GEOSPATIAL MODELLING OF UNGULATE HABITAT RELATIONSHIPS IN TADOBA-ANDHARI TIGER RESERVE, MAHARASHTRA

Thesis for the Award of the Degree
of
Doctor of Philosophy
in
Wildlife Science

Submitted to the
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Rajkot (Gujarat)

by
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Certificate

This is to certify that the thesis of **Ms. Ambica Paliwal** entitled **"Geospatial Modelling of Ungulate Habitat Relationships in Tadoba-Andhari Tiger Reserve, Maharashtra"** is an original piece of work submitted to the Saurashtra University, Rajkot (Gujarat), for the award of the **Doctor of Philosophy in Wildlife Science.**

Ms. Ambica Paliwal has put in more than six terms of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted for any degree of any other University or Institution.

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Dedicated To My Parents

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Summary

1. Wildlife conservation planning *inter-alia* requires basic information on distribution and abundance of natural resources. Knowledge of presence or absence of wildlife species and their distribution across a landscape is critical for making sound wildlife management decisions. Ungulate species form a major prey base and therefore play a pivotal role in maintenance of forest ecosystem equilibrium, as they help in shaping its structure, composition and also directly or indirectly affect other animals. However, efforts towards conservation and management of wildlife are often hampered due to non-availability of good quality data on species, habitats and suitability of the habitats for different species. *In-situ* conservation of biodiversity requires multi-disciplinary approaches sustained by a foundation of sound scientific and technological information. With this background the study aims to map landuse/landcover patterns and to assess spatial structure and configuration of landscape; structure and composition of vegetation types in landscape; spatial and ecological distribution of ungulate species in response to seasons and management status and habitat suitability and site occupancy using spatially explicit ungulate-habitat model.

2. The present study was carried out in Tadoba-Andhari Tiger Reserve (TATR). It lies in civil district of Chandrapur, eastern edge of Maharashtra. The area lies between 20º 04' 53"N to 20º 25' 51"N latitude to 79º 13' 13"E to 79º 33' 34"E longitude. The extent of the total area of TATR is 625.40 km² out of which Tadoba National Park (TNP) comprises 116.55 km² while Andhari Wildlife Sanctuary (AWS) covers 508.85 km². TNP forms the core northern zone of TATR while AWS consists of two ranges Moharli and Kolsa, which form central and southern zones of the TATR respectively.

3. Data was collected from primary and secondary sources. Field work was carried out between February 2005 and January 2007. A total of

810 GPS points were collected for ground truthing. The area was sampled using systematic stratified sampling approach. Stratification was done using administrative unit *i.e.* a forest beat. A total of 50 line transects of 2 km length were laid in all 34 beats of TATR covering all vegetation types of the study area. On these transects 500 circular plots were laid for vegetation quantification, equidistant at 200 m interval, while 20 plots were also laid randomly. For ungulate density estimation, transects were walked in summer and winter seasons. Each transect was repeated 4-6 times in each season so as to capture the variation. IRS-P6 LISS IV data was used for landuse/landcover mapping and canopy density mapping of TATR. Spatial structure of TATR landscape was described using software package FRAGSTATS. Data from vegetation plots was used to quantify structure and composition of five major vegetation types delineated from satellite data. Transect data was used to derive ungulate density estimates using 'DISTANCE', program. The estimates were compared with previous studies and some other tropical studies. Biomass and other population parameters were also estimated and compared as a part of the study. For ungulate-habitat modelling, Ecological Niche Factor Analysis (ENFA) was used. ENFA assumes that the environmental conditions are optimal where species is most frequently found. Each transect was considered as the representative of the animal presence data. Mean encounter rate (ER) for each species on each transect was derived and was categorized under five wieghtage classes. A grid of 157 cells each of 4 km² (2X2km) was overlaid on the study area. A total of 21 ecogeographical variables were used for analyses which were categorized under four environmental descriptor classes, topographic variables; anthropogenic variables; habitat variables; and hydrological variables. Habitat suitability maps were then evaluated for predictive accuracy by a cross validation procedure and validated maps were obtained.

4. Vegetation maps serve as a valuable tool in natural resource management and conservation planning. Cluster analysis was used to

for mapping ten landuse/landcover classes. Mixed Bamboo Forest occupied the maximum proportion of study area (75.81%) while the Riparian Forest occupied the least (0.61%). As a result of canopy density mapping the forests were sub grouped into five canopy density classes. The structural analysis of TATR landscape reveals its heterogeneous nature with large variations in patch size, but with low diversity, low evenness and intermediate interspersion of forest types. This study has focussed on integrating satellite forest classification and forest inventory data for studying forest landscape patterns. IRS P6 LISS IV data has been observed to have an immense potential to minutely capture the structural details of the landscape precisely due to its high resolution and multispectral nature.

5. Knowledge of floristic composition and vegetation structure is critical for understanding the dynamics of forest ecosystems. Vegetation structure and composition of five major vegetation types delineated from satellite data were studied. The cluster analysis grouped the species into seven different communities. A total of 3779 tree individuals belonging to 55 species were recorded. Floristic analysis of TATR revealed that *Tectona grandis* had maximum Importance Value Index (IVI). Fabaceae, Combretaceae and Caesalpiniaceae were found to be dominant families in TATR. The population structure characterized by the presence of adequate number of seedlings, saplings and young trees depicts satisfactory regeneration status of major tree species.

6. Population density, structure and biomass are the measures to examine the complex relationships between wild animal species and their habitats. Among management units TNP had higher density of ungulates compared to AWS. However, AWS contributed maximum biomass to entire TATR. The three herbivore species, Chital, Sambar and Gaur together contributed 84% to the total biomass of TATR. A considerable increase in densities of all the ungulates was observed on comparison with previous studies. TNP has larger mean group sizes of

Chital, Sambar and Wild pig than AWS. It was attributed to open spaces in TNP. Chital showed significant difference in the mean group size (MGS) between the seasons. The sex ratios were found to be in favour of females. The fawn per female ratio was found to decrease as compared to earlier estimates.

7. The association between both habitat variables and ungulate abundance was examined by conducting habitat modelling. ENFA was used to model the habitat of five ungulate species. Model identified that the presence of canopy was one of the main determinants of habitat utilization by large ungulates at TATR, with all species associating with various canopy classes. All canopy classes except non-forest were favoured by ungulates. Canopy density below 30% and 30-40% was most favoured. The model emphasized that the burnt areas had positive influence on the ungulate distribution. Further, the ungulates showed the proximity towards open areas dominated by road network. Chital showed highest affinity towards open areas and least was shown by Sambar. High elevation was generally avoided by ungulates except Sambar. A majority of ungulates responded negatively towards habitations as due to these, some good habitats were rendered inhabitable. It is concluded that ENFA helps to blend statistical theory with ecological practice. A spatially explicit model like ENFA provides decisive assistance in the task of determining species basic ecological needs.

8. The present study is an amalgamation of ecological theory, scientific technology and modern statistical modeling. It provides a sound basis for effective management of TATR including preparation of science-based management plans.

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Chapter 1
INTRODUCTION

1.1. BACKGROUND

India's altitudinal, terrain and diverse climatic variations support a wide array of habitats and species. Over the years, the populations of many wild animal species have declined due to intensive and unwise human activities. Destruction of natural ecosystems and habitats of large number of species is one of the biggest threats to the planet earth. Human activities have accelerated the species extinction process by polluting the environment and destroying habitats. Overall, the IUCN Red List now includes 44,838 species, of which 16,928 are threatened with extinction (38 percent). Of these, 3,246 are in the highest category of threat *i.e.* Critically Endangered, 4,770 are Endangered and 8,912 are Vulnerable to extinction (IUCN Red List 2008). Worldwide destruction of natural environment is reducing the number of wild species and biodiversity in general. Therefore, to protect species of wild animals from extinction, *inter-alia* a regional conservation planning is required which needs basic information on the distribution of habitat of animal and plant species throughout the region of interest.

Habitat is a place occupied by a specific population within a community of populations for their survival (Giles, 1978). It is often selected as the basis for species-habitat association models to assist in planning since the habitat provides integration between concepts of population and carrying capacity. It includes a wide variety of factors such as soil, topography, water availability, vegetation cover and its characteristics including human influence on all of these. Each species require a particular habitat that provides the space, food, cover and other requirements for survival. Habitat has been defined to incorporate several interrelated concepts dealing with space, time and function. It may also be characterized by a description of the environmental features that are important in determining the distribution and abundance of a species (Burgman and Lindenmayer, 1998). Burgman and Lindenmayer

(1998) add that such descriptions are often based on field experience and non-quantifiable human perceptions.

It has been realized that efforts towards conservation and management of wildlife are often hampered due to non-availability of good quality data on species, habitats and suitability of the habitats for different species. The solution to conserve biodiversity *in-situ* requires major investments and multi-disciplinary approaches sustained by a foundation of sound scientific and technological information with careful analysis. Recent advances in the understanding of ecological processes and technological understanding have made management of wildlife more scientific. Spatial and non spatial databases are becoming available to wildlife managers and decision makers to look at species habitat relationships in a much better way (Pabla 1998, Dubey 1999, Kumar *et al.,* 2002 and Jayapal *et al.,* 2007). Better integration of technology with more sophisticated modelling of species habitat requirements is required to evaluate current and potential impacts of management practices on landscape composition and structure, the availability of ecological resources, habitat quality and the viability of species populations. Such tools and models have to be flexible and should include appropriate analytical techniques for evaluating the effects of management practices on the conservation of biological diversity among multiple scales of time and space.

1.2. ROLE OF REMOTE SENSING AND GIS

The quickest possible way for inventory and evaluation of the natural resources is through application of Remote Sensing and Geographic Information System (GIS). These technologies provide vital geoinformation support in terms of relevant, reliable and timely information needed for conservation planning (Khushwaha & Madhavan Unni 1986, Nell's *et al.,* 1990, Nagendra & Gadgil 1999, Gouch & Rushton 2000, Weiers *et al.,* 2004). The advancement in science and technology has revolutionalized the process of data gathering and map making and their application in habitat inventory, evaluation and wildlife census. Wildlife habitat mapping is similar to any type of land cover mapping (Lindgren, 1985). Both biotic and abiotic surface features including vegetation composition, density and landforms can be mapped. Interspersion of habitat components, the extent of habitat types and the distance to other critical habitat components can be measured (Best, 1984).

The NOAA (National Ocean and Atmospheric Administration), IKONOS, SPOT (Le systeme pour l'Observation de la Terre) and IRS (India Remote Sensing Satellite) series of satellites have added a temporal dimension to habitat mapping and change detection (Kushwaha & Roy, 2002). Osborne *et al.,* 2001 advocated the potential of satellite imagery and GIS datasets in mapping species distributions at large spatial scales. Radeloff *et al.,* (1999) commented that the incorporation of location-specific knowledge of field biologists is a key step to improving GIS based wildlife models, and thus improving wildlife management. The potential of using high resolution satellite data in wildlife habitat characterization is essentially required for intensive and effective management of park resources. This can often be achieved in real-time, which minimizes the amount of data entry that is required by a large cohort of experts. In addition, the GIS provides experts with a spatial context when providing data through the inclusion of other data layers such as digital elevation model, road network or vegetation distribution.

Recently, India has placed a satellite RESOURCESAT in 2003 in the orbit equipped with high resolution LISS-IV sensor (5.8 m spatial resolution). High resolution data provides information on vegetation cover type and area, land cover diversity, size of open spaces and vegetation units, landscape heterogeneity (as indices of fragmentation and form complexity), indivisibility etc. which are useful parameters for habitat suitability analysis with more information and with higher levels of accuracy (Gupta & Jain 2005 and Rao & Narendra 2006). IRS P 6 LISS IV data facilitate better discrimination of different forest types and detailed micro level information by delineating crown density levels due to high spatial resolution, (Pandey & Tiwari 2004 and

Sudhakar *et al.,* 2004). Therefore, this study has been conducted using of IRS P6 LISS IV data.

1.2.1. Geospatial Habitat Modelling

A model is any formal representation of some part of the real world (Hall & Day, 1977). Models are often simplifications of a system they depict. Models can be used to describe the responses of a species to changes in its habitat. Modelling habitat requirements of species is increasingly becoming an important tool both for investigating the requirements of species and planning conservation measures. Geospatial modelling is carried out using geoinformatics in gathering information on physical parameters of the wildlife habitat as well as analyses of spatial data in GIS domain. This kind of modelling has a profound advantage over traditional techniques in terms of accuracy of the information. These models are generally developed to explain wildlife distribution and predict habitat use (Patton 1992 and Morrison *et al.,* 1992), and in all cases assume that habitat quality is indexed by distribution (Van Horne 1983 and Scamberger & O' Neill 1986) so that model output predict habitat quality. Predictive habitat modelling has gained importance both as a research tool and as a method to evaluate possible consequences of changing land use and environmental conditions on species distribution and relative abundance (Austin 2002 and Lehmann *et al.,* 2002). The most common approach used to develop habitat models is to establish a statistical relationship between certain number of environment predictor variables and response variables *i.e.* presence-absence data. It is as much art as science. The conceptualization phase of model cannot be reduced to a set of synthetic rules (Sklar *et al.,* 1985). The art is in finding the most appropriate variables and hierarchical level of organization for modelling objectives at hand (Allen & Starr, 1982).

A number of habitat suitability indices have been developed for various ungulate species. These include models for roe deer (Radeloff *et al.,* 1999), red deer (Debeljak *et al.,* 2001), white-tailed deer (Lehmkuhl *et al.,* 2001 and

Plante *et al.,* 2004), mule deer (Lehmkuhl *et al.,* 2001) sambar (Ray and Burgmann, 2006) and moose (Dettki *et al.,* 2003). However, there is a dearth of literature on habitat modelling using multiple variables in terms of wild ungulates in Indian context.

1.3. SIGNIFICANCE OF THE STUDY

Ungulates form a major prey and resource base and therefore play a vital role in maintenance of forest ecosystem equilibrium. Maintaining viable populations of wild ungulates and carnivore species is the goal of protected area management. Ungulates may exert a profound influence on ecosystem processes, including nutrient cycling, primary productivity and disturbance regimes (Hobbs, 1996). They strongly influence plant population processes and vegetation dynamics in a variety of ways, and over a broad range of scales. The direct effects of ungulate herbivory on plants are certainly the most noticeable (Danell *et al.,* 1991).

Wild ungulate habitats have become fragmented, concentrated and diminished throughout much of the world, due to anthropogenic influences such as land use change and livestock grazing. In combination with predator control or extirpation in many regions, this has resulted in situations of local overabundance, causing shifts in plant species composition (Rooney & Waller, 2003), problems for forest regeneration (Gill, 1992) or conflicts with domestic herbivores (Hobbs, 1996). Elsewhere, the result is endangerment or extirpation of the ungulate species. Our ability to find solutions to these problems is limited because we often lack sufficient understanding of how ungulate species interact with habitat, forage, competing species, predators and humans at multiple scales from small foraging patches to large regions.

In order to successfully manage ungulate populations it is necessary to understand now wildlife habitat changes spatially. A habitat suitability model thus estimates the importance of variables needed for the survival of species. Ungulates have been selected as study species for two reasons. Firstly, owing to their broad spatial habitat requirements, they can be used to study species-habitat relationships. Secondly, for the inevitability of long term conservation of large carnivores, the protection of the viable populations of wild ungulates is necessary which can only be ensured by protecting their habitats. The present study has major conservation implications for the ungulates and their habitats and also has direct relevance to predators specifically and the ecosystem at large. It also forms part of a pilot project 'Mapping of National Parks and Wildlife Sanctuaries' sponsored by the Ministry of Environment and Forests, Government of India under National Natural Resource Management System (NNRMS).

1.4. RESEARCH QUESTIONS AND OBJECTIVES

Keeping in view the above background, the following questions were set forth in context of landscape of Tadoba-Andhari Tiger Reserve (TATR):

- What is the present pattern of landuse/landcover in TATR?
- What is the structure and composition of landscape of TATR?
- What are the physiognomy, structure and composition of vegetation types in TATR?
- How different management zones differ in abundance and distribution of wild ungulates (Chital, Sambar, Nilgai, Gaur and Wild pig)?
- Is there any substantial decrease or increase in wild ungulate populations in TATR?
- Which are the suitable habitats for different ungulate species in TATR?
- What are the main determinants of habitat utilization by these ungulates?
- How Ecological Niche Factor Analysis (ENFA) based modelling can assist in above?

In order to address above questions, the following objectives were set forth for the present study:

1. To map the landuse/landcover patterns of Tadoba Andhari Tiger Reserve (TATR) and to describe structure and composition of TATR landscape.
2. To describe physiognomy, structure and composition of vegetation in TATR.
3. To quantify spatial and ecological distribution of ungulate species in response to seasons and management status.
4. To develop spatially explicit ungulate-habitat models describing habitat suitability and site occupancy.

1.5. ORGANIZATION OF THE THESIS

The thesis is organized in seven chapters. Chapters 1, 2 and 7 deal with introduction, study area and conclusion respectively. Rest of the four Chapters (3, 4, 5 and 6) are based on the above four objectives. Each of these chapters includes a brief introduction with review of literature followed by methodology, results and discussion. The Chapter 1 provides general introduction and explains the background of the present study, the role of remote sensing and GIS and aspects of geospatial modelling. It further explains the significance of the study, includes the relevant research questions and objectives. Chapter 2 deals with the study area, its physical environment, socioeconomic environment, unique biodiversity and the previous studies carried out in TATR. Chapter 3 deals with landuse/landcover classification of TATR and the assessment of the spatial patterns of landscape. Chapter 4 explains the ecological structure and composition of the vegetation types delineated in the previous chapter. Chapter 5 deals with distribution and abundance of ungulate species in different management zones. Chapter 6 deals with habitat modelling of five wild ungulate species using different variables and GIS. Chapter 7 concludes the above theme based chapters. It highlights the significant findings and the implications for prospective research and management practices.

Chapter 2

STUDY AREA

Tadoba-Andhari Tiger Reserve (TATR) represents a pristine and unique habitat for wildlife in Central India. It is the second Tiger Reserve in the State. It contains some of the best of forest tracks and is endowed with rich biodiversity.

2.1. PHYSICAL ENVIRONMENT

2.1.1. Area, Location and Constitution

TATR is situated in the civil district of Chandrapur, eastern edge of Maharashtra. The area lies between 20º 04' 53"N to 20º 25' 51"N latitude to 79º 13' 13"E to 79º 33' 34"E longitude (Fig. 2.1). The extent of the total area of the TATR is 625.40 km^2 out of which Tadoba National Park comprises 116.55 km^2 while Andhari Wildlife Sanctuary covers 508.85 km^2. Tadoba National Park which was established as the first national park of Maharashtra, forms the core northern zone of TATR. In the year 1986, the Government of Maharashtra established the Andhari Wildlife Sanctuary, which consists of two ranges Moharli and Kolsa, which form central and southern zones of the Tiger Reserve respectively. The National Park derives its name from local tribal god "Taru" (Plate 2.1) whereas the Andhari River flowing through the forests gives the sanctuary its name. Andhari Wildlife Sanctuary along with Tadoba National Park forms the composite area of Tadoba-Andhari Tiger Reserve. It was established in Februrary, 1994. The TATR covers four tehsils namely Chandrapur, Bhadrawati, Chimur and Warora. A picturesque Tadoba lake is located in the central part of Tadoba National Park (Plate 2.2).

2.1.2. Climate

The area has a subtropical climate with three distinct seasons- summer, monsoon and winter. Climate is characterized by hot and prolonged summer months from March to June while winter is short and mild from December to

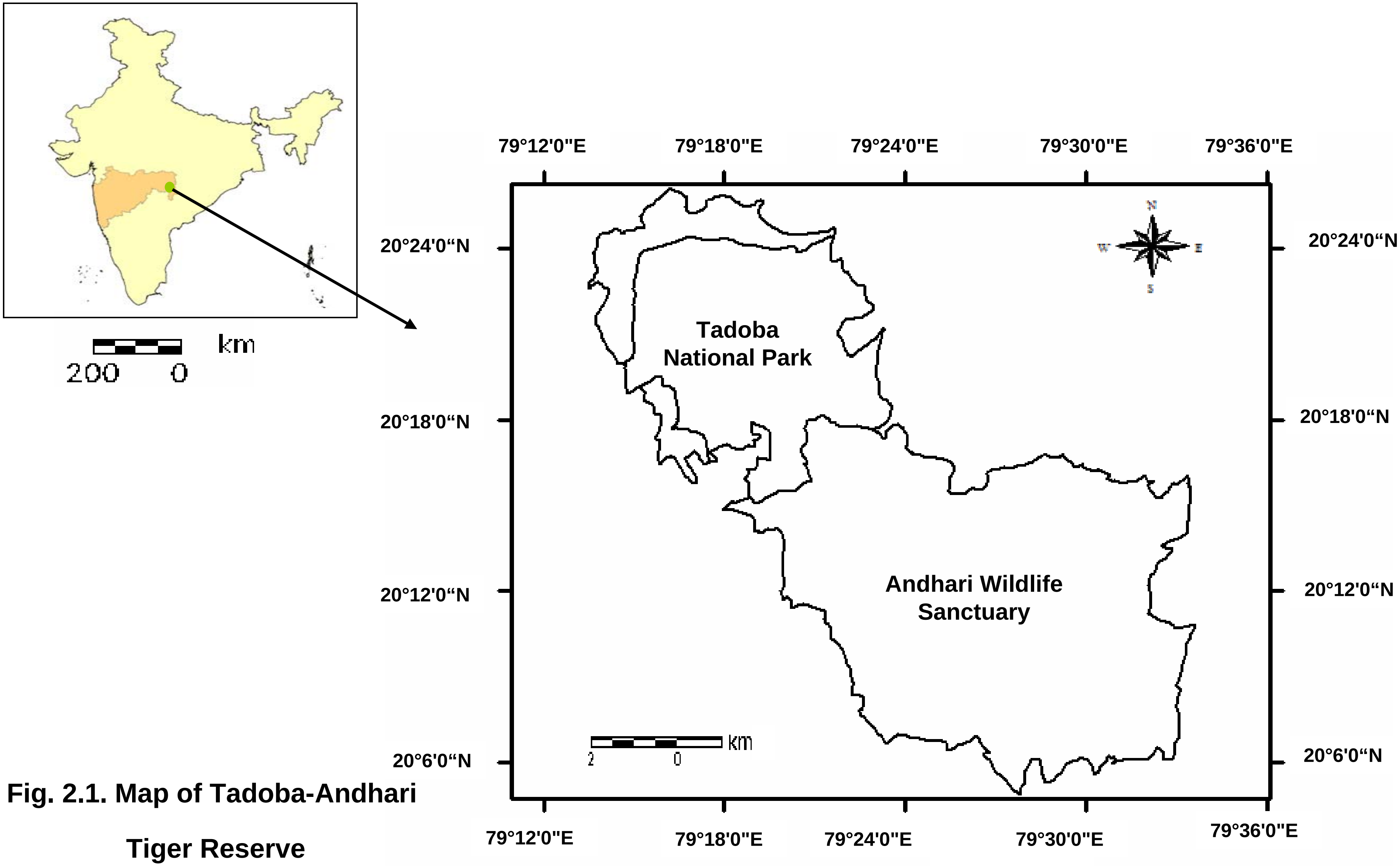


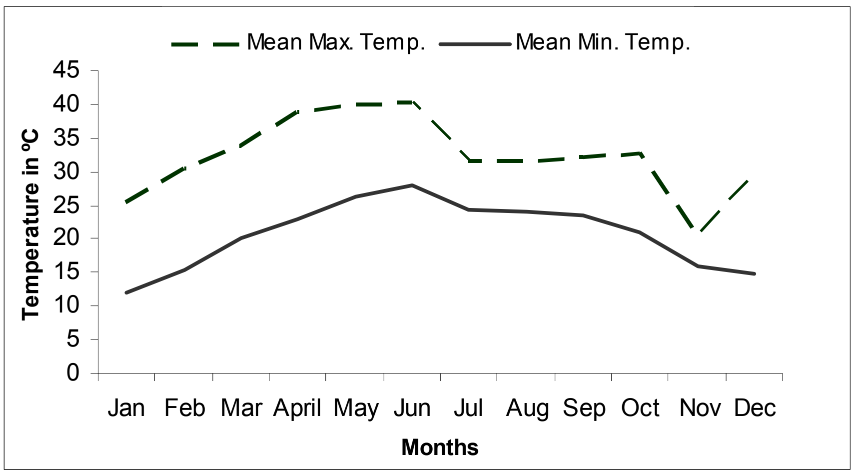
Fig. 2.1. Map of Tadoba-Andhari Tiger Reserve

Plate 2.1. Local Tribal God "Tadoba Deo or Taru"

Plate 2.2. A picturesque Tadoba Lake situated in Tadoba National Park

February. Rainfall is well distributed during southwest monsoons. The monsoon arrives in mid June and continues till September.

Temperature: The maximum recorded temperature is 49.2ºC and the minimum in the year is 3ºC. Temperature rises rapidly after February till May which is the hottest moth of the year. The mean maximium and minimum temperature is about 42ºC and 24º C respectively in May (Fig. 2.2). After October both day and night temperature decreases till December which is the coldest moth of the year.

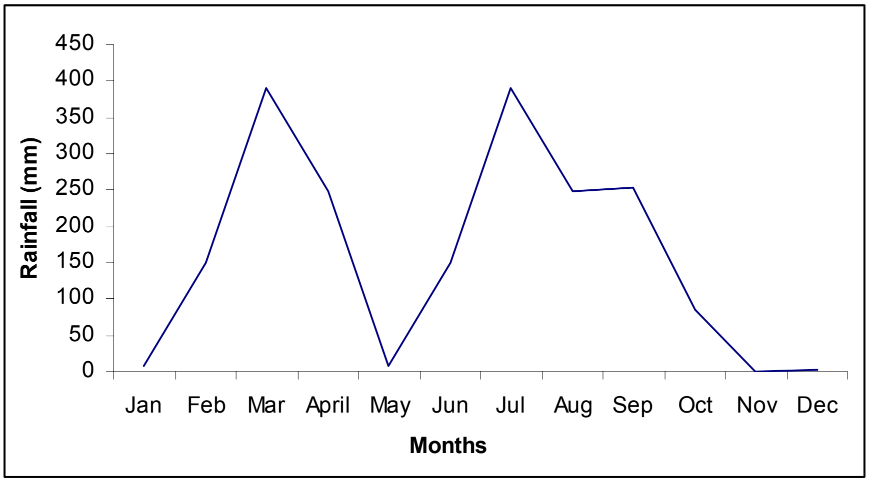


Source: Indian Meteorological Dept. (Govt. of India), 2005

Figure 2.2. Variation in mean maximum and mean minimum temperature in 2005

Humidity: The air is generally dry except during the southwest monsoon season when the humidity exceeds 70%. The summer months are driest when the relative humidity in afternoon is between 20-25%. The winds are generally light.

Precipitation: The bulk of rainfall (92%) is received from June to September. The average numbers of rainy days are approximately eighty. The average annual rainfall is 1175mm. Figure 2.3 shows the monthly variation in rainfall.



Source: Indian Meteorological Dept. (Govt. of India), 2005

Figure 2.3. Variation in mean monthly rainfall in TATR in 2005

2.1.3. Geology and Soil

Vindhyan sand stones occur in almost all the areas, which consist of sandstone, shales and limestone. The shale is intercalated with limestone. The prominent rocks are the grained vitreous sandstone. Broad geological divisions can be made for TATR based on the disposition of the rock types. In north, a small patch of detrital mantle consists of alluvial deposits. In south western side, the Gondwana sediments expose the Kamathi formations and Lamteas at surface. Archean metamorphic rocks as patches are present along the north east corner and in the western border. The soil in the greater part is sandy with stretches of yellow brown and black loam. True black cotton soil is found in the plains except where forests are heavily degraded. On the slopes the soil layer is thin and vegetation is sparse. The tops of the hillocks are mostly barren with exposed rocks.

2.1.4. Topography

The area is mostly undulating and hilly in north. The southern part of the TATR is mostly plain. The Chimur hills start from the east of Chimur and run southwards with gradually diminishing height. In the basin of hills lies Tadoba

Lake, which has a spread of *ca.* 120 ha spread. The highest elevation points in the study area reaches 380 m above mean sea level.

2.1.5. Drainage Pattern

There are two major rivers draining the TATR. Erai river in the western half and Andhari, the main river in the eastern half. Both these rivers are flowing from north to south and their course seems to be controlled by the major boundary *fault.* The presence of base flow in these rivers confirms the fact that they are gaining rivers *i.e.* ground water is being discharged into the rivers. Since the area is undulating there are numerous streams passing through. Andhari river originates in eastern part of national park and flows down southwards joining Wainganga, a tributary of river Godavari. Erai is fed by Bhanushikhandi nala, which originates from western part of national park. The streams are seasonal and, have flowing water only till the end of November. Other important surface water bodies in the area are Tadoba and Kolsa lake.

2.2. BIODIVERSITY

2.2.1. General Account of Flora

Tadoba-Andhari Tiger Reserve has southern tropical dry deciduous forest - 5A/16 (Champion and Seth, 2005). Fairly large area is dominated by *Tectona grandis*. The main associates of Teak (*Tectona grandis*) are Bija *(Pterocarpus marsupium),* Dhaora *(Anogeissus latifolia),* Ain *(Terminalia tomentosa),* Mahua *(Madhuca indica),* Tendu *(Diospyros melanoxylon),* Salai *(Boswellia serrata),* Sehna *(Lagerstroemia parviflora)*. Bamboo *(Dendrocalamus strictus)* forms the middle storey in almost all the communities and in certain cases under storey also. The area includes both angiosperms and pteridophytes comprising 667 species, 393 genera and 110 families (Malhotra & Moorthy, 1992). A total of 85 species of trees, 43 species of herbs and shrubs, 23 species of climbers and 35 species of grasses have been reported by Forest Department. The undergrowth is generally rich after monsoon but ephemeral in nature. According to Management Plan of Tadoba Andhari Tiger Reserve (Khawarey & Karnat, 1997) six classes have been defined in area are as follows:

- *Tectona grandis-Tamarindus indica* community.
- *Diospyros melanoxylon- Tectona grandis - Terminalia arjuna* community.
- *Tectona grandis-Chloroxylon- Lagerstroemia* community
- *Syzygium cumini-Terminalia arjuna* community.
- *Mangifera indica- Terminalia arjuna* community.
- Grassland with few trees.

2.2.2. General Account of Fauna

A total of 42 mammals have been check listed in the study area. Tiger *(Panthera tigris)* is keystone species and major management inputs are focused towards its conservation. Other carnivores include Leopard *(Panthera pardus),* Striped hyaena *(Hyaena hyaena),* Wild dog *(Cuon alpinus),* Jungle cat *(Felis chaus),* and Desert cat *(Felis sylvestris ornata)*. Rusty spotted cat *(Priobailurus rubiginosa),* Jackal *(Canis aureus)* and a Wolf *(Canis lupus)* occur in the western fringe of TATR. Sloth bear *(Melursus ursinus)* also occurs in fairly large numbers. Major herbivores in TATR are Gaur *(Bos guarus),* Sambar *(Cervus unicolor),* Chital *(Axis axis),* Barking deer *(Muntiacus muntjac),* Nilgai *(Boselaphus tragocamelus),* Chowsinga *(Tetracerus quardricornis),* Wild pig *(Sus scrofa)* and Langur *(Presbytis entellus).* There are 195 species of avifauna recorded in the area. There are three endangered species of reptiles namely, Marsh crocodile, Indian Python and Common Indian Monitor.

2.3. SOCIOECONOMIC ENVIRONMENT

2.3.1. People

There are six villages inside the TATR which lie in the Andhari Wildlife Sanctuary. These villages are completely dependent on TATR for their requirements of fuel wood, grazing of their livestock etc. The area is dominated by Gond and Mana tribes. Gonds have rich history in the area. Once the rulers of the southern Vidarbha area they were pushed into forest by repeated invasions by Marathas. Gonds and Manas mainly survive on the products derived from trees like Tendu and Mahua in the forest. Due to increase in population in past few years, expansion of habitation has been observed there by changing the landuse pattern which in turn has affected the forested landscape. The main sources of livelihood are agriculture, minor forest produce and labour works, if available in the lean season. The cattle population most of which is unproductive is traditionally considered as symbol of social status.

2.3.2. Communication and Infrastructure

TATR has an extensive road network. The entire area is covered under wireless a communication system. There are fourteen entry points to the protected area. Out of which ten points have check gates to regulate entry in TATR.

2.3.3. Agriculture

It is the major occupation of the villagers. Rice, soyabean and pulses are the major crops grown.

2.3.4. Management

The Management Plan for Tadoba-Andhari Tiger Reserve for the period 1997-98 to 2006-2007 has been approved by the Chief Conservator of Forests (Wildlife). Management inputs as prescribed in the plan have been initiated since 1997-98. Protection is most important management input in TATR. A novel method of protecting the forest with the help of tribal youth from the six villages within the Andhari Sanctuary has been initiated. Fifteen patrolling parties have been formed in which along with the field staff, three village protection force volunteers have been assigned the job of daily patrolling the

Tadoba-Andhari Tiger Reserve and help in curbing all illegal activities. These volunteers are kept for a maximum of three months for which wages are given as per available grants. However, after three months new tribal youths are taken as members of the village protection force so that all the families of the six villages get some wages for their livelihood and feel a sense of responsibility for protection of TATR.

2.4. REVIEW OF LITERATURE ON TATR

Few research studies have been carried out in TATR. First attempt to study plants of Tadoba National Park was initiated by Haines (1916). Malhotra and Moorthy (1992) gave the floristic account of Tadoba National Park and its surroundings. Mathur (1991) studied the ecological interaction between habitat composition, habitat quality and abundance of some wild ungulates in Tadoba National Park. Computerized wildlife database was established for conservation, monitoring and evaluation in Tadoba-Andhari Tiger Reserve (Dubey and Mathur 1999, Dubey 1999, Dubey & Mathur 2000). A study on vegetation ecology of Tadoba National Park was carried out by Kunhikannan (1999). TATR was surveyed as a part of study carried out by Forest Survey of India (2006) to estimate the status and changes in forest cover in all the tiger reserves of country. Paliwal & Mathur (2007) carried out study in TATR on spatial analysis of landscape patterns and their relevance for large mammal conservation. TATR had also been studied as a part of the country wide study conducted by Jhala *et al.,* (2008) in all the tiger reserves to describe the status of tigers, co-predators and prey.

Chapter 3

LANDSCAPE COMPOSITION AND PATCH DYNAMICS

"The emergence of landscape ecology as a discipline has catalyzed a shift in paradigms among ecologists … resource managers and land use planners. Having now seen the faces of spatial patterns and scale… we can never go back to the old ways of viewing things."

Wiens, 1999

3.1. INTRODUCTION

The management of wildlife and protected areas is aimed at conservation and optimal use of forest resources and meeting the demands for scientific underpinnings of managing landscapes and incorporating the consequences of spatial heterogeneity. The sensitivity of ecological effects of resource management towards spatial configuration is gaining acceptance worldwide. Since landscape structure is often regarded as an important pre-requisite that governs the distribution and abundance of species, the first step is to understand the landscapes and their dynamics. It is not only important to understand how much there is of a particular component but also how it is arranged (Turner, 2001). The underlying premise is that the explicit composition and spatial form of landscape mosaic affect ecological systems in ways that it would be different, if mosaic composition or arrangement were different (Wiens, 1995). Moreover, recent studies have demonstrated that land use and landscape changes significantly affect biodiversity (Cousins & Eriksson 2002, Gachet *et al.,* 2007 and Miyamoto & Sano 2008). The above studies have been conducted using the comparative analysis of remotely sensed temporal data sets.

3.1.1. Remote Sensing for Vegetation Mapping

Satellite remote sensing plays a crucial role in generating information about forest cover, vegetation types and land use changes (Cherill & McClean, 995).

This technology has given an impetus to resource mapping and monitoring (Lilesand & Kiefer 1994 and Krishna *et al.,* 2001). Remotely sensed estimates of regional variation in biodiversity can be used in analyzing diversity patterns, monitoring changes and aiding conservation efforts (Stohlgreen *et al.,* 1997 and Gould 2000,). The land cover classification from remote sensing data is a powerful tool that can provide repetitive and spatial information concerning the landscape (Chust *et al.,* 2004). Joyce *et al.,* (1987), Justice *et al.,* (1985), Jadhav *et al.,* (1990), Innes &Koch (1998), Skole & Tucker (1993) and Franklin *et al.,* (1994), highlighted the role of remote sensing data from earth observation satellites. It is now convenient to map and monitor short and long term changes in forest cover and land use classes, which would have been far too expensive and time consuming through earlier conventional methods. Broad vegetation type stratification using coarse resolution data like NOAA-AVHRR has been reported in the study conducted by Milanova *et al.,* (1999) and mapping at finer resolution data of LANDSAT TM+ has also been reported in several studies (Daniel *et al.,* 1987, Miles *et al.,* 1996, Roy *et al.,* 1993, Groom *et al.,* 1996 and Guillem *et al.,* 2004).

Indian remote sensing satellites (IRS) are now providing opportunities to map and monitor changes and these are superior to conventional ground based methods of vegetation mapping (Roy *et al.,* 1993, Dubey and Mathur 1999, Dubey 1999, Naithani 2001, Sankar *et al.,* 2000, Uniyal 2001, Kumar *et al.,* 2002 and Joshi *et al.,* 2006). New high resolution satellites with improved spatial, spectral and temporal resolution therefore, have significantly enhanced the potential of remote sensing in forest ecology. It facilitates detailed assessment of vegetation, identification of smaller patches and is also considered helpful in evaluation of impacts on biodiversity of specific management policies (Innes & Koch, 1998).

India has added a new satellite *i.e.* IRS P6 to the series of IRS satellites, also known as Resourcesat-1. It was launched into polar orbit on 17 October, 2003 from Satish Dhawan Space Centre, Srihrikota, by the Indian PSLV C5. Data from its high resolution sensor *i.e.* Linear Imaging Self-Scanner IV (LISS IV) can be obtained at the spatial resolution of 5.8 m. It has immense potential to be used in various fields of resource management. A few studies have assessed the competence of LISS IV in different fields. Gupta and Jain (2005), carried out urban mapping, Kumar and Martha (2004) assessed damage from landslide. Sudhakar *et al*., (2004) studied its application in forestry. Rao & Narendra, (2006) mapped and evaluated urban sprawling. Kulkarni *et al.,* (2007) studied glacial retreat in Himalaya. Bahaguna (2004), Sarangi *et al.,* (2004) and Rajankar *et al*., (2004) studied application of IRS P6 in coastal and marine zones.

3.1.2. Landscape Characterization

It is widely acknowledged that patterns of landscape elements strongly influence the ecological characteristics. Therefore, spatial pattern characterization and quantification of land cover classes to relate pattern and process is a pre-requisite at landscape level (Turner, 1987). Quantification of landscape pattern is necessary for understanding the composition and configuration of landscapes. Spatial patterns (structures) have a strong influence on information content of ecosystem components. The concept of landscape unit, also called patch, has a relevant role in the study of habitat selection and habitat fragmentation. Recent landscape ecology studies have sought to define the underlying structure of landscape pattern as quantified by landscape pattern metrics. Spatial tools of remote sensing and GIS have a capacity to quantify landcover patterns and understand spatial heterogeneity (Turner, 1990). Analyses of landscape patterns are conducted on landcover/landuse map derived from satellite imageries. O'Neill *et al.,* (1988) concluded that methods are needed to quantify aspect of spatial patterns that can be correlated with ecological processes. In a study carried by Ritters *et al.,* (1995) a total of fifty five metrics of landscape patterns and structures were calculated for 85 landcover/landuse maps. Hulshoff (1995) carried out a study to evaluate the indices of landscape pattern developed in US to describe Dutch landscape. Landscape pattern metrics are the measurements designed to quantify and capture aspects of landscape pattern. A large number of spatial indices are based on patch metrics that quantify the spatial pattern at three different levels of organization: the patch, the land cover and the landscape using the programme FRAGSTATS (McGarigal & Marks, 1994). Numerous studies have advocated the authenticity of this spatial pattern analysis programme (Lu *et al.,* 2003, Cushman *et al.,* 2008, Lele *et al.,* 2008 and Jhala *et al.,* 2008). Griffith *et al.,* (2000) analysed the landscape structure of Kansas at three scales by calculating the landscape pattern metrics. Correy *et al.,* (2005) studied the utility of landscape pattern indices for judging the habitat implications of alternate landscape plans or designs.

Studies conducted previously in the study area (Dubey & Mathur 1999 and Dubey 1999) were restricted to the classification of vegetation using IRS LISS II data of 36.5m coarse resolution and did not deal with landscape structure. Since high-resolution satellites are expected to provide a new opportunity to make detailed vegetation cover maps efficiently for large study areas, this study was initiated with the aim to document and map current status of forest in the study area using IRS P6 LISS IV data of 5.8m high resolution and to describe the landscape structure of Tadoba-Andhari Tiger Reserve at three levels of organization *viz.,* landscape level, class level and patch level.

3.2. METHODS

3.2.1. Vegetation Type Mapping

The different stages are elaborated below:

3.2.1.1. *Data Used*: Three digital scenes of IRS- P6 LISS IV with 5.8m resolution were acquired from NRSA for December 2004, January 2005 and January 2006, since during this period the vegetation was in full bloom and cloud free data could be obtained (Fig 3.1).

Ancillary data: Range maps and beat maps were taken from Maharashtra Forest Dept. for planning field data collection.

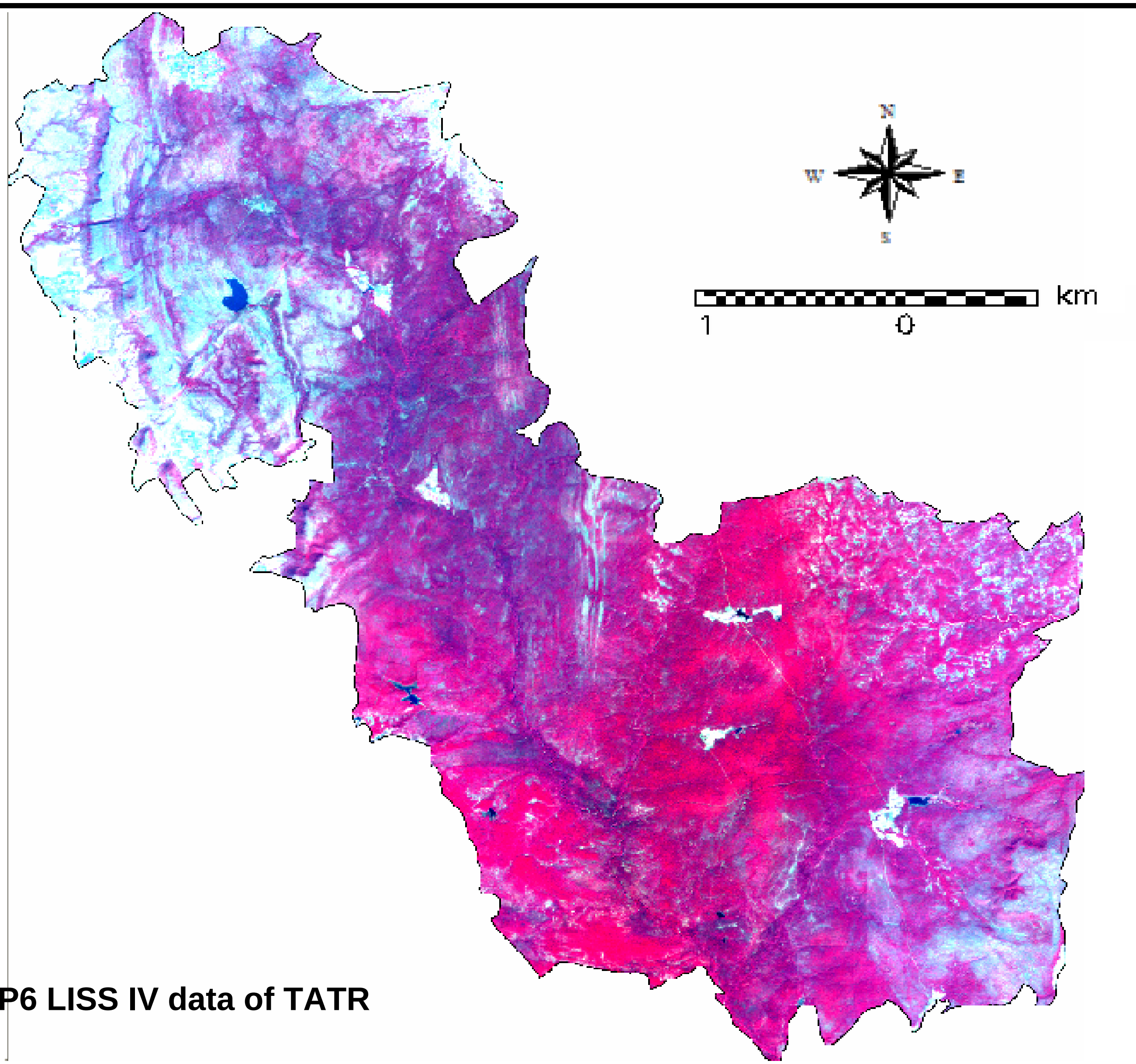


Fig. 3.1. FCC of IRS P6 LISS IV data of TATR

Table 3.1. Scenes of IRS P6 LISS IV

Path	Row	Date of pass
202	82	12-Dec-04
202	81	5-Jan-05
102	81	20-Jan-06

Softwares used: ERDAS 8.7 was used for digital image processing, georefrencing and digital classification of satellite image. Arc View 3.2 (ESRI, 1996) has been used for plotting GPS points on the image.

3.2.1.2. ***Radiometric Corrections:*** Unwanted artifacts like additive effects due to atmospheric scattering were removed through set of pre- processing or cleaning up routines. First-order radiometric corrections were applied using dark pixel substraction technique (Lilesand & Kiefer, 1994). This technique assumes that there is a high probability that at least a few pixels within an image should be black (0% reflectance). However, because of atmospheric scattering, the imaging system records a non-zero Digital Number (DN) value at the supposedly dark- shadowed pixel location. Therefore the DN value was substracted from the data to remove the first- order scattering component.

3.2.1.3. ***Geometric Corrections:*** Images were registered geometrically. Uniformally distributed Ground Control Points (GCPs) were marked with root mean square error of less than one pixel and the image was resampled by nearest neighborhood method. All the scenes were mosaiced and the study area was extracted using digital boundary.

3.2.1.4. ***Ground Truthing:*** A reconnaissance survey was conducted from February- June 2005 to have the fair idea of broad vegetation types of study area, Range maps were used to stratify the area for ground truthing. Later, the intensive ground truthing was done and a total of 810 GPS points including 520 vegetation plots were collected to capture the variation in spectral signatures of different vegetation types over the entire study area and to achieve higher accuracy of vegetation mapping. GPS points were then plotted on the image and some were left for the accuracy assessment. The data collected from the plots was subjected to cluster analysis to determine the vegetation communities existing in the field.

3.2.1.5. ***Classification****:* Remotely sensed data is classified on the basis of spectral reflectance of different pixels *i.e.* different pixel types manifests different combinations of DNs based on their inherent spectral reflectance and emittance properties (Lilesand & Kiefer, 1994). Unsupervised classification was done on image, using the nearest neighbour algorithm for differentiating spectral reflectance of various objects (Lilesand & Kiefer, 1994). It examines the similar pixels in an image and aggregates them into a number of classes. Initially, the entire area was classified into forty classes which were iterated 10 times with convergence threshold of 0.98.

Classification Scheme: According to Champion and Seth (2005), the area is classified under group 5 and subgroup 5A as Southern Tropical Dry Deciduous Forest. Considering the previous studies in TATR (Mathur 1991 and Mathur & Dubey, 1999) area was divided into 40 classes initially. Later, these forty classes were classified under the broad classes of forest, waterbody, scrub, open forest and agriculture/settlement. The non-forest classes were masked and then the forest classes were classified into 6 vegetation classes. Finally, forty classes were merged into 10 classes including six vegetation classes which were well observed on the ground.

3.2.1.6. ***Smoothening:*** The pixellated classified output image was obtained. The map was subjected to two 3x3 filters and the patches below 0.5ha were removed so as to avoid errors of misclassification and accurate indices for landscape structures could be determined. Finally, the area was calculated for each class.

3.2.1.7. ***Accuracy Assessment:*** The accuracy of the map was done using some of the ground truth points which were not used during classification. The land cover information of these locations was compared to classified maps. Accuracy was tested using Kappa Statistics (K_{hat} coefficient) (Lillesand & Kiefer, 1994).

The methodology in the form of flowchart is given below in Fig 3.2.

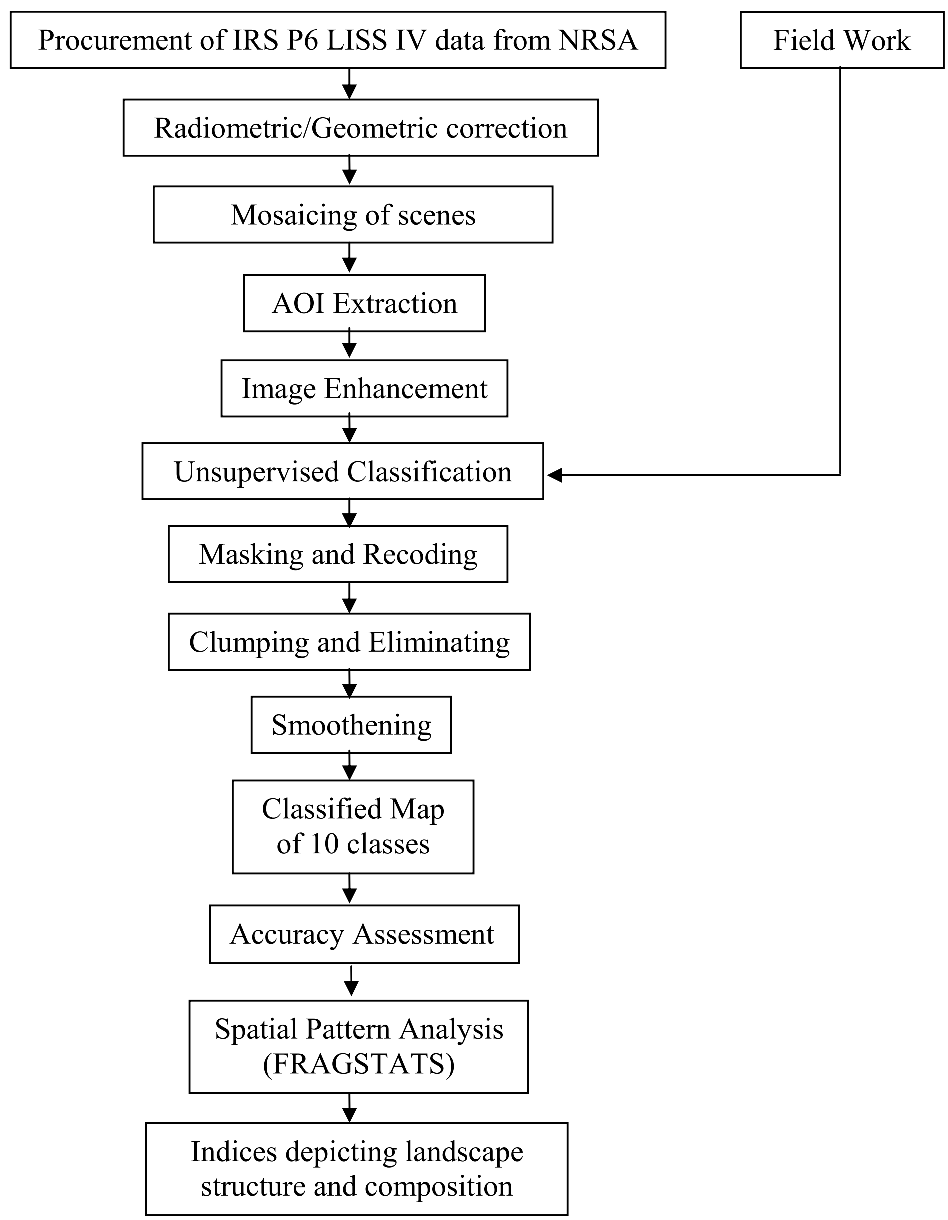


Figure 3.2. Flow chart of methodology used in the study

3.2.2. Canopy Density Mapping

As a part of field work canopy density for each vegetation plot was recorded. An unsupervised classification using nearest neighbour algorithm was performed. Initially the area was classified into fifteen classes which were later reduced to five canopy density classes by integrating the field knowledge/data and spectral characteristics of classes.

3.2.3. Landscape Characterization

For the quantification of the landscape of TATR, use of statistical measures or indices were made that describe landscape configuration and composition. These indices were calculated by FRAGSTATS (Mcgarigal and Marks, 1994). The FRAGSTATS is a spatial pattern analysis programme for categorical maps. It simply quantifies the areal extent and spatial configuration of patches within landscape. There are two versions of FRAGSTATS, Vector (ARC/INFO) & Raster (Image Maps) versions. The raster version has been used in this study to compute metrics. The landscape structure was analyzed at three different scales *viz.,* landscape, class and patch level using 12 set of indices as shown in Table 3.2. Numerous studies have supported the authenticity of these indices (Griffith *et al.,* 2000 and Cushman & Neel 2008).

Table 3.2. Metrics used for the landscape characterization of TATR

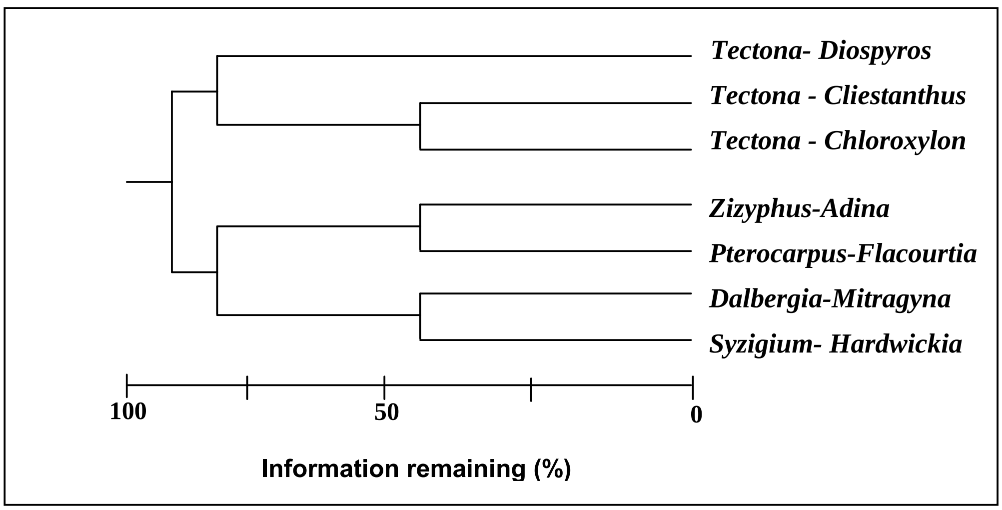
Level	Metrics	Description	Unit
L1 Landscape	No. of Patches (NP)	No. of patches in a landscape	None
L2 Landscape	Patch Density (PD)	No. of patches in a landscape divided by total landscape area.	No./100ha
L3 Landscape	Largest Patch Index (LPI)	Area of the largest patch in the landscape divided by total landscape area	%
L4 Landscape	Interspersion and Juxtaposition (IJI)	Adjacency among patches of different class	%
L5 Landscape	Simpson Diversity Index (SIDI)	Diversity of patches in the landscape	None
L6 Landscape	Simpson Evenness Index (SIEI)	Even distribution of area among patch types	None
C1 Class	Percentage of Landscape (PLAND)	Percentage of landscape comprised of corresponding class.	%
C2 Class	No. of Patches (NP)	No. of patches of corresponding class.	None
C3 Class	Patch Density (PD)	No. of patches of corresponding class.	No./100ha
C4 Class	Mean Patch size (MPS)	Average patch size of the corresponding class	ha
C4 Class	Interspersion and Juxtaposition (IJI)	Adjacency among patches of corresponding class	%
P1 Patch	Patch area (Area)	AREA equals the area (m^2) of the patch divided by 10,000 (to convert to ha)	ha

3.3. RESULTS

3.3.1. Vegetation Type Mapping

Seven communities were identified from cluster analysis *viz., Tectona, Tectona-Cliestanthus, Tectona-Chloroxylon, Zizyphus-Adina, Pterocarpus-Flacourtia, Dalbergia-Mitrigyna* and Riparian community. Mapping was done using the cluster analysis as a premise (Fig. 3.3). As a result 10 landcover/landuse classes were delineated *i.e.* Teak Forest, Teak Mixed Bamboo Forest, Mixed Forest, Mixed Bamboo Forest, Riparian Forest, Grassland, Scrub, Open Forest, Agriculture/Settlements and Water Body as shown in Fig. 3.4. These classes are described as follows:

Figure 3.3. Dendrogram showing the different communities using hierarchical cluster analysis



1. **Teak Forest:** Teak was the most dominant tree species in the study area. This class comprised pure teak patches *i.e.* 70% of teak along with its associates like *Lagerstroemia parviflora, Chloroxylon swietinia* and *Wrightia tinctoria* forms the middle storey. This class covered a small proportion of the study area and was found around the Tadoba Lake and some hill tops in Tadoba National Park.

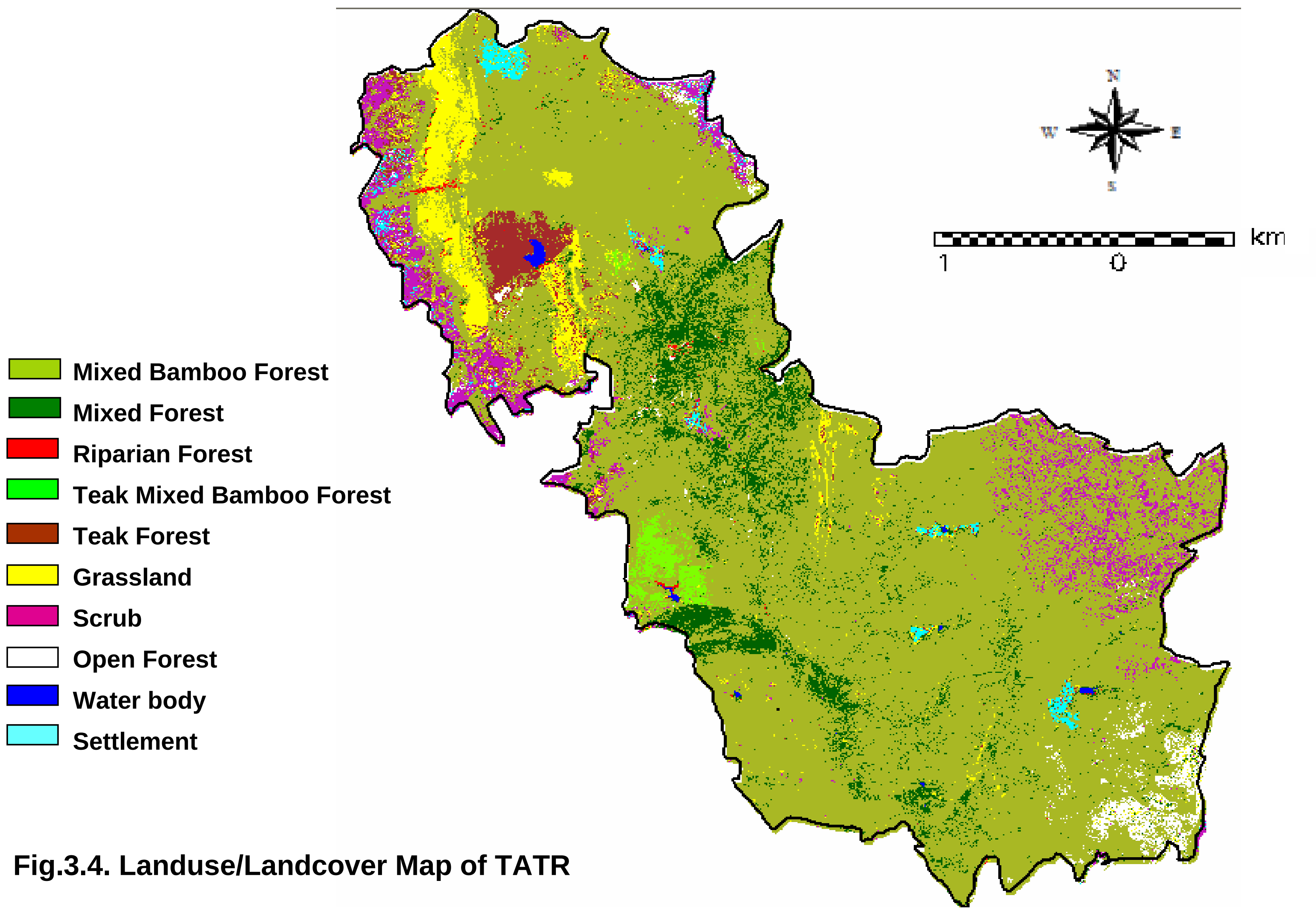


Fig.3.4. Landuse/Landcover Map of TATR

2. **Teak Mixed Bamboo:** This vegetation type comprises of Teak as a dominant tree species which formed the top storey of the forest and bamboo as the middle storey. Though this class did not occupy much extent of the study area but wherever it occurred it was found intact in nature. It was found in moist central zone of Tadoba-Andhari Tiger Reserve where old Teak plantations were present.

3. **Mixed Forest:** This association was composed of mixed tree species like *Anogeissus latifolia, Terminalia tomentosa, Gardenia latifolia, Adina cordifolia, Mitrigyna parviflora and Madhuca indica.* Middle storey was occupied by *Calycoptreis floribunda* and *Helictris isora.* This class was found in low lying and flatter areas.

4. **Mixed Bamboo Forest:** It was the most dominant class of the study area and was composed of mixed tree species and dense bamboo. Bamboo was interspersed among the tree species in higher proportions. This class was found in almost entire study area, predominantly on gentle slopes and flat areas.

5. **Riparian Forest:** This class of forest included species like *Syzygium cumini, Mangifera indica, Terminalia arjuna* as dominant species. This vegetation type was found in water rich areas specifically along rivulets, streams and in low lying valleys.

6. **Grassland:** Grassland did not occupy much portion of the study area. *Aristida* spp., *Themeda triandra, Eragrostis tenella, Heteropogon contortus* were the dominant species. The grasslands have come up on the sites of abandoned villages. This class was found in flatter areas and on the tops of undulating hills and plateau.

7. **Scrub:** This class included the degraded vegetation, mainly present near human settlement areas and was composed of *Zizyphus* spp. and *Butea monosperma.*

8. **Open Forest:** This type included *Diospyros melanoxylon* and *Chloroxylon swietinia* primarily. The crown cover was less than 25% and can be found on slopes and on the areas close to human habitations.

9. **Agriculture/Settlements:** This class included both agriculture as well as human settlements in the Tadoba-Andhari Tiger Reserve.

10. **Water Body:** All the water bodies of the study area were included in this class.

3.3.2. Area of Each Class

Mixed Bamboo Forest occupied the maximum proportion of study area *i.e.* 75.81% while the Riparian forest occupied the least, represented by 0.61%. Table 3.3 shows the areas of different classes mapped.

Table 3.3. Area of landcover classes delineated from satellite data

S.No.	Class	Area(in ha)	% Area
1.	Teak Forest	1385.4	2.22
2.	Teak Mixed Bamboo Forest	789.5	1.26
3.	Mixed Forest	3996.2	6.39
4.	Mixed Bamboo Forest	47402.4	75.81
5.	Riparian Forest	380.3	0.61
6.	Grassland	2717.4	4.35
7.	Open Forest	1585.9	2.54
8.	Scrub	3174.7	5.08
9.	Agriculture/Settlement	755.4	1.21
10.	Water Body	337.7	0.54
	Total	62525.4	100

3.3.3. Canopy Density Mapping

As a result of canopy density mapping the forest was sub grouped into five canopy density classes *viz.,* (a) above 60%; (b) 40-60%; (c) 30-40%; (d) below 30%; (e) Non Forest. (Fig.3.5).

(a) Canopy above 60%: Dense canopy is a peculiar feature of Teak Forest and Riparian Forest, which are not widely distributed in forest of TATR. Therefore, canopy above 60% is not common of canopy density attribute in TATR landscape. It is found in the northwestern and south western parts of the sanctuary.

(b) Canopy between 40-60%: Density between 40-60% was prominent feature of Riparian forest and Mixed Forests. It was found in national park and northern part of wildlife sanctuary.

(c) Canopy between 30-40%: This canopy class was seen in the forest of Mixed Bamboo, where the canopy openings were there because of bamboo in the understorey. It is widely distributed in the sanctuary.

(d) Canopy below 30%: This type of canopy class was mostly found in the degraded forests and forests with abundant bamboo growth. This is distributed in the north eastern part of national park and south western part of sanctuary.

(e) Non Forest: It is found in the grassland patches, open spaces inside the forest habitations present inside the sanctuary and the plateaus of the hills where there was sparse vegetation.

Overall accuracy of 85% and 91% have been achieved for landuse/landcover map and canopy density map respectively.

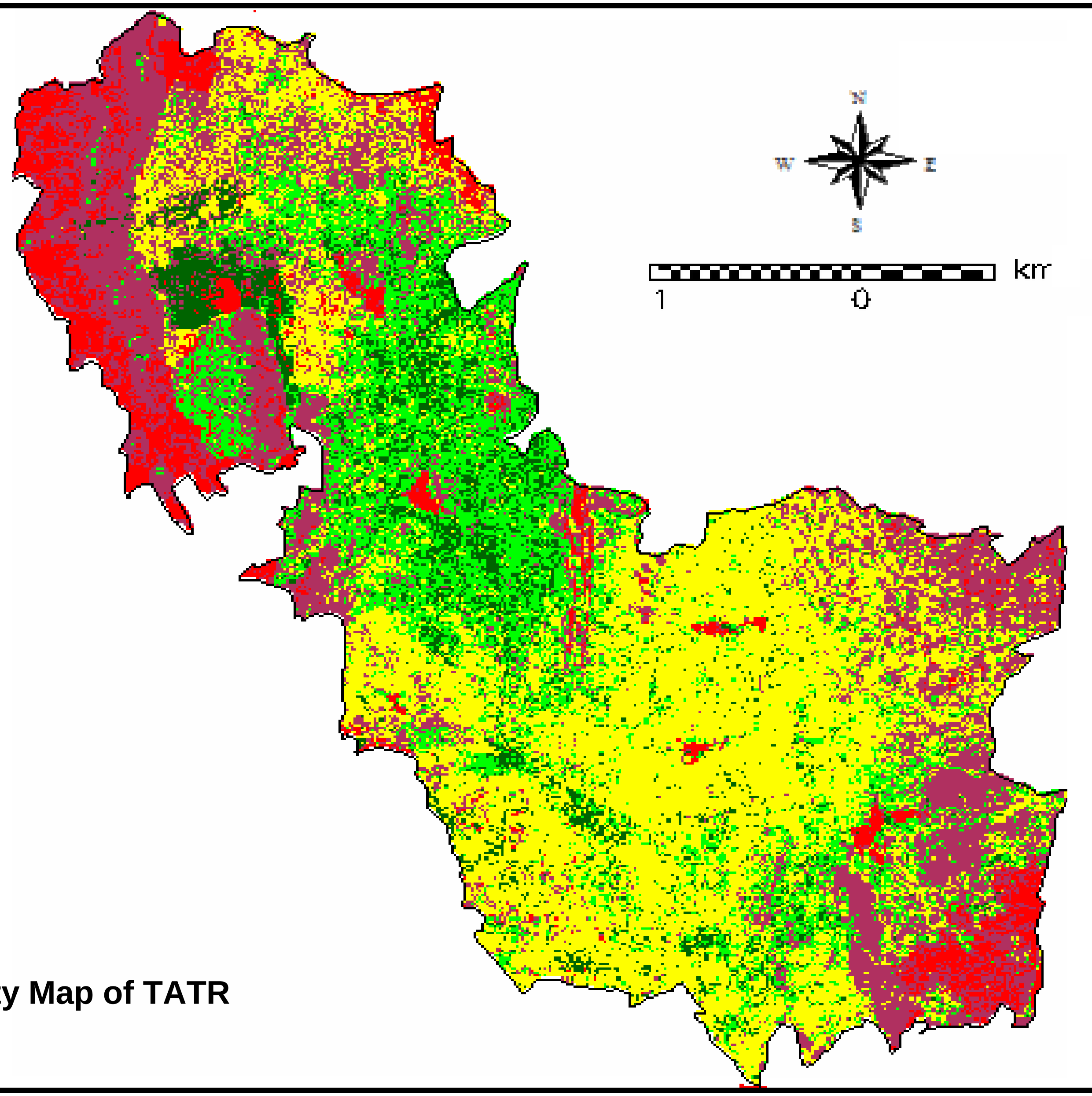


Fig.3.5. Canopy Density Map of TATR

3.3.4. Landscape Characterization

Landscapes of the study area had been defined at three levels of hierarchy starting from broader levels to narrower levels *i.e.* landscape level, class level and patch level. An attempt has been to study landscapes in terms of its vegetation types.

3.3.4.1. ***At Landscape Level***: Tadoba-Andhari Tiger Reserve's landscape was found to be heterogeneous in nature with fine patch richness. As shown in Table 3.4, a total of 2307 patches of different types with varying patch sizes (mean patch size= 25.67) could be recognized in the landscape with patch density of 1.7 patch per km. The landscape was evenly interspersed by different forest types as indicated by the interspersion value of 50. The landscape was not very diverse and uniform in its nature as shown by low values of Simpson Diversity index 0.38 and Simpson Evenness index 0.42.

Table 3.3. Landscape metrics for TATR landscape

Landscape Metrics	Values
No. of Patches (NP)	2307
Patch Density (PD)	1.7/km^2
Largest Patch Index (LPI)	32.53%
Interspersion and Juxtaposition (IJI)	50
Simpson Diversity Index (SIDI)	0.38
Simpson Evenness Index (SIEI)	0.42

3.3.4.2. ***At Class Level***: Proceeding towards the finer levels of the landscape structure *i.e.* class level, it was found the landscape was composed of six vegetation types *viz.,* Mixed Bamboo Forest, Mixed Forest, Teak Forest, Teak Mixed Bamboo Forest, Riparian Forest and Grassland have described. The result of all the metrics computed at the class level is given in Table 3.5.

Table 3.5. Class level metrics for landscape of TATR

Vegetation Types	PLAND (%)	NP	PD (No./100ha)	MPS (ha)	LPI (%)	IJI (%)
Mixed Bamboo Forest (MBF)	77.9	340	0.25	136.1	32.5	68.2
Mixed Forest (MF)	6	671	0.49	5.3	0.6	5.8
Teak forest (TF)	2	182	0.13	6.6	0.6	61.6
Teak Mixed Bamboo Forest (TMB)	1	42	0.03	13.7	0.2	14
Riparian Forest (RF)	0.3	35	0.03	2.3	0.02	62.8
Grassland (GL)	4.1	225	0.16	7.2	0.6	42.8

Area /Density Metrics: Amongst all vegetation types, maximum percentage of land was covered by Mixed Bamboo Forest (77.99%) with highest mean patch size (136.09 ha) and largest patch index (32.53%) as shown in Fig.3.6 and 3.7. Mixed Forest has highest number of patches (671) therefore has the highest patch density (0.49) (Fig. 3.8 and 3.9). However, Riparian forest acquired least landscape area (0.32) with lowest number of patches (35) and lowest mean patch size (2.25). The average patch size varies from 2.25 ha to 136 ha. Except Mixed Bamboo Forest all forest types have mean patch size below 15 ha.

Interspersion Metrics: The value of interspersion / juxtaposition metric was found to be highest in Mixed Bamboo Forest (68.23%) followed by Riparian forest (62.79) and Teak Forest (61.63%). The least interspersion was found in Mixed Forest (5.78%) (Fig.3.10)

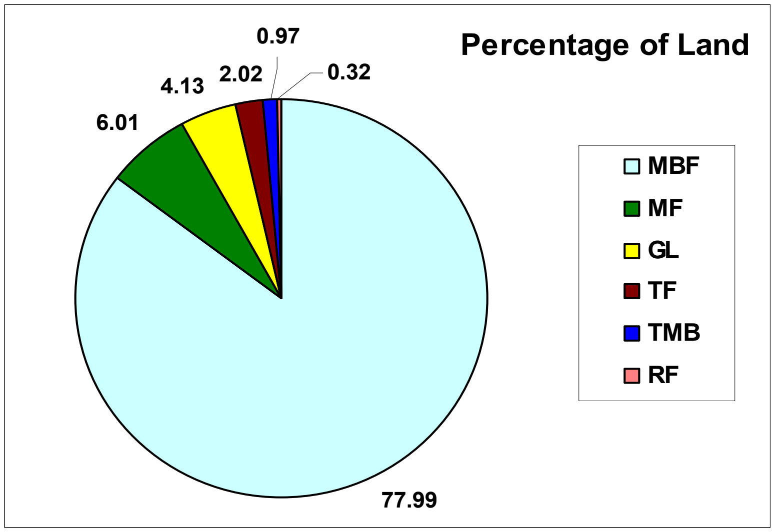


Figure 3.6. Percentage of land occupied by each vegetation type

(MBF: Mixed Bamboo Forest, MF: Mixed Forest, GL: Grassland, TF: Teak Forest, TMB: Teak Mixed Bamboo Forest, RF: Riparian Forest)

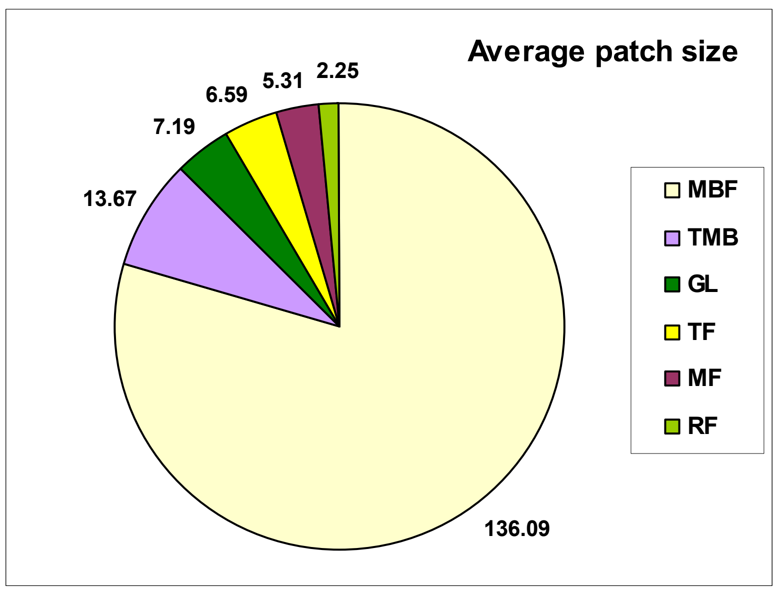


Figure 3.7. Average patch size for each vegetation type

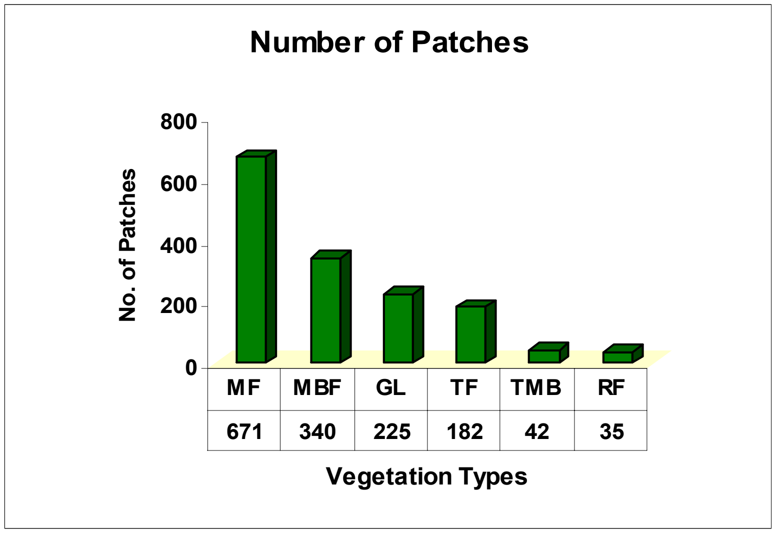


Figure 3.8. Number of patches in each vegetation type

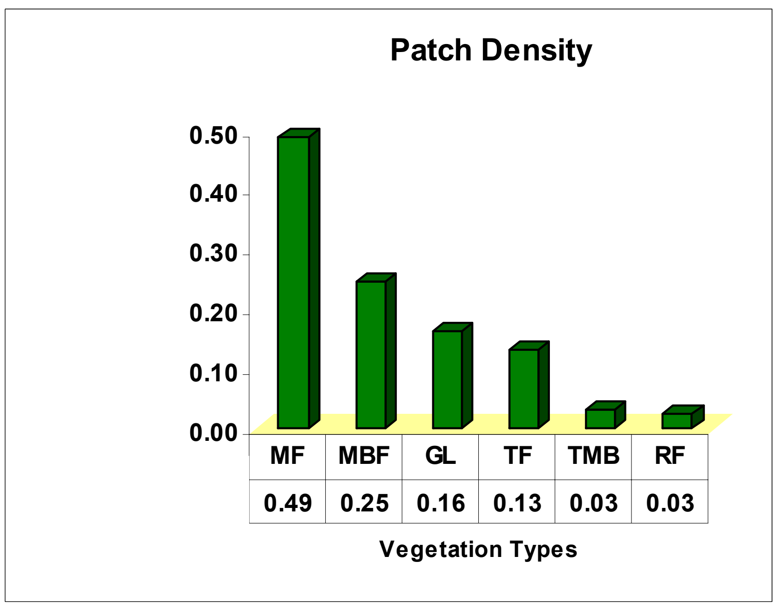


Figure 3.9. Patch density for each vegetation type

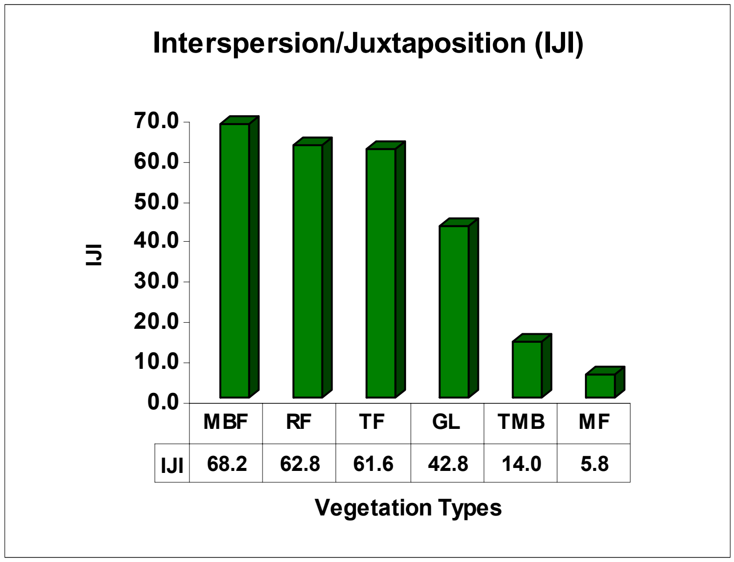


Figure 3.10. Interspersion/Juxtaposition (IJI) for each vegetation type

3.3.4.3. *At Patch level*: The area of each patch comprising a landscape mosaic is most useful piece of information contained in a landscape. The analyses revealed that among all the vegetation classes, Mixed Forest has maximum number patches among all vegetation classes. The small patches ranging from 0.5 to 5 ha were high in number (599). However, a very few large patches (above 100ha) were present in this vegetation type as shown in Fig. 3.11. On the other hand, Riparian forest had fewest patches (35) among all vegetation classes in the landscape TATR, with 18 patches of size ranging from 0.5-5 ha and only one big patch of 22 ha (Fig 3.12).

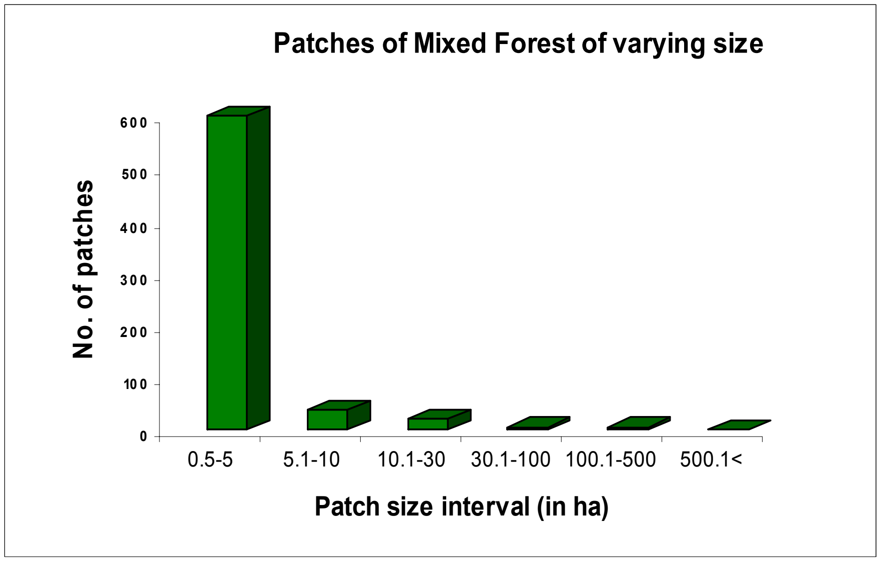


Figure 3.11. Number of patches with varying size in Mixed Forest type

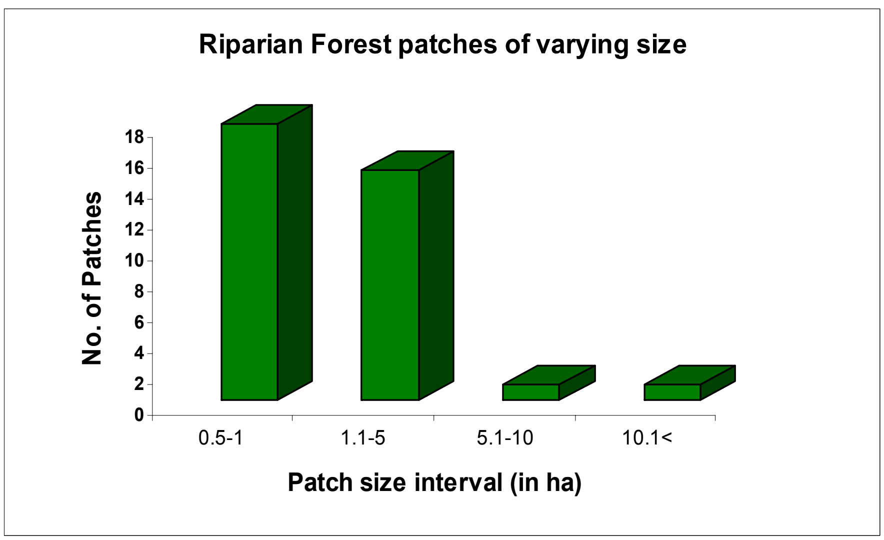


Figure 3.12. Number of patches with varying size in Riparian Forest type

3.4. Discussion

Vegetation Mapping

Landscape elements type coupled with satellite imagery can be effectively used to monitor biodiversity (Nagendra & Gadgil, 1999). It was observed that at high spatial resolution, many factors affect the recorded reflectance of the plant communities (species, crown closure, crown geometry, stand density, soil moisture and sun angle). This made it possible to map the communities using cluster analysis to a finer level, inspite of heterogeneous landscape. However, despite using high resolution satellite data, problems were encountered while mapping the canopy density, since presence of bamboo in the understorey created a spectral overlap with spectral signatures of crown cover. Special consideration was given to the compatibility of ground data collected and the spectral qualities measured by satellite. As a result different land cover classes and canopy density were adequately mapped.

Among the land cover classes, Mixed Bamboo Forest was the most dominant class in TATR because of extensively flourishing bamboo growth. As TATR comes under Vidarbha, which is the hottest region of Maharashtra, water is one of the limiting factor. Therefore, least area is acquired by Riparian Forest. Teak being a dominant tree species in the study area, very less area was occupied by pure Teak patches. It is present only in the northern part of Tadoba National Park. Teak was present along with its associates and bamboo in other forest types. The old plantations of teak have now been converted into Teak Mixed Bamboo Forest, this could be due to extensive flowering of bamboo in TATR in the mid 1980s. The scrub and open forest were mostly found in the southern part of the Andhari Wildlife Sanctuary, this could be attributed to the villages present in the periphery of the southern zone, which exert an anthropogenic pressure which leads to the degradation of the surrounding forests. All six vegetation types delineated by satellite data were present in the Tadoba National Park in more or less uniform fashion than in Andhari Wildlife Sanctuary. Presence of natural water sources and high protection status are major reasons contributing to the presence of all vegetation classes in Tadoba National Park.

Landscape Characterization

The structural analysis of landscape helps in problem identification and its severity, which is useful in planning ecosystem management (Formon & Godron, 1986). The analysis support the observation that a small set of indices can capture significant aspects of landscape pattern. These measures are more sensitive than simple comparisons of class proportions. The structural analysis of TATR landscape reveals its heterogeneous nature with large variations in patch size, but with low diversity, low evenness and intermediate interspersion of forest types. Mixed Bamboo Forest covers the maximum area of TATR, acquiring maximum percentage of TATR landscape (77.99%), indicating its dominance in terms of vegetation classes. Mixed Forest was found to be most patchy as it has highest number of patches (671) with highest patch density (0.49%) followed by Mixed Bamboo Forest and Grassland (Fig. 3.5). However, results have shown an interesting pattern that inspite of being dominant in the area, Mixed Bamboo Forest has low patch density (0.25/100ha) almost half of the Mixed Forest (0.49%). This is because even though Mixed Bamboo Forest has few patches (340) but it has highest mean patch size (136 ha) in comparison to Mixed Forest (671) which has second lowest mean patch size (5.31 ha) in TATR landscape. This indicates that dominance of Mixed Bamboo forest is attributed to large size patches, inspite being less in number.

The Mixed Bamboo Forest followed by Riparian Forest had the highest adjacencies among all the vegetation types, indicating that these two forest type share their edges with rest of the forest types. Nevertheless, Teak Mixed Bamboo Forest and Mixed Forest had least interspersion among all forest types. This was due to the clumped distribution of Mixed Forest in the landscape.

This study has focussed on the approach of integrating satellite forest classification and forest inventory data for studying forest landscape patterns. IRS P6 LISS IV data has proved to have an immense potential to minutely capture the structural details of the landscape precisely due to its high resolution and multispectral nature. This attribute has been further used for analyzing the patch dynamics in the landscape. Results presented here support focusing on few metrics that represent overall landscape structure for landscape characterization and monitoring. At present, park managers should consider indices as tools for comparing different landscapes patterns. The trends depicted by the application of landscape metrics may be assimilated into prognostic models and scenarios to support strategic decision making for regional conservation and policy development.

4.1. INTRODUCTION

Measuring and monitoring biodiversity is the first step towards effective conservation and sustainable development of natural resources. Knowledge of floristic composition and vegetation structure is critical for understanding the dynamics of forest ecosystems and empirical data is needed for planning and sound management.

Tropical forests cover approximately 11% of the earth's land surface (Dixon *et al.,* 1994), but provide significantly large share of ecosystem services. These forests provide habitat for a diverse assemblage of species and thereby support a considerably large proportion of terrestrial biodiversity. Myriad studies on tree community structure and composition have been conducted throughout the tropics to document and understand patterns of tree species diversity found in earth's tropical forests (Condit 1995, Pitman *et al.,* 2001). Fashing & Gathua (2004) compared the distribution and density of tree species in two sites of East African tropical forests. The effect of structure and species composition of tropical forests of Tanzania on species diversity was studied by Huang *et al.,* 2003. Chandrashekra & Ramakrishnan (1996) studied the dynamics of tropical wet evergreen forest in Western Ghats of Kerala. Studies have concluded that tropical forest tree community structure and composition varies widely between forests of same continent (Ter Steege *et al.,* 2000) and even between different sites within the same forest (Proctor *et al.,* 1983).

Dry tropical forests account for 46% of the total forest cover in India (Singh & Singh, 1988). Dry forests are generally characterized by flora of lower species richness than rain forest, (Gentry 1995, Timilsina *et al.,* 2007). Much of the floristic studies have been devoted to moist and wet tropical forests, whilst dry tropical forests inspite of being considered one of the endangered ecosystems

(Janzen, 1988) have received a little attention. Local species extinction rates appear to be very high in case of tropical species (Farnworth & Golley 1974). Palomino & Alvarez (2005) studied the patterns of tree community in dry tropical forests in Peru. Generally, there is a dearth of literature pertaining to structure, floristic composition and diversity of dry tropical forests in India. Sukumar *et al.,* (1992) have initiated vegetation monitoring in a tropical dry deciduous forest. Reddy *et al.,* (2008) determined structure and floristics composition tree diversity within three hectare plots in tropical dry deciduous forests of Eastern Ghats of southern Andhra Pradesh.

Tadoba Andhari Tiger Reserve represents typical tropical dry deciduous ecosystem in Central India. Earlier attempts at floristic studies and qualitative description of vegetation in Tadoba National Park of this reserve include Haines (1916) and Malhotra & Moorthy (1992). Mathur (1991) studied the ecological interactions between habitat parameters and wild ungulate abundance, in which vegetation types of Tadoba National Park were regarded as most important habitat factors. A study on vegetation ecology of Tadoba National Park was carried out by Kunhikannan (1999). Dubey (1999) studied structure of vegetation communities in TATR. However, in none of the earlier studies have conducted landscape level analysis of vegetation, based on empirical data along with geospatial analysis of major communities.

This chapter deals with floristic structure, composition and diversity of five spatially explicit vegetation types as discerned through satellite remote sensing data (see chapter 3). The study also assessed population structure and regeneration status of prominent tree species.

4.2. METHODS

4.2.1. Stratification and Sampling Units

After a preliminary reconnaissance survey of TATR in February 2005, intensive vegetation sampling was carried out from March 2005 to January 2007. The area was sampled using systematic stratified sampling approach. Stratification was done using administrative unit *i.e.* a forest beat. A total of 50 transects were laid in all 34 beats of TATR covering all vegetation types of the study area. On these transects 500 circular plots were laid, equidistant at 200 m interval, while 20 plots were also laid randomly (Fig. 4.1).

4.2.2. Data Collection Protocols

Data on species composition and structure were collected using circular plots method following Muller-Dombois & Ellenberg (1974). Circular plots are expeditious in allowing accurate area sampling with relatively less effort for plot layout (a single central marker for permanent location) and they reduce the number of edge decisions because they minimize perimeter to area ratio (Mc Cune & Grace, 2002). The following details were collected from the plots:

4.2.2.1. Tree Species: At each sampling point, a circular plot of 10 m radius was laid for enumeration of trees. The individuals with > 30cm girth at breast height (gbh) and height > 1.37 m with distinct bole were considered as trees (Muller-Dombois & Ellenberg 1974). In each plot parameters like species names, number of trees, gbh and % canopy cover were recorded. Tree saplings (gbh > 10.5cm and < 30 cm; height >30cm and 1.37m) (Singh *et al.,* 1995) in 5m radius nested plot were also recorded.

4.2.2.2. Shrub Species: Names and number of shrubs were enumerated from nested circular plot of 5m radius.

4.2.2.3. Herb Species: Nested 1m×1m quadrat was laid for estimation of ground vegetation. Name of species and percentage of herb cover, grass cover, litter cover, weed cover were recorded from each quadrat.

Bamboo was enumerated in the 5m radius nested plot. The number of culms in each clump was recorded. The plants (trees, herbs, shrubs, grasses) in the field were recorded and identified to the species level utilizing the knowledge of field staff, which formed the basis for the initial identification, using the checklist from forest inventories by Forest Department (Khawarey & Karnat

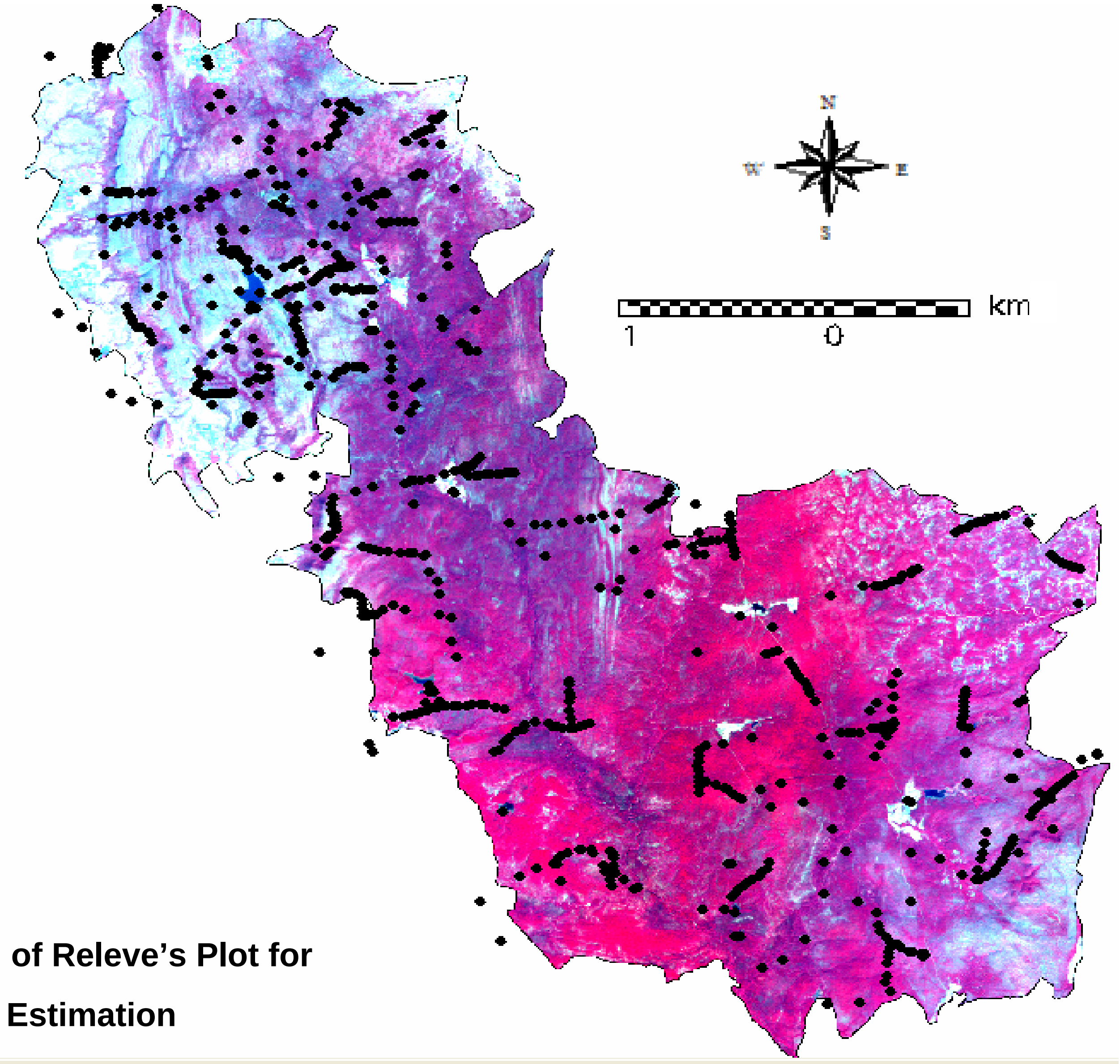


Fig.4.1. Distribution of Releve's Plot for Vegetation Estimation

1997) and flora of Tadoba National Park (Malhotra & Moorthy 1992). The ambiguous specimens were collected and brought to Herbarium of Wildlife Institute of India for further verification.

4.3. ANALYSIS

The phytosociological analysis was done for the following:

4.3.1. Community Classification

Tree data collected from all the plots laid in entire study area was subjected to cluster analysis using Wards linkage method (Ward, 1963) and Euclidean distance matrix (McCune & Grace 2002). This analysis was done using SPSS (Statistical Package for Social Sciences-Version 8.0).

Data from the plots, laid in different vegetation types were segregated and were analyzed separately to understand the structure and composition of each vegetation type, as delineated from remote sensing data.

4.3.2. Distribution of Tree Species

The data collected on tree species were analyzed for density, frequency and dominance following Misra (1968). Density is an indicator of abundance of the species and it helps to identify the dominant and rare species (Ravindranth & Premnath 1997). Frequency, if considered with abundance, gives an idea of the distribution pattern of the species dominance which reflects standing biomass of the species. The relative values of frequency, dominance and density (Philips, 1959) were used for determining Importance Value Index (IVI) (Curtis & McIntosh 1950 and Brown & Curtis 1952). The values for above were computed using following formulae:

$$\text{Density} = \frac{\text{No. of individuals of a species in all sampled plots}}{\text{Total no. of studied sample plots}}$$

$$\text{Frequency} = \frac{\text{No. of plots in which the species has occurred}}{\text{Total no. of studied sample plots}}$$

$$\text{Dominance} = \frac{\text{Total Basal Area of one species}}{\text{Total area of all studied sample plots}}$$

4.3.3. Diversity, Richness and Evenness

Species diversity is a product of two components: species richness and evenness (Simpson, 1949). Species diversity was estimated using Shannon-Wiener Index (Pielou 1975 and Magurran 2004). It is most commonly used index in community ecology. It is a measure of average degree of uncertainty in predicting as to what species an individual chosen at random from a collection of S species and N individuals will belong. This average uncertainty increases as the number of species increases and as the distribution of individuals among the species becomes even (Magurran, 2004). The Shannon's Index can be computed as below.

$$\mathbf{H' = S\ pi.\ log.\ pi}$$

where,

H´= Shannon-Wiener Diversity Index

S = Number of species in the community

pi = Proportion of ith species in the community.

Species Richness is simply the number of species in the unit of study. It was calculated using Menhinick's Index (Whittaker 1972 and Magurran 2004)

$$\mathbf{DMn = S/\sqrt{N}}$$

where,

DMn = Species Richness

S = Number of species in the community

N = Number of individuals of all species in the community

Evenness describes the variability in the species abundance. A community in which all species have approximately equal number of individuals would be rated as extremely even. Conversely, a large disparity in the relative abundances of the species would result in the descriptor “uneven” (Magurran 2004). It was calculated using Shannon Evenness Index.

$$J = H'/\log S$$

where,

J = Evenness Index

H´ = Shannon-Wiener Diversity Index

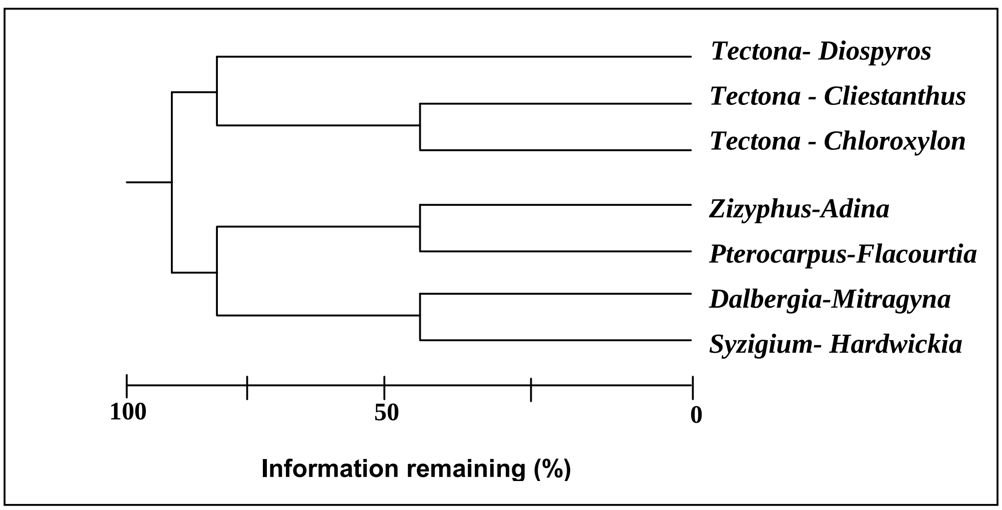
S = Total number of species in a community

4.4. RESULTS

4.4.1. Community Classification Based on Dominant Tree Species

A total of seven communities were identified as a result of cluster analysis *i.e. Tectona grandis-Diospyros melanoxylon* community, *Zizyphus xylopara-Adina cordifolia* community, *Tectona grandis-Chloroxylon swietenia* community, *Tectona grandis-Cliestanthus collinus* community, *Dalbergia paniculata-Mitragyna parviflora* community, *Pterocarpus marsupium-Flacourtia ramontchi* community and *Syzygium cumini-Mangifera indica* community (Fig. 4.2).

Figure 4.2. Dendrogram showing the different communities using hierarchical cluster analysis



All the seven communities were observed on the ground and were found in five vegetation types delineated from the satellite data in the TATR. In this study an attempt was made to correlate the satellite data with the empirical data collected from the field. These communities were identified as a part of different vegetation types discerned from satellite data. An effort has been made to understand the structure, composition and diversity of five vegetation types *viz.,* Mixed Bamboo Forest, Mixed Forest, Teak Mixed Bamboo Forest, Teak Forest, Riparian Forest (Plate 4.1-4.4)

4.4.2. Species Composition and Diversity Across Forest Types

i) Mixed Bamboo Forest: This is the dominant forest type of the study area (Plate 4.1). A total of 2260 individuals of 46 species belonging to 30 families were recorded in this forest type. Fabaceae and Combretaceae were most diverse and dominant families with 40% of species belonging to them. The prominent trees were *Madhuca indica, Tectona grandis, Chloroxylon swietenia, Cleistanthus collinus* and *Diospyros melanoxylon,* while *Dendrocalamus strictus* was the major understorey. *Madhuca indica* had the highest IVI value (40.94) followed by its associates *Tectona grandis* (27.03) and *Chloroxylon swietenia* (26.14) (Table 4.1). The total tree density of this vegetation type was 231.6/ha. The mean tree density was 4.3 ± 6.9 per hectare. The total basal area of trees in this vegetation type was 2187.3/ha. The sapling density was 1.84±1.6.

Table 4.1. Density, Frequency, IVI, A/F ratio and Basal Area of different tree species in Mixed Bamboo Forest (MBF)

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m^2/ha)
Madhuca indica	18.74	0.01	43.94	77.75	0.0163
Tectona grandis	27.03	0.05	27.03	61.88	0.0037
Chloroxylon swietenia	23.35	0.27	26.14	9.81	0.0056
Cleistanthus collinus	26.01	0	21.65	311	0.0022
Diospyros melanoxylon	18.74	0.37	20.87	6.21	0.0029
Terminalia tomentosa	14.23	0.27	18.27	5.98	0.0032
Lagerstroemia parviflora	15.97	0.01	17.32	155.5	0.0019
Anogeissus latifolia	12.8	0.02	14.87	51.83	0.0021

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m^2/ha)
Lannea grandis	8.5	0.01	11.45	77.75	0.0017
Pterocarpus marsupium	7.88	0.16	11.29	9.58	0.0023
Zizyphus xylopyra	6.25	0.05	6.42	38.88	0.0004
Bombax ceiba	4.51	0.3	5.84	5.73	0.0009
Albizzia odoratissima	3.69	0.05	4.32	28.56	0.0004
Xylia xylocarpa	3.99	0.01	3.6	233.25	0.0005
Emblica officinalis	2.46	0.07	3.3	16.93	0.0003
Gardenia latifolia	3.28	0.27	3.3	11.2	0.0004
Dalbergia sissoo	2.66	0.01	3.3	77.75	0.0003
Acacia catechu	3.17	0.01	3.08	77.75	0.0002
Terminalia bellirica	1.64	0.05	3.07	22.12	0.0007
Dalbergia paniculata	1.54	0.23	2.81	7.29	0.0007
Flacourtia ramontchi	1.64	0.03	2.37	31.1	0.0032
Buchanania lanzan	1.84	0	2.16	311	0.0002
Butea monosperma	1.64	0.2	1.86	6.72	0.0001
Mitragyna parviflora	1.02	0	1.69	311	0.0003
Aegle marmelos	1.13	0.03	1.64	34.21	0.0002
Schleichera oleosa	0.51	0.01	1.41	116.63	0.0005
Semecarpus anacardium	1.13	0.03	1.32	42.23	0.0001
Soymida febrifuga	0.92	0.02	1.14	62.2	0.0001
Bridelia retusa	0.92	0.02	1.11	77.75	0.0001
Saccopetalum tomentosum	0.92	0.04	1.09	34.56	0.0001
Terminalia arjuna	0.31	0.01	1.08	233.25	0.0005
Schrebera swietenioides	0.41	0.35	0.79	4.79	0.0002
Grewia abutilifolia	0.61	0.05	0.78	33.36	0
Stereospermum suaveolens	0.51	0.01	0.78	155.5	0.0001
Careya arborea	0.61	0	0.77	622	0.0001
Ixora parviflora	0.41	0.02	0.67	62.2	0.0032
Gardenia turgida	0.51	0.02	0.66	62.2	0
Dalbergia latifolia	0.41	0.1	0.61	14.24	0.0001
Acacia leucophloea	0.41	0.13	0.57	12.47	0.0001
Gmelina arborea	0.31	0.07	0.49	18.34	0.0001
Boswellia serrata	0.2	0.02	0.4	57.12	0.0001
Erythrina indica	0.2	0.04	0.29	34.56	0

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m²/ha)
Bauhinia racemosa	0.2	0.01	0.27	155.5	0
Acacia nilotica	0.2	0	0.26	622	0.0001
Tamarindus indica	0.1	0.01	0.24	138.22	0.0001
Cassia fistula	0.1	0	0.14	311	0

ii) Mixed Forest: This forest type mostly occurs in the Andhari Wildlife Sanctuary (Plate 4.2). A total of 691 individuals of 37 species belonging to 22 families were recorded in this forest type. Among all the families, Combretaceae and Euphorbiaceae were found to be most diverse and dominant family as 50% of total species present belong to these families. *Terminalia tomentosa, Chloroxylon swietenia, Cleistanthus collinus, Tectona grandis* and *Diospyros melanoxylon* were the prominent tree species in this forest type. *Gymosporia spinosa, Bridelia hamiltoniana, Iaxora parviflora* were the major shrub species in this forest type. *Tectona grandis* and *Terminalia tomentosa* had highest IVI value of 30.36 and 30.35 respectively, followed by *Chloroxylon swietenia* (29.11) (Table 4.2). The total tree density of this vegetation type was 1484.9/ha. The mean tree density was 35.4±52.7 per hectare. The total basal area of this vegetation type 3.6m²/ha. The mean GBH of the trees in this type is 68.4±33.2. The total shrub density was 429.3/ha. The sapling density was 5.7±5.

Table 4.2. Density, Frequency, IVI, A/F ratio and Basal Area of different tree species in Mixed Forest (MF)

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m²/ha)
Tectona grandis	195.06	12.19	30.36	12.96	0.42
Terminalia tomentosa	171.18	10.7	30.35	9.56	0.45
Chloroxylon swietenia	183.12	11.45	29.11	18.17	0.44
Cleistanthus collinus	145.3	9.08	21.36	9.65	0.21
Diospyros melanoxylon	111.46	6.97	20.97	6.22	0.26
Madhuca indica	55.73	3.48	20.37	2.65	0.36

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m^2/ha)
Lannea grandis	75.64	4.73	17.77	5.02	0.25
Lagerstroemia parviflora	65.68	4.11	12.05	8.25	0.13
Pterocarpus marsupium	35.83	2.24	11.31	4.5	0.17
Anogeissus latifolia	37.82	2.36	10.15	3.75	0.11
Gardenia latifolia	51.75	3.23	9.97	8.49	0.1
Zizyphus rotundifolia	45.78	2.86	6.56	23	0.05
Bombax cieba	25.88	1.62	6.4	5.78	0.06
Terminalia bellirica	19.9	1.24	6.37	4.44	0.07
Mitragyna parviflora	13.93	0.87	5.22	4.48	0.06
Acacia catechu	19.9	1.24	4.63	6.4	0.03
Dalbergia sissoo	19.9	1.24	4.43	6.4	0.02
Aegle marmelos	11.94	0.75	4.08	3.84	0.02
Emblica officinalis	13.93	0.87	3.65	12.44	0.04
Soymida febrifuga	5.97	0.37	3.1	5.33	0.04
Stereospermum suaveolens	5.97	0.37	2.58	5.33	0.02
Albizzia odoratissima	5.97	0.37	2.33	5.33	0.01
Xylia xylocarpa	7.96	0.5	2.12	16	0.02
Bauhinia racemosa	9.95	0.62	2.03	20	0.01
Flacourtia ramontchi	7.96	0.5	1.87	16	0.01
Buchanania lanzan	3.98	0.25	1.37	8	0
Syzygium cumini	1.99	0.12	1.36	16	0.03
Dalbergia paniculata	3.98	0.25	1.22	32	0.02
Boswellia serrata	1.99	0.12	1.13	16	0.02
Acacia leucophloea	3.98	0.25	0.99	32	0.01
Careya arborea	1.99	0.12	0.9	16	0.01
Cassia fistula	1.99	0.12	0.78	16	0
Bridelia retusa	1.99	0.12	0.74	16	0
Dolichandrone falcata	1.99	0.12	0.73	16	0
Semecarpus anacardium	1.99	0.12	0.7	16	0
Erythrina indica	1.99	0.12	0.7	16	0
Schleichera oleosa	1.99	0.12	0.69	16	0

iii) Teak Mixed Bamboo Forest: This forest type is found in the places where earlier Teak plantations coupled with profuse bamboo regeneration. A total of 376 individuals of 32 species belonging to 21 families were recorded in this forest type. *Pterocarpus marsupium, Zizyphus xylopyra, Lagerstroemia parviflora, Tectona grandis* and *Diospyros melanoxylon* were prominent tree species in this forest type. *Dendrocalamus strictus* forms the major understorey. *Tectona grandis* (116.83) had highest IVI value followed *Lagerstroemia parviflora* (27.94) (Table 4.3). The total tree density of this vegetation type was 1108.9/ha. The mean tree density was 32.6±103.4 per hectare. The total basal area of this vegetation type was 3.6m²/ha. The mean GBH of the trees in this type was 67.4±36.6. The total shrub density was 3745.2/ha. The sapling density was 40.7±36.9.

Table 4.3. Density, Frequency, IVI, A/F ratio and Basal Area of different tree species in Teak Mixed Bamboo Forest (TMBF)

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m²/ha)
Tectona grandis	607.99	1	116.83	19.09	1.89
Lagerstroemia parviflora	115.81	0.82	27.94	4.62	0.34
Diospyros melanoxylon	40.53	0.64	15.58	3.14	0.16
Zizyphus xylopyra	40.53	0.64	13.1	3.14	0.06
Pterocarpus marsupium	17.37	0.36	11.79	4.13	0.22
Chloroxylon swietenia	34.74	0.36	11.63	8.25	0.15
Madhuca indica	28.95	0.45	10.66	4.4	0.09
Emblica officinalis	31.85	0.45	9.86	4.84	0.05
Albizzia odoratissima	14.48	0.27	6.58	6.11	0.07
Schleichera oleosa	5.79	0.18	6.41	5.5	0.14
Grewia abutilifolia	20.27	0.27	6.06	8.56	0.03
Bombax ceiba	31.85	0.27	5.68	7.33	0.03
Cleistanthus collinus	14.48	0.18	5.12	13.75	0.06
Terminalia tomentosa	26.06	0.09	4.84	99	0.05
Terminalia bellirica	5.79	0.09	4.46	22	0.11
Butea monosperma	8.69	0.27	4.36	3.67	0.01
Anogeissus latifolia	8.69	0.18	3.54	8.25	0.02
Xylia xylocarpa	11.58	0.09	3.42	44	0.05

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m^2/ha)
Gardenia latifolia	8.69	0.09	2.88	33	0.04
Terminalia chebula	5.79	0.09	2.85	22	0.05
Flacourtia ramontchi	5.79	0.09	2.49	22	0.03
Mitragyna parviflora	2.9	0.09	2.38	11	0.04
Careya arborea	2.9	0.09	2.21	11	0.03
Dalbergia sissoo	2.9	0.09	1.95	11	0.02
Lannea grandis	5.79	0.09	1.81	22	0.01
Semecarpus anacardium	2.9	0.09	1.73	11	0.01
Bridelia retusa	2.9	0.09	1.56	11	0.01
Saccopetalum tomentosum	2.9	0.09	1.55	11	0.01
Dolichandrone falcata	2.9	0.09	1.53	11	0.01
Bauhinia racemosa	2.9	0.09	1.52	11	0.01
Acacia catechu	2.9	0.09	1.47	11	0
Cassia fistula	2.9	0.09	1.43	11	0

iv) Teak Forest: This forest type is restricted to a small patch near the Tadoba Lake (Plate 4.3)A total of 396 individuals of 29 species belonging to 18 families were recorded from this forest. Combretaceae was found to be relatively dominant and diverse family as 20% of species belong to it. *Tectona grandis, Diospyros melanoxylon, Chloroxylon swietenia, Zizyphus xylopyra* and *Lagerstroemia parviflora* were prominent tree species. *Tectona grandis* had the highest IVI value (136) followed by *Lagerstroemia parviflora* (19.17) (Table 4.4). The total tree density of this vegetation type was 359.3/ha. The mean tree density was 10.9±37.3 per hectare. The total basal area of this vegetation type was 0.4m^2/ha. The mean GBH of the trees was 63.06±35.40. The total shrub density was 280.3/ha. The sapling density was 32.8±29.9.

Table 4.4. Density, Frequency, IVI, A/F ratio and Basal Area of different tree species in Teak Forest (TF)

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m^2/ha)
Tectona grandis	216.81	1	136.33	6.81	0.17
Lagerstroemia parviflora	16.81	0.22	19.17	10.69	0.03
Zizyphus xylopyra	23.89	0.25	17.26	12	0.01
Chloroxylon swietenia	15.93	0.22	16.62	10.13	0.02
Diospyros melanoxylon	12.39	0.19	14.25	10.29	0.02
Terminalia tomentosa	4.42	0.11	8.92	11.25	0.02
Soymida febrifuga	3.54	0.08	8.52	16	0.02
Bombax ceiba	6.19	0.14	7.39	10.08	0.01
Anogeissus latifolia	5.31	0.11	6.65	13.5	0.01
Lannea grandis	3.54	0.11	5.7	9	0.01
Emblica officinalis	6.19	0.11	5.48	15.75	0
Terminalia bellirica	3.54	0.08	4.79	16	0.01
Grewia abutilifolia	5.31	0.06	3.84	54	0
Mitragyna parviflora	0.88	0.03	3.69	36	0.01
Stereospermum suaveolens	1.77	0.06	3.46	18	0
Aegle marmelos	2.65	0.06	3.1	27	0
Pterocarpus marsupium	1.77	0.06	3.01	18	0
Acacia leucophloea	2.65	0.06	2.64	27	0
Albizzia odoratissima	1.77	0.06	2.56	18	0
Bridelia retusa	1.77	0.06	2.33	18	0
Terminalia arjuna	1.77	0.03	2.03	72	0
Feronia elephantum	0.88	0.03	1.92	36	0
Cleistanthus collinus	2.65	0.03	1.9	108	0
Xylia xylocarpa	1.77	0.03	1.88	72	0
Butea monosperma	0.88	0.03	1.22	36	0
Gardenia latifolia	0.88	0.03	1.18	36	0
Cassia fistula	0.88	0.03	1.13	36	0
Acacia catechu	0.88	0.03	1.13	36	0
Ixora parviflora	0.88	0.03	1.12	36	0

v) Riparian Forest: This is the least represented but highly significant vegetation type (Plate 4.4). This type is confined along the streams and areas adjoining the water bodies. A total of 65 individuals of 9 species belonging to 8 families were recorded from this vegetation type. No single family represents the forest, as species belong to several families. The prominent tree species were *Syzygium cumini, Hardiwickia binata, Terminalia arjuna* and *Mangifera indica. Syzygium cumini* had highest IVI value (89.71) followed by *Mangifera indica* (14.01) and *Hardwickia binata* (12.74) (table 4.5). The overall tree density of this vegetation type was 68.8/ha. The mean tree density was 7.6±8.2 per hectare. The total basal area of this vegetation type was 8.9m²/ha The mean GBH of the trees was 120.2±69.8.

Table 4.5. Density, Frequency, IVI, A/F ratio and Basal Area of different tree species in Riparian Forest (RF)

Tree species	Density /ha	Frequency	IVI	A/F ratio	BA (m²/ha)
Syzygium cumini	24.2	1	89.71	3.8	2.48
Hardiwickia binata	12.74	0.4	75.9	12.5	4.16
Mangifera indica	14.01	0.6	55.99	6.11	1.75
Terminalia arjuna	10.19	0.2	24.01	40	0.37
Albizzia odoratissima	2.55	0.4	14.74	2.5	0
Tamarindus indica	1.27	0.2	7.98	5	0.06
Madhuca indica	1.27	0.2	7.59	5	0.02
Saccopetalum tomentosum	1.27	0.2	7.54	5	0.02
Ficus rumphii	1.27	0.2	7.46	5	0.01

4.4.2.1. Tree Density: The maximum tree diversity was found in Teak Mixed Bamboo forest (607.9/ha) and minimum was found in Teak forest (0.9/ha). The Mixed Forest was found to have highest average density of 35.4/ha ± 52.7 (Table 4.6).

Plate. 4.1.
Mixed Bamboo Forest

Plate. 4.2
Mixed Forest

Plate. 4.3.
Teak Forest

Plate. 4.4. Riparian Forest

Plate. 4.5.Grassland

Table 4.6. Tree density in different vegetation types

Vegetation Types	Mean Density±SD	Maximum Density/ha	Minimum Density/ha
Mixed Bamboo Forest	4.3±6.9	27	0.1
Mixed Forest	35.4±52.7	195.1	1.9
Teak Mixed Bamboo Forest	32.6±62.4	607.9	2.9
Teak Forest	10.9±37.3	216.8	0.9
Riparian Forest	7.6±8.2	24.2	1.3

4.4.2.2. Tree Diversity: It was found that the maximum tree diversity was in Mixed Bamboo Forest, the dominant forest type of the study area, while Teak forest being the least diverse and also most uneven in species distribution. The highest species richness was found in mixed forest. Inspite of being the most diverse forest type, mixed bamboo forest had lowest number of species. Riparian Forest is most even distribution of species with their not much difference in their frequency values (Table 4.7)

Table 4.7. Diversity, Richness and Evenness indices for different vegetation types

Vegetation Types	Diversity	Richness	Evenness
Mixed Bamboo Forest	3.08	1.14	0.39
Mixed Forest	2.98	1.79	0.45
Teak Forest	1.85	1.69	0.31
Teak Mixed Bamboo Forest	2.07	1.78	0.35
Riparian Forest	2.01	1.47	0.49

4.4.3. Regeneration and Population Structure

The GBH of the trees recorded were analyzed to understand the structure of the vegetation types. The tree individuals in each vegetation type were classified according to GBH into seven girth classes of 30 cm interval *viz.,* I: 31-60cm, II: 61-90cm, III: 91-120cm, IV: 121-150cm, V: 151-180cm, VI: 181-210, VII: >211.

i) Mixed Bamboo Forest: This forest type had lowest sapling density. *Madhuca indica* being the most dominant species had very few saplings showing its poor regeneration, *Chloroxylon swietenia* also being co-dominant species did not show very good regeneration. Table 4.8 depicts some of the trees showing good regeneration. 42% of trees were found in the class first *i.e.* within the range of GBH 31-60 cm and number of individuals decreased from class I to class VII. The least number of individuals (0.62%) were found to be having GBH above 211 cm (Fig. 4.3). Population structures of some of the important trees like *Madhuca indica, Tectona grandis* and *Diospyros melanoxylon* were studied for this type (Fig. 4.4)

Table 4.8. Sapling density of few important species in Mixed Bamboo Forest

Species	Saplings density/ha
Tectona grandis	98.48
Diospyros melanoxylon	41.50
Lagerstroemia parviflora	18.86
Cleistanthus collinus	31.13
Anogeissus latifolia	16.03

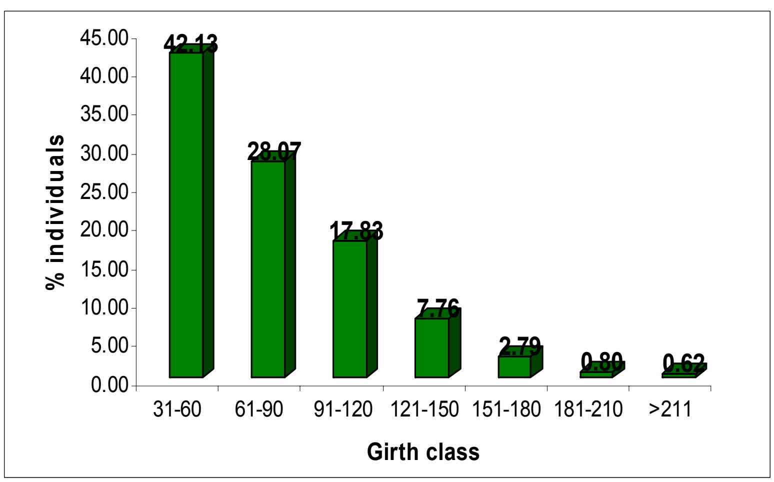


Figure 4.3. Girth class distribution of trees in Mixed Bamboo Forest

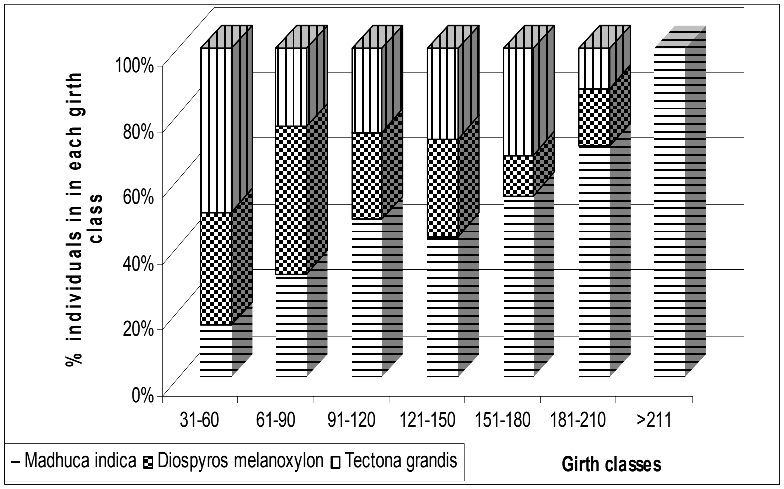


Figure 4.4. Population structure of important tree species in Mixed Bamboo Forest

ii) Mixed Forest: In this forest type *Cassia fistula, Bauhinia racemosa, Aegle marmelos* and *Xylia xylocarpa* had poor regeneration as they were present as trees but not as saplings. *Lannea grandis*, being important species of this forest type had very few saplings. Table 4.9 depicts some of the trees showing good regeneration. 50% of trees were found in the class first *i.e.* with in the range of GBH 31-60 cm and number of individuals decrease from class I to class VII. The least number of individuals (0.4%) were found to be having GBH above 211 cm (Fig.4.5). Population structure of important trees like *Terminalia tomentosa, Tectona grandis* and *Chloroxylon swietenia* are shown in Fig.4.6.

Table 4.9. Sapling density of few important species of Mixed Forest

Species	Sapling density/ha
Diospyros melanoxylon	81.29
Tectona grandis	80.08
Terminalia tomentosa	42.47
Cleistanthus collinus	32.76
Chloroxylon swietenia	14.56

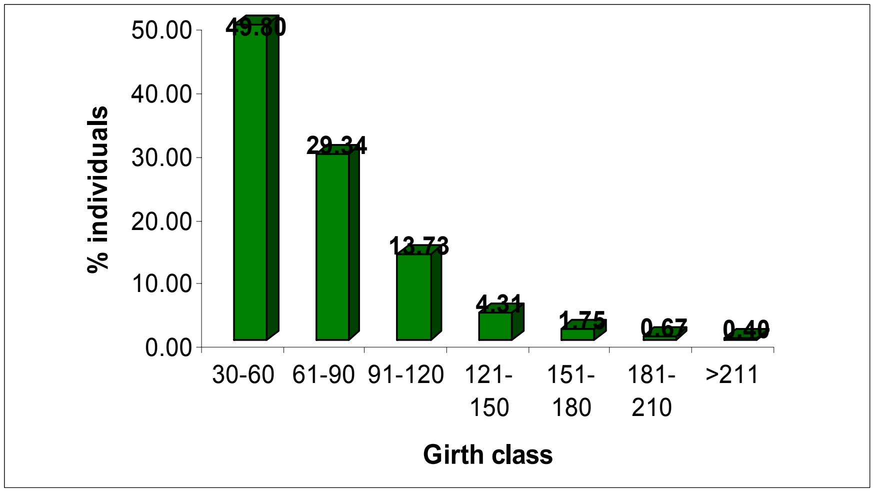


Figure 4.5. Girth class distribution of trees in Mixed Forest

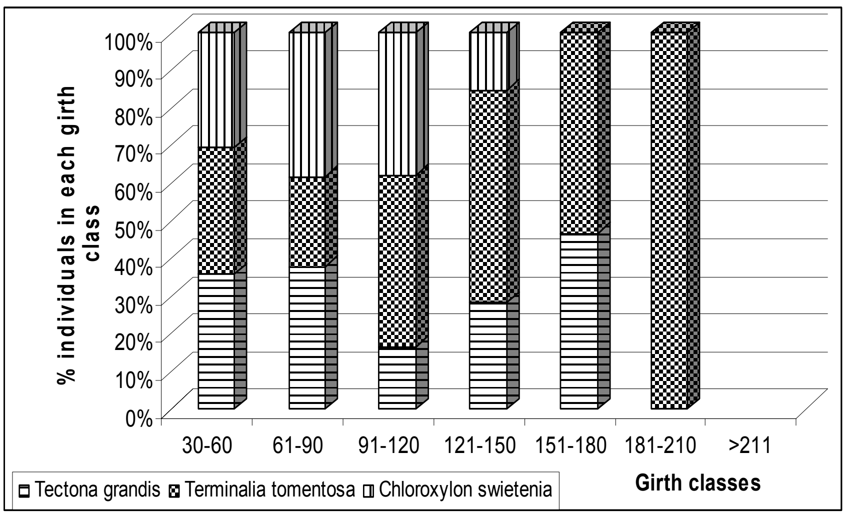


Figure 4.6. Population structure of important tree species in Mixed Forest

iii) Teak Mixed Bamboo Forest: This forest type had very few plants in the sapling stage. Some of the trees showed good regeneration as shown in Table 4.10. 56% of trees were found in the class first *i.e.* with in the range of GBH 31-60 cm and number of individuals decreased from class I to class VII. The least number of individuals (0.52%) were found to be having GBH above 211 cm, but no tree was found having GBH ranging 181-210 (Fig.4.7). Population structures of important trees like *Tectona grandis, Diospyros melanoxylon* and *Lagerstroemia parviflora* were studied for this type (Fig.4.8).

Table 4.10. Sapling density of few important species in Teak Mixed Bamboo Forest

Species	Sapling density/ha
Tectona grandis	245.10
Lagerstroemia parviflora	29.41
Diospyros melanoxylon	29.41
Zizyphus xylopyra	39.22
Pterocarpus marsupium	19.61

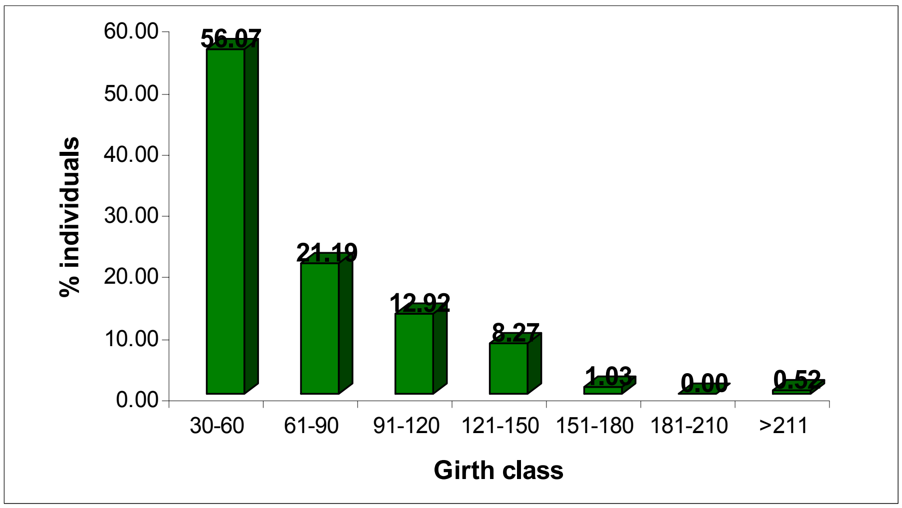


Figure 4.7. Girth class distribution of trees in Teak Mixed Bamboo Forest

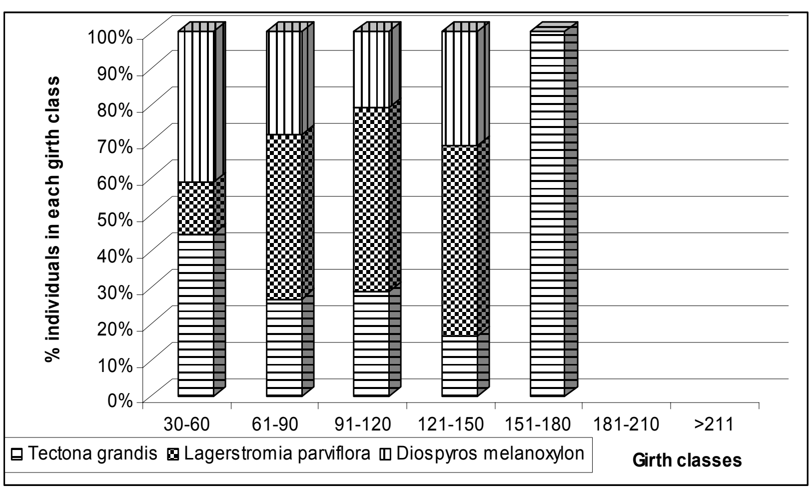


Figure 4.8. Population structure of important tree species in Teak Mixed Bamboo Forest

iv) Teak Forest: The species in this vegetation type showed good regeneration potential (Table 4.11). 61% of trees were found in the class first *i.e.* within the range of GBH 31-60 cm and number of individuals decrease from class I to class VII. The least number of individuals (0.74%) were found to be having GBH above 211 cm, just one tree was found in class VI (GBH ranging 181-210) (Fig.4.9). Population structure of important trees like *Tectona grandis, Diospyros melanoxylon* and *Lagerstroemia parviflora* were studied for this type (Fig.4.10).

Table 4.11. Sapling density of few important species in Teak Forest

Species	**Sapling density/ha**
Tectona grandis	447.49
Zizyphus xylopyra	54.79
Diospyros melanoxylon	50.23
Cleistanthus collinus	41.10

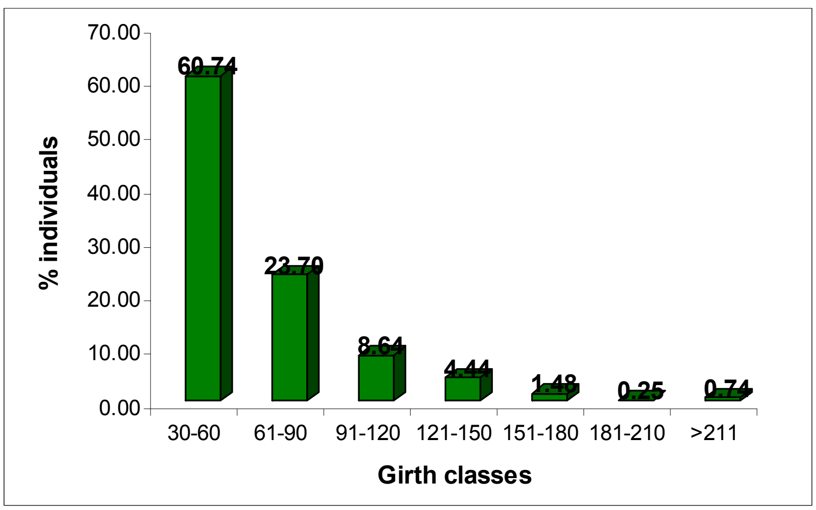


Figure 4.9. Girth class distribution of trees in Teak Forest

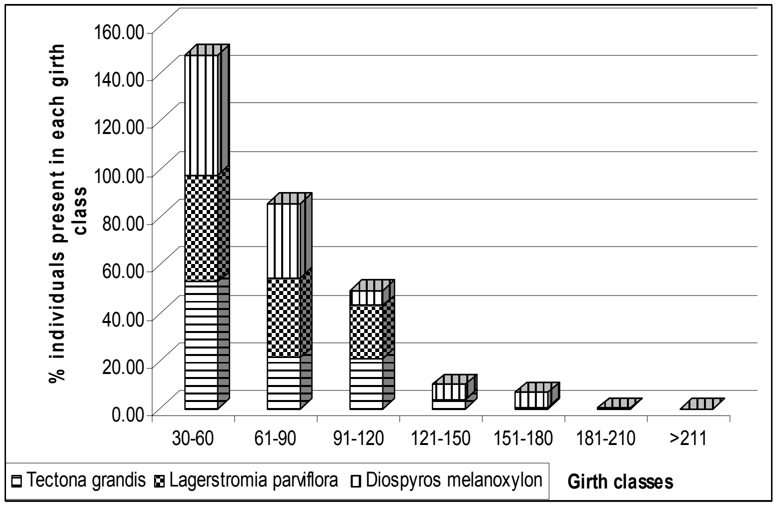


Figure 4.10. Population structure of important tree species in Teak Forest

v) Riparian Forest: This forest type has highest sapling density hence reflecting excellent regeneration (Table 4.12). *Hardwickia binata* is one of the important species but its saplings were not found. 29% of trees were found in the class first *i.e.* with in the range of GBH 31-60 cm. The least number of individuals (3.85%) were found in class II (GBH ranging 61-90) (Fig.4.11). Most of the individuals had large girth values. *Syzygium cumini, Hardwickia binata, Mangifera indica, Terminalia arjuna* (Fig.4.12).

Table 4.12. Sapling density of few important species of Riparian Forest

Species	Sapling density/ ha
Syzygium cumini	2165.61
Terminalia arjuna	509.55
Mangifera indica	254.78

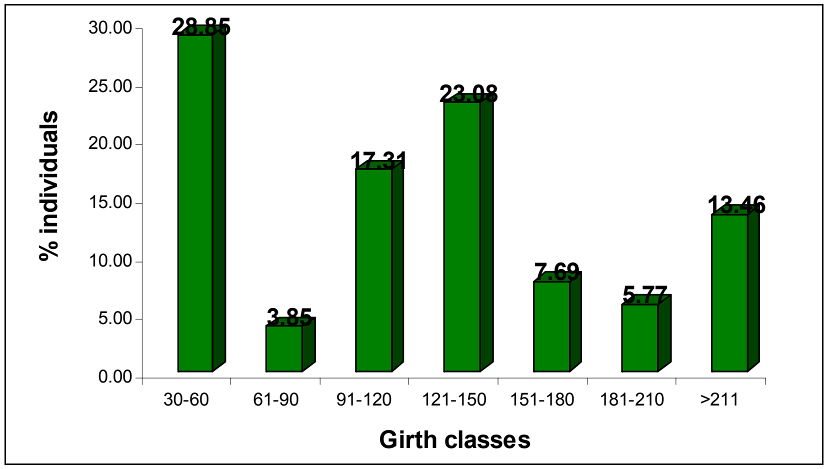


Figure 4.11. Girth class distribution of trees in Riparian Forest

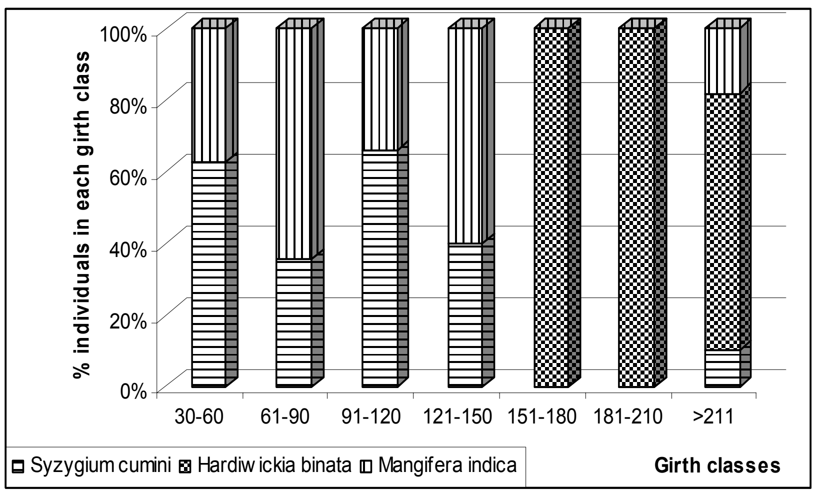


Figure 4.12. Population structure of important tree species in Riparian Forest

The overall maximum sapling density was found to be highest in Riparian Forest and lowest in Mixed Bamboo Forest (Table 4.13).

Table 4.13. Sapling density in different vegetation types

Vegetation types	Sapling density/ha	Sapling density/ha ± SD	No. of species
Mixed Bamboo Forest	496.21	1.84±1.67.	48
Mixed Forest	594.48	5.72±5.02	36
Teak Mixed Bamboo Forest	529.41	40.72±36.86	28
Teak Forest	917.8	32.77±29.93.	29
Riparian Forest	2929.93	976.64±1037	9

4.4.4. Ground Layer

4.4.4.1. Bamboo Density: Teak Mixed Bamboo Forest (TMBF) has highest bamboo density (3745/ha) while, Teak Forest (TF) has lowest bamboo density (79/ha) (Fig. 4.13).

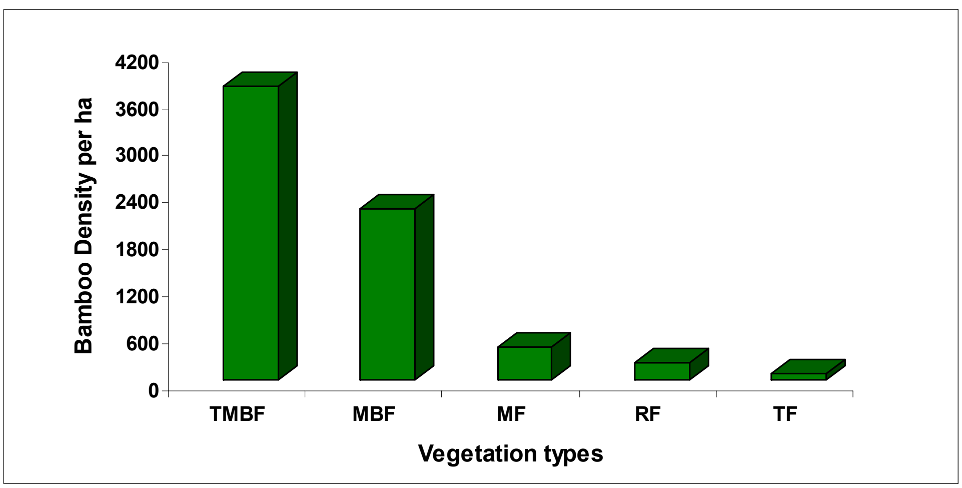


Figure 4.13. Bamboo density in each vegetation types

4.4.4.2. Herbs and Grasses: The overall percentage herb cover was found to be 15.2 ± 18.2 (mean ± SD), grass cover was 19.5 ±27.3, litter 20.1±19.1 weed cover was 1.6±4.8 exposed ground was 17.6±17.3. Total density was recorded 44857/m². The mean density was found to be 8971.4. Among the herbs and grasses *Heteropogon contortus* was found in most of the plots (0.90) followed by *Eragrostis tenella* (0.076) and *Hemidesmus indicus* (0.049). The frequency values of some prominent species are given in Table 4.14 (Plate 4.5).

Table 4.14. Frequency of prominent herbs and grass species of TATR

Species	Frequency
Heteropogon contortus	0.090
Eragrostis tenella	0.076
Hemidesmus indicus	0.049
Desmodium pulchellum	0.040
Cassia tora	0.029
Themeda triandra	0.015
Andrographis paniculata	0.013
Dioscorea pentaphylla	0.013
Imperata cylindrica	0.010
Gardenia turgida	0.008
Setaria intermedia	0.007
Dicanthium aristatum	0.006
Dicanthium annulatum	0.004
Eragrostis interrupta	0.003

4.5. DISCUSSION

The dry deciduous forest of TATR does not show a distinct difference in structure and composition within different vegetation types due to less heterogeneity. The cluster analysis based on similarities in abundance pattern, grouped the species into seven different communities. Some of the communities classified were common to several vegetation types. A total of 3779 tree individuals belonging to 55 species were recorded. Floristic analysis of TATR revealed that *Tectona grandis* had maximum IVI ranging from 27 to

136 followed by *Chloroxylon swietenia, Terminalia tomentosa* and *Lagerstroemia parviflora*.

A gradual decrease in number of tree species *i.e.* from 46 to 9 was recorded while moving from the Mixed Bamboo Forest to Riparian Forest. Analysis of the forest inventory data of different vegetation types of TATR revealed that Teak had highest density, frequency and IVI in all the forest types, except in Mixed Bamboo Forest and Riparian Forest, where highest IVI was shown by *Madhuca indica* and *Syzygium cumini* respectively. Despite highest density of teak and highest frequency of *Diospyros melanoxylon* in Mixed Bamboo Forest, *Maduca indica* had highest IVI, due to highest basal area acquired by it.

On comparing the values of Importance Value Index (IVI) among different vegetation types of TATR, it was found that IVI values for Mixed Bamboo Forest ranged from 0.14 to 43.94, for Mixed Forest from 0.7-30.4, for Teak Mixed Bamboo Forest 1.4 to 116, for Teak Forest 1.1 to 136.3 and for Riparian Forest 7.46 to 89.71. Interestingly, highest variation in the IVI values was found in Teak Forest followed by Teak Mixed Bamboo Forest depicting a dominance of a particular species over others. Apart from teak all the species in all vegetation types had frequencies below 1%, except Mixed Forest in which 46% of species had frequency above 1%. Mixed forest has highest mean tree density and Mixed Bamboo Forest has the least. However, maximum tree density per hectare was found in Teak Mixed Bamboo Forest. Mixed Bamboo Forest (76%) and Teak Forest (72%) had highest percentage of species having density below 5%.

The population structure characterized by the presence of adequate number of seedlings, saplings and young trees depicts satisfactory regeneration behaviour, while inadequate number of seedlings and saplings of tree species in a forest indicates its poor regeneration (Saxena & Singh, 1984). The regeneration status/potential of a species in a community can be assessed from the population dynamics of seedlings and saplings in the forest (Duchok *et al.,* 2005). In all the vegetation types, 45-50% trees were young which fall in girth class I (31-60cm), except in Riparian Forest where 29% of trees fall in class I (31-60cm) and the rest of the individuals fall in class III (91-120) and IV (121-150). The above data indicates relatively uniform tree distribution in TATR. Another interesting finding was the presence of *Hardiwickia binata* as prominent tree species of Riparian Forest. However, *Hardiwickia binata* is not a typical species of this forest type. This fact was confirmed by its poor regeneration status in Riparian Forest.

In all the vegetation types the species with high IVIs showed good regeneration potential except in Mixed Bamboo Forest, where *Madhuca indica* had highest IVI value but it showed least regeneration since less number of individuals were found in girth class I (16%) and very low sapling density. In contrast, Teak showed very good regeneration as it had relatively maximum number of individuals in class I and highest sapling density. Mixed Bamboo Forest depicted lowest regeneration and this may be attributed to the fact that the presence of extensive bamboo as the understorey hampered the growth of the seedlings. The dominance of one stratum may affect the diversity of another stratum (Whittaker, 1972). However, Riparian Forest showed maximum regeneration potential due to availability of favourable conditions and with no under-growth of bamboo, the seedling and saplings of tree attained maturity.

Fabaceae, Combretaceae and Caesalpiniaceae were found to be dominant families in TATR. In spite of having lowest species richness, Mixed Bamboo Forest was found to be the most diverse vegetation type. This statement is supported by the fact that when number of individuals per species is high but the number of species is low, the diversity would vary because of its partial dependence on the equitability of the distribution of individuals among species (Saxena & Singh, 1982).

On comparing results of this study it was observed that the diversity values of forest of TATR vary from 1.9 to 3.1, which is much lower compared to diversity recorded in tropical dry deciduous forest of Eastern Ghats *i.e.* 4.1 to

4.9 (Reddy *et al.,* 2008). However, the range of tree density per hectare in tropical rain forest of south India, is from 20 to 223 (Parthasarathy & Sethi, 1997) and in dry deciduous forest of Eastern Ghats maximum 69 species per hectare was recorded but in present study it varied from 0.1 to 608 per hectare. It supports the fact that despite being less diverse in nature the density is higher in TATR.

The study corroborates the fact that the density and species richness have consistently decrease with increasing girth class of tree species from 30 to more than 211cm gbh (Reddy *et al.,* 2008). The maximum numbers of species were encountered in lowest gbh claas (30-90cm). Species numbers gradually decrease with increasing girth classes.

Amongst the vegetation types, the Mixed Bamboo Forest has highest average shrub density with a major contribution of species like *Holarrhena antidysenterica, Nyctanthus arbortristis, Bridelia hamiltoniana and Zizyphus mauritiana.*

Bamboo formed the major understorey of Mixed Bamboo Forest and Teak Mixed Bamboo Forest. This forest is characterized by low shrub and herb diversity. This can be attributed to two reasons. Firstly, the dominance of bamboos has impeded the growth of other herbs and shrubs in TATR. Secondly, as the forest is dry deciduous in nature, maximum percentage of the ground was found to be covered by litter, thereby also contributing to low diversity of herbs and grasses in the area. Most herb species are ephemeral in nature as maximum species of herbs are found in the monsoon and they immediately disappear after monsoons.

Chapter 5

SPATIAL AND ECOLOGICAL DISTRIBUTION OF UNGULATES

5.1. INTRODUCTION

Wildlife conservation planning *inter-alia* requires basic information on distribution and abundance of natural resources. Ungulate species form a major prey base and therefore play a vital role in maintenance of forest ecosystem equilibrium, as they help in shaping its structure, composition and also directly or indirectly affect other animals (Crawley 1983, Kortlandt 1984, Owen & Smith 1987 and Naimann 1988). Maintaining viable populations of wild ungulates and carnivore species is the goal of protected area management. Ungulates form the major component of the diet of large carnivores, hence are crucial for survival of predators. Knowledge of ungulate abundance and factors influencing abundance is essential in many areas of ecological research, management and policy making (Stanely & Royle, 2005). Proper ungulate management requires a good understanding of all aspects of its population dynamics. Therefore, ecological monitoring of ungulate populations is a vital component of any conservation task, so that effects of management can be assessed (Kremen *et al.,* 1994). Several techniques (Rodgers, 1991) and methodologies are available for such monitoring (Brochers *et al.,* 2002). Population density, structure and biomass are the measures to examine the complex relationships between species and its environment (Eisenberg & Seidensticker 1976, Brown 1984 and Mathur 1991). Many studies have been conducted to estimate the prey density and have proposed conservation practices for wild animal species (Berwick 1974, Seidensticker 1976, Johnsingh 1983 and Sankar 1994). However, these studies have largely focused on population parameters and prey density estimation using methods like belt transects, vehicle transects, block counts and roadside counts, which do not statistically address the critical problems associated with population estimates. An attempt to arrive at accurate estimates of the herbivore density has been made by the use of distance sampling theory (Burnham *et al.,* 1980 and Buckland *et al.,* 1993). The line transect method is considered to be most appropriate method for estimation of herbivore abundance and has been used extensively to determine animal abundance (Karanth & Sunquist 1992, Varman & Sukumar 1995, Khan *et al.,* 1996, Raman *et al.,* 1996, Karanth & Nicholas 1998, Dubey & Mathur 1999, Plumptre 2000, Biswas & Sankar 2002, Bagchi *et al.,* 2003 and Focardi *et al.,* 2005). As estimating animal densities using distance sampling method corrects the bias of non-detection, this method is preferred over others. But to have better long term implications for future management, one time estimates of the population would not be very reliable. Hence, a concern has always been expressed by wildlife biologists and field managers to have population estimation exercise at regular intervals, so that better inferences can be drawn and population trends can be predicted for any future management interventions for improving habitat quality. Monitoring trends in abundance over several survey periods can improve the detection of change (Plumptre, 2000).

Wide-ranging field methods have been used for density estimation. Direct and indirect methods have been used to estimate densities in tropical forests. Estimation of herbivore abundance using line transect method (Burnham *et al.,* 1980) is considered to be most cost effective and useful method as it needs little manpower and can be tested rigorously in terms of precision. It has been found to be very effective and reliable in estimating densities of ungulates in Indian scenario (Karanth *et al.,* 2004). Generally the animals become harder to detect with increasing distance from the observer, resulting in fewer detections with increasing distance. The key to distance sampling analyses is to fit a detection function, $g(x)$, to the observed distances and use it to estimate the proportion of animals missed by the survey (Buckland *et al.,* 2001), assuming that all animals on the line transect are detected (*i.e.* $g(0) = 1$). The assumptions of distance sampling have been discussed by Buckland *et al.*, (2001).

Few studies have been conducted on ungulates in TATR. Mathur (1991) analyzed estimates of density and biomass of three species of ungulates (Chital, Sambar and Nilgai) in Tadoba National Park. Dubey (1999) analyzed density, biomass and habitat utilization by ungulates in TATR. In the present study an attempt has been made to quantify spatial and ecological distribution of ungulate species *viz.,* Gaur (*Bos gaurus*), Nilgai (*Boselaphus tragocamelus*), Sambar (*Cervus unicolor*), Chital (*Axis axis*) and Wild pig (*Sus scrofa*) (Plate 5.1 to 5.5), in response to seasons and management status. The data was analyzed for Tadoba National Park, the northern zone of TATR and Andhari Wildlife Sanctuary which comprises of central and southern zones of TATR.

The study has adressed the following questions:

1. What are the mean ecological densities of different ungulate species in different management zones? How ungulate densities differ in various similar types of forests?
2. What is the species-wise contribution to the total wild ungulate biomass in TATR? What are the biomasses of ungulate species in different management zones?
3. What are the seasonal variations in mean group sizes of different species and do they differ in different management zones?
4. What is the population structure and composition of ungulates in TATR? Do the sex ratio and age structure vary in various similar habitats?

5.2. METHODS

Reconnaissance survey was carried out in February-March 2005 to develop the sampling strategy and to have better representative samples from the area. Intensive sampling was carried out from April 2005- January 2007.

Plate. 5.1.
Gaur (*Bos gaurus*)

Plate. 5.2.
Nilgai (*Boselaphus tragocamelus*)

Plate. 5.3.
Sambar (*Cervus unicolor*)

Plate. 5.4.

Chital (*Axis axis*)

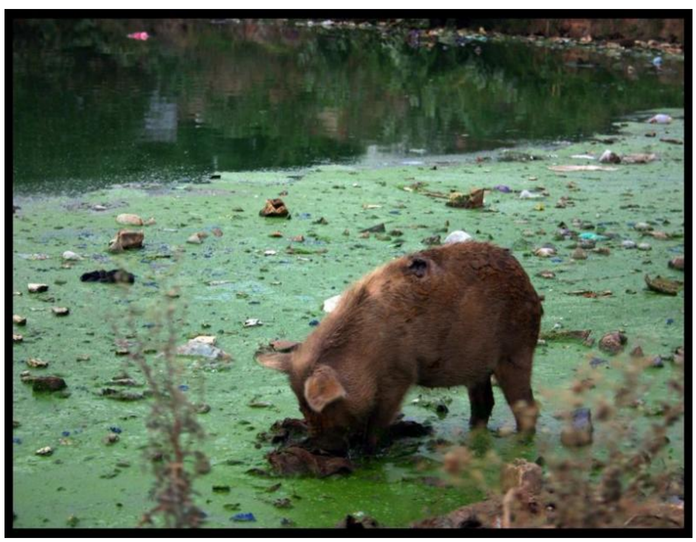


Plate. 5.5.

Wild Pig (*Sus scrofa*)

5.2.1. Density Estimation Method

Line transects were established for ungulate density estimation. The area was systematically stratified using forest beat (smallest administrative unit), as the sampling unit. A total of 50 permanent line transects of 2km length were laid covering all the habitat types of the study area (Fig. 5.1). Transects were monitored in summer and winter seasons, both in morning (6:30hrs- 9:00hrs) and evening (16:00hrs-19:00hrs), when 90% of the animals are actively foraging or moving (Miura, 1981). To estimate the densities of ungulate species, data on following parameters were collected: (a) species, (b) number of individuals, (c) sighting angle and (d) angular sighting distance. Each transect was repeated 4-6 times in each season so as to capture the variation and to present results with high confidence intervals. Field data were analyzed using 'DISTANCE', a computer program (Laake *et al.,* 1999 and Thomas *et al.,* 2004) in case the sightings were more than forty for each species by using formula:

$$\mathbf{D = \frac{n}{2(PDS)\,L}}$$ (Buckland *et al*., 1993)

where,

D= Density

n = no. of animal groups (for group density) or no. of animals (for individual density) recorded on the transect.

PDS = mean perpendicular sighting distance of animal groups from transect

Perpendicular Sighting Distance (PDS) = $\sin\Theta$ x Angular Sighting Distance

L = Transect Length

The density estimation based on distance sampling theory

$$\mathbf{D = \frac{n \times f_o}{2L}}$$ (Buckland *et al*., 1993)

f_o= probability density function of perpendicular distances

Data from all transect walks were pooled seasonwise and the estimates of encounter rates (animal/km), group density (per km²) and animal density (per

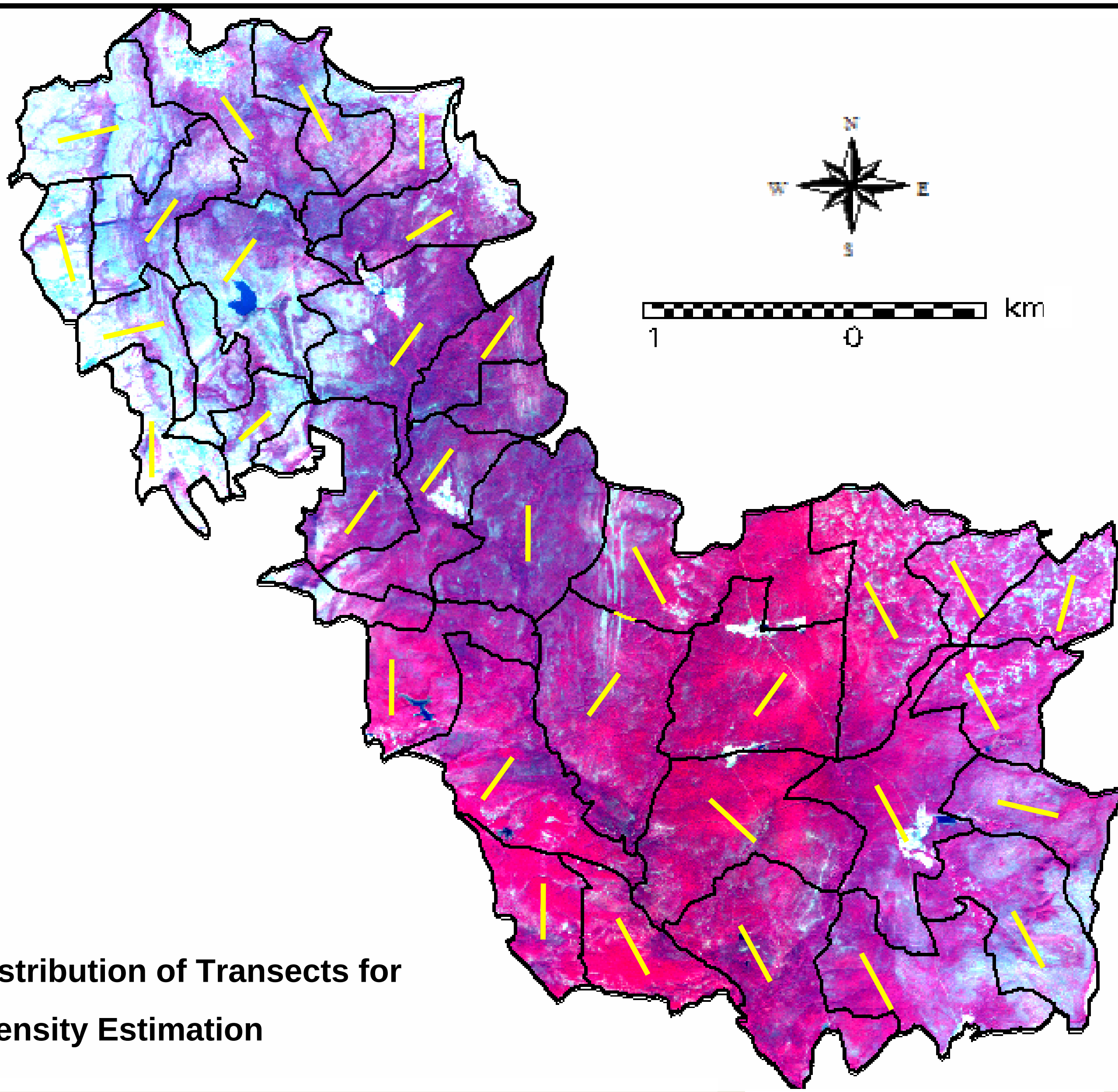


Fig.5.1. Beat wise Distribution of Transects for Ungulate Density Estimation

km²) were derived. The selection of the best model was based on the Akaike Information Criteria (AIC). Overall densities of ungulates were estimated on two spatial scales *i.e.* at large scale for entire landscape of TATR and at small scale *i.e.* for all three management zones, northern zone (Tadoba National Park), central and southern zones (Andhari Wildlife Sanctuary). Since all the three units differ ecologically and spatially, data was analyzed separately for all of them. Density values were log transformed to normal. Student's t-test (Zar, 2004) was used to check the difference between the mean density estimates of Chital and Sambar in Tadoba National Park and Andhari Wildlife Sanctuary using statistical softwares NCSS and SPSS.

5.2.2. Biomass Estimation

To estimate the biomass contributed by each ungulate species (in kg km^{-2}) in study area, the average body weight of ungulates, as estimated in some studies (Schaller 1967, Eisenberg & Seidensticker 1976, Tamang 1982 and Johnsingh 1983) were multiplied by their mean ecological density (D).

5.2.3. Growth Rate of Ungulate Population

The estimates of previous studies (Mathur 1991 and Dubey 1999) along with some other tropical studies were compared with present study to determine the trend of population.

5.2.4. Group Size and Population Structure

Data on group sizes and age-sex composition were recorded during regular sampling of the line transects. Two measures of group sizes *i.e.* Mean Group Size (MGS) and the Typical Group Size (TGS) were estimated management zonewise and seasonwise for each ungulate species. MGS is the average value of the groups observed by the observer and may not reflect the experience of an individual in the same manner as TGS (Raman, 1997). The TGS gives the measure of the size of the group that the average individual finds itself in and has been proposed as a more animal-centeric index of group size (Barrette, 1991). It is a biologically more significant measurement as natural selection acts on individuals. The TGS is calculated by squaring the sizes of groups, summing across all groups and dividing the sum by total number of individuals observed (Jarman, 1974). The MGS of all ungulate species were tested for the significant variation among the seasons using non-parametric Mann-Whitney test (Zar, 2004). The ungulates were classified into adult male (AM), adult female (AF), sub adult male, sub adult female and fawn (FN) following the classification adopted by Schaller (1967), Eiesenberg & Lockhart (1972) and Mishra (1982): Fawn- less than a year, Sub adult- 1 to 2 years, Adult- more than 2 years. Some individuals were difficult to classify into above categories and were classified as unidentified. This exercise was done to evaluate the population status and demographic status.

5.3. RESULTS

5.3.1. Density Estimates

An overall number of 429 ungulate sightings were made on a total walk of 702 km on 50 transects in TATR. Out of which 145 sightings of Chital, 98 sightings of Sambar, 50 sightings of Nilgai, 57 sightings of Wild Pig, 50 sightings of Gaur and 22 sightings of Barking deer and 7 sightings of Chowsinga were made. Density estimates of five ungulate species *viz.,* Chital, Sambar, Nilgai, Wild pig and Gaur were computed as shown in Table 5.1. Density was not calculated for remaining two species on account sample constraints. The densities of ungulates in similar forests of country as well as density estimates obtained by previous studies in TATR were compared in Table 5.2.

Table 5.1. Density estimates of wild ungulates in TATR

	Tadoba National Park (northern zone)	**Andhari Wildlife Sanctuary** (central & southern zones combined)	Central Zone	Southern Zone	**Overall TATR**
	Density/km²(SE), Group density/km²(SE)				
All ungulate (Pooled data)	50.11(±7.1) 19.1(±1.98)	44.7(±6.2) 11(±0.8)	35.4(±5.7) 9.7(±0.99)	33.43(±4.6) 9.2(±1.1)	40.2(±4.3) 12.13(±1.2)
Chital	29.15(±7.2) 7.2 (±1.7)	15.2(±5.06) 3.17(±0.63)	19.31(±6.9) 3.2(±0.82)	6.1(±2.4) 2.1(±0.7)	21.2(±4.1) 4.9(±0.87)
Sambar	9.4(±2.2) 5.5(±1.06)	3.1(±0.91) 2.03(±0.51)	4.76(±1.4) 2.6(±0.64)	1.4(±0.44) 1.2(±0.33)	7.67(±1.3) 3.8(±0.66)
Nilgai	3.9(±1.2) 1.5(±0.57)	3.2(±1.09) 1.5(±0.45)	1.69(±1.28) 1.7(±1.2)	2.1(±0.97) 1.6(±0.75)	3.2(±0.75) 1.5(±0.35)
Wild Pig	13.72(±3.8) 2.4(±0.59)	11.7(±3.8) 3(±0.8)	8.5(±4.5) 2.3(±0.9)	7.6(±3.9) 2(±1)	10.3(±2.5) 2(±0.41)
Gaur	1.27(±0.86) 0.6(±0.29)	10.7(±3.4) 2.4(±0.48)	4.9(±4.12) 1(±0.65)	11.5(±4.3) 2.5(±0.55)	7.04(±1.65) 1.1(±0.29)

Among the three zones of TATR, wild ungulate density was found to be highest in the Tadoba National park (northern zone) (50.11±7.1/km²) followed by central and southern zones (35.4±5.7/km²), (28.43±4.6/km²) respectively of Andhari Wildlife Sanctuary. Among the wild ungulates, Chital was the most abundant (21.2±4.1/km²) and Nilgai, the least (3.2±0.75/km²). The density values of Chital and Sambar in Tadoba National Park and Andhari Wildlife Sanctuary showed significant difference (Chital, t=2.20, d.f. =47, $p<0.05$; Sambar t=4.10, d.f.=48, $p<0.05$). Among management units, the Tadoba National Park had highest ungulate densities. The ungulates densities showed decreasing gradient southwards. On the contrary, Gaur showed decreasing density gradient northwards, having highest density in southern zone of Andhari Wildlife Sanctuary. Spatial distribution of all five ungulate species is shown in Fig. 5.2 to Fig. 5.6.

Table 5.2. Density comparisons of wild ungulates in different tropical forests

Studies in Tropical Forests	Location	Density(km^{-2})				
		Chital	Sambar	Nilgai	Wild Pig	Gaur
Karanth & Sunquist (1992)	Nagarhole	50.6	5.5	4.2	4.2	9.6
Karanth & Nicholas (2000)	Kanha	9.6	1.5	*	*	**
Chundawat (2001)	Panna	10.8	9.16	6.02	1.27	**
Biswas & Sankar (2002)	Pench	51.3	9.6	0.7	0.8	0.7
Bagchi *et al.,* (2003)	Ranthambore	31	17.1	11.4	9.8	**
Jathanna *et al.,* (2003)	Bhadra	4.5	0.89	*	*	1.48
Avinandan (2003)	Sariska	27.6	8.4	5.2	17.5	**
Jhala (2004)	Gir	47.20	4.26	1.43	3.86	**
Mathur (1991)	Tadoba	22.87	7.72	6.42	*	*
Dubey (1999)	Tadoba	17.23	5.1	1.04	4.36	2.75
This Study (2008)	Tadoba	21.2	7.67	3.2	10.3	7.04

* *Not estimated*; ** *Not present in area*

5.3.2. Biomass Estimates

As shown in Fig. 5.7, in the entire landscape of TATR, Gaur contributed the highest percentage (52.2%) to the total ungulate biomass followed by Sambar (17.1%), Chital (15.7%), Nilgai (9.5%) and Wild pig (5.4%). Andhari wildlife sanctuary contributed maximum biomass km^{-2} to TATR (Table 5.3) and among the two zones of Andhari Wildlife Sanctuary, southern zone had a highest contribution of biomass (42.16%) by Gaur to the whole TATR (Fig.5.8). In Tadoba National Park, Chital contributed to the highest biomass,

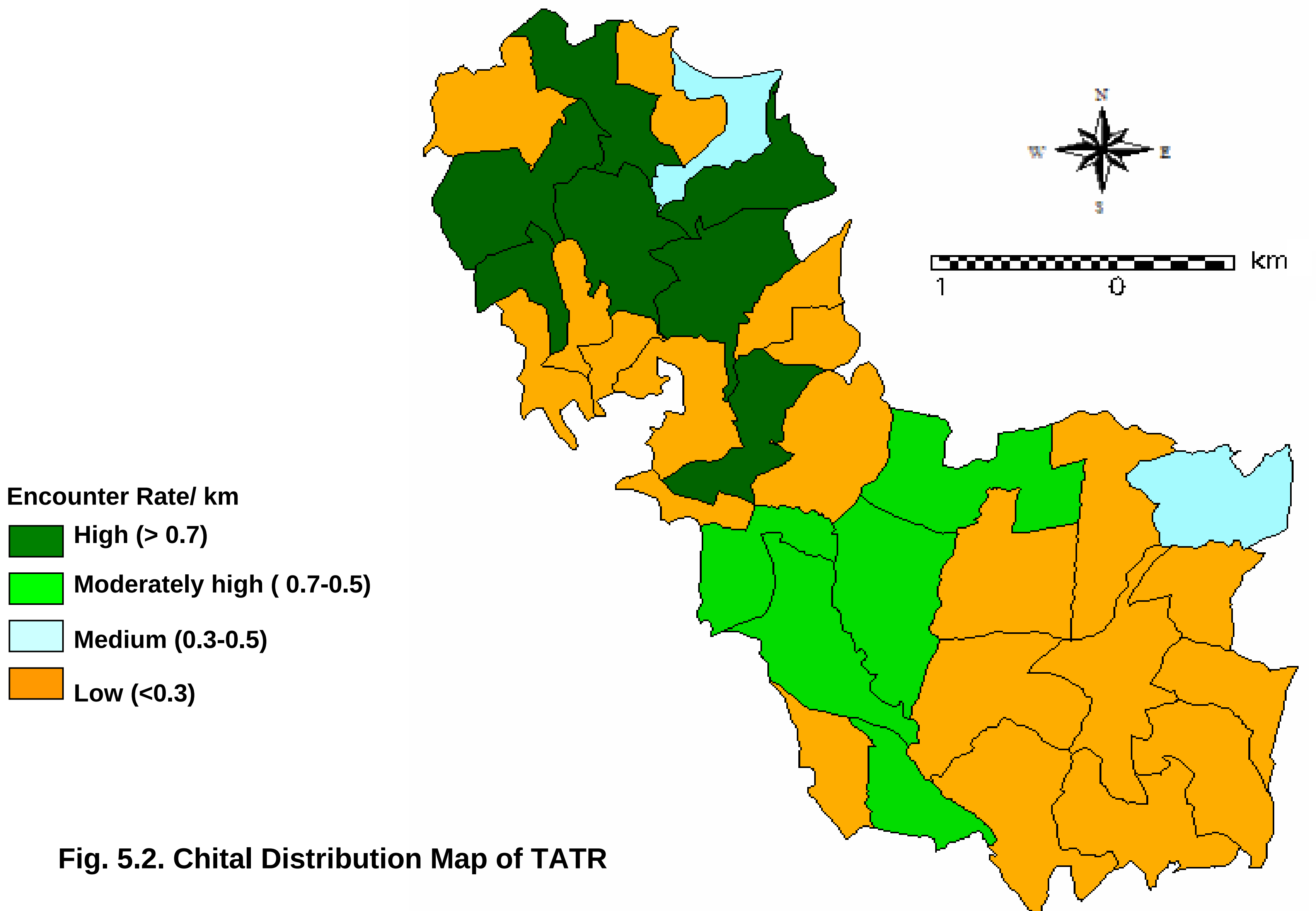


Fig. 5.2. Chital Distribution Map of TATR

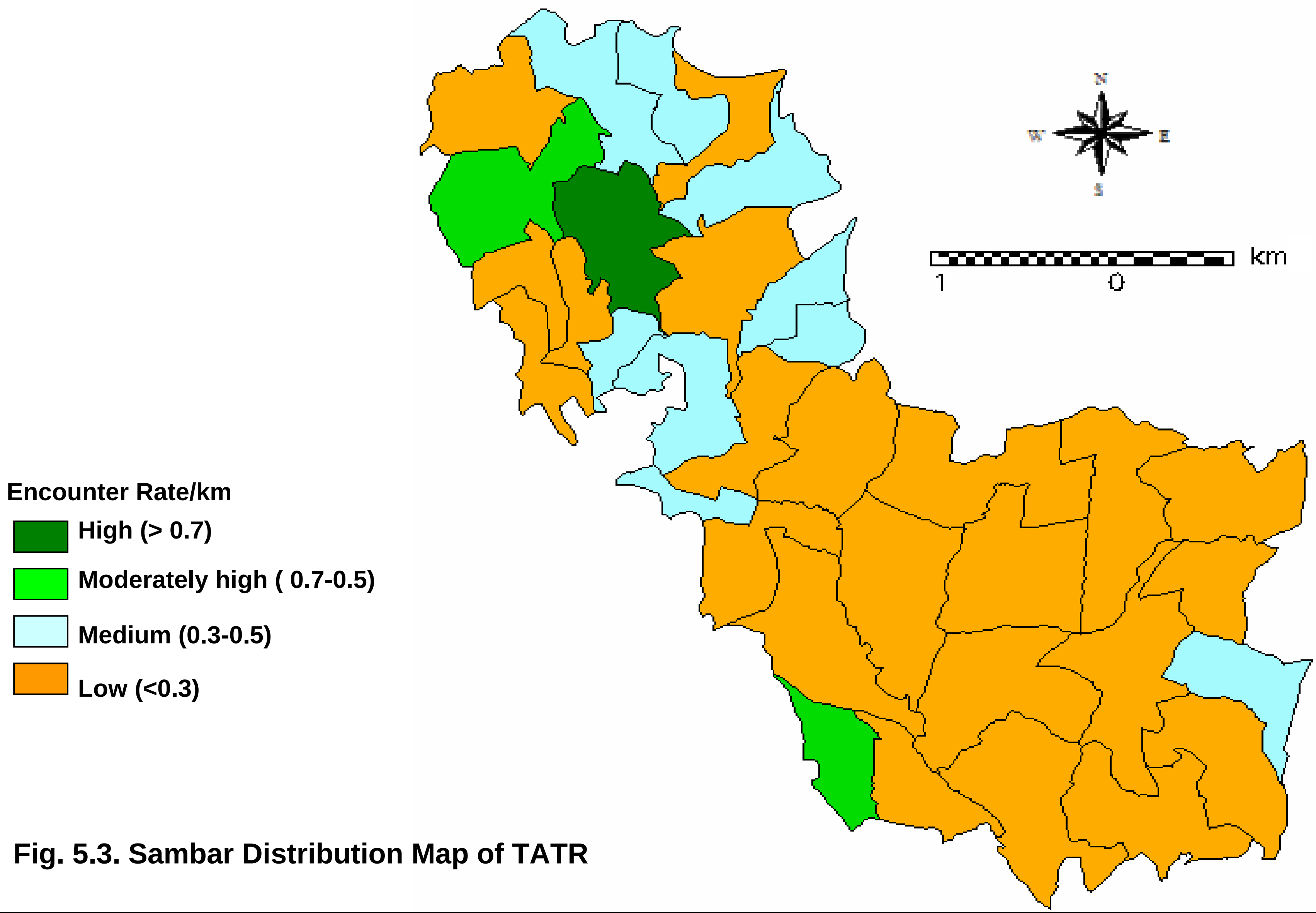


Fig. 5.3. Sambar Distribution Map of TATR

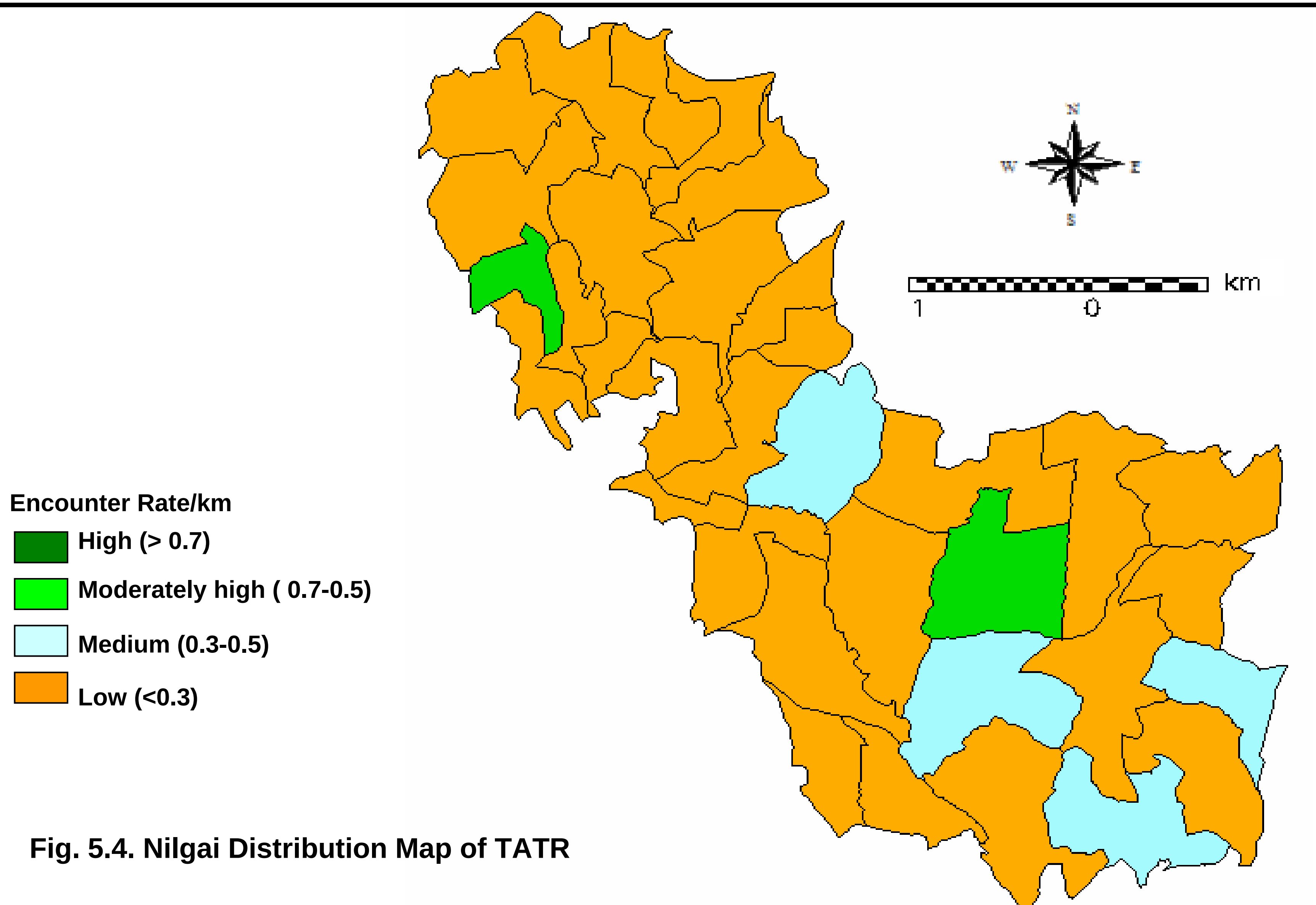


Fig. 5.4. Nilgai Distribution Map of TATR

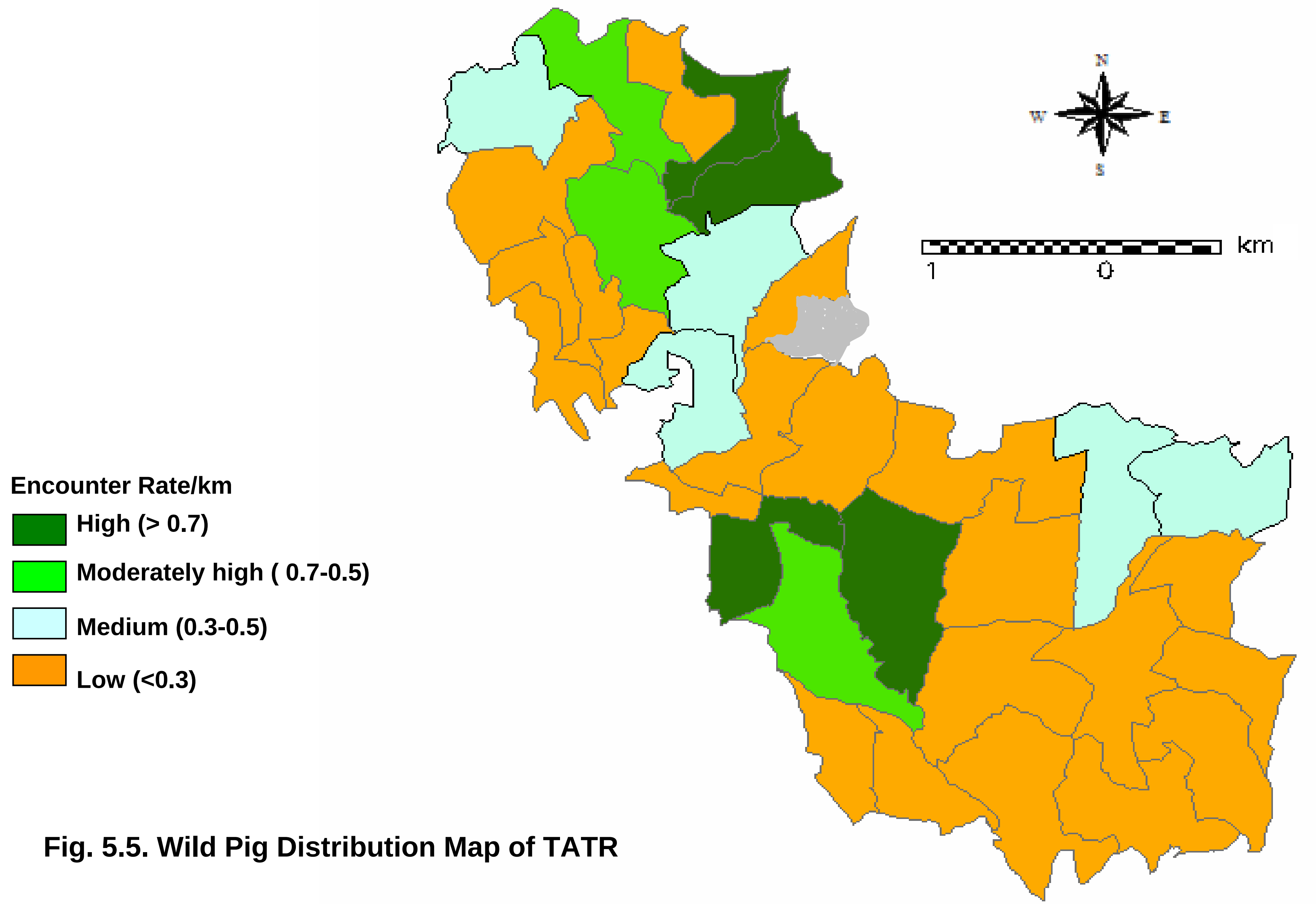


Fig. 5.5. Wild Pig Distribution Map of TATR

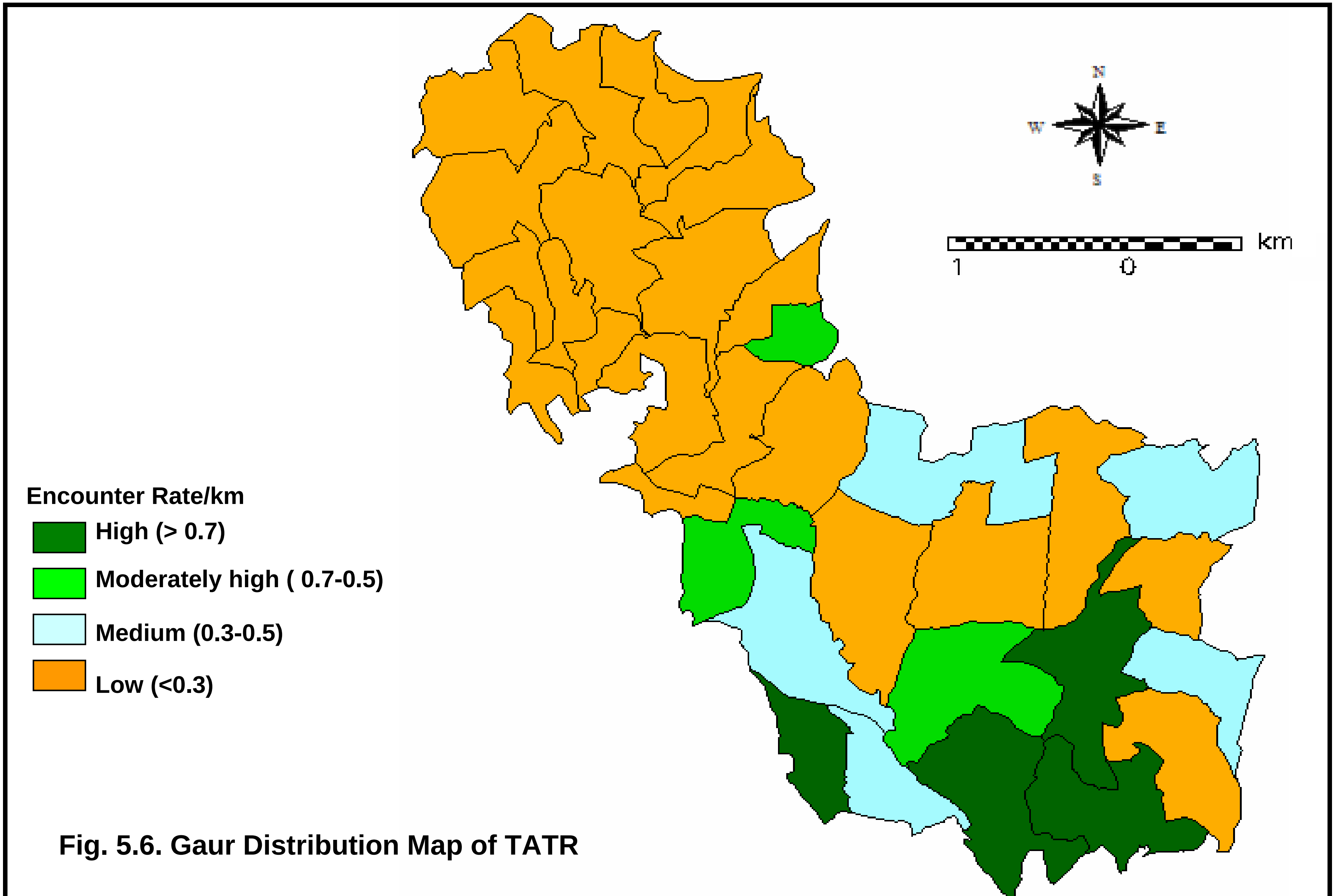
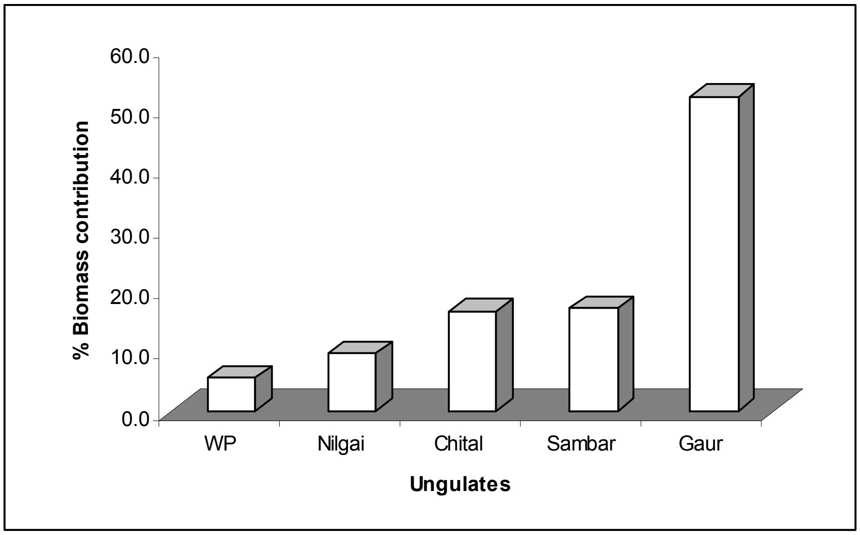


Fig. 5.6. Gaur Distribution Map of TATR

and Gaur in Andhari Wildlife Sanctuary. Wild pig contributed to the least biomass in Tadoba National Park, while Sambar in Andhari Wildlife Sanctuary. Biomasses of ungulates in different tropical studies were compared in Table 5.4.



WP: Wild pig

Figure 5.7. Biomass contribution (%) by ungulates

Table 5.3. Biomasses of ungulate species in different management zones

Species	**Body weight**(kg)	**Tadoba National Park Biomass** (kg km^{-2})	**Andhari Wildlife Sanctuary Biomass** (kg km^{-2})
Chital	47	1370.05	714.4
Sambar	134	1259.6	415.4
Nilgai	180	702	576
WP	32	439.04	374.4
Gaur	450	571.5	4815

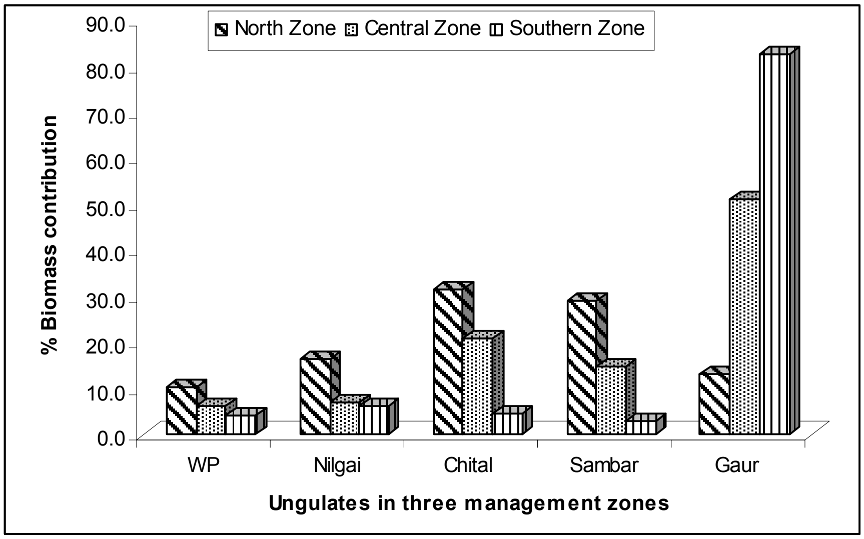


Figure 5.8. Biomass contribution (%) by ungulates in different management zones

Table 5.4 Biomass comparisons of wild ungulates in various tropical forests

Studies in Tropical Dry forests	**Location**	**Biomass Density** (kg km^{-2})
Jathanna *et al.,* (2003)	Ranthambaore Tiger Reserve	6263
Avinandan (2003)	Sariska Tiger Reserve	5503
Biswas & Sankar (2002)	Pench Tiger Reserve	6013
Karanth & Sunquist (1992)	Nagarhole National Park	7638
Khan (1996)	Gir Lion Sanctuary	2764
This study (2008)	Tadoba-Andhari Tiger Reserve	6098

5.3.3. Group size and Population Structure

As shown in Table 5.5, the central zone has highest MGS and north zone has the least. Among all the ungulate species in the TATR landscape, Chital forms the largest group and Sambar forms the smallest group. However, among the different management zones the MGS of Chital, Sambar and Wild pig decrease from north zone to south. On the contrary, mean group size of Gaur increase from north to south zone.

Table 5.5. Mean and typical group sizes of ungulates in zones of TATR

	TATR		North zone		Central zone		South Zone	
	MGS	**TGS**	**MGS**	**TGS**	**MGS**	**TGS**	**MGS**	**TGS**
All Ungulates	3.76 ±0.20)	11.03	3.6(±0.23)	11.7	4.19(±.76)	13.2	3.9(±0.38)	7.07
Chital	5.07(±0.46)	15.9	6.3(±0.79)	15.8	6.05(±2.14)	20.5	2.6(±0.46)	5.04
Sambar	1.7(±0.11)	2.4	1.8(±0.12)	2.5	1.76(±0.32)	2.4	1.16(±0.16)	1.25
Nilgai	2.06 ±0.20)	3	2.03(±0.24)	2.7	2.42(±0.71)	3.7	1.2(±0.16)	3.06
WP	4.89(±0.56)	8.49	5.86(±0.79)	8.9	3.6(±1.3)	10.5	1.2(±0.17	5.3
Gaur	4.4(±0.59)	8.1	2.5(±0.47)	3.5	4.7(±1.2)	8.5	6.13(±0.76)	9

The results of the analyses showed that ratio of overall ungulates were favoured by the females by constituting 41 – 50% of the total population. The maximum females were encountered in Sambar. Contribution of population of fawns and youngs varies from 17-30% to the total population. (Chital had 20.2% of fawn and young population; Sambar, 17%; Nilgai, 30.6%; Wildpig, 23.18% and Gaur, 25%). The maximum fawns were recorded in Wild pig (Table 5.6).

Table 5.6. Population structure of ungulates in overall TATR

	Population Structure by (%) age and sex classes				
	Adult Male	**Adult Female**	**Sub adult Male**	**Sub adult Female**	**Fawn**
Chital	29.70	50.09	2.21	3.78	14.21
Sambar	31.25	51.79	2.68	5.36	8.93
Nilgai	28.36	41.04	5.97	18.66	5.97
Wild Pig	31.76	45.06	1.29	5.58	16.31
Gaur	27.47	47.53	4.67	8.52	11.81

Winter: Among all the wild ungulates Gaur formed the largest group in winters (5.5±0.8 MGS and 9 TGS). Sambar formed the smallest group among the ungulates (1.7 ± 0.17 MGS and 2.3 TGS), as maximum sightings of Sambar (47%) were recorded in group of one. The average population composition of ungulates, their MGS and TGS in winter is given in Table 5.7. The ratio is dominated by females in the composition by 47%. The adult sex ratio (male: female) in Chital is 1:1.6, in Sambar 1:0.21, In Nilgai 1: 1.3 and in Gaur 1:0.2. The fawn contributes to 12% of the population. The maximum fawn: female ratio is found in Chital (1:4.3).

Table 5.7. Population composition and group size of ungulates in winter

	Group size		**Population Composition (%) in Winter**					
	MGS	**TGS**	**Adult Male**	**Adult Female**	**Sub adult Male**	**Sub adult Female**	**Fawn**	**Unidentified**
Chital	4.9(±0.57)	8.2	32.4	45.0	3.5	4.6	11.6	3.0
Sambar	1.7(±0.17)	2.3	27.2	54.0	4.9	2.5	7.4	4.0
Nilgai	2.2(±0.3)	3.3	32.1	40.7	4.9	6.3	9.9	6.0
Wild Pig	4.04(±0.52)	5.6	25.9	48.1	*	*	19.8	6.2
Gaur	5.5(±0.8)	9	24.0	47.7	6.6	6.2	13.3	2.2

Summer: Results from the analyses showed that in summer season Chital has highest MGS (6.5±1 MGS and 19.3 TGS). Similar to winter season Sambar were found to form smallest groups (1.7±0.15 MGS & 2.5 TGS) because of maximum sightings of Sambar (44%) were recorded as single individual. Table 5.8 shows the population composition in summers which is again favoured by females by 45%. The adult sex ratio (male: female) in Chital is 1:1.7, in Sambar 1:1. 4, In Nilgai 1: 1.8 and in Gaur 1:1.3. The fawns contribute to 7% of the population. The maximum fawn: female ratio is found in Chital (1:3.8).

Table 5.8. Population composition and group size of ungulates in summer

	Group size		Population Composition (%) in summer					
	MGS	TGS	Adult Male	Adult Female	Sub adult Male	Sub adult Female	Fawn	Unidentified
Chital	6.5(±1)	19.3	28.99	50.19	5.00	8.12	6.92	0.78
Sambar	1.7(±0.15)	2.5	32.57	46.25	4.40	6.59	3.20	6.00
Nilgai	1.8(±0.23)	2.5	22.64	41.51	7.55	11	7.30	10.00
WP	5.5(±0.8)	10	34.87	43.42	0	-	10.47	11.24
Gaur	5.08(±0.7)	7.8	35.85	47.17	3.5	6.83	2.50	4.15

There was no significant difference found among both the seasons in the mean group sizes of Sambar, Nilgai, Wild pig and Gaur (Sambar: **z** = 1.66, **p**>0.05; Nilgai: **z** = 0.08, **p**>0.05; Wild pig: **z** = 1.04, **p**>0.05; Gaur **z** =0.27, **p**>0.05). However, mean group size of chital showed the significant difference between summers and winters (**z** = 1.99, **p**<0.05).

The sex structure and age structure of ungulate population was compared with few earlier studies and the results are showed in Table 5.9 and 5.10.

Table 5.9. Comparison of sex structure of ungulate populations with other studies

Species	Sex Ratio (M: 100 F)				
	Present study	Dubey (1999)	Karanth &Sunquist (1992)	Pabla (1998)	Schaller (1967)
Chital	59	40	72	37	71
Sambar	50	51.45	42	44	30
Nilgai	103	47	-	37	59
Wild Pig	-	-	-	89	-
Gaur	58	47	18	34	80

Table 5.10. Comparison of age structure of ungulate populations with other studies

Species	Age Ratio (Fawn: 100F)				
	This study (2008)	Dubey (1999)	Sankar (1994)	Pabla (1998)	Schaller (1967)
Chital	28	31.39	22	28.67	67
Sambar	17	31.18	27-45	33.03	33.7
Nilgai	22	16.35	48	31.9	68
Wild Pig	36	20.24	-	96.56	-
Gaur	25	20.18	-	37.32	-

5.4. DISCUSSION

Ecological Comparison of Densities and Biomasses Among Habitats in TATR

Analysis of the data revealed that TATR harbours fairly high ungulate density. Among all the ungulate species, Chital was most abundant both in Tadoba National Park and Andhari Wildlife Sanctuary. Nilgai was observed to have least density. However, in terms of Tadoba National Park, Gaur was found to have least density and Sambar had the least density in Andhari Wildlife Sanctuary.

Among management units Tadoba National Park had higher density of ungulates compared to Andhari Wildlife Sanctuary. The density of Chital, Sambar, Nilgai and Wild pig decreased from northern zone *i.e.* Tadoba National Park to southern zone of Andhari Wildlife Sanctuary, thereby illustrating a southward decreasing trend in densities. This can be attributed to many facts. Firstly, Tadoba National park has a good mosaic of open grasslands and woodlands like Teak Forest, Mixed Forest, Mixed Bamboo Forest, Riparian Forest and Scrub. Since the ungulate growth is governed by forage availability, the high interspersion of different micro- habitat increases habitat heterogeneity and thereby creates ecotones (Leopold, 1961) which, makes the habitat more productive for browsers and grazers. Secondly, Tadoba National Park has the maximum perennial sources of water, Tadoba Lake being the largest. Consequently, various riparian patches are found which provides excellent habitat for animals, since water becomes a limiting factor in TATR during prolonged dry summer season. Thirdly, Tadoba National Park has the fairly undulating topography comprising hillocks as well as plains and this makes the habitat suitable for species like Sambar (Schaller, 1967). All these factors together contribute to make the Tadoba National Park, a favourable habitat for almost all ungulate species.

In contrast, Gaur showed the opposite trend from other ungulate species. The highest density of Gaur was found in southern zone of Andhari Wildlife Sanctuary which decreases northwards. Firstly, this supports the fact that even in large continuous forest tracts, Gaur has the tendency to congregate in some parts of the forest almost to the exclusion of the other (Schaller, 1967). Secondly, since Gaur is a mixed feeder, their diet chiefly includes young and mature leaves of trees, shrubs, herbs, bamboo shoots (*Dendrocalamus strictus* and *Bambusa arundinacea*), buds and fruits of *Aegle marmelos, Bauhinea spp., Cassia fistulla, Diospyros melanoxylon* and *Terminalia bellerica* (Brander 1923, Schaller 1967, Krishnan 1972, Sankar *et al.,* 2000), the southern zone primarily comprises of Mixed Bamboo Forest with interspersion of tall grasslands, which provides forage and therefore provides the excellent habitat for Gaur.

Despite low densities of ungulates in Andhari Wildlife Sanctuary, it contributed maximum biomass to entire reserve. This is attributed to the presence of Gaur. The three herbivore species, Chital, Sambar and Gaur together contribute 84% to the total biomass of TATR. As stated by Mathur (1991) the contribution of over 75% of total wild prey biomass by three species indicates the occupancy of uniform position in the ecosystem, in areas of comparable habitats.

Ecological Comparisons with Other Tropical Forests

On comparing the densities with some studies conducted in western, central and southern tropical forests of India, it became evident, that amongst all places TATR holds second highest densities of Gaur and Widpig. It was also found that Chital density of TATR was higher than Kanha, Panna and Bhadra Tiger Reserves. Sambar density was also found to be higher than Nagarhole, Kanha, Bhadra Tiger Reserves and Gir Lion Sanctuary. Nilgai had second lowest density among all places, higher than Gir. The density estimates from this study were compared to the previous study conducted in the study area (Dubey, 1999), it was found that there has been considerable increase in densities of all the ungulates. Firstly, it could be attributed to management interventions like uniform distribution of waterholes throughout the TATR than earlier times and meadow interspersion among woodlands also contributed in increase in densities. Secondly, it could be attributed due to increase in bamboo over the years, which provide excellent habitat for ungulates in terms of forage and cover and thirdly, the stringent regulation on tourism in the protected area is also one of the reason for increase in densities of ungulates.

Group Size

Chital had the highest mean group size among all ungulates, as it occupies mostly the open habitats and edges. Since group size increases when density increases because of higher encounter rate and fusion of groups (Caughley 1977 and Raman 1997), largest MGS of Chital, Sambar and Wild pig were recorded in Tadoba National Park. Moreover, the Tadoba National Park was found to have maximum resource availability, and as observed by some studies, group sizes increases directly in relation to food availability (Graf & Nicholas 1966, Saratchandra & Gadgil 1975, Mishra 1982, Johnsingh 1983 and Khan *et al.,* 1995). Tadoba National Park has largest MGS of Chital, Sambar and Wild pig were recorded in Tadoba National Park compared to Andhari Wildlife Sanctuary, which favours the formation of larger groups of Chital (Barrette 1991 and Raman 1997) as this is described as one of the antipredator strategy (Saratchandra & Gadgil 1975, Mishra 1982, Karanth & Sunquist 1992, Khan *et al.,* 1995 and Raman *et al.,* 1996). Among the seasons, no significant difference was found in the MGS of Sambar, Nilgai, Wild pig and Gaur. However, Chital showed significant difference in the MGS between the seasons. This finding was corroborated with few studies (Saratchandra & Gadgil 1975, Mishra 1982 and Khan *et al.,* 1995) which indicated that an average Chital groups changes monthly and in seasonal time periods. Larger groups of Chital were observed in months of rutting, thereby facilitating social interactions and breeding opportunities (Graf & Nicholas, 1966).

Population Structure

The sex ratios were found to be in favour of females. This could be due to many reasons Firstly, solitary habits of males make them vulnerable to predation. Secondly, injuries caused by intra-specific aggression and thirdly, lack of alertness during rut and dispersal behaviour (Johnsingh 1983 and Karanth & Sunquist 1992). In addition, as density increases the adult sex ratio in ungulate populations typically favours females (Festa *et al.,* 2003). In the present study the fawn per female ratio was found to decrease as compared to the estimates by Dubey (1999). This finding supports the fact that changes in ungulate population density affect age structure. As the ungulate population increases in density they typically show high juvenile mortality and lower fecundity (Gaillard *et al.,* 2000) leading to an increase in average age of adult females. The age and sex ratios of the TATR were compared to other studies conducted in different tropical areas and it was found that overall results of this study are within the range of variation cited in literature.

HABITAT MODELLING

6.1. INTRODUCTION

Wildlife habitat includes attributes in the environment that serve as life requisites for wildlife allowing them to follow the repeated patterns of survival and reproduction. When expressed in structured meaningful representation of natural system, these patterns form the foundation of modelling in wildlife management. Habitat models are simplified representations of complex ecological processes and cannot include every factor that influences a species occurrence or abundance (Reichert & Omlin, 1997). Predicting species distribution has become an important component of conservation planning in recent years, and wide variety of modelling techniques have been developed for this purpose (Guisan & Thuiller, 2005).

6.1.1. Purpose of Habitat Modelling

Conservation planning requires basic information about distribution and status of natural resources. This task requires mapping of optimum habitats. Knowledge of presence or absence of wildlife species and their distribution across a landscape is critical for making sound wildlife management decisions. However, direct inventories and wildlife surveys are expensive and time consuming (Mack *et al.,* 1997). Because of the expense and impracticability of sampling across a landscape, wildlife habitat models have been frequently used in wildlife management. Habitat models are useful tools for a variety of wildlife management objectives. Distribution of wildlife species can be predicted for geographical areas that have not been extensively surveyed. Predictions of areas of high species diversity (Butterfield *et al.,* 1994) or locations of species of concern (Sperduto & Congalon, 1996) can be used to identify geographic locations for more intensive study. Habitat models are also useful for predicting areas of suitable habitat that may not be currently used by wildlife species (Lawton & Woodroffe, 1991), serving as an aid to species re-introduction or prediction of the spread of an introduced species (Fielding & Haworth, 1995). The primary interest of managers and planners is in the predictions of the impacts of habitat manipulations and management decisions on wildlife species (Anderson & Gutzwiller 1994 and Austin *et al.,* 1996). Models are helpful in providing a framework for formulating hypothesis and research designs which are essential parts of adaptive management. Thus models are crucial for resource decision- making process (Starfield & Bloloch, 1986)

6.1.2. Premise of the Habitat Models

The concept of habitat modelling is based on the Hutchinson's concept of ecological niche (Hutchinson, 1957). Attempts are made to quantify important niche components and to predict a population's response to change in those components (Hirzel & Arlettaz, 2003). All habitat suitability models predict the species occurrence on the basis of ecogeographical predictors. This hypothesis implies that the species are at some sort of equilibrium with their environment.

6.1.3. Modelling Approaches

Models are based on two kinds of approach. Deductive approach where, habitat models are created using existing knowledge of species habitat preferences, physiology and behaviour (Guisan & Zimmerman, 2000) and from these known relationships a model can be constructed to deduce the locations across the landscape where suitable sites for species will occur. Inductive approach where, habitat models are developed from known locations of wildlife species and inferences about quality habitat are derived from habitat measures surrounding these locations.

The procedure of species distribution model ideally follows six main steps: conceptualization, data preparation, model fitting, model evaluation, spatial predictions and assessment of model applicability (Guisan & Zimmerman, 2000).

6.1.4. Habitat Modelling with GIS

Geographic information system (GIS) technology provides efficient means for modelling potential distributions of species and habitats (Johnson, 1990). It has the ability to construct models of habitat that rely on existing or readily obtained information (e.g., remotely sensed images, soil surveys, digital elevation models, geological surveys, topographic maps, etc.). Such models offer the possibility to minimize field work and to conduct focused activities in much smaller areas. It can be easily updated as new information becomes available. GIS-based habitat models are usually based on an exclusively deductive or inductive approach, but few habitat modelling studies have integrated both the techniques. Clark *et al.,* (1993) developed a deductive multivariate model of female black bear (*Ursus americanus*) habitat in the Ozark National Forest based on forest cover and several topographic and spatial parameters. Rudis & Tansey (1995) modelled black bear habitat on a regional basis for the entire south-eastern United States using deductive rules based on Forest Inventory Analysis surveys from the U.S. Forest Service. Homer *et al.,* (1993) used Landsat Thematic Mapper (TM) data to model sage grouse (*Centrocercus urophasianus*) habitat in Northern Utah. Sperduto & Congalton (1996) used GIS to predict potential habitat for the small whorled pogonia (*Isotria medeoloides*), the rarest orchid in eastern North America. Store & Jokimaki (2003) conducted habitat suitability analysis using empirical evaluation models and models based on expertise in GIS. Posillico *et al.,* (2004) modelled brown bear in the central Apennines. GIS based habitat model was developed for the Virginia northern flying squirrel in West Virginia (Menzel *et al.,* 2005). Suitability of habitat was predicted for the large grazing ungulates by Traill & Bigalke (2006).

In the Indian context, there is a dearth of literature pertaining to species habitat modelling. Most of the studies follow the deductive modelling approach. Kushwaha *et al.,* (2000), evaluated the habitat suitability of Chilla sanctuary for Goral. Roy *et al.,* (1995) developed the habitat suitability maps for Rajaji National Park using GIS deductive approach. Habitat of Sambar was analysed in terms of food, cover, water and extent of edge using remote sensing and GIS by Pant *et al.,* (1999). Habitat suitability analysis of Rhino was conducted using remote sensing and GIS by Kushwaha *et al.,* (2000). Porwal *et al.,* (1996) studied habitat suitability analysis of Sambar in two ranges of Kanha National Park using Landsat Thematic Mapper (TM). Study highlighting synergiestic use of field survey, geostatistical analysis and geospatial tools for evaluation of Sambar and Muntjak habitats was carried out by Kushwaha *et al.,* (2004).

An attempt has been made in this study to develop habitat models for five major ungulate species *i.e.* Chital, Sambar, Nilgai, Gaur, Wild pig using Ecological Niche Factor Analysis (ENFA) and GIS. The environment envelope approach has been opted because absence of evidence cannot be equated with evidence of absence. The objective of the exercise is to assess the current status of these species and to explore the species specific ecological habitat requirements to devise sound management practices which may be applied for effective management.

6.2. METHODS

6.2.1. Species Studied

The five major ungulate species of TATR *viz.,* Chital (*Axis axis*), Sambar (*Cervus unicolor*), Gaur (*Bos gaurus*), Nilgai (*Boselaphus tragocamelus*) and Wild pig (*Sus scrofa*), were studied for the purpose of habitat modelling. These species were selected for the following reasons. First, owing to their broad spatial habitat requirement, they can be used to study species-habitat relationships. Secondly, for the inevitability of long term conservation of large carnivores, the protection of the viable populations of wild ungulates is necessary which can only be ensured by protecting their habitats.

6.2.2. Species Data

The entire TATR was sampled using line transects adopting a systematic stratified design. The data which was collected from the line transects for the ungulate density estimation was used for sampling. Each transect was walked 4-6 times. The mean Encounter Rate (ER) of each species on each transect was derived. The ERs of the species where categorized under five wieghtage classes. ER ranging from 0.01-0.2 in Class 1; 0.21-0.3 in class 2; 0.31-0.4 in class 3; 0.41-0.5 in class 4 and > 0.51 in class 5. Each transect was then considered as the representative of the animal presence data. The weightages of species presence data was used instead of boolean.

6.2.3. Ecogeographical Variables (EGVs)

The study area was modelled as a raster map based on UTM (Universal Transverse Mercator), coordinate system, consisting of 157 cells of 4 km^2 (2X2km) each. A total of 21 continuous variables were used for preliminary analyses which were categorized under four environmental descriptor classes as given in Table 6.1 (i) Topographic variables (elevation) (Fig. 6.1) (ii) Anthropogenic variables (distance from villages, roads, area of fire occurrence and fire frequency) (Fig. 6.2 to Fig. 6.4) (iii) Habitat variables (comprise of canopy classes, vegetation types and NDVI) (Fig. 6.5 and Fig. 6.6) (iv) Hydrological variables (distance from water and drainage) (Fig. 6.7. and Fig. 6.8.). These variables were chosen on the basis of information provided by Schaller (1967) and supplemented by field knowledge.

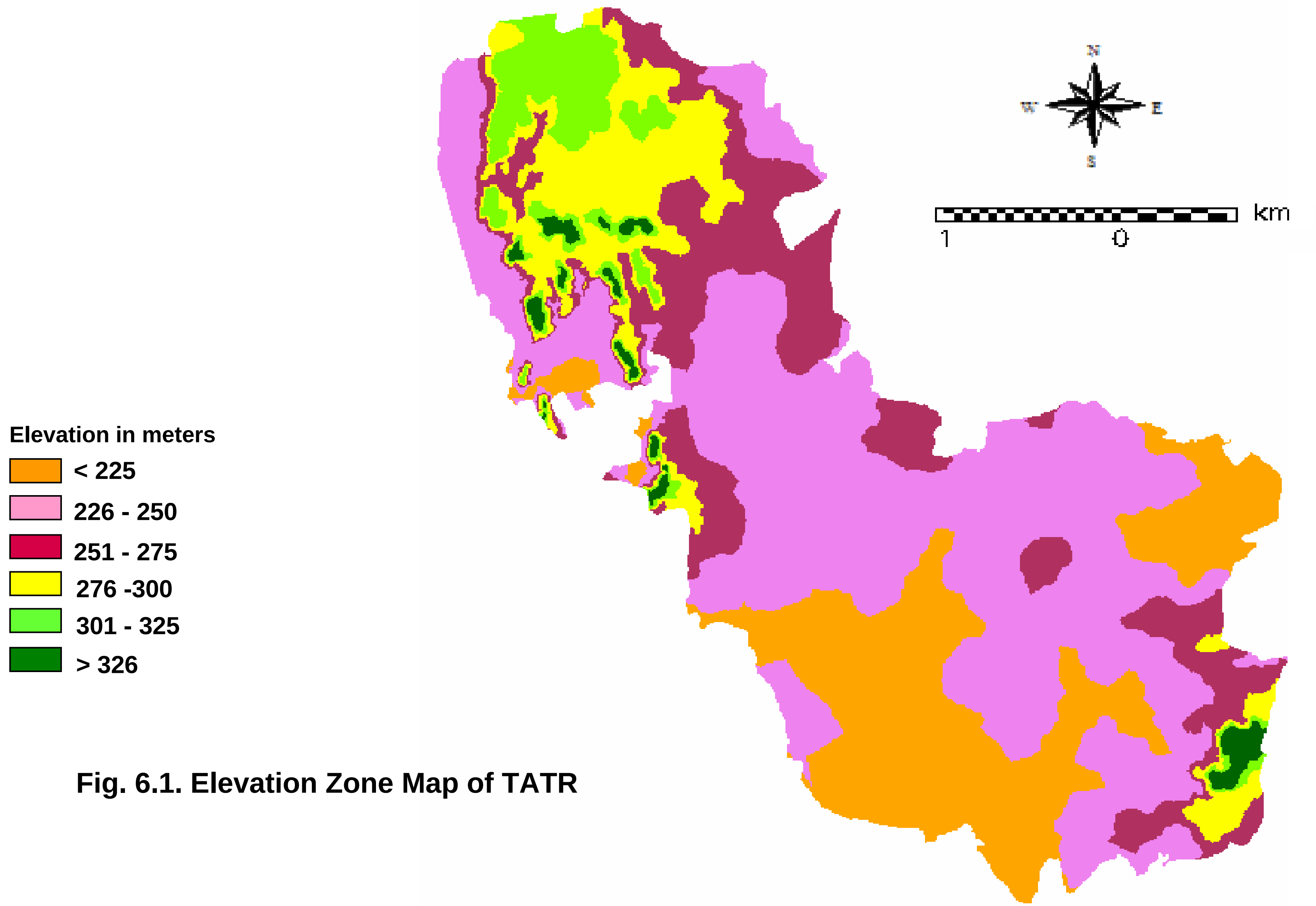
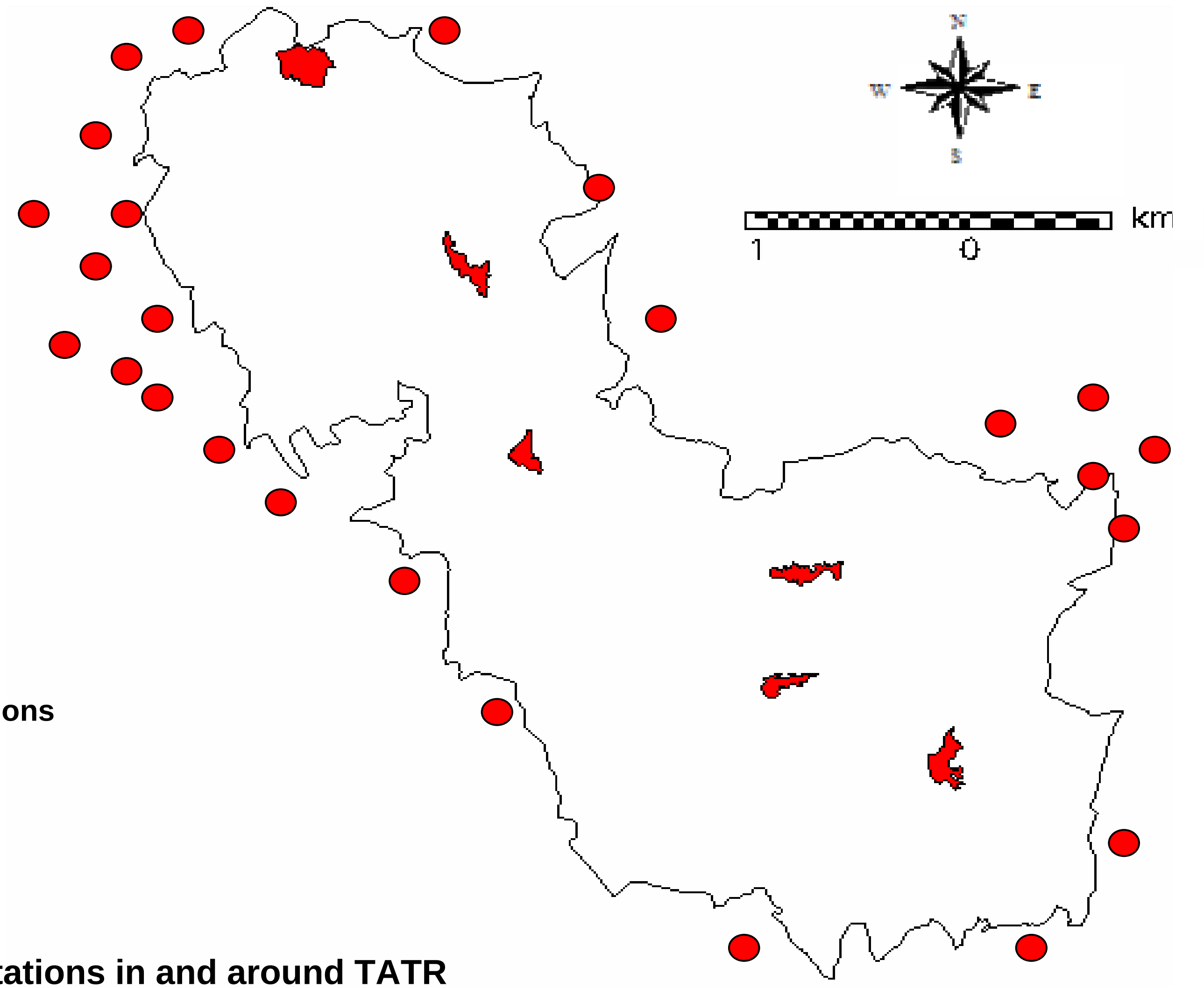


Fig. 6.1. Elevation Zone Map of TATR



Human Habitations

Fig. 6.2. Human habitations in and around TATR

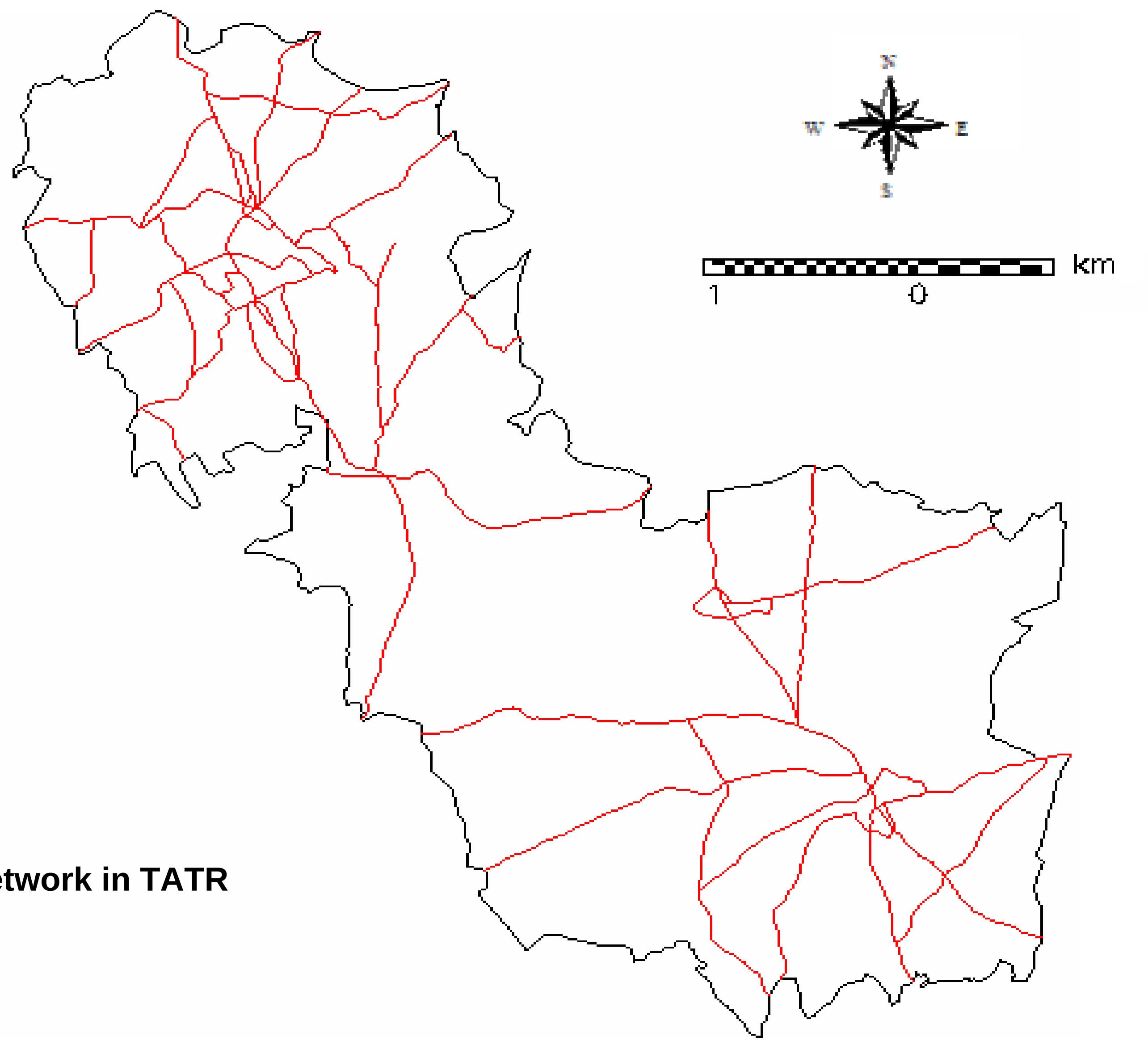


Fig. 6.3. Road Network in TATR

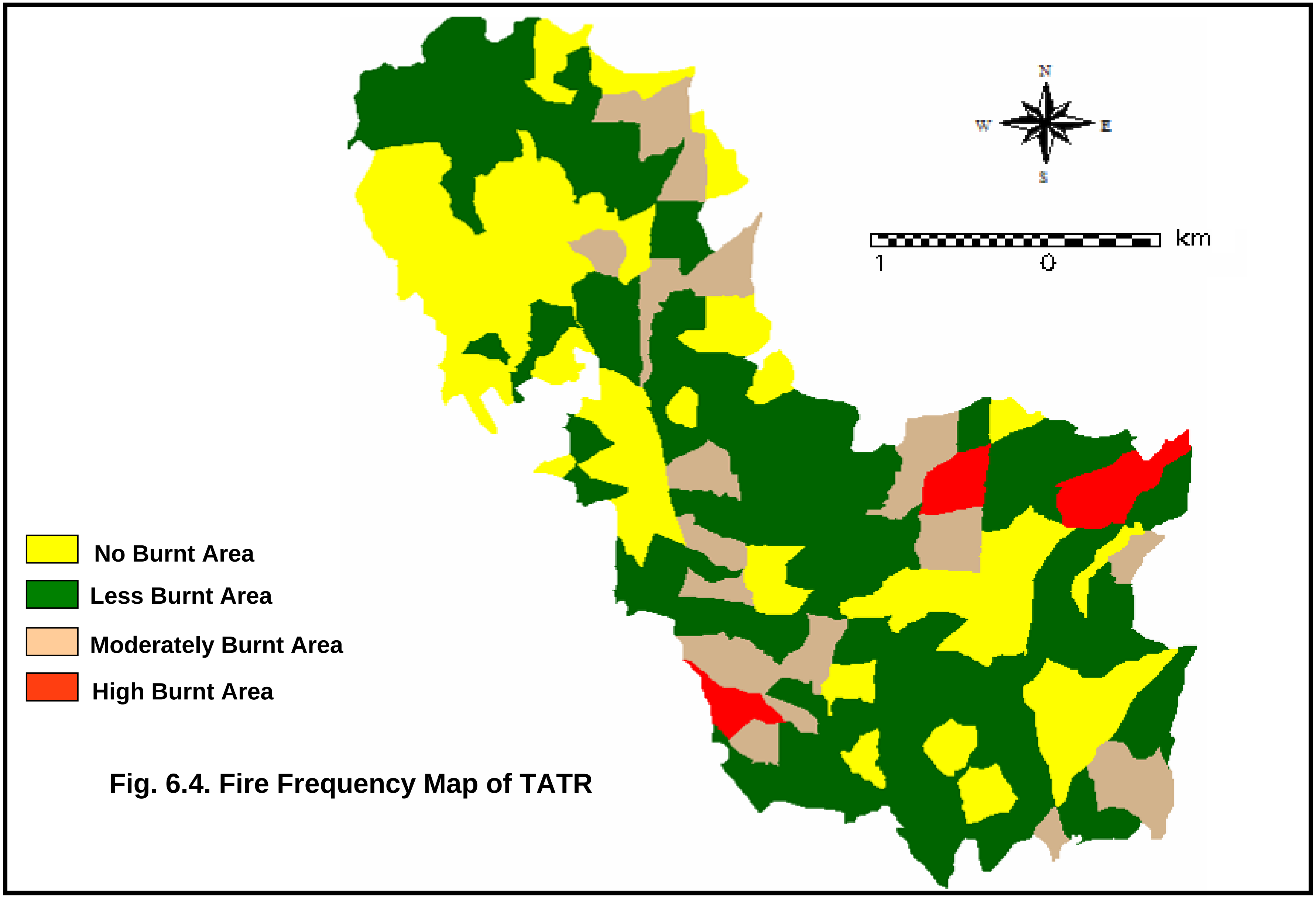


Fig. 6.4. Fire Frequency Map of TATR

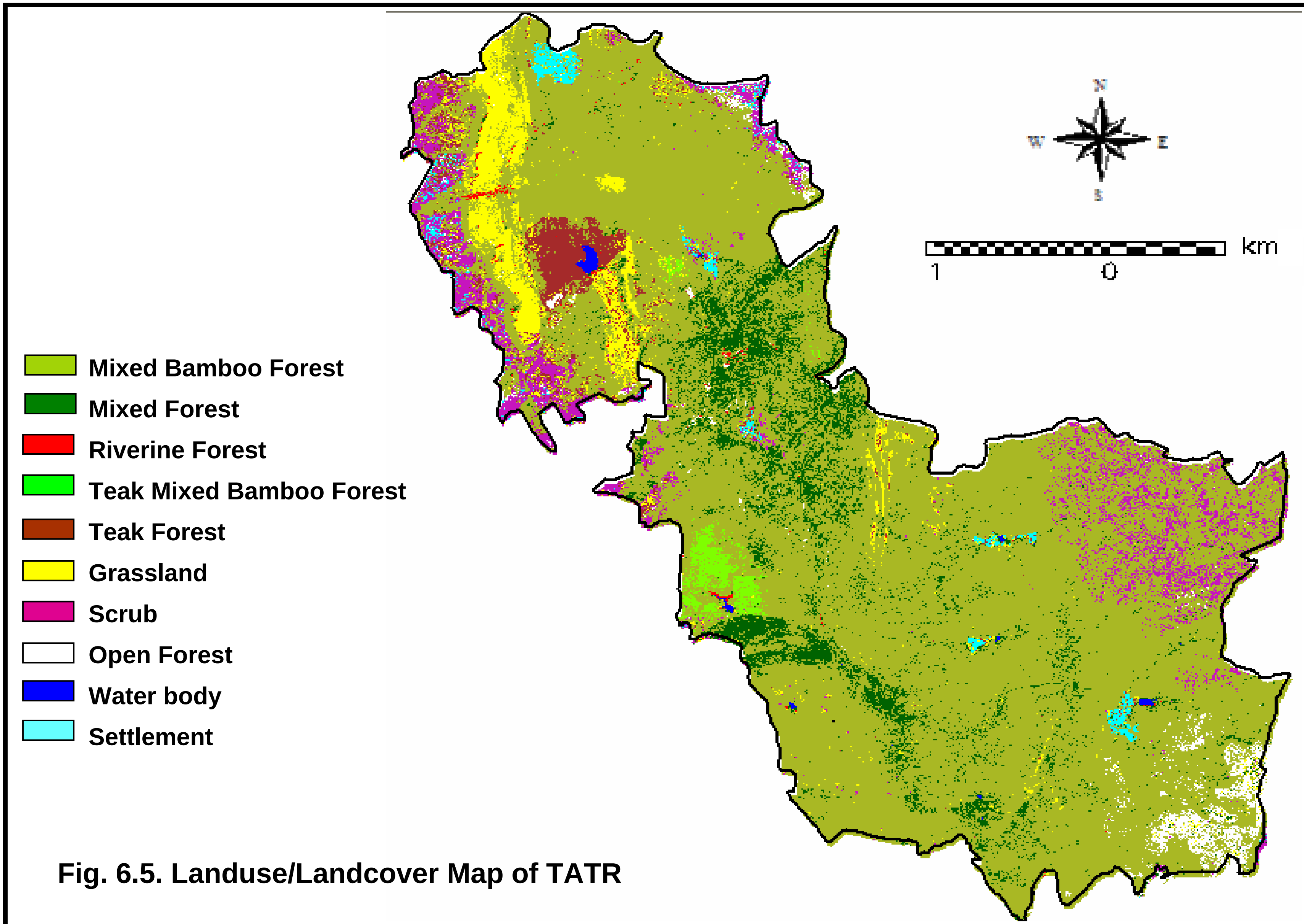


Fig. 6.5. Landuse/Landcover Map of TATR

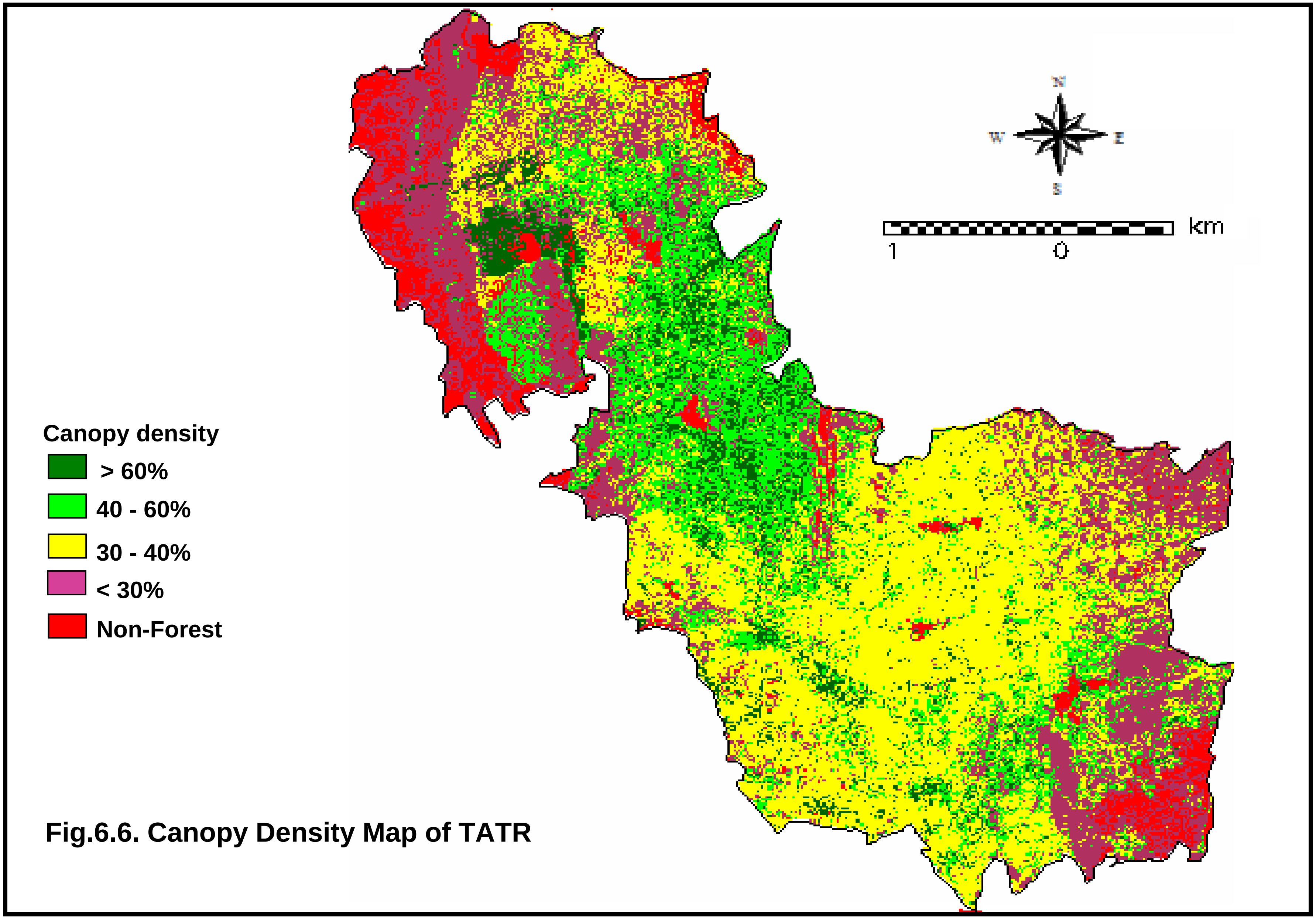
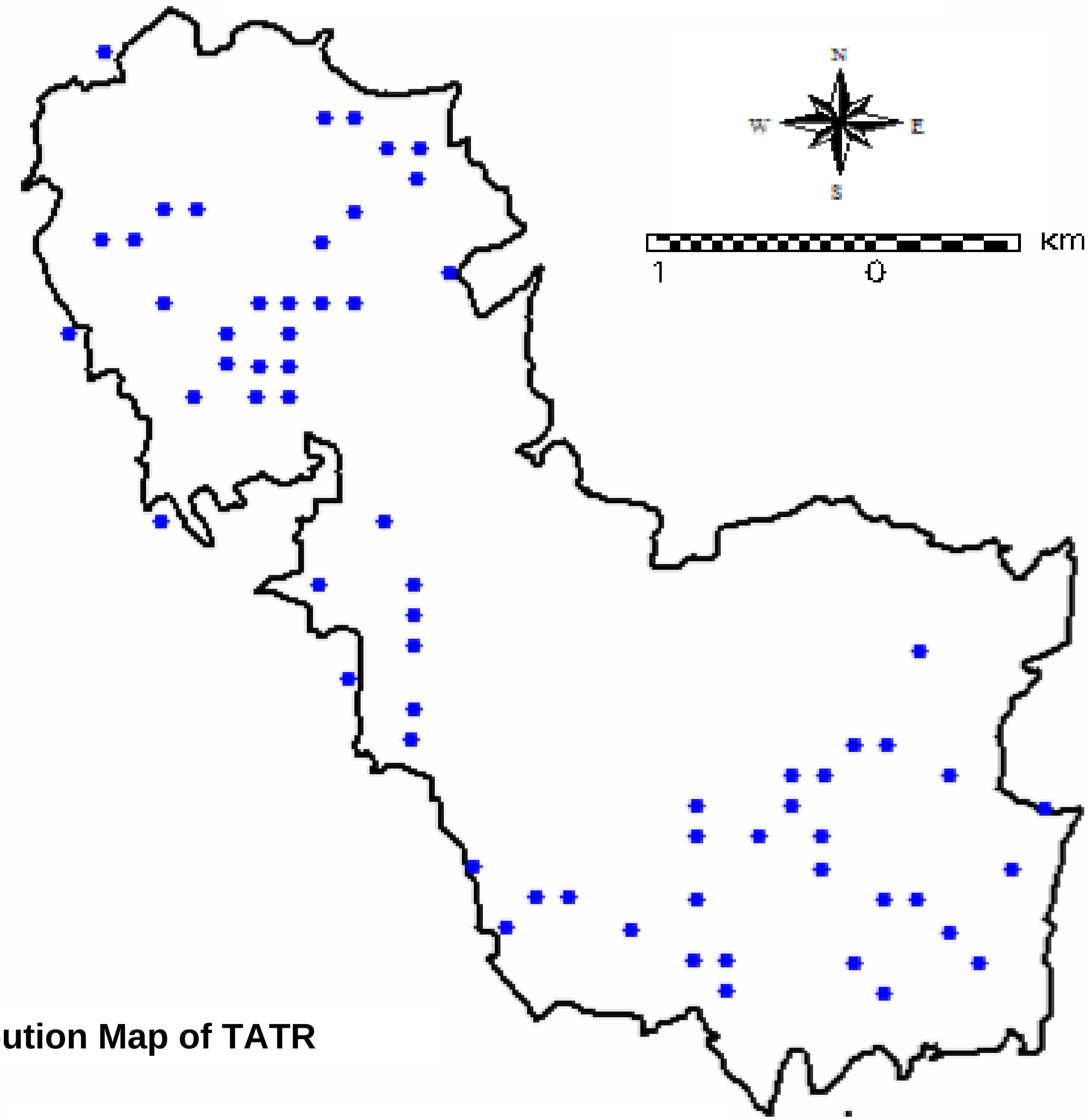


Fig.6.6. Canopy Density Map of TATR



Waterholes

Fig. 6.7. Waterhole Distribution Map of TATR

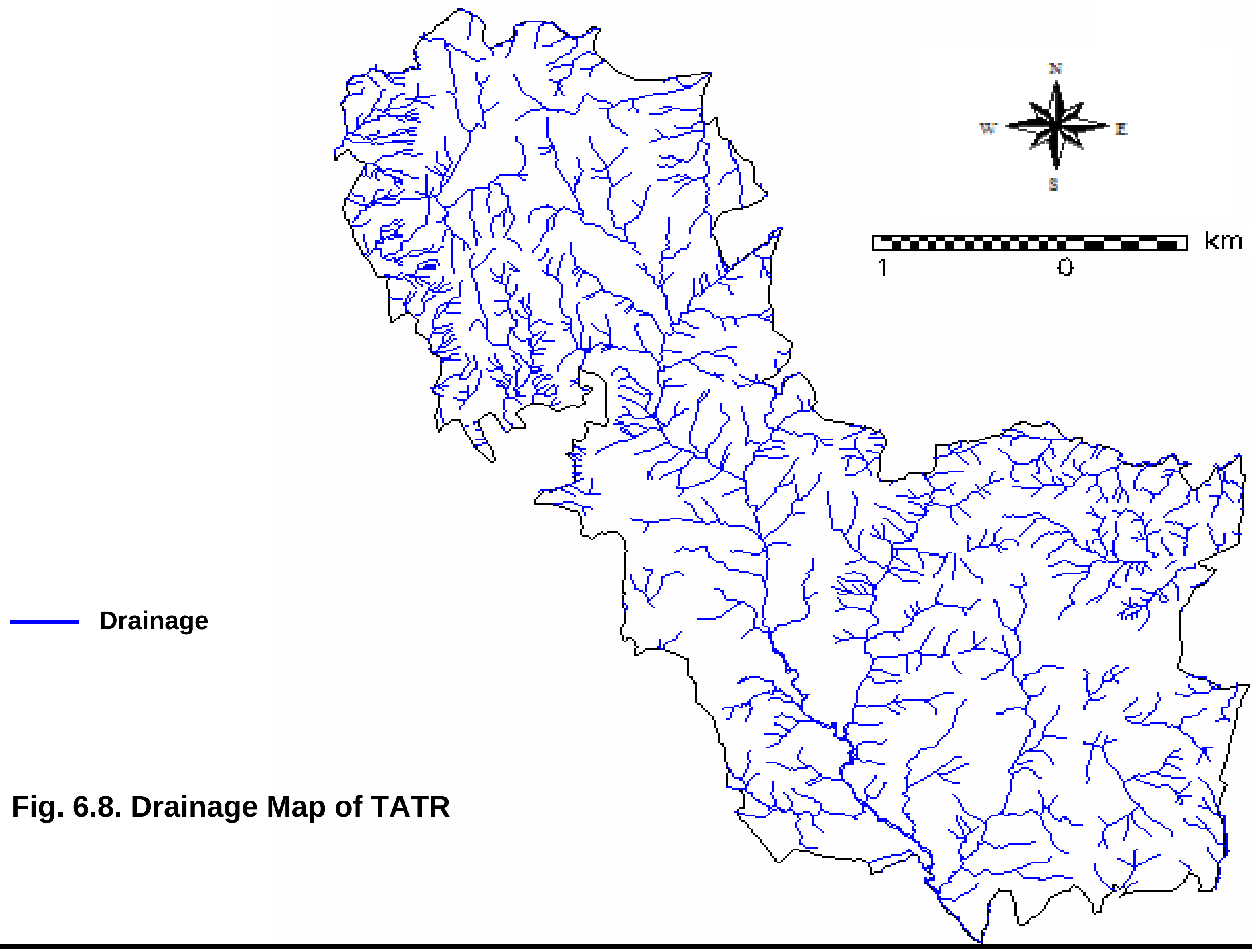


Fig. 6.8. Drainage Map of TATR

Table 6.1. Environmental variables used in ENFA

	Descriptor	Ecogegraphical variable	Data source
1.	Habitat variables	Mixed forest Mixed bamboo forest Riparian forest Teak forest Teak mixed forest Open forest Scrub Grassland	Land use/cover map from IRS P6 LISS IV data
		Canopy nil Canopy < 30% Canopy 30-40% Canopy 40-60% Canopy >60% NDVI	Forest density map from IRS P6 LISS IV data
2.	Anthropogenic variables	Distance from villages (mean)	Village location map (WII)
		Distance from roads (mean)	Road map
		Area burnt (mean)	Forest department, TATR
		Fire frequency (mean)	Forest department, TATR
3.	Topographic variable	Elevation (mean)	Contour map
4.	Hydrological variables	Distance from water sources(mean)	Water source map
		Distance from drainage (mean)	Drainage map

Area occupied by each vegetation type and canopy density class was extracted grid-wise (2X2 km) from vegetation map and canopy density maps. A separate layer was prepared for each vegetation type thereby computing the area for each habitat variable. Toposheets were digitized to create layers of roads, drainage and contour. Digital elevation model was prepared using 10 m contour interval data. Village polygon data was taken from the village database of Chandrapur district available at Wildlife Institute of India and a centroid was generated to make it a point data. The Euclidean distance was then computed for villages and roads. The five year (2000-05) data on fire incidences and area burnt was taken from forest department. The database of fire was then generated in GIS domain. All water points were recorded using GPS. The locations were then downloaded and a coverage representing the Euclidean distance from each water point was created. All the maps were rasterized using Arc View 3.2 (ESRI, 1996) and Arc Map (ESRI 2004). The fishnet of 2X2 km was laid over all the raster layers and the data was extracted for each cell. The maps were then converted to IDRISI (Eastman, 1990). All the variables were then tested for the correlation. Two or more variables which were strongly correlated (r >0.7), were discarded to avoid redundancy in the predictors. Based on quality of information 14 variables were retained for the model (Table 6.2).

Table 6.2. Environmental variables retained for ENFA

	Ecogegraphical variables (EGVs)	Discard criteria and action taken
1.	Mixed forest	Correlated with Canopy 40-60% (r =0.85) & >60% (r =0.88), discarded
2.	Mixed bamboo forest	Correlated with Canopy <30% (r =0.75) & 40-60% (r =0.77), discarded
3.	Riparian forest *	Used in analysis
4.	Teak forest *	Used in analysis
5.	Teak mixed forest *	Used in analysis
6.	Open forest *	Used in analysis
7.	Scrub	Used in analysis
8.	Grassland	Correlated with canopy nil (r =0.88), discarded
9.	Non-forest	Used in analysis
10.	Canopy < 30% *	Used in analysis
11.	Canopy 30-40%	Correlated with Teak forest (r =0.79) & Teak mixed forest (r =0.82), discarded
12.	Canopy 40-60% *	Used in analysis
13.	Canopy >60% *	Used in analysis
14.	NDVI	Correlated with Canopy 40-60% (r =0.90) & Canopy >60% (r =0.95), discarded
15.	Distance from villages *	Used in analysis
16.	Distance from roads *	Used in analysis
17.	Area burnt *	Used in analysis
18.	Fire frequency	Correlated with fire occurrence area (r =0.72), discarded
19.	Elevation *	Used in analysis
20.	Distance from water sources *	Used in analysis
21.	Distance from drainage	Correlated with drainage (r =0.76)

** Variables retained for analysis in the present study*

6.2.4. Ecological Niche Factor Analysis (ENFA)

It is modelling technique developed to predict species potential distribution from presence only data (Hirzel *et al.,* 2002). It is based on niche theory and provides habitat suitability maps that implicitly reveal potential distribution of species. ENFA is an alternative approach to modelling species potential distributions when there is no reliable absence data available. It was developed using Biomapper 3.2 (Hirzel *et al.,* 2006). It assumes that the environmental conditions are optimal where species is most frequently found (Hirzel *et al.,* 2001). This programme has been used in several studies (Hirzel & Arlettaz 2003, Chefaoui *et al.,* 2004, Traill & Bigalke 2006, Santos *et al.,* 2006, Sattler *et al.,* 2007, Braunisch *et al.,* 2008). Redundancies in the environmental predictors are removed and are replaced by few uncorrelated factors summarizing most of the environmental information. The factors have ecological meaning: the first factor is the 'marginality' and reflects the direction in which the species niche mostly differs from the available conditions from the global area. *Marginality* (*M*) is defined as absolute difference between global mean (m_G) and species mean (m_S), divided by 1.96 standard deviations (σ_G) of global distribution.

$$M = \frac{|m_G - m_S|}{1.96\,\sigma_G}$$

Subsequent factors represent the 'specialization'. They are extracted successively by computing the direction that maximizes the ratio of the variance of the global distribution to that of the species distribution. *Specialization (S)* is defined as the ratio of standard deviation of the global distribution (σ_G) to that of focal species (σ_S),

$$S = \frac{\sigma_G}{\sigma_S}$$

The inverse of specialization is therefore a measure of species 'tolerance'. *Marginality* and *Specialization* are uncorrelated factors, with the major information contained in with in the first factor (Hirzel *et al.,* 2002).

The marginality factor expresses the marginality of the focal species on each EGV. The negative coefficients indicate that the focal species prefers values that are lower than the mean with respect to the study area, while positive coefficients indicate preference for higher than mean values. The interpretation of the subsequent factors is different. The higher the absolute value, the more restricted is the range of focal species on the corresponding variable. The signs are arbitrary in these variables.

6.2.5. Habitat Suitability Algorithm

The habitat suitability maps were calculated by median algorithm. To compute the median algorithm, the species range was divided on each factor in 25 classes, in such a way that the median would exactly separate two classes. For every point in environmental space, the number of observations that are either in same class or in any class further apart from the median were counted. To achieve normalization, twice this number was divided by the total number of observations. Thus, a point lying outside the observation distribution got a value of zero. Lastly, the overall suitability index for this point was computed by the weighted average of its scores on each dimension and the weights were given by amount of information explained by each dimension. This algorithm makes an assumption that the best habitat is at the median of the species distribution.

6.2.6. Validation/Evaluation

The habitat suitability map was evaluated for predictive accuracy by a cross validation procedure (Boyce *et al.,* 2002). The species locations were randomly partitioned into k mutually exclusive but identically sized sets. Each k minus 1 partition was used to compute a habitat suitability model and a left out partition was used to validate it on independent data. The process was repeated k times, each time by leaving out a different partition. The process resulted in k different habitat suitability maps and the comparison of these maps and how they fluctuated, provided an assessment of predictive power. The number of partition used was four. Each map was reclassified into *i* bins, where each bin *i* covered some proportion of total study area (*Ai*) and contained some proportion of validation points (*Ni*). The number of bins used were three. The area adjusted frequency for each bin was computed as *Fi= Ni/ Ai.* The expected *F*i was 1 for all the bins if the model was completely random. If the model was good, low values of habitat suitability should have low F (below 1) and high values a high *F* (above 1) with a monotonic increase in between. The approach followed in overall modelling is shown by Fig.6.9.

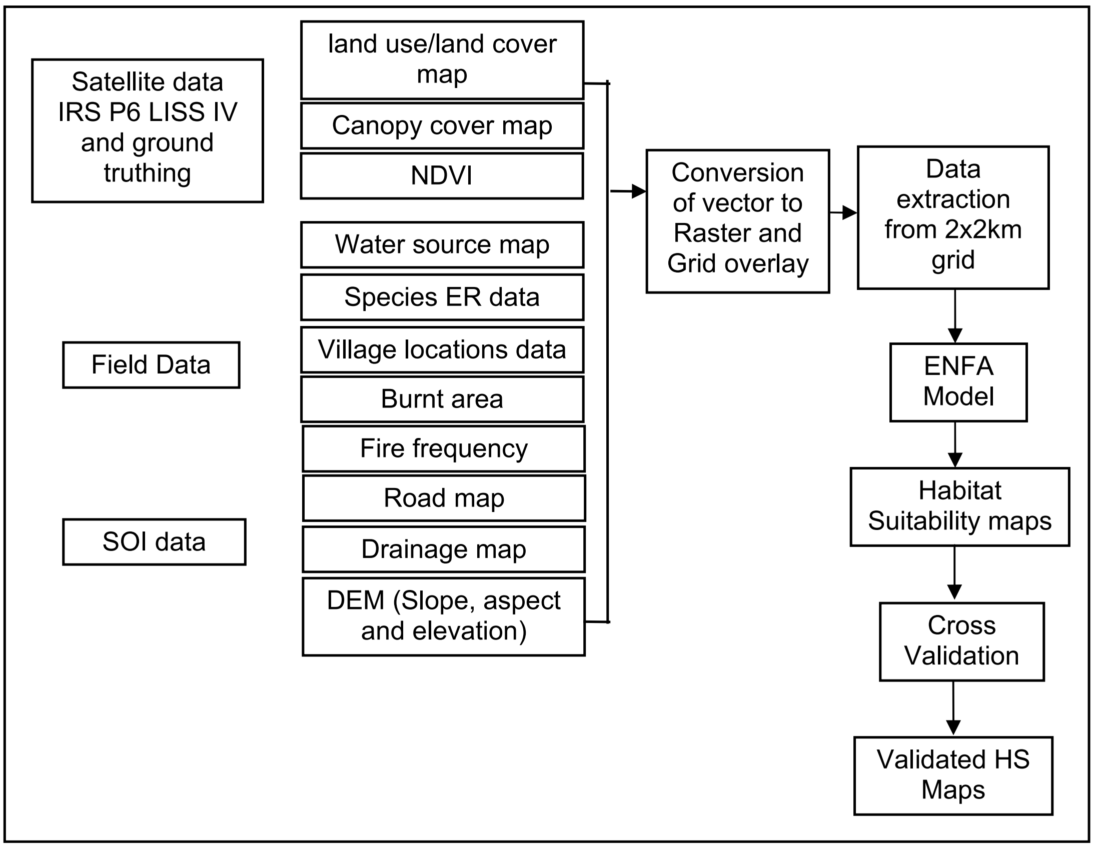


Figure 6.9. Approach used in habitat modelling

6.3. RESULTS

6.3.1. Habitat Suitability Model for Chital

Out of 14 factors, seven factors were retained which accounted for 83% of information. The marginality accounted for 20% of total specialization. The model resulted in marginality (*M*) of 0.58 and specialization (*S*) of 1.39.

Marginality coefficients shown in Table 6.3 indicate that the Chital showed affinity towards roads (-0.502), canopy < 30% (0.448), canopy > 60% (0.308), burnt area (0.262) and Riparian Forest (0.207). However, it avoided elevation (-0.334), villages (0.296), Scrub (-0.06) and Open Forest (-0.099).

The rest of the other factors explained specialization. High values of EGVs in other factors indicated the narrow range of the species on these variables. Elevation, distance from road and distance from water in Spec.1. Open Forest, non-forest and distance from road in Spec.2. Distance from road, canopy 40- 60% and distance from water in Spec.3. Elevation, Open Forest in Spec.4. Scrub in Spec.5 and distance from village in Spec.6.

Table 6.3. Correlation between ENFA factors and EGVs for Chital

EGVs	**Marginality (20%)**	**Spec 1 (18%)**	**Spec 2 (16%)**	**Spec 3 (10%)**	**Spec 4 (8%)**	**Spec 5 (6%)**	**Spec 6 (5%)**
Canopy<30%	0.448	0.026	-0.148	-0.195	-0.22	0.041	0.141
Canopy40-60%	0.224	-0.105	-0.41	-0.435	-0.214	-0.006	0.51
Canopy>60%	0.308	0.028	-0.341	-0.239	-0.099	-0.107	0.048
Non-forest	-0.029	-0.131	-0.387	0.073	0.356	-0.094	0.239
Elevation	-0.334	-0.562	-0.262	-0.028	-0.685	0.257	0.032
Area Burnt	0.262	0.099	-0.157	0.125	0.144	0.372	0.295
Open Forest	-0.099	-0.093	-0.408	-0.015	0.439	0.037	-0.168
Riparian Forest	0.207	0.154	0.034	0.024	-0.052	0.137	0.079
Distance from road	-0.502	0.544	-0.376	-0.507	0.027	0.153	0.243
Scrub	-0.06	-0.134	0.105	-0.175	-0.128	-0.845	-0.142
Teak Forest	0.195	0.035	0.103	0.074	0.005	0.073	0.132
Teak Mixed Forest	0.197	0.032	-0.006	0.091	0.033	0.001	-0.022
Distance from village	0.296	-0.015	-0.142	-0.288	-0.087	-0.04	-0.654
Distance from water	0.001	0.544	-0.315	0.556	-0.242	-0.089	-0.115

6.3.2. Habitat Suitability Model for Sambar

Six factors were retained out of 14 factors which accounted for 85% of information. The marginality accounted for 9% of total specialization. The model resulted in marginality (*M*) of 1.002 and specialization (*S*) of 1.77.

As shown in Table 6.4. the presence of sambar was positively associated with canopy > 60% (0.502), elevation (0.421), Teak Forest (0.467) and Riparian Forest (0.347). On the contrary it responded negatively to distance from villages (0.137), Scrub (-0.129) and Open Forest (-0.121).

The other factors accounted for some more specialization thereby showing some sensitivity to shifts away from their optimal values on these variables. In Spec.1 Open Forest and Scrub, in Spec.2 Scrub and distance from water, distance from road inS.3 & 4, non-forest in Spec.5.

Table 6.4. Correlation between ENFA factors and EGVs for Sambar

EGVs	Marginality (9%)	Spec.1 (35%)	Spec.2 (15%)	Spec.3 (13%)	Spec.4 (7%)	Spec.5 (6%)
Canopy<30%	0.183	-0.058	-0.208	0.022	0.025	0.46
Canopy40-60%	0.058	-0.144	-0.031	0.294	0.473	0.224
Canopy>60%	0.502	-0.061	0.015	-0.001	0.204	0.346
Non-forest	-0.001	0.096	-0.171	-0.074	0.052	0.464
Elevation	0.421	0.311	0.391	-0.415	0.073	-0.36
Area Burnt	0.051	-0.077	0.126	0.251	0.233	-0.249
Open Forest	-0.121	0.694	0.277	0.413	0.154	-0.158
Riparian Forest	0.347	-0.031	0.027	-0.032	0.001	-0.131
Distance from road	-0.296	0.151	-0.04	-0.471	0.712	-0.102
Scrub	-0.129	-0.573	0.622	0.242	0.035	0.024
Teak Forest	0.467	-0.004	0.016	0.116	0.032	-0.306
Teak Mixed Forest	0.214	0.001	0.021	0.025	-0.065	-0.028
Distance from village	0.137	0.036	-0.038	-0.069	0.175	0.234
Distance from water	-0.099	0.158	0.538	-0.449	-0.323	-0.098

6.3.3. Habitat Suitability Model for Gaur: Five factors were retained out of 14 factors which accounted for 85% of information. The marginality accounted for 9% of total specialization. The model resulted in marginality (*M*) of 0.56 and specialization (*S*) of 2.608.

The presence of gaur showed the positive association (Table 6.5) with canopy 40-60% (0.548), canopy < 30% (0.234), roads (-0.493), .However, it was negatively associated with elevation (-0.41), non-forest (-0.205), Riparian forest (-0.224), Scrub (-0.081), Teak Forest (-0.195), Teak Mixed Forest (-0.097).

The other factors accounted for some sensitivity to shifts away from their optimal values on following variables. In Spec.1, Riparian Forest, elevation and nil canopy in Spec.2, Teak Mixed Forest in Spec.3 & 4.

Table 6.5. Correlation between ENFA factors and EGVs for Gaur

EGVs	Marginality (29%)	Spec.1 (34%)	Spec.2 (9%)	Spec.3 (8%)	Spec.4 (6%)
Canopy<30%	0.234	-0.105	-0.236	-0.076	-0.106
Canopy40-60%	0.548	-0.118	-0.426	0.022	-0.215
Canopy>60%	0.099	-0.112	-0.374	-0.133	-0.128
Non-forest	-0.205	0.186	-0.456	0.244	0.016
Elevation	-0.41	-0.106	-0.532	-0.082	0.069
Area Burnt	0.194	-0.082	-0.014	-0.171	-0.224
Open Forest	0.069	-0.038	-0.046	0.035	-0.011
Riparian Forest	-0.224	-0.909	0.159	0.131	0.092
Distance from road	-0.493	0.048	-0.207	-0.434	-0.403
Scrub	-0.081	0.09	-0.014	0.379	0.352
Teak Forest	-0.195	0.115	0.229	-0.04	0.04
Teak Mixed Forest	-0.097	0.077	-0.051	0.484	-0.753
Distance from village	0.185	-0.122	-0.029	-0.163	0.087
Distance from water	0.034	-0.193	-0.074	-0.518	0.011

6.3.4. Habitat Suitability Model for Nilgai

Six factors were retained out of 14 factors which accounted for 80% of information. The marginality accounted for 17% of total specialization. The model resulted in marginality (*M*) of 0.684 and specialization (*S*) of 1.424.

Marginality component of Table 6.6 revealed strong positive association of nilgai with canopy below 30% (0.581), non-forest (0.373), Scrub (0.424), roads (-0.312) and village (0.078). It was found to be negatively associated with canopy > 60% (-0.155), elevation (-0.009).

The narrow range of the species was indicated on the different variables of subsequent specialization factors. Canopy > 60% in Spec.1, canopy 40-60% and distance from road in Spec.2, canopy > 60% in Spec.3, elevation in Spec.4, and nil canopy and elevation in Spec.5.

Table 6.6. Correlation between ENFA factors and EGVs for Nilgai

EGVs	Marginality (17%)	Spec.1 (26%)	Spec.2 (15%)	Spec.3 (9%)	Spec.4 (8%)	Spec.5 (5%)
Canopy<30%	0.581	-0.006	-0.241	-0.08	-0.236	-0.04
Canopy40-60%	0.081	-0.14	-0.548	0.098	-0.101	-0.123
Canopy>60%	-0.155	-0.328	-0.401	-0.646	-0.125	0.202
Non-forest	0.373	-0.044	-0.117	0.109	-0.046	0.526
Elevation	-0.009	0.086	-0.284	-0.016	0.681	-0.441
Area Burnt	0.153	-0.061	-0.068	0.011	0.176	0.272
Open Forest	0.101	0.044	-0.157	0.238	0.272	0.41
Riparian Forest	0.238	0.046	0.051	0.122	0.063	0.03
Distance from road	-0.312	0.294	-0.525	0.27	-0.462	0.171
Scrub	0.424	0.062	0.033	0.065	-0.285	-0.285
Teak Forest	0.257	-0.024	-0.031	-0.347	0.094	-0.18
Teak Mixed Forest	0.23	0.044	0.093	-0.041	0.092	0.054
Distance from village	-0.078	0.246	-0.217	0.118	0.116	-0.252
Distance from water	0.021	0.838	0.146	-0.52	0.133	0.139

6.3.5. Habitat Suitability Model for Wild pig: Seven factors were retained out of 14 factors which accounted for 81% of information. The marginality accounted for 12% of total specialization. The model resulted in marginality (*M*) of 0.485 and specialization (*S*) of 1.367.

The marginality coefficients shown in Tables 6.7 indicate that the Wild pig prefers canopy > 60% (0.518), roads (-0.451), canopy < 30 % (0.412), Teak Forest (0.348), burnt area (0.305) and water (-0.034). On the contrary it avoided elevation (-0.234), Open Forest (-0.037), villages (0.132), Scrub (-0.011), and non-forest (-0.006).

Some sensitivity to shifts away from their optimal values was accounted by other variables on following factors. Distance from road, distance from water and elevation in Spec.1; nil canopy and canopy 40-60% in Spec.2; elevation and distance from water in Spec.3. non-forest and Open Forest in Spec. 4; canopy 40-60% in Spec.5 and Scrub in Spec.6.

Table 6.7. Correlation between ENFA factors and EGVs for Wild pig

EGVs	Marginality (12%)	Spec.1 (25%)	Spec.2 (14%)	Spec.3 (11%)	Spec.4 (8%)	Spec.5 (6%)	Spec.6 (5%)
Canopy<30%	0.412	0.153	0.179	-0.113	0.199	-0.212	-0.323
Canopy40-60%	0.114	0.124	0.435	-0.059	-0.045	-0.624	-0.076
Canopy>60%	0.518	0.207	0.279	0.005	0.004	-0.214	0.016
Non-forest	-0.006	0.2	0.619	0.119	0.653	0.13	-0.39
Elevation	-0.234	-0.355	0.309	-0.602	-0.261	-0.266	-0.094
Area Burnt	0.305	0.162	0.078	0.197	-0.219	0.157	0.036
Open Forest	-0.037	0.051	0.101	0.156	-0.413	0.372	0.406
Riparian Forest	0.22	0.007	-0.023	-0.032	-0.02	-0.017	0.034
Distance from road	-0.451	0.64	0.25	0.367	-0.186	-0.273	-0.072
Scrub	-0.011	-0.141	-0.136	0.046	0.153	-0.304	0.706
Teak Forest	0.348	-0.038	-0.297	-0.009	-0.36	0.12	0.197
Teak Mixed Forest	0.096	0.043	-0.058	0.118	-0.055	0.044	0.064

EGVs	Marginality (12%)	Spec.1 (25%)	Spec.2 (14%)	Spec.3 (11%)	Spec.4 (8%)	Spec.5 (6%)	Spec.6 (5%)
Distance from village	0.132	-0.004	0.058	0.002	-0.234	0.109	-0.075
Distance from water	-0.034	0.539	-0.173	-0.626	0.006	0.272	0.093

6.3.6. Cross Validation

Species data were randomly partitioned into 10 mutually exclusive but identically sized sets. Using cross validation procedure (Boyce *et al.,* 2002) the models were trained iteratively on 9 of the 10 data sets by leaving out a different partition. Validation was based on remaining test data. It was observed that area adjusted frequencies were highly correlated with RSF scores. The closer the value of Boyce's indexes to one, the higher the prediction accuracy of the model. The Boyce's evalualtion index for all ungulate species is given in Table 6.8. The mean value of Boyce's index and sigmoid nature of the curves (Fig. 6.10 to Fig. 6.14) predicted accuracy of the model.

Table 6.8. Evaluation index for habitat suitability maps computed with 10 fold cross validation. High mean indicates high consistency with evaluation dataset.

Boyce's Index		
	Mean	SD
Chital	0.84	± 0.14
Sambar	0.77	± 0.28
Gaur	0.79	± 0.23
Nilgai	0.88	±0.05
Wild pig	0.87	± 0.13

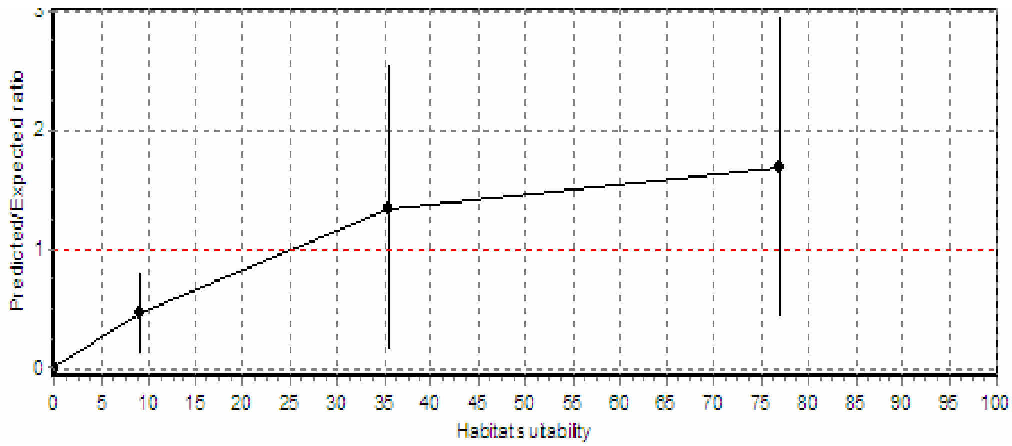


Figure 6.10. Area adjusted frequency showing the mean and standard deviation of Boyce index values for Chital

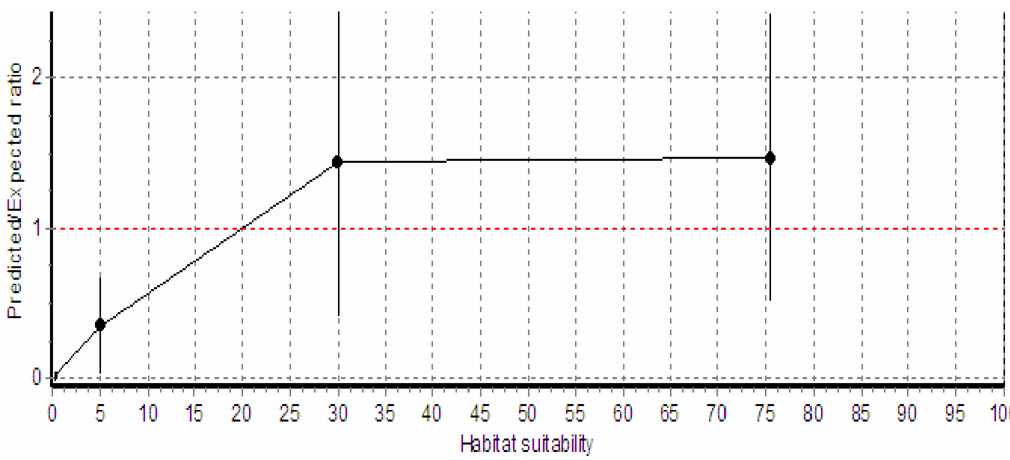


Figure 6.11. Area adjusted frequency showing the mean and standard deviation of Boyce index values for Sambar

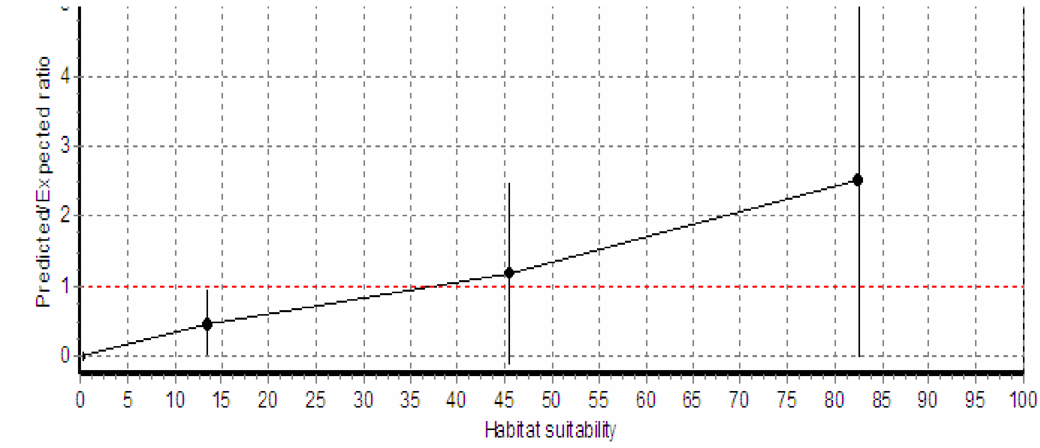


Figure 6.12. Area adjusted frequency showing the mean and standard deviation of Boyce index values for Gaur

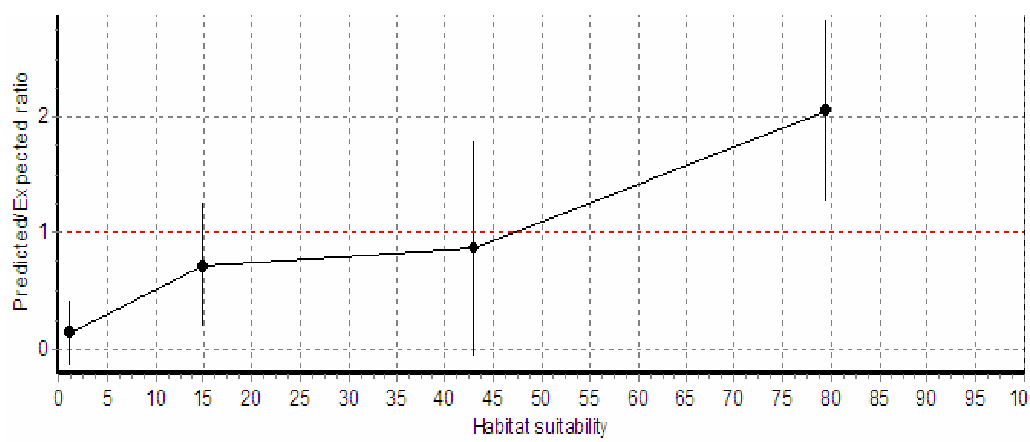


Figure 6.13. Area adjusted frequency showing the mean and standard deviation of Boyce index values for Nilgai

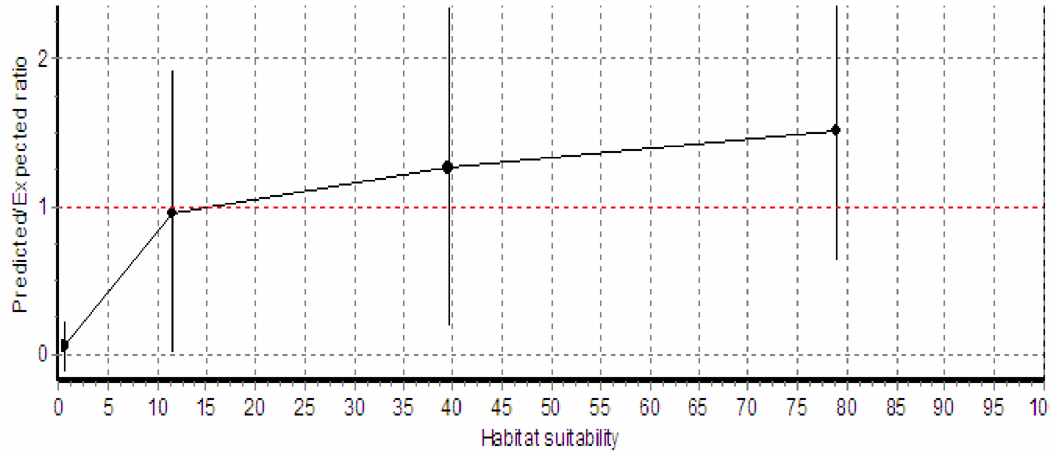


Figure 6.14. Area adjusted frequency showing the mean and standard deviation of Boyce index values for Wild Pig

6.4. DISCUSSION

Chital (*Axis axis*)

The low marginality and high tolerance suggested the generalist nature of Chital. It was moderately distributed throughout the TATR. Chital was observed to prefer the habitat with canopy less than 30% as it was mostly observed in grasslands with scattered trees. The canopy below 30 % was highly correlated with grassland (r =0.75). It was also found in forest with canopy between 40–60% and in dense canopy forest above 60% which comprises of four forest types *i.e.* Teak Forest, Teak Mixed Forest, Mixed Forest and Riparian Forest, thus, depicting a wide spread distribution of Chital in the dry deciduous forest of TATR. In concurrence with the literature (Eisenberg and Seidensticker 1976, Chakrabarty 1991 and Bagchi *et al.,* 2003), Chital prefers ecotones, reflecting preference for habitat heterogeneity. Open Forest and Scrub were avoided by Chital. Apart from these, there were other optimal environmental factors which contributed for the presence of Chital in these contrasting habitats.

In accordance with the results of the model, the negative eigen value of variables, distance from road and elevation, indicates the species preference of low values from the global mean *i.e.* proximity of Chital towards open areas. It avoids the areas near human habitations and high rugged terrain. This is consistent with the findings of Chakrabarty (1991) and Bagchi *et al.,* (2003)

Chital was found to show its affinity towards the large burnt areas. It was assumed that the fire is favoured to promote the growth of grasses. Young shoots come up which forms the preferred diet of Chital.

Less distances from water were favoured. This is due to the fact that Chital usually drink water once in a day, or more frequently in summer. This has made them widely scattered inhabitants of forest tracts with assured presence of water (Schaller, 1967).

The specialization factors showed that Chital was mostly selective about roads, water, elevation and village. As a result, it can be concluded that Chital prefers almost all forest type of TATR shared by close proximity with roads and water and avoids human habitations. This type of habitat is more commonly found in Tadoba National Park and northern part of Andhari Wildlife Sanctuary of TATR (Fig.6.15).

Sambar (*Cervus unicolor*)

The high marginality and low tolerance signified the preference specific type of habitat by Sambar at local scale. However, if observed at the global scale, no Indian ungulate has adapted itself to wider variety of forest types and environmental conditions than Sambar (Schaller, 1967). It was found to prefer dense canopy forest (above 60%) which is found in two types of forests in TATR *viz.,* Mixed Forest and Teak Mixed Bamboo Forest. Numerous studies point out (Prater 1971, Schaller 1967 and Johnsingh 1983) Sambar's preference towards dense cover. Sambar was also found to prefer the forest

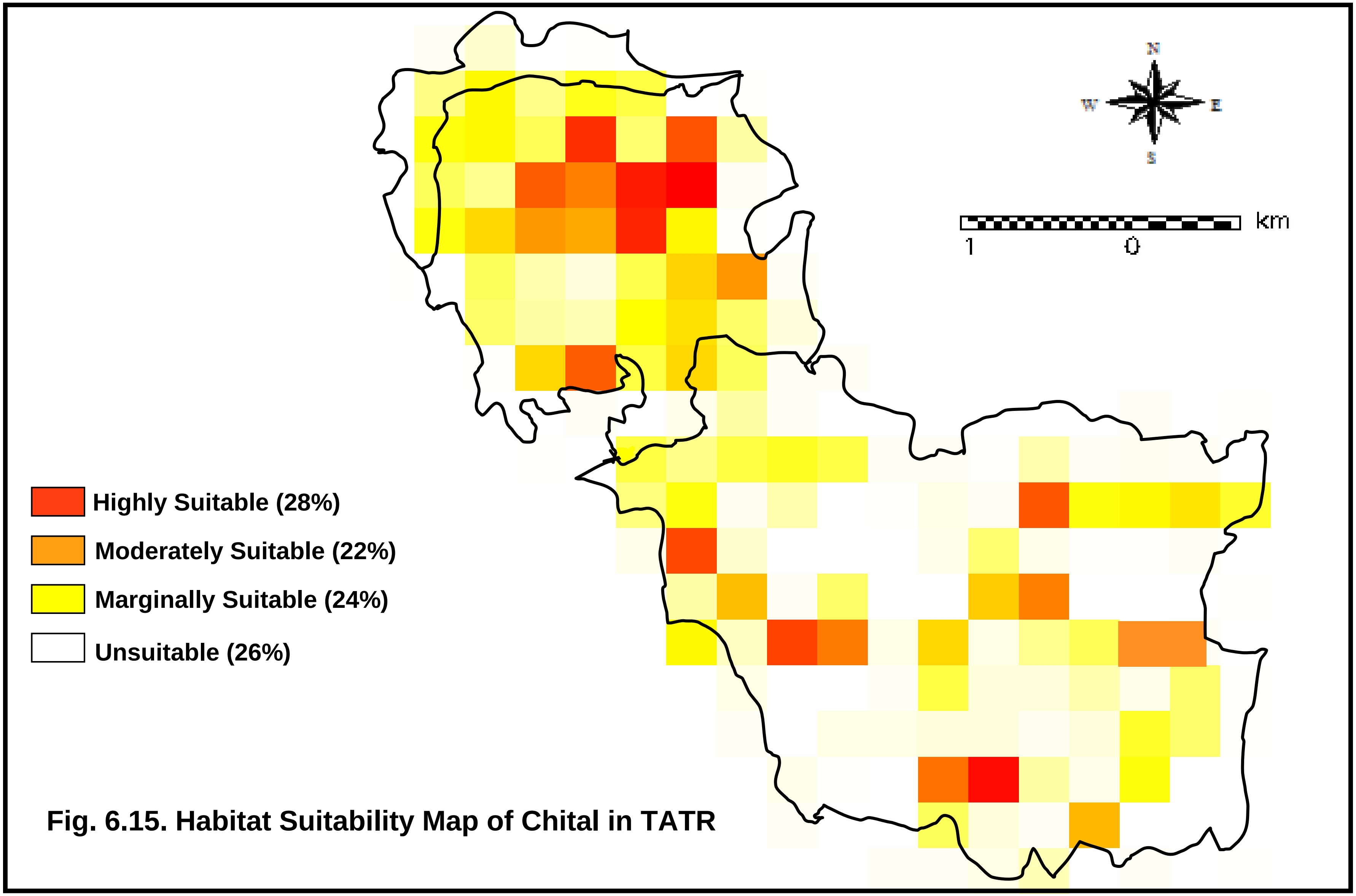


Fig. 6.15. Habitat Suitability Map of Chital in TATR

dominated by thick bamboo cover and scattered trees with canopy less than 30%. Due to the solitary, alert and shy nature of Sambar, it has propensity to remain under cover which is considered to be the possible reason to select these habitats. Sambar was also observed to respond positively to Riparian Forest and Teak dominated forest with higher habitat heterogeneity. Interspersion of dense habitats is preferred by Sambar (Bhatnagar, 1991).

Besides, the above factors presence of Sambar was also related to elevation levls. They were sighted at the slopes of hillocks partially hidden by grass quite invisible. The above statement is in concordance with the studies conducted by Schaller (1967), Johnsingh (1983), Chakrabarty (1991) and Bhatnagar (1991). Sambar showed a less preference towards open areas as it was seen to avoid roads.

The species showed the preference towards burnt areas as green grass which appear after the burning provide them with much of their food in the season supplemented with new leaves (Schaller, 1967).

Sambar preferred relatively less distances from water than Chital, since being an animal of hilly terrain they cannot travel long distances to drink water (Sankar & Acharya, 2004).

Sambar occurrences were limited in Scrub, Open Forest owing to its solitary nature. It also avoided areas close to villages or human habitation. (Schaller 1967 and Chakrabarty 1991).

The specialization factors show that Sambar is mostly selective about elevation, dense canopy, distance from water and Scrub. It can be concluded that the habitats preferred by this animal were with high elevation, dense forest cover, proximity to water and away from habitations. All these variables were found to be present in Tadoba National Park of TATR which makes the excellent habitat for Sambar to survive (Fig.6.16).

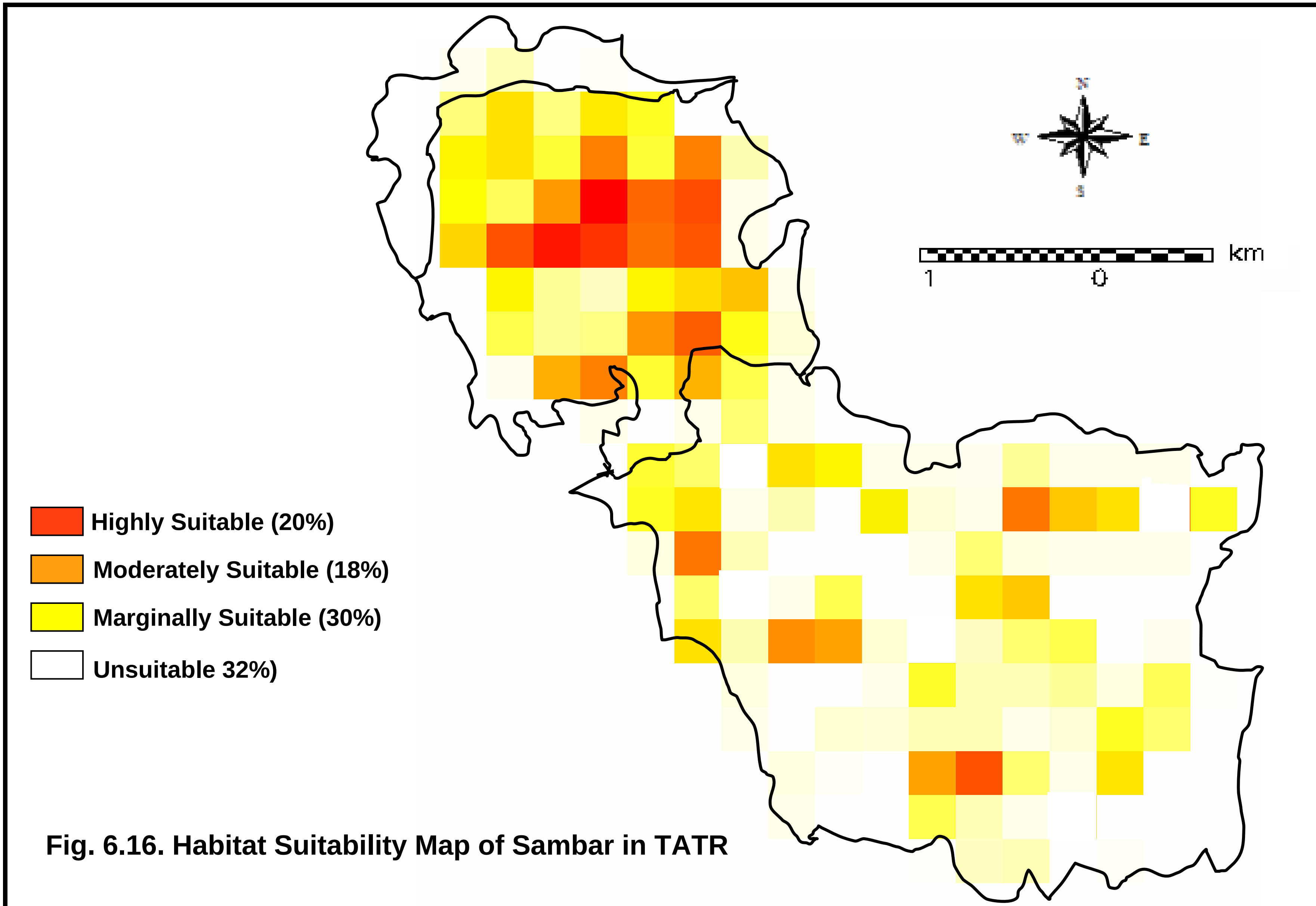


Fig. 6.16. Habitat Suitability Map of Sambar in TATR

Gaur (*Bos gaurus*)

The moderate marginality and low tolerance of the species implied that even though the species had the widespread habitat but it was found to be restricted in certain patches. As stated by Schaller (1967), even in large continuous forest tracts, Gaur has the tendency to congregate in some parts of the forest almost to the exclusion of the other. The occurrence of Gaur was correlated mostly with habitat variables like canopy density less than 30% which included Mixed Bamboo Forests and Grasslands, canopy density between 40-60% which comprised Mixed Bamboo Forests and Mixed Forests. During summer teak debarking by gaur occurs in many areas (Pasha *et al.,* 2002). Among all the forest types the continuous tract of Mixed Bamboo Forest was most commonly used by Gaur. This habitat type provide forage as their diet chiefly includes fruits of *Aegle marmelos, Diospyros melanoxylon* etc., young mature leaves of trees, shrubs, herbs, bamboo shoots (*Dendrocalamus strictus*) (Brander 1923 and Sankar *et al.,* 2000).

The occurence of Gaur was also connected with water availability. Gaur was found to occupy relatively large distances away from water. However, as an obligatory feeder Gaur needs water every day (Schaller, 1967).

The favourable habitats of the animal were in the proximity towards open habitats hence roads were preferred. However, it avoided the human presence as suggested by the model.

Gaur was also observed to have affinity to towards burnt area for the green grass which becomes available after burning.

On the contrary, Gaur avoided forest types like Teak Forest, Teak Mixed Forest, Riparian Forest and Scrub because of absence of bamboo in them. It responded negatively to high elevation, thereby avoiding hillocks.

Scores of specialization factors suggests that Gaur was restricted by absence of bamboo, elevation, water availability. In summary, Gaur preferred large tracts of Mixed Bamboo Forest with water presence. This type of habitat is present in southern part of Andhari Wildlife Sanctuary, which encompasses the Gaur population (Fig.6.17).

Nilgai (*Boselaphus tragocamelus*)

The high marginality and high tolerance values of Nilgai showed the narrow optimal range of habitat. However, species is eurioic in nature *i.e.* it has tendency to live in very narrow range of conditions and hence has high adaptability. The species was observed to prefer forests with nil canopy or canopy less than 30% comprising Teak Forest and Teak Mixed Forest. The presence of Nilgai was observed in the forest types like Open Forest, Scrub or degraded forest and Riparian Forest, this fact is in confirmation with some of the earlier studies (Prater 1971 and Bagchi *et al.,* 2003) It is apparent that they avoid dense hilly forests and prefer Scrub with low tree and shrub densities (Chakraborty 1991, Sankar 1994 and Khan 1996).

The occurrence of Nilgai showed preference for open habitats and human habitation. Nilgai occur in human habitations and crop fields outside protected areas. As reported by Haque (1990), Nilgai raid the agriculture crops. Blanford (1888) and Prater (1971) suggested presence of Nilgai in a variety of habitats, from level ground to undulating hills, in thin brush with scattered trees to cultivated plains, but not in dense forests and steep hills. The species also showed the preference to burnt areas.

Nilgai prefers relatively longer distances from water source as compared to Chital and Sambar. According to Prater (1971) Nilgai can go for long periods without water and do not drink water regularly.

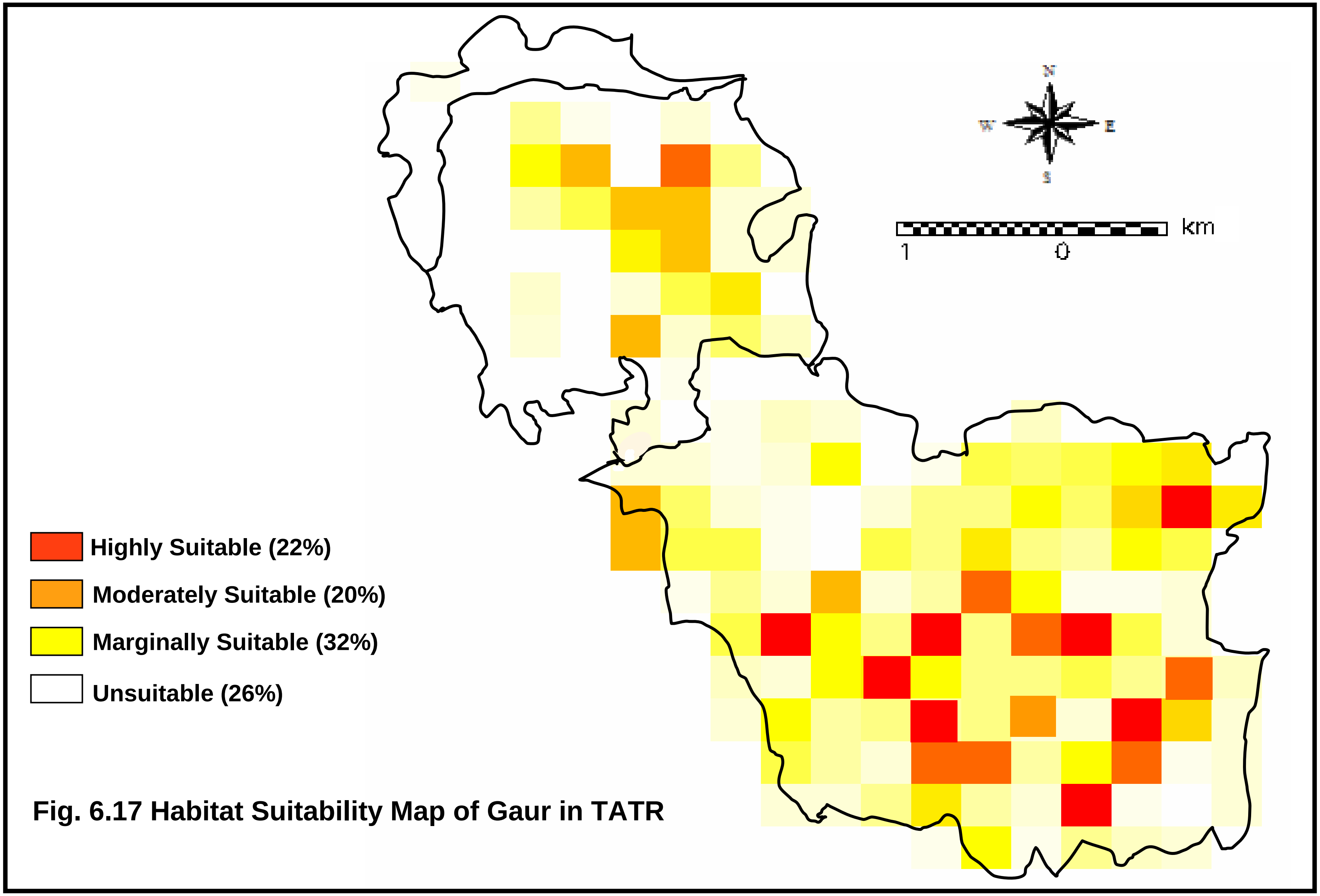


Fig. 6.17 Habitat Suitability Map of Gaur in TATR

Nilgai showed aversion towards Mixed Forests, Mixed Bamboo Forests and elevation. Chakrabarty (1991) reported that Nilgai uses flat terrain and low canopy.

Specialisation factors suggest species selectivity to some habitat variables *i.e.* dense canopy, proximity to roads, Scrub and Open Forest. Nilgai prefers degraded forest or Scrub and avoids dense forest and hills. As TATR is the protected area so not much degradation of forest is present, as a result the population of Nilgai is confined to areas close to villages present inside the reserve and also to the fringes having high anthropogenic pressures (Fig.6.18).

Wild Pig (*Sus scrofa*)

The low score of marginality and high score of tolerance indicated the generalist nature of the species. As suggested by the model, the species has the tendency to adapt itself in almost all the habitats. Wild pig was observed to prefer almost all the forest types. Haque (1990) reported that Wild pig did not show any preference for tree cover. Its presence has been depicted in different canopy density classes of forest which comprised Mixed Forest, Mixed Bamboo Forest, Teak Forest, Teak Mixed Forest, Riparian Forest except open habitats. This statement concords the fact by Prater (1971) that Wild pig inhabits forested habitats and not open habitats.

The occurrence of Wild pig revealed positive association with presence of water. They were found near the habitats closer to water sources. To support this, a large family of 20 was observed near water hole comprising of two females and many piglets.

Wild pig occurrence was positively correlated with presence of human settlements. As reported by Prater (1971) and Haque (1990) no animal is more destructive to crop than Wild pig.

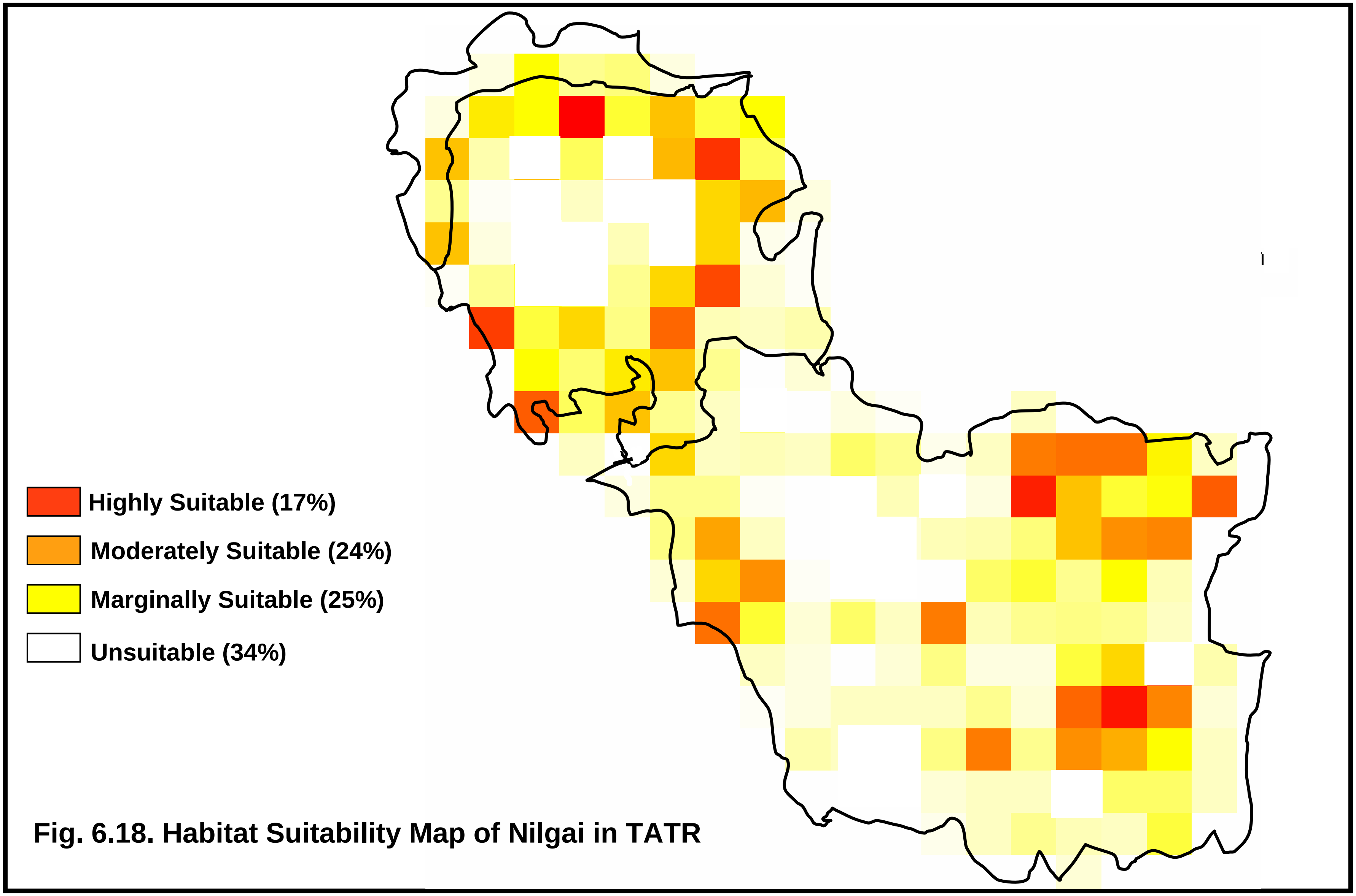


Fig. 6.18. Habitat Suitability Map of Nilgai in TATR

Wild pig is distributed more or less throughout TATR with high percentage of it in Tadoba National Park due to availability of more optimal conditions (Fig.6.19).

Main Determinants

As shown in Table 6.9, presence of canopy was one of the main determinants of habitat utilization by large ungulates in TATR, with all species associating with various canopy classes. The key finding here is that ungulates separated themselves ecologically by canopy density classes. All canopy classes except non-forest were favoured by ungulates. Canopy density below 30% was most favoured. The burnt area had the positive influence. High elevation was generally avoided with the exception of Sambar. It is inferred from the models that a majority of ungulates respond negatively towards habitations. Ungulates showed the proximity towards open areas and interspersion of habitat types which provide good blend of food and cover values. Leopold (1961) recognized greater habitat interspersion as a favourable facet for most ungulates.

Table 6.9. Scores of marginality factors for all ungulates studied

	Species				
EGVs	**Chital**	**Sambar**	**Gaur**	**Nilgai**	**Wild Pig**
Canopy<30% * **	**0.448**	0.183	0.234	**0.581**	**0.412**
Canopy40-60%	0.224	0.058	**0.548**	0.081	0.114
Canopy>60% **	0.308	**0.502**	0.099	-0.155	0.518
Non-forest	-0.029	-0.001	-0.205	0.373	-0.006
Elevation **	-0.334	0.421	-0.41	-0.009	-0.234
Area Burnt	0.262	0.051	0.194	0.153	0.305
Open Forest	-0.099	-0.121	0.069	0.101	-0.037
Riparian Forest *	0.207	0.347	-0.224	0.238	0.22
Distance from road ******	**-0.502**	-0.296	**-0.493**	-0.312	**-0.451**
Scrub	-0.06	-0.129	-0.081	**0.424**	-0.011
Teak Forest **	0.195	**0.467**	-0.195	0.257	0.348
Teak Mixed Forest	0.197	0.214	-0.097	0.23	0.096
Distance from village	0.296	0.137	0.185	-0.078	-0.132
Distance from water	0.001	-0.099	0.034	0.021	-0.034

** Determinant variables, greater the number of asterix narrower the range*

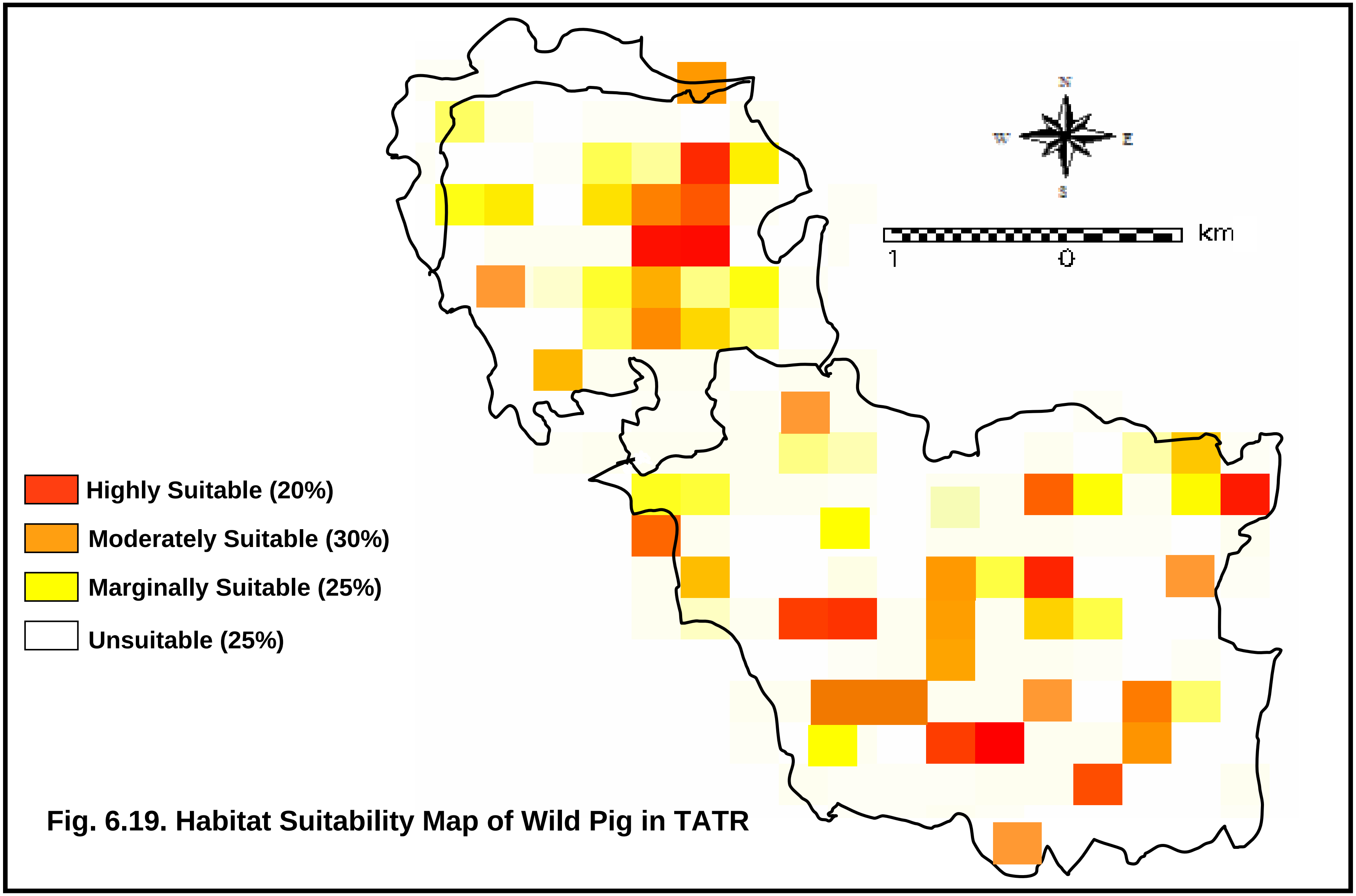


Fig. 6.19. Habitat Suitability Map of Wild Pig in TATR

Chapter 7

CONCLUSIONS & MANAGEMENT IMPLICATIONS

The present study has amply exemplified the use of remote sensing and GIS technologies in biodiversity characterization of flora, fauna and predictive habitat modelling of ungulate species. The major conclusions of the various components of this study are summarized below:

7.1. LANDUSE/LANDCOVER MAPPING

Information about landuse/landcover patterns is fundamental for monitoring change, understanding environment relationships, prediction of future changes, modelling, landscape planning and management. Remote sensing has proved to be most efficient tool available for determining landscape-scale elements of forest biodiversity, such as relative proportion of patches and their physical arrangement.

In the present study (Chapter 3) on land cover assessment and patch dynamics, detailed mapping and analyses of land cover patterns was carried out using remotely sensed and field data. It revealed that the landscape comprised of 10 landuse/landcover classes including seven forest types, two non-forest categories and Grassland. Six major vegetation types *viz.,* Mixed Bamboo Forest, Mixed Forest, Teak Forest, Teak Mixed Bamboo Forest, Riparian Forest and Grassland were delineated. Mixed Bamboo Forest was the most dominant class covering 76% of TATR and Riparian Forest was the least represented class (0.61%). Since nine classes except human settlement were found in Tadoba National Park (TNP), it was found to be more heterogeneous with high interspersion amongst the vegetation types. On account of presence of six villages in Andhari Wildlife Sanctuary (AWS), Scrub and Open Forest occupy relatively large areas compared to National Park. Largest patch of Riparian Forest was present in TNP, while small patches were present in AWS. Besides the above, the study has also revealed that pure Teak Forest is present only in TNP but not in AWS. The canopy cover map of TATR revealed five canopy density classes (a) above 60%; (b) 40-60%; (c) 30-40%; (d) below 30%; (e) Non-Forest. Canopy density between 30-40% was found to be the dominant canopy density class. Dense canopy (density > 60%) was only found in Riparian and Teak Forest which was present in TNP.

Detailed landscape level analysis on the number of patches, patch characteristics (composition) and spatial arrangement and proximity of different patches (configuration) has provided crucial information on the landscape structure. The structural analysis of TATR landscape reveals its heterogeneous nature with large variations in patch size. The landscape was found to be less diverse with uneven distribution of the patches and intermediate interspersion of forest types. The dominance of Mixed Bamboo forest is attributed to large size patches, despite being less in number. Mixed Forest was found to have highest number of patches (671) with highest patch density (0.49/ha), while Riparian Forest has lowest patch density (0.03/ha). The results indicate that the landscape metrics in the FRAGSTATS are effective in characterizing the landscape.

This component of the study has demonstrated the efficacy of high resolution satellite IRS P6 LISS IV data with multispectral capability in detailed mapping of forest types with sharp boundaries and accurate area estimates, which has led to very detailed assessment of landscape structure. The canopy density information can work as effective spatial database to better manage the degradation in crown density levels, increasing fragmentation and secondary vegetation formation. This study not only illustrates the spatial distribution patterns of vegetation types but also their ecological interface, and has thus extended the significance of the vegetation maps.

7.2. VEGETATION STRUCTURE AND COMPOSITION

Spatially explicit information on species composition and structure of forest vegetation is needed at spatial scales both for natural resource policy analysis and for ecological research. With this background, a detailed assessment of structure and composition of vegetation was carried out in this study. All tree species were grouped into seven communities *viz., Tectona grandis-Diospyros melanoxylon* community*, Zizyphus xylopara-Adina cordifolia* community*, Tectona grandis-Chloroxylon swietenia* community, *Tectona grandis-Cliestanthus collinus* community, *Dalbergia paniculata-Mitragyna parviflora* community, *Pterocarpus marsupium-Flacourtia ramontchi* community and *Syzygium cumini-Mangifera indica* community. A total of 3779 tree individuals belonging to 55 species and 27 families were recorded. Fabaceae, Combretaceae and Caesalpiniaceae were found to be dominant families in TATR. Calculations of IVI values have helped in understanding the relative ecological significance of the species in the tropical dry deciduous forest landscape.

Teak was the dominant species in TATR as it had the highest density, frequency and IVI values in three major vegetation types *viz.,* Mixed Forest, Teak Mixed Bamboo Forest and Teak Forest. Apart from teak, all the species in all vegetation types had frequencies below 1%. The number of plant species recorded in each vegetation type varied from 9 to 46. The Mixed Bamboo Forest was the most diverse type in terms of species, while Riparian Forest was the least diverse among the five major vegetation types.

In all the vegetation types the species with high IVIs showed good regeneration potential except in Mixed Bamboo Forest, where *Madhuca indica* had highest IVI value but showed least regeneration. Maximum regeneration was observed in Riparian Forest while, Mixed Bamboo Forest showed least regeneration potential. The possible reason for this is that the dominance of bamboo in understorey hampers seedling-sapling growth. The study also inferred that the density and species richness consistently decrease with increasing girth class of tree species. The regeneration of prominent tree species is satisfactory in TATR.

A comparative assessment of the tropical dry deciduous forests of TATR with tropical dry deciduous forest of Eastern Ghats indicates that TATR forests are less diverse. Nevertheless, tree density per hectare in TATR was found to be higher than that in tropical dry deciduous forest of Eastern Ghats as well as tropical rain forest of south India. This indicates that despite being less diverse in nature the tree densities are higher in TATR.

Mixed Bamboo Forest has highest average shrub density with a major contribution of species like *Holarrhena antidysentrica, Nyctanthus arbortristis, Bridelia hamiltoniana and Zizyphus zozuba.* Bamboo formed the major understorey of Mixed Bamboo Forest and Teak Mixed Bamboo Forest. Teak Mixed Bamboo Forest has highest bamboo density among all forest types. The forest floor is characterized by low shrub and herb diversity due to dominance of bamboos. Majority of herbs are ephemeral in nature. *Hemidesmus indicus*, *Heteropogon contortus*, and *Eragaostis tenella* are the dominant grasses, while *Cassia tora* and *Desmodium pulchellum* are the dominant herbs.

7.3. UNGULATE DISTRIBUTION

It is important to monitor the status, distribution and trends in the populations of the prey species for better conservation planning of predators. The present study (chapter 5) quantified spatial and ecological distribution of ungulate species *viz.,* Chital, Sambar, Nilgai, Gaur and Wild pig, in response to seasons and management status for TNP, the northern zone of TATR and AWS which comprises the central and southern zones of TATR.

TATR harbours fairly high ungulate density. TNP has higher densities of ungulates compared to Andhari Wildlife Sanctuary. Chital was found to be most abundant in TATR among all the ungulate species and least was Nilgai. However, in terms of TNP, Gaur was found to have the least density while Sambar had least density in AWS. The density of Chital, Sambar, Nilgai and Wild pig decreased from northern zone *i.e.* TNP to southern zone of AWS. In contrast, the highest density of Gaur was found in southern zone of AWS which decreased northwards. The three herbivore species, Chital, Sambar and Gaur together contribute 84% to the total biomass of TATR.

On comparing the densities with some tropical forests of India, it is apparent, that, TATR holds the second highest densities of Gaur and Widpig, while Nilgai had second lowest density amongst all places higher than Gir. Substantial increase in densities of all the ungulates has been observed in this study compared to the previous study conducted in the study area. This reflects the positive impact of interventions carried out by the park management of uniformly distributing the waterholes throughout TATR, regulating tourism and restricting the pilgrimage to Tadoba, which used to be held in months of April, December and January, where pilgrims camped and used forest resources. The reason for increase in densities is also attributed to the increase in Bamboo cover and grasslands.

The group sizes of all ungulate species were analyzed and it was found that group size increased with the increase in density. Chital had the highest mean group size (MGS) amongst all species. Among the seasons, no significant difference was found in the MGS of Sambar, Nilgai, Wild pig and Gaur. However, Chital showed significant difference in the MGS between the seasons, larger groups were found in summers as compared to winters. The sex ratios were found to be in favour of females with increasing densities. It was observed that as the ungulate population increases in density it typically shows high juvenile mortality and lower fecundity, leading to an increase in average age of adult females. The age and sex ratios of the TATR were compared with other studies conducted in different tropical areas and it was found that overall results of this study are within the range of variation cited in literature.

7.4. HABITAT MODELLING

The predictive distribution modelling in this study (chapter 6) has provided fine scale information on potential distribution which can be used to assess the status of tiger reserve and also assist in more efficient habitat management. Models greatly improve the availability of information and provide habitat assessment tools to professionals involved in conservation and development planning. Pinpointing the areas where appropriate environmental conditions exist to sustain species is also vital for conservation planning. It also allows identifying environmentally suitable regions still not colonized by species. The association between both habitat variables and ungulate abundance has been examined in this study by conducting habitat modelling.

Ecological Niche Factor Analysis (ENFA) was used to model the habitat of five ungulate species *viz.,* Chital (*Axis axis*), Sambar (*Cervus unicolor*), Gaur (*Bos gaurus*), Nilgai (*Boselaphus tragocamelus*) and Wild pig (*Sus scrofa*). ENFA indicates that species abundance is a useful indicator of habitat quality. It assumes that the environmental conditions are optimal where species is most frequently found. Robustness of ENFA makes it suitable and efficient for modelling habitat suitability where absence data is either lacking or unreliable. The models generated in this study have identified that presence of canopy was one of the main determinants of habitat utilization by large ungulates at TATR, with all species associating with various canopy classes. The key finding here is that ungulates separated themselves ecologically by canopy density classes. All canopy classes except non-forest were favoured by ungulates. Canopy density below 30% was most favoured. The model emphasized that the burnt areas had positive influence on the ungulates. Further the ungulates showed proximity towards open areas dominated by road network. Chital showed highest affinity towards open areas and least was shown by Sambar. High elevation was generally avoided by ungulates except Sambar. A majority of ungulates responded negatively towards habitations as due to these some good habitats were rendered inhabitable. The results of habitat modelling of ungulate species are summarized:

Chital was found to be habitat generalist in TATR, since only 26% area is unsuitable. The habitat of Chital was found to be most widespread compared to other ungulates. Model showed the positive effects of Grassland mosaics, low canopy woodlands, Open Forest and perennial water sources. However, it identified negative effects of Scrub, Elevation and Habitations present in some parts of AWS. Since all the variables having positive influence are present in TNP, hence most of the suitable and moderately suitable habitats for Chital are also found in it.

Sambar was observed to be a habitat specialist, as its habitat was mostly confined to TNP. Model showed the positive effects of dense canopy woodlands, high elevation, Riparian Forest and Teak Forest. However, model identified negative effects of Scrub, Open Forest and Habitations. The variables exerting positive influence were found to be present in TNP and variables exerting negative influence were present in AWS. Therefore, TNP has most suitable habitats of Sambar.

The habitat of Gaur was found to be wide spread. Model showed the positive effects of less dense canopy, canopy density between 30-40%, Mixed Bamboo Forest, Grassland, Open Forest and Burnt areas. However, model identified negative effects of Teak Forest, Teak Mixed Forest, Riparian Forest, Scrub and high elevation. Variables which encompass Gaur's presence were found in southern zone of AWS.

Nilgai's habitat is least widespread among all ungulates. Model showed the positive effects of Scrub, Open Forest, low canopy woodlands and habitation. These variables were found in AWS and fringes of TNP. Model identified negative effects of dense canopy and elevation hence habitat favoured by Nilgai was not found in the core zone of TATR.

Wild pig can also be called as habitat generalist as its habitat is prevalent in almost entire TATR. Model showed the positive effects of burnt areas, less distance from water and open areas. Model identified negative effects of Scrub and elevation.

It can be concluded that ENFA has helped to blend statistical theory with ecological practice. Habitat suitability maps obtained from this model are reliable, as they provide reasonable ecological justification of the occupied species niche. However, the model has some limitations as it does not take into account factors like source-sink dynamics, metapopulation dynamics and degree of competition among species. Inspite of this, habitat suitability modelling still provides a useful tool to address important issues in ecology and conservation planning. Spatially explicit models like ENFA provide some decisive assistance in the task of determining species basic ecological needs.

7.5. MANAGEMENT IMPLICATIONS

From the present study it can be concluded that TATR harbours high ungulate prey base and has the potential to accommodate higher density of predators, making it comparable to few of the best remaining tiger reserves of India. The following are the major management implications:

1. High spatial resolution and multispectral nature of IRS P6 LISS IV satellite data is very useful in forest types and density mapping at fine level.
2. The time for the satellite data acquisition for TATR should be carefully chosen so as to capture maximum variations amongst forest types. November and December months are the best time for satellite data acquisition since vegetation is in the peak of its biomass and cloud free data can also be obtained.
3. Landuse/landcover mapping exercise should be repeated at every five year interval to monitor changes in landscape.
4. Data on forest inventory should be collected at five year interval to monitor changes in floristics.

5. Permanent transects marked in this study over entire TATR need to be properly maintained and used for subsequent monitoring of ungulate populations.
6. The maps generated in this study from ungulate modelling could be employed in monitoring and management of ungulates and their habitats.
7. Presence of human habitations tends to lower habitat suitability for wild ungulates and therefore appropriate village relocation programmes should be planned and implemented.
8. Ecological separation amongst wild ungulates is mediated by canopy densities which has implications for habitat management.
9. Controlled burning has positive influence on wild ungulate abundance and distribution, hence need to be practiced but with due caution.
10. Intensive training of all frontline staff with regard to use of GPS and recording of information on to datasheet is highly desirable to ensure more rigorous and scientific approach to the population estimation exercise.

The neglect of ecological knowledge is often a limiting factor in the application of statistical modelling in ecology and conservation planning and therefore an amalgamation of ecological theory and modern statistical modelling is needed. This study has a direct application to the conservation of not only ungulates but also of large carnivores implicitly. The present study will also serve as a primary input for planning management interventions for sustaining the phytodiversity of tropical dry deciduous forests in TATR. In order to achieve the more dynamic and multispecific species distribution models, modelers, biogeographers, community ecologists, population biologists and ecophysiologists need to work synergistically. It is expected that the results of this research will be linked with the results of other biodiversity research both globally and locally and will be used to improve conservation and management plans in near future.

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Appendix-1

Check list of tree species

	Common name	Botanical name	Family
1	Ain	*Terminalia tomentosa*	Combretaceae
2	Amaltas	*Cassia fistula* L.	Caesalpiniaceae
3	Anjan	*Hardiwickia binata,* Roxb	Caesalpiniaceae
4	Apta	*Bauhinia racemosa* Lam.	Caesalpiniaceae
5	Arjun	*Terminalia arjuna* Wght & Arn.	Combretaceae
6	Awla	*Emblica officinalis* Gaertn	Euphorbiaceae
7	Baheda	*Terminalia bellirica* (Breyn ex Gaertn) Roth	Combretaceae
8	Bel	*Aegle marmelos,*Correa	Rutaceae
9	Bhirra	*Chloroxylon swietenia,*D.C.	Rutaceae
10	Biba	*Semecarpus anacardium,* linn f.	Anacardiaceae
11	Bibuli	*Acacia nilotica,* linn	Mimosaceae
12	Bija	*Pterocarpus marsupium,*Roxb	Fabaceae
13	Char	*Buchanania lanzan,*Spreng	Anacardiaceae
14	Chichwa	*Albizzia odoratissima,* Benth	Fabaceae
15	Dhaman	*Grewia abutilifolia,* Vent ex juss	Tiliaceae
16	Dhawra	*Anogeissus latifolia,*wall	Combretaceae
17	Dhoban / Satpuda	*Dalbergia paniculata,* Roxb	Fabaceae
18	Garadi	*Cleistanthus collinus,* Benth & hock f	Euphorbiaceae
19	Ghogli	*Gardenia latifolia* Ait	Rubiaceae
20	Ghoti/ Ghotbor	*Zizyphus xylopyra,* Wild	Rhamnaceae
21	Gongal	*Cochlospermum gossypium,* D. C	Czchlospermaceae
22	Haldu	*Adina cordifolia*	Rubiaceae
23	Hirda	*Terminalia chebula,* Retz	Combretaceae
24	Hivar	*Acacia leucophloea,* wild	Mimosaceae
25	Imli	*Tamarindus indica* L.	Caesalpiniaceae
26	Jaamun	*Syzygium cumini,* Linns, Skeels	Myrtaceae
27	Kadam	*Mitragyna parviflora,* Roxb worth	Rubiaceae
28	Kakai	*Flacourtia ramontchi,* (India), L.Herit	Flacoutiaceae
29	Kala kuda	*Wrightia tinctora*	Apocynaceae
30	Karai	*Saccopetalum tomentosum,* hook F.A. Thomes.	Anonaceae
31	Karu	*Sterculia urens*	Sterculiaceae
32	Kasai	*Bridelia retusa* Spreng	Euphorbiaceae
33	Kavat	*Feronia elephantum,* Corr	Rutaceae
34	Khair	*Acacia catechu,* wild	Mimosaceae
35	Kudurli	*Bridelia hamiltoniana,* Wall. Ex Hook. F.	Euphorbiaceae
36	Kumbhi	*Careya arborea,* Roxb	Lecythidiaceae
37	Kusum	*Schleichera oleosa*	Sapindaceae
38	Mahua	*Madhuca indica* L.	Sapotaceae
39	Mango	*Mangifera indica*	Anacardiaceae
40	Medsingh	*Dolichandrone falcata,* L.	Spindaceae

	Common name	Botanical name	Family
41	Mokha	*Schrebera swietenioides*	Aristolochiaceae
42	Mowai	*Lannea grandis*	Anacardiaceae
43	Pakhad	*Ficus rumphii*	Moraceae
44	Palas	*Butea monosperma,* Lamk, o.(kuntaze)	Fabaceae
45	Panjra	*Erythrina indica,* Lam	Fabaceae
46	Parad	*Stereospermum suaveolens* DC	Bignoniaceae
47	Rohan	*Soymida febrifuga* A. Juss	Meliaceae
48	Salai	*Boswellia serrata,* Roxb	Burseraceae
49	Sehna	*Lagerstroemia parviflora,* Roxb	Lythraceae
50	Semal	*Bombax ceiba*	Bombaceae
51	Shevdar	*Dalbergia latifolia,* Roxb	Anacardiaceae
52	Shisham	*Dalbergia sissoo*	Fabaceae
53	Shivan	*Gmelina arborea,* Linn	Verbenceae
54	Surya	*Xylia xylocarpa,* Roxb	Annonaceae
55	Teak	*Tectona grandis,* Linn	Verbenceae
56	Tendu	*Diospyros melanoxylon,* Roxb	Ebenaceae

Appendix 2

Check list of shrubs, herbs, climbers and grasses

	Common name	Botanical name	Family
		Shrubs	
1	Aruni	*Zizyphus mauritiana*	Rhamnaceae
2	Bharati	*Gymnosporia spinosa,* forsk, firori	Celesrtraceae
3	Gatruli	*Grewia hirsuta,* vahl	Tiliaceae
4	Jilbili	*Woodfordia fruticosa,* salish	Lythraceae
5	Kaharasali	*Nyctanthus arbortristis*	Oleaceae
7	Kuda	*Holarrhena antidysentrica,* B.R.	Apocynaceae
8	Kudarasi	*Bridelia hamiltoniana,* WII	Euphorbiaceae
9	Lokhandi	Ixora parviflora, vahl	Rubiaceae
10	Kala Phetra	*Tamilnadia uliginosa*	Rubiaceae
11	Murudseng	*Helicteris isora,* L.	Steculiaceae
12	Neel	*Indigofera arborea,* Roxb	Fabaceae
13	Raanbhindi	*Dodonaea viscosa,* L.	Spindaceae
14	Safed Phetra	*Gardenia turgida*,Roxb.	Rubiaceae
15	Shataori	*Asparagus racemosus*	Liliaceae
16	Sindi	*Phoenix acaulis,* Buch	Plamaceae
17	Thuar	*Euphorbia tirucalli,* L.	Euphobiaceae
18		*Flemingia strobilifera*	Fabaceae
19		*Lantana*	Verbenaceae
		Herbs & Climbers	
1	Bhuineem	*Andrographis paniculata*	Acanthaceae
2	Budhganja	*Waltheria indica*	Steculiaceae
3	Chikna	*Sida cordifolia,* L.	Malvaceae
4	Chilati	*Acacia pinnata*	Mimosaceae
5	Chipdi	*Desmodium pulchelium,* Benth	Fabaceae
6	Khobervel	*Hemidesmus indicus,* L.	Periplocaceae
7	Musdi	*Dioscorea pentaphylla,*L.	Dioscoraceae
8	Raantulasi	*Ocimum basilicum*	Labiateae
9	Cucutranjha	*Calycopteris floribunda,* Lam	Combretaceae
10	Tarota	*Cassia tora*	Caesalpiniaceae
11		*Elephantopus scaber*	Asteraceae
12		*Pteracanthus sp*	Lamiaceae
13		*Justicia quinquangularis*	Acanthaceae
14		*Crotolaria albida*	Fabaceae
15		*Polygala sp*	Polygalaceae
16		*Acrocephalus hispidus*	Lamiaceae

	Common name	Botanical name	Family
17		*Phyllanthus simplex*	Euphorbiaceae
18		*Canscora decussata*	Gentianaceae
19		*Rungia pectinata*	Acanthaceae
20		*Cassia mimosoides*	Caesalpiniaceae
21		*Hemigaphis latibrosa*	Acanthaceae
22		*Borreria articularis*	Rubiaceae
23		*Evolvulus alsinoides*	Conudvulaceae
24		*Ipomoea eriocarpa*	Convolvulaceae
25		*Ludwegia perensis*	Onagraceae
26		*Lepidogathus hamiltoniana*	Acanthaceae
	Grasses		
1	Bamboo/bans	*Dendrocalamus strictus*	Poaceae
2	Bhurbhusi	*Eragaostis tenella*	Poaceae
3	Chikta	*Setaria intermedia,*	Poaceae
4	Dub	*Cynodon dactylon*	Poaceae
5	Ghonyad	*Themeda triandra*	Poaceae
6	Kusari	*Heteropogon contortus*	Poaceae
7	Marvel big	*Dicanthium aristatum* (Poir)	Poaceae
8	Marvel small	*Dicanthium annulatum*	Poaceae
9	Pandari	*Aristida funiculata*	Poaceae
10		*Chryzopogon fulvus*	Poaceae
11		*Aristida adscensionis*	Poaceae
12		*Apluda mutica*	Poaceae
13		*Oplismenus burmanii*	Poaceae