; most of these are seasonal. The Pench river runs through the Park covering a length of 24 km. and bisecting it into almost equal halves. The hills have gradual to steep slopes with almost flat tops. (Map –3) depicts the detailed terrain outlay of PTR.

Some of the prominent hills of the area are Chindimatta, Khumbadeo, Khairban matta, Arjal matta and Kalapahar. The term “matta” implies the hills in local Gondi dialect. Of the hills present in the area, Kalapahar is the highest with an altitude of 650 m. In Chindwara block on the west bank of Pench, the land has risen and resulted in the formation of the plateau between Jamtara, Naharjhir and Gumtara villages. A number of valleys and ravines have resulted due to much dissected terrain. The mean altitude is 550 m and maximum height reaches up to 640 Msl.


Pench Tiger Reserve, Madhya Pradesh
Map 3 : Digital Elevation Model
DEM in meters
380 - 430
431 - 480
481 - 540
541 - 590
591 - 650
N
2 0 2 4 km
Wildlife Institute of India
GIS Cell, 2000
79°0'0'
79°5'
79°10'
79°15'
79°20'
79°25'
79°30'
21°55'
21°50'
21°45'
21°40'

2.3.2 Soil types

Four major soil types are found in PTR. The sandy loam, red soil, kankar and saline soil and the alluvial soil.

1. Sandy loam soil: Most of the area inside the reserve is covered with sandy loam soil. The soil is the result of weathering of granites gneisses. This soil type most commonly occurs on gentle slopes and valleys.
2. Red soil: The higher elevated areas are predominantly covered with red soil. The soil varies from the shallow, poor, gravely and light coloured varieties on elevated areas to much more deep, fertile and darker varieties occupying the lower plains and valleys.
3. Kankar and saline soil: This soil type is found in the foothills in areas with less tree cover and forests gaps. They contain large proportions of silica and orthoclase quartz and have low water holding capacity. They are generally mineral deficient and have low productivity. They are easily eroded under insufficient vegetation cover.
4. Alluvial soil: This soil type is mainly confined to the banks of streams and Pench river. Alluvial soil consists mostly of the siliceous debris, washed down from the hills, mixed with humus. This soil varies to a great extent in the chemical and physical properties owing to the variation in the rocks, which form the debris from place to place. The colour is yellowish brown. This soil supports good teak (*Tectona grandis*) along the Pench river.

The National Bureau of Soil Studies (NBSS), Nagpur has identified 10 different soil types in PTR as shown in detail below (Table 2.1).

Table 2.1 Different soil types in Pench Tiger Reserve, Madhya Pradesh.

S.No.	Soil Types	Description	Proportion occupied in PTR
1.	***Loamy, mixed, isohyperthermic, Lithic Ustorthents, & Loamy, mixed, isohyperthermic, Lithic Ustropepts (6)***	Extremely shallow, somewhat excessively drained, loamy soil on steep slopping hills and will range with severe erosion and moderately stony, *associated with* shallow, somewhat excessively drained with loamy soil on steeply sloping with severe erosion and strongly stony.	14.21% of PTR.
2**.**	***Fine, montmorillonitic, hyperthermic, Typic Haplusterts, & Loamy, mixed, hyperthermic, Typic Ustochrepts (48)***	Deep, moderately well drained, clayey soils on gently sloping undulating plateau with mounds, with slight erosion, *associated with*: shallow, well drained, loamy soils on gently sloping with moderate erosion and slightly stony.	1.0% of PTR
3	***Loamy, mixed, hyperthermic, Typic Ustorthents & Clayey, mixed, hyperthermic, Lithic Ustothents (50):***	Very shallow, somewhat excessively drained, loamy soils on gently slopping undulating plateau with mounds with severe erosion, *associated with,* very shallow, well drained, clayey soils on moderately sloping with moderate erosion.	29.82% of PTR
4	***. Fine, montmorillonitic, hyperthermic, Vertic Ustochrepts & Clayey, mixed, hyperthermic, Typic Ustochrepts (79):***	Deep, moderately well drained, clayey soils on gently sloping plain land with moderate erosion, *associated with*: Shallow, well drained, clayey soils on gently sloping with severe erosion.	10.62% of PTR
5	**Fine, montmorillonitic, (Cal.), isohyperthermic, Typic Ustropepts & Fine, montmorillonitic, (Cal.),**	Deep, moderately well drained, calcareous, clayey soils on gently sloping plainland with narrow valleys with severe erosion, *associated with*:	0.00013 % of PTR

	isohyperthermic, Typic Haplusterts (83):	Deep, moderately well drained, calcareous, clayey soils on very gently sloping with slight erosion.	
6	***Loamy-skeletal, kaolinitic, isohyperthermic, Typic Ustropepts & Loamy, kaolinitic, isohyperthermic, Lithic Ustropepts (91):***	Shallow, somewhat excessively drained, loamy-skeletal soils on moderately sloping hills and hill ranges with severe erosion and slightly stony, *associated with* : Shallow, somewhat excessively drained, loamy soils on moderately sloping with severe erosion and slightly stony	17.40% of PTR
7	***Loamy, kaolinitic, isohyperthermic, Typic Ustropepts & Loamy kaolinitic, isohyperthermic, Lithic Ustropepts (107):***	Shallow, well drained, loamy soils on moderately sloping beds (slightly dissected) with moderate erosion, *associated with*: Shallow, well drained, loamy soils on gently sloping with moderate erosion.	7.81% of PTR.
8	***Fine, mixed, isohyperthermic, Typic Haplusterts & Fine, mixed, isohyperthermic, Typic Ustropepts (108):***	Deep, moderately well drained, clayey soils on very gently sloping beds (moderately dissected) with moderate erosion, *associated with*: Slightly deep, well drained, loamy soils on moderately sloping with severe erosion.	0.608% of PTR.
9	***. Fine - loamy, kaolinitic, hyperthermic, Typic Ustochrepts & Fine, mixed, hyperthermic, Vertic Ustochrepts (113):***	Slightly deep, well drained, loamy soils on moderately sloping undulating lands with valleys with severe erosion, *associated with*: Deep, moderately well drained, clayey soils on very gently sloping with moderate erosion.	6.96% of PTR.
10	***Loamy, kaolinitic, hyperthermic, Typic Ustorthernts & Loamy, kaolinitic, hyperthermic, Typic Ustochrepts (137):***	Soils of undulating to rolling lands, very shallow, well drained loamy soil on gently sloping undulating rolling lands with severe erosion, *associated with*: shallow, well drained loamy soil on gently sloping with moderate erosion	10.129% of PTR.

2.3.3 Geology and geomorphology

Geomorphologically this area falls in the Peninsular Foreland of the peninsular division. The Peninsula is Archean and Pre-Cambrian in formations (Mani 1974). PTR is an extension of the Satpura – Mahadeo – Maikal Scarps. PTR has the following geological constituents: quartzite, granulites and dolomite marble.

The Deccan trap formation that occurred towards the end of Cretaceous (Mani 1974), otherwise prevalent in other parts of both Seoni and Chindwara districts, is absent within the limits of present boundary of National Park (Suhas Kumar 1990). Nine different geological zones are found in PTR, *viz.* Amphibolites, Basalt, Chorbaoli formation, Gneisses, Lameta formation, Laterite, Lohangi formation and Manganese ore (Map –4 & 5). Gneisses occupy 72.54% of Park and is the major geological formation. This is followed by Basalt (20.73%), Chorbaoli formation (1.82%), Lameta formation (1.7%), Pench River (1.4%), Lohangi formation (0.82%), Laterite (0.7%), Manganese ore (0.17) and Amphibolites (0.12%). On the basis of the image characteristics and convergence of evidence the geomorphologic units have been distinctly identified in the study area. They are Denudation Hills, Inselbergs, Pediments, Buried pediments, alluvial plains and Plateaus (Map 8). A detailed account of these geomorphologic units is given below:

Denudational Form

A) Denudational Hill: These are the long continuous or isolated hills, showing-weathering residue of the parent rock. Different trends can be found on the top of the hills. These are basically located in the South-East portion of the study area and composed of granite and granitic gneisses. They can rise abruptly from the pediment. The erosion is also prominent on these hilltops.

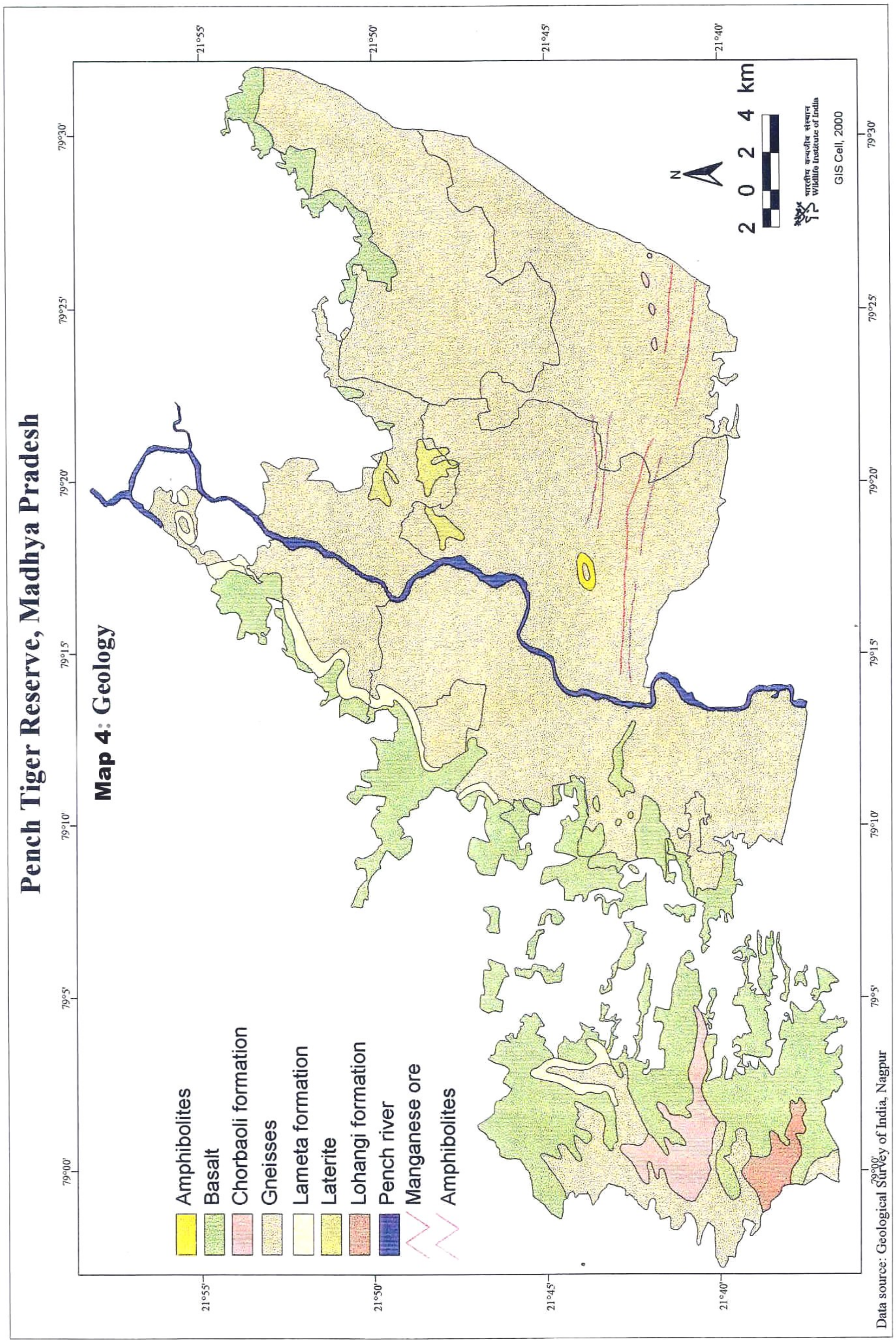
B) Plateau: Plateau is an extensive upland region at high elevation with respect to its surroundings. These are vastly spread on the North-West and Western part of the study area. The Deccan Trap Complex (plateau) is made up of Basalt showing weathering followed by high erosion. The forms in the trap are observed like, Mesa and Butte. Some part of the trap is also lying in North and North-West direction in the study area.

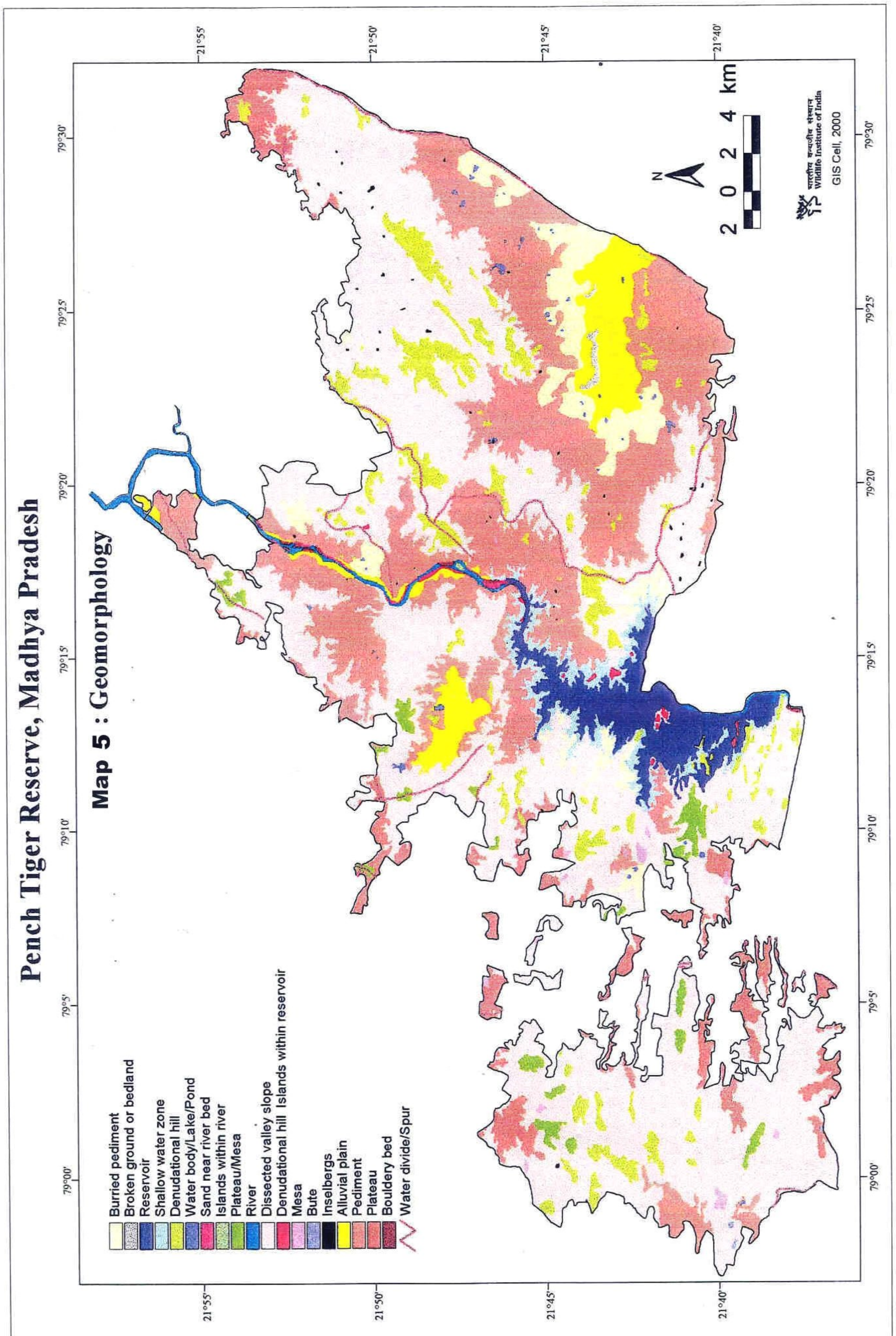
C) Mesa: A flat-topped, steep sided upland. They are larger than Butte in size and have been observed mostly in the basaltic terrain of West and North-West portion of the study area.

D) Bute: A steep side and flat top hill formed by erosion of flat lying strata where remnants of a resistant layer protect softer rocks underneath. The Butte has been observed in the Basaltic terrain. These forms are basically smaller than Mesa in size.

E) Pediment: The Pediments are the indication of semi-arid climate. During their formation debris of varying size accumulates on them. The Pediments diverge from the point where the profile is convex.

F) Buried Pediments: The occurrence of Pediments and Buried Pediments at different levels in the same area reflects the change in slope, local base level with thick regolith soil or alluvium soil. They are a result of numerous rills and sheet floods. They are fertile part and expression of denudational hills with extensive cultivation. The occurrence is found between alluvial plains and pediment.


Pench Tiger Reserve, Madhya Pradesh
Map 4: Geology
Amphibolites
Basalt
Chorbaoli formation
Gneisses
Lameta formation
Laterite
Lohangi formation
Pench river
Manganese ore
Amphibolites
N
2 0 2 4 km
Wildlife Institute of India
GIS Cell, 2000
79°00'
79°5'
79°10'
79°15'
79°20'
79°25'
79°30'
21°55'
21°50'
21°45'
21°40'
Data source: Geological Survey of India, Nagpur


Pench Tiger Reserve, Madhya Pradesh
Map 5 : Geomorphology
Burried pediment
Broken ground or bedland
Reservoir
Shallow water zone
Denudational hill
Water body/Lake/Pond
Sand near river bed
Islands within river
Plateau/Mesa
River
Dissected valley slope
Denudational hill Islands within reservoir
Mesa
Bute
Inselbergs
Alluvial plain
Pediment
Plateau
Bouldery bed
Water divide/Spur
N
2 0 2 4 km
Wildlife Institute of India
GIS Cell, 2000
79°00'
79°5'
79°10'
79°15'
79°20'
79°25'
79°30'
21°55'
21°50'
21°45'
21°40'

G) Water Divide: Water divides act as a firebreak in any region. They are the margins, which forms the catchments of macro and micro watersheds of the area. Eleven major and minor water divides have been observed in the study area, which in fact govern the water carrying capacity with other parameters like geology, soil, climate and drainage.

H) Dissected Valley Slope: This unit has been observed as a vast extensive unit in the study area, which is distributed all around the plateau and denudational hills. This zone is maximum subjected to rill and gully erosion. This terrain is more undulating with sparse rocky exposure. This is highly dissected with dendrite pattern. In some area some old debris slides or removals of blocks are also noticed.

I) Inselbergs: These are also isolated denudational ridges, which stand above the surrounding plains. These projections are rather abrupt. These may be conical or dome shapes. The rocks in these forms are of the same type.

Fluvial Forms

A) Alluvial Plain: These are gentler in slope almost flat with river borne sediments. They are either found on riverbanks or restricted within large drainage. They show the extensive cultivation on them. The soil type found on these landforms is sand, silt and clay. The river in summer is comparatively sluggish and channel depth is not much and as a result of sand bar the boulder bed has been deposited and exposed near the bank. Few Channel Islands have also been observed within the river.

B) Erosional Features: Erosion is a term, which is used to denote geological agencies of movement, which remove rock debris and associated materials. The erosion agencies are of various types, of which running water is the predominant. In the study area most of the genesis terrain is subjected to sheet erosion, rill erosion and gully erosion.

C) Sheet Erosion: When water just removes the topsoil from the pediment slopes, this results in the irregular patches of country rock. This is a major process in the denudation of the land surfaces.

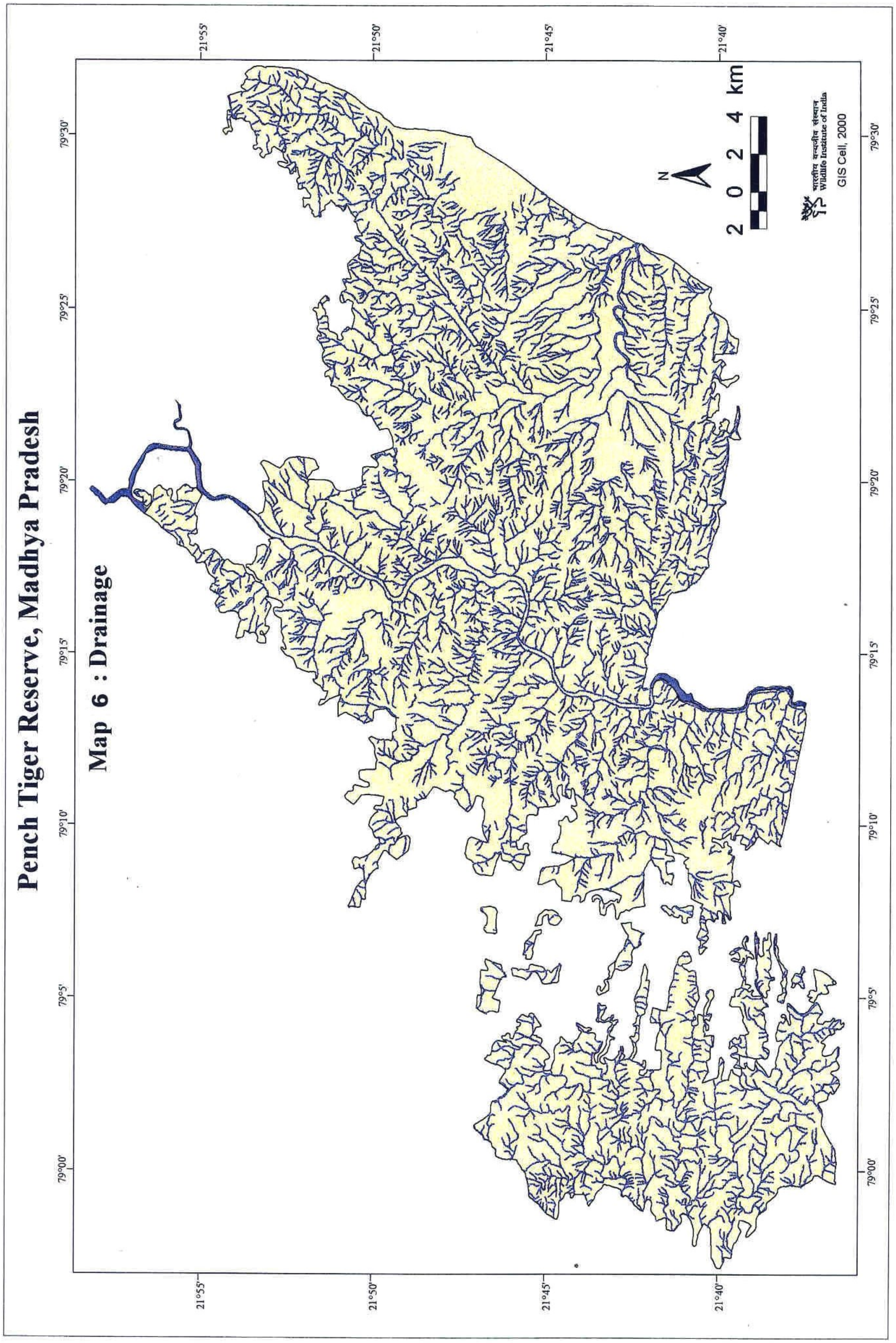
D) Rill Erosion: These are observed basically on water divides when sheet erosion merges into network of rills. This erosion is confined to particular hilltops.

E) Gully Erosion: Next to rills are the gullies. These have a tendency to have close network and drainage lines. This occurs because of thinning of vegetation cover, climatic change and other man-made interventions. The head-ward erosion may also consider within it.

2.3.4 Drainage

The Reserve has number of streams and nullahs, but most of them are seasonal. The Pench river that flows almost through the center of the Park is the lifeline for the area. The river dries out by the month of April and as a result several puddles of water are formed, locally known as ‘doh’ or ‘kassa’. There are also few perennial water sources occurring in the sanctuary and as well as the national park. In 1990, 54.51-sq. km. area of the Park was submerged as a result of the construction of the hydroelectric dam. This has led to the formation of a large reservoir that not only attracts animals during the lean period but also many waterfowl and migratory birds during the winter. In addition to this there are two small tanks, the Bodhanala tank in the eastern block of the Park and the Dudhgaon tank occurring in the west block of the Park.

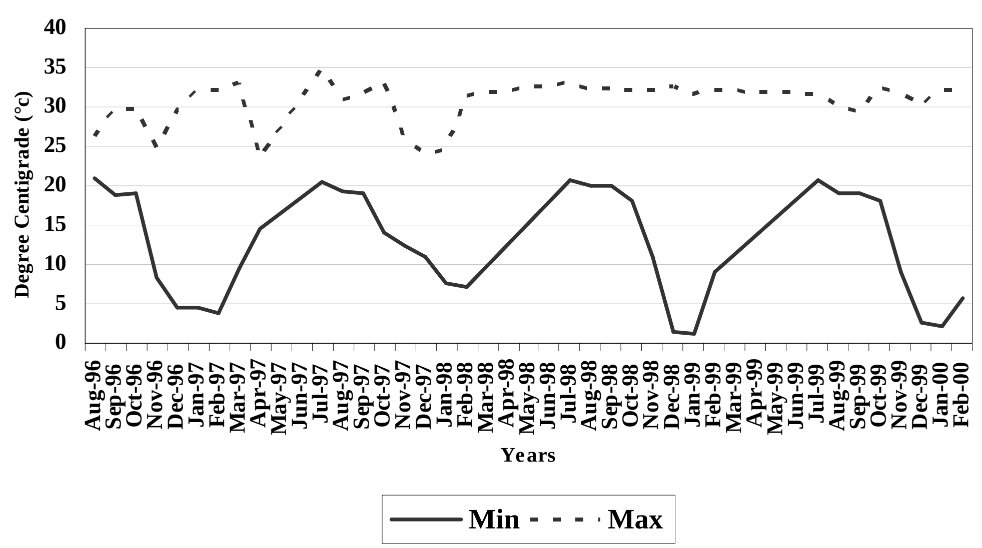
During the summer the water resource becomes limited and scattered. To combat this problem at several places the management in PTR has constructed artificial water holes. The water is supplied to these water holes with the help of installed hand pumps in the near vicinity. Of late many anicuts and check dams have also been built to trap the available water. The detailed drainage pattern of PTR is given in (Map –6).


Pench Tiger Reserve, Madhya Pradesh
Map 6 : Drainage
N
2 0 2 4 km
Wildlife Institute of India
GIS Cell, 2000
79°00'
79°5'
79°10'
79°15'
79°20'
79°25'
79°30'
21°40'
21°45'
21°50'
21°55'

2.4 Climate

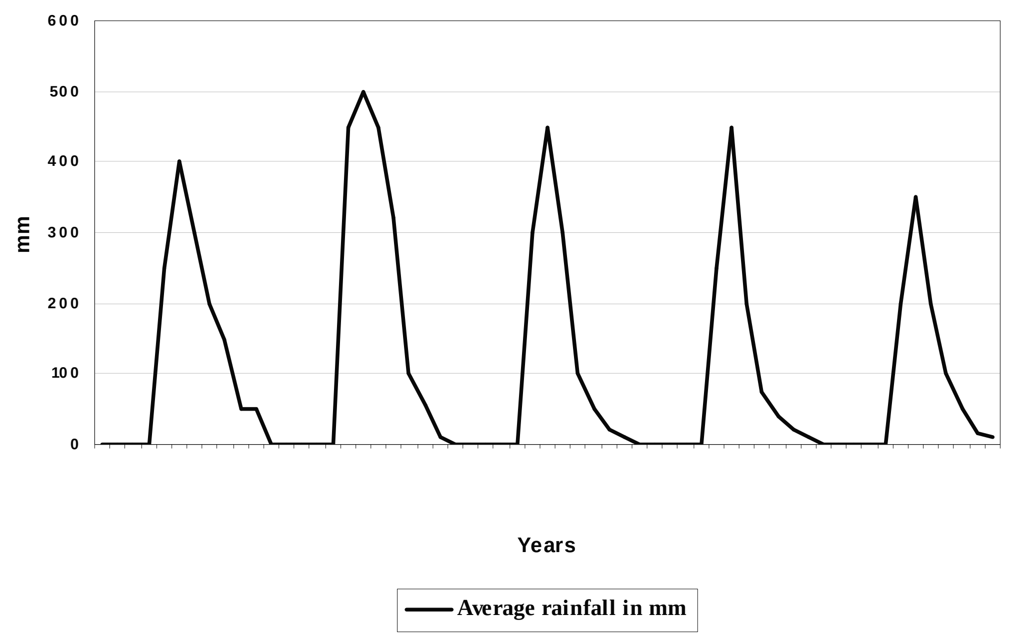
Climatically the area has four seasons. The summer, lasting from March to June, monsoon (July to August), a short post monsoon from September to October and winter (Mid November to February). The annual range of temperature varied from as low as -2°C in peak winter to as high as 49°C in peak summer (Fig. 1). The average monthly temperature varied from a minimum of 1.5°C in winter to a maximum of 35°C in summer. The lowest average minimum temperature (1.5°C) was recorded in the month of December 1998 & January 1999. The average maximum temperature (35°C) recorded in Pench was in the month of June 1997. During the year 1998, the average maximum temperature showed little variation and remained almost 32°C throughout the summer. The average daily maximum and minimum temperature fluctuation ranged up to 18°C.

Figure .1. Minimum & Maximum Temperature in Pench Tiger Reserve, M.P. (1996-2000)



The average annual rainfall in Pench ranged form 1300 mm to 1400 mm (Fig. 2). The highest rainfall was recorded in the month of August 1997 with 500 mm. The lowest rainfall was recorded in the year 1996 & 2000, which were drought periods in the Pench Tiger Reserve. Pench experienced pre-monsoons showers in the month of April & May and post-monsoon showers during the months of September to November, leaving the months December to March dry.

Figure.2. Monthly Average Rainfall in Pench Tiger Reserve, M.P. (1996-2000)



2.5 Biological attributes (flora and fauna)

Zoo-geographically PTR is a part of Oriental region and floristically it belongs to the Indo-Malayan region. The vegetation of PTR is tropical dry deciduous forest (Champion and Seth, 1968). Teak dominant, Teak-Miscellaneous, *Butea-Zizyphus* woodland, Miscellaneous forests with bamboo, *Anogeissus-Boswellia* mixed forest and Riparian vegetation are the major vegetation associations found in PTR.

PTR is one of the potential habitats of gaur in Central India. In addition to gaur, the other wild ungulates occurring in PTR are chital (*Axis axis*), sambar (*Cervus unicolor*), nilgai (*Boselaphus tragocamelus*), barking deer (*Muntiacus muntjack*), chausinga (*Tetraceros quadricornis*), chinkara (*Gazella benetti*) and wild pig (*Sus scrofa*). The key predator species existing in the area are tiger (*Panthera tigris*), leopard (*Panthera pardus*) and wild dog (*Cuon alpinus*).

As far as the avifauna is concerned a total of 262 species of birds have been recorded from PTR. **(**Pasha et al. 2003) Among the birds sighted, 162 are resident, 77 winter visitors, 5 summer visitors, 17 local migratory and 5 vagrant / straggler species. Among the lower vertebrates there are 19 species of snakes, 4 species of turtles, 5 species of amphibians and 18 species of fishes (Suhas Kumar 1990).

2.6 Fire

PTR, being mainly a dry deciduous habitat, experiences fire annually in the summer months. Pench River has been severely affected in the past as a result of increased anthropogenic pressures. The fire occurring in PTR can be broadly termed as below canopy fires. These fires largely remain restricted to the shrub layer and result in the depletion of the ground herbage. They also pose a serious threat to the ground dwelling fauna, as most of the species breed at this time of the year. To combat such situations the management in PTR has taken preventive measures by constructing fire lines.

2.7 Socio-economic attributes

Several tribes, among whom the Gonds are most prominent, inhabit this part of the central Indian highlands. In the early 17th century the Gonds were politically very active and ruled much of this tract (Rangarajan 1996). The gonds ruled over the plateau region of Satpura in 17th century. The first gond king was Jataba who built the Deogarh fort and formed the gond Kingdom. It is the gonds who have given this country their name to this country the “Gondwana Land” (Forsyth 1871).

The lingual similarity between gonds and Tamil folks of southern India bear the testimony that the gonds are a part of the same lineage as the Dravidians of South India (Forsyth 1871). In the past, gonds inhabiting the interiors of the forest and hills were largely hunter-gatherers while those in the foothills and on the fringes of the woods took to agriculture.

At present there are 99 villages within five-kilometer radius of the periphery of the Pench Tiger Reserve. The total population of these villages stands to be 50,000 heads (1981 Population Census Report).

2.8 Major Research conducted in Pench Tiger Reserve.

Pench has a long history of research and studies conducted so far include both floral and faunal component of the park. Earlier study done by Shukla (1990) described the ecological interaction between wild animals and vegetation in Pench sanctuary and its environs.

Jeyapal (1997) carried out the intensive study on bird community relationship with vegetation community structure. Bhaskar (1997) carried out research on the wild ungulate population density estimate of Pench Tiger Reserve. Sayantan (1998) conducted research on the prey base density estimate for tigers in Pench Tiger Reserve. David (2001) conducted a study on Protected Area Management and human Wildlife conflict interface. Bhaskar (2007) studied on Ecology of Wild dog in Pench Tiger Reserve.

Chapter 3

Vegetation communities, composition, and species richness

3.1 Introduction

Forests are very important to the developing world because they protect watersheds needed for agriculture activity, they provide timber needed for construction and industrial development and fuel wood for cooking and heating, serve as sources for genetic material and regulate global bio-geochemical cycles. (Brown et al. 1995).

Tropical forest covers only seven percent of the earth's land surface, yet they consist between 40 and 50 percent of all animal and plant species. A much as 86 percent of the forested area of India is under tropical forest, of which 53 percent is dry deciduous, 37 percent moist deciduous, and the rest is wet evergreen or semi evergreen. (Kaul et al. 1991). Tropical dry deciduous forest represents some of the world's most threatened ecosystem (Janzen 1988). Teak dominated vegetation has been recognized as the second largest Indian biogeographic province covering a potential area of 53 million hectares encompassing much parts of central and southern Indian peninsula. (Gadgil and Homji 1982).

Anthropogenic activities (eg. clear felling, cutting, selective logging, agriculture encroachment) and natural disturbance (eg. forest fires, insect attack) have resulted in substantial losses of the forest and fragmentation in tropical forest landscape. (Buch 1991, Prasad and Pandey 1992, Raven and Roy 1995, Roy and

Joshi, 2001). Disturbances is prevalent factor in the tropical dry deciduous forests. Factors like climate, season, canopy architecture, timing of canopy gap formation and insects out break governs the dynamics of the forest in terms of their structure and function of the ecosystem (Sukumar et al. 1992). In recent past there has been growing concerns for the preservation of tropical forests. More and more attention is being drawn to the conservation of all kinds of forests for their protective regulative and productive role in maintaining the earth's ecosystem. These forests are being degraded due to increasing demand for the forest resource as a consequence of rapidly expanding human population. Tropical forest has been exploited in several ways. One is the extraction of a variety of plant and animal products for the local use by people. Increasing pressure on these lands has resulted in rapid changes in such natural areas. The structural characteristics of the vegetation cover and their spatial distribution are the most important among the various others parameter. (Roy et al. 1992). Conservation management of forest requires understanding of the composition of particular forest in relation to other forests, the effects of past impacts on the present status of the forest and the present relationship of the forest with the surrounding land use. (Geldenhuys and Murray 1993). Information on these parameters at spatio-temporal scale also helps in conservation planning and restoration of degraded ecosystem.

Quantitative and qualitative study of vegetation is required to understand the ecology of the region. Enumeration of species richness, composition, distribution abundance in tropical forest provides important baseline information for research, conservation planning and management (Tackaberry et al. 1997). Vascular plants richness is an important ecosystem characterstics. (Hooper and Vitousek 1997, Tilman et al. 1997). Plant community concepts were derived in the beginning of the century from (Clements 1916). Clements believed that plant communities can be easily recognized, defined and these repeat with regularity. The importance of soil moisture was advocated by (Mall and Khan (1958), Daubenmire (1959), and Trivedi (1976) in development of herbaceous vegetation. Favorable condition of soil moisture and temperature initiate seed germination and sprouting of propagules and thus numerical strength of a species in a community (Agnihotri 1979).

Plant community structure can be characterized by six components: composition, size distribution, age distribution, spatial distribution, density of the individual and the history of disturbance that influence the population each of these components interacts at different spatial and temporal scales resulting in patterns of plant structure distributed in the landscape (Larsen et al. 1998).

Vegetation community structure has been described in many ways using bar charts for number of individuals by species, illustrating composition and histograms for number of individuals by size classes, illustrating size and age distribution (Harper 1997, Knox et al. 1989). It is imperative to understand the presence, abundance and distribution of plant species which is one of the significant constitutes of the animal habitat. The constituent elements of vegetation *viz*. plants species, and their assemblages also form the component of the biodiversity of a region that depends on various factors such as topography, soil, geology, altitude, aspects, slope and anthrogenic pressure.

According to Champion and Seth (1968), the vegetation of the Pench Tiger Reserve comprises of

I. South Indian Tropical Moist deciduous-

- 3 BC 1 C. Slightly moist teak forests.

II. Southern Tropical Dry Deciduous Teak bearing Forest:

- 5A/C1b Dry teak forests
- 5A/C3 Southern dry mixed deciduous forests.

However the following two vegetation types have been identified in the study area (Shukla 1990).

1. Teak deciduous forest
2. Miscellaneous deciduous forest.

This chapter deals with the overall vegetation communities characteristics, and their composition, abundance, Importance Value Index (IVI) of the Tiger Reserve and comparing species richness, density and diversity along with different management units of the Pench Tiger Reserve. The scientific names of plants are based on Champion and Seth (1968) and Bennet 1986) for the latest nomenclature.

3.2 Methodology

3.2.1 Field methods

Initially a reconnaissance survey was conducted to study the vegetation community distribution of the Pench Tiger Reserve. Based on the field observation different vegetation types were identified for stratified random sampling. Circular plots of 10 m (0.01 ha) were laid randomly within each vegetation type for measuring vegetation structure and composition. (Fig-3.1) Species circumference at breast height (CBH, 1.37 m above ground), height of the individual species, crown cover and GPS location of the plot were noted down. Nested within a radius of 10 m, a plot of 5 m radius was considered for the shrub and herb layer. Four 0.5 meter quadrats were laid within the plot at each major direction (North, South, East, West) for collecting information on ground cover such as litter, grass, etc. Individuals of the shrub and herb species were encountered and noted down. The size and the number of sampling units were determined by species area curve and running mean method respectively (Mueller-dombois and Ellenberg 1974). Individuals with CBH < 20 m were treated as trees, > 20 cm were categorized as saplings, and seedlings.

3.3 Data analysis

Data collected from the field were analysed for density, frequency, dominance, and abundance. The relative values of frequency, dominance, and abundance and density were used for determining IVI (Importance Value Index) (Curtis and Mcintosh 1950). Also, the above values were calculated for each species independent of their community association. Diversity of communities can be measured using species richness, species abundance or evenness. The Shannon and Wiener diversity index , evenness and richness were calculated using software package “PAST”. The distribution pattern were determined based on the abundance to frequency ratio (A/F). (Curtis and Cottam 1956). The IVI were calculated for each tree species, by adding relative frequency, relative abundance, and relative density. (Zang and Cao 1995), for each community. Also, overall IVI for each species were calculated from the pooled data observed in the sampling plot. The relative frequency, relative density and relative abundance of tree species were calculated using the following formula:

$$\text{Relative frequency} = \frac{\text{No of occurrence of species A}}{\text{Total number of occurrence of all species}} \times 100$$

$$\text{Relative density} = \frac{\text{Total number of individual of a species A in all plots}}{\text{Area of all the plots}} \times 100$$

$$\text{Relative abundance} = \frac{\text{Total basal area of the species A in all plots}}{\text{Total area of plots}} \times 100$$

The abundance value of the species was used for community classification using TWINSPAN (Hill 1979) software. The pseudospecies cut levels for abundance were chosen as

1-10% = 1
11-30% = 2
31-55% = 3
56-75% = 4
>75 = 5

Instead of default 0, 1-2%, 3-5 %, 6-10% and 11-20% cut levels as mentioned were used to reflect typical values of species abundance in Pench Tiger Reserve. A pseudospecies is quantitative equivalent of a differential species (one with a clear ecological preference). The presence of differential species can be used to identify particular environmental conditions.

Non-parametric one way analysis of variance (ANOVA) at ($P<0.05$) was used to determine the statistical significance of the differences in tree and shrub species density, richness, among the three management units of the Pench Tiger Reserve, *Viz*. Seoni, Chindwara, and Sanctuary.

3.4 Results and Discussion:

3.4.1 Community classification

Total of 492 plots were used for the analysis of community classification using two way indicator species anaysis (TWINSPAN). A general description of different communities observed in Pench Tiger Reserve is shown below (Figure 3.2), with eigen values and indicator species at each division. TWINSPAN classified the vegetation in to finer level of association and present output in two way table with the details of indicators, *ie.* preferential and non preferential species. The nomenclature of an association depends on the numerical value of the species and therefore varies greatly. List of plant species recorded in vegetation plots were 218 species from 49 families. The detail of the family, genera and species are given in (Appendix 1).

It was observed that the species *Clistanthus collinus* is good differential species and it is present only in the left side of division is an indicative of more relatively moist conditions. (Figure 3.2). Presence of *Tectona grandis* is another good differential species on the right side of the division which clearly indicates the drier conditions. Out of nine community except two, seven of them have more than two species associated in the nomenclature; hence, it has been termed as associations. The major vegetation communities shown below (Figure 3.2) are described community wise in detail.

Fig 3.1 Location of Vegetation Plots in Pench Tiger Reserve

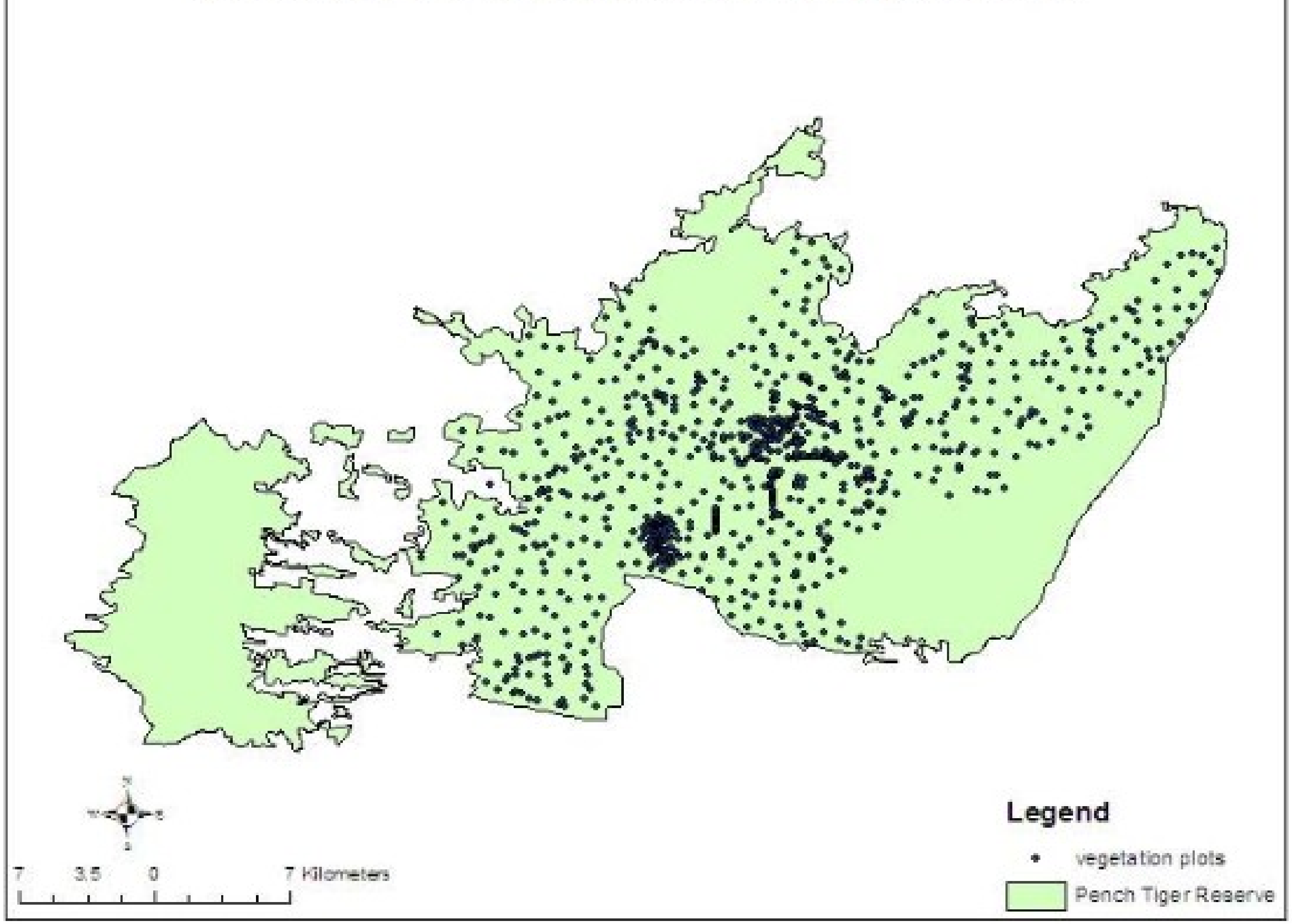
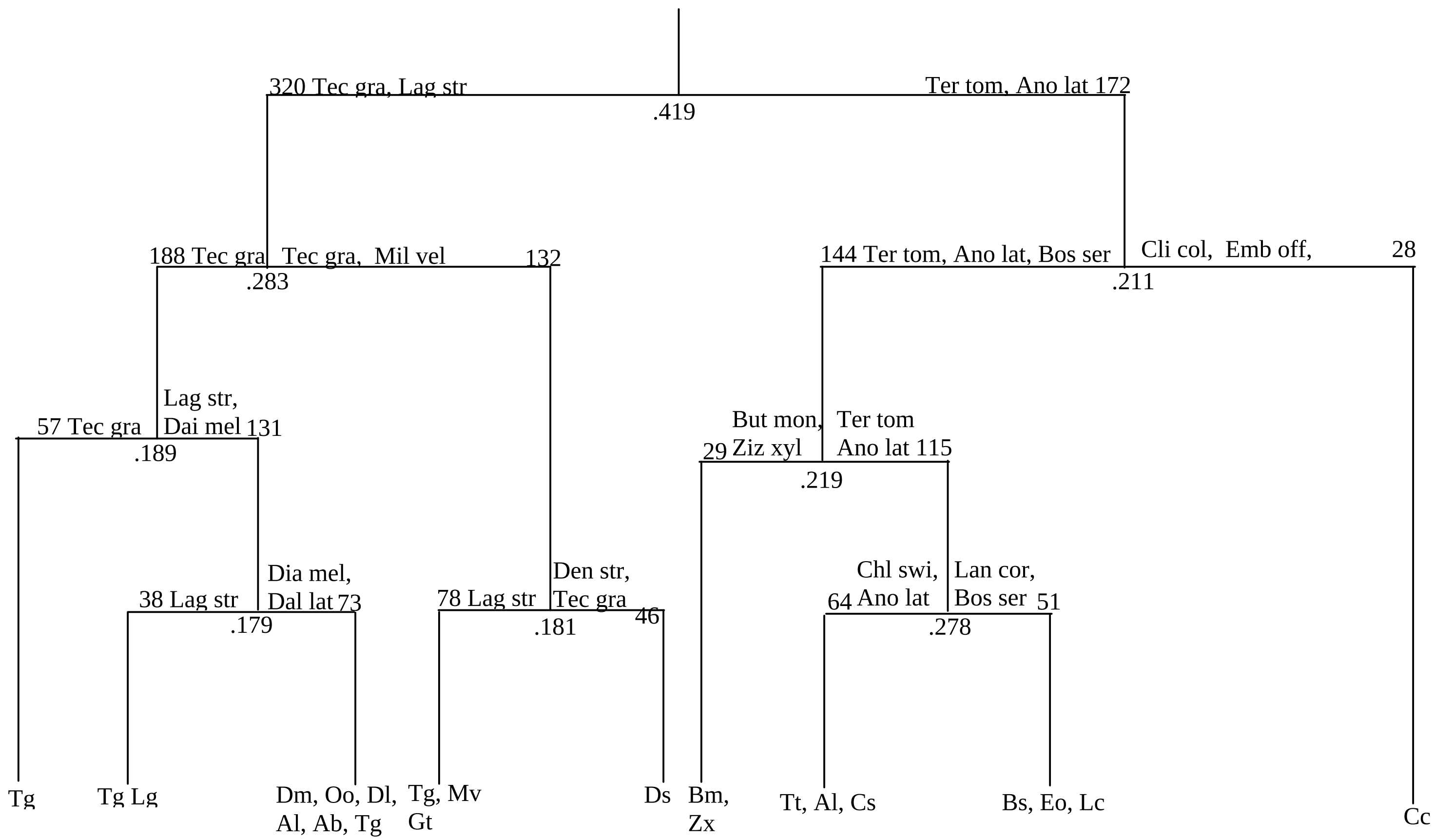


Figure 3.2. Dendrogram of plant communities in Pench Tiger Reserve, Madhya Pradesh



There are nine major communities association that could be identified from the twinspan result. *Viz*. Pure *Tectona grandis*, *Tectona grandis* associated with *Lagerstromia purviflora*, *Tectona grandis* with *Diospyros melanoxylon, - Ougenia oogenesis* - *Dalbergia latifolia- Anogeisus latifolia* association, *Tectona grandis* with *Grewia taeliafolia* - *Miliusa velutina*, *Dendrocalamus strictus* community, *Butea monosperma– Zizyphus xylopora* association, *Termanalia tomentosa* - *Anogeisus latifolia* - *Chlroxylon swietnia* association, *Boswellia serrata-Embellica officinalis-Lannea corromendalica* association, and pure *Clistansthus collinus* community The overall communities clearly depict the complex nature of the vegetation in Pench Tiger Reserve. A total of 49 families with 218 species of plant species were observed in the sampling plots (Appendix 1).

3.4.2 Community 1: *Tectona grandis*.

This community was of monoculture plantation in nature, present at certain pockets of the Pench Tiger Reserve. There were few large patches of teak forest present in the National Park area, There were no under storey present below the teak forest canopy. The shrub species encountered under this forest were *Grewia hirsuta, Lantana camara*, *Asparagu recemosus* and saplings of *Tectona grandis*. . The mean tree density of the community was 480 ± 30 trees per hectare (n=57) and shrub density was 302 ±121 individuals per hectare (n=43). The total basal area of the community was 39.86 m^2/ha. The IVI value was 87.9. The A/F ratio showed that the trees were randomly distributed.

3.4.3 Community 2: ***Tectona grandis - Lagerstromia purviflora***.

This community was found commonly near the roadside opening, forest edge, and Alikatta range. Similar to the community 1, there was less under cover storey observed in this forest type with *Grewia hirsuta*, *Lantana camara* and saplings and seedlings of both *Tectona grandis* , and *Lagerstromia purviflora* . Grass species found under this community were *Apluda mutica and Dichathium annulatum,*. The mean tree density of the community was 223± 25 trees per hectare (n=38), and the shrub density was 181±87 individuals per hectare (n=31). The total basal area of the community was 27.28 m^2 /ha. The IVI values of *Tectona grandis* was 39.94 and *Lagerstromia purviflora* was 14.34. The A/F ratio showed that the trees were randomly distributed (Table 3.1).

3.4.4 Community 3: ***Tectona grandis - Diospyros melanoxylon, - Ougenia oogenesis - Dalbergia latifolia- Anogeisus latifolia*.**

This association was found throughout the Tiger Reserve. The under storey observed were *Grewia hirsuta, Gmnosporia spinosa, Lantana camara, Cassia tora,, Holarrhena antidysentrica and Woodfordia fruticosa.* Climbers such as *Bauhnia vahlii, Abrus precatorius, Achyranthes aspera were* commonly found in this community. The grass species present under this community were, *Arundinella setosa, Chloris virgta, Cymbopogon aciculatus and Cynodon dactylon.* The mean tree density of the community was 423 ± 60 trees per hectare (n=73) and shrub density was 607 ±121 individuals per hectare (n=62). The total basal area of the community was 41.56 m^2 /ha. The IVI value was 27.50 for teak and the *Diospyros melanoxylon* had 15.76. The A/F ratio showed that the trees were randomly distributed (Table 3.1).

3.4.5 Community 4: ***Tectona grandis - Grewia taeliafolia - Miliusa velutina*,.**

This community association was generally occupyed the central area of the National Park. It was found more in gentle slopes. The under storey were occupied by *Spinosa sps, Lantana camara, Cassia tora, Woodfordia fruticosa, Helicteres isora, Vitex negundo, Phoenix humilis,* and *Butea superba.* The grass species found in this community was *Apluda mutica, Aristida sps, Imperata cylindrical* and *Cyperus distans*. The mean tree density of the community was 373± 68 trees per hectare (n=78), and the shrub density was 231±67 individuals per hectare (n=51). The total basal area of the community was 37.18m^2 /ha. The IVI value of Tectona *grandis* was 29.94, for *Grewia taeliafolia* it was 10.34, and for *Miliusa velutina* it was 3.45. The A/F ratio showed that the trees were randomly distributed (Table 3.1).

3.4.6 Community 5: ***Dendrocalamus strictus* .**

This was found in patches distributed mainly in the wet and moist area of the Tiger Reserve. The terrain was more of a undulating in nature along with gentle slopes. The *Dendrocalamus strictus* was also found occurring along with *Tectona grandis* in few areas. The number of clumps encountered were counted for the abundance value in the sampling plot. The understorey were generally occupied by bamboo shoots, along with *Tectona grandis* sapling . The mean tree density of the community was 112± 32 trees per hectare (n=46), and the shrub /sapling/shoots density was 131±27 individuals per hectare (n=41). The total basal area of the community was 12.18m^2 /ha. The IVI value of *Tectona grandis* was 9.94, and *Dendrocalamus strictus was* 5.92. The A/F ratio showed that the *Tectona grandis* trees were randomly distributed and whereas the *Dendrocalamus strictus* was uniformly distributed (Table 3.1).

3.4.7 Community 6: *Butea monopsperma – Zizyphus xylopora* .

This community was mostly found in the disturbed area of the Tiger Reserve. It occupied those areas where earlier villages existed. The under storey were generally occupied by gregariously growing *Butea monopsperma* sapling. The mean tree density of the community was 45± 7 trees per hectare (n=29), and the shrub /sapling/shoots density was 71±17 individuals per hectare (n=12). The total basal area of the community was 9.8 m^2 /ha. The IVI value of *Butea monopsperma* was 3.23, and *Zizyphus xylopora* was 1.02. The A/F ratio showed that the *Butea monopsperma* and *Zizyphus xylopora* trees were randomly distributed (Table 3.1).

3.4.8 Community 7: *Termanalia tomentosa - Anogeisus latifolia - Chlroxylon swietnia.*

This community was mostly found in the moist and undulating terrain with gentle slope area of the Tiger Reserve. The under storey was predominantly dominated by species such as *Holarrhena antidysentrica, Spinosa sps, Lantana camara, Zizyphus jujuba woodfordia fruticosa, Helicteres isora,vitex negundo and Phoenix humilis.* The grass species found under this community was *Dichathium annulatum, Digitario chinenris,* was *Apluda mutica, Aristida sps,Imperata cylindricl* and *Cyperus distans*. The mean tree density of the community was 345± 87 trees per hectare (n=64), and the shrub /seedling and sapling density was 261±57 individuals per hectare (n=53). The total basal area of the community was 32.9m^2 /ha. The IVI value of *Termanalia tometosa* was 15.23, followed by *Anogeisus latifolia* 10.43 and *Chlroxylon swietnia* was 3.02. The A/F ratio showed that the all the three species were randomly distributed (Table 3.1).

3.4.9 Community 8: *Boswellia serrata-Embellica officinalis- Lannea corromendalica*

This community was found generally in the rocky terrain with gentle slopes. This association was found more in the drier regime of the Tiger Reserve. The under storey constituted mainly shrub and herbs *Phoenix humilis*, *Urena lobata Sida cordifolia Litsea sebifora Lantana camara and Achyranthes aspera.* The grass species found in this community was *Apluda mutica, Aristida sps, Imperata cylindrical*, *Cymbopogon aciculatus and Cynodon dactylon.* The mean tree density of the community was 235± 43 trees per hectare (n=51), and the shrub /seedling and sapling density was 121±27 individuals per hectare (n=43). The total basal area of the community was 22.9m^2 /ha. The observed IVI value of *Embellica* officinalis the highest 14.76 followed by *Lannea corromendalica* (10.53) and *Boswellia serrata* (8.32). of the A/F ratio showed that the two species (*Embellica* officinalis and *Lannea corromendalica)* were uniformly distributed and the *Boswellia serrata* was randomly distributed (Table 3.1).

3.4.10 Community 9: *Clistansthus collinus*.

This community was more of a mono specific community with confined distribution to few pockets of the submergence area of the Tiger Reserve. Due to its allelopathy effects there was absolutely no growth observed underneath of this community. The under storey was more of barren ground with devoid of any herb, shrub or grass. The mean tree density of the community was 202± 13 trees per hectare (n=28), and the shrub /seedling and sapling density was 11±7 individuals per hectare (n=12). The total basal area of the community was 9.1m^2 /ha. The IVI value of *clistanthus collinus* was 11.32. The A/F ratio showed that the species had highly clumped distribution (Table 3.1).

Table 3.1. The Mean density, basal area, IVI and A/F ratio of different tree species in the vegetation community observed in Pench Tiger Reserve, Madhya Pradesh.

Community	**Tree Mean density/ha**	**Shrub Mean density/ha**	**Total basal area**	**IVI value**	**A/F ratio**
Tectona grandis	480 ± 30	302 ±121	39.86 m^2 /ha.	87.9	1.10
Tectona grandis Lagerstromia purviflora	223± 25	181±87	27.28m^2 /ha.	39.94, 14.34.	.81 .74
Tectona grandis Diospyros melanoxylon, Ougenia oogenesis, Dalbergia latifolia, Anogeisus latifolia	423 ± 60	607 ±121	41.56 m^2 /ha.	27.50 15.76	.94 .64 .72 .74 .62
Tectonagrandis Grewia taeliafolia, Miliusa velutina	373± 68	231±67	37.18m^2 /ha.	29.94, 10.34 3.45	.84 .76 .63
Dendrocalamus strictus	112± 32	131±27	12.18m^2 /ha.	9.94 5.92	1.00
Butea monopsperma, Zizyphus xylopora	45± 7	71±17	9.8m^2 /ha	3.23 1.02.	.97 .89
Termanalia alata Anogeisus latifolia, Chlroxylon swietnia.	345± 87	261±57	32.9m^2 /ha.	15.23, 10.43 3.02	.67 .89 .76
Boswellia serrata, Embellica officinalis, Lannea corromendalica	235± 43	121±27	22.9m^2 /ha.	8.32 14.76 10.53	.96 1.00 1.00
Clistansthus collinus.	202± 13	11±7	9.1m^2 /ha.	11.32.	1.21

3.4.11 Community characterstics

The vegetation types were classified and named based on the association of different tree species. The organization of population and community in an ecosystem is an outcome of interactions among themselves under the prevailing conditions. (Lindman 1982, Odum 1971). Population in a natural community is not distributed independently (Misra and Misra 1981). Individual species with their IVI value, abundance, frequency and A/F ratio were calculated based on the data collected from the sampled plots, to study whether there is difference in their distribution pattern when they are treated as individual species or within the community. The IVI was a better indicator of ecological success and dominance of a species in a forest. Single character of vegetation cannot form a dependable parameter for the characterization and composition of vegetation.

Result clearly indicated that *Tectona grandis* was randomly distributed (Table 3.1, 3.2) within the communities except in plantation where it showed clumped nature. The random distribution pattern of species is indicative of uniform environment. Similar pattern are reported from temperate forest by Saxena and Singh (1982), and Singhal et al., (1986), and from tropical plantation by Pande et al., (1988). Spatial distribution of tropical tree can be linked to microenvironmental heterogeneity especially edaphic factors. (Hubell and Fosters 1986, and Ashton 1988). The TWINSPAN ordination result clearly showed that in PTR, *Clistanthus collinus* was a unique community make up. It was also observed that *Clistanthus collinus* showed a clumped distribution pattern. (Table 3.2). Since the species was monospecific in nature, it confined its presence to a localized area, which was closer to submergence and due to its allellopathic nature, no other species was regenerating under its storey

(Areendran 1997). According to old compartment history of the Tiger Reserve, it was mentioned that the frequent fire and removal of *Tectona grandis* was replaced by gregarious growth of *Clistanthus collinus.* The pattern of distribution of a population of plant community is fundamental characterstics of that population (Clark and Evans 1954).

Dendrocalamus strictus was more uniformly distributed within the community, but overall in the vegetation surface, the pattern observed was of more random distribution. In the field it was observed that the *Tectona grandis* also occurred along with the *Dendrocalamus strictus* but less in number. Also, *Boswellia serrata* had random distribution within the community, whereas its other member *Embellica officinalis and Lannea corromendalica* had shown a uniform distribution. The *Boswellia serrata* also preferred rocky hill terrain. It was also observed that few species such as *Haldina cordifolia*, *Chochlospermum gosipium, Careya arborea, Soymida februga* were represented by one or two individuals with large girthwhich are class are inferred as either relicts or nomads in the population (Steenis 1985).

We also compared the IVI value of each species amongst the three management units to see whether tree species exhibited any difference in their occurrence. It was observed (Table 3.3) that the *Tectona grandis* dominated the IVI value in all the three managements units followed by *Clistanthus collinus*, *Grewia tilifolia, Dendrocalamus strictus and Lagerstroemia parviflora.* It was also observed that *Butea monosperma* had higher IVI value in the Chindwara portion of the National park, which clearly indicated the disturbance nature. The *Anogeissus latifolia* and *Aegle marmelos* had the highest IVI value in the Chindwara than the other two management units. The *Lannaea coromandelica* one of the important gaur food plant species had the highest IVI value in the Chindwara portion.

Table 3.2. Individual plant species IVI, abundance, frequency and A/F values in Pench Tiger Reserve, Madhya Pradesh.

Tree species	IVI	abundance	Frequency	A/F
Cleistanthus collinus	12.14	16.72	13.82	1.21
Emblica offcinalis	11.89	1.97	36.32	0.05
Bauhinia racemosa	4.68	1.64	20.94	0.08
Madhuca indica	7.44	1.51	19.09	0.08
Lagerstroemia parviflora	25.54	3.80	65.95	0.06
Ziziphus xylopyrus	8.54	1.78	30.48	0.06
Diospyros melanoxylon	15.48	2.77	50.71	0.05
Grewia tilifolia	10.11	2.06	40.74	0.05
Bridelia retusa	4.51	1.74	18.95	0.09
Ougeinia oojeinensis	7.25	2.71	24.22	0.11
Launaea coromandelica	17.42	2.10	40.46	0.05
Buchania lanzan	7.94	1.76	30.34	0.06
Terminalia alata	16.85	2.43	35.47	0.07
Tectona grandis	47.50	7.13	57.83	0.12
Kydia calycina	2.25	1.67	9.54	0.18
Anogeissus latifolia	12.49	2.03	31.05	0.07
Miliusa velutina	16.20	2.36	52.56	0.04
Careya arborea	0.12	1.00	0.71	1.40
Soymida fabrifuga	2.05	1.74	5.41	0.32
Semcarpus anacardium	2.57	1.44	12.39	0.12
Boswellia serrata	4.15	1.49	11.68	0.13
Schleichera oleosa	3.08	1.35	8.55	0.16
Cassai fistula	3.01	1.37	15.38	0.09
Chloroxylon swietenia	4.22	2.53	8.40	0.30
Dalbergia paniculata	1.99	1.39	6.55	0.21
Casearia tomentosa	2.59	1.51	10.68	0.14
Nyctanthus arbortnstis	0.91	1.58	3.42	0.46
Mitragyna parviflora	2.47	1.50	6.27	0.24
Butea monosperma	5.42	2.15	12.54	0.17
Schrebra swietenioides	1.86	1.35	7.83	0.17
Ventilago denticulata	1.11	1.23	5.70	0.21
Butea Superba	2.01	1.85	8.69	0.21
Dendrocalamus strictus	2.41	5.28	6.70	0.79
Albizia lebbeck	0.48	1.29	1.99	0.64
Aegle marmelos	7.85	2.07	8.69	0.24
Albizia procera	0.39	1.17	1.71	0.68

Acacia pennata	1.05	3.00	3.28	0.92
Zizyphus oenophila	1.25	1.62	5.98	0.27
Pterospermum acerifolium	1.07	1.09	4.70	0.23
Garuga pinnata	0.15	2.00	1.71	1.60
Gardenia turgida	0.53	1.12	2.42	0.46
Gardenia latifolia	0.85	1.26	3.85	0.33
Haldina cordifolia	0.33	1.17	0.85	1.37
Dalbergia sissoo	0.07	1.00	1.43	0.69
Casearia graveolens	1.17	2.00	5.41	0.37
Flacourtia ramontchi	2.79	1.61	11.40	0.14
Ixora parviflora	1.50	2.34	4.99	0.47
Ficus fruticosa	0.07	1.00	1.43	0.69
Randia uliginosa	0.77	1.42	3.42	0.41
Morinda tinctoria	0.11	1.50	1.57	0.95
Limonia acidissima	0.24	1.33	1.28	1.04
Zizyphus rotundus	1.06	4.00	2.85	1.40
Salmalia malabarica	0.73	1.00	1.71	0.59
Cordia dichotoma	0.15	1.00	0.85	1.17
Morinda pubescens	0.05	1.00	1.28	0.78
Bauhinia vahlii	1.13	2.45	4.70	0.52
Litsea clutinosa	0.08	1.00	1.43	0.69
Cordia myxa	0.59	1.36	1.99	0.68
Hymenodictyon execelsum	0.38	1.22	1.28	0.95
Syzygium cuminii	0.38	1.43	1.99	0.72
Acacia catechu	2.07	2.10	5.84	0.36
Flacourtia indica	0.10	1.00	0.57	1.76
Alangium lamarki	0.16	1.40	0.71	1.97
Ficus benghalensis	0.02	1.00	1.14	0.87
Chochlospermum gosipium	0.18	1.29	1.00	0.97
Ailanthus excelsa.	0.11	1.00	1.28	0.78
Diospyros Montana	0.10	1.00	0.87	1.14
Terminalia arjuna	0.07	1.00	1.43	0.69
Randia dumetorum	0.11	1.00	0.87	1.14
Albizia odoratissima	0.12	1.00	0.71	1.40
Wrightia arborea	0.02	1.00	1.14	0.87
Sterculia urens	0.29	1.00	1.28	0.78
Ficus religiosa	0.02	1.00	1.14	0.87
Ixora arborea	0.14	1.50	0.57	0.95
Ichnocarpus frutescens	0.30	1.43	1.00	1.43
Miliusa tomentosa	0.21	2.20	1.71	1.28
Moringa oleifera	1.68	1.11	1.28	0.87
Dalbergia latifola	0.12	1.00	1.71	0.58
Wendlandia heynei	0.37	1.18	1.57	0.75
Toona ciliate	0.06	1.00	1.28	0.78
Anogeissus acuminata	0.32	1.10	1.42	0.77

Table 3.3. The IVI values of tree species between three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

Tree species	Seoni_IVI	Chindwara_IVI	Sanctuary_IVI
Cleistanthus collinus	42.52	5.28	0.45
Emblica officinalis	7.17	8.44	14.18
Bauhinia racemosa	4.30	6.23	3.80
Madhuca indica	4.62	5.50	6.37
Lagerstroemia parviflora	21.55	19.51	23.53
Ziziphus xylopyrus	4.99	8.19	13.22
Diospyros melanoxylon	13.63	13.46	14.42
Grewia tilifolia	39.11	7.06	5.94
Bridelia retusa	5.51	2.14	2.30
Ougeinia oojeinensis	7.76	7.41	4.03
Launaea coromandelica	7.71	12.01	19.66
buchania lanzan	6.81	8.42	7.14
Terminalia alata	8.18	18.48	19.89
Tectona grandis	45.26	31.99	38.35
Kydia calycina	1.94	2.70	3.12
Anogeissus latifolia	9.30	8.76	17.74
Miliusa velutina	12.50	12.63	15.97
Careya arborea	0.15	0.86	0.00
Soymida fabrifuga	0.76	1.87	2.42
Semcarpus anacardium	3.56	1.36	1.10
Boswellia serrata	3.09	2.02	3.05
Sohleichera oleosa	1.55	1.97	3.14
Cassai fistula	2.97	3.77	2.77
Chloroxylon swietenia	1.51	2.33	5.89
Dalbergia paniculata	1.68	0.99	1.23
Casearia tomentosa	1.83	1.44	4.14
Nyctanthus arbortnstis	0.78	0.77	1.39
Mitragyna parviflora	0.78	2.86	3.42
Butea monosperma	2.52	3.82	9.27
Schrebra swietenioides	1.54	1.59	1.79
Ventilago denticulata	0.84	1.95	1.54
Butea Superba	1.85	40.93	1.83
Dendrocalamus strictus	24.22	2.23	0.32
Albizia lebbeck	0.40	0.88	0.38
Aegle marmelos	2.09	2.40	9.15
Albizia procera	0.32	0.56	0.22
Acacia pennata	0.87	0.79	1.62
Zizyphus oenophila	0.96	2.40	1.10
Pterospermum acerifolium	0.90	6.88	0.52
Garuga pinnata	0.04	0.62	0.00
Gardenia turgida	0.20	0.58	1.20

Gardenia latifolia	0.96	0.58	0.55
Haldina cordifolia	0.04	0.23	0.61
Dalbergia sissoo	0.08	0.19	0.00
Casearia graveolens	1.59	15.00	0.41
Flacourtia ramontchi	1.67	2.61	4.49
Ixora parviflora	0.66	1.43	2.81
Ficus fruticosa	0.12	0.03	0.00
Randia uliginosa	0.36	1.10	1.16
Morinda tinctoria	0.14	0.01	0.13
Limonia acidissima	0.13	1.35	0.00
Zizyphus rotundus	0.27	2.04	0.63
Salmalia malabarica	0.21	0.11	1.24
Cordia dichotoma	0.20	0.00	0.14
Morinda pubescens	0.08	0.04	0.00
Bauhinia vahlii	1.56	0.85	0.27
Litsea clutinosa	0.04	0.21	0.14
Cordia myxa	0.17	0.72	0.96
Hymenodictyon execelsum	0.31	0.45	0.28
Syzygium cuminii	0.48	0.79	0.00
Acacia catechu	1.12	1.47	2.49
Flacourtia indica	0.16	0.01	0.00
Alangium lamarki	0.06	0.11	0.42
Ficus benghalensis	0.06	0.00	0.00
Chochlospermum gosipium	0.32	0.00	0.00
Ailanthus excelsa	0.04	0.00	0.19
Diospyros montana	0.13	0.11	0.00
Terminalia arjuna	0.13	0.00	0.00
Randia dumetorum	0.08	0.03	0.28
Albizia odoratissima	0.12	0.92	0.00
Wrightia arborea	0.00	0.11	0.00
Sterculia urens	0.42	0.12	0.27
Ficus religiosa	0.01	0.13	0.00
Ixora arborea	0.11	0.27	0.33
Ichnocarpus frutescents	0.00	1.02	0.36
Miliusa tomentosa	0.00	0.31	0.79
Moringa oleifera	0.12	0.45	1.75
Dalbergia latifola	0.00	0.11	0.53
Wendlandia heynei	0.00	0.70	0.96
Toona ciliata	0.00	0.22	0.15
Anogeissus acuminata	0.24	0.21	0.25

3.4.12 Diversity and Richness

Maximum tree diversity (3.13) was observed in the Seoni (Table 3.4, Fig 3.3) and minimum in the Sanctuary portion of the Tiger Reserve. Maximum tree richness was observed in the Sanctuary (8.084) (Table 3.4) followed by Seoni and Chindwara.

Similarly the shrub and herb diversity (Table 3.5) was the highest in the Seoni (3.309) followed by Chindwara (3.273) and Sanctuary (3.143). Richness of shrub and herb also had the similar trend of diverisity, having highest richness value in the Seoni (6.16), followed by Chindwara and Sanctuary area.

The total number of tree and shrub species observed from the sampling plots in the Pench Tiger Reserve was 81 and 50 species. Seoni, constituted 74 tree and 50 shrub species, followed by Chindwara, with 70 tree and 38 shrub species, and Sanctuary had the lowest number of 65 tree and 36 shrub species. (Fig-3.3, 3.5). The disturbance of varying magnitude affects diversity or species richness of communities. (Ravan, and Roy 1997). One way ANOVA was performed to find out whether there was any significance difference in the tree density and richness, shrub density and shrub richness between the three management units of the Pench Tiger Reserve. The result obtained from the analysis clearly depicted that there was a significance difference in the tree species richness between the management units, P= (.001) (Figure 3.5, Table 3.6) though the tree density between the units did not show any significant difference. Meanwhile the shrub richness and density clearly showed significanct difference, (P= .001), amongst the three management units of the Tiger Reserve (Table 3.7, Fig 3.9, and 3.10).

Also, the tree diversity value in different the units was higher for the Seoni than the other two units, richness value was found to be higher for the Chindwara unit (Table 3.4 Fig 3.4). This could be due to a few rare species with few individual encountered in the sampling plots. In case of shrub diversity and richness it was clearer that Seoni unit had higher diversity and richness value (Table 3.5 Figure 3.6).

Several studies have shown that mesoscale species richness reaches a maximum in areas of high landscape heterogeneity (Gould and walker 1997, 1999, Heikkinen and Neuvonen 1997, Pollock et al. 1998). Although we cannot directly compare tree and shrub species richness due to difference in the total area sampled, estimates of diversity based on the sample size independent, indices suggest species richness (on a per individual basis) is lower for shrubs and herbs, compared to the trees in the plots. The lower diversity of shrub and herb may be result of shrub and herb species failing to regenerate or damaged due to disturbance such as fire, and grazing. Micro climatically induced shifts in disturbance regime could have implications for landscape heterogeneity and hence on the species distribution and abundance . If different ecological process is dominant at different spatial scales, plot size can significantly affect the interpretation of the vegetation pattern.

Topographic and substrate attributes clearly affect the distribution and abundance of woody species in the forest of PTR. The difference in the species richness among the management units could be due to variables associated with the topographic relief, amount of surface, soil characteristics, geomorphology, soil organic content, slope, Ph. Also, frequent ground fire in PTR, at interval of 1-2 years could have contributed to the higher mortality rate of shrub and herb, due to which there is difference between the units. Sanctuary had the lowest shrub density as well as the richness which could be due to livestock grazing, which reduces species richness at smaller scale.

Species diversity is deceptively difficult to characterize. The most common measure of diversity is on an area basis (ie. species density, diversity at the number of species present in given area). However area-based estimates of species diversity can be confounded by population density. If the number of individual sampled varies among sampling plots, such sampling effects can have important consequences to our understanding of factors such as insularity and productivity that influence taxonomic diversity. The overall floristic composition of the forest in the Pench Tiger Reserve is generally similar to that found in central Indian highlands dry deciduous forests. The present study has demonstrated that forest types of PTR contain several wide spread species *viz. Tectona grandis, Lagerstroemia purviflora, Termanalia tomentosa, Diaspyros melanoxylon, Miliusa velutina* and *Anogeisus latifolia.* However, there is the clear distribution of continuum of species occurrence from east to west as identified by Champion and Seth (1968). The microclimate also plays a major role in the species distribution pattern. The length of the dry or wet period is one of the climatic factors which plays an important role in the selection of species and consequently in the distribution of the main types of the community. (Pascal 1988). Similar study in the central India region, at Sakata and Seoni districts by Prasad and Pandey (1992) states that *Syzygium cummini* was the dominant species having the maximum density than the Teak, in few of their sites, whereas in our study the teak was the most dominant species with highest IVI values. Variations in phytosociological attributes such as IVI values, density, basal cover, and distribution of the tree species at different management units in the Reserve clearly indicates the complex plant succession resulting from varying degree of pressure such as livestock grazing, forest fire, from the outside units.

Tree basal cover in the present study varied from 41.56 m^2 /ha to 9.1m^2 /ha, from the Tiger Reserve. As discussed by Singh et al. (2003) from the study of tropical moist deciduous forest in Achankmar Wildlife Sanctuary, these basal cover values were higher than the values reported for several dry tropics forest community in Vindhyan region by Jha and singh (1990) ranged from 6.58 to 3.2 1m^2 /ha. Also, Singh and Singh (1991) reported from Vindhyan region, similar range between 3.84 and 10.36 m^2 /ha. The total forest basal cover trees, in the present study can be compared with the range 17 to 40 m^2 /ha from dry tropical forest reported by Murphy and Lugo (1986b). Basal cover in a Puerto Rico sub tropical dry forest was 19.8 m^2 /ha. (Murphy and Lugo 1986c). In the present study, the tree density ranged from 45 to 480 mean density /ha. Comparing the present study with the result from the Thailand's dry dipterocarp forest, was 554 to 789 density /ha was higher (Visaratana et al. 1980), at mixed deciduous forest was 253 reported by Sahunalu et al., (1979), and in teak forest it was 262 to 395 reported by Bunyavejchewin (1983) and Sahunalu (1992). In comparison to tropical rainforest which had 818-1540 density /ha which was the highest among the different forest types (Kiratiprayoon 1986). Tree density in Vindyan region ranges between 294 and 627 denstiy /ha for several tropical forest communities. However, Rodgers (1990) reported very high values of basal cover 131 m^2 /ha for the forest of Sariska Tiger Reserve, Rajasthan. It will be difficult to compare species diversity of different tropical forest due to difference in the sample size and plot size in the taxonomic group. Among the three sites the Shannon-Weiner Index species richness ranged from 3.3 to 3.1 which was low in comparison to dipterocarp forests and mixed deciduous forests of Thailand 3.75 to 4.49 as reported by Kiratiprayoon et al., (1995). It was observed that stand density, basal cover, species richness showed higher value for PTR than Vindhyan region. It was also observed for few species having high IVI values, the reason could be attributed to similar ecological requirement for their growth and development form the association and communities.

Tropical rain forest in silent valley, South India had a diversity value of 3.8 to 4.8 which was higher than the present study (Singh et al. 1984). Diversity parameter (Shannon-Wiener) in the tropical dry communities of the Vindyan region had ranges from 0.68 to 2.08 and in the fry forest of the Vindhyan hill had ranges from 1.93 to 2.82 as reported by Singh and Singh (1991). It is also argued that species richness decreases with environmental stress, such as drought condition (Holdridge et al. 1971). In comparison to above diversity value, the overall diversity of the Pench Tiger Reserve was on the higher side of the scale. Also, PTR was more of a transitional zone between the dry deciduous forest and moist deciduous forest which would have influence of both the vegetation regime on the distribution of the species.

Table 3.4. Diversity Indices for tree species in Pench Tiger Reserve, Madhya Pradesh

Diversity indices	Seoni	Chindwara	Sanctuary
Shannon_H	3.138	3.086	3.036
Margalef R	8.066	7.493	8.084

Figure 3.3. Tree species richness amongst three management units ((Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

Figure 3.4. Shannon_H diversity of tree species amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

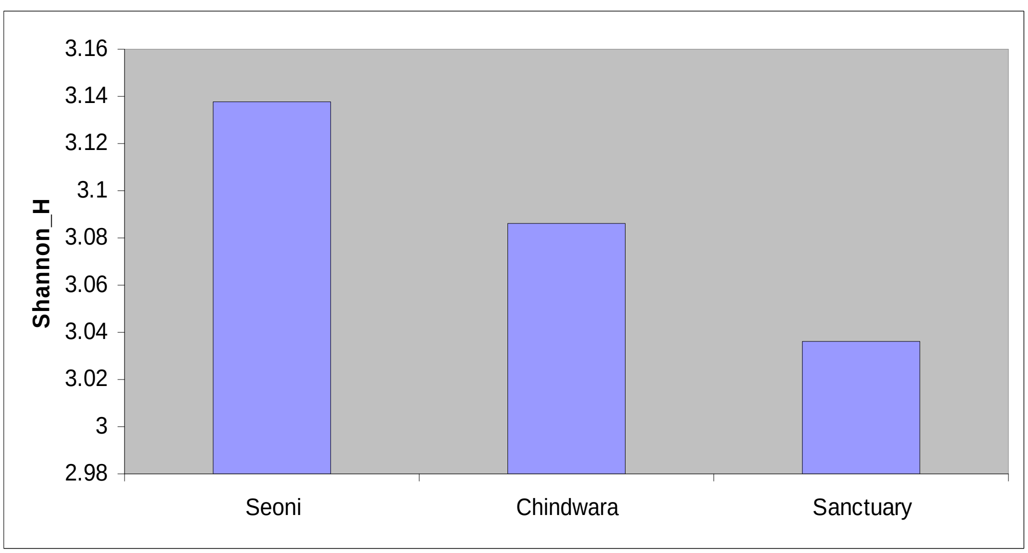


Table 3.5. Diversity Indices for shrub and herb in Pench Tiger Reserve, Madhya Pradesh.

Diversity indices	Seoni	Chindwara	Sanctuary
Shannon_H	3.309	3.273	3.143
Margalef R	6.16	6.081	6.005

Figure 3.5. Shrub and herb species richness amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

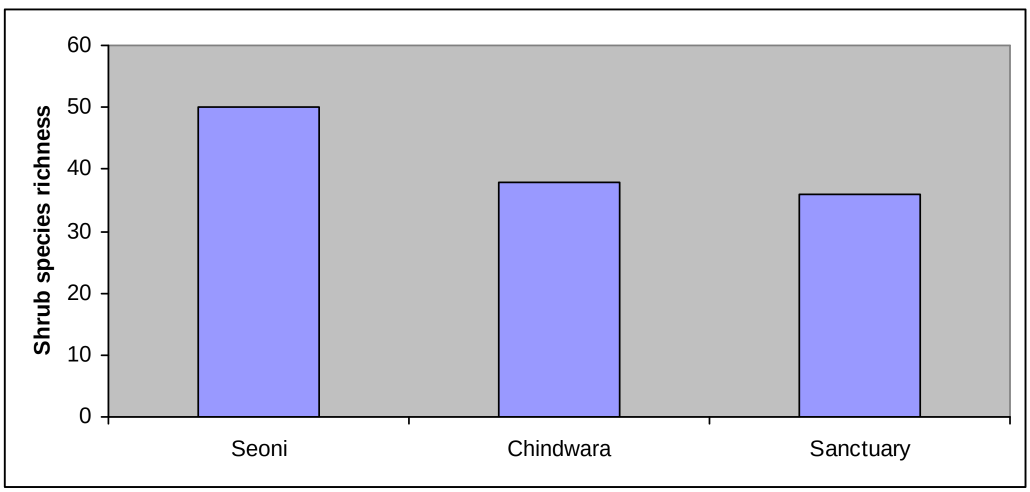


Figure 3.6. Shannon_H diversity of shrub and herb species amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

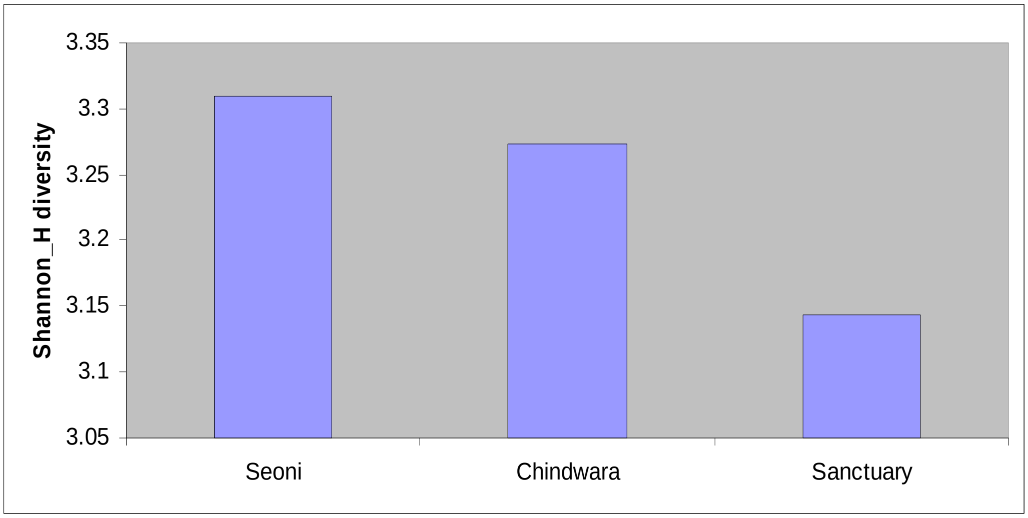


Table 3.6. The result of one way ANOVA for tree density and tree richness amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
TREE_DEN	Between Groups	407.249	2	203.624	2.461	.086
	Within Groups	57829.083	699	82.731		
	Total	58236.332	701			
tree_rich	Between Groups	173.416	2	86.708	7.183	.001
	Within Groups	8437.418	699	12.071		
	Total	8610.833	701			

Figure 3.7. Mean tree density amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

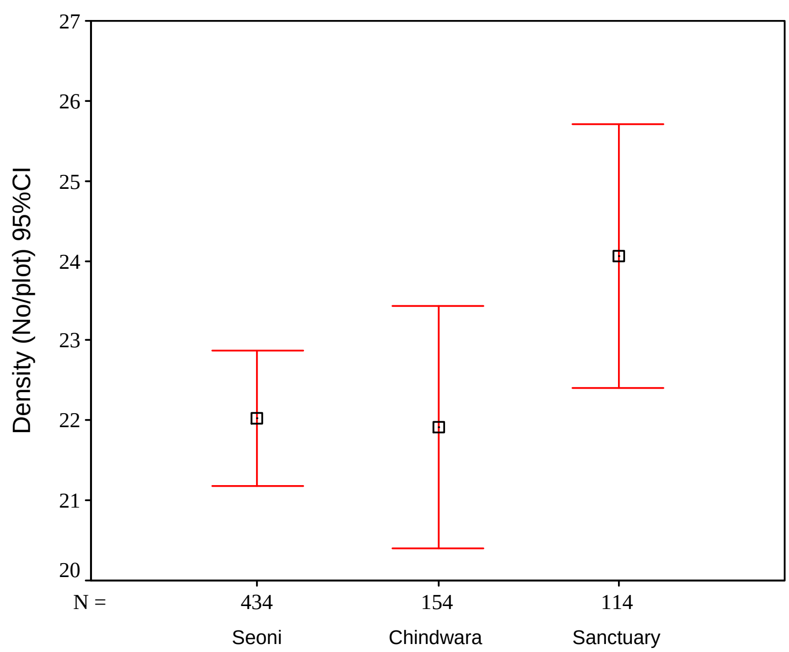


Figure 3.8. Mean tree richness amongst three management units. (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

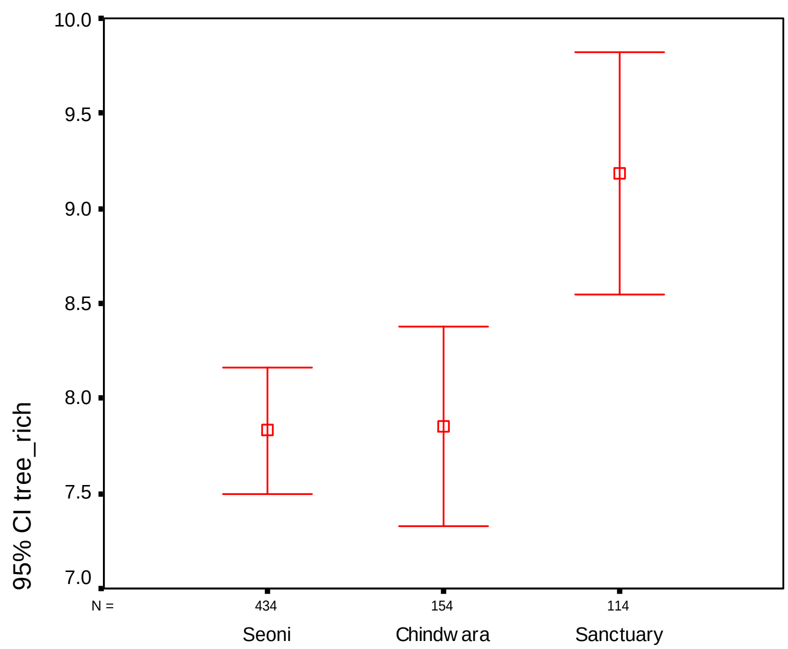


Table 3.7. Showing the results of one way ANOVA for shrub and herb density and richness amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
SH_DEN	Between Groups	1756.257	2	878.128	20.044	.001
	Within Groups	30623.243	699	43.810		
	Total	32379.500	701			
SH_RICH	Between Groups	168.606	2	84.303	58.156	.001
	Within Groups	1013.269	699	1.450		
	Total	1181.875	701			

Fig 3.8 Showing Significant difference in the shrub and herb density between three management units

Figure 3.9. Observed significance difference in shrub and herb density amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.

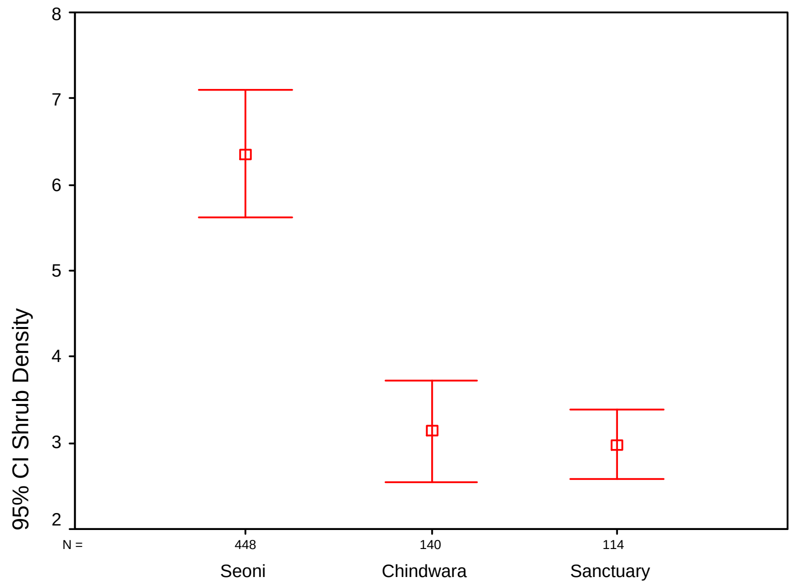
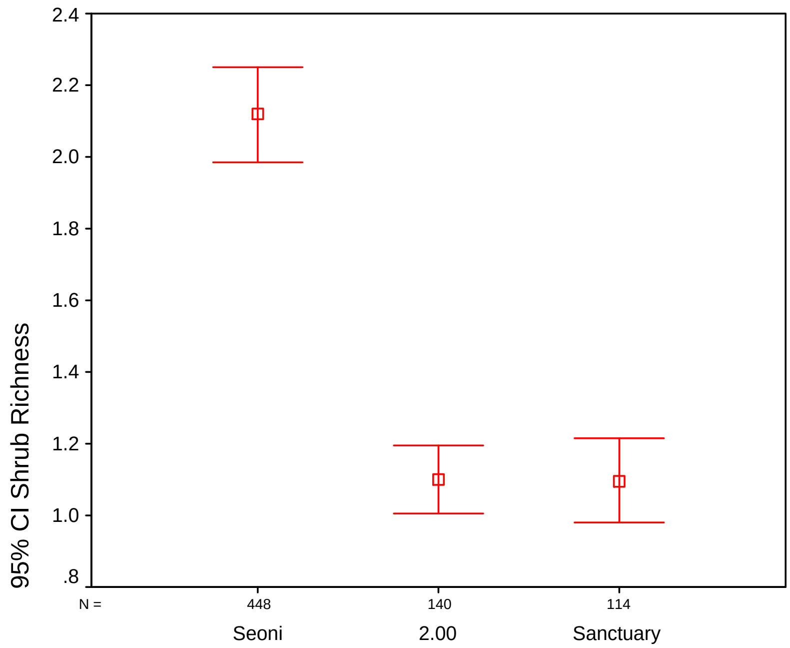


Figure 3.10. Observed significant difference in the shrub and herb richness amongst three management units (Seoni, Chindwara, Sanctuary) in Pench Tiger Reserve, Madhya Pradesh.



3.5 Conclusion

There was significance difference in shrub species richness and diversity amongst the three management units, in PTR. Vegetation patterns were observed consistent across broader spatial scale, but there was most variation at the finer scale. In PTR, nine major communities were observed based on the TWINSPAN ordination analysis. *Viz*. *Tectona grandis*, *Tectona grandis Lagerstromia purviflora*,, *Tectona grandis Diospyros melanoxylon*, *Ougenia oogenesis*, *Dalbergia latifolia*, *Anogeisus latifolia*, *Tectona grandis Grewia taeliafolia*, *Miliusa velutina*, *Dendrocalamus strictus*, *Butea monopsperma*, *Zizyphus xylopora*, *Termanalia tomentosa* , *Anogeisus latifolia* and *Chlroxylon swietnia.*

A total of 49 families with 214 species were documented during the vegetation study carried out in the PTR. Teak and its associates dominated the communities with high IVI values which were comparable with similar tropical forests from Vindhyan regions, Sariska Tiger Reserve, and Thailand forest. Unique plant community such as *Clistanthus collinus* was identified separately in the community association, which was a monospecific community with allelopathy effect, which altered the growth of any ground cover from regenerating beneath its understorey. Maximum tree diversity (3.13) was observed in the Seoni and minimum in the Sanctuary area. Also the maximum tree richness was observed in the Sanctuary (8.084), followed by Seoni and Chindwara. Similarly the shrub and herb diversity was the highest in the Seoni (3.309) followed by Chindwara (3.273) and Sanctuary (3.143). Richness of shrub and herb also had the similar trend of diverisity, having highest richness value in the Seoni (6.16), followed by Chindwara and Sanctuary area. One way ANOVA was performed to find out whether there was any significance difference in the tree density and richness, shrub density and shrub richness amongst the three management units of the Pench Tiger Reserve. There was a significance difference in the tree species richness amongst the management units P= (.001),though the tree density amongst the units did not show any significant difference. Meanwhile the shrub richness and density clearly showed significance difference P= (.001) amongst the three management units of the Tiger Reserve.

Chapter 4

Mapping vegetation types, patch properties and landcover change in Pench Tiger Reserve, Madhya Pradesh

4.1 Introduction

Better knowledge of the habitats implies information about their extent, composition and potential including their rate of transformation. The principal source of such information has been vegetation mapping as it provides basis for making inventories of physical, biological and anthropological attributes towards planning and better management of these interacting forces. However, the design and execution of these comprehensive inventories is a function of clear definition of management options and priorities. Vegetation management relevant to any specific species begins by a classification of its habitats along with a clear understanding of pattern and process of landscape elements. Remotely sensed estimates of regional variation in biodiversity can be useful in analyzing diversity patterns, monitoring changes, and aiding in conservation efforts (Mooney and chapin 1994). Regular and continuous monitoring of the habitats permits the detection of change in vegetation components and immediate surroundings useful for fixing deterministic factors.

Remote Sensing and the processing of remotely sensed data through Geographical Information System (GIS) are two most important synergistic technologies and these tools of tremendous potential value offers present ecologists and resource managers to address their needs and process their information (Roughgarden et. al. 1991, Sample 1994). GIS and Remote Sensing allows the processing and viewing the recorded information on different spatial scales. These tools have been termed as geostatistical tools (Rossi et. al. 1992) and are useful for modeling and interpreting ecological data in spatial form (Howard et. al. 1996) has highlighted the importance of remotely sensed data in linking ecological information recorded from ground, air and space Cornett and Sample (1994) emphasized that GIS and Remote Sensing are catalysts for effective public involvement in ecosystem management planning, analysis and policy making.

Satellite remote sensing data has emerged as a potential tool to study land cover, vegetation type and human interventions at fine to coarse scales. The data provides details on habitat with very high accuracy and in a low cost effective manner. The information base can be judiciously combined with the ground-based studies for comprehensive analysis and modeling. Information content available in the multi-spectral data can form a common database for integrated resource inventories, which are necessary for the habitat characterization, monitoring and management. Due to the similarity of the temporal data set and repetitiveness, monitoring of the habitat can be accomplished with very high reliability. On the other hand, the GIS allow storage, retrieval, and analysis of spatial and non-spatial data in digital form. Updating of GIS information base for monitoring purposes is an efficient as well as cost-effective means. Remote sensing with multi-spectral and multi-temporal data collection systems allows one to perform the work of data collection and integration more quickly and effectively (Blamont and Méring 1987).

Most natural resources (vegetation, water, and soil) are responsive to human interaction and these together with various bio-physical character of the landscape determine land use pattern, which is also in some way reflects the cultural, social and economic conditions (Vink 1975). Planning for natural resource without endangering the environment is the crucial issue as has been increasingly realized across the globe (Kachhwaha 1985, Sharma et al. 1989). It is evident that human induced land use change is an important driver underlying current global change trends (Vitousek 1994).

Land-cover change detection has been focus of great interest and research for decades. Many applications require change information to identify the magnitude, direction and rate of land-cover change (Lud et al. 2005). Remote sensing and GIS is only practical means to monitor landscape to regional scale level changes of land cover (Jensen 2000). Recent review on assessment of large-scale degradation in Sonitpur district of Assam by Srivastava et al. (2002) demonstrates the potential of remote sensing and GIS for estimating landcover change. In the present study, efforts were made to use Remote sensing and GIS techniques for mapping and quantifying spatial and temporal pattern of vegetation cover in Pench Tiger Reserve, Madhya Pradesh. This was made possible by availability of excellent database of the existing infrastructure and the important biological, anthropological and environmental processes operating and interacting within a given PA. This database when collated and processed with the help of the geostaistical tools mentioned form the plinth for manager in policy and decision making. Specifically, the study addressed mapping of vegetation types in terms of extent and physiognomic property. The structural attributes and temporal changes in the landcover pattern formed an important component of the study.

4.2 Methodology

4.2.1 Procurement of digital data

IRS LISS III P6 data was procured from NRSA Hyderabad for Pench Tiger Reserve (PTR) and its surrounding areas. The data received was in two scenes (Path & Row 99-57 & 100-57) with spatial resolution of 23.5 m^2. In addition, Landsat MSS (1977) and Landsat ETM+ (2001) were downloaded in the GeoTIFF format from the Global Land Cover Facility (GLCF) on the geoportal -http://glcfapp.umiacs.umd.edu. As the season plays an important role in remote sensing causing variability of ground features, November 2006 data of P6 with 0% cloud cover was used (Table 4.1, 4.2 , and 4.3) for mapping latest vegetation types and patch property of the area, while Landsat data of winter season was used for change detection. IRS data provided in BIL format was imported in to Image format for further processing. The GeoTIFF files downloaded from the GLCF were converted to image format later and were mosaiced using the ERDAS software. Each GeoTIFF file imported gets converted in to individual spectral band which were combined to form False Color Composite (FCC). Comparison of each sensors of landsat and IRS is given in the detail. (Table 4.4)

Table 4.1. Characteristics of Indian Remote Sensing Satellite IRS-ID P6.

Image characteristics	LISS-III Sensor
Acquisition date	13th Nov, 2006
No of scenes	2
Scanner type	Push Broom
No of bands	4
Spectral resolution (in µ meter)	Band 1(Blue): 0.52 - 0.59, Band 2(Green): 0.62 - 0.69, Band 3(Red): 0.77 - 0.86, Band 4(Infra-Red): 1.55 - 1.70
Radiometric resolution	7 bits
Spatial resolution	23 / 70 meters
Temporal resolution	24 days
Swath width	142 km, 148 km

Source: Anon 1994

Table 4.2. Characteristics of LANDSAT satellite images.

Satellite	L 2	L 7
Sensor	MSS multi-spectral	ETM+ multi-spectral
Date	23rd Jan, 1977	26th Dec, 2000
Spectral Range	0.5 - 1.1 µm	0.45 - 2.35 µm
Bands	1, 2, 3, 4	1, 2, 3, 4, 5, 7
Scene Size	185 X 185 km	185 X 185 km
Citation	NASA Landsat Program, 1977	NASA Landsat Program, 2000

Table 4.3. Radiometric characteristics of LANDSAT satellite images.

Satellite	Spectral resolution		Band	Spatial resolution
		(µm)		(meters)
Landsat 1-3	MSS			
	Band 1:	0.50 - 0.60	Green	60
	Band 2:	0.60 – 0.70	Red	60
	Band 3:	0.70 – 0.80	Near IR	60
	Band 4:	0.80 – 1.10	Near IR	60
Landsat 7	ETM+			
	Band 1:	0.450 – 0.515	Blue	30
	Band 2:	0.525 – 0.605	Green	30
	Band 3:	0.630 – 0.690	Red	30
	Band 4:	0.760 – 0.900	Near IR	30
	Band 5:	1.550 – 1.750	Mid IR	30
	Band 6:	10.40 – 12.5	Thermal	60
	Band 7:	2.080 – 2.35	Mid IR	30
	Band 8:	0.52 – 0.92	Pan	15

The decision to use either LANDSAT or IRS image for vegetation classification is based on a number of parameters as indicated in Table 3.4.

Table 4.4. Comparison of LANDSAT and IRS images.

Parameters	LANDSAT-7 ETM+ Image	IRS-IC LISS III Image
Spectral range	5 spectral bands	3 spectral bands
Spatial resolution	30 meters	23 meters
Georeferencing	Georeferenced image available	Individual georeferencing has to be carried out
Ease in change detection	Old images of MSS sensor available from 1970s onwards	Oldest image available is 1980s onwards
Costs incurred	Freely available in geoportal	Needs to be purchased from NRSA

4.2.2 Procurement of SOI topographic maps

Topographical maps of 1:50 000 scales were obtained from Survey of India covering the entire park and surrounding areas. The total area of PTR to be mapped covers the following toposheets: 55 O/2, O/5, O/6, O/9, and 55 K/13 and K/14.

4.2.3 Hardware and Software used

The toposheet was scanned and later converted in to digital format for digitization. ESRI ArcGIS version 9.0 was used for the digitization of toposheets and ERDAS version 8.7 was used for the digital image processing (DIP). Various themes such as drainage, contour, transport network and village location, water holes, camps, and other management units were mapped using the GIS software. Various spatial themes such as slope, aspects, DEM, were derived from the above layers. Geology, as well as the soil map was also created along with the above maps for documentation and database purpose.

4.2.4 PTR boundary map and other information

PTR authorities have provided the report and maps giving details about the official boundary of the Tiger Reserve (covering topo-sheets 55 O/2, O/5, O/6 and O/9), forest compartments with number, location of artificial and natural water-bodies, fire lines, location of eco-development villages, range head quarters, forest rest house and other buildings, watch towers etc. Later on another map was provided by the PTR authorities that included topo-sheets 55 K/13 and K/14 along with other areas mentioned in topo-sheets 55 O/2, O/5, O/6 and O/9.

4.3 Data analysis

4.3.1 Satellite data processing

After acquisition of raw digital data several processes are involved for the final product. Accurate geometric and atmospheric calibrations are two important aspects in image processing. The satellite data was processed using ERDAS-Imagine 8.7., using the toposheet as the reference map the image were georeferenced. Both scenes were geometrically rectified to Universal Transverse Mercator (UTM) projection using 50 ground control points (GCP'S) from the georeferenced SOI. Rectification involves conversion of geometry of an image (rows & columns) to planimetric coordinates (latitude & longitude). First order affine transformation was performed for geocoding, with 0.0004 root mean square (RMS) per pixel. It was below the accepted threshold limit of 0.5. Nearest neighborhood algorithm was used for re-sampling, as it does not alter the orginal pixel value. Rectified scene was mosaiced to obtain the complete scene of the Tiger Reserve. The desired study area was extracted from mosaiced scene using the subset function. False Colour Composite (FCC) maps were generated for the entire Tiger Reserve (Figure 4.1).

4.3.2 Classification

Classification of remotely sensed data involves assigning each pixel on the image a ground class based on its spectral reflectance (Lillesand and Kiefer 1994). Multi spectral imagery is used to identify the spectral signature of the spectral classes present in the image. Both unsupervised and supervised clustering was used for classifying vegetation types. Classification was performed using maximum likelihood classifier as it has been proven very efficient vegetation mapping (Bolstad and Lillesand 1991, Reddy and Reddy 1996). Also hybrid approach was extensively used for deriving the pure class.

4.3.3 Unsupervised classification

The classification uses ISODATA algorithm for differentiating spectral reflectance of various objects. Unlike supervised classification unsupervised classification does not require analyst –specified training data. For the present classification, 50 clusters with 10 iterations were specified. Iteration is the maximum number of times the ISODATA utility will re-cluster the data. Convergence threshold was set to 0.95. It is the maximum percentage of pixels whose cluster assignment can go unchanged between iterations. The 50 classes derived from the iteration were later merged into 4 major vegetation classes: (1) Teak dominant (pure teak dominant patches with more than 75 % teak), (2) Mixed dry deciduous (constitutes mixed species like *Boswellia serrata*, *Anogeissus latifolia*, *Lagerstroemia parviflora*, *Diospyros melanoxylon*), (3) Teak Mixed (areas with both *Tectona grandis* and mixed species in almost equal proportion), (4) *Butea monosperma* or *zizyphus* species with open ground.

4.3.4 Supervised classification

The out put of unsupervised classification at 1:50,000 scale was taken to the field for the ground truthing. Thirty homogeneous training sets were selected for each class and their corresponding coordinates were noted down in the field using the Magellan Pro-5000 Global positioning systems (GPS) with 10 meter accuracy for each location. Later using these ground truthing information few classes were derived using the spectral signature. Few point information collected during the field verification were used for the accuracy assessment.

4.3.5 Hybrid classification

Both unsupervised and supervised classification was used to overcome the lacunae of their respective techniques. Few classes such as *Butea* woodland, *Cleistanthus collinus*, and *Zizyphus* woodland were not clearly delineated using both the above techniques. These errors are not due to error in the pixels but due to the similar spectral reflectance value of the feature class (Jansen et al. 1990). Manual recoding was done to resolve this using ground truthing and field sampling information as a parameter. Manual recoding increases the classification accuracy.

4.2.6 Accuracy Assessment

The accuracy assessment was conducted through a standard method described by Congalton (1991). Accuracy assessment is an important part of classification and change detection process. A common method for accuracy assessment is through use of an error matrix. The kappa coefficient is a measure of overall statistical agreement of a matrix. Kappa analysis was recognized as a powerful technique used for analyzing a single error matrix and comparing the difference between different error matrix (Congalton 1991, Smits et al. 1999). The result of accuracy assessment was executed for six classes of the classified image. A total of 200 random points generated upon the classified image, with a minimum of 20 points for each class. The reference points were entered manually based on the observation value. The accuracy assessment was done using the build in algorithm function of ERDAS software.

4.3.7 Spatial and temporal change detection

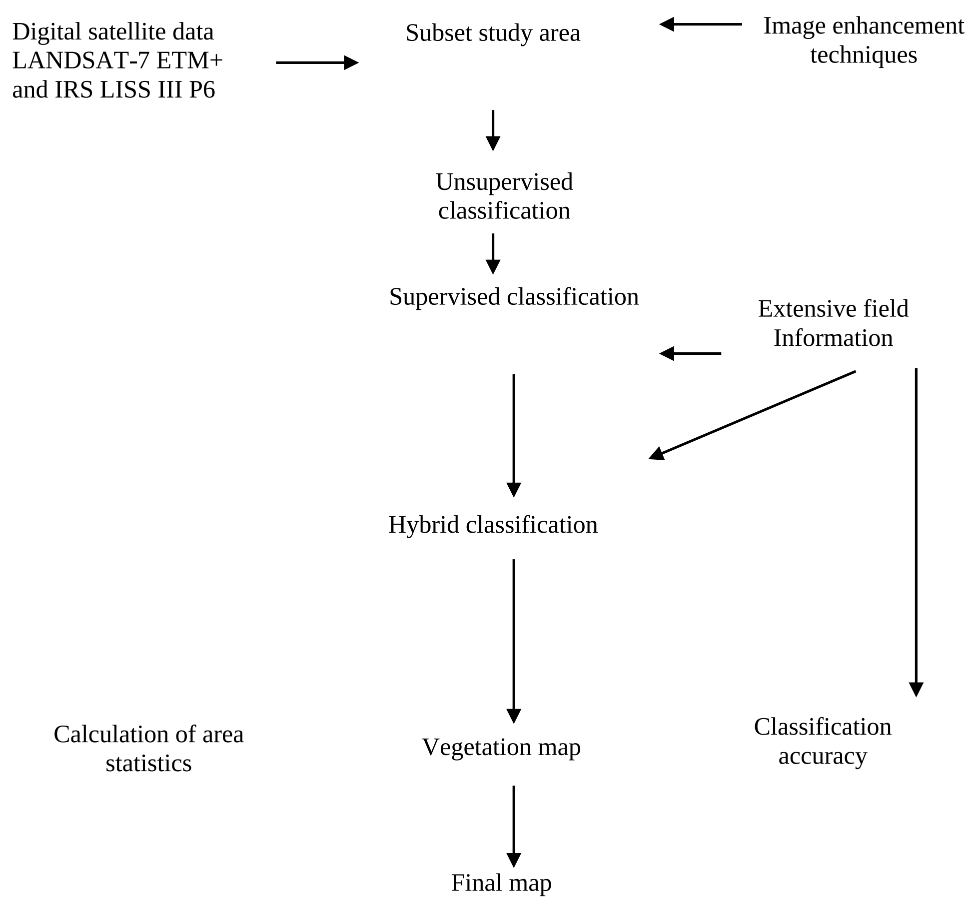
Digital change detection is affected by spatial, spectral, temporal and thematic constraints. Type of method implemented can profoundly affect the qualitative and quantitative estimates of the change (Muttutanon and Tripathi 2005). To date at least six different methods for extracting thematic changes information have been developed. Post classification change comparison (PCC), Spectral-Temporal combined analysis, EM detection (expectation maximum algorithm), Unsupervised change detection, Hybrid change detection, and Artificial neural networks (Lu et al. 2003, Copping et al. 2004). Analyzing land-use and land-cover conversion allows different combinations of changes to be revealed, thus providing further information concerning the nature of change. For this study, image differencing technique was employed, which simply compares the class categories or vegetation index values between the images. Initially, the FCCs of 1977 and 2001 were brought in same spatial resolution of 57 m, and vegetation index (VI = Intra Red – Red) was computed in ERDAS. These indices were compared and the changes in the vegetative cover were detected for a magnitude of 10%, and this was useful to understand the overall change between these years and location of change.

4.3.8 Landscape analysis

Loss and fragmentation of indigenous vegetation presents a formidable challenge to conservation management. Development of landscape indices which is measurement of fragmentation has been receiving considerable attention. Most often fragmentation implies division of natural vegetation in to smaller patches due to human developmental activities. Analysis on landscape configuration including fragmentation status was carried out using FRAGSATS software version 3.3 (McGarigal et al. 2002**)**. FRAGSTATS is a computer software program designed to compute a wide variety of landscape metrics for categorical map patterns. Non-Spatial indices describe landscape composition and measurement of number of patches or proportion of total area (Rutledge 2003). Most studies represent landscape as grid or raster map as they are commonly correspond with the remotely sensed data (O'neil and Krummer et al. 1988). The most common method to quantify the landscape patterns is to capture information on spatial pattern in to a single variable, which is known as the landscape metrics, or landscape indices. A wide variety of landscape metrics and software are used for calculating these indices are been discussed and described (O'Neil et al. 1998, Turner 1989, Cullinan and Thomas 1992, Frohn 1997).

The grain of the study is the spatial resolution of the satellite image which is 24 m, while the extent is 871 km^2 which is the area of the Pench Tiger Reserve (PTR). All natural vegetation classes were used in the analysis. The final classified image of the study area which had 6 classes or patch types namely dry teak, teak mixed, mixed forest, butea woodland, water and barren land was used as an input file. The input file with the above thematic layers was converted from unsigned 8 bit to signed 16 bit using the subset option in ERDAS. The class descriptor file was prepared with the above classes and standard run parameters were used. Indices relating to core area were not generated since they would be species dependent. The results were aggregated thematically at vegetation class level and spatially for entire PTR level. The landscape characteristics were determined from the patch, class and landscape level metrices generated. Landscape indices, symbols and units used are as defined in the FRAGSTATS software version 3.3 (McGarigal et al. 2002). In the present study the aerial extent and spatial distribution of patches were quantified.

Figure 4.1. Flow chart depicting the process of developing landcover map



4.4 Results and Discussion

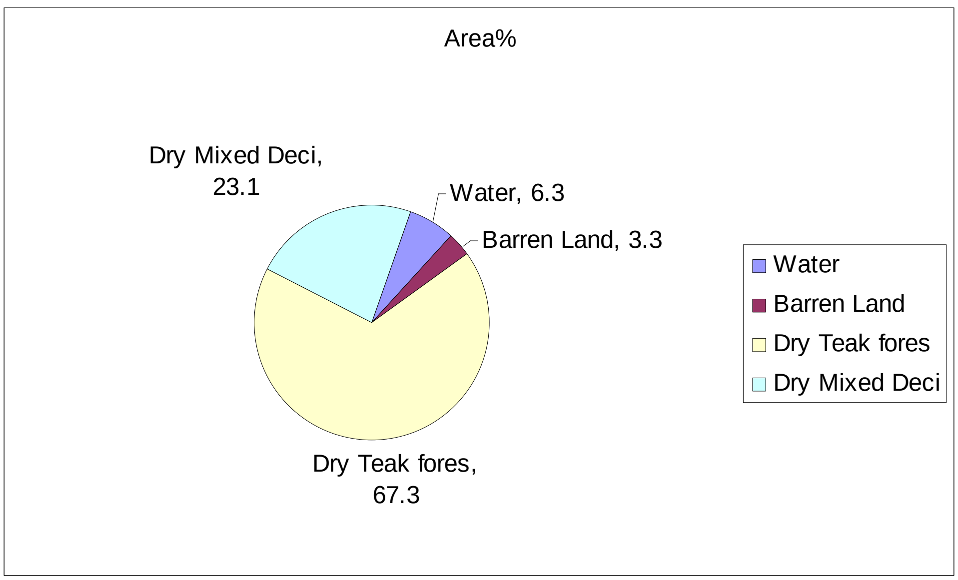
4.4.1 Landcover types and accuracy

The result of the vegetation types in the study area, with reference to Champion and Seth (1968) (Figure-4.3) classification scheme indicates that the forest type is dominated by dry Teak forest occupying 67.6% of the total forested area, followed by dry mixed forest which occupies 9.7% of the total Pench Tiger Reserve. The non-forest category included barren land and water together occupied 9.6% of the total area. Further detailed analysis was carried out to determine the vegetation community, spatial extent, and vegetation association class, based on ground sampling using the plot method (details given in Chapter 3). The vegetation class derived from the satellite data was Teak dominant, which dominated the entire vegetation community with 47.1% followed by Teak with mixed species 20.7% and mixed species 9.7 % of the vegetation community. Butea woodland, contributed 13.7% which was more than the mixed vegetation. Water and barren land occupied the 9.6% of the area. The distribution of Teak dominant type vegetation was distributed throughout the Reserve (details given in Table 4.5, Figure 4.2, Table 4.6 and Figure 4.4). It was observed that the buffer zone in the Chindwara region of the Reserve had the highest concentration of the teak dominant vegetation. The map also suggests that the National Park has the Teak with mixed species as its major vegetation type followed by mixed vegetation. The Butea woodland also was conspicuous in their spatial representation all along the disturbed location such villages and grazing grounds. The Sanctuary part of the PTR had Teak with mixed species as dominant vegetation type, and the remaining area occupied by mixed species vegetation.

Table 4.5. Forest types of Pench Tiger Reserve, Madhya Pradesh, based on Champion and Seth (1968) Classification

Class names	Area in km^2	Area (%)
Dry Teak forest	587.0	67.3
Dry Mixed Deciduous	201.2	23.1
Total	**788.2**	**90.4**

Figure 4.2. Proportion of forest types in Pench Tiger Reserve.



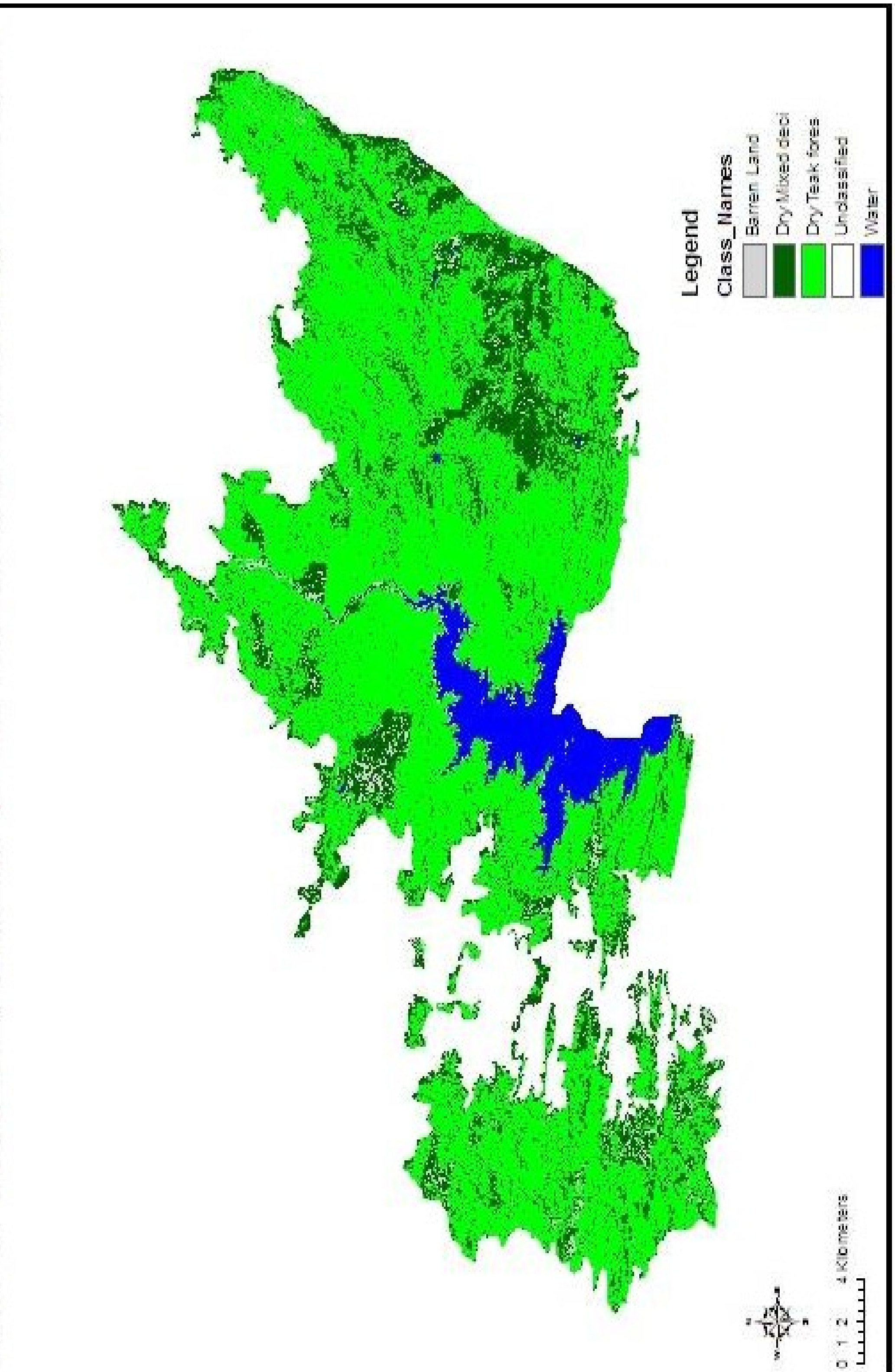


Figure 4.3 Champion & Seth (1968) classification of Forest types in Pench Tiger Reserve, MP

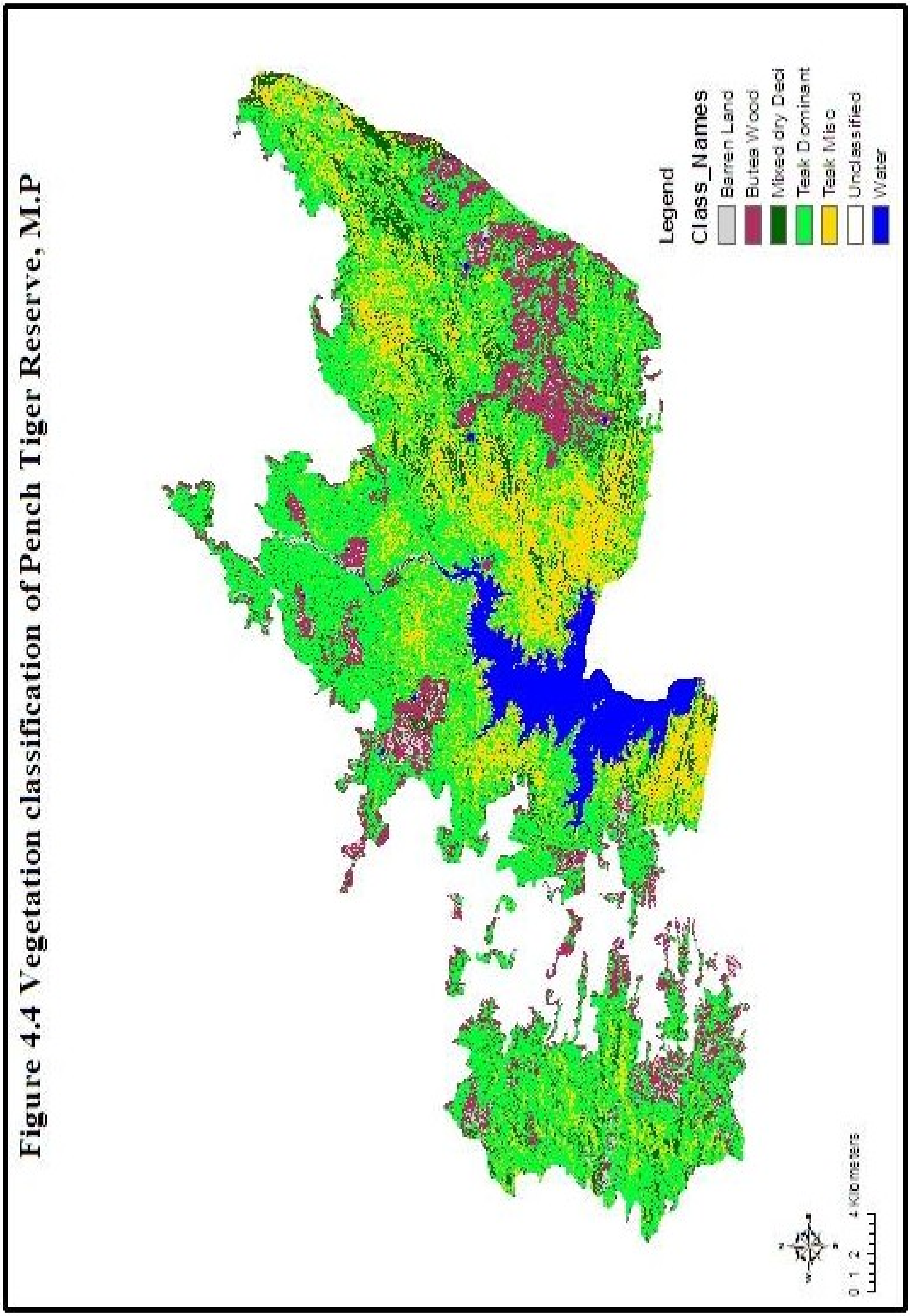
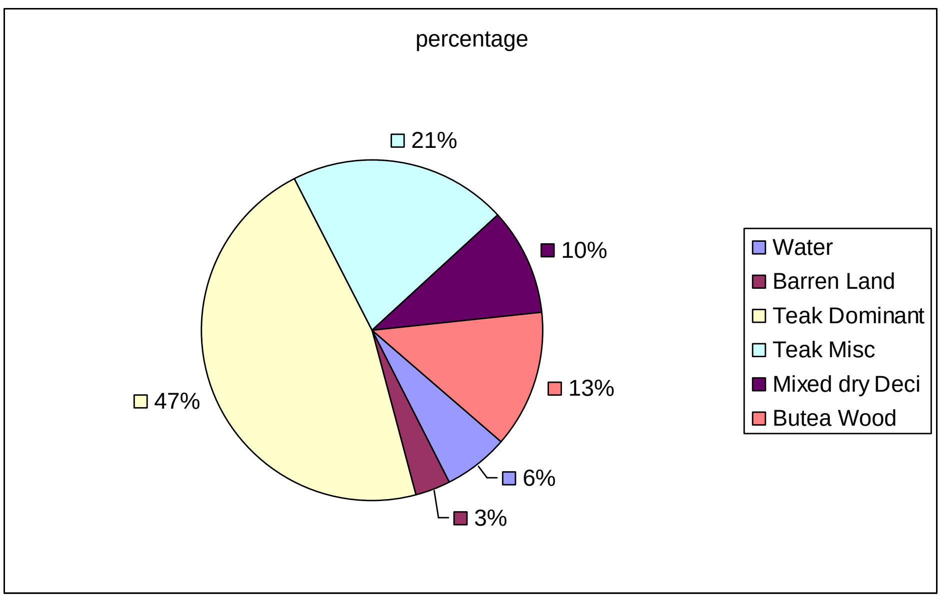


Figure 4.4 Vegetation classification of Pench Tiger Reserve, M.P

Table 4.6. Broad vegetation types in Pench Tiger Reserve and their spatial extent.

Class	Area in Km^2	Area (%)
Water	54.2	6.2
Barren land	28.7	3.3
Teak dominant	406.0	46.6
Teak misc	181.9	20.9
Mixed dry deci	87.7	10.0
Butea woodland	113.4	13.0
Total	871.9	100

Figure 4.5. Proportion of vegetation class in Pench Tiger Reserve



The proportion of each class (Figure-4.5) clearly states that Teak dominant was highest with 47% of the total vegetation type followed by Teak miscellaneous occupying 21%, and Butea woodland with 13 % of the proportion and Mixed dry deciduous contribtuin 10 % of the total vegetation. It was observed that the Butea woodland contribtuted more than mixed deciduous. This was for the reason that the area outside the National Park had more woodland than the mixed dry deciduous had higher proportion value. Water and the barren land contributed 6% and 3% respectively. As per the accuracy assessment carried out (Table-4.7) he overall accuracy was above 80% for all the classes, with water class showing the highest accuracy of 91% followed by Teak mixed with 89% mixed dry deciduous 88%, Teak dominant 87%, and Butea woodland at 80%.

Table 4.7. Result of accuracy assessment of vegetation classification.

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistics*
Water	22	23	21	95.45%	91.30%	0.88
Barren Land	27	20	17	62.96%	85.00%	0.73
Teak Dominant	61	64	56	91.80%	87.50%	0.86
Teak Mixed	35	37	33	94.29%	89.19%	0.79
Mixed Dry Deciduous	29	26	23	79.31%	88.46%	0.92
Butea Woodland	26	30	24	92.31%	80.00%	0.96

*Overall Kappa Statistics = 0.85

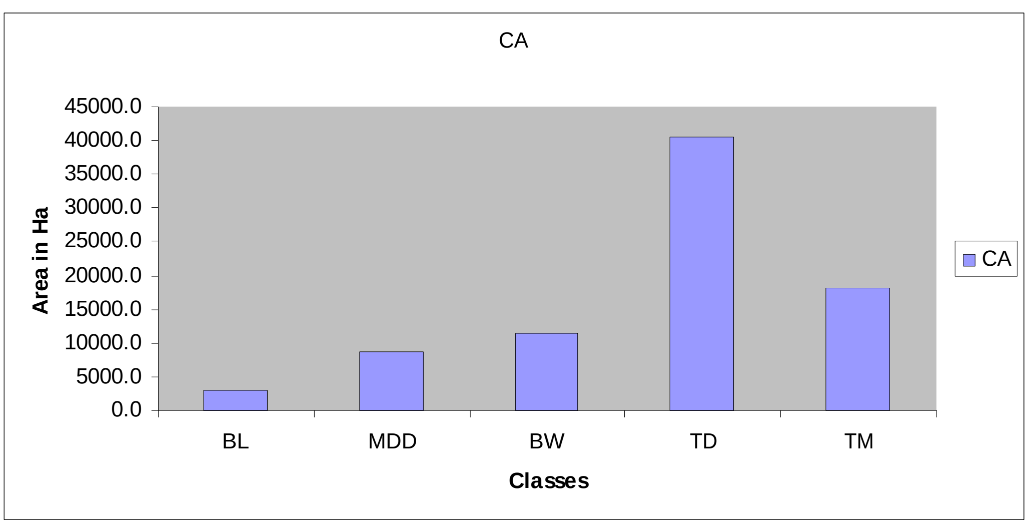
4.4.2 Patch properties

Area Metrics: Patch analysis indicated that the largest patch Index (LPI) was of teak vegetation. This was 5.5 %, as indicated in (Table-4.8). This was also the dominant vegetation type of the PTR (Figure-4.6, 4.4). Teak with mixed species association contributed the second largest patch. The smallest patch in the PTR is of mixed dry deciduous class which is one of the major vegetation classes and Butea woodland, which occupies the disturbed area of the PTR with patch size of 1.5%.

Table 4.8. Area metrics of the Pench Tiger Reserve.

Vegetation Classes	Total Area (km^2)	Percentage in the landscape	Largest patch Index - (LPI) %
Mixed dry deciduous	87.7	4.1	0.1
Butea woodland	113.4	5.3	1.5
Teak dominant	406	19	5.5
Teak mixed	181.9	8.5	2.6

Figure 4.6. Class area distribution in Pench Tiger Reserve.

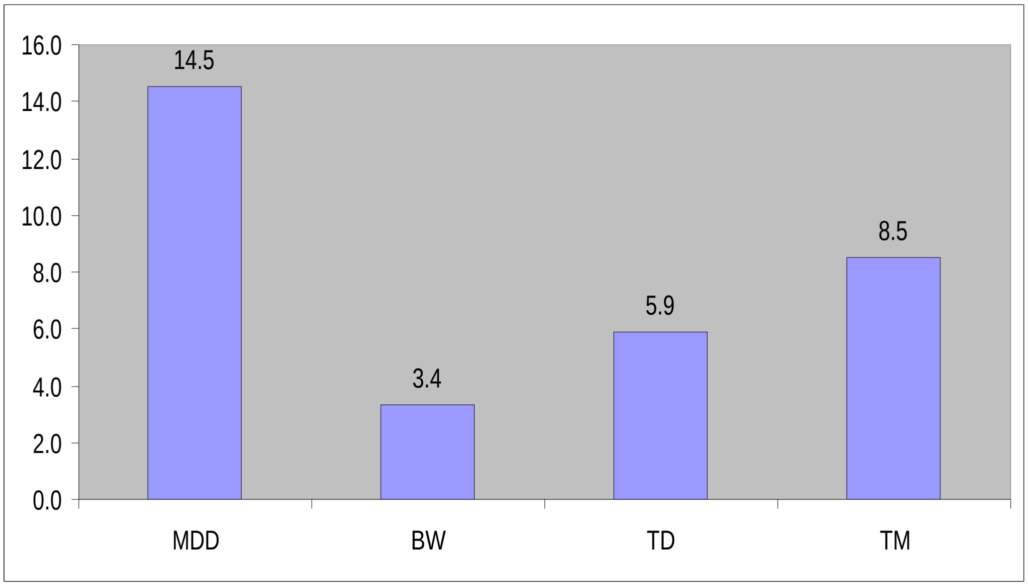


Patch Metrics: The patch numbers varied from 7154 to 30970 in the vegetation classes of PTR. Mixed dry deciduous (MDD) had the maximum patch number, while Butea woodland had the minimum patches (Table 4.9, Figure-4.7). The Teak dominant vegetation within the National Park was more of homogenously distributed, as compared to Teak with mixed species association. Patch density varied from 3.4 patches per/km^2 to 14.5 patches/km^2, largely contributed by dry mixed vegetation that constituted the highly heterogeneous characteristics (Figure 4.4) . Mean Patch Size (MPS) ranged from 0.3 to 3.2, wherein the mixed dry deciduous had the lowest value and the teak dominant had the highest. The simplest way to measure the variability of the patches distribution is the patch size standard deviation (PSSD) and patch size coefficient of variation (PSCV). The Patch size standard deviation is the measure of difference in patch size among the patches. The Teak dominant vegetation with the high value of PSSD 149.5 denoted the variation in patch size, whereas the mixed dry deciduous showed a lower value of 2.4 where the patch size was more similar to each other.

Table 4.9. Patch density, patch size and variability metrics.

Vegetation class	Patch Number	Patch Density/km^2	Mean Patch Size (ha)	SD of Patch Size
Mixed dry deciduous	30970	14.5	0.3	2.4
Butea Woodland	7154	3.4	1.6	40.6
Teak Dominant	12581	5.9	3.2	149.5
Teak Mixed	18128	8.5	1.0	44.3

Figure 4.7. Patch density among various vegetation classes in Pench Tiger Reserve.



Shape Metrics: The patch shape complexity at the patch and class level is presented in (Table-4.10). Important process such as animal migration, plant colonization, and herbivore foraging strategy have shown to influence by the patch size and their shape (Buechner, 1989). The overall shape index of all classes in the PTR landscape was closely similar to each other. The value varied from 1.2 to 1.3 for the various classes. Mixed dry deciduous forest obtained the lowest mean shape index of 1.2 which showed that habitat has the lower edge. Fractal dimension actually calculates the degree of shape complexity and the mean patch fractal dimension of all the vegetation class was almost the same except in Butea woodland where the value was 1.1 which, indicates that the Butea woodland was more complex than the other classes.

Table 4.10. Shape index of patches of various vegetation classes in Pench Tiger Reserve.

Vegetation class	Landscape Shape index	Mean Shape Index	Shape Index (SD)	Mean Patch Fractal Dimension	Patch fractal Standard Deviation
Mixed dry deciduous	205.4	1.2	0.4	1.0	0.1
Butea Woodland	117.4	1.3	0.9	1.1	0.1
Teak Dominant	206.2	1.3	1.6	1.0	0.1
Teak Mixed	201.4	1.3	1.0	1.0	0.1

Patch composition: Composition indices basically describe the characteristics of the fragmentation. The splitting index, effective mesh size and Interspersion/Justaposition are among the indices which are looked in to for identifying the landscape fragment characteristics. The results of class level patch composition are shown below in the (Table- 4.11).

Table 4.11. Patch composition at class level in Pench Tiger Reserve.

Vegetation class	Effective Mesh size	Splitting Index	Interspersion and Juxtaposition Index (%)
Mixed dry deciduous	**0.8**	**256267.3**	**64.2**
Butea Woodland	**55.5**	**3840.5**	**70.0**
Teak Dominant	**1319**	**161.5**	**80.1**
Teak Mixed	**167**	**1276.4**	**39.9**

Teak dominant had the largest mesh size (1319) of equal number of patches, whereas mixed dry deciduous had the smallest size and equal number of patches, but the splitting index showed that the mixed dry deciduous forest had the largest number of equal sized patch followed by Butea woodland. The value of Interspersion and justaposition varied from 39.9 % to 80.1 %. Teak dominant vegetation also indicated the highest degree of aggregation (80.1 %), which was well interspersed in the landscape among the classes. Teak with mixed class had the lowest interspersion and juxtapositions value (39.9%) due to its very limited distribution.

4.4.3 Vegetation change detection

Vegetation cover change was determined for the Pench Tiger Reserve, for 24 years (1977-2001), with an emphasis on vegetation index using the ERDAS software. The images used were of Landsat MSS (Figure-4.9, 4.11) and Landsat ETM+ (Figure-4.10, 4.12). The spatial resolution of ETM+ image were resampled and degraded to 57 meter to match the older image. Since both the image was from the same sensor, the latest IRS image was not used in the change detection analysis. The results of the Change matrix in form of positive change and negative change are given in the (Table-4.12, Figure-4.8).

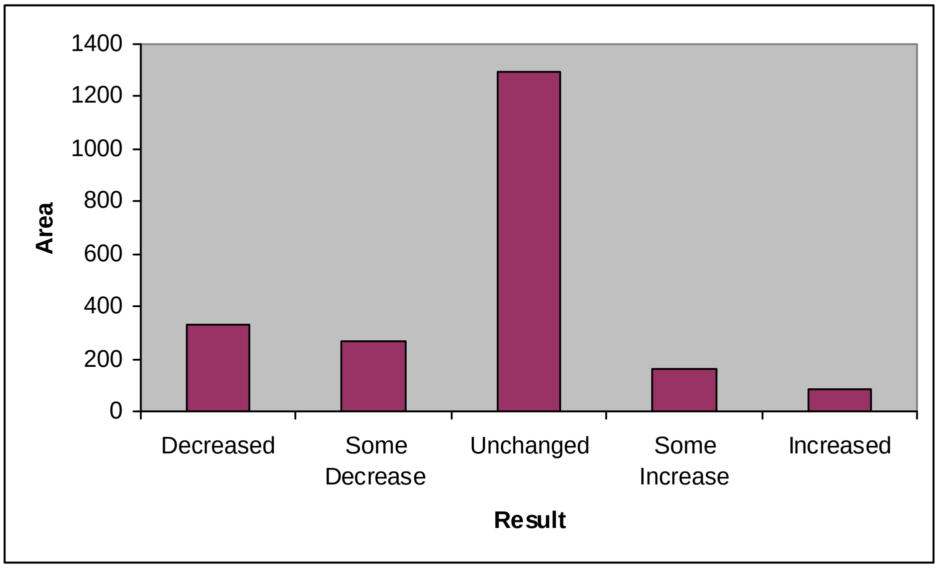
The change map clearly depicted vegetation cover condition in the Pench Tiger Reserve (PTR) in the last 25 years. The major loss of vegetation cover was in the buffer area of the PTR and the submergence. It was clearly understood that due to the dam construction in the late 80's, the major chunk of the prime forest from the PTR was submerged. The loss of forest cover over 10% was seen in 328 km^2 of the PTR, which includes substantial portion of areas in around human habitation, and reservoir area. However, the analysis indicated increase in vegetation cover in National Park and Sanctuary, and this could be attributed to stringent protection measure preventing canopy loss from lopping and other source of degradation which was prevailing earlier. Specifically, increase in forest cover in the Seoni portion of National Park was very prominent. The cover status in the PTR has increased over 162 km^2 area of which the Seoni portion of the park and Sanctuary alone contributed more than 80 % of the increment. On the other hand, Chindwara portion of the National Park had the maximum loss of vegetation cover, and this loss could be directly attributed to the anthropogenic disturbance.

It was also observed from the change map (Figure-4.13) that the area close to the dam in southern portion of the Chindwara part of the park had increase in the vegetation cover. This could be due to the presence of Totladoh irrigation staff and few check gates of forest department, to protect the illegal fishing from the dam. The presence of above staff could deter the illegal logging of the wood in these areas. The status of Sanctuary also seems to be improving in cover in comparison to previous years. Though the expectation of Sanctuary condition is normally to be a degraded cover, the result indicated that there is a possibility of increase with increased protection measure.

Table 4.12. Showing the Change matrix of the forest cover change between 1977-2001 in Pench Tiger Reserve, Madhya Pradesh

Result	Area km2
Decreased	328.071
Some Decrease	266.78
Unchanged	1294.75
Some Increase	162.30
Increased	83.32

Figure 4.8. Difference in the vegetation cover between 1997 and 2001 in Pench Tiger Reserve.



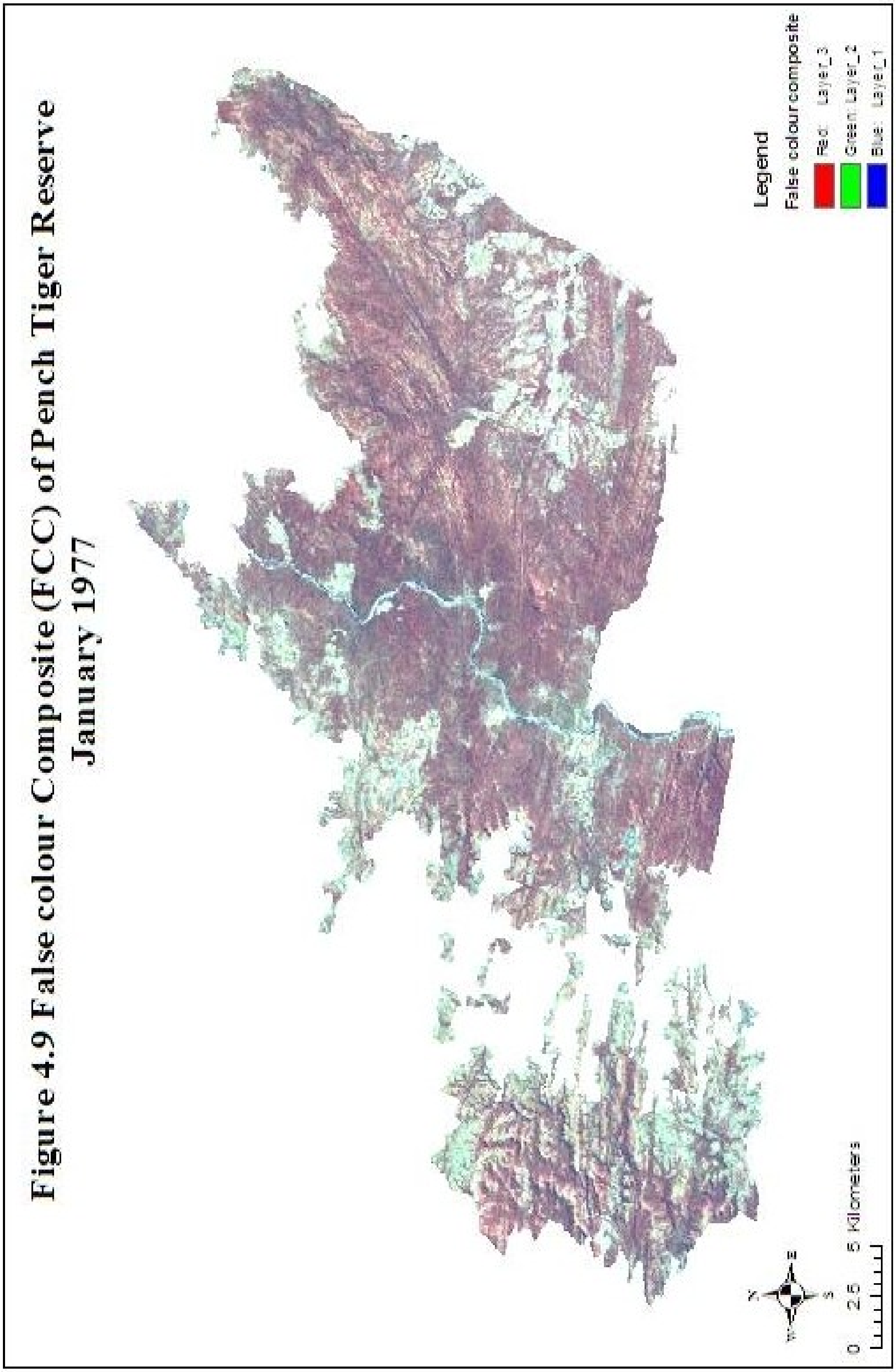


Figure 4.9 False colour Composite (FCC) of Pench Tiger Reserve January 1977

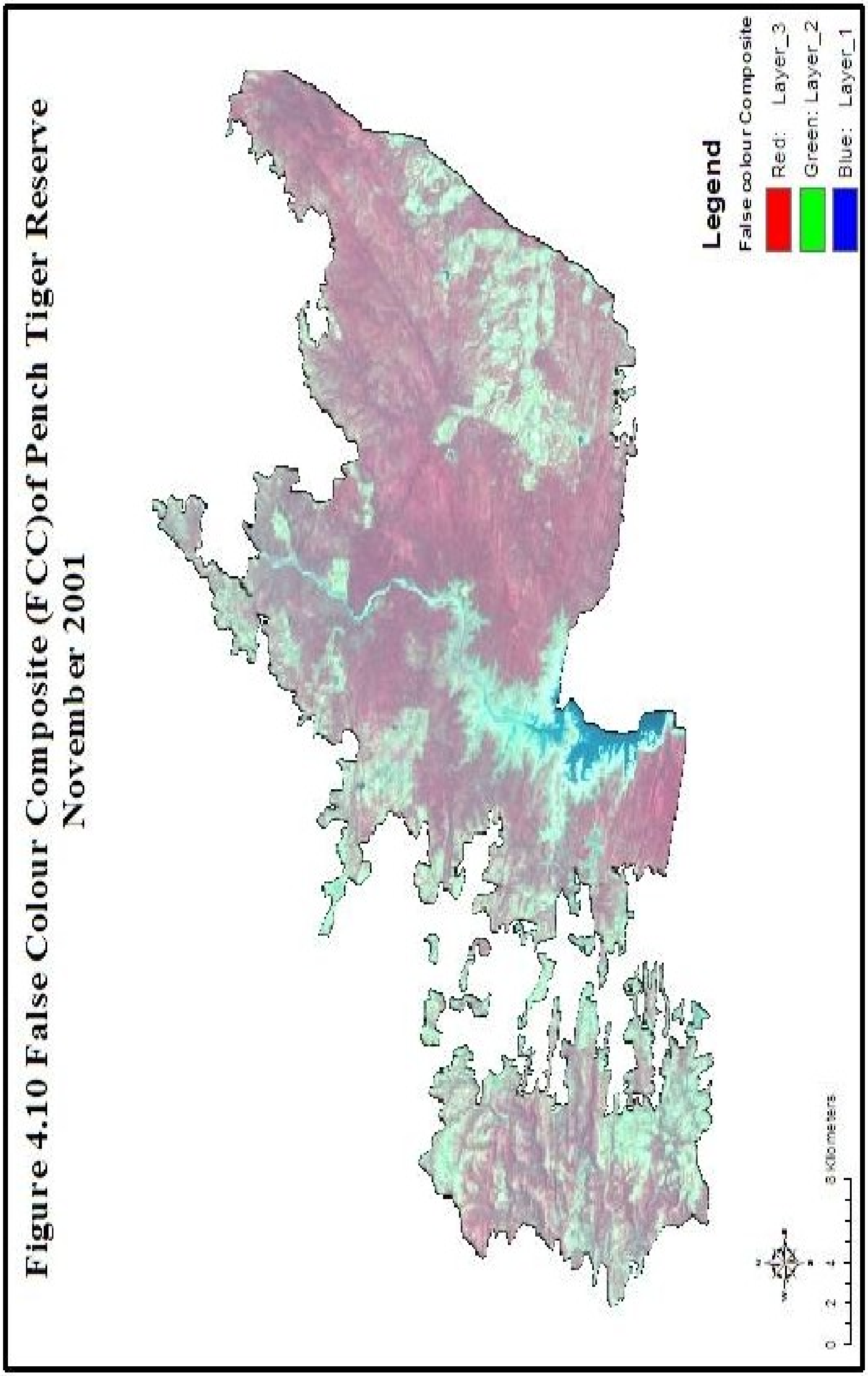


Figure 4.10 False Colour Composite (FCC)of Pench Tiger Reserve November 2001

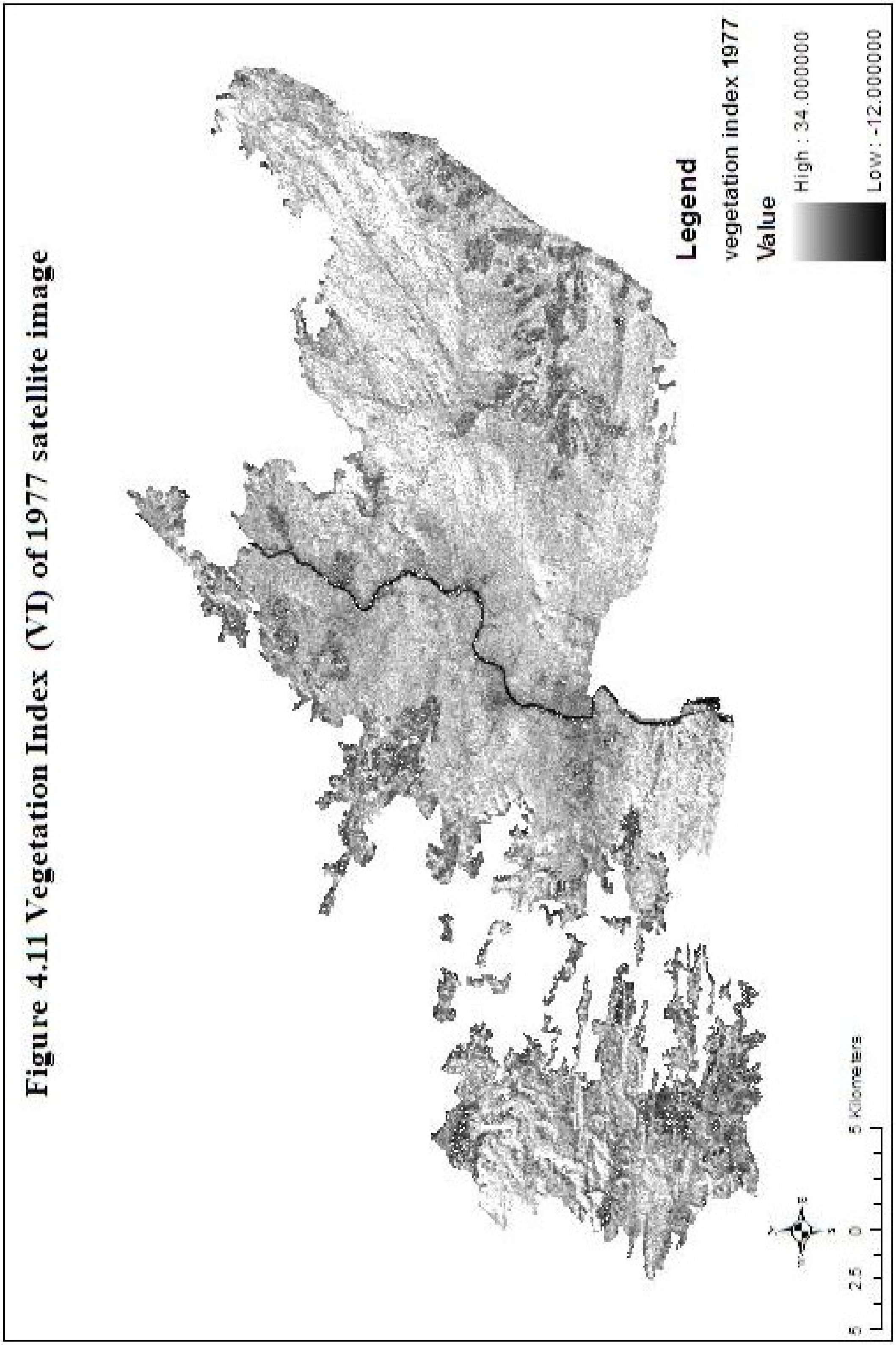


Figure 4.11 Vegetation Index (VI) of 1977 satellite image

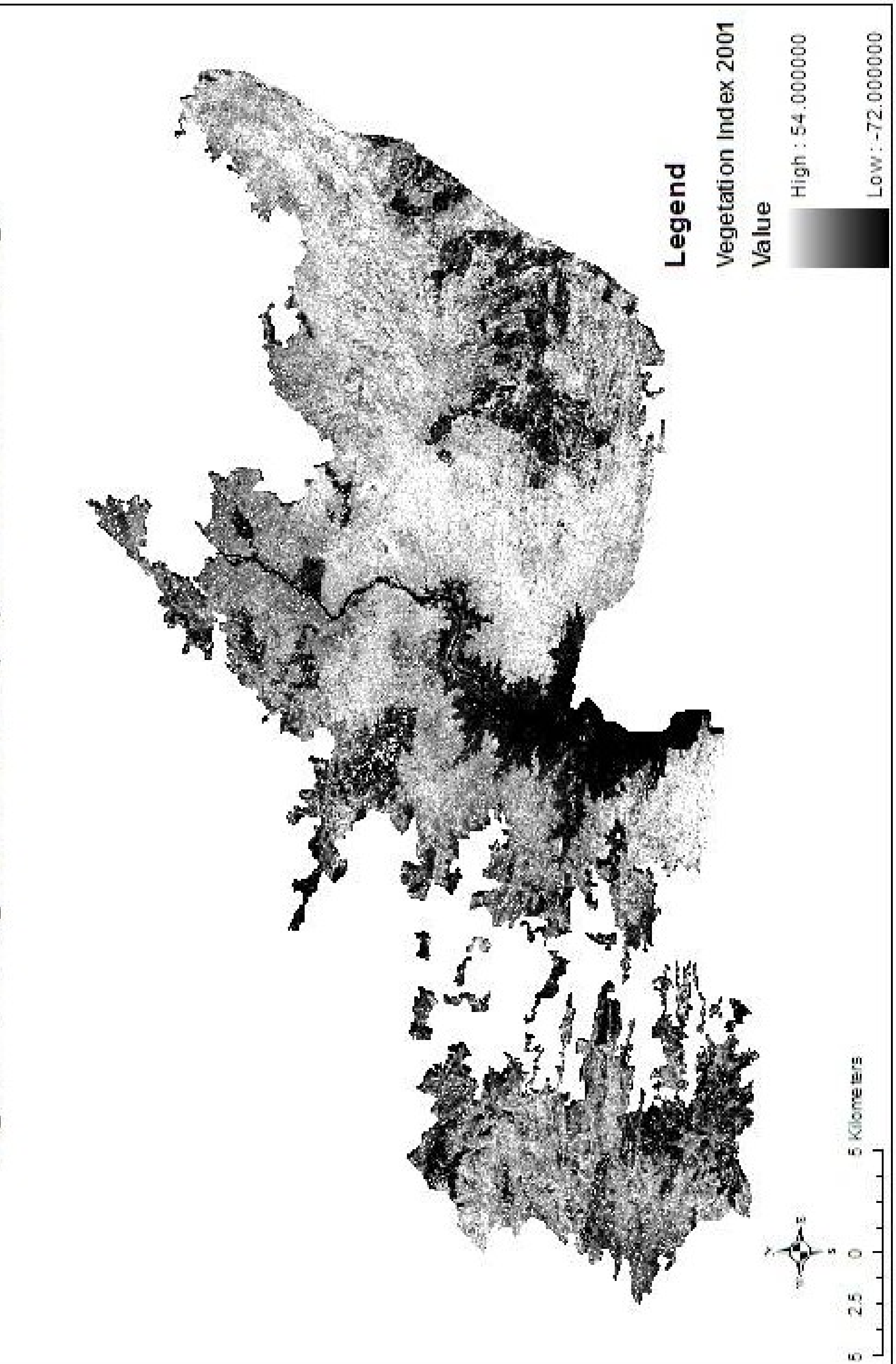


Figure 4.12 Vegetation index (VI) of 2001 Satellite Image

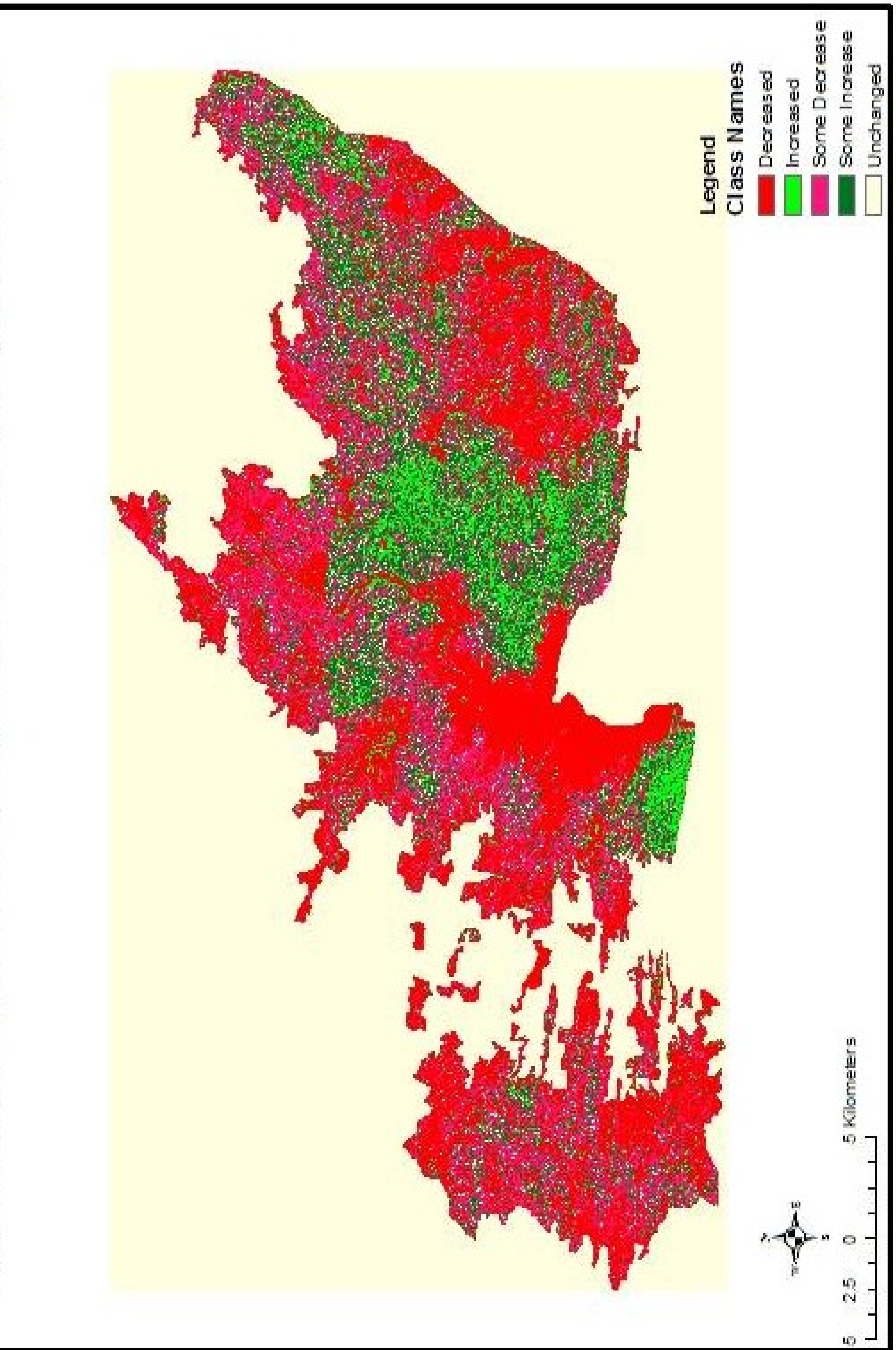


Figure 4.13 Change Detection of vegetation index in Pench Tiger Reserve,M.P

4.5 Conclusion

The vegetation map derived from the satellite imagery using Remote sensing technique in Pench Tiger Reserve broadly categorized the vegetation cover into three major types of forest, i.e. Teak dominant, Teak Mixed, and Dry Mixed Deciduous. As per the Champion and Seth classification (1968), PTR broadly falls under the Southern Tropical Dry Deciduous Forest type $5A/C_{ib}$ and Southern dry mixed deciduous forest Type $5A/C_{3.}$ It was observed from the spatial distribution of each vegetation type, that Teak dominant type was occupying the major extent (46.6 %) of the park. It was also observed that in the park where Teak dominant vegetation occurred it was more of a plantation done by the forest department in the early period in 1950's (compartment history) when the logging operation was legally carried out for the log extraction.

In the Teak mixed vegetation type, association of Teak with species such as *Lagerstroemia parviflora*, *Grewia taeliafolia* , *Miliusa velutina*, and *Dendrocalamus* was more prominent. They constituted 20 % of the total area. In comparison, the Seoni portion of the Tiger Reserve had the maximum occupancy of the class. This could be due to the geological factor controlling their distribution. Mixed forest type was the lowest in the distribution covering 87 km^2 and occupying 10 % of the total area. The detail of the mixed forest type and their species composition is discussed in the vegetation community chapter (chapter 4). Interestingly the Butea woodland category had contributed 13 % of the forest cover in the Tiger Reserve. They occupied 113 km^2 of the area mainly distributed along the disturbed area such as villages, and agriculture fields. It was observed in the park, near the Alikatta area, the Butea woodland had gregarious growth after the village was relocated in the early nineties, as it was under the submergence area due to dam construction. The barren land category which was other wise the forest opening and the grassland close to Alikatta and submergence area was very conspicuously shown by the imagery. It contributed 28 km^2 of area in the Reserve, with 3.3 % proportion of the total area. It also may change based on the season, where it increases during the summer and decreases during the monsoon due to inundation. Also the river and rivulet banks contributed for the barren area category. The submergence area is another category, where depending upon the monsoon season of the year, the water availability in the dam increased or decreased. During summer when the water level decreases, the ungulates were seen concentrated in the submergence area which contributes more than 54 km^2 covering 6.2 % of the total area of the Reserve.

The spatial complexity of the landscape was assessed using the FRAGSTAT at class level within the Tiger Reserve. The patch statistics revealed some interesting results of the landscape elements. Teak dominant had the largest patch Index with 5.5%, while the mixed dry deciduous had the smallest Patch Index at 0.1 %. It was evident from the result that the Teak dominant had a larger contiguous patch than the mixed forest which was more of smaller isolated forest fragments. The area statistics clearly indicates that larger contiguous patch occupied 46.6% of the total area.

The total number of patches varied from 7154 to 30970 among the classes of the landscape. However, this could be result of variation in actual constituent of the classes in the landscape. The mixed dry deciduous (MDD) had the maximum number of patches, while Butea woodland had the minimum number of patches in the entire landscape. It clearly denotes that the MDD had heterogeneous distribution in the landscape and whereas the Butea woodland were homogeneously distributed. It was also observed in the field that Butea woodland was slowly occupying the disturbed area, mainly close to the forest fringes into the Park. The greater number of patches in the MDD indicated the extent of their fragmentation or spatial heterogeneity in finer scale, while in the forest category the Teak dominant forest had the lower number of patches, which denotes the homogeneity of the class.

In terms of patch density, mixed dry deciduous had the maximum patch density (PD) with 14.5 patches per sqkm. The maximum value of PD in case of MDD was due to the heterogeneous nature of the vegetation class *(ie*. mixed dry deciduous was more patchily distributed or discontinuously distributed)). Mixed deciduous patches were more fragmented than the other classes. It was also observed in the field, that the MDD was occurring in small patches among the Teak mixed class and they were distributed more in hilly terrain of the Reserve. As expected, the mixed deciduous patch showed the lowest mean patch size (0.3), while the Teak dominant had the highest mean patch size (3.2). This is due to the large patch size of the Teak dominant vegetation which is more of contiguous distribution, whereas the Mixed deciduous was of more fragmented patch. Teak with mixed vegetation and Butea woodland showed more or less similar mean patch size.

Change detection of vegetation cover was done using the Landsat 1977 image and landsat ETM + 2001 image. The forest loss was very prominent in the buffer areas and Chindwara portion of the National Park. There was a conspicuous increase in the forest cover within the National Park and Sanctuary, and areas close to southwest portion adjoining the reservoir. The better protection status of the National

Park could have contributed to the increase of forest cover. The villages outside the PTR showed clear decrease of vegetation cover. This also indicates the increase in the size of the village area due to expansion of population in the nearby areas of the National Park periphery. The status of Sanctuary also has shown a positive increase in forest cover. In a nutshell, the landscape in PTR contains relatively homogenous land cover types represented by highly heterogeneous patch properties. This would mean that the pattern in spatial configuration of patches account for high habitat heterogeneity favoring wildlife richness as is evident in the park with high wildlife diversity and abundance. This is also an example offering scientific evidence that active protection can lead to increased forest cover, and that forest cover is lost to developmental project and local human need.

Chapter 5

Habitat Suitability Model for Gaur

5.1 Introduction

Prediction of species distribution is an important element of conservation biology. Management, species re-introduction and ecosystem restoration often rely on habitat suitability model (Hirxel *et al.* 2001). Food plant abundance and favorable climatic condition governs distribution of any life form, both spatial and temporal (Darlington 1957, Newton 1980, Ford 1982, Woodward 1987, Hill and Robertson 1988, Gill 1996, Franco *et al*. 2000, Walker 1990). Availability of food resources, climatic condition and biotic disturbances are highly variable across space and time, and in response, species distribution is generally aggregated in patches, thus exhibiting relative preference to such areas. Hence documentation of such pattern is necessary in designing the research objective for that species, which has considerable implication on conservation initiatives. Though the information generated through intensive field research focusing on one or more species provide useful empirical data, the approach to map distribution on a spatial scale offers an efficient platform to address conservation issues both at local and landscape level.

To predict geographical distribution of a species based on the environment parameters of sites of known occurrence form important techniques in analytical biology, with its application in conservation and reserve planning (Corsi *et al*. 1999, Peterson and Shaw 2003, Peterson *et al.* 1999, Scott et al. 2002, Welk et al. 2002, Yom-Tov and Kadmon 1998). Remote Sensing and Geographical

Information System (GIS), has opened up a new paradigm in mapping spatial pattern of species distribution and wildlife habitats (Worah *et al*. 1989, Buckland and Elston 1993; Andries *et al*. 1994, Mladenoff *et al*. 1995, Nagendra and Gadgil 1999). The application of these tools are cost effective considering the vast area of landscape to be covered and also allows accessibility to wide variety of potential correlates that affect the presence of species and consequently, enables to model species distribution. India being one of the largest users of satellite-based information, the technical application in natural resource management has not advanced to the expectation. Development of wildlife-habitat models is facilitated by increased availability and coverage of remote sensing data, e.g. satellite imagery, allowing detailed assessment of amounts and distribution of resources over large areas. Application of GPS-technique in animal habitat-use studies brings forward large amounts of positional data with unprecedented accuracy (Dettki et al. 2003).

The research using these techniques have so far focused primarily on image processing and visual interpretation for vegetation types and land cover classification (Negi 1980, Porwal and Pant 1989). Application of these techniques for detecting land cover/land use changes and identifying wildlife habitat has rapidly developed in the recent years (Lal et al. 1991, Pant and Kharakwal 1995, Dutt *et al*. 1986, Worah et al. 1989).

Any attempts to map species distribution would have to consider identification of similar represented features (such as habitat characteristics, food availability, climate, influence of other biotic factors, etc.). It is practically difficult to correctly identify and quantify the ‘appropriate representation’ simply because it is impossible to measure all the factors involved, some have only limited influence on the species and some are unknown (Gough and Rushton 2000). It is also redundant to quantify each one of them, when there is scope to detect fewer surrogates that can potentially explain the species occurrence. Therefore, it becomes important to develop a model (a simplified representation of the relationship between species and, biotic and a biotic factors) using minimum possible variables that account for maximum influence on the species occurrence. The other important aspect or usefulness of the model is that it allows for extrapolation in both space and time (Starfield and Bleloch 1986).

It is observed, that habitat model building generally adopt either the deductive or the inductive approach. In the deductive approach habitat-species relationships are drawn from the knowledge of an expert. In the inductive approach, instead, the relationships are generalized from a sample of observations where species’ presence is matched with specific values of the environmental variables (Boone and Krohn 2000, Corsiet et al., 2000).The correct approach strictly depends on the availability of data on species occurrence (Stockwell and Peterson 1997). Generally it is observed that data availability is a major constraint in building large-scale models of species distribution (Osborne et al.. 2001).The sampling design should be correctly identified for each species being investigated and should capture the variability on the spatial scale (Guisan and Zimmermann 2000, Osborne and Suarez-Seoane 2002). Prior knowledge on relationship between habitat features and presence/absence of animal would play a supportive role in collecting information for mapping species distribution.

Habitat models may provide viable tools for co-management of large mammals and forest resources, yet their applicability has not been comprehensively evaluated in managed forest (Dettki et al. 2003). Development of wildlife-habitat models is facilitated by increased availability and coverage of remote sensing data, e.g. satellite imagery, allowing detailed assessment of amounts and distribution of resources over large areas. Application of GPS-technique in animal habitat-use studies brings forward large amounts of positional data with unprecedented accuracy

Literature review on modeling species distribution in GIS domain reveals that there is an increasing trend in such studies since 1990s, but majority of them represent deductive approach towards habitat-species relationships.

Little work has been done on modeling animal-habitat suitability in managed forests. In this study we have attempted to model the habitat suitability and predict distribution of gaur in Pench National Park based on Ecological niche factor analysis (ENFA) using Biomapper software (*Hirzel* et al.2001). Gaur being a generalist feeder, exhibits local migration pattern. During summer it largely browses and during winter and monsoon (Sankar et al. 2001) it largely feeds on ground layer. Gaur depends on water to a larger extent, and to drink very often. Keeping in view of the above observation the data parameter collected for the habitat suitability model in the present study constituted, food plant distribution, water availability, ground cover, terrain condition, major vegetation type, tree and shrub cover, and the record of gaur sightings including the group composition. The model was attempted to understand the factors influencing the distribution of gaur in the Pench Tiger Reserve. Identification of suitable habitat can help in formulating plan for better management and conservation of gaur in Pench Tiger Reserve.

5.2 Methodology

Different variables that were used in the model to predict the suitable habitat and distribution of Gaur are discussed here. Individual gaur sightings were recorded based on opportunistic sampling. Whenever gaur was feeding the location and habitat type, and details of the food plant consumed were noted. The data was recorded throughout the year, irrespective of the season. Each location was recorded using pro Magellan 5000 model Global Positioning sytems (GPS). The latitude and longitude on each sighting were noted down and plotted in the GIS domain. (Figure-5.1).The gaur location points were used in the model as the animal presence data.

Due to the multiplicity of factors involved in feed intake regulation and feeding behavior, we used the data collected on food plants eaten by gaur in PTR. Data on food habits of gaur was collected based on adlibitum observations in the entire PTR.

The food plant species and the parts eaten were noted down on each observation. The food plant availability (70 species from 30 families) was quantified from the vegetation plots laid down for the community study. The sampling was carried out for the vegetation community study, but the presence of the gaur food plant species were also noted down from the sampling plots. The number of shrubs and herbs present in the plots were noted. The Table 5.1 show the details of the gaur food plants along with the details of the parts consumed.

Table 5.1 Food plants of Gaur in Pench Tiger Reserve, Madhya Pradesh.

Family	***Plant Species***	***Plant Part***	***Season***
DICOTYLEDONEAE			
Annonaceae	*Miliusa velutina*	L	s,w,m
Malvaceae	*Abutilon indicum*	L	s
	Kydia calycina	L	s,w
	Sida cordifolia	L	s
	Sida spp	L	s
	Urena lobata	L	s
Sterculiaceae	*Helicteres isora*	L	s
Tiliaceae	*Grewia hirsuta*	L,FL,FR	s,w
	Grewia tiliaefolia	L,FL,FR	s,w,m
	Grewia rothii	L	s
Rutaceae	*Aegle marmelos*	L,FL,FR	s,w,m
Celastraceae	*Celastrus paniculata*	L	s
Rhamnaceae	*Ventilago maderaspatana*	L,FL,FR	s,w,m
	Zizyphus oenoplia	L,FL,FR	s,w
	Zizyphus xylopyrus	L,FL,FR	s,w,m
	Zizyphus mauritiana	L,FL,FR	s,w
	Zizyphus nummularia	L	s

Family	***Plant Species***	***Plant Part***	***Season***
Fabaceae	*Abrus precatorius*	L	m
	Butea superba	L	m,w
	Dalbergia paniculata	L	s,w,m
	Desmodium dichotomum	L	s
	Indigofera arborea	L,FL	w,m
	Millettia auriculata	L	w,m
	Ougeinia dalbergioides	L	s,w,m
	Uraria spp	L	s
Caesalpiniaceae	*Bauhinia racemosa*	L	s,w,m
	Bauhinia vahlii	L,FL	s,w
	Cassia tora	L	s
Mimosaceae			
	Acacia pennata	L	s
	Albizzia odoratissima	L	s
	Albizzia procera	L	s,w
Combretaceae			
	Anogeissus latifolia	L,FL	s,w,m
	Terminalia arjuna	L	m
	Termanalia alata	L,FL	s,w,m
Myrtaceae	*Syzygium cumini*	L,FL,FR	w,m
Flacourtiaceae	*Casearia tomentosa*	L,FL	s,w
	Casearia graveolens	L	s,w
	Flacourtia indica	L,FR	s,w
	Haldina cordifolia	L	s,w

Family	***Plant Species***	***Plant Part***	***Season***
Rubiaceae	*Mitragyna parviflora*	L	m,w
	Catunareguam uliginosa	L	s,w
	Catunaregam spinosa	L	s,w
Ebenaceae			
	Diospyros montana	L	s,w
	Diospyros melanoxylon	L,FR	s,w,m
Nyctaginaceae	*Nyctanthes arbor-tristris*	L,FL	m
Apocynaceae	*Holarrhena antidysenterica*	L	s
Ehretiaceae	*Cordia myxa*	L	s,w,m
Verbenaceae	*Lantana camara*	L	s
	Tectona grandis	L,BR	s
	Vitex spp	L,FL	s
Euphorbiceae	*Bridelia retusa*	L	s,w
	Euphorbia hirta		
	Phyllanthus emblica	L,FR	s,w
	Phyllanthus niruri	L	
Moraceae	*Ficus hispida*	L	m
Sapotaceae	*Madhuca latifolia*	FL,FR	s
MONOCOTYLEDONEAE			
Zingiberaceae	*Curcuma reclinata*	L	m
	Zingiber spp	L	m

Family	***Plant Species***	***Plant Part***	***Season***
Hypoxidaceae	*Curculigo orchiodies*	L	m
Liliaceae	*Asparagus racemosus*	L	m
	Chlorophytum tuberosum	L	m
Arecaceae	*Phoenix humulis*	L	s,w,m
Bambusaceae	*Dendrocalamus strictus*	L,SD	s,w,m
Gramineae	*Adropogon spp*	L	m,w
	Anthistiria spp	L	m
	Apluda mutica	L	m,w
	Chloris dolychostachya	L	m
	Cynodon dactylon	L	s,w
	Dicanthium spp	L	m,w
	Heteropogon contortus	L	s,w,m
	Ischaemum spp	L	m,w
	Sorghum halepense	L,FL	w
	Themeda spp	L	s,w
Commelinaceae	*Commelina benghalensis*	L	M
Cyperaceae	*Cyperus spp*	L	m

Plant parts: (L= Leaf, FL=Flower, FR=Fruit, SD=Seed, B= Bark)

Season: (s= Summer, w= Winter, m=Monsoon)

Various derived thematic layers (Table-5.1) such as Digital Elevation Model, (DEM) and drainage density map were derived from the contour and Drainage map respectively. Other layers used in the model include slope, aspect map, food plant density map, ground cover map, vegetation index map, vegetation type map, vegetation change cover map, were used in the model to predict the probable gaur distribution. All layers were converted in to raster format and resample for 100 meter resolution.

Table 5.2. Different layers used in the model.

S.No	Name of the layer	Data source	Format	Resolution
1	Gaur distribution	Gaur sighting GPS locations	Vector point	
2	Drainage	Survey of India	Vector stream	
3	Contour	Survey of India	Vector line	20meter interval
4	Food plant availability	Field sampling GPS locations	Vector point	
5	Vegetation map	IRS LISS III P6	.Img	23.5 meter
6	Ground cover	Field sampling GPS locations	Vector Point	
7	Vegetation index	Landsat ETM +	.Img	30 meter
8	Vegetation cover change	Landsat ETM+ &Landsat MSS	.Img	30 meter
9	Digital elevation model (DEM)	Contour	Grid	100 meter
10	Slope	Dem	Grid	100 meter
11	Aspect	Dem	Grid	100 meter

5.3. Data analysis

5.3.1 Method adopted in applying Ecological Niche Factor Analysis (ENFA)

Ecological niche factor analysis was carried out using the Biomapper software, 3.2 (Hirzel 2004) to prepare habitat suitability map for gaur. The input data for ENFA analysis are discussed in detail below. Requiring only presence data as input, the Ecological-Niche Factor Analysis (ENFA) computes suitability functions by comparing the species distribution in the Eigen Value (EV) space with that of the whole set of cells.

Preparation of ecogeographical maps is the first step in the analysis. The field data maps are initially converted in to grid format then imported in to IDRISI to convert in to RST format, since the biomapper accepts the maps in IDIRSI format only. The spatial extent for each map was corrected to same extent as these could cause problem in overlay and analysis. Also the maps were sampled to same resolution of 100 meters. The maps thus converted are termed as eco-geographical variables, which are used for the ENFA analysis.

We used raster maps, which are grids of *N* isometric cells covering the whole study area. Each cell of a map contains the value of one variable. Eco-geographical maps contain continuous values, measured for each of the descriptive variables. Species maps contain boolean values (0 or 1), a value of 1 meaning that the presence of the focal species was proved on this cell. A value of zero simply means absence of proof. Each cell is thus associated to a vector whose components are the values of the EGV in the underlying area, and can be represented by a point in the multidimensional space of the EGVs. If distributions are multinormal, the scatterplot will have the shape of a hyper-ellipsoid. The cells where the focal species was observed constitute a subset of the global distribution and are plotted as a smaller hyperellipsoid within the global one.

The ENFA makes all the maps over layable for the model. The function verifies that no discrepancies exist in any of the layers. All the layers are normalised and ENFA is performed to get the value of scores and correlation matrix. The factor maps generated as a result of ENFA function. The factor maps are used in the habitat suitability (HS) model to compute the final habitat suitability map. The median algorithm was used for calculating the HS, since it is quick, accurate, and species distribution on each factor was more or less symmetrical. Other statistics such as correlation matrix, distribution of species on each variables, marginality, specialization and tolerance value were also derived from the software output.

The detail description of the layer variables used is discussed in detail below. The methods adopted for preparing the eco-geographical variables (EGVs) are discussed under the corresponding layer along with their maps.

Figure 5.1 Record of Gaur Sightings During the Study Period in Pench Tiger Reserve

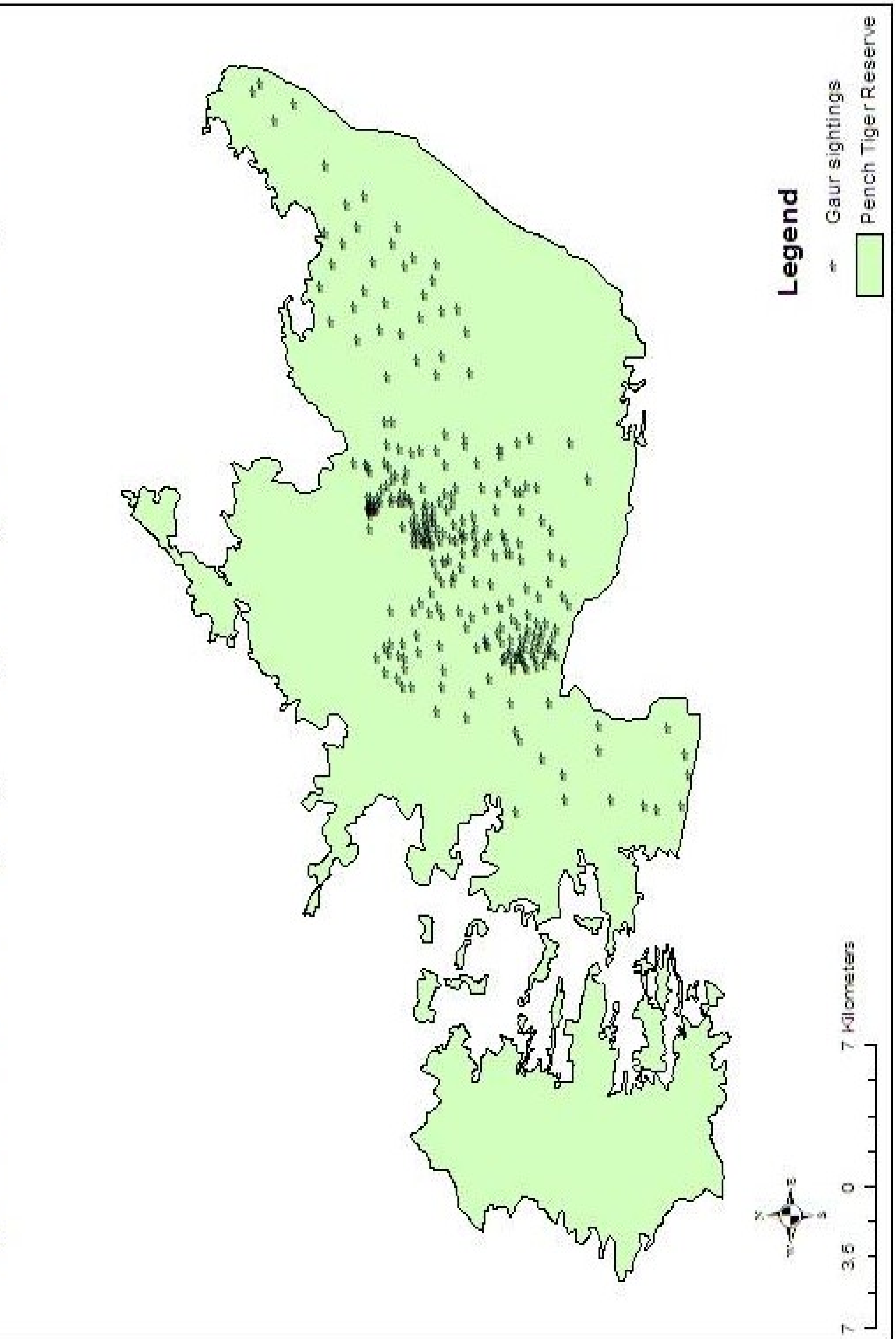


Figure 5.2 Interpolated density of Gaur distribution in Pench Tiger reserve

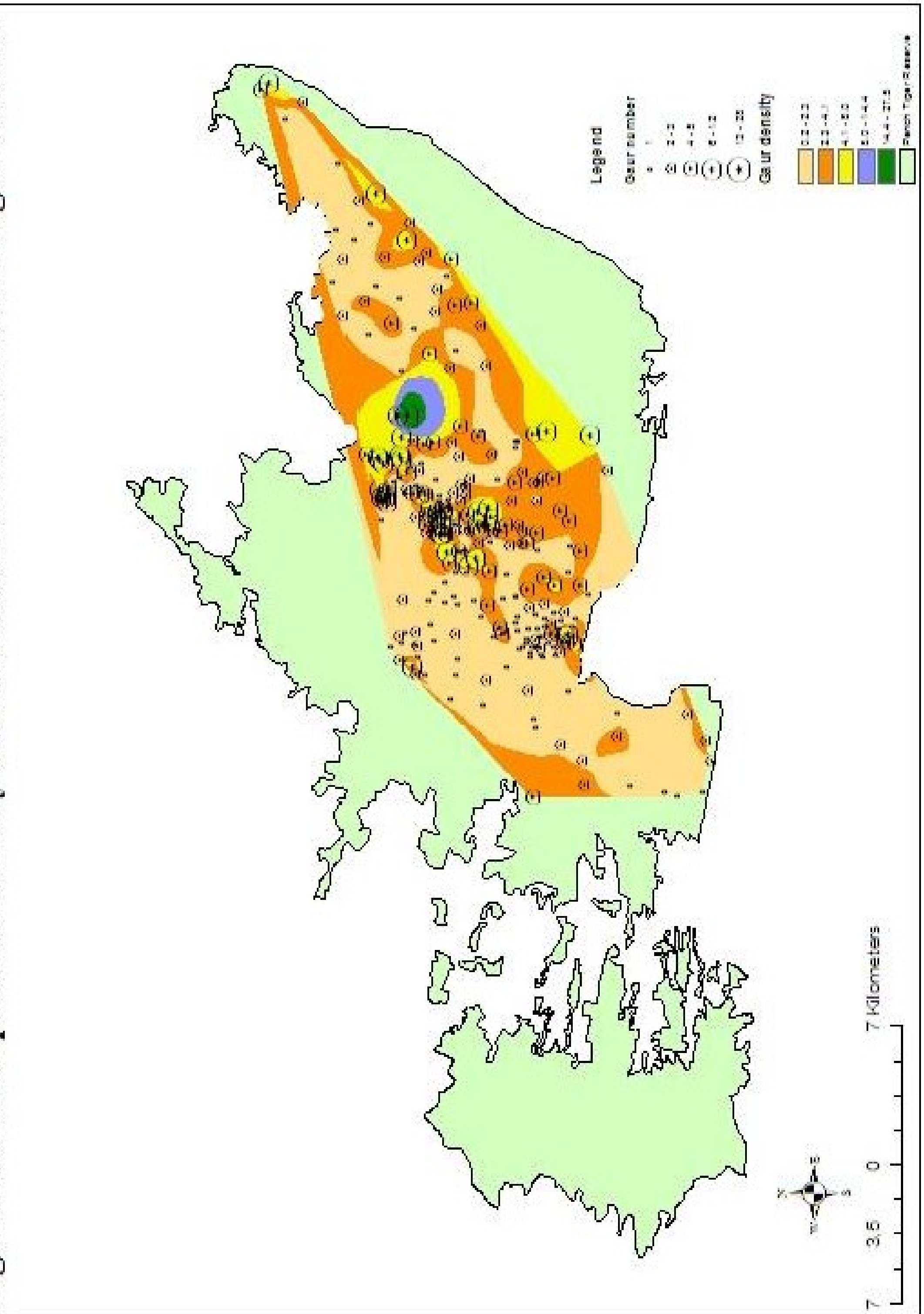


Figure 5.3 Gaur Food Plant Density Distribution in Pench Tiger Reserve

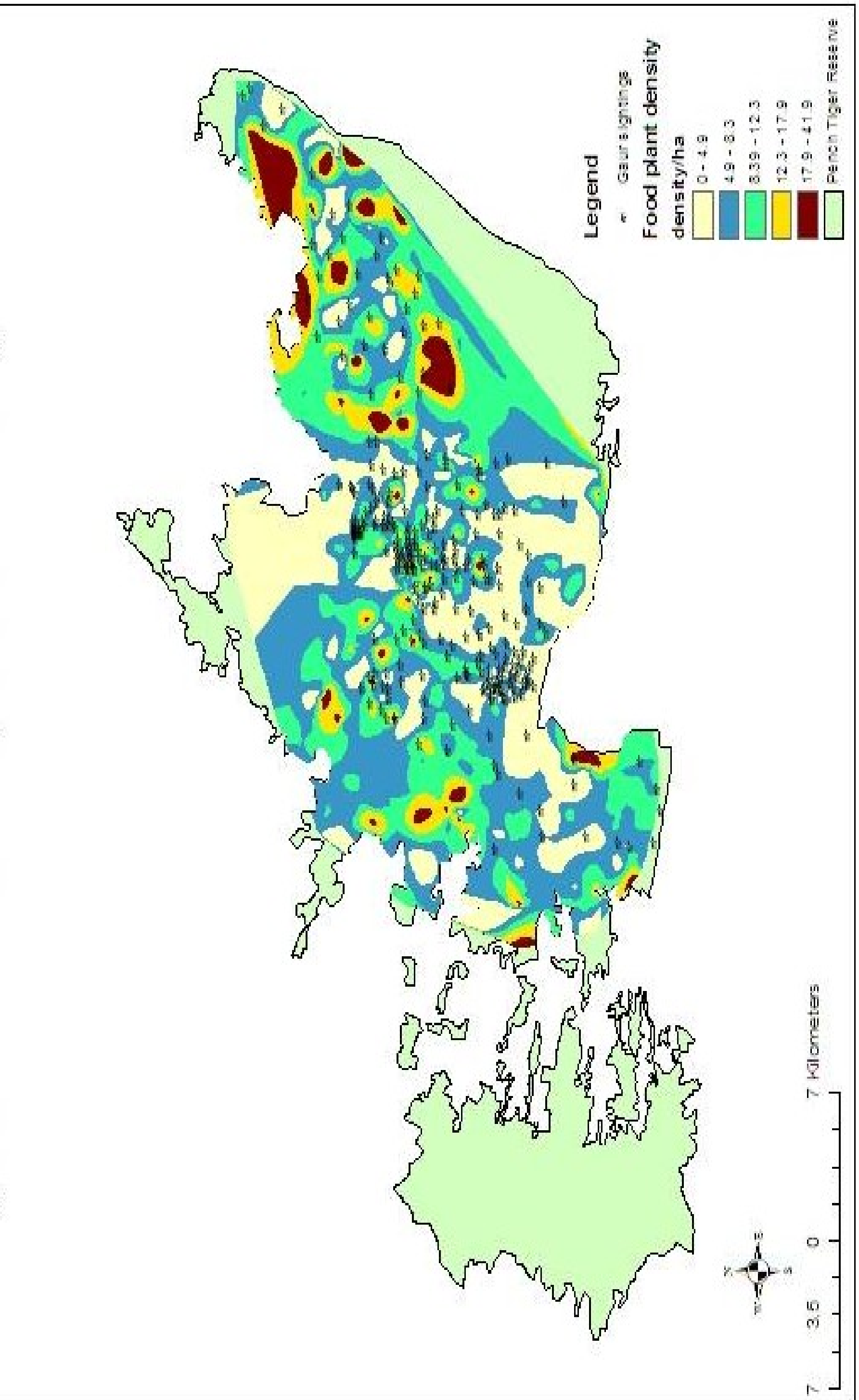


Figure 5.4 Ground Cover Density in Percentage in Pench Tiger Reserve

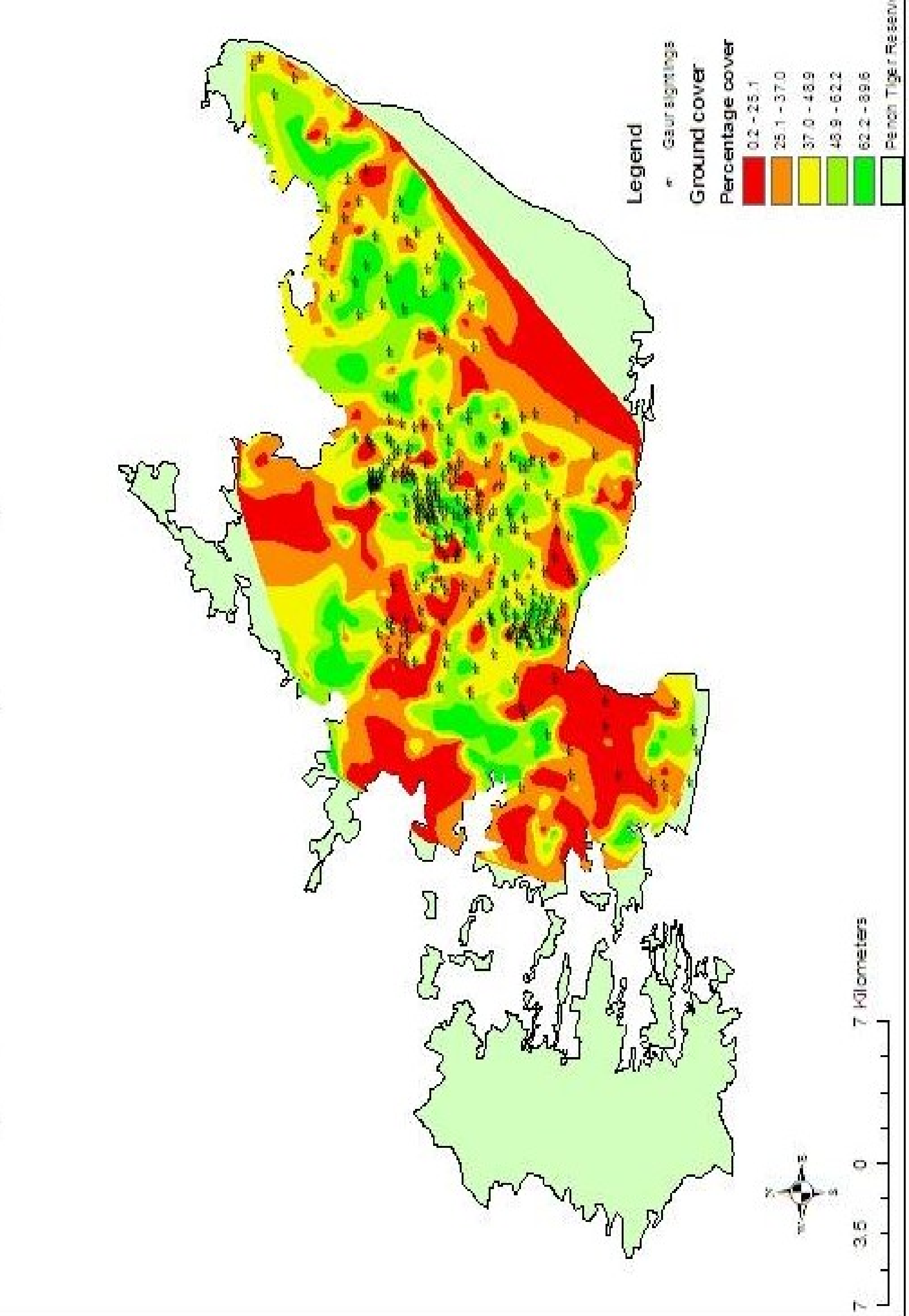
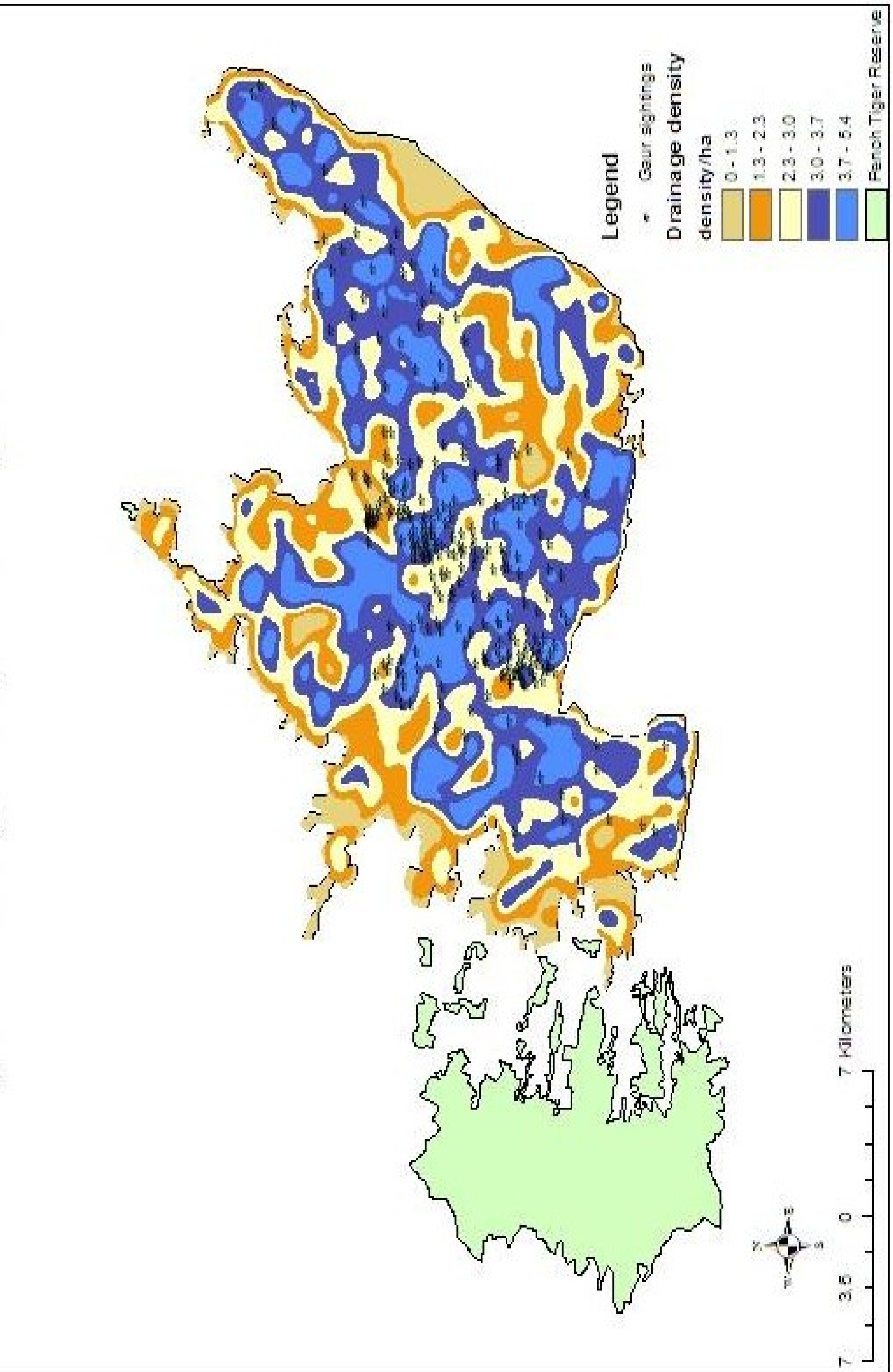


Figure 5.5 Drainage Density in Pench Tiger Reserve



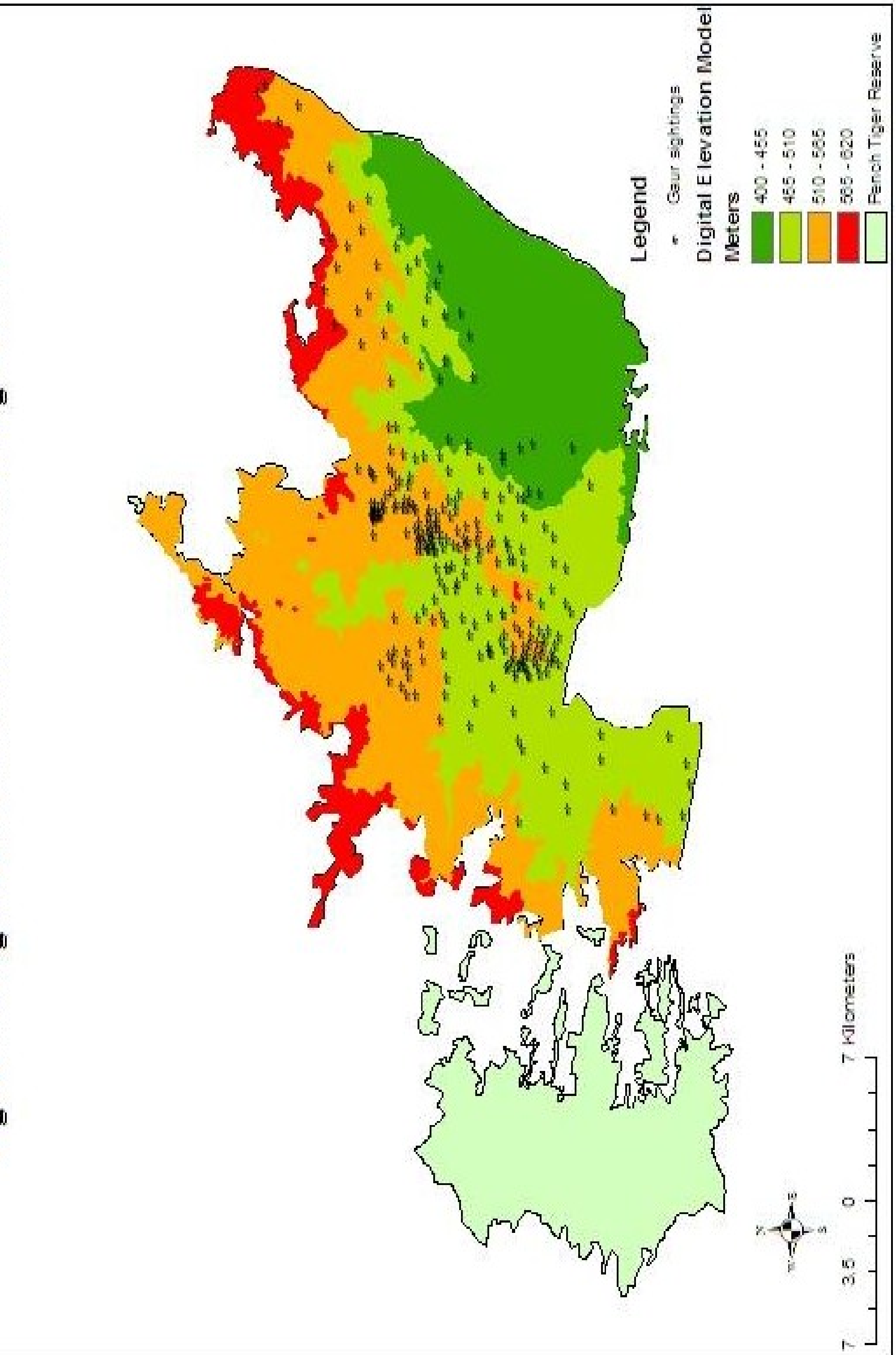
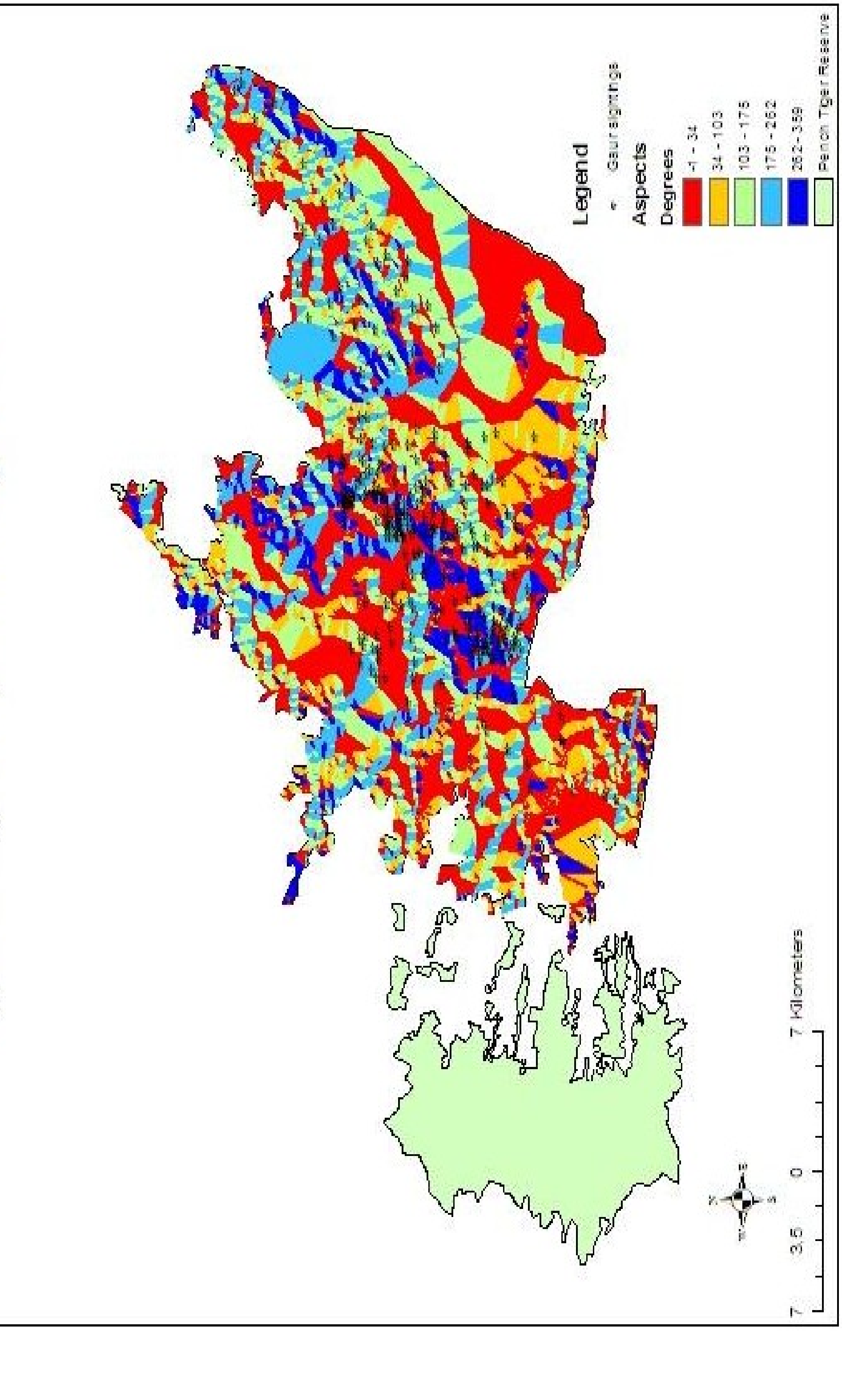


Figure 5.6 Digital Elevation Model of Pench Tiger Reserve

Figure 5.7 Aspects Map of Pench Tiger Reserve



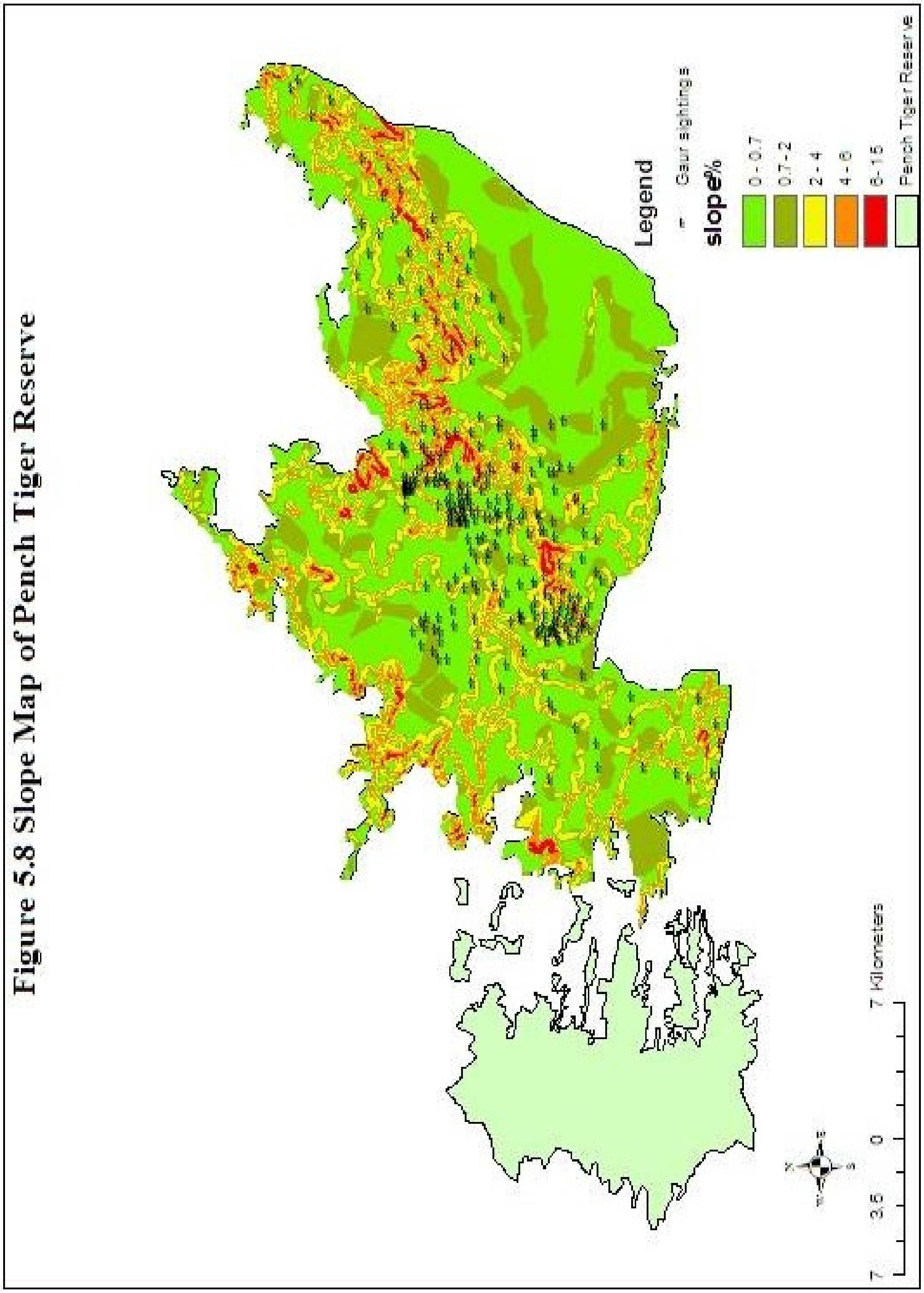


Figure 5.8 Slope Map of Pench Tiger Reserve

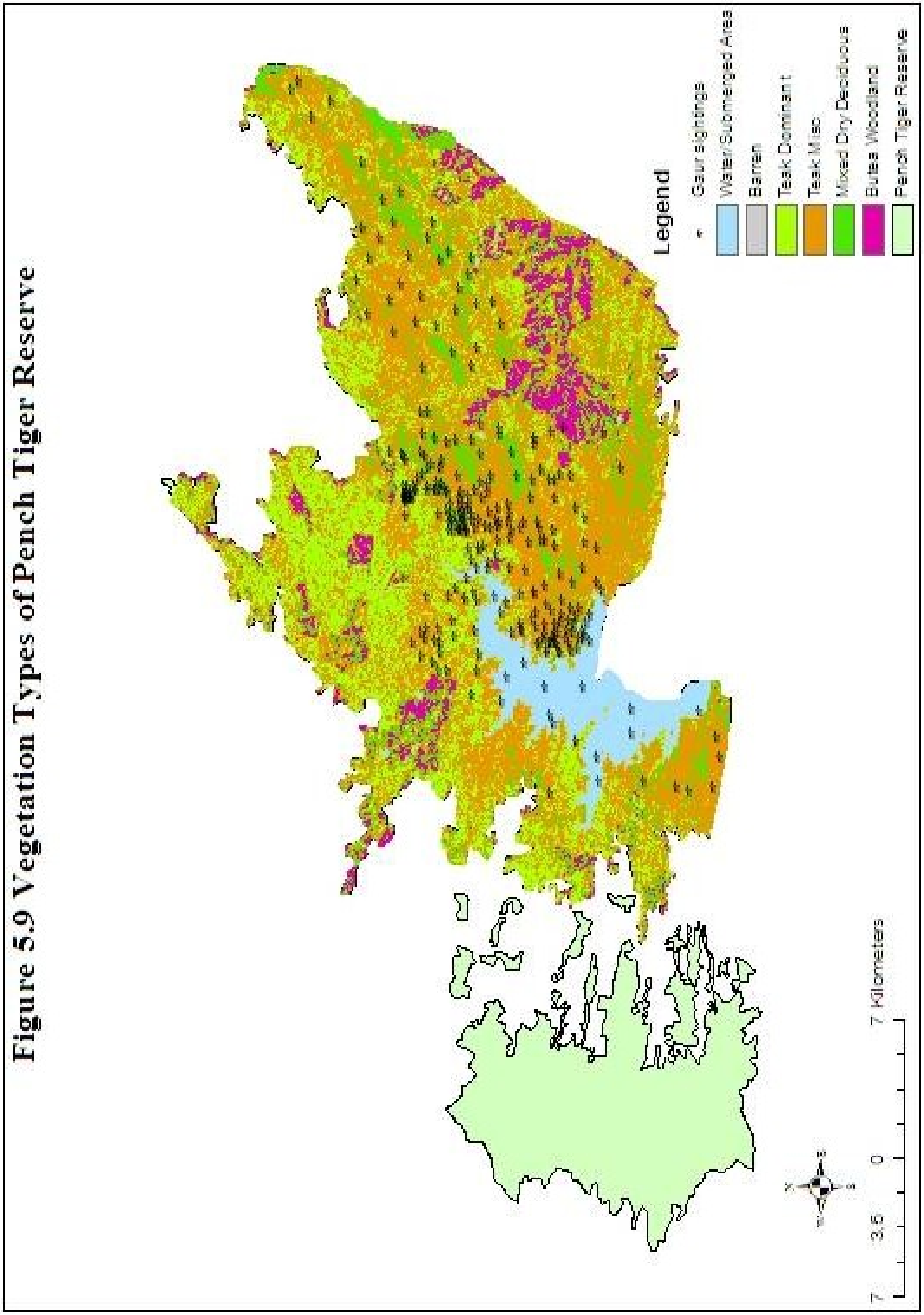
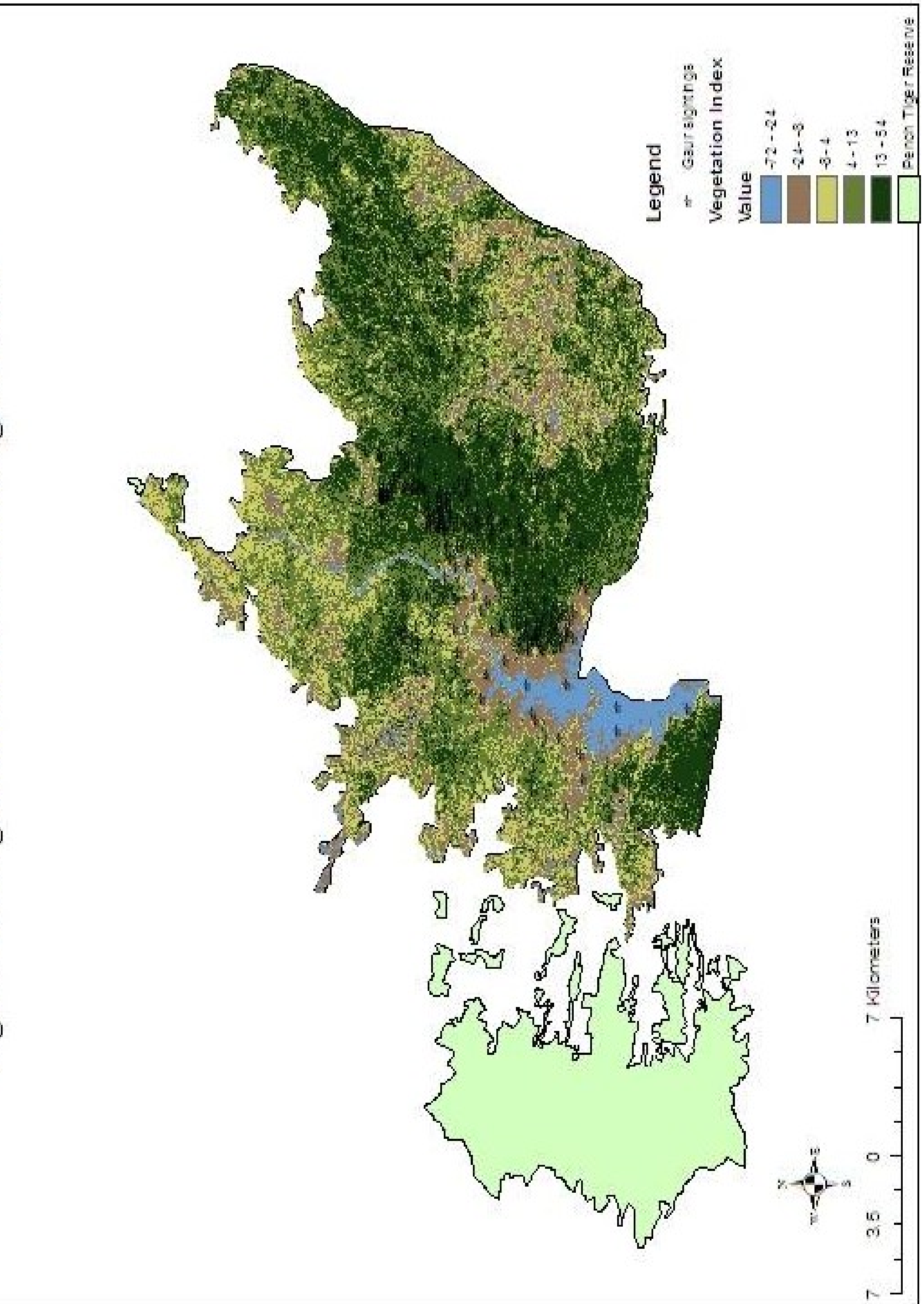


Figure 5.9 Vegetation Types of Pench Tiger Reserve

Figure 5.10 Vegetation Index of Pench Tiger Reserve



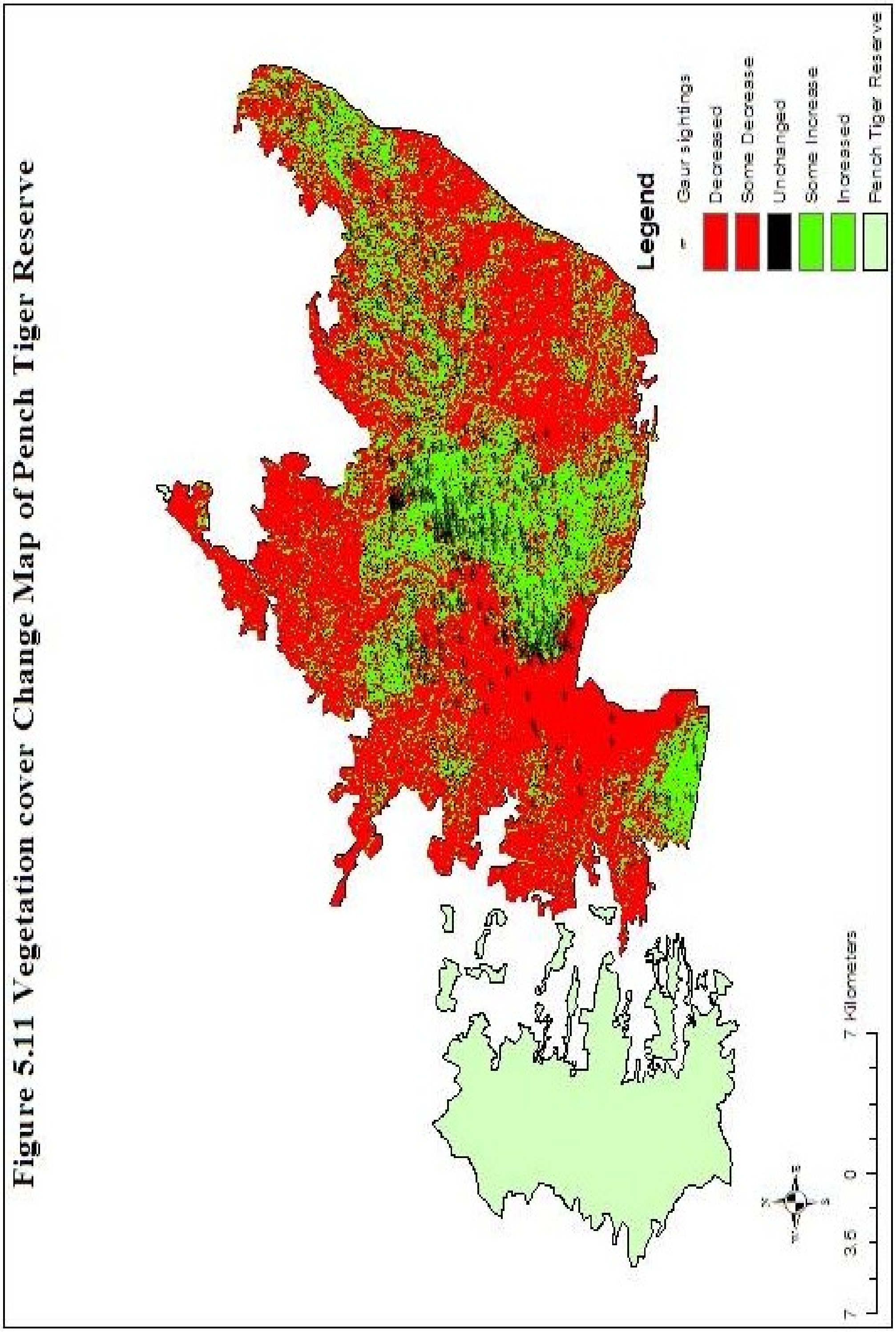


Figure 5.11 Vegetation cover Change Map of Pench Tiger Reserve

5.4 Results and Discussion

5.4.1 Gaur distribution in Pench National Park (PNP)

The distribution map of gaur in (Figure-5.1) clearly showed that most of the animal locations were concentrated towards the eastern portion of the park (n=621).

It was observed that the gaur was found largely in the Seoni and Sanctuary portions of the Tiger Reserve. A few individuals were seen crossing the Pench River and grazing in the Chindwara portion, but they were always seen close to the river banks. The density map (Figure-5.2) created from the point data using the interpolation method clearly showed that the density of gaur was not equally distributed within the park. The map clearly depicts the area of high density of gaur, which is in contrast to the frequent gaur sightings, observed more towards the Pench River. This could be due to large size groups of gaur observed in that location. Overall the gaur distribution in PTR comprised largely of single indiduals and small groups (2-4). It was observed that the Pench Sanctuary had evenly distributed gaur sightings, but the observed group size was low.

5.4.2 Ecogeographical variables used to generate prediction model

5.4.2.1 Food plant distribution

One of the major habitat variables collected in the field to understand what gaur feeds on is the food plant availability. The vegetation plots laid for collecting the structural and composition data encompassed the details of food plant present in each plot. The food plant was categorized in to shrub and herb and grasses. Plots with information on food plant and their number of individual present, along with the GPS location value was used for the mapping food plant density distribution. The highest density of food plant were available in the Sanctuary portion along with north eastern portion of the park. (Figure 5.3). The observation made from the result indicates that gaur distribution was influenced by the the high density food plant availability. Although the western portion of the PTR had few patch of high density food plant availability, gaur presence was not recorded in these areas. This clould be due to the influence of the water availability that is governing gaur movement. Also another important factor that influences the gaur movement is the disturbance, where gaur prefers the less disturbed areas.

5.4.2.2 Ground cover

Ground cover information was collected along with food plant availability during the vegetation sampling. The ground cover (Figure-5.4) was categorized in to grass, litter, shrub, herb, wood and bare soil using the quadrat method. Cover information in a plot was calculated and converted to percentage cover for each plot. Using the percentage cover, layer was generated using the interpolation method in the ArcGIS software. It was observed from the map that high concentration of gaur were seen in the high ground cover area, which means that gaur preferred the high ground cover areas despite the presence of low food plant density. It was observed from the distribution of ground cover and the concentration of the food plant species that there was no spatial relation between the two variables. Independent of the ground cover, the food plant was distributed.

5.4.2.3 Drainage density

Drainage density was calculated using the drainage pattern digitized from the Survey of India map at 1:50,000 scale. Drainage with third level streams was used for the density calculation using the density function, Kernel method in the ARCGIS software. The density of drainage per km^2 was calculated and a map was derived in raster format (Figure 5.5). It was observed from the map that gaur distribution was influenced by water availability. This could be due to gaur being the obligatory drinker, it needs water every day and may visit water bodies twice a day during the hottest periods. While feeding along they move to the water hole and return back resuming the feeding activity. Though Vairavel (1998) reported that gaur in Parambikulum WLS was seen drinking water only during noon hours, in PTR dawn and dusk hours were observed as the most frequent periods of visitation to waterholes by gaur.

5.4.2.4 Elevation

Digital elevation model (DEM), (Figure 5.6), was derived from the contours using the ARCGIS software. The contour was interpolated using the height values to generate Triangular Irregular Network (TIN). The TIN was converted in to DEM using the grid converter. The DEM was resampled in to 100 meter resolution for the analysis. It was observed that gaur was using more gentle terrain than the elevated terrain. The elevation within the park was distributed uneven. The eastern portion including the Sanctuary was more undulating than the western portion. The elevation rose from 400 msl to 640 msl. Gaur was more frequently using the lower elevation area than the higher ground. There were few elevated plateau, which was the highest location in the Reserve The field observation also confirmed that gaur avoided the undulating terrain as well as the hilly plateau in the PNP.

5.4.2.5 Aspect

Aspect (Figure. 5.7) was derived from the DEM layer using the surface analysis function in the ARCGIS software. PTR had higher percentage of area under the north facing slope. It is difficult to interpret whether the aspect plays a major role in the distribution of gaur in PNP, as the aspect factor is negligible due to less variation in the altitude of PNP. Assuming, aspect may be play an important influence in the food plant distribution, it was considered for the model.

5.4.2.6 Slope

Slope map (Figure. 5.8) was derived from the DEM using the similar surface analysis function. The slope were calculated in degree and categorized in to five categories viz 0-0.7^0, 0.7°- 2°, - 4°, 4°-6°, 6°-15° degrees. Gentle slope category was observed across PTR. More than 80% of the area falls under the 0-7% category. Based on the gaur distribution, it is concluded that gaur prefers very gentle slope than the steep slopes. The direct observation made in the field also corroborates with the results as evident from the slope model.

5.4.2.7 Vegetation type

Vegetation map (Figure. 5.9) was prepared using the Indian Remote Sensing satellite (IRS) LISS III P6 image with 23.5 meter resolution of the year 2006. The image were classified using the ERDAS imagine software, where six major classes were derived. Later vegetation map was converted in to grid format and resampled in to 100 meter resolution for the modeling. The map indicates that the gaur used more of Teak mixed forest type than the other category of forests. Though it was discussed from the earlier map that gaur distribution was observed more frequent in high cover percentage areas, the Teak with miscellaneous vegetation type supported the high percentage of ground cover. Gaur used Teak with miscellaneous forest type follwed by Teak, dominant and mixed forest types significantly higher than other vegetation associations (Sankar et al. 2001).

5.4.2.8 Vegetation Index

Vegetation index was used as a measure of tree cover available for the animal usage. The rationing of bands (band4-band3) using ERDAS indices function was applied to derive the vegetation index map (Figure-5.10). The negative value shown in the map represented the poor cover and positive value indicated good vegetation cover. The gaur sightings were predominantly distributed along the good ground cover throughout the PTR. The data also supports significantly the less usage of western portion area by the gaur population which could be due to heavy anthropogenic disturbance. As vegetation is also important factor in influencing the habitat, it was used for the model.

5.4.2.9 Vegetation cover change

Vegetation cover change was derived using the vegetation index of 1977 Landsat MSS image and 2001 Landsat ETM+ (Figure-5.11). Since the resolution of both the images was different, they were resampled to same resolution for analysis. The change in vegetation cover was maximum in the Chindwara portion of the Tiger Reserve . Gaur distribution clearly indicated that it preferred the habitat which was relatively undisturbed and with improved forest cover. It was evident from the map that the vegetation cover was improving in the Seoni part and Sanctuary portion in comparison to the Chindwara portion of the Pench Tiger Reserve.

5.4.2.10 Working map

The working map or Boolean map is the focus species map with the data on sightings and information on location in spatial reference. The point data is converted and rasterized, for the anlaysis. The layer was recorded for presence absence data in to 0 and 1. In our case the gaur sightings were plotted in a shape file format. Later converted in to raster layer and recoded for the presence of data as 1. The software automatically calculates the absence value.

Figure 5.12 Habitat suitability model for Gaur (Bos gaurus) in PTR as computed from ENFA

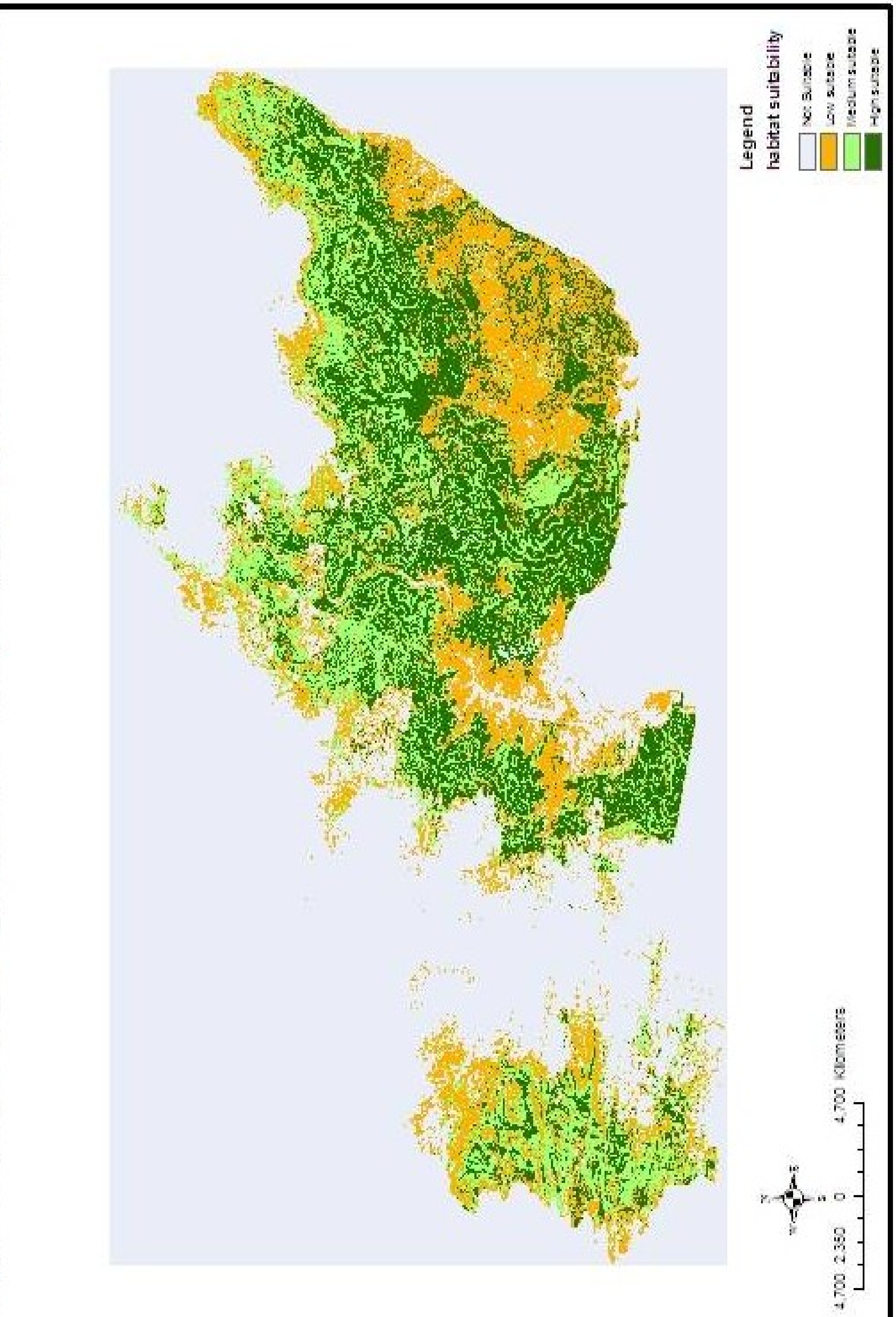


Table 5.2. Correlation matrix value among the variables used in the model.

	Aspect	**Cover change**	**Drainage**	**Elevation**	**Food Density**	**Ground Cover**	**Slope**	**Vegetation type**	**Vegetation index**
Aspect	1.0								
Cover change	**0.64**	1.0							
Drainage	**0.74**	0.77	1.0						
Elevation	**0.82**	0.77	**0.87**	1.0					
Food density	0.05	0.07	0.07	0.06	1.0				
Ground cover	0.06	0.09	0.09	0.07	**0.73**	1.0			
Slope	0.25	0.37	0.41	0.47	0.02	0.02	1.0		
Vegetation type	**0.75**	**0.82**	**0.86**	**0.90**	0.07	0.08	0.46	1.0	
Vegetation index	**0.80**	**0.83**	**0.89**	**0.97**	0.07	0.08	0.46	**0.96**	1.0

Habitat suitability map derived from the biomapper software clearly segregated the high, medium, and less suitable areas for gaur in the Tiger Reserve (Figure 5.12). The resultant model had marginality of 1.8, specialization of 1.5 and tolerance of 0.7, suggesting that gaur had preferred sites within PTR and that they showed restrictive distribution pattern. According to Hirzel et al. (2002) low value close to 0 indicates that the species tends to live in average conditions throughout the study area, whreas a high value close to 1 indicates a tendency to live in extreme habitats. A positive value means that the species prefers the high value of the EGVs. In this study the species had a high preference for the EGVs. In support, the field data followed closely the predicted distribution, except in eastern portion where gaur is absent either due to physical removal (e.g. poaching) in the past or other suitable factors which are not known. In any case, the proportion of highly suitable habitat predicted were available in the eastern portion, which could sustain a large population of the gaur species.

Though the Chindawara portion of the reserve had of highly suitable areas, gaur were not recorded from these locations. (Figure 5.12). The buffer zones in the western part of the Tiger Reserve had few areas under the high suitable category, but it was a disjunctive forest patch away from the main management unit. This area later could be used for gaur reintroduction if given enough protection. There are few patch left in the eastern buffer portion of the Tiger Reserve, but it has the similar condition of being disjunct from the main unit. Gaur exhibited relative importance of biotic versus abiotic factors. Brown et al.. (1996) discussed that ‘‘in most ecological gradients, the majority of species appear to find one direction to be physically stressful and the other to be biologically stressful (Guisan et al. 1998, Dobzhansky, 1950 and McArthur, 1972). In our study gaur was stressed for an elevation gradient and water availability.

It is observed from the correlation matrix (Table 5.2) that aspect variable had the maximum positive correlation with other variables. It had the highest value of 0.80 with the vegetation index, followed by elevation and vegetation types. These three factors overall contributed more towards behavior of model. Vegetation index and the elevation had the highest correlation between them. It was also observed from the result that 93% variation was explained by the three factors.

The species distribution over different variables were calculated and shown in Figure-5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19, 5.20, and 5.21. The gaur did not show any preference to the specific aspect. It widely used all variations of aspect. Vegetation cover changes did influence gaur preference. It was observed that gaur used unchanged and increased cover more than its availability. It was observed that gaur equally used the decreased forest cover area. It should be noticed that in Pench Tiger Reserve the large forest cover loss was contributed by the submergence area. Earlier in 1977 the submergence portion of the Tiger Reserve was covered with dense forest cover, latter in late 80's due to the dam construction the major habitat was inundated due to the water logging. This factor might have contributed to the fact that gaur is using equal proportion of decreased cover area.

Gaur seems to prefer high density drainage area. The Figure-5.5 indicates that gaur sightings were recorded more towards high density drainage. Gaur being obligatory drinker, it tend to move close to river and water source in the reserve. During the summer they were invariably found close to the water sources. Water played a major role in determining the gaur movements within the reserve. The analysis also revealed that gaur preferred gentle terrain. As indicated in Figure-5.6, gaur were using extensively the mid elevation areas of the Tiger Reserve. It preferred 450 to 550 MSL elevations. It was observed that the core area of the reserve falls in this elevation range. As these areas were relatively undisturbed, the gaur must be using them. The food plant density distribution graph with response to gaur was a surprising finding. It was always assumed that gaur preferred high density food plant availability and whereas the Figure-5.3 explains a different scenario. Gaur completely neglected the dense food plant available area and it did not show any strong preference for the high density of food plant species areas. It was rather seen concentrated more towards the lesser dense food plant species areas. Similarly the ground cover also did not show any influence in the gaur occurrence. The Figure-5.4 clearly indicates that gaur used all the classes of ground cover equally without any preference. Though the graph showed that gaur was using the 5-10 % cover area more than the other classes, the ground cover did not contribute to the high suitable habitat preferences of gaur.

It was observed from the result that the gaur had preference for the slope (Figure-5.8). Gaur was using the gentle slope more than other categories. The 0 to 7 degree slope category was used extensively by the gaur. More than 80 percent of the Tiger Reserve comes under the gentle slope category. Also this has direct influence on the distribution of drainage. May be this category slope constitutes maximum drainage of water resource which is preferred by gaur. Vegetation type had the maximum influence on the gaur distribution. It was observed that (Figure 5.9) the gaur preference for the Teak mixed followed by Teak dominant vegetation type in comparison to other vegetation type. It was also observed that gaur used mixed forest more than its availability. The number of sightings encountered in the Teak mixed habitat was higher than the other vegetation types. It was also inferred from the study that gaur used teak mixed forest more than the Teak dominant, and mixed forest (Sankar et al. 2001). The gaur preferred high vegetation index values, the preference by gaur. The result inferred from Figure-5.10 showed that gaur had a positive correlation with the high vegetation cover. Field information and direct sightings also supported these findings. Gaur was always found in densely covered area. It preferred to stay inside the forest, until it moved for the water resource. It was observed in the reserve that gaur avoided the open and disturbed areas. Overall the model seems to explicitly representing the field conditions. The marginality value of 1.8 and specialization value of 1.4 were achieved in this model which showed that gaur had high preference for high value of the variables. The correlation tree (Figure-5.22) derived from the analysis showed that the factor variables were separated based on their significance value. Food density and the ground cover had strong correlation and were considered in the same category. Slope and all other categories combined together formed the association of other two factors. The total area available for gaur with high suitable category was 264 km^2, and medium suitable area available was 367 km^2 and low suitable area calculated to be 199 km^2 in the Tiger Reserve.

Figure 5.13. Gaur distridistribution in different aspect in Pench Tiger Reserve, M.P.

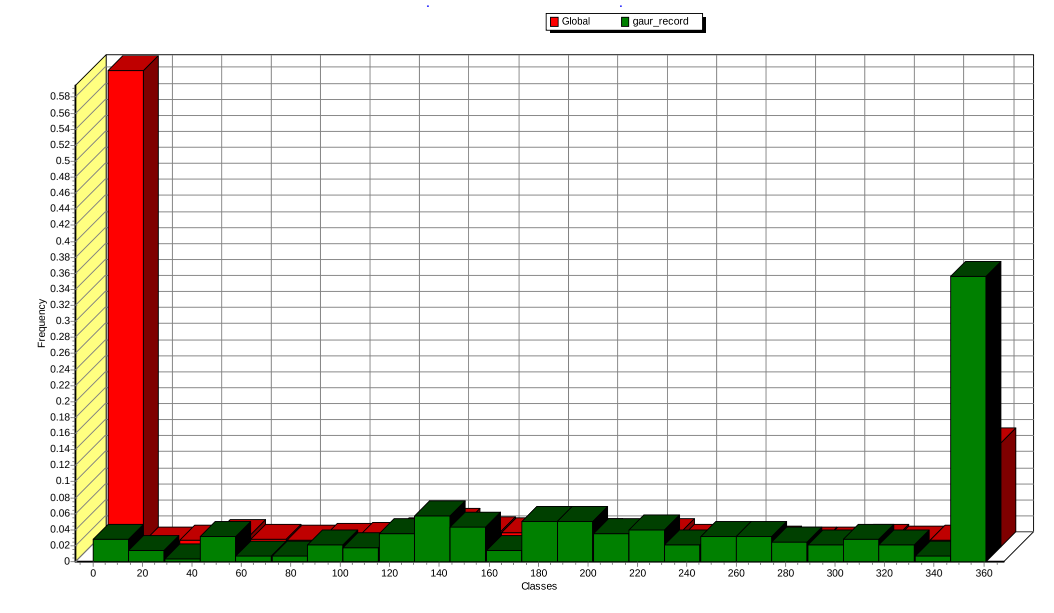


Figure 5.14. Gaur distribution in different vegetation cover change in Pench Tiger Reserve, M.P.

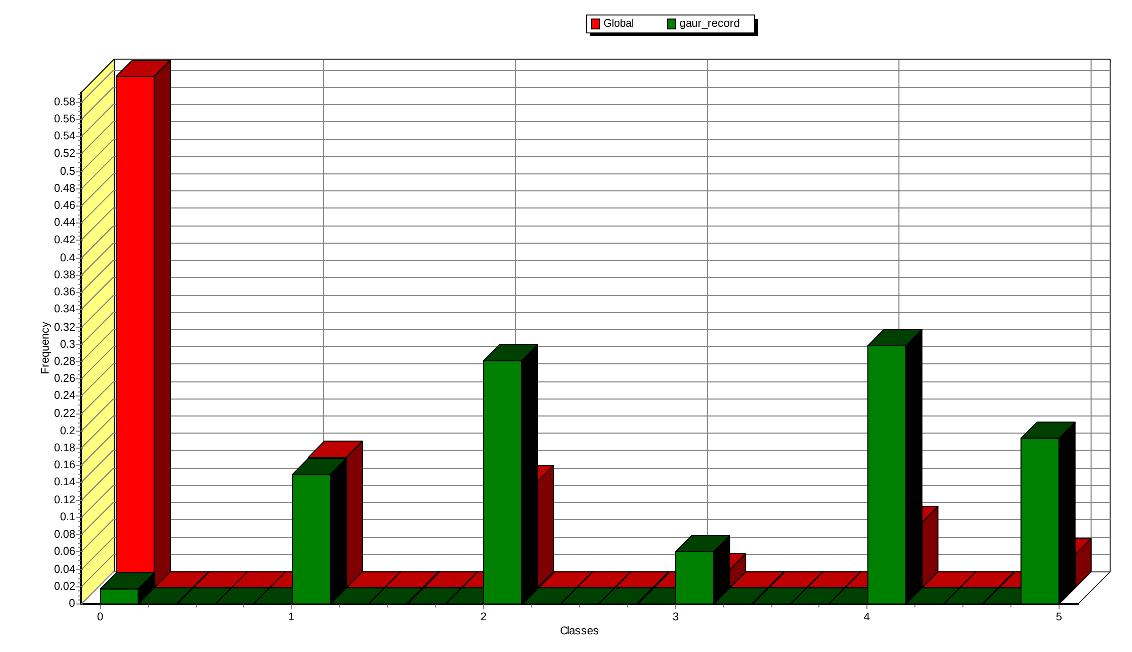


Figure 5.15. Gaur distribution in different drainage classes in Pench Tiger Reserve, M.P.

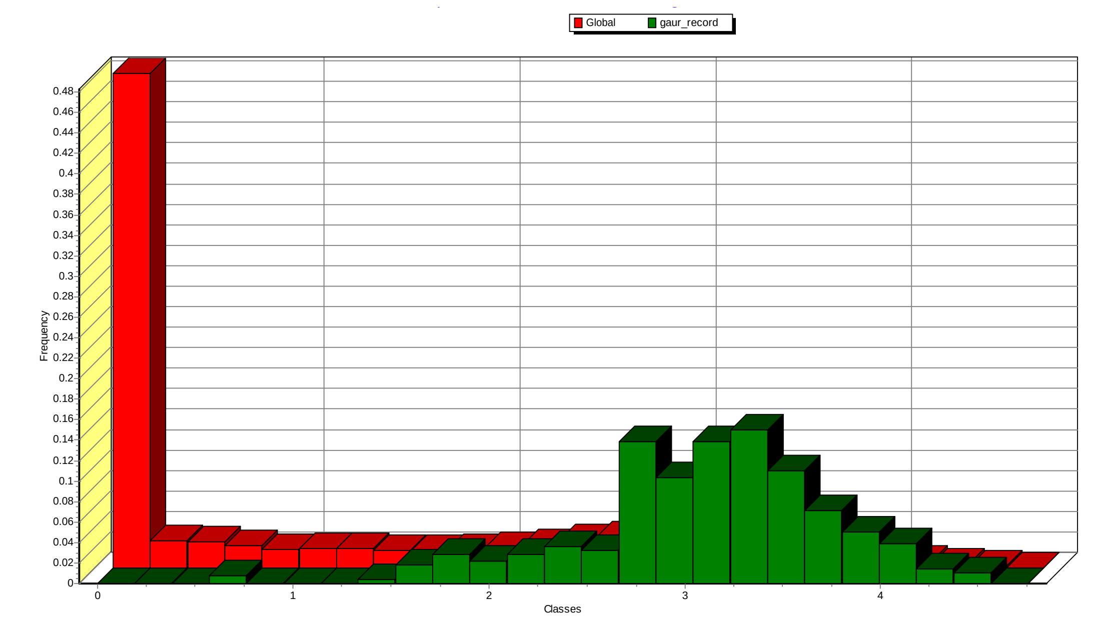


Figure 5.16. Gaur distribution in different elevation in Pench Tiger Reserve, M.P.

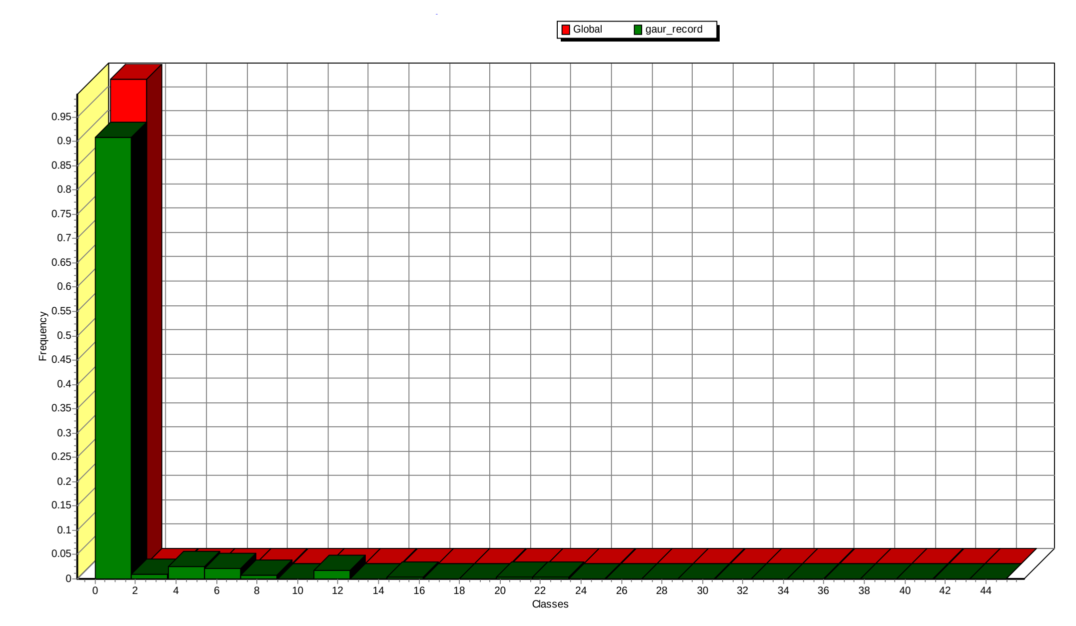


Figure 5.17. Gaur distribution in different food plant density areas in Pench Tiger Reserve, M.P.

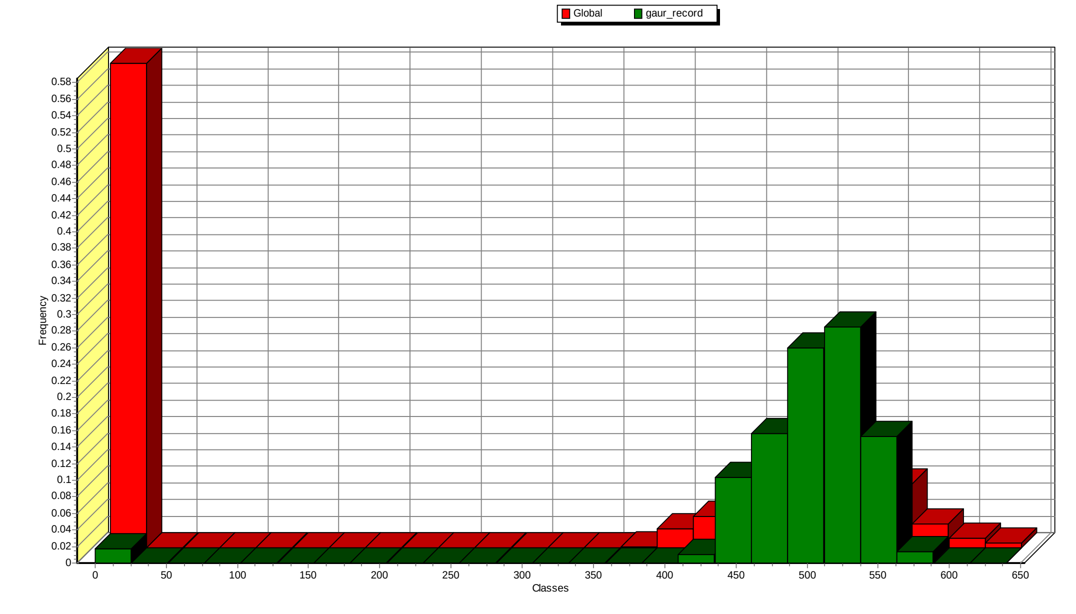


Figure 5.18. Gaur distribution in different groundcover classes in Pench Tiger Reserve, M.P.

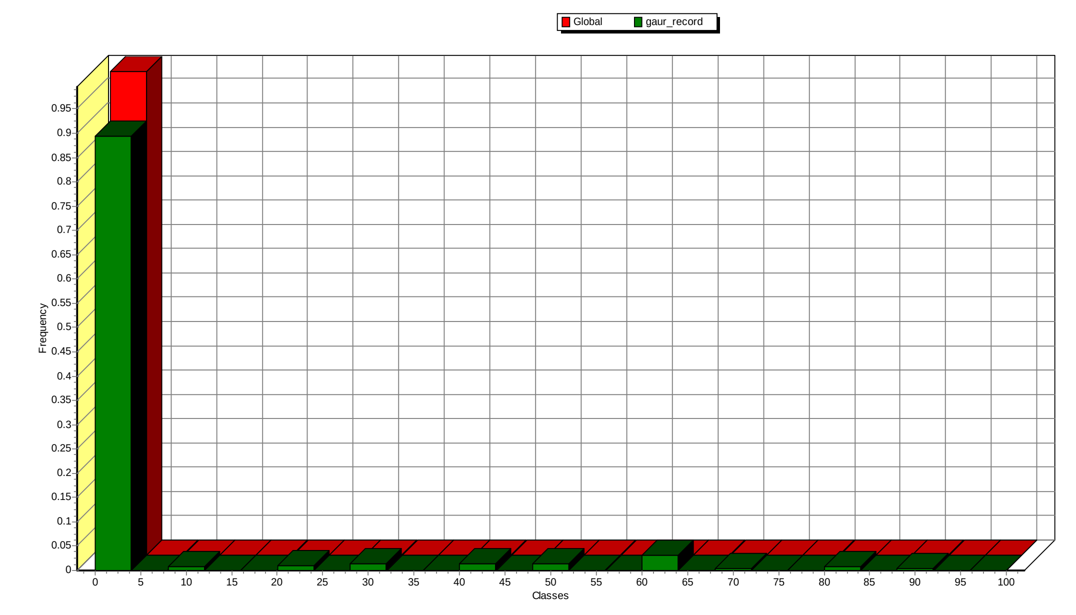


Figure 5.19. Gaur distribution in different slope categories in Pench Tiger Reserve, M.P.

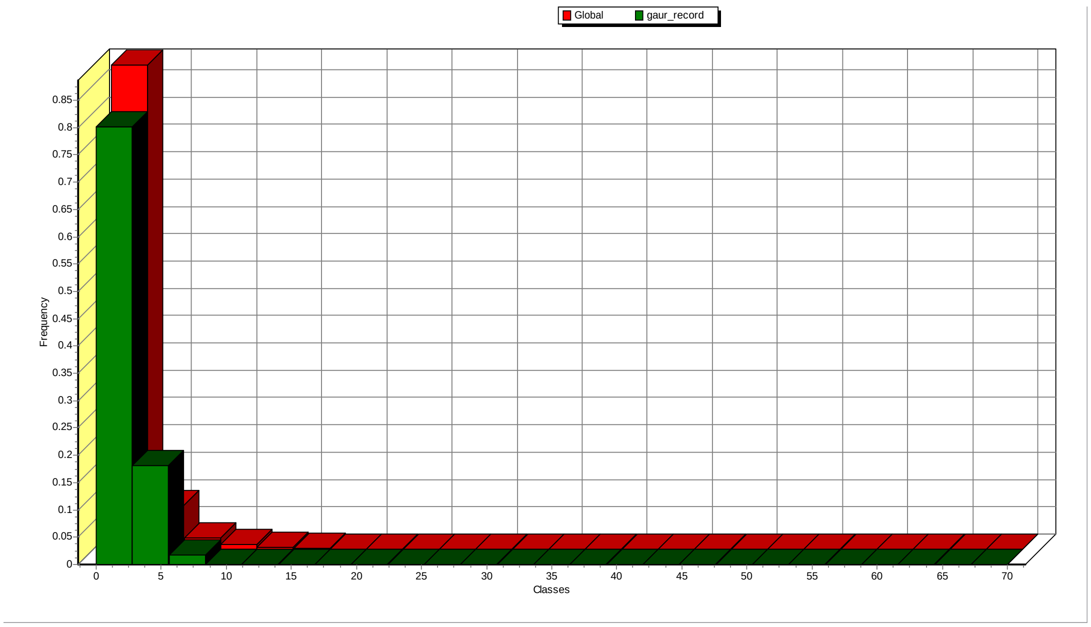


Figure 5.20. Gaur distribution in different vegetation type in Pench Tiger Reserve, M.P.

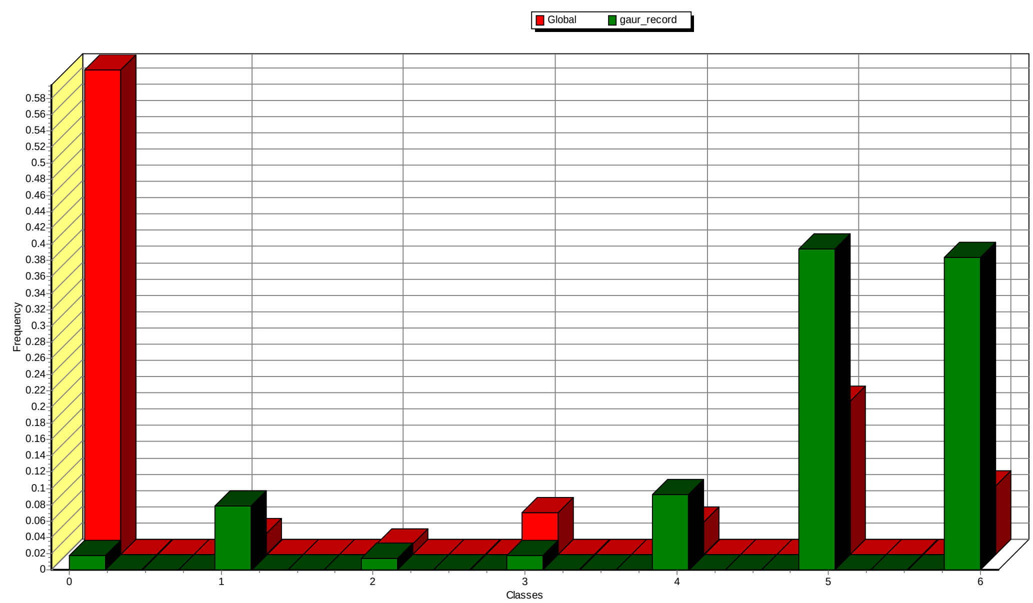


Figure 5.21. Gaur distribution different vegetation index in Pench Tiger Reserve, M.P.

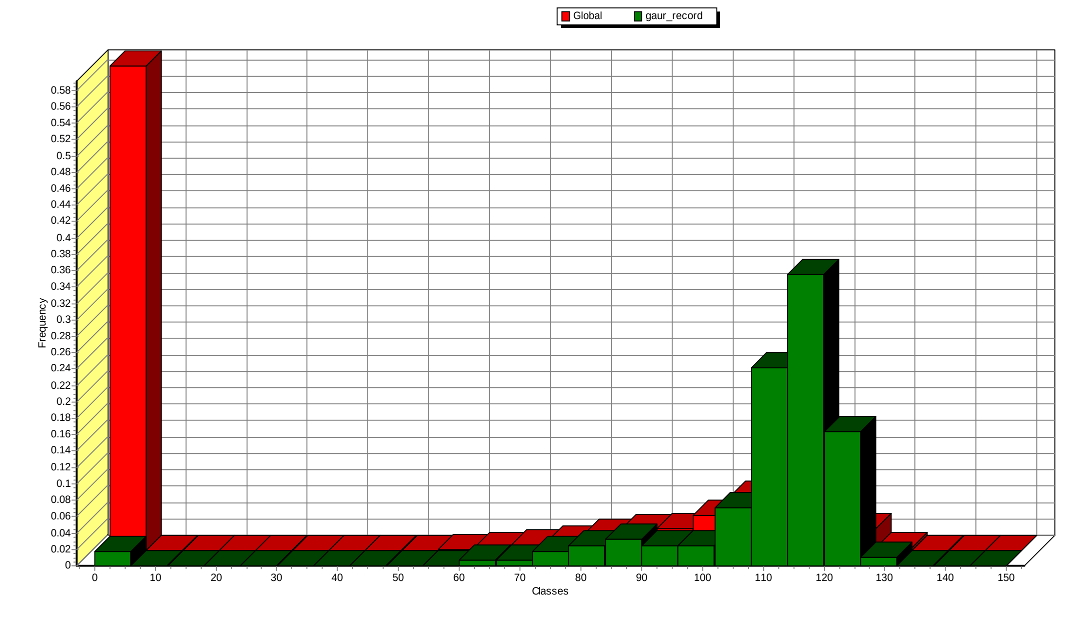
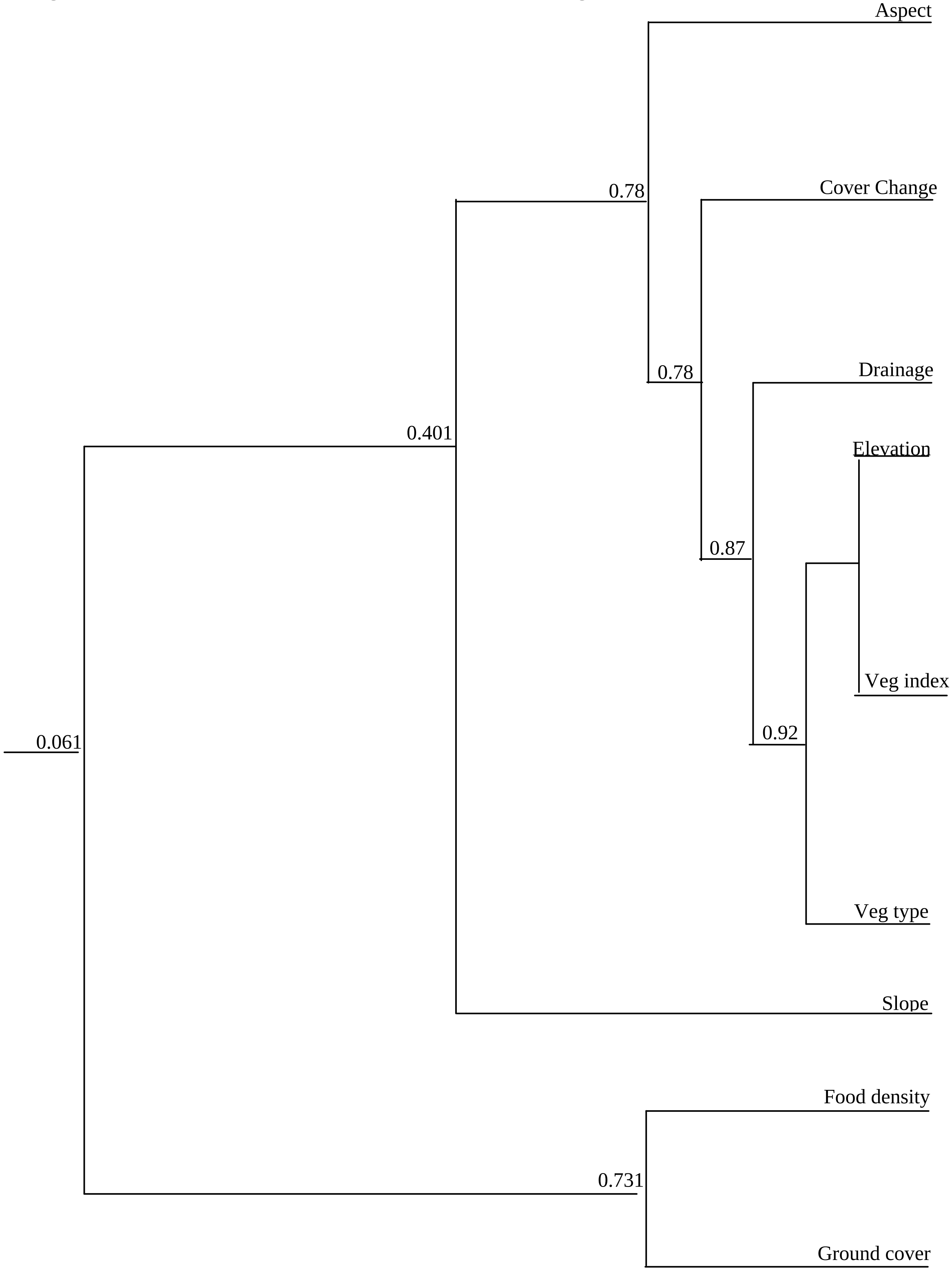


Figure 5.22. Correlation tree of variable and their significance



5.5 Conclusion

Habitat modeling may help to mitigate or resolve complex issues in co-management of large ungulates and forest resources. In this study we examined gaur relation ship with the habitat preference and their suitability in the Pench Tiger Reserve. We used ENFA biomapper to derive with the Habitat Suitability Model (HS) for the gaur. Choosing the right variables can improve the result accuracy and the prediction of habitat suitability. Initial observations, made an assumption that food plant density and ground cover and Teak mixed forest type were the driving factors for gaur distribution, but the factors responsible for the suitable habitat were found to be gentle slope, mid elevation range (450 to 550 msl), and the water availability.

Presence of available suitable gaur habitat in the Tiger Reserve also varied in their distribution. The eastern portion of the reserve had the maximum area under the high suitable category which was more continuous in nature, whereas the western portion was fragmented in nature. This could be due to the disturbance factor such as grazing, human interference, and limited water availability within these portions of the reserve, which deterred the gaur from using the available habitat. It was observed that during the study period large cattle population were often seen inside the western portion of the park. The suitable habitat available for the gaur was eventually used by livestock also which in turn contributed to the fact that gaur had to restrict their movement only to the eastern portion of the reserve. In this sense, our present observation on the factors affecting gaur occurrence indicate that biotic, abiotic, and also human related activities influenced the overall gaur distribution. Thus, the GIS modeling technique applied for this study will be a method to contribute to the evaluation of the conservation status of habitat available for the species that need to be conserved in a managed space.

Chapter 6

Conservation of Gaur in Pench Tiger Reserve

6.1 Gaur and domestic elephants

Five domestic elephants (2 male, 2 female & 1 calf) were brought into PTR by the Park management Authorities during the year 1999, in order cater to the tourism needs and for the anti-poaching patrolling. Historically there exists no record of elephant occurrence in Pench. The stall-feeding of these camp elephants is almost negligible. The elephants are let loose in the night hours for feeding into the forest. A list of plants on which elephants largely feed in Pench Tiger Reserve is given in Appendix III. It has been observed that the domestic elephants found feeding on 16 important gaur food plants. The vegetation of Pench being dry deciduous in nature show seasonal changes in the availability of food plants to the wild ungulates. During summer, more than 95% trees and shrubs remain leafless and the ground layer is yellow-brown in colour. It is expected that for the available browse in summer, including bamboo, the competition between gaur and the domestic elephants will be much higher. In Pench, the bamboo patches are located only in very few localities. Their patch size is very small (not greater than 5 hect.) and it is an important food plant of gaur during summer. If the present browsing pressure of elephants on these bamboo patches continue, it will lead in to depletion of food recourses for gaur in the coming years. It has been observed that elephants in Pench uproot the *Lannia coramandelica* trees and feed only on its bark. This tree species is sparsely distributed in Pench and has low regeneration rate. Thus it is expected that in the long run *Lannia coramandelica* population may severely be affected in Pench.

It is suggested that the park authorities should initiate a short-term study covering all the major seasons, in order to understand the level of competition between domestic elephants and gaur for the available recourses in Pench. As elephants are mega herbivores, wasteful feeders and they are not native to Pench Tiger Reserve, it is cautioned that their number should not be allowed to increase in PTR. In addition, it is suggested that the camp elephants should be stall-fed with fodder raised from crop fields to supplement the dietary requirements.

6.2 Cattle grazing influence areas in Pench Tiger Reserve

Point locations on domestic cattle were collected during the entire study period (1996-2000) using Global Positioning System (GPS) for mapping the cattle grazing influence areas in the entire Tiger Reserve. These Locations were later transferred on to I: 50,000-scale baseline map of PTR. In addition, four different map layers *viz.* Location of villages within 1 km radius of PTR, major road network, vegetation & land cover, and water hole distribution, were super imposed on the domestic cattle location point map using GIS as a tool to derive at the final cattle grazing influence areas map. The final map output showed five categories of cattle grazing influence areas in PTR as very high, high, medium, low and very low (Fig 6.1). It is evident that, most of the Seoni part of National Park (145.24 sq.km), and some part of Sanctuay had very low level of cattle grazing influence as compared to other areas in PTR. On the other hand, the Chindwara side of the National Park had various levels of cattle grazing pressure areas. The Peripheral areas of the Sanctuary and its adjoining Reserved Forests had high to very high cattle grazing pressure zones. The cattle grazing pressure zone model has identified, in total, 10 discrete very high pressure cattle grazing zones within PTR. Significanty these 10 areas exist around the highly populated villages like Turia, Awarghani, Telia, Tikari, Gandatola, inkapar, Kohka, Dodhgaon, Katangi & Murer.

There is a high risk of cattle transmitted diseases, the gaur can get from areas, which have cattle grazing influences. In such areas both domestic livestock and gaur are sharing the water holes, which is again a matter of concern.

6.3 Fire risk zones in Pench Tiger Reserve

Location and extent of fire were collected during the course of work from the entire Tiger Reserve from 1996 to 2000. The Global Positioning System (GPS) was used to take the exact location and the extent of fire in burnt areas. These Locations were later transferred on to I: 50,000-scale baseline map of PTR. In addition, four different map layers *viz*. Villages found within 1 km radius of PTR, road network, cattle grazing influence areas and vegetation & land cover were super imposed on the burnt area point map using GIS as a tool to derive at the final fire risk zones in PTR. Based on the values obtained from the above layers the final fire risk zone map was prepared (Fig 6.2).

The fire risk model has categorized the area in PTR into 5 zones varying from very low to very high. The prepared model has identified 10 different areas in the entire Tiger Reserve, in which the incidence of fire occurrence is very high. It is suggested that adequate fire protection measures in these 10 areas is the need of the hour.

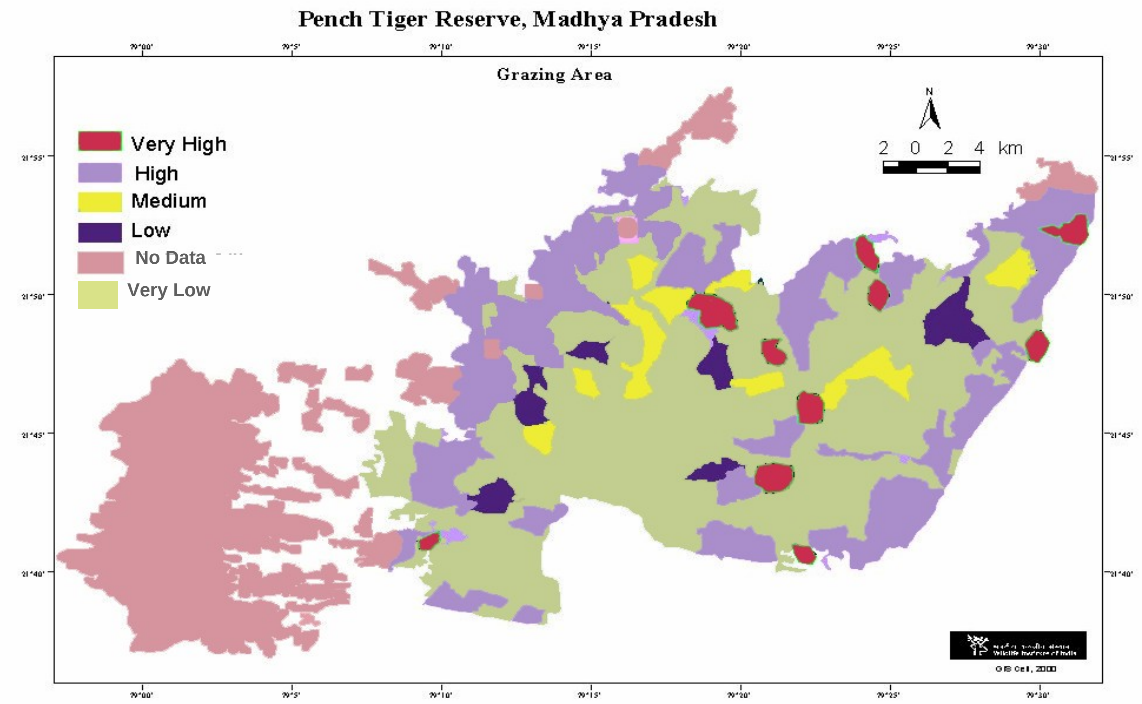


Figure 6.1 Cattle grazing influence areas in Pench Tiger Reserve

The fires are more frequent in Pench during the months of February to June. During the summer, the dry litter on the forest floor and the other dry vegetation makes Pench more prone to fires. Accidental and some times intentional forest fire happens in Pench during the *Diospyros melanoxylon* leaf collection, *Madhuca latifolia* flower collection and illegal antler collection by the locals residing around the Pench Tiger Reserve. Such fire incidences are more frequent in Chindwara block of the Pench National Park and the northern part of the Pench Sanctuary. It is observed during the present study, gaur completely avoided burnt areas. It is suggested that in high fire risk areas, regular patrolling is required during summers to prevent fire occurrences.

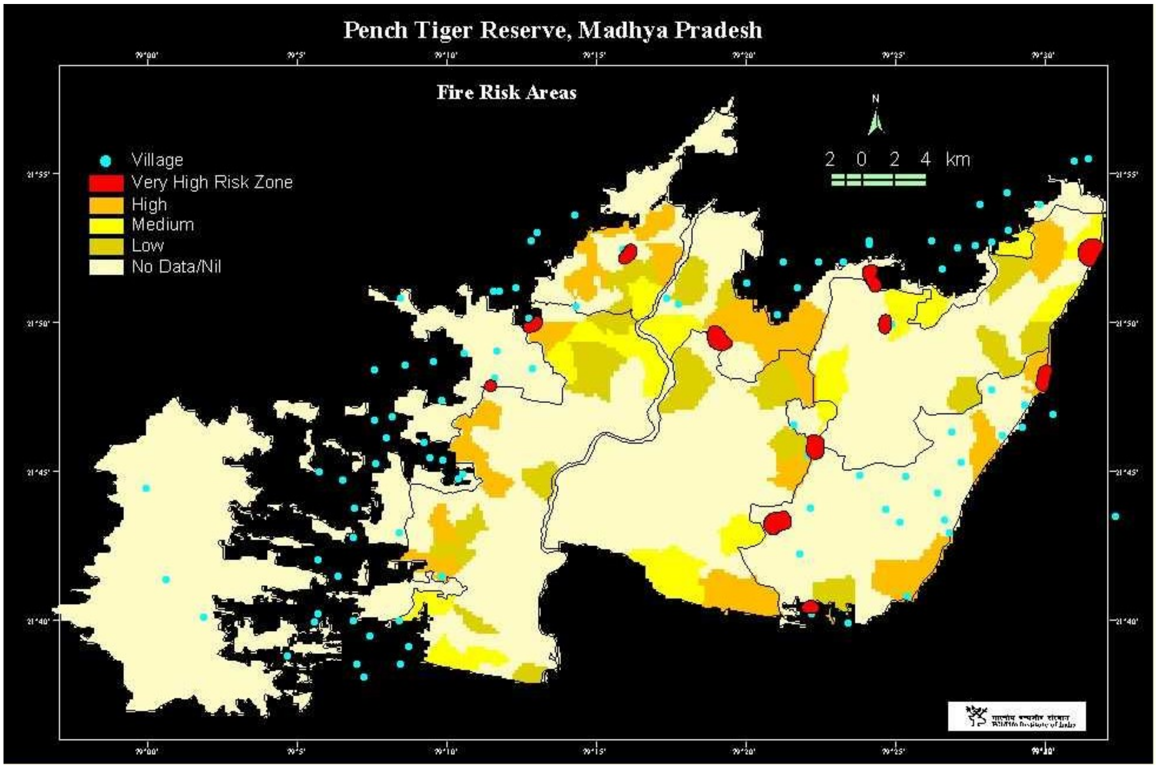


Figure 6.2. High risk fire zone area in Pench Tiger Reserve

6.4 Vaccination for domestic cattle in and around Pench Tiger Reserve

Past records in the country indicate that populations of gaur have succumbed to epidemics of foot and mouth disease (FMD), rinderpest and anthrax in many areas of distribution. This is largely due to the fact that gaur has little immunity to some cattle diseases. In fact no wild animals in India are so profoundly influenced by transmitted infections from domestic livestock as gaur (Krishnan 1972). The data on livestock diseases reported around PTR (from the records of veterinary hospitals – Kurai, Seoni and Chindwara) revealed that the Foot and Mouth Disease (FMD) was the most prevalent among the livestock population. The other domestic livestock diseases reported are black quarter, anthrax, bovine tuberculosis and some parasitic infections. The only cattle transmitted disease infection that was noticed in gaur in Pench during the study period, was Foot and Mouth Disease (FMD). Nevertheless, no gaur was found dead in PTR due to FMD infection. The FMD was observed in gaur population soon after the rains in October. At the same time, we had noticed the FMD infection in the domestic cattle and buffaloes also in villages like Karmajhiri, Alikatta and Kamreet. The reserve authorities with the help of local veterinary hospitals conduct vaccination programme for the domestic cattle in some villages located around PTR. This service needs to be extended to all the 99 villages located in and around PTR, which are currently under `Ecodevelopment Programme'.

6.5 Greater Pench Conservation Unit

As evident from the present study there is a movement of gaur between Madhya Pradesh Pench and Maharashtra Pench and also between Sanctuary area of Pench Tiger Reserve (M.P.) and Rookhad Reserved Forests that comes under South Seoni Territorial Forests Division. The Pench Tiger Reserve shares its boundary with South Seoni Territorial Forests Division on the north and north-eastern side. These areas are important seasonal movement routes for gaur during summer. Our radio-collared gaur (BB1) male had moved in to Maharashtra forests during 1998 summer and later had come back to Madhya Pradesh Pench within a few days. The forest cover in these three areas is very similar and is managed as different administrative units by the Madhya Pradesh Forest Department (South Seoni Territorial Forest Division and Pench Tiger Reserve) and Maharashtra Forest Department (Maharashtra Pench Tiger Reserve). The total area of the above mentioned continuous forest cover comes to 1166 sq.km (Madhya Pradesh Pench 757.9 sq.km, Maharashtra Pench 256.26 sq.km and South Seoni Forest Division –

Rookarh 150 sq.km). Inter state coordination between Maharashtra and Madhya Pradesh Sates in managing the `Greater Pench Conservation Unit' (GPCU) is the need of the hour. It is suggested that the Rookahard Territorial Forest Division, currently managed by the South Seoni Forest Division, should be included in the Pench Tiger Reserve in order to make is as a single administrative unit for effective management and conservation of large mammals. For tiger conservation also we require such larger areas in the country. Already Pench Tiger Reserve (National Park & Sanctuary) along with Khana Tiger Reserve, Madhya Pradesh are being identified as one of the 11 level I Tiger Conservation Units (TCU) in India Wickramanayake, *et al.* (1999), where tiger has the highest possibility of survival.

6.6 Status of gaur in Central Indian Highlands

The Central Indian Highlands harbor approximately one fourth of the present gaur population surviving in the country. But the exact status of the present thriving populations and the condition of their habitat is not known. In Madhya Pradesh, the gaur population is found in ten isolated districts, geographically isolated from one another.

The limited information on status of gaur, threats to the gaur population due to increasing trends in habitat degradation and livestock grazing and disease surveillance in gaur habitats as suggested needs to be extensively survey and assess the status of gaur in Central Indian Highlands.

The suggested survey on the `Status of gaur in Central Indian Highlands' will provide a comparative analysis of the sites in which long term ecological studies on gaur should be conducted, important corridor used by gaur populations, help in understanding the distributional patterns of gaur in areas with similar habitats as well as of dissimilar floristic composition.

The information that will be collated from the suggested work and the results that will emerge are likely to be of great significance in planning a long-term conservation of gaur in the Central Indian Highlands. The suggested study has scope of going much beyond and will have wider implications that can later be extended to the other distributional ranges of gaur for the assessment of the countrywide conservation status of gaur.

References

Acharya, B.B., (1997). Habitat use by wild ungulates in Pench National Park. Msc, Dissertation. Submitted to Saurashtra University, Rajkot.

Acharya, B.B., (2007). Ecology of the Asiatic wild dog (*Cuon alpinus*) in Pench Tiger Reserve, M.P, Ph.D thesis submitted to Saurasthra university.

Agnihotri, G.K., (1979). Ecological studies of some grasslands of Mandla, PhD thesis, University of Sagar, Sagar, India.

Anderson, K., (1954). Nine man-eaters and one rouge. London.

Anderson, M.A., Thornhill. A., koopowitz, H., (1997). Tropical forest disruption and stochastic biodiversity losses. In Laurance, W. F., Bierregard jr., R.O. (eds) Tropical forest remants. Ecology, management and conservation of fragmented communities. The University of Chicago press, Chicago, Pp 281-291.

Areendran, G., (1997). Monospecific dominance of *Clistanthus collinus* in Pench Tiger Reserve , Madhya Pradesh. *Abstract*. Eleventh Annual Research Seminar, 15th - 17th September. Wildlife Institute of India, Dehra Dun.

Ashton, P.S., (1988). Dipterocarp biology as a window to the understanding of tropical forest structure. Annu. Rev. Ecology systematics. 19: Pp70-347.

Behera, M.D., Srivastava S., Kushawha S.P.S. and Roy P.S. (2000). Stratification and mapping of *Texus baccata* L. bearing forests in Talle valley using remote sensing and GIS. Current Science, 78(8): Pp 1008 – 1013.

Bennet, S.S.R., (1986). Name changes in flowering plants of India and adjacent regions, Triseas Publishers. Dehradun.

Blamont, D. and Méring, C., (1987). Adv. Space Res., 7: Pp 41–46.

Brown, S., Lenart, M., Mo, j., (1995). Structure and organic matter dynamics of a human –impacted pine forest in a MAB reserve of subtropical china. Biotropica 27 (3): Pp 276-289.

Brander, A.D., (1923). Wild animals in central India. Edward Arnold. Co. London.

Buch, M.N., (1991). The forest of Madhya Pradesh, Madhya Pradesh mandhyam, Bhopal.

Buckland, S.T. and Elston, D.A. (1993). Empirical models for the spatial distribution of wildlife. Journal of Applied Ecology, 30: Pp 478 – 495.

Bunyarejchewin, S., (1983). Analysis of the tropical dry deciduous forest of the Thailand , Charecterstics of dominance type. Nat. His. Bull. Siam. Soc. Vol 31 (2): pp109-122.

Champion, F. W. and Seth, S. K. (1968). A revised survey of the forest types of India. Nasik, India: Manager, Government of India Press.

Champion, H.G. and S.K. Seth., (1968). A revised survey of forest types of India.. Manager of Publications, Government of India, New Delhi. Pp 404.

Clark, P.J., and Evans, F.C., (1954). Distance to nearest neighbhour as measure of spatial relationships in population. Ecology. 35: Pp 445-453.

Clemets, F.E., (1916). Plant sucession: An analysis of the development of the vegetation. Caregie Institute, Washington Publication. Pp 242.

Congalton, R., (1991). A review of assessing the accuracy of classification of remotely sensed data. Remote sensing Environment. 37: Pp 35-46.

Copping, R.R., Jonckeeri, I., Nackaers, K., and Muys, B., (2004). Digital change detection methods in ecosystem monitoring; a review. International Journal of Remote Sensing, 25: Pp 1565-1596.

Cornett, Zane J., (1994). GIS as a catalyst for effective public involvement in ecosystem management decision making: Remote Sensing and GIS in ecosystem management. V. Alaric Sample (ed.) Island Press. Washington, D.C. Pp 369.

Cottam, G. and Curtis, J.T., (1956). The use of distance measure in phytosociological (Spellings?) sampling. Ecology. 37: Pp 451-460

Curtis, J.T. and Mc Intosh., (1950). The interrelations of certain analytic and systematic phytosocialogical character. Ecology. 31: Pp 434-455.

Darlington P. J., (1957). Zoogeography: the geographical distribution of animals. John Wiley and Sons, New York.

Darlington P. J., (1957). Zoogeography: the geographical distribution of animals. John Wiley and Sons, New York.

David, A., (2002). Protected area management and human-wildlife interface conflicts: Astudy of Pench Tiger Reserve, Department of Humanities and social science. Indian Institute Of Technology, Bombay. Pp 283.

Dettki, H., Löfstrand, R., and Edenius, L., (2003). Modeling Habitat Suitability for Moose in Coastal Northern Sweden: Empirical vs Process-oriented Approaches. Ambio Vol. 32 No. 8, Dec. 2003

Dobzhansky, T.,(1950). Evolution in the Tropics. Am. Sci. 38: Pp 209–211.

Eisenberg, J.F., (1981). The mammalian radiations: An analysis of trends in evolution, adaptation, and behaviour. The Athlone Press Ltd. London.

Ford, M. J., (1982). The Changing Climate: Responses of the Natural Fauna and Flora. George Allen and Unwin, London.

Forsyth, J., (1889). The highlands of Central India. Notes on their forests and wild tribes, natural history and sports. London. Chapman & Hall.

Franco, A. M. A., Brito J. C. and Almeida J., (2000). Modeling habitat selection of Common Cranes, *Grus grus* wintering in Portugal using multiple logistic regression. Ibis, 142: Pp 351 – 358.

Gadgil, M. and Meher-Homji, V.M., (1982). Conserving India's biological diversity. Indo U.S. ninational workshop on conservation and management of diversity. Dept. of Environment, New Delhi and India Inst. of Science, Bangalore.

Geldenhuys, C.J., Murray, B., (1993). Floristic and structure compostion of hanglip forest in the south-panberg, Northern Transvall. South Africa forestry Journal. 165:Pp 9-20.

Gentry, A. W., (1992). The subfamilies and tribes of the family bovidae. Mammal. Rev. 22(1):1-32.

Gill, J. A., (1996). Habitat choice in pink-footed geese: quantifying the constraints determining winter site use. Journal of Applied Ecology, 33: Pp 884 – 892.

Gough, M. C. and Rushton S. P., (2000). The application of GIS-modeling to mustelid. Landscape ecology. Mammal Review, 30 (3 & 4): Pp 197 – 216.

Gould, W.A., and Walker, M.D., (1997). Landscape-scale patterns in plant richness along artic river, Canadian Journal of Botany. 75: Pp 1748-1765.

Gould, W.A., and Walker, M.D., (1999). Plant communities and landscape diversity long a Canadian artic river. J. of vegetation science. 10: Pp 537-548.

Guisan, A., Theurillat, J.P., Kienast, F., (1998). Predicting the potential distribution of plant species in an alpine environment. Vegetation Science. 9: Pp65–74.

Grzimek, 1., (1972). Grzimek's animal life encyclopedia. Vol. 13. Van Nostrand Co.

Hammer, O., Harper, D.A.T. and Ryan, P.D., (2001). PAST: Palaeontological statistics software package for education and data analysis. Palaeontologia Electronica 4 (1): Pp 9.

Harper, J.I., (1997). Population Biology of Plants. Academic Press, London, New York, San Francisco.

Hedges, S., (1997). Asian wild cattle and buffaloes: Status and an Action Plan for their Conservation, Final draft. WWF Project 3950 / Asia.

Heikkinen, R.K., and Neuvonen, S., (1997). Species richness of vascular plants in the subartic landscape of northern Finland: Modelling relatioship to the environment. Biodiversity and conservation 6: Pp 1181-1201.

Hill, D. and Robertson, P., (1988). The Pheasants: Ecology, Management and Conservation. BSP Professional Books, Oxford, U.K.

Hirzel, A., Helfer, V., Metral, F., (2001).Assessing habitat-suitability models with a virtual species. Ecological Modeling, 145 : Pp 111–12.

Hirzel, A.H., Hausser, J. & Perrin, N., (2006). Biomapper 3.2. Lab. of Conservation Biology, Department of Ecology and Evolution, University of Lausanne, Switzerland. URL: http://www.unil.ch/biomapper.

Hirzel, A.H., Hausser, J., Chessel, D., Perrin, N., (2002). Ecological-niche factor analysis:how to compute habitat-suitability maps without absence data? Ecology. 83: Pp 2027-2036.

Holdridge, L.R., Grenke, W.C., Hatheway, W.H., Liang, T., and Tosi, J.A., Jr., (1971). Forest environment in tropical life zones, A pilot study, Pergamon press, new York: Pp747.

Hooper, D.U., and Vitousek, P.M., (1997). The effects of plant composition and diversity on ecosystem processes. Science 277: Pp1302-1305.

Howard, D.C., Fuller R.M. and Barr C. J., (1996). Linking ecological information recorded from ground, air and space: examples from Countryside Surveys 1990. Global Ecology and Biogeography Letters. (5): 227-234.

Hubbell, S.P., and Foster, R.B., (1986). Commonness and rarity in neotropical forest:implications for tropical tree conseration, In conservation biology, the science of scarcity and diversity (M. E. Soulè, ed.) Sunderland,M.A: Sinauer Associates, Pp 32-205

Janzen, D., (1988). Tropical dry forest. The most endangered major tropical ecosystem In E.O Wilson (eds.) Biodiversity, Pp 130-137. National academy press, Washinton, DC.

Jensen, J.R., (1996). Introductory digital image processing: A remote sensing perspective. 2nd edition, Prentice Hall, New Jersey.

Jensen, J.R., (2000). Remote sensing of the environment: An earth resource perspective. Upper saddle river, NJ: Prestice Hall.

Jensen, J.R., (2005). Introduction to digital image processing: A remote sensing perspective. Upper saddle river, NJ: Prestice Hall.

Jayapal, R., (1997). A syudy on Bird communities-habitat structure relationship in Pench National Park, M.P. Msc, Dissertation. Submitted to Saurashtra University, Rajkot.

Jha, C.S., and Singh, J.S., (1990). Comparison and dynamics od fry tropical forest in relation to soil texture. J. of vegetation science, 1: pp 609-614.

Kachwaha, T.S., (1985). Temporal monitoring of forestland for change detection and forest cover mapping through satellite remote sensing. Roc. Sixth Asian conference on Remote sensing, Hyderabad. Pp 77-85.

Kaul, O. N. and Sharma , D.C., (1991). Forest type statistics, Indian Foresters 97: Pp435-436.

Kiratiprayoon, S., (1986). Comparative study on the structure of the rattan bearing tropical rain forest. M.Sc. Thesis, Kasetsart University.

Kiratiprayoon, s., Luangiame, J., Damrongthia and Thrunmatsawas, M., (1995). Species diversity of the second growth at Ngao demonstration forest, lampang provinc. In Boyle ,T.J.B., and Boontawee (eds.) measuring and monitoring biodiversity in tropical and temperate forests. Centre for Internationla forestry research, Bogor, Indonesia. Pp 237-245.

Knox, R.G, Peet, R.K., and Christensen, N.L., (1989). Population dynamics in loblolly (check this word??) pipe stands: Changes in skewness and size in equality. Ecology. 70: Pp1153-1166

Krishnan, M., (1972). An ecological survey of mammals in India. The Gaur. J. Bombay Nat. Hist. Soc. 69 (2): Pp 322-349.

Kumar, Suhas., (1990). Management Plan of Pench Tiger Reserve, Madhya Pradesh, 1990-1995.

Larsen, R., David., Bliss, C., Lawrence., (1998). An analysis of structure of tree seedling population on a lahars. Landscape ecology 13: Pp 307-322.

Leopold, A., (1933). Game management. Scribener's, New York.

Lillesand, T.M. and Kiefer, R.W., (2000). Remote Sensing and Image Interpretation. 4th edition, John Wiley and Sons (ASIA) Pvt. Ltd, Singapore.

Lindman, R.L., (1982). The tropics dynamics aspects of ecology. Ecology, 2: Pp 399-418.

Lu,D., Mausel,P., Batistella, and Moran, E., (2005). Landcover binary change detection method for use in the moist tropical region of the Amazon. International journal of remote sensing, Vol(26)., No.1: Pp 101-114.

Lu,D., Mausel,P., Brondizio,E., and Moran, E., (2003). Change detection techniques. International Journal of Remote Sensing, 25: Pp2365-2407.

Mall, L.P. and Khan, M.S., (1974). Ecological study of herb layer of Patharia forest. Bull. Soc., University of Sagar, Sagar, India.

Margalef, R., (1958). Information theory in Ecology. General systematics. 3 : Pp 36-71.

McArthur, R.H., (1972). Geographical Ecology: Patterns in the distribution of Species. Harper and Row, New York.

McCune, B. and Mefford. M.J., (1999). PC-ORD for Windows. Multivariate Analysis of Ecological Data. Version 4.20. MjM Software, Gleneden Beach, Oregon, USA.

McGarigal, K., Cushman, S. A., Neel, M. C. and Ene. E., (2002). FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, USA.

Misra, M.K., and Misra, B.N., (1981). Association and correlation of plant species in a tropical grassland community. Tropical ecology. 22: Pp 88-98.

Mooney, H.A., and Chapin, H.S., III., (1994). Future direction of global change research in terrestrial ecosystems. Trends in Ecolgy and Evolutions. 9: Pp 371-372.

Mooney, H.A., Bullock, S.H., Medina, E., (1995). (eds.) Seasonally Dry Tropical Forests. Cambridge Univeristy Press, Cambridge, PP 9-34.

Mueller-Dombois, D., and Ellenberg, H., (1974). Aims and methods in vegetation ecology, John Wiley and sons. Pp350.

Murphy, P.G., and Lugo, A.E., (1986a). Ecology of tropical dry forest. Annual review of ecology and systematics. 17: Pp 67-88.

Murphy, P.G., and Lugo, A.E., (1986b&C). Structure and biomass of a sub tropical dry forest in Puerto rico. Biotropica. 18: Pp 89-96.

Muttitannon,W., and Tripathi, N.K., (2005). Landuse/landcover change in the coastal zone of Bon Don Bay, Thailand using Landsat 5 TM data. International Journal of remote sensing, Vol 26 (11): Pp 2311-2323.

Nagendra, H. and Gadgil M., (1999). Satellite imagery as a tool for monitoring species diversity: an Assessment. Journal of Applied Ecology, 36: Pp 388 – 397.

NASA Landsat Program, (1977). Landsat MSS scene p149r41_2m19770123, Orthorectified, GeoCover, USGS, Sioux Falls, 01/23/1977.

NASA Landsat Program, (1990). Landsat TM scene p139r41_5t19901105, Orthorectified, GeoCover, USGS, Sioux Falls, 11/05/1990.

NASA Landsat Program, (2000). Landsat ETM+ scene p139r041_7t20001226, Orthorectified, GeoCover, USGS, Sioux Falls, 12/26/2000.

Newton, I., (1980). The role of food in limiting bird numbers. Ardea, 69:Pp 11 – 30.

O'Neill, R.V., Krummel, J.R., Gardner,R.H., Sugihara, G., Jackson, B., DeAngelis,D.L., Milne, B.T., Turner, M.G., Zymunt, B., Christensen, S.W., Dale, V.H., Graham, R.L., (1998). Indices of landscape pattern. Landscape ecology 1: Pp 13-162.

Odum, E.P., (1971). Fundamentals of Ecology. Saunders, Philadelphia, Pennsylvania.

Osborne, P. E. Alonso, J. C. and Bryant, R. G., (2001). Modelling landscape-scale habitat use using GIS and remote sensing: as case study of great bustards. Journal of Applied Ecology, 38: Pp 458 – 471.

Pande, P.K., Bisht, A.P.S., and Sharma, S.C., (1988). Comparative vegetation analysis of some plantation ecosystem. Indian Forester. 114: Pp 379-388.

Pascal , J.P., (1988). Wet evergreen forest of the western ghats of India. Institute. Fr. De Pondicherry. Pp 337.

Pasha, M. K. S., Jayapal, R., Areendran, A., Qureshi, Q., and K. Sankar. (2004). Birds of Pench Tiger Reserve, Madhya Pradesh, central India. Newsletter for Ornithologists 1:2-3.

Pollock, M.M., Naiman, R,R., and Hanley, T.A., (1998). Plant richness in riparian wetlands – a test of biodiversity theory. Ecology 79: Pp 94-105.

Prasad, R., Pandey, R.K., (1992). An observation on plant diversity of Sal and Teak forest in relation to intensity of biotic impact at various distances from habitation in Madhya Pradesh: A case study. J. vegetation ecology, 8 (1): 62-83.

Rangarajan, M., (1996). Fencing the forest: conservation and ecological change in India's central provinces, 1860-1914. Oxford University Press.

Raven, A,S., and Roy, P.S., (1995). Phenological stages of dry deciduous forest for improving digital classification accuracy a case study using landsat TM. ISRS silver jubilee year symposium on Remote sensing for monitoring and management with emphasis on Hill region. Feb 22-224, IRRS, Dehradun. Pp 304-311.

Raven, A. S., and Roy, P.S., (1997). Satellite remote sensing for ecological analysis of forested landscape. Plant ecology. 131: Pp 129-141.

Rodgers, W.A., (1990). A preliminary ecological survey of Algual spring Sariska Tiger Reserve, Rajasthan. J. of Bombay natural history scoeity. 87: Pp 201-209.

Rossi, Richard E., David J. Mulla, Andre G. Journel and Eldon H. Franz., (1992). Geostatistical tools for modeling and interpreting ecological spatial dependence. Ecological Monograph. 62(2): Pp277-314.

Roughgarden, J., Running S.W. and Matson, P.A., (1991). What does remote sensing do for ecology? Ecology. 72: Pp 1918-1922.

Roy P.S., and Joshi, P.K., (2002). Landscape fragmentation and biodiversity conservation. Map India 2001. 5th Annual international conference and exhibition in GIS, GPS, Remote sensing, Feb 6-8 : Pp 281-285

Roy, P.S. and Joshi, P.S., (2002). Biodiverity characterization of landscape level using geographical techniques. Biological conservation. 95 (1): Pp 95-109.

Roy, P.S., Moharana, S.C., Prasad S.N., Singh, J.J., (1992). Vegetation analysis and study of its dynamics in Chnadaka (spelling?) wildlife sanctuary (Orrisa) using Aerospace remote sensing, J. Indian remotes sensing, 20 (4): Pp 223-235.

Sayantan, B., (1998). Prey base estimate of Tigers in Pench Tiger Reserve. M.P. M.sc, Dissertation. Submitted to Saurashtra University, Rajkot.

Sahunalu, P.M., Chamrenpruk, B., Puriyakanu, P., Dhanmanonda, W., Suwannapia, and Prachaiya, B., (1979). Structure of three forst types in the Prom basin, Chaiyaphum province forest research bullentin. 63, Faculty of forestry, Kasetsart University (in Thai)

Sankar, K., Qamar, Q., Pasha, M.K.S., Areendran,G., (2001), Ecology of Gaur (Bos gaurus) in Pench Tiger Reserve, Madhya Pradesh. Final Report, Wildlife Institute of India: Pp 124.

Saxena, A.K., and Singh, J.S., (1982). A phytosociological analysis of forest communities of a part of Kumuan Himalaya . Vegetation. 50: Pp 3-22.

Scott, J.M., Heglund, P.J., Haufler, J.B., Morrison, M.,Raphael, M.G., Wall, W.B. & Samson, F., (2002). Predicting Species Occurrences. Issues of Accuracy and Scale. Island Press, Covelo, CA.

Shannon, C.E., and Weiner, W., (1949). The mathematical theory of communication. Urbana, Univ. Illinois press. Pp117

Sharma, K.D., Singh, S.N., and Bohra, D.N., (1989). Satellite remote sensing for detection of temporal change in the grazing lands. International journal of remote sensing, 17(4): Pp 55-99.

Shukla, R., (1990). An Ecological study of interactions between wild animals and vegetation in Pench Sanctuary and its environs. PhD thesis. University of Sagar, Sagar, India.

Simpson, G. G., (1945). The principles of classification and a classification of mammals. Bulletin of the American Museum of Natural History. 85: Pp 1-350.

Singh, A., (1989). Digital change detection techniques using remotely-sensed data. International journal of remote sensing, 10 : Pp 989-1003.

Singh, L., and Singh, S., (1991). Species structure dry matter dynamics and carbon flux of a dry tropical forest in India, Annuals of Botany, 68: Pp 263-273.

Singh, L., Sharma, B., Agarawal, R., (2003). Species composition and plant diversity of a representative tropical mosit deciduous forest fo Achnakmar sanctuary. J. of Tropical forestry. 19 (1&2): Pp 25-34.

Singhal, R.M., Rawat, U.R.S., Pramod Kumar, Sharma, S.D., and Singh, H.B., (1986). Vegetation analysis of woody species of some forest of Chakrata Himalayas. Indian Forester. 112 (2): Pp 819-823.

Skidmore , A.K. Witske, B., Schmidt, K., and Kumar, L., (1997). Use of remote sensing and GIS for sustainable land management, ITC, Journal., (314): Pp 302-215.

Smit, P.C., Dellepiane, S.G., and Schowengerdt, R.A., (1999). Quality assessment of image classification algorithm for land cover mapping: A review and a proposal for a cost based approach. International journal of remote sensing, 20: Pp 1461-1486.

Srivastava, S., Singh, T.P. Singh, H., Kushwaha, S.P.S., and Roy, P.S., (2001) An assessment of large scale deforestation in Sonitpur district of Assam. Current science. 82 (2): Pp 1479-1484.

Starfield A.M. and Bleloch L., (1986). Building models for conservation and wildlife management (2nd edn). Burgess International, Edina, Minnesota.

Steenis, C. G. G., Van, J., (1995). Regeneration as a factor for judging the status of vegetation types the biological nomad theory. In pro Kandy symposium. Study of Tropical vegetation UNESCO, Paris. Pp159-163.

Strendale, R.A., (1887). Seonee – Camp life on the Satpura Range. A tale of Indian Adventure. II Edition. Thacker, Spink & Co., Calcutta, India.

Sukumar, R., Dattaraja, H.S., Suresh, H.S., Ramakrshnan, J., Vasudev, Nirmala, N., Joshi, N.V., (1992). Long term monitoring of vegetation in a trpical forest in Mudumalai, southern India, Current science. 62: Pp 608-616.

Tackaberry,R., Brokaw, N., Kellman, M., and Mallory, E., (1997). Estimating species richness in tropical forests: the missing species extrapolation technique, J. tropical ecology. 13: Pp 449-458.

Tillman, D.J., Knops, D., Wedin, P., Reich, M., Ritchie, and Siemen, E., (1997). The influence of functional diversity ad composition on ecosytem processes. Science 277: Pp 1300-1302.

Trivedi, B.K., (1976). Ecological studies of some grasslands of central India. PhD. Thesis, University of Sagar, Sagar, India.

Veblen, T.T., (1989). Tree regeneration response to gaps along transdean gradient, Ecology, 70: Pp 539-576.

Vink, A.P.A., (1975). Landuse in advancing agriculture. Springer-verlag. Berlin. Pp394.

Visaratana, T.K., Pitprecha, S., Kiratiprayoon, T., Kampan, and Higuchi, K., (1986). Structural characterstics and species composition of dry dipterocarpus tuberculatus roxb. Community type at salak phra wildlife sanctuary, technical paper No to forest ecology section. Frd (in Thai).

Vitousek., (1994). Beyond global warming; Ecology and global change. Ecology, 75: Pp1861-1876.

Vrba, E., (1985). African Bovidae: evolutionary events since the Miocene. S. Afr. J. Sci. 81: Pp 263-266.

Walker, P.A., (1990). Modelling wildlife distributions using a geographical information system: Kangaroos in relation to climate. Journal of Biogeography, 17, 279 – 289.

Whitaker, R.H., and Levin, S.A., (1997). The role of mosaic phenomena in natural community's theoretical population biology. 12: Pp117

White, P.S., (1979). Pattern, process and natural disturbance in vegetation. Botanical review, 45: Pp 229-299.

Wikramanayake, E. D., Dinerstein, E., Robinson, J. G., Karanth, K. U., Rabinowitz, A., Olson, D., Mattews, T., Hedao, P., Connor, M., Hemley, G. & Bolze, D., (1999). People, tiger habitat availability, and linkages for the tiger's future. In Riding the tiger: Tiger conservation in human dominated landscapes:. Seidensticker, J., Christie, S. & Jackson, P. (Eds.) Cambridge: Cambridge University Press.: Pp 255–272

Woodward, F. I., (1987). Climate and plant distribution. Cambridge University Press, Cambridge, U.K.

Worah, S., Bharucha E.K. and Rodgers W.A., (1989). The use of Geographic Information Systems in identifying potential wildlife habitat. Journal of Bombay Natural History Society, 86(2): Pp 125 – 128

Zang, J.I. and Cao, M., (1995). Tropical forest vegetation of Xishuanbana. SW China and its secondary changes, with special reference to some problems in local nature conservation. Bilological conservation. 73: Pp 229-238

Appendix 1. List of Plant species observed during the sampling in Pench Tiger Reserve, Madhya Pradesh.

Name of Family	Species	Habit
Acanthaceae	*Barleria critata*	S
Agavaceae	*Agave sps*	S
Alangiaceae	*Alangium lamarckii*	T
Amaranthaceae	*Aerva lanata*	H
Amaryllidaceae	*Crinum defixum*	H
Anacardiaceae	*Buchnania lanzan*	T
Anacardiaceae	*Lannea corromandelica*	T
Anacardiaceae	*Semecarpus anacardium*	T
Annonaceae	*Miliusa tomentosa*	T
Annonaceae	*Miliusa velutina*	T
Apiaceae	*Pimpinella diversifolia*	H
Apocynaceae	*Ichnocarpus frutescens*	C
Apocynaceae	*Holarrhena antidysenterica*	T
Apocynaceae	*Wrigtia arborea*	T
Arecaceae	*Phoenix sylvestris*	T
Arecaceae	*Phoenix humulis*	S
Asteraceae	*Acanthospermum hispidum*	H
Asteraceae	*Ageratum conyzoides*	H
Asteraceae	*Blumea balsamifera*	H
Asteraceae	*Conyza stricta*	H
Asteraceae	*Conyza bonariensis*	H
Asteraceae	*Lagascea mollis*	H
Asteraceae	*Tridax procumbens*	H
Bambusaceae	*Dendrocalmus strictus*	G
Bombacaceae	*Bombax ceiba*	T
Burseraceae	*Boswellia serrata*	T
Burseraceae	*Garuga pinnata*	T
Caesalpiniaceae	*Bauhinia racemosa*	T
Caesalpiniaceae	*Bauhinia vahlii*	C
Caesalpiniaceae	*Caesalpinia decapetala*	S
Caesalpiniaceae	*Cassia absus*	H
Caesalpiniaceae	*Cassia tometosa*	T
Caesalpiniaceae	*Cassia tora*	H
Caesalpiniaceae	*Cassia fistula*	T
Campanulaceae	*Lobelia alsinoides*	H
Celastraceae	*Celastrus paniculata*	C
Cochlospermaceae	*Chochlospermum religiosum*	T
Combretaceae	*Anogeissus latifolia*	T
Combretaceae	*Calycopteris floribunda*	S
Combretaceae	*Terminalia arjuna*	T
Combretaceae	*Terminalia alata*	T
Commelinaceae	*Commelina benghalensis*	S
Cyperaceae	*Cyperus spp*	H
Ebenaceae	*Diospyros melanoxylon*	T

Name of Family	Species	Habit
Ebenaceae	*Diospyros montana*	T
Ehretiaceae	*Cardia myxa*	T
Ehretiaceae	*Cordia dichotoma*	T
Euphorbiaceae	*Bridelia retusa*	T
Euphorbiaceae	*Cleistanthus collinus*	T
Euphorbiaceae	*Euphorbia hirta*	H
Euphorbiaceae	*Euphorbia heterophylla*	S
Euphorbiaceae	*Euphorbia pulcherrima*	S
Euphorbiaceae	*Phyllanthus niruri*	H
Euphorbiaceae	*Phyllanthus emblica*	S
Fabaceae	*Alysicarpus vaginalis*	H
Fabaceae	*Butea monosperma*	T
Fabaceae	*Butea superba*	C
Fabaceae	*Crotolaria hirsuta*	H
Fabaceae	*Dalbergia latifolia*	T
Fabaceae	*Dalbergia paniculata*	T
Fabaceae	*Dalbergia sissoo*	T
Fabaceae	*Desmodium dichotomum*	S
Fabaceae	*Indigofera arborea.*	H
Fabaceae	*Indigofera glabra*	H
Fabaceae	*Ougenia dalbergioides*	T
Fabaceae	*Pteroscarpus marsupium*	T
Fabaceae	*Vigna radiata*	H
Fabaceae	*Abrus precatorius*	C
Fabaceae	*Desmodium spp*	H
Fabaceae	*Indigofera arborea*	H
Fabaceae	*Millettia auriculata*	H
Fabaceae	*Uraria spp*	H
Flacourtiaceae	*Flacourtia indica*	T
Flacourtiaceae	*Casearia graveolens*	T
Flacourtiaceae	*Casearia tomentosa*	T
Flindersiaceae	*Chloroxylon swietenia*	T
Hypoxidaceae	*Curculigo orchiodies*	H
Lamiaceae	*Colebrookea oppositifolia*	S
Lamiaceae	*Leucas zeylanica*	H
Lamiaceae	*Ocimum sanctum*	H
Lauraceae	*Litsea glutinosa*	H
Lecythidaceae	*Careya arborea*	T
Liliaceae	*Asparagus racemosus*	C
Liliaceae	*Chlorophytum tuberosum*	H
Lythraceae	*Lagerstroemia purviflora*	T
Lythraceae	*Rotala rotundifolia*	H
Lythraceae	*Woodfordia fruticosa*	S
Malvaceae	*Abutilon indicum*	H
Malvaceae	*Kydia calycina*	T
Malvaceae	*Sida cordifolia*	H
Malvaceae	*Urena lobata*	S
Meliaceae	*Soymida febrifuga*	T

Name of Family	**Species**	**Habit**
Meliaceae	*Toona ciliate*	T
Mimosaceae	*Acacia catechu*	T
Mimosaceae	*Acacia pennata*	UC
Mimosaceae	*Albizia odoratissima*	T
Mimosaceae	*Albizia lebbeck*	T
Mimosaceae	*Albizia procera*	T
Molluginaceae	*Mollugo pentaphylla*	H
Moraceae	*Ficus bengalensis*	T
Moraceae	*Ficus hispida*	T
Moraceae	*Ficus infectoria*	T
Moraceae	*Ficus religiosa*	T
Myrtaceae	*Syzygium cuminii*	T
Nyctaginaceae	*Nyctanthes arbor-tristis*	T
Oxalidaceae	*Oxalis corymbosa*	H
Poaceae	*Alloteropsis cimicina*	G
Poaceae	*Apluda mutica*	G
Poaceae	*Andropogon ascinodis*	G
Poaceae	*Arthraxon ciliaris*	G
Poaceae	*Arthraxon quartinianus*	G
Poaceae	*Arundinella pumila*	G
Poaceae	*Arundinella setosa*	G
Poaceae	*Bambusa arundinacea*	G
Poaceae	*Bothriochloa intermidia*	G
Poaceae	*Bothriochloa parviflora*	G
Poaceae	*Bothrichloa pertusa*	G
Poaceae	*Brachiaria ramosa*	G
Poaceae	*Brachiaria reptans*	G
Poaceae	*Chionachne koenigii*	G
Poaceae	*Chloris virgata*	G
Poaceae	*Chrysopogon aciculatus*	G
Poaceae	*Coix gigantea*	G
Poaceae	*Cymbopogon martinii*	G
Poaceae	*Cynodon dactylon*	G
Poaceae	*Desmostachya bipinnata*	G
Poaceae	*Dactyloctenium aegyptiacum*	G
Poaceae	*Dendrocalamus strictus*	G
Poaceae	*Dicanthium annulatum*	G
Poaceae	*Dicanthium aristatum*	G
Poaceae	*Digitaria chinensis*	G
Poaceae	*Digitaria ternata*	G
Poaceae	*Digitaria setigera*	G
Poaceae	*Digitaria stricta*	G
Poaceae	*Dimeria connivens*	G
Poaceae	*Echinochloa colonum*	G
Poaceae	*Eleusine indica*	G
Poaceae	*Eragrostiella bifaria*	G
Poaceae	*Eragrostiella brachyphylla*	G
Poaceae	*Eragrostis gangetica*	G

Name of Family	**Species**	**Habit**
Poaceae	*Eragrostis tenella*	G
Poaceae	*Eragrostis pilosa*	G
Poaceae	*Eragrostis tenuifolia*	G
Poaceae	*Eragrostis unioloides*	G
Poaceae	*Eulaliopsis binata*	G
Poaceae	*Hackelochloa granularis*	G
Poaceae	*Heteropogon contortus*	G
Poaceae	*Imperata cylindrica*	G
Poaceae	*Isachne globosa*	G
Poaceae	*Ischaemum pilosum*	G
Poaceae	*Ischaemum indicum*	G
Poaceae	*Ischaemum semisagittatum*	G
Poaceae	*Iseilema prostratum*	G
Poaceae	*Manisuris clarkei*	G
Poaceae	*Manisuris myurus*	G
Poaceae	*Melanocenchris jacquemontii*	G
Poaceae	*Oplismenus burmanii*	G
Poaceae	*Oplismenus compositus*	G
Poaceae	*Panicum brevifolium*	G
Poaceae	*Panicum prostratum*	G
Poaceae	*Panicum repens*	G
Poaceae	*Panicum notatum*	G
Poaceae	*Panicum sumatrense*	G
Poaceae	*Paspalidium sp.*	G
Poaceae	*Paspalidium flavidum*	G
Poaceae	*Paspalum scrobiculatum*	G
Poaceae	*Pennisetum pedicellatum*	G
Poaceae	*Petrotis indica*	G
Poaceae	*Saccharum spontaneum*	G
Poaceae	*Sacciolepis indica*	G
Poaceae	*Sacciolpis myosuroides*	G
Poaceae	*Setaria sp.*	G
Poaceae	*Setaria pumila*	G
Poaceae	*Setaria intermedia*	G
Poaceae	*Sporobolus indicus*	G
Poaceae	*Themeda quadrivalvis*	G
Poaceae	*Themeda triandra*	G
Poaceae	*Thysanolaena maxima*	G
Poaceae	*Urochola panicoides*	G
Poaceae	*Vetiveria zizanioides*	G
Rhamnaceae	*Ventilago maderas patana*	C
Rhamnaceae	*Zizyphus mauritiana*	S
Rhamnaceae	*Zizyphus nummularia*	S
Rhamnaceae	*Zizyphus oenoplia*	C
Rhamnaceae	*Zizyphus xyloporus*	T
Rubiaceae	*Haldina cordifolia*	T
Rubiaceae	*Argostemma sarmentosum*	H
Rubiaceae	*Gardenia latifolia*	T

Name of Family	**Species**	**Habit**
Rubiaceae	*Gardenia turgida*	T
Rubiaceae	*Hymenodictyon execelsum*	T
Rubiaceae	*Pavetta crassicaulis*	H
Rubiaceae	*Ixora arborea*	T
Rubiaceae	*Ixora parviflora*	T
Rubiaceae	*Mitragyna parviflora*	T
Rubiaceae	*Morinda pubescens*	T
Rubiaceae	*Spermadictyon suaveolens*	S
Rubiaceae	*Wendlandia heynei*	T
Rubiaceae	*Catunaregam uliginosa*	T
Rubiaceae	*Catunaregam spinosa*	T
Rutaceae	*Aegle marmelos*	T
Sapindaceae	*Schleichera oleosa*	T
Sapotaceae	*Madhuca latifolia*	T
Sapotaceae	*Madhuca indica*	T
Simaroubaceae	*Ailanthus excelsa*	T
Sterculiaceae	*Helicteres isora*	S
Sterculiaceae	*Sterculia urens*	T
Sterculiaceae	*Waltheria indica*	T
Tiliaceae	*Grewia hirsute*	S
Tiliaceae	*Grewia helicterifolia*	S
Tiliaceae	*Grewia rothii*	S
Tiliaceae	*Grewia tiliaefolia*	T
Verbenaceae	*Lantana camara*	S
Verbenaceae	*Lantana indica*	S
Verbenaceae	*Tectona grandis*	T
Verbenaceae	*Vitex spp.*	H
Verbenaceae	*Vitex negundo*	US
Zingiberaceae	*Curcuma reclinata*	H
Zingiberaceae	*Zigiber spp*	H

Appendix II. Food plants of gaur and domestic elephant in Pench Tiger Reserve, Madhya Pradesh.

Family	***Plant Species***	***Plant Part***	***Season***	***Elephant food***
DICOTYLEDONEAE				
Annonaceae	*Miliusa velutina*	L	s,w,m	*
Malvaceae	*Abutilon indicum*	L	s	
	Kydia calycina	L	s,w	*
	Sida cordifolia	L	s	
	Sida spp	L	s	
	Urena lobata	L	s	
Sterculiaceae	*Helicteres isora*	L	s	*
Tiliaceae	*Grewia hirsuta*	L,FL,FR	s,w	
	Grewia tiliaefolia	L,FL,FR	s,w,m	*
	Grewia rothii	L	s	
Rutaceae	*Aegle marmelos*	L,FL,FR	s,w,m	*
Celastraceae	*Celastrus paniculata*	L	s	
Rhamnaceae	*Ventilago maderaspatana*	L,FL,FR	s,w,m	
	Zizyphus oenoplia	L,FL,FR	s,w	
	Zizyphus xylopyrus	L,FL,FR	s,w,m	
	Zizyphus mauritiana	L,FL,FR	s,w	
	Zizyphus nummularia	L	s	
Fabaceae	*Abrus precatorius*	L	m	
	Butea superba	L	m,w	
	Dalbergia paniculata	L	s,w,m	
	Desmodium dichotomum	L	s	
	Indigofera arborea	L,FL	w,m	
	Millettia auriculata	L	w,m	
	Ougeinia dalbergioides	L	s,w,m	*
	Uraria spp	L	s	
Caesalpiniaceae	*Bauhinia racemosa*	L	s,w,m	
	Bauhinia vahlii	L,FL	s,w	
	Cassia tora	L	s	

Family	***Plant Species***	***Plant Part***	***Season***	***Elephant food***
Mimosaceae				
	Acacia pennata	L	s	
	Albizzia odoratissima	L	s	
	Albizzia procera	L	s,w	
Combretaceae				
	Anogeissus latifolia	L,FL	s,w,m	
	Terminalia arjuna	L	m	
	Termanalia alata	L,FL	s,w,m	
Myrtaceae				
	Syzygium cumini	L,FL,FR	w,m	
Flacourtiaceae	*Casearia tomentosa*	L,FL	s,w	
	Casearia graveolens	L	s,w	
	Flacourtia indica	L,FR	s,w	
	Haldina cordifolia	L	s,w	*
Rubiaceae	*Mitragyna parviflora*	L	m,w	
	Catunareguam uliginosa	L	s,w	
	Catunaregam spinosa	L	s,w	
Ebenaceae				
	Diospyros montana	L	s,w	
	Diospyros melanoxylon	L,FR	s,w,m	
Nyctaginaceae	*Nyctanthes arbor-tristris*	L,FL	m	
Apocynaceae	*Holarrhena antidysenterica*	L	s	*
Ehretiaceae	*Cordia myxa*	L	s,w,m	
Verbenaceae	*Lantana camara*	L	s	
	Tectona grandis	L,BR	s	*
	Vitex spp	L,FL	s	
Euphorbiceae	*Bridelia retusa*	L	s,w	*
	Euphorbia hirta			
	Phyllanthus emblica	L,FR	s,w	*
	Phyllanthus niruri	L		
Moraceae	*Ficus hispida*	L	m	
Sapotaceae	*Madhuca latifolia*	FL,FR	s	
MONOCOTYLEDONEAE				

Family	***Plant Species***	***Plant Part***	***Season***	***Elephant food***
Zingiberaceae	*Curcuma reclinata*	L	m	
	Zingiber spp	L	m	
Hypoxidaceae	*Curculigo orchiodies*	L	m	
Liliaceae	*Asparagus racemosus*	L	m	
	Chlorophytum tuberosum	L	m	
Arecaceae	*Phoenix humulis*	L	s,w,m	*
Bambusaceae	*Dendrocalamus strictus*	L,SD	s,w,m	*
Gramineae	*Adropogon spp*	L	m,w	
	Anthistiria spp	L	m	
	Apluda mutica	L	m,w	
	Chloris dolychostachya	L	m	*
	Cynodon dactylon	L	s,w	*
	Dicanthium spp	L	m,w	
	Heteropogon contortus	L	s,w,m	
	Ischaemum spp	L	m,w	
	Sorghum halepense	L,FL	w	*
	Themeda spp	L	s,w	
Commelinaceae	*Commelina benghalensis*	L	M	
Cyperaceae	*Cyperus spp*	L	m	

Plant parts: (L= Leaf, FL=Flower, FR=Fruit, SD=Seed, B= Bark)
Season: (s= Summer, w= Winter, m=Monsoon)
* Domestic elephant food plants

Appendix III. Vegetation types in Pench Tiger Reserve, M.P.

Plate 1. Teak dominant forest

Plate 2. Miscellaneous forest

Plate 3. *Clistanthuss collinus* forest

Plate 4. *Zizyphus – Butea* mixed woodland

Plate 5. Bamboo forest

Plate 6. Riparian forest

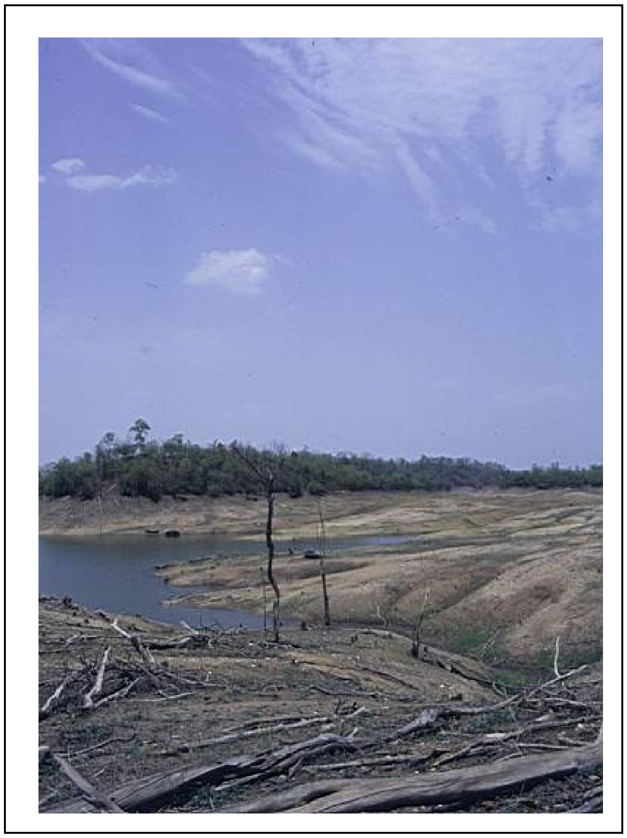


Plate 7. Submergence area

Plate 8. Teak mixed forest

Plate 9. Forest fire in Pench Tiger Reserve

Plate 10. Pench reservoir

Plate 11. Gaur resting in miscellaneous forest

Plate 12. Gaur herd at water hole during summer