Ecology of the Leopard *(Panthera pardus fusca)* in Satpura National Park and Bori Wildlife Sanctuary

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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Preface

Leopard was among the least studied large felid in India, largely the information on leopard ecology was anecdotal or based on African studies. This study was conducted to bridge the gap in understanding the ecology of leopard in India. Leopard was persecuted over time because of its beautiful skin or killed to avenged for livestock or human losses. The trend in leopard poaching has reached alarming proportion, the seizures of wildlife material over time indicate increasing ratio of leopard : tiger skins. There is an urgent need to understand conflict pattern of leopard and human, there are few studies on conflict, more information is needed to understand the driving force behind increasing leopard-human conflict.

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Barlow has beautifully described leopard

He is aloof with confidence; you can see it in his stance.
Laying quietly on his own, his branch could almost be his throne.
A guttural purr of contentment, then quick to show resentment.
The quiver of the upper lip, then quick down the tree does slip.

Summary

The leopard study was undertaken in Satpura Tiger Reserve to study ecology of species in relatively conflict free area. Even basic information on leopard is poor, except for food habits. Leopards have been in the news in popular media in India largely because of instances of human conflict that have occurred in many places. . There is a perception that attacks on humans have increased in the last few years. It is speculated that the probable causes have been decrease in habitat, decline in leopard prey populations or increase in leopard densities close to human populations. Historical data on leopard or prey abundances in any of the conflict areas are lacking, and therefore the reasons given remain speculative. Management of the conflict would be easier if the reasons were reliably known. The study was conducted from 2001 to 2007.The objective of this study were a) habitat use and preference, b) prey preference and food habits, c) validate methods for leopard population estimation and d) territoriality and ranging pattern. We achieved all the objectives except ranging pattern due to problems in radio collaring permissions. By the time we got permission it got too late to capture leopards and meaningfully execute this objective and was thus dropped.

The vegetation map of the study area was prepared based on remotely sensed data. Thirteen vegetation and landuse classes were identified. The spatial layer for habitat quality, climate and topographic feature were used for occupancy mapping. The prey occupancy maps with topographic data was in turn used to model predator occupancy. Most of the species were 80% correctly classified. The presence only modeling was used to estimate the area occupied by leopard in the 13 districts of south-central Madhya Pradesh. 'Optimal' habitat was 5.2% of the study area, ranging from 0.5 to 8 percent of each district. As an absolute measure it can be said that approximately 11500 sq km of habitat is likely to support leopard populations. The districts with the most optimal habitat are Betul, Hoshangabad and Chhindwara. These districts are geographically adjacent to each other and constitute a compact block of about 2000 sq km of optimal habitat. The Satpura Tiger Reserve lies in Hoshangabad district and is already protected, but Betul and Chhindwara districts can be prioritized when allocating resources for leopard conservation efforts in Madhya Pradesh. ENFA model seems to work better at larger scales for a generalist species like the leopard. It is a useful tool to explore the characteristics of the species occupancy as well as to produce habitat

suitability maps that can aid in conservation management. The suitability area in select districts are as follows:

District	Unsuitable	Marginal	Suitable	Optimal
Betul	5031.5	2387.9	1172.1	857.5
Chhindwara	5621.2	3528.2	1931.6	744.1
Dewas	776.2	288.8	166.5	66.2
East Nimar	1141.3	453.3	343.0	168.5
Harda	2187.3	490.4	415.2	238.7
Hoshangabad	3325.6	1577.5	1371.0	465.3
Narmsimhapur	3265.4	638.8	303.9	215.6
Raisen	2464.1	535.5	282.8	14.0
Sehore	1590.6	882.5	583.7	212.6

Leopard as most diverse diet, the frequency of occurrence of prey was ordered as sambar>chital>hare>langur>birds>rodents>porcupine>wild pig>cattle. The diets of the tiger, leopard and dhole overlap to a great extent. The tiger diet overlaps more with that of the leopard than the dhole because of shared inclusion of wild pig, cattle, rodents and birds in their diet. The dhole-leopard overlap is more than the dhole-tiger overlap because the former species-pair hunt in open areas also and both thus take a significant amount of chital, unlike the tiger. Chital comprises about 20 % of leopard's biomass intake. Along with chital, sambar is a preferred prey for the dhole. Tigers seem to prefer large prey species that are more easily available, the mean size of prey being 115 kg. The leopard and dhole tend to take medium sized prey. The leopard being a solitary animal takes a mean prey size of 27 kg, while the pack living dhole takes larger prey of more than 25 kg. The leopard also has the largest range of prey size, taking small prey like hare, birds, rodents and porcupines that dhole did not kill in this study.

There has recently been increased attention to the need for reliable estimates of carnivore density in India, but most of the work has been done on tigers scanty information is available for leopards. Camera trapping has been used in conjunction with the mark-recapture technique to estimate the densities of species in which individuals can be uniquely identified based on the coat patterns or other external marks. Large felid populations are difficult to estimate because the species are generally low in abundance, nocturnal or crepuscular and have large home ranges. The mean of the four estimates of density in Satpura Tiger Reserve is 8.87 (S.E. 0.9) per 100 sq km. It is recommended that an index of density calculated using the area of the minimum convex polygon (MCP) be used to compare different sites, and half MMDM used to estimate absolute density until further data are available on movement patterns of leopards.The sex ratios are female biased in all areas except Kamti. The average ratio is 1.68 (S.E. 0.38) females per male. For 4 estimates the capture success for males is higher than for females, and in one estimate they are the same.

. The larger spatial area model had a higher predictive accuracy than the smaller scale one as quantified by the higher continuous Boyce Index. This is possibly because the Satpura Tiger Reserve has fewer disturbances and is a less heterogeneous area given its smaller size. Given the high density of leopards in the area and requiring large tracts of contiguous habitat they probably move through and live in habitats that are not highly preferred, but are still inhabitable. Very few areas in the Reserve are likely to be completely unsuitable for leopards. Proportion of dhole tracks found per sampling occasion per section declined from 24 percent to 7 percent over the three years. The decline was continuous for the first two years, before recovering in the last year. Mean proportion of leopard tracks were less variable between years, except for second year summer, where they declined drastically. C-scores were higher than expected only in winter for the four large carnivores. which suggests that competitive structuring and subtle patterns of avoidance, if present, are more likely to break down in summer. In summer habitat selection for all carnivores is likely to be more influenced by the presence of water and shade than by the presence of competitors. The understanding how these carnivore species coexist could be important in managing large carnivores in areas where more than one species is found in sympatry. Interspecific competition is a major process in the structuring of many communities and seems that resource partitioning along a combination of temporal, spatial and dietary axes has structured the large carnivore community.

Introduction

The leopard study was undertaken in Satpura Tiger Reserve to study ecology of species in relatively conflict free area. Even basic information on leopard is poor, except for food habits. Leopards have been in the news in popular media in India largely because of instances of human conflict that have occurred in many places. . There is a perception that attacks on humans have increased in the last few years. It is speculated that the probable causes have been decrease in habitat, decline in leopard prey populations or increase in leopard densities close to human populations. Historical data on leopard or prey abundances in any of the conflict areas are lacking, and therefore the reasons given remain speculative. Management of the conflict would be easier if the reasons were reliably known. The study was conducted from 2001 to 2007. The objective of this study were a) habitat use and preference, b) prey preference and food habits, c) validate methods for leopard population estimation and d) territoriality and ranging pattern. We achieved all the objectives except ranging pattern due to problems in radio collaring permissions.

Satpura Tiger Reserve is a part of Central highlands Province of the Deccan Peninsula biogeographic zone (Rodger & Panwar, 1988) encompasses 1427 sq. kms of unique Central Indian Highland. It is the only protected area in the main Satpuras. The fascinating deep valleys, high mountains, rivulets, waterfalls and Tawa's vast reservoir combine to give this Park a unique beauty. The terrain is extremely rugged and consists of sandstone peaks, narrow gorges, ravines and dense forests. The altitude ranges from 300 Mts. to 1352 Mts. from the 1352 m Dhoopgarh peak to the almost level plains of Churna. described about the terrain tribes vegetation and major animals of this area. The forests of Bori declared reserve forest in 1859, are the oldest reserved forest in India(Forsyth 1889). Bori has a history of scientific forest management dating from 1897. Bori was first declared a wildlife sanctuary in 1931. In 1975 Bori wildlife sanctuary was notified under the wildlife Protection act with an area of 1400 km^2. In 1977 Panchmari wildlife sanctuary was carved out of Bori sanctuary with an area of 654.49 km2. In 1981 Satpura National park was created out of Bori sanctuary and Panchmari sanctuary so that the present area of Bori sanctuary, Panchmari sanctuary and Satpura national park are 485.72 sq.km., 417.78 sq.km. and 524.37 sq.km. respectively giving a total figure of 1427.87 sq.km. for the conservation unit (Fig1). In the year 1999-2000 Satpura National park, Bori WLS and Panchmari WLS was declared as a Tiger Reserve by Govt. of India. Pachmarhi area was designated as Biosphere Reserve by Government of India in 1999. It has an area of 4926.28 sq km including Satpura Tiger Reserve with parts of Hoshangabad, Betul and Chindwara district. The Satpura Tiger Reserve lies between the latitudes 22° 15'N and 22 ° 45'N and longitudes 77 ° 50' E and 78 ° 30' E. The two nearest railheads are Itarsi and Pipariya. Panchmari is about 60 kms from Pipariya while Churna in Bori WLS is about 50 kms from Itarsi. Bhopal, Hosangabad, Betul, Chhindwara and Nagpur are the important cities nearby and are all easily accessible by road. The Satpura Tiger Reserve is divided into six ranges; Bori, Bhoura, Kamti, Park Panchmari, Matkuli and Panchmari. These ranges are divided into 107 beats in total. The lowest unit is compartment which is used for the management practices

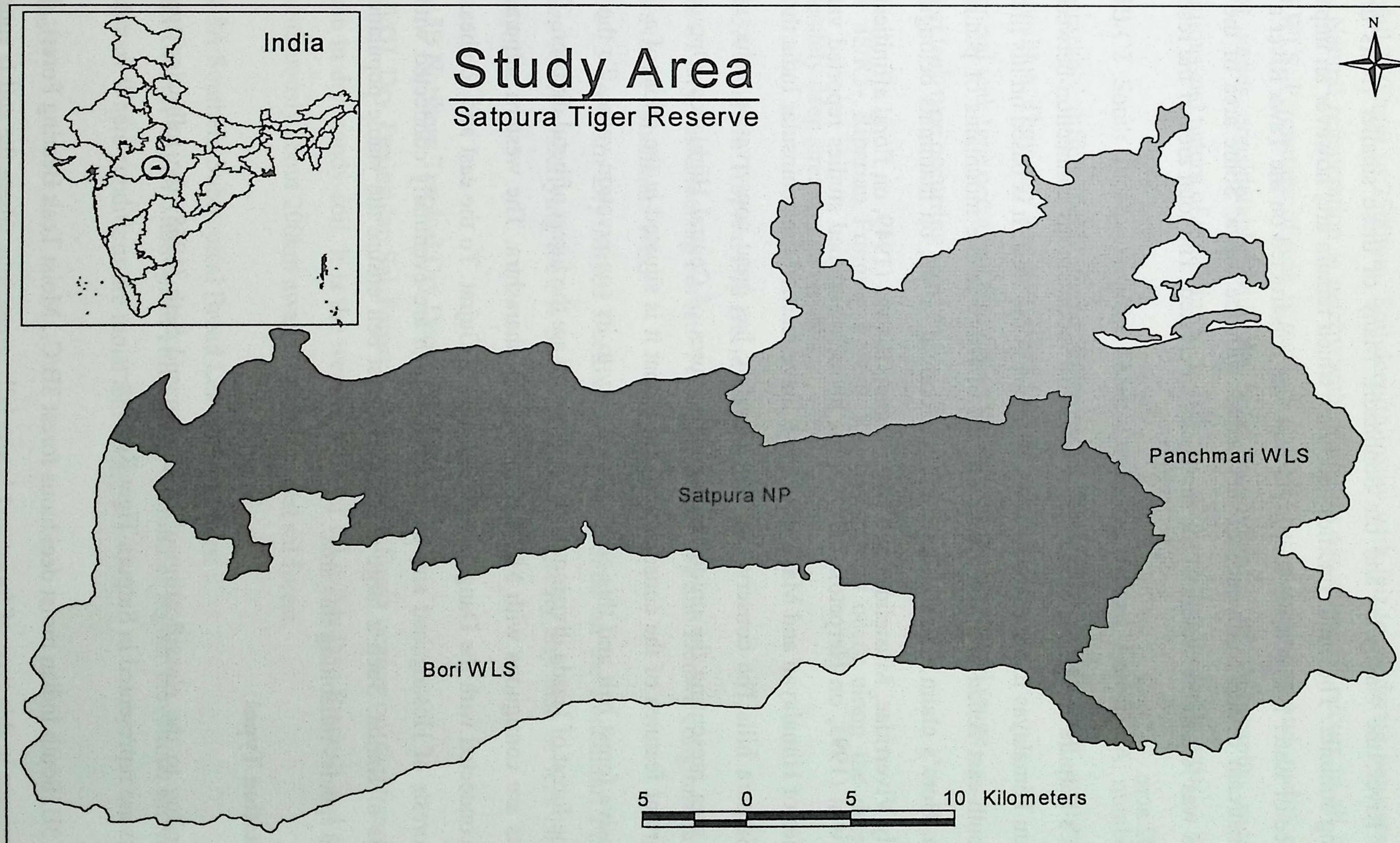
Satpura hill range run west to east. The terrain is generally rugged and broken up into scarp like formation. To the north of the Satpuras is Vindhyas running parallel to it and between the two is the valley of the Narmada River. The Satpura and the Vindhya with the Vindhyan scarp lands constitute the central highlands. Running generally east-west through the conservation unit are the Mahadev hills, an offshoot of the Satpuras on which the Satpura national park is mainly located.The entire conservation unit forms part of the catchments area of the Narmada. The runoff water from the area flows into the Tawa or the Denwa which are tributaries of the Narmada. Sandstone, conglomerate and trap are the three main types of rock found in the unit. In the Bori WLS the underlying rock is mainly of Deccan Trap which is basaltic in nature. In the west of the unit the rocks are sandstones and conglomerates of the Gondwana system with intrusion of Deccan trap. The soil derived from sandstone is sandy and lacking in nutrients. It generally supports poor quality mixed forest with very little teak. Conglomerates give a shallow black soil which supports good quality mixed forest of saja and khair with a fair admixture of teak. Partly weathered trap gives coarse murramy soil which supports poor quality teak forest. However fully weathered and mature soil derived from trap supports good quality teak forests.

The conservation unit has a tropical monsoonal type of climate. There are three major seasons; winter from November to February, summer from March to mid June and the rainy season from mid June to September. The hottest months are April, May and June.

At Hosangabad the mean daily maximum temperature varies from 26.5^0 C in January to 42^0 C in May. The mean daily minimum temperature varies from 12^0 C in January to 27^0 C in May. Bori on the whole enjoys a cooler climate than Hosangabad. Some localities in Bori are frost prone. At Panchmari station, the mean daily maximum temperature varies from 22^0 C in January to36^0 C in May and the mean daily minimum temperature varies from 8^0 C in January to 24^0 C in May. The temperature rarely becomes subzero in winter or above 40.5^0 C in summer. The average rainfall in Bori WLS is 2067.5mm ranging from 1188mm to 3273mm. The average rainfall at Panchmari is 2265mm. The no of rainy days in a year ranges from 60 to 80 with an average of around 65. In the Bori WLS the rainfall decreases from east to west.

The conservation unit has two main rivers flowing through it, namely Tawa and Denwa. The Denwa flows through deep gorges, cut over the edges in the Panchmari Plateau. The Tawa flows along the western boundary of Bori WLS and Satpura NP.

Satpura Tiger Reserve with management units



Both join together and flow into the Narmada River.The Tawa is fed by smaller tributary rivers such as the Koti and the Malni. The tributaries of the Denwa include the Bori River, the Nagdwari and the Sonbhadri. Many of these smaller rivers dry up during summer. The small puddles and holes which remain are, however an important source of water for wildlife. In 1967 a dam was constructed on the Tawa River a little downstream of the confluence of the Denwa with the Tawa. Some area of the Bori WLS was lost in the waters of the reservoirs so created. The total area of the reservoir is 202 acre.

Hora's Satpura Hypothsis (1949) proposes a lost mountainous connection between the Assam Himalayas in the east and Western Ghats in the west. It is based on his findings of south-east Asian and Himalayan species of fishes in the mountains of peninsular India. Hora's claim was substantiated by Roonwal (1949, on mammals belonging to family Viverridae, Mustelidae and Hemitragus), Biswas (1949, on floral affinities) and by Swan (1993, on Herpetofauna). All the above mentioned studies reported various species of Himalayan and Malayan origin to have reached the peninsular India through the Satpura hills.The conservation unit therefore has great conservation value as the only area presenting the unique biological features of Central Highlands. One of the important features of the conservation unit is that it is situated in the midst of a large, extensive forest belt and this adds considerably to its conservation value. To the west are the forest of Harda division while to the south are the forest of betul division. These forests are contiguous with Melghat forest in Maharashtra. The western satpuras are also connected with the Dang and Panchmahal in Gujrat. To the east and southeast are the forests of Hosangabad and Chhindwara which are eventually connected with the forests of Kanha. Such a large contiguous forest belt ensure the viable population of varios species inhabiting this area..

Vegetation Types:

According to the classification of Champion and Seth (1968) the following type of forests are represented in Satpura Tiger Reserve—

Type 3B, South Indian moist deciduous forest $3B/C_1$, Moist Teak Bearing Forest: Teak is dominant in this type of forest and is specially gregarious where the soil is suitable-generally form from basalt.

It has two subtypes:

a) 3B/C1 South Indian Tropical Moist Deciduous Forest Slightly Moist Teak Forest – Rainfall 1600mm to 2500mm. Soil deep to loamy with fair to moderate percentage of teak. Natural regeneration is patchy with deciduous associates. It occurs in all of the Bori WLS. Percentage of teak is medium to high. The composition and quality of the forest varies considerably with the local combinations of topography, moisture conditions and nature of underline rock. Because of this within the basic type

b) 3B/C2 South Indian Tropical Moist Deciduous Mixed Forest:- A number of recognizably differentiable forest subtypes are seen differing in their quality and composition. They may be classified as follows—

i) General teak type occurring throughout the sanctuary except Bori range

ii) Bori teak type occurring range

Type 4F/R5- Riparian Fringing Forest: Riparian forests occur along the deep and moderately deep streams and rivulets.

Type 5A Southern Tropical Dry Deciduous Forest:

a) 5A/C1 Dry Teak Bearing Forest:- Found in deccan trap and Denwa conglomerates. It occurs in the Panchmari WLS.

b) 5A/C3 Southern Dry Mixed Deciduous Forest:- Found on the Panchmari Plateau. Occurs where underlying rock is Sandstone. Contain hardly any teak or less bamboo than 5A/C1.

Type 5B Northern Tropical Dry Deciduous Forest

a) 5B/C1 Dry Peninsular Sal Forest:- This type of forest occurs on the Panchmari plateau in dry, sandy soil. It is the western limit of sal in Madhya Pradesh and occurs discontinuously about 200km away from the nearest sal forest.

Type 8A Southern Subtropical Broad Leaved Hill Forest :

8A/C3 Central Indian Subtropical Hill Forest: - Found at higher elevations on hills of Panchmari Where conditions are moist and cooler.

Bamboo:

Bamboo occurs everywhere in the Bori WLS and also in Satpura NP. In Panchmari WLS it is much reduced due to overexploitation. The only species found is

Dendrocalamus strictus except for some clumps of *Bambusa polymorpha* near Dhain. Bamboo likes well drained areas and is specially abundant in teak forests.

Teak Plantations:

The oldest existing plantation in the conservation unit is Davidson's 1869 plantation. From 1976 to 1987 the Forest development corporation carried out large scale plantation work, in Bori 1779.49 Ha, in Churna 1834.03Ha.

Grasslands:

Grasslands are found along the nala banks on the shores of the Tawa Reservoir in failed plantation areas, relocated village sites, in the clear felling forest areas and in the open forest areas.

The bird diversity of this area was broadly studied by many people like Osmaston (1921), Bates (1927), D'Abreau (1931), Ali (1939, 1949). Rodger and Hall (1988) carried out an assessment of floral diversity of the preservation plot in the eastern portion of Bori Wildlife Sanctuary. Sawarkar & Panwar (1990) proposed on integrated land use strategy for the conservation of wildlife in the Satpuras. Sawarkar(1990) also studied the biodiversity of this area. Dutta (1993) studied the spatio-temporal heterogeneity of food supply and the consequent effects on food resource use and space-use patterns of the Indian Giant Squirrel (*Ratufa indica*). Pai (1993) quantified bird species diversity, avian guilds and avail community structure found in four riparian areas of Bori sanctuary and documented 214 species. Mehta (1998) studied the effect of different forestry practices on bird species diversity in Satpura. Musavi *et al* (2000) made a socio-economic study of tribals and non-tribals of this area to develop area specific management guidelines for conservation of biodiversity, considering existing forestry practices and local people's needs. Pant *et al* (2002) in a WII-USDA Forest service collaborative project studied biological diversity and socio-economic scenario of this area broadly.

Chapter 1

PREY SELECTION AND DIET OVERLAP BETWEEN TIGER, LEOPARD AND DHOLE IN SATPURA TIGER RESERVE

Advait Edgaonkar, Ravi Chellam and Qamar Qureshi

INTRODUCTION

Large carnivores may play a key role in the regulation of prey (Terbogh 1990). Understanding how these carnivore species coexist could be important in managing the conservation of large carnivores in areas where more than one species is found in sympatry. Interspecific competition is a major process in the structuring of many communities and one hypothesis is that resource partitioning along a combination of temporal, spatial and dietary axes would occur as a result (Schoener 1974). In the presence of competitors one would expect a niche shift to take place, and resource overlap to decrease (MacArthur 1972). Numerous factors have been shown to influence the choice of prey by large carnivores. Prey abundance, size, behavior and competitive interactions with other predators are some of them. In India, habitat loss and poaching has increased the pressure on the populations of many large carnivores. Intensive management rather than a 'hands off' policy of protection might be necessary in the future in order to stop the decline in their populations.

Information about interactions between tropical large carnivore species is scarce. Some studies have been conducted on single species to get needed information on food habits of these predators (Bagchi et al. 2003, Biswas and Sankar 2002, Reddy et al. 2004 Edgaonkar and Chellam 2002). Information about diet selection and overlap is available on tigers, leopards and dholes from southern India (Johnsingh 1983, Karanth and Sunquist 1995), and on leopards and tigers (Sankar and Johnsingh 2002) and lions and leopards (Ravi Chellam 1993) in western India. Differential spatial use by tigers and leopards has been found in one study in Nepal (Seidensticker 1976), but not in another (Karanth and Sunquist 1995). In the neotropics one study found evidence of spatial avoidance of jaguars by pumas (Scognamillo et al. 2003) at fine scales, but another (Taber et al. 1997) did not find a similar pattern. Emmons (1987) found some degree of dietary separation between pumas and jaguars, with jaguars tending to take slightly larger prey. Tigers and leopards are opportunistic stalking predators and are expected to kill more randomly as opposed to the dhole, which is a coursing predator (Schaller 1967). Dhole are more diurnal than tigers and leopards (Johnsingh 1983). They are group living, smaller, and coursing predators, so their dietary overlap with the felids may be less than that of the tigers with leopards. Anecdotal evidence exists of aggressive interactions between the three carnivores, especially between leopards and dholes. There is need for more data on the potential for competition and resource overlap of these major predators in tropical forest assemblages over a range of resource availabilities. The present study describes the prey taken, quantifies the dietary overlap and measures the prey selectivity of tigers, leopards and dholes in a site where the abundance of prey is lower than other places where food habits of these carnivores have been studied.

METHODS

Study Area

The study was conducted in the Satpura Tiger Reserve (STR). STR covers 1428 sq km in area, and is located in the Hoshangabad district of the central Indian state of Madhya Pradesh in India. It includes three administrative units, the Pachmarhi and Bori Wildlife Sanctuaries, and Satpura National Park. An intensive study area of approximately 200 sq km was located in Bori Wildlife Sanctuary and Satpura National Park.

The forest in STR (22°19' to 22°30' N and 77°56' to 78°20' E) is mainly of the moist deciduous type (Champion and Seth 1968) . The intensive study area is a mosaic of dry and moist deciduous forest dominated in many places by teak. Teak plantations have replaced mixed forests in some areas. Other common species found there include *Butea monosperma*, *Madhuca latifolia*, *Lagerstroemia parviflora*, *Schleicheria oleosa*, *Terminalia arjuna* and *Diospyros melanoxylon*..

A diverse assemblage of fauna is found including wild pig (*Sus scrofa*), mouse deer (*Tragulus memmina*), chousingha (*Tetracerus quadricornis*), chital (*Cervus axis*), barking deer (*Muntiacus muntjak*), sambar (*Cervus unicolor*), chinkara (*Gazella gazella*), nilgai (*Bosephalus tragocamelus*) and gaur (*Bos gaurus*). The common langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mulatta*) are the primates found here. Carnivores are represented by tiger (*Panthera tigris*), leopard (*Panthera pardus*), wild dog (*Cuon alpinus*), jackal (*Canis aureus*), striped hyena (*Hyaena hyaena*), sloth bear (*Melursus ursinus*), jungle cat (*Felis chaus*), palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), ruddy mongoose (*Herpestes smithii*), common mongoose (*Herpestes edwardsi*) and ratel (*Mellivora capensis*), among others. Rufous tailed hare (*Lepus nigricollis ruficaudata*), porcupine (*Hystrix indica*), Indian giant squirrel (*Ratufa indica*) and the large Indian flying squirrel (*Petaurista petaurista*) are some of the smaller mammals found here.

Reconstruction of carnivore diets

Scats were collected opportunistically as well as systematically along animal and man made trails in the study area. Identification of tiger and leopard scats was based on associated tracks or sign. Scat size or diameter was not used as the criterion for discriminating between species as there is suspected to be overlap in scat size amongst the three species and this may lead to significant misidentification of scats (Farrel et al. 2000). Only scats of tigers and leopards that had associated tracks or sign near them were collected to ensure correct identification. Scats of dholes were easy to identify as they were deposited at communal defecation sites (Johnsingh 1983). Scats were washed and undigested remains of hair in them were mounted on a slide and compared under a microscope with a reference collection of hair at the Wildlife Institute of India following the method of Mukherjee et al. (1993). Bird and rodent taxa were not identified to species level, but were lumped into their respective categories. In total we analyzed 193 leopard scats, 90 tiger scats and 80 dhole scats. The percentage frequency of occurrence of all the major species was calculated along with their bootstrap confidence intervals.

Sample size adequacy

Assuming an infinite population of scats, the number of samples required to quantify a particular prey item to required level of precision (with 95% confidence) is given by the formula :

$N = (1.96^2) * (1-P) / (l^2 P)$

Where N is the sample size required,

P is the frequency of occurrence of food type in the scats, and

l is the acceptable percentage of error (Reynolds and Aebischer 1991).

For rarer species, the sample size needed for an acceptable error is very high, and logistically infeasible. The assumption of sampling from an infinite population of scats also is needlessly restrictive. Trites and Joy (2005), based on simulation studies, suggested that about 94 scats are necessary to obtain sufficient power to detect differences in species consumed at moderate effect size. To check for the stability of percent frequency of occurrence in the diet, all the scats for each carnivore were randomized and the percentage frequency of occurrence of each prey item in the diet was plotted cumulatively, at an interval of 10 scats. The number of scats it took for the frequencies to reach an asymptote was considered sufficient to quantify that prey item in the diet reliably.

Estimation of the relative biomass and numbers of prey species in the diet.

The frequency of occurrence is biased towards smaller sized prey, since relatively more scats are produced for smaller prey than larger prey. To correct for this relative frequencies were converted to relative biomass consumed using the equations of Ackerman et al. (1984) for tigers and leopards, and Floyd et al. (1978) for dholes.

These are:

$Y = 0.38 + 0.020X$ (for dhole)

And

$Y = 1.98 + 0.035X$ (for tigers and leopards)

Where X is the average weight of the prey and Y is the number of field collectable scats for that weight of prey. Y can then be converted into the relative biomass of prey taken by multiplying it with the relative frequencies found in the scats, and into relative numbers by dividing relative biomass by average weight of the prey species. The weight of various prey species killed by tiger, leopard and dhole was assumed to be similar to that from the study by Karanth and Sunquist (1995).

The relative number of each prey species killed was obtained by dividing the relative biomass by the average weight of the species taken by tiger, leopard and dhole respectively. The mean weight of prey killed was calculated as the sum of the weight of prey species multiplied by the proportional number taken.

Estimation of prey selection

Selectivity can be defined as taking a prey at frequencies different from that expected given its availability (Chesson 1978). If there is no selection one would expect a prey item to be taken at relative frequencies similar to the relative frequency of its availability. Any statistically significant deviation, whether positive or negative, from availability would indicate, respectively, preference or avoidance of that prey type.

Availability of a prey species is likely to be a function of its abundance, anti-predatory behavior, habitat selection at fine scale and time of activity. We assumed, as in other studies (Karanth and Sunquist 1995, Bagchi et al. 2003, Biswas and Sankar 2002), that abundance was the major component of availability. Abundance was therefore estimated as the density of groups of the major prey species, since the probability of encountering prey is likely to be proportional to the density of groups, rather than of individuals (Karanth and Sunquist 1995). The prey density was estimated by the line transect method. Twenty permanent transects were laid randomly and repeatedly walked between 10 and 20 times each for a total effort of 1260 km. The species, group size, angle and angular distance from the transect was noted. Distance measurements were taken with a laser rangefinder (Bushnell Yardage Pro 400) and angles were measured with a magnetic compass. Program Distance v 5 (Thomas et al. 2005)was used to estimate the density of prey species.

Selectivity was quantified by comparing the observed frequency of each prey species in the scats to expected frequencies (Link and Karanth 1994). Expected frequencies were derived from the densities estimated by line transects. If a kill of species i with a density d_i , produces λ_i scats, then the proportion of scats produced when the carnivore takes prey in proportion to their density is given by:

$$\Pi_i = \frac{d_i \lambda_i}{\sum_i d_i \lambda_i}$$

The program SCATMAN (Hines and Link 1999) was used to estimate prey selection by comparing the π_i to the the observed proportion based on random samples of predator scats. The program uses the estimated d_i and λ_i, and the variation associated with these parameters. It implements a parametric bootstrap designed to handle the problem of excessive Type I error caused by comparison of estimated frequencies as opposed to exact frequencies (Link and Karanth 1994). Inputs to the program are the estimated availability and standard error of each prey species, and the number of collectable scats that are produced by an average kill of each prey species, along with their standard errors. High chi-square values in the output indicate that observed frequencies are significantly different from expected, and the presence of selectivity. The contribution of each species to the total chi-square indicates whether the prey species is taken more or less than expected.

The Jacobs index (Jacobs 1974) has been used to estimate dietary preference in carnivores (Hayward et al. 2006). It has the advantage of being simple to compute and can be used to compare across studies easily. We computed this index of preference for the prey species, using the formula:

$$D = \frac{r - p}{r + p - 2rp}$$

where r is the proportion of total kills of a prey species, and p is the proportion of the total abundance of that species. The values of the index range from +1 to -1, indicating maximum preference and maximum avoidance respectively.

Dietary overlap

The extent of dietary overlap between all three species pairs was calculated by Pianka's index. The program EcoSim version 7.72 (Gotelli and Entsminger 2001) was used on the percent frequency matrix assuming all availabilities to be equal, as well as on an electivity matrix (Lawlor 1980), which is a matrix of frequencies of prey taken weighted by their densities. The calculated index can take values from 0 to 1, where 1 stands for identical diets or complete ovelap and 0 indicates completely different diets, or no overlap. The formula used for calculating the overlap of $species_1$ with $species_2$, O_{12} is

$$O_{12} = O_{21} = \frac{\sum_{i=1}^{n} p_{2i} p_{1i}}{\sqrt{\sum_{i=1}^{n} (p_{2i}^2)(p_{1i}^2)}}$$

Where p_{ij} is the percentage frequency of species j taken by carnivore species i. The index was also calculated on the electivity matrix comprising of electivities e_{ij} where R_j is the availability of prey species j.

$$e_{ij} = {p_{ij}}/{R_j}$$

The program randomizes the electivities for each combination of predator and prey species to generate a null model to compare with the observed mean index. If the mean overlap index value is at either tail of the distribution of simulated values then it can be judged to be significantly different than expected by chance. The density of the major prey species was derived from the results of the line transects. Porcupines density was assumed to be similar to that reported by Sever and Mendelssohn (1991).

Results

Density of potential prey species

The densities of groups and individuals of the potential prey species for 4 years is given in Table 1-1 and the mean density over all the years is presented in Table 1-2 . Common langur are the most abundant prey, while muntjac are found at the lowest densities.

Sample size adequacy:

Figure 1-1 shows the stability of the results of the scat analyses for various prey species in the diet of the three carnivores. It can be seen that for most species, the percentage frequency of that prey in the diet seems to stabilize at about 60 scats. The sample size of scats that were used in the analysis can therefore be considered adequate for quantifying the major species found in the diet of these carnivores.

Composition of tiger, leopard and dhole diets

Leopard preyed on the most number of species, followed by tiger. Only 4 species were found in the diet of the dhole. The percentage frequency and relative biomass of the major prey species in the scats is given in Table 1-3. Using the Ackerman et al. (1984) equation, the conversion to relative biomass gives similar results. It can be seen that sambar is the major prey in the diet of all the three predators. Chital is taken by dhole and to a lesser extent by leopard, but is not an important component of the diet of the tiger in this study. Livestock is also not an important constituent of the diet in this study, especially by leopards and dholes. Rodents, birds, porcupines, and wild pigs also do not figure in the diet of the dhole. Porcupine was only taken by leopards, while hare was taken by both leopards and dhole but not by tiger. Relative biomass and number were not estimated for the categories of bird and rodent species because of uncertainty about their weights. However, since they are a minor component of the diet, it would have little effect on the results.

Tigers take the highest mean weight of prey (115.0 kg), followed by dhole (46.1 kg) and leopard (27.0 kg). The percentage of prey taken by tiger, leopard and dhole as a function of prey body size is given in figure 2. Leopards take prey from each size class, though they take medium sized prey the most. Tigers and dholes seem to specialize on large and medium sized prey respectively. A small percentage of smaller sized prey is taken by both species, but dhole do not seem to take larger prey at all.

The diet overlap (Table 1-4) exhibited a similar pattern when calculated with percent frequencies or with electivities. All the 3 species overlapped considerably in their diet. Tiger and leopard diets overlapped extensively as did leopard and dhole diets. The dhole and tiger had less of a diet overlap, though this overlap increased when electivities were used to calculate the index.

Prey selection

Tiger ($\chi^2 = 69.0$, d. f = 4, p = 0.00), leopard ($\chi^2 = 61.9$, d.f. = 4, p= 0.00) and dhole ($\chi^2 = 48.7$, d.f. = 3, p= 0.00) all exhibited overall selectivity in their diet. Table 1-5 gives the partitioned χ^2 table, showing which prey species was significantly preferred or avoided. We find that tiger and leopard significantly preferred sambar, while chital, langur and wild pig was significantly avoided. Dhole significantly preferred both chital and sambar, while avoiding wild pig and langur. Both leopard as well as dhole took hare in proportion to its availability. The pattern of preference is similar with the Jacobs index (Table 1-6). This shows that the tigers prefer sambar and avoid all the other species, while leopards prefer sambar and hare while avoiding wild pig, and marginally, chital. Dholes prefer chital, sambar and hare, while avoiding wild pig and langur.

Discussion

Sambar is the preferred prey of all three species, and forms the bulk of the diet of the tiger in this study. Sambar has been found to be a preferred prey of the tiger in other studies too (Bagchi et al 2003, Biswas and Sankar 2002, Karanth and Sunquist 1995). It is a large sized deer, found in moderate density, and is known to choose dense forest areas (Varman and Sukumar 1993). This probably makes it more vulnerable to tiger predation, unlike the chital. The minor role of chital in the tigers' diet probably has to do with its habitat selection and density. In Bori-Satpura, chital are found in open plain areas near villages, where there is a lot of human disturbance. Their abundance is also not as high as that found in other national parks in India. Their habit of congregating near human inhabitation at night has been speculated to be the reason why they are not found in tiger diet in Bandipur (Johnsingh 1983). In Pench National Park (Biswas and Sankar 2002) in central India and in Nepal's Royal Bardia tiger reserve (Stoen and Wegge 1996), chital congregate in large numbers along low lying areas. They comprise a larger proportion of the tiger's diet there, though they are still not highly preferred. Wild pig are also taken less than expected, and this may be because of their low densities. In Bardia and Nagarjunasagar (Reddy et al. 2004) wild pig are more commonly taken, and they were found to be preferred prey in Pench (Biswas and Sankar 2002). Common langur are also taken less than expected. Though langur is less important in the diet of the tiger than of the leopard with respect to biomass, relatively more langur are taken by the tiger than by leopard. This is surprising since the langur is a mainly arboreal and small sized species. The tree climbing leopards should be able to hunt more langur than the tiger. A similar, pattern was seen in Sariska Tiger Reserve (Sankar and Johnsingh 2002), while only marginally more langur were taken by leopards in Nagarhole (Karanth and Sunquist 1995).

Although one tiger kill of gaur was seen, gaur, nilgai and muntjac were not found to be a part of the diet of the tiger at all. This could be because of the low density of these species in the study area. The nilgai also chooses disturbed and open areas which are not used by the tiger. Livestock were also not an important component of the diet, being found in about 5% of scats. This figure is comparable with some other studies, being about 7% in Srisailam Tiger Reserve (Reddy et al. 2004), and in 4.3% Pench Tiger Reserve. The importance of chital and sambar in tiger diets is given in Table 1-7.

Chital comprises about 20 % of leopard's biomass intake. Unlike the tiger, the leopard is also found close to human inhabitation, where chital congregate at night. Its relative lack of importance in the leopards diet may be due to the larger mean group size of the chital (3.3 per group) as compared to the sambar (2.1 per group), which increases vigilance and helps avoid stalking predation. In studies where chital is a major part of the diet, the chital density is quite high as compared to sambar density (Table 1-8). This is not the case in Bori-Satpura, where densities of the two ungulates are roughly similar. Hayward et al. (2006) reviewed leopard prey across many studies and concluded that preferred prey were likely to be in smaller groups and in denser vegetation than avoided prey. Chital are likely to be in larger groups and in more open vegetation than sambar, and therefore seem to be less preferred. Wild pig were not an important component of the leopards diet in Gir National Park (1%, Mukherjee et al. 1993), in Sariska National Park (0%,Sankar and Johnsingh 2002) and in Bandipur (0%, Johnsingh 1992) or Nagarhole (4.5%, Karanth and Sunquist 1995). In this study too, wild pig were avoided, the adults are probably dangerous prey for the leopard who likely only prey on subadults and young ones. Hares were taken in proportion to their availability by leopards and by dholes.

Along with sambar, chital is a preferred prey for the dhole. The herding behaviour and congregation by chital is not an effective strategy against a diurnal, coursing predator. Many chases were observed, usually in the morning. The antipredatory strategy of the chital sometimes included running towards the village, where the dhole would not follow (Johnsingh 1983).

The diets of the three predators overlap to a great extent. The tiger diet overlaps more with that of the leopard than the dhole because of shared inclusion of wild pig, cattle, rodents and birds in their diet. The dhole-leopard overlap is more than the dhole-tiger overlap because the former species-pair hunt in open areas also and both thus take a significant amount of chital, unlike the tiger.

Tigers seem to prefer large prey species that are more easily available, the mean size of prey being 115 kg. The leopard and dhole tend to take medium sized prey. The leopard being a solitary animal takes a mean prey size of 27 kg, while the pack living dhole takes larger prey of 46 kg. The leopard also has the largest range of prey size, taking small prey like hare, birds, rodents and porcupines that dhole did not kill in this study.

Figure 1.1: Relationship between sample size of scats and the percent frequency of occurrence of various species in tiger, leopard and dhole diet.

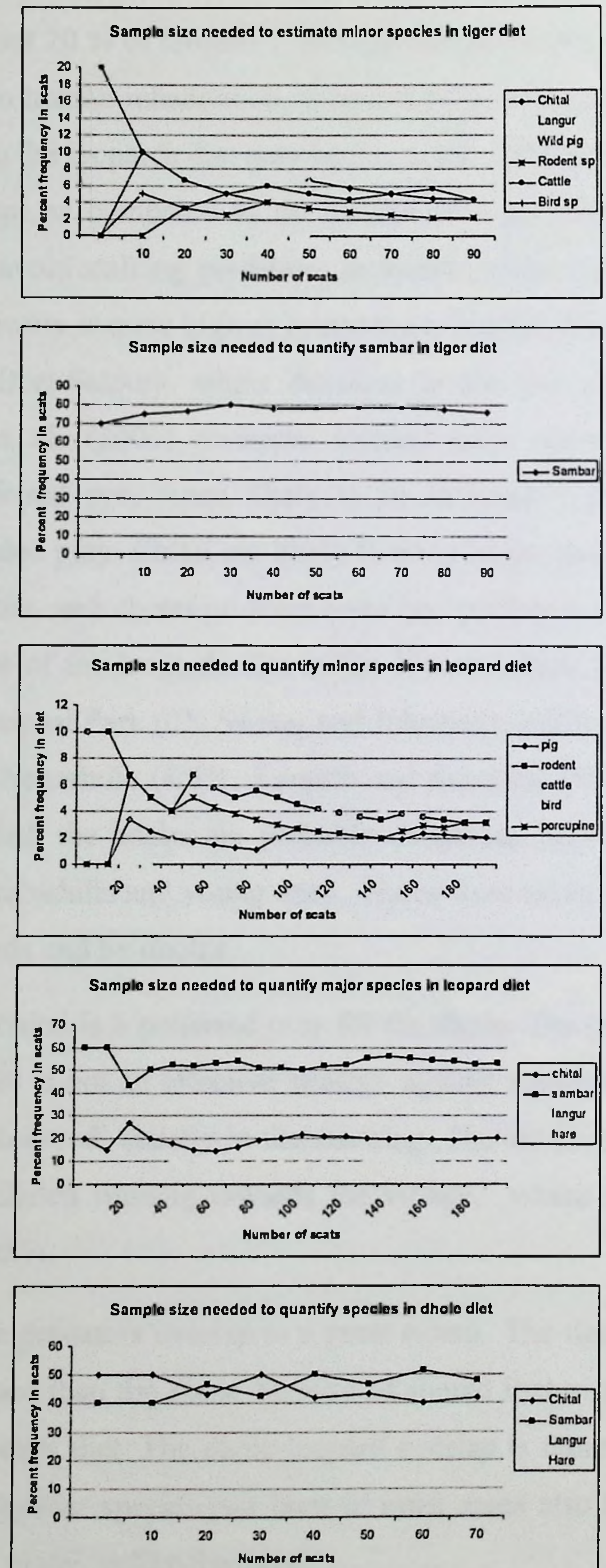


Figure 1-2: Prey taken as a function of body size by tiger, leopard and dhole.

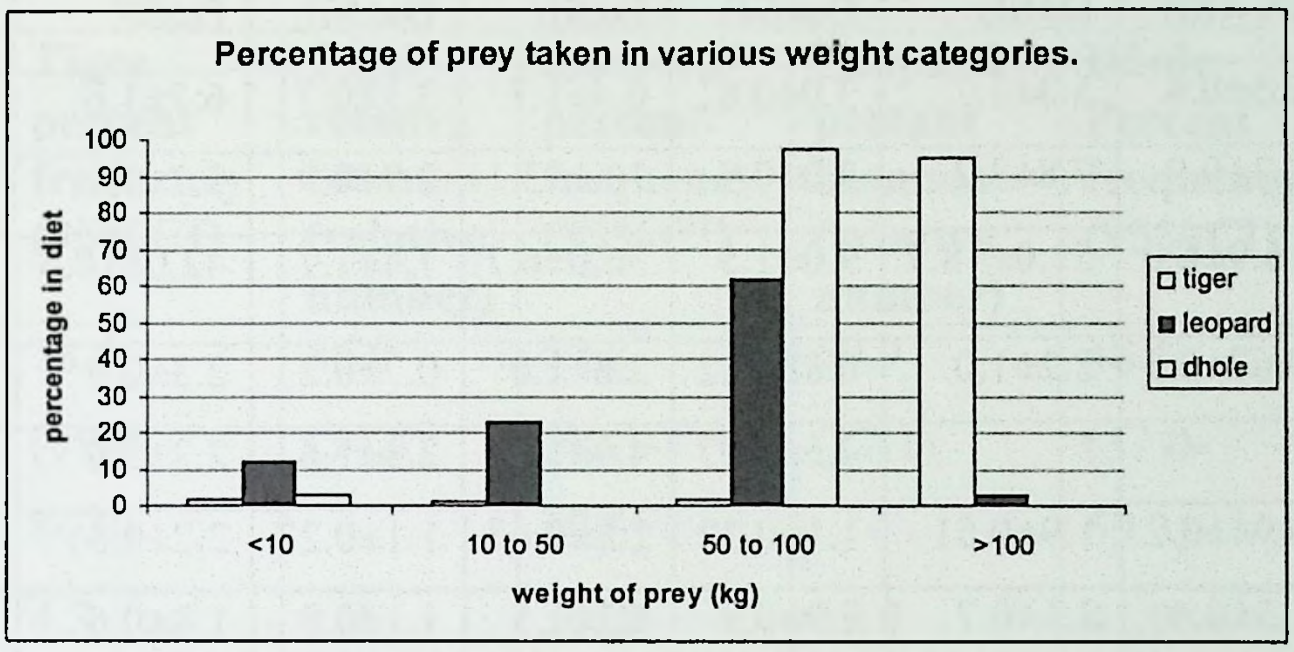


Table 1-1: Densities of potential prey in various years (per sq. km)

Year	2002		2003		2004		2005	
	Ds ±SE	D±SE	Ds±SE	D±SE	Ds±SE	D±SE	Ds±SE	Ds±SE
Sambar	2.5±0.8	5.3±1.7	3.0±0.81	6.4±1.7	3.1±0.7	6.7±1.6	1.4±0.45	3.1±0.97
Chital	2.3±0.9	7.8±3.2	3.0±0.9	10.1±3.1	2.9±0.9	9.7±3.1	1.6±0.6	5.8±2.1
Common Langur	16.9±6.0	51.0±18.3	9.0±1.5	36.0±6.7	7.4±1.7	42.0±10.4	5.7±1.1	32.7±6.9
Wild Pig	0.67±0.3	2.2±1.0	0.88±0.2	2.8±1.0	0.7±0.2	2.3±0.9	0.29±0.06	0.95±0.3
Hare	*	*	4.5±0.97	4.9±1.1	2.3±1.6	2.3±1.6	2.1±0.6	2.2±0.6
Nilgai	0.94±0.2	1.9±0.51	1.1±0.32	2.2±0.67	1.1±0.27	2.2±0.57	0.42±0.08	0.84±0.2
Indian Peafowl	1.3±0.4	2.1±0.7	2.9±0.9	4.7±1.5	1.1±0.3	1.8±0.6	0.99±0.2	1.6±0.4

*Not enough sightings to estimate density.

Table 1-2: Mean Density of potential prey (per sq. km)

Species	Ds±SE	D±SE
Sambar	2.3±0.35	4.9±0.77
Chital	2.3±0.43	7.5±1.5
Common Langur	8.14±1.32	35.8±6.0
Wild Pig	0.73±0.15	2.3±0.67
Hare	2.9±0.58	3.0±0.62
Nilgai	0.74±0.11	1.5±0.26
Muntjac	0.96±0.2	1.1±0.23
Indian Peafowl	1.3±0.25	2.1±0.44
Gaur	0.23±0.05	0.97±0.3

Ds: Density of groups/ sq. km
D: Density of individuals/ sq. km

Table 1-3: Percent frequency of prey (with bootstrapped 95 % C.I.), relative biomass and relative number (out of 100) of various prey species eaten, as estimated by scat analysis of tiger, leopard and dhole .

Species	Tiger percent frequency (95%CI)	Tiger relative biomass (relative number)	Leopard percent frequency (95%CI)	Leopard percent biomass (relative number)	Dhole Percent frequency (95%CI)	Dhole percent biomass (relative number)
Sambar	78.5 (69.9-86.0)	86.0 (54.8)	52.8 (46.1-59.6)	59.9 (27.1)	48.1 (37.0-59.3)	56.0 (36.8)
Chital	4.3 (1.1-8.6)	1.9 (4.8)	20.2 (15.0-25.9)	19.9 (11.6)	41.9 (31.5-51.9)	40.7 (34.1)
Common Langur	7.5 (2.2-12.9)	2.0 (33.6)	10.9 (6.7-15.5)	6.8 (23.7)	6.2 (1.2-12.3)	2.2 (12.6)
Black naped Hare	0	0	5.7 (2.6-9.3)	3.1 (29.2)	3.7 (0.00-8.6)	1.1 (16.4)
Wild pig	2.2 (0.0-5.4)	0.8 (2.9)	2.1 (0.5-4.1)	1.8 (1.3)	0	0
Cattle	5.4 (1.1-10.8)	5.2 (3.9)	1.6 (0.0-3.6)	2.9 (0.5)	0	0
Porcupine	0	0	3.1 (0.0-3.6)	1.8 (6.4)	0	0
Rodent spp	2.2 (0.0-5.4)	*	3.1 (1.0-3.6)	*	0	0
Bird spp	2.2 (0.0-5.4)	*	3.6 (1.0-6.2)	*	0	0

*Not estimated.

Table 1-4: Diet overlap index of Pianka (1973) between tiger, leopard and dhole.

Species pair	Index (using percentage frequency)	Index (using electivity)
Tiger- Leopard	0.94	0.96
Tiger-Dhole	0.79	0.88
Leopard-Dhole	0.93	0.95

Table 1-5: Prey selection by tiger, leopard and dhole.

Species	Tiger			Leopard			Dhole		
	Obs.	**Exp.**	**X^2 (p-value)**	**Obs**	**Exp**	**X^2 (p-value)**	**Obs**	**Exp**	**X^2 (p-value)**
Sambar	73	35.5	67.4 (0.00)	102	57.4	51.2 (0.00)	39	21.6	19.0 (0.00)
Chital	4	22.1	20.1 (0.00)	39	50.5	3.6 (0.06)	34	20.4	12.0 (0.00)
Common Langur	7	19.7	10.6 (0.00)	21	48.3	21.2 (0.00)	5	28.8	30.5 (0.00)
Hare	0	2.8	2.9 (0.09)	11	7.0	2.4 (0.12)	3	4.7	0.7 (0.41)
Wild pig	2	5.7	2.6 (0.11)	4	13.8	7.6 (0.01)	0	5.4	5.8 (0.02)

Table 1-6: Jacobs index values of preference, ranging from -1 indicating complete avoidance to +1, indicating complete preference.

Species	Tiger	Leopard	Dhole
Sambar	0.87	0.61	0.71
Chital	-0.46	-0.05	0.53
Common langur	-0.44	-0.66	-0.86
Hare	-1	0.77	0.54
Wild pig	-0.23	-0.58	-1

Table 1-7: Importance of chital and sambar as prey in tiger diets, and density of chital and sambar (individuals per sq. km) at various study sites in India.

Place	Percent of chital in diet	Chital density	Percent of sambar in diet	Sambar Density
Bandipur[1]	39	40	30.5	7
Nagarhole[2]	31.2	49	24.9	3.4
Pench[3]	53	80.7	13.8	6.1
Panna[4]	17.7	1	24.4	1.8
Ranthambore[5]	45.7	6.7	36.8	4.6
Sariska[6]	21[6]	27.6[7]	51.4	8.4[7]
Bori-Satpura[8]	20	7.5	78.5	4.9

[1]Johnsingh (1983) [2]Karanth and Sunquist (1995), [3]Biswas and Sankar (2002), [4]Chundawat et al. (1999), [5]Bagchi et al. (2003) [6]Sankar and Johnsingh (2002) [7]Avinandan, D (2003) [8]This study.

Table 1-8 Importance of chital and sambar as prey in leopard diet, and density of chital and sambar (individuals per sq. km) at various study sites in India.

Place	Percent of chital in diet	Chital density	Percent of sambar in diet	Sambar Density
Gir[1]	66	57.3	18	2.0
Bandipur[2]	51	40	14	7
Nagarhole[3]	44	49	13.5	3.4
Mudumalai[4]	67	25	11.7	6.6
Mundanthurai[4]	24	1.9[5]	9	2.8[5]
Sariska[6]	21[6]	27.6[7]	20	8.4[7]
Bori-Satpura[8]	20	7.5	52.8	4.9

[1]Khan et al. (1996) [2]Johnsingh (1983) [3]Karanth and Sunquist (1995) [4]Ramakrishan et al.(1999), [5]Varman and Sukumar(1995) , [6]Sankar and Johnsingh (2002) [7]Avinandan, D (2003). [8]This study.

Table 1-9. Importance of chital and sambar as prey in dhole diet, and density of chital and sambar (individuals per sq. km) at various study sites in India.

Place	Percent of chital in diet	Chital density	Percent of sambar in diet	Sambar Density
Bandipur[1]	52	40	14	7
Nagarhole[2]	49.7	49	10.2	3.4
Mudumalai (Kargudi)[3]	70.4	16	21.7	7.9
Mudumalai (Masanagudi)[3]	41	19.4	23.3	1.8
Pench[4]	38.7	80.7	49	6.1
Bori-Satpura[5]	41.9	7.7	48.1	4.9

[1]Johnsingh(1983) [2]Karanth and Sunquist (1995) [3]Venkataraman et al. (1995)
[4] Biswas and Sankar (2002) [5]Varman and Sukumar, [6]Sankar and Johnsingh (2002)
[7]Avinandan, D (2003). [5]This study.

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Chapter 2

ESTIMATION OF LEOPARD ABUNDANCE IN INDIAN FORESTS USING CAMERA-TRAPS AND MARK-RECAPTURE METHODS

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INTRODUCTION

There has recently been increased attention to the need for reliable estimates of carnivore density in India, but most of the work has been done on tigers (Karanth and Nichols 1998, Karanth et al. 2004, Harihar et al. 2006, Chauhan et al. 2005). Even basic information on other large felids is poor, except for food habits. Leopards have been in the news in popular media in India largely because of instances of human conflict that have occurred in many places. There is a perception that attacks on humans have increased in the last few years. It is speculated that the probable causes have been decrease in habitat, decline in leopard prey populations or increase in leopard densities close to human populations. Historical data on leopard or prey abundances in any of the conflict areas are lacking, and therefore the reasons given must remain speculative. Management of the conflict would be easier if the reasons were reliably known.

Camera trapping has been used in conjunction with the mark-recapture technique to estimate the densities of species in which individuals can be uniquely identified based on the coat patterns or other external marks. Large felid populations are difficult to estimate because the species are generally low in abundance, nocturnal or crepuscular and have large home ranges. The primary method of censusing tiger, leopard and lions by the government agency in India has been the pugmark method (Panwar1979). This involves taking plaster casts or paper traces the tracks of the carnivores in the entire survey area. The assumption is made that the tracks of all individuals are recorded and that all individuals can be identified on the basis of the tracings of their tracks. The method has been criticized for its subjective nature and the lack of incorporation of correction for detectability (Karanth et al. 2003).

The use of statistically robust indices to monitor populaton trends have been suggested, like track indices (Karanth et al. 2003), camera trapping rates (Carbone et al. 2001, Karanth and Nichols 2002) or occupancy models (Mackenzie and Nichols 2004), but there is a need to know the number of individuals in the protected area that is not met by these methods.

The mark-recapture method has been long used to estimate biological populations (Otis et al. 1978). Recently the method has been adapted to estimate tiger populations in India using remote camera traps. There are now estimates for tigers (Karanth and Nichols 1998, O'Brein et al. 2003, Johnson et al. 2006), leopards (Spalton et al. 2006), jaguars (Soisalo and Cavalcanti 2006, Silver et al. 2004) and snow leopards (Jackson et al. 2006) using mark recapture for other parts of the world and it is now the accepted method. In India there are few published studies on population estimation for carnivores other than the tiger. This paper will contribute to knowledge about densities. It is expected that more studies of leopard abundances will soon be available for this part of the world.

Leopard densities were estimated at three adjacent sites in Satpura Tiger Reserve and one site in Sariska Tiger Reserve. The Satpura Tiger Reserve (22°19' to 22°30' N and 77°56' to 78°20' E) covers 1428 sq. km in area, and is located in the Hoshangabad district of the central Indian state of Madhya Pradesh in India. It consists of three administrative units, the Pachmarhi and Bori Wildlife Sanctuaries, and Satpura National Park. The forest is mainly of the moist deciduous type (Champion and Seth 1968). The major ungulate fauna includes chital, sambar, muntjac and gaur. The major carnivores are tiger, leopard, sloth bear and dhole. The Sariska Tiger Reserve (25°05' to 25°27' N and 74°17' to 76°74' E) is 800 sq km in area and located in the north-western state of Rajasthan, in the Alwar district in India. The forest is mainly of the tropical dry deciduous and thorn type (Champion and Seth 1968). The major ungulates are chital, sambar and nilgai. Gaur and muntjac do not occur there. Major carnivores are the leopard, the striped hyena, jungle cat and the golden jackal. Sloth bears and dhole are not found there while the tiger has recently gone locally extinct due to illegal hunting.

METHODS

Four sites were chosen for estimation of leopard abundances. Trapping effort at these sites ranged from 33 days (396 trap nights) to 76 days (1216 trap nights). Three of the sites (Churna, Kamti and Lagda) were adjacent to each other in the Satpura Tiger Reserve in central India while the fourth was in Sariska Tiger Reserve. Camera trap locations were chosen after reconnaissance to maximize the probability of getting photos of leopards. Locations close to villages or on routes where there was a great deal of human movement were excluded to minimize the possibility of theft. Trailmaster 1550 (Goodson Associates, Lenexa, Kansas) camera traps were used with Olympus and Canon autofocus cameras. At two sites (Churna and Sariska), a one-camera setup was used at most stations, and a two camera setup was used at a few stations. These two camera setup locations were changed when both flanks of individuals in that area were obtained. At the other two sites each camera location had a two camera setup to photograph both flanks at the same time. Camera traps were activated at dusk and deactivated at dawn. The minimum interval between two photos was 6 seconds. Camera sensors were placed at a height that allowed photographs of smaller species like black napped hare and gray jungle fowl. Each period was considered 7 days post facto. Any number of photos of an individual leopard within a period was considered as one capture of that leopard. All photos were scanned and printed (Fig. 1). Each leopard photo of the same flank was compared to every other leopard photo. Printouts of the photos were scrutinized under a magnifying glass to identify patterns of similar looking spots. Photos which were underexposed due to the leopard being further away from the camera, or where the coat patterns were distorted because the individual was not approximately parallel to the camera, were difficult to identify. Difficult photos were enlarged and matched on the computer after some image processing to enhance contrast and brightness. If a pattern was detected then a separate area of the flank was checked to confirm the identity of the leopard. Leopards whose identities could not be confirmed were discarded and not used in the analysis. The population was estimated for the right flank and the left flank separately. Sometimes photos of both the flanks were available, usually in cases where two cameras were used. In one case a clear photograph of the face was available to link the two flanks. In these cases the identity of the leopard was unambiguous, and the leopard was included in analyses of both the flanks. Analysis of mark recapture data was done using Program Capture (Otis et al. 1978) to estimate densities. The jackknife procedure was used to estimate parameters of the Mh model, as suggested by Karanth and Nichols (1998). The test for population closure was not used as it has been shown to be unreliable (White et al. 1982). Instead, in Churna where trapping was conducted for 22 weeks, two estimates were obtained for 11 weeks each, and closure was assumed within these two shorter sessions.

Density of leopards was estimated as the number of leopards per 100 sq km. Effective area of sampling was obtained by three methods. The first method was simply the area occupied by the minimum convex polygon (MCP) calculated by joining the outermost points of the camera trap locations. This is an underestimate of the area sampled by the cameras, but has the advantage of being comparable to many other studies. The other methods involved adding a buffer area around the camera trap location points. Two distances were used in the calculation of the buffer: Half MMDM and full MMDM (Parmenter et al. 2003).

The mean maximum distance moved (MMDM) for all leopards in Satpura Tiger Reserve was calculated. Because a relatively smaller area (MCP of 26 sq km) was sampled in Sariska, the data from this site were not used in the MMDM estimation. MMDM was approximated by the mean of the maximum distance between two photos of each individual leopard for all leopards photographed at more than one camera trap location. Half this distance was used as a buffer around all camera trap locations for the half MMDM, and the full distance was used for full MMDM. Any area of the buffer that lay outside the boundaries of the Tiger Reserve area was subtracted, and the remaining area was considered the effective sampled area.

An index of relative abundance (RAI) for leopards was also calculated for each site. This was the number of independent leopard and prey photos at each site per camera trap night. Photos of leopards were considered independent if they were of different individuals or if they were of the same individual but not taken on the same day or at the same camera trap location. Each photo, regardless of flank, was considered a separate capture, unless there was a possibility that different flanks of the same individual had been photographed at a given camera trap location on the same date. In such a case only one photo was counted.

RESULTS

A total of 288 leopard photos were obtained, twenty were unidentifiable and were removed from the analysis. Of the identifiable photos 141 were of the left flank and 127 were of the right flank. Table 2-1 shows the number of photos per flank at each site. Trapping success was higher in session 2 at Churna than in session 1. Sampling intensity varied between sites, being lowest in Sariska and highest in Churna (Table 2-2).

Adequacy of sampling

A measure of the adequacy of sampling is if new individuals are no longer photographed with additional sampling. Figure 1 shows the addition of new leopards for the 4 sites. It can be seen that the curves have reached an asymptote for the sites in Satpura Tiger Reserve at 5 or 6 occasions. No asymptote was reached in Sariska suggesting that further sampling would have yielded photographs of additional new individuals. The shape of the curves and the number of individuals identified were very similar for the right and the left flanks.

Models for leopard numbers

Two estimates of leopard numbers were obtained, one for each flank. Estimates for the left flank and for the right flank were similar. The estimate for the flank with the lower standard error is presented in Table 3. Where Mo was selected, the next best model was used. All Mh were estimated with the jackknife estimator. Probabilty of capture, p-hat was similar in most sites except for the second session at Churna, which was higher.

Sex ratios

The sex ratios are female biased in all areas except Kamti. The average ratio is 1.68 (S.E. 0.38) females per male. For 4 estimates the capture success for males is higher than for females, and in one estimate they are the same. Males seem more likely to be photographed than females (Table 2-4):

Because the sites in Satpura Tiger Reserve were right next to each other, two of the leopards photographed at Churna a total of 25 times were also were also photographed in the adjacent Kamti area 3 times. No other individuals were photographed at adjacent sites (Table 2-6).

The Relative abundance index (Table 2-7) was also highest for Sariska followed by the second session at Churna. A Pearsons correlation between RAI and the density estimates for the four sites was calculated for MCP, half MMDM and full MMDM yielded r^2 values of 0.88, 0.79 and 0.43 respectively. An arithmetic mean for the values of the two sessions in Churna was used for the correlation.

Discussion

Ideally it is important to obtain photos of both flanks of the body so that identification of individuals is unambiguous. When camera numbers are limited, it seems possible to obtain unambiguous photographs of both flanks for a large proportion of the population using two cameras at a few locations, while using one camera at the remaining locations, provided the trapping goes on for a long enough period. This would maximize coverage of the area with the available number of cameras. The individual identification of leopards from photographs was found to be quite easy except when the animals walked farther away from the cameras, resulting in underexposed photos. This was likely to happen when the distance between the two sensors was more than 10 meters.

Tigers were sometimes observed to avoid camera traps, leaving the trail just before the camera location and getting back on the trail afterwards. Other studies have also observed this behaviour (Wegge et al. 2004). On the basis of tracks, leopards were never observed to avoid cameras traps, and seemed unafraid of the flash. Leopards of both sexes were photographed while standing or sitting in front of the camera, and did not rapidly move away. Sometimes more than one photograph was taken at the same time, indicating that the leopard stayed in that position for at least 6 seconds after the flash of the first photograph. However, rates of photocaptures for males seemed to be consistently higher than for females, when controlled for by the number of each sex. The existence of heterogeneity in capture probabilities relative to gender is likely. Bailey (1993) found it easier in Kruger National Park to capture males as opposed to females in box traps.

The calculation of effective area of sampling is a noteworthy issue in the estimation of density using camera traps. There is generally no measurement of the home range of the sample of individuals used in the estimation. It has been recommended that half the mean maximum distance moved (MMDM) be used as the buffer for estimation of densities (Wilson and Anderson 1985). A recent study on jaguars comparing MMDM obtained by telemetry to half MMDM and full MMDM found that the full MMDM results were much closer to densities based on actual movement rates, and that half MMDM seemed to overestimate densities (Soisalo and Cavalcanti 2006). The problem with the full MMDM is that there is still not enough data available for movement in leopards to advocate a shift to full MMDM. As the area of the buffer increases, it is more likely to include habitat that is unsuitable for the species and unrepresentative of the probability of capture at the camera trap location. In this study densities obtained using the half MMDM gave results that were better correlated with the relative abundance index than those with the full MMDM. It is recommended that an index of density calculated using the area of the minimum convex polygon (MCP) be used to compare different sites, and half MMDM used to estimate absolute density until further data are available on movement patterns of leopards.

The density of leopards was highest in Sariska Tiger Reserve, where tigers have been extirpated recently (Sankar et al. 2005), while it was lowest at Lagda, which had relatively the highest activity of tigers amongst all sites (pers obs) though it is not a high density tiger area. Variation in density of carnivores is associated with density of prey as has been shown in the case of tigers (Karanth et al. 2004) and other carnivores (Carbone et al. 1999) but other factors like presence of human disturbance (Woodroffe 2000) and tiger presence (Seidensticker 1976, Sunquist 1981) will also play a role, though there is some evidence that leopard densities may not be unduly depressed by presence of other large carnivores (Marker and Dickman 2005).

Leopard density estimates are available for various parts of the world, but using different methods. Schaller (1972) thought it was about 3.8-4.5 per 100 sq km for the Serengeti. Pienaar (1969) thought it was about 3.4 for Kruger. Jenny (1996) estimated it as about 7.1 in the rain forest of the Ivory Coast, and in Wilpattu National Park in Sri Lanka it was estimated as about 3.4 (Eisenberg and Lockhart 1972). Marker and

Dickman (2005) reported a mean of 10.5 (S.E. 4.0) inside protected areas (n =6), and 2.1 (S.E. 1.6) outside protected areas.

Photocapture rates calculated per 100 trap nights by Karanth and Nichols (1998) for 4 sites in India ranged from a low of 0.18 for Kaziranga National Park, a medium 2.3 for Pench National Park to a high of 5.44 in Nagarhole National Park. Estimates of RAI for the present study, ranging from 2.2 to 6.8 seem to be within the range found in these other areas in India.

The second session in Churna, conducted in spring-summer, had higher capture rates and a higher density estimate than the first session, conducted in winter-spring. Camera traps were mostly placed along topographic contours, where signs of leopard signs were high, and water tended to be found. It is possible that movement of leopards around such places increased in summer when water sources in the hills dried up, leading to higher capture rates.

The relative abundance index gave identical rankings to densities using half MMDM and was highly correlated. Similar results were obtained for tigers (Carbone et al. 2001) where it was recommended that the index be used as a surrogate in case obtaining actual abundance is problematic. In low leopard density areas it takes a long time to get a sufficient number of captures to use in the mark recapture framework. If the assumption of population closure is severely violated, then the RAI may be used as a substitute to density estimation. Individual identities are also not crucial in estimating the index and so it can be used on species that do not have individually identifiable markings.

How many leopards are found in Satpura Tiger Reserve? Since four estimates are available, the mean of these estimates is more likely to be a robust estimate to use for extrapolation to the entire Tiger Reserve. The mean of the four estimates of density in Satpura Tiger Reserve is 8.87 (S.E. 0.9) per 100 sq km. If this is assumed to be representative of the entire reserve, there are an estimated 126 leopards in the reserve. The precision around this estimate is poor because of the associated variance between sites, variance at each site and also the variance associated with the measurement of the buffer.

The leopard densities seem comparable to other study sites in India, though Sariska Tiger Reserve seems to have the highest densities in spite of there being a history of human disturbance and poaching. This may be related to the recent removal of the tiger from Sariska and the occupation of prime habitats by the leopard. The leopard densities at Satpura, where tiger density is relatively low, also seem to be higher than at Kanha and Pench, which have higher tiger densities.

Figure 2-1: Identification of leopards based on spot patterns. The first two photos are of the same leopard, the third photo is of a different leopard.

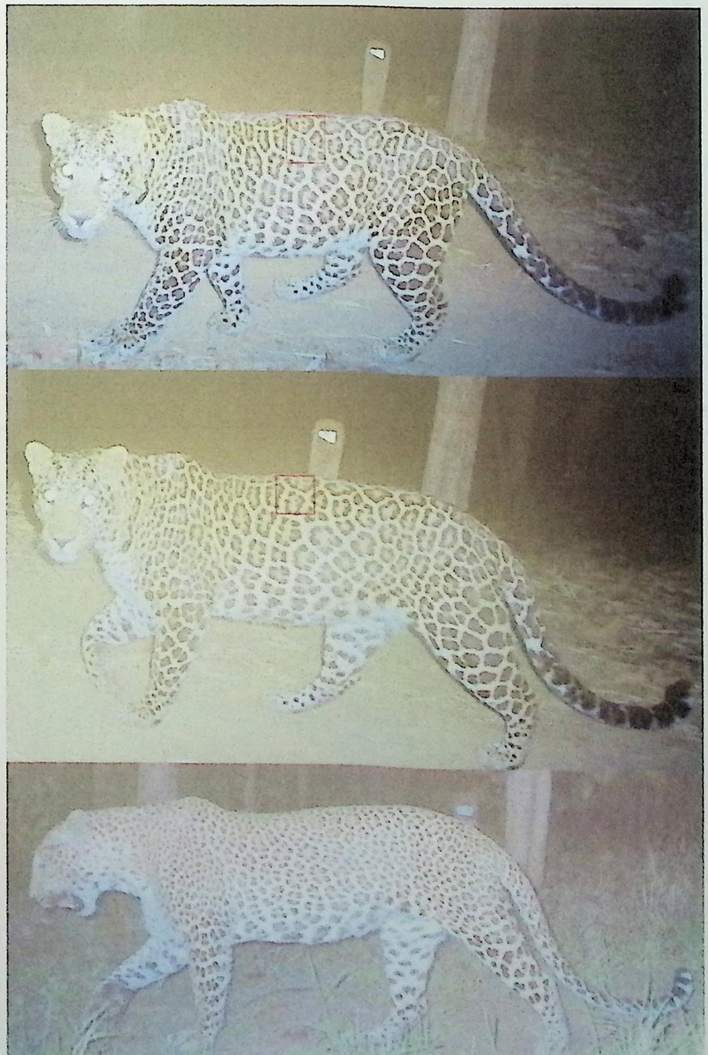


Figure 2-2: Camera trapping in 3 sites (Churna, Kamti and Lagda) in Satpura Tiger Reserve.

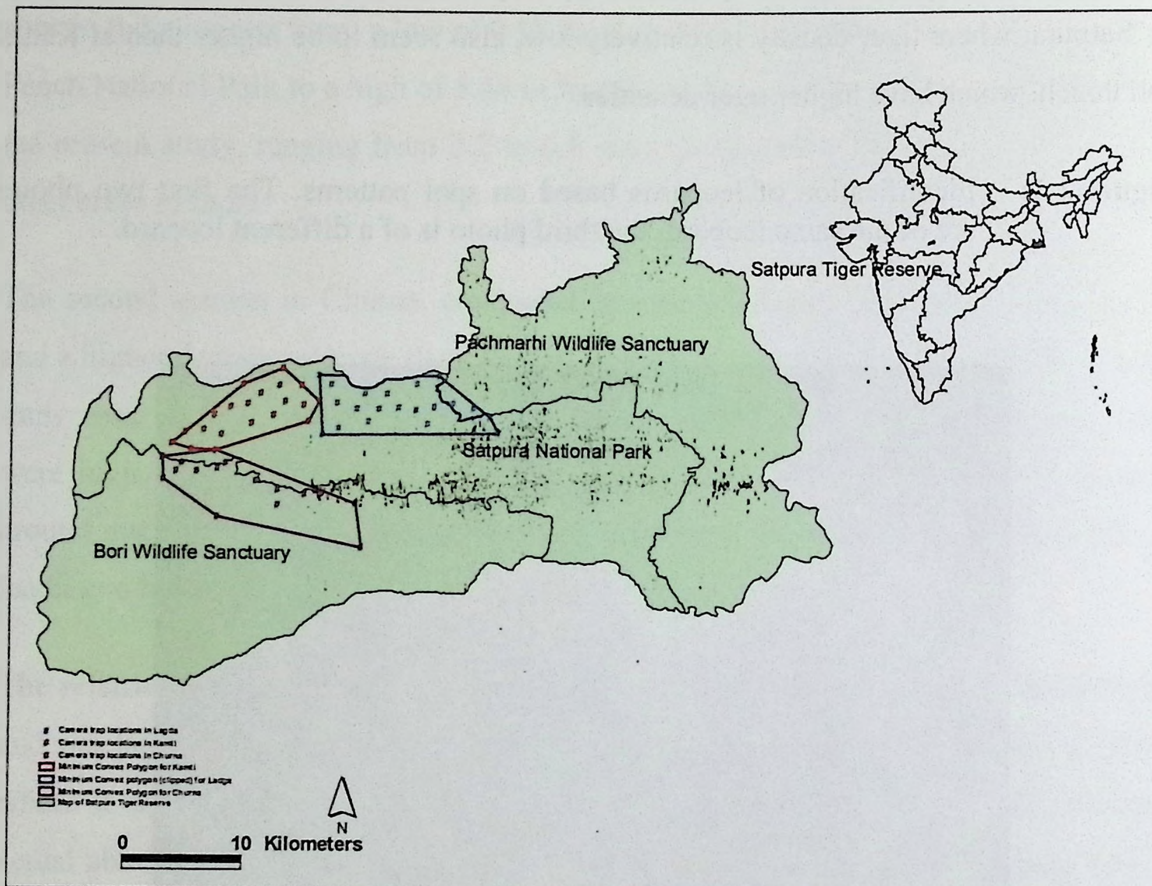


Figure 2-3: Camera trapping in Sariska Tiger Reserve.

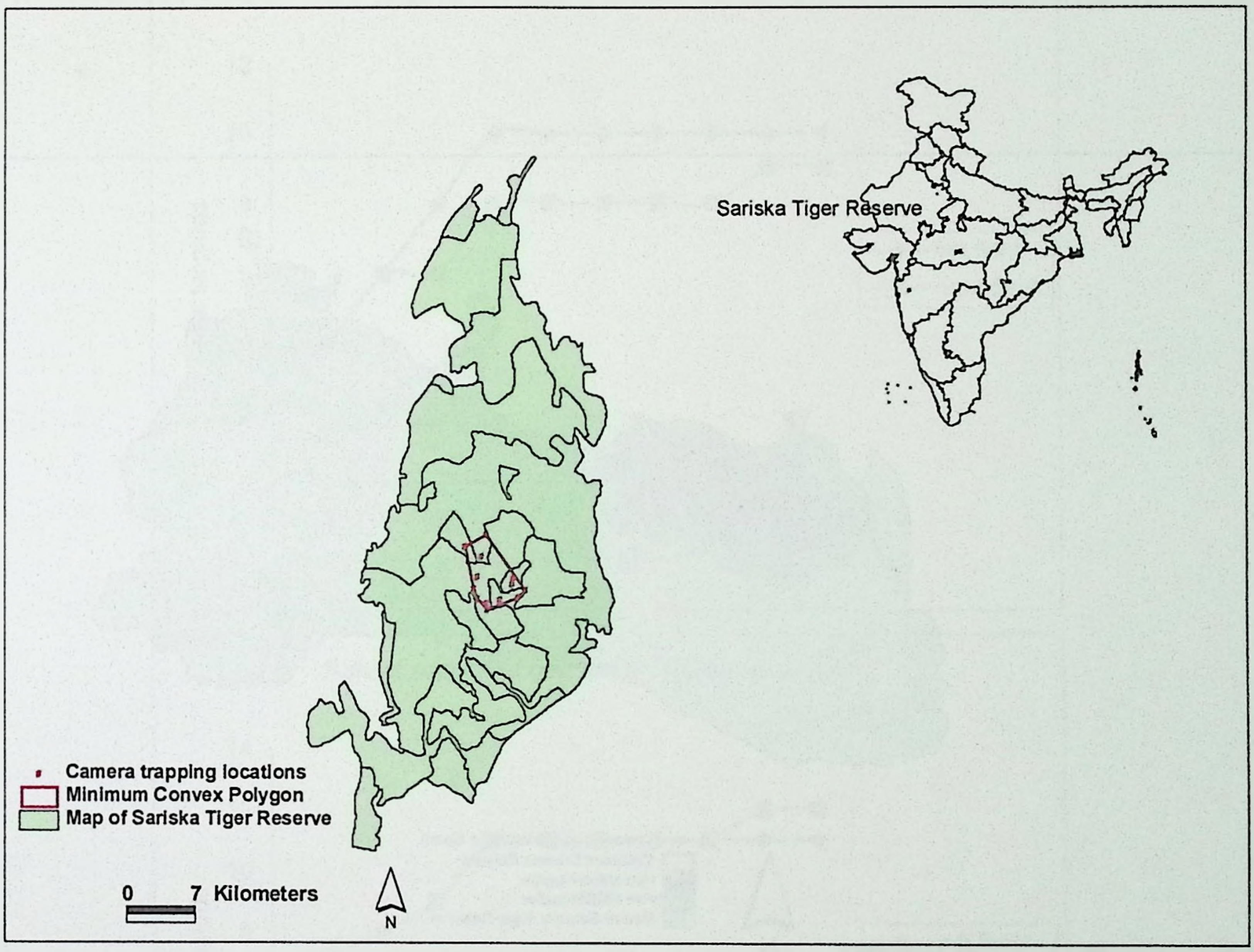


Figure 2-4: Map showing camera trap locations, MCP, half MMDM and full MMDM buffers for one site (Kamti).

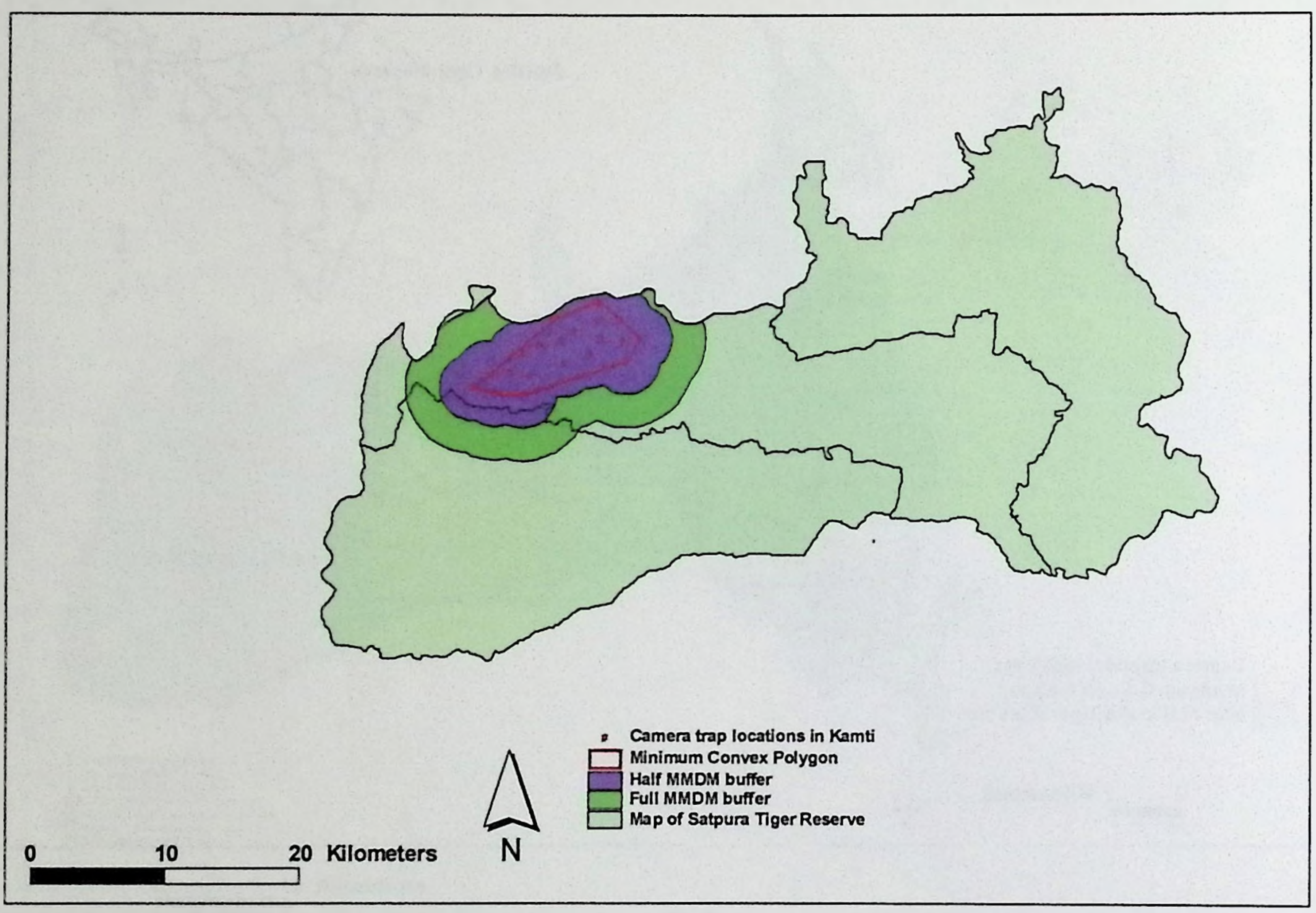
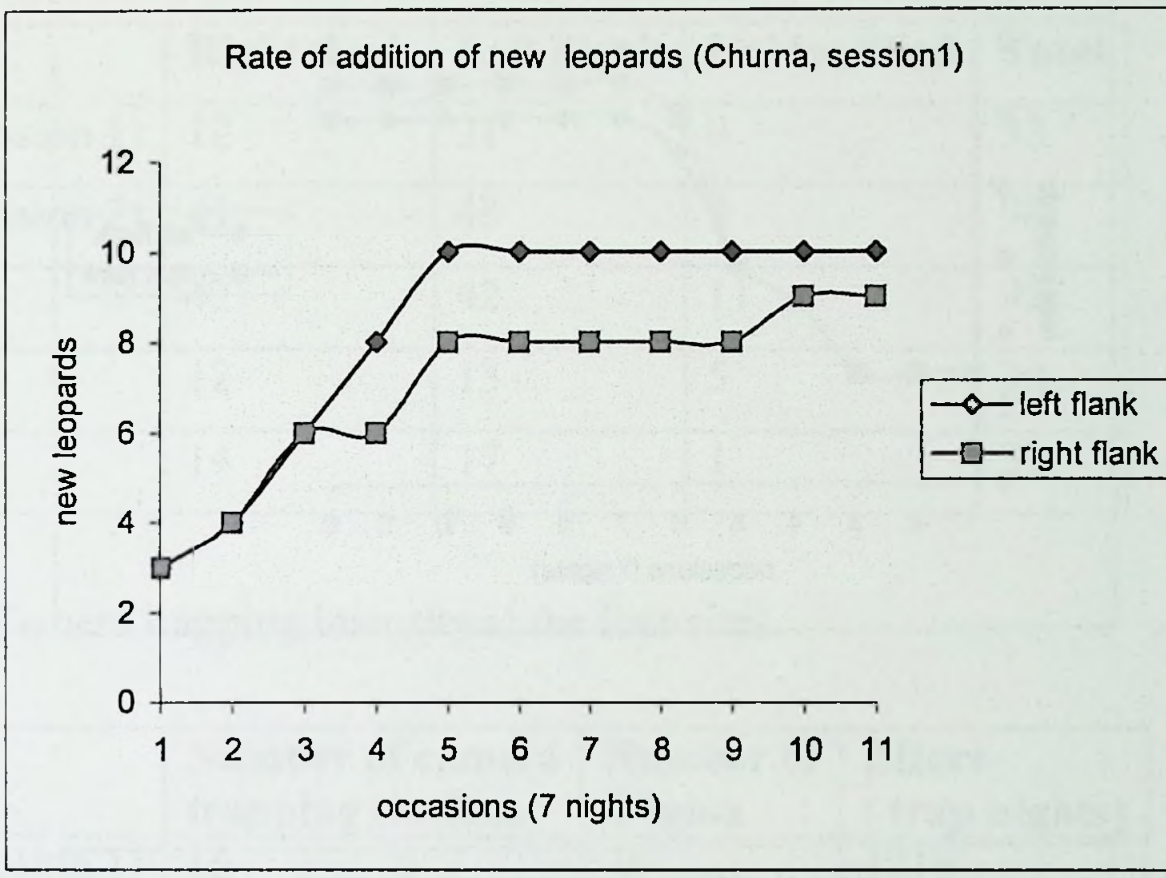
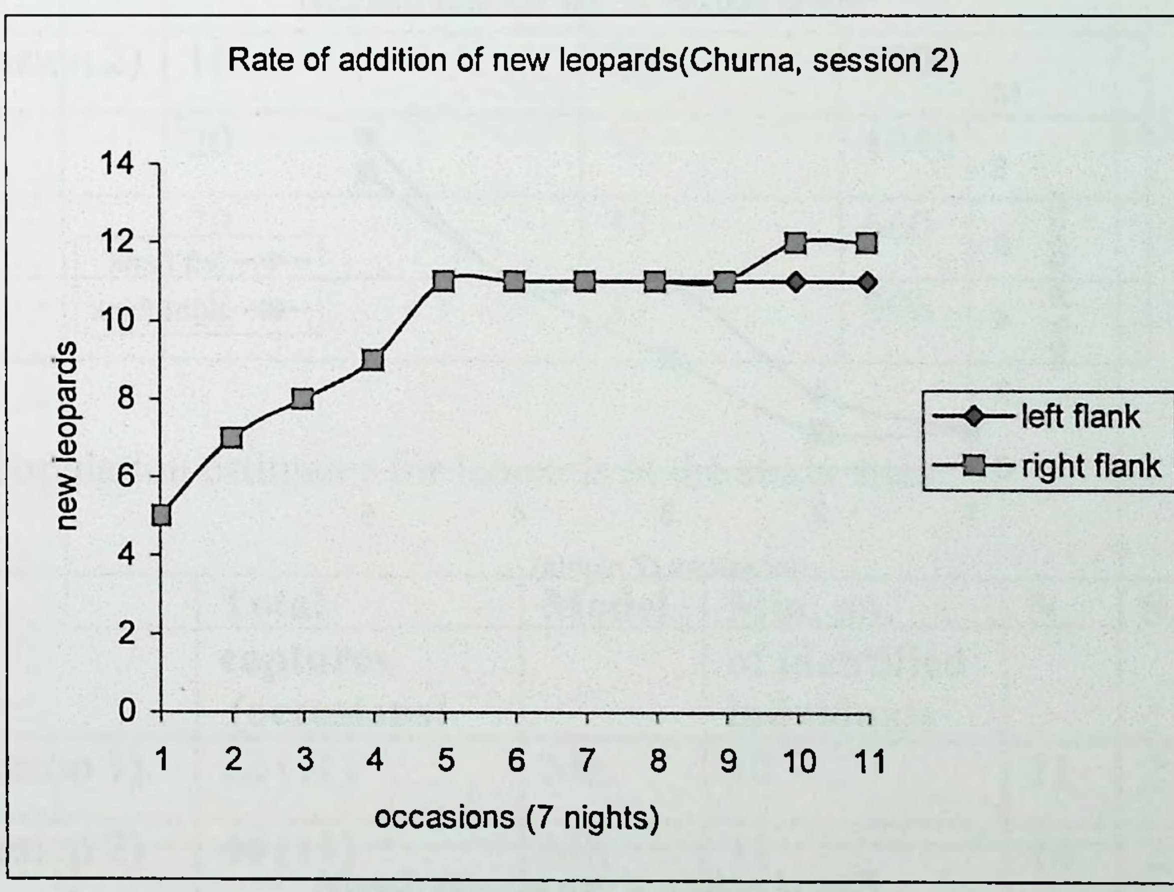
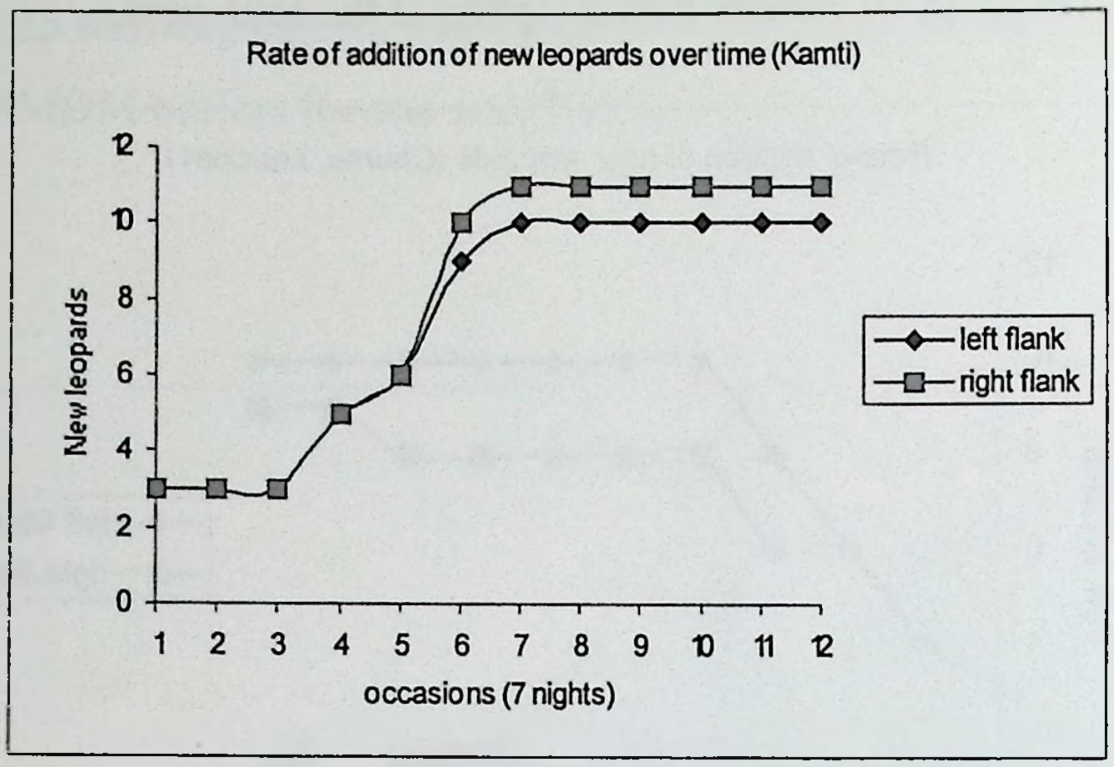
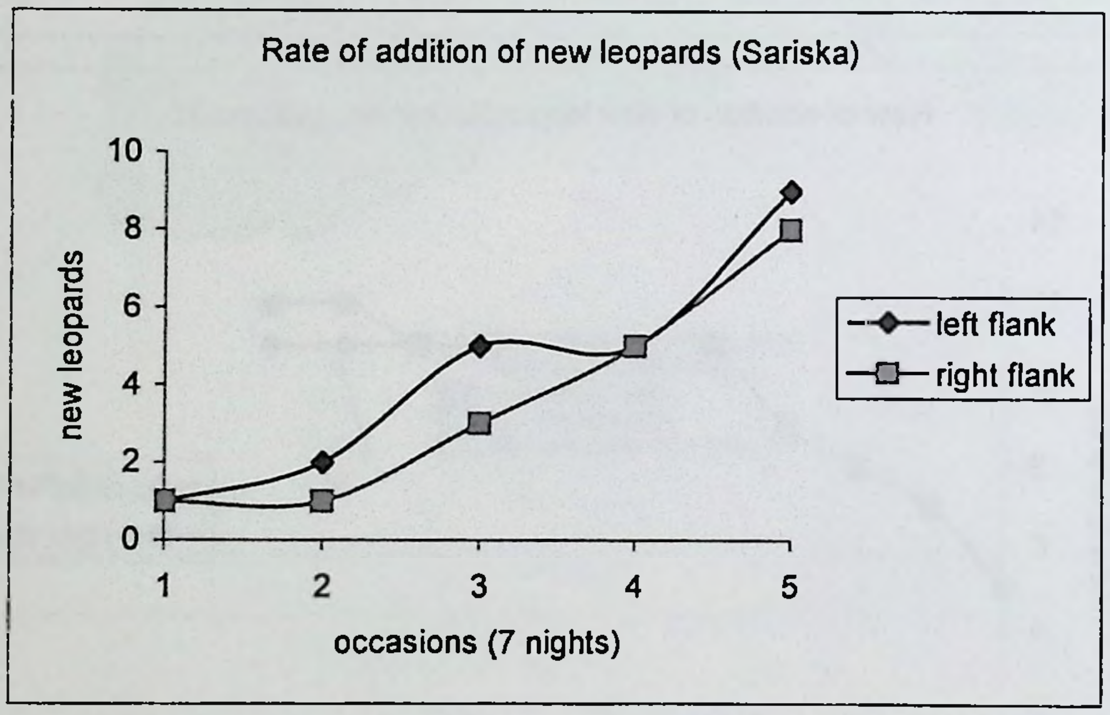


Figure 2-5: Adequacy of camera trap sampling at the four sites.






Rate of addition of new leopards over time (Kamti)
New leopards
occasions (7 nights)
left flank
right flank


Rate of addition of new leopards (Sariska)
new leopards
occasions (7 nights)
left flank
right flank

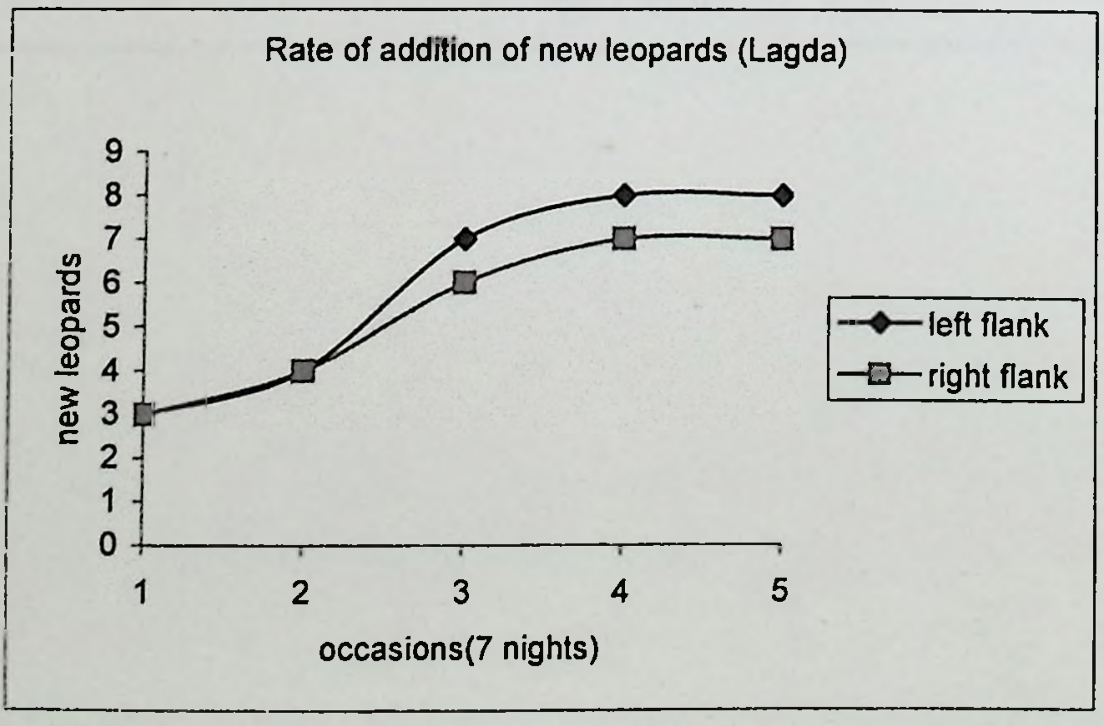

Rate of addition of new leopards (Lagda)
new leopards
occasions(7 nights)
left flank
right flank

Table 2-1: Total number of photos obtained during camera trapping at the four sites.

Site	Right flank	Left Flank	Unidentified	Total
Churna (session 1)	12	21	0	33
Churna (session 2)	47	48	3	98
Kamti	42	42	11	95
Lagda	12	13	5	30
Sariska	14	17	1	32

Table 2-2: Camera trapping intensity at the four sites.

Site	Number of camera trapping stations	Number of Nights	Effort (trap nights)
Churna (session 1)	16	76	1216
Churna (session 2)	16	75	1200
Kamti	20	52	1040
Lagda	20	33	660
Sariska	12	33	396

Table 2-3: Population estimates for leopards at the study sites.

Site	Total captures (occasions)	Model	Min. no. of identified indviduals	N	S.E	p-hat
Churna (session 1)	22 (11)	Mh	10	11	2.78	0.18
Churna (session 2)	44 (11)	Mh	11	14	2.39	0.29
Kamti	29 (12)	Mh	11	12	2.78	0.20
Lagda	17 (5)	Mh	8	10	1.75	0.34
Sariska	12 (5)	Mh	9	12	3.37	0.20

Table 2-4: Sex ratios and capture success for the different study sites.

Site	Males (captures)	Number of Captures/ occasion/male	Females (captures)	Number of Captures/ occasion/female
Churna (session 1)	4 (11)	0.25	6 (11)	0.17
Churna (session 2)	3 (22)	0.33	8 (22)	0.12
Kamti	7 (20)	0.24	4 (9)	0.19
Lagda	3 (8)	0.44	5 (9)	0.36
Sariska	3 (4)	0.27	6 (8)	0.27

Table 2-5: Density of leopards and estimates of sampled area at the different study sites.

Sites Estimates	Churna (session 1)	Churna (session 2)	Kamti	Lagda	Sariska
MCP (sq km)	71.05	71.05	42.95	59.48	26.41
Density (per 100 sq km)	15.5	19.7	27.9	16.9	45.4
Effective area (half MMDM) sq km.	151.47	151.47	110.34	123.91	91.42
Density (per 100 sq km)	7.3	9.2	10.9	8.1	13.1
Effective area (full MMDM) sq km.	322.06	322.06	201.2	237.96	205.37
Density (per 100 sq km)	3.41	4.35	6.0	4.2	5.84

Table 2-6: Individual leopards found in more than one site in Satpura Tiger Reserve.

Site	Churna	Kamti	Lagda
Churna	-	2	0
Kamti	2	-	0
Lagda	0	0	-

Table 2-7: Relative abundance index values for the 5 estimates.

Site	No of camera trap locations	No of independent captures	RAI (per 100 trap nights)	S.E of RAI
Churna (session 1)	16	27	2.2	0.65
Churna (session 2)	16	80	6.7	1.85
Kamti	20	39	3.9	0.71
Lagda	20	24	3.8	0.89
Sariska	12	27	6.8	2.21

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Chapter 3

SEASONAL PATTERNS OF SPATIAL CO-OCCURRENCE BETWEEN LEOPARDS (*PANTHERA PARDUS*) AND DHOLES (*CUON ALPINUS*) IN SATPURA TIGER RESERVE

Advait Edgaonkar, Ravi Chellam and Qamar Qureshi

INTRODUCTION

Mechanisms governing the coexistence of species have been a topic of investigation in ecology for a long time (MacArthur and Levins 1967). Coexistence of sympatric species is hypothesized to be facilitated by the partitioning of resources along a combination of temporal, spatial and dietary axes (Schoener 1974). In carnivores, coexistence has been linked to dietary separation (Johnson and Franklin 1994; Karanth and Sunquist 1995; Taber et al. 1997). Some differences in peak temporal activity between sympatric carnivores have been observed (Karanth and Sunquist 2000; Jacomo et al. 2004). Interspecific avoidance behavior, taking the form of movement to seek refuge from the dominant predator (Durant 1998; Creel and Creel 1996) or shifts in habitat use have also been suggested as promoting coexistence (Seidensticker 1976; Palomares et al. 1996; Kruuk et al. 1994).

In sites where tigers and leopards are sympatric, the evidence for avoidance is mixed. In Chitwan, leopards were found to be avoiding areas of high tiger activity (Seidensticker 1976), while in Nagarhole there was complete overlap in space use between the three species (Karanth and Sunquist 2000). There has been anecdotal evidence of leopards being killed by tigers, and dholes and leopards have also been known to show agonistic interactions, with observations of dholes treeing leopards (Karanth and Sunquist 2000; Venkatraman et al. 1995), and evidence of leopards preying on dholes (Karanth and Sunquist 1995). Dietary overlap has been correlated with high levels of agonistic interactions between carnivore species (Donadio and Buskirk 2006). In the case of pumas and wolves, though the same spatial extent was used, the two species were found to use different habitat attributes within the landscape, and in different seasons (Alexander et al. 2006). Little overlap was observed at a fine scale between jaguars and puma in the Venezuelan llanos, though they shared the same spatial extent (Scognamillo et al. 2003). Dholes and leopards have a high degree of dietary overlap, interact agonistically to each other, and so may be predicted to have evolved mechanisms to minimize interactions with each other. At a study area scale, no evidence of spatial exclusion was detected in tigers, leopards and dholes in Nagarhole, though hunting activity of the mainly diurnal dholes was somewhat temporally separated from the mainly nocturnal large cats (Karanth and Sunquist 2000).

In this paper we look at patterns of space used by leopard and dholes in Satpura Tiger Reserve at a fine scale using co-occurrence of fresh tracks of the two species. Specifically whether leopards and dholes use different areas or the same areas on different occasions, so that physical encounters are avoided. Because it was not possible to identify the time a track was made, temporal separation less than approximately 15 to 20 hours could not be distinguished.

STUDY AREA

The study area was conducted in the Satpura Tiger Reserve (STR). STR covers 1428 sq km in area, and located in the Hoshangabad district of the central Indian state of Madhya Pradesh in India. It includes three administrative units, the Pachmarhi and Bori Wildlife Sanctuaries, and Satpura National Park. An intensive study area of about 200 sq. km was located in Bori Wildlife Sanctuary and Satpura National Park.

The forest in STR (22°19' to 22°30' N and 77°56' to 78°20' E) is mainly of the moist deciduous type (Champion and Seth 1968) . The intensive study area is a mosaic of dry and moist deciduous forest dominated in many places by teak (*Tectona grandis*)and its associates. The carnivore community in STR is diverse. Tiger (*Panthera tigris*) and striped hyaena (*Hyaena hyaena*)is found at low densities (*pers obs*), while leopard, dhole, sloth bear (*Melursus ursinus*), are relatively abundant. Small carnivores are represented by jungle cat (*Felis chaus*), palm civet (*Paradoxurus hermaphroditus*), ratel (*Mellivora capensis*) and ruddy mongoose (*Herpestes smithii*). Gaur (*Bos gaurus*), sambar (*Cervus unicolor*), chital (*Axis axis*), Indian muntjac (*Muntiacus muntjac*), nilgai (*Bosephalus tragocamelus*), chowsingha (*Tetracerus quadricornis*), wild pig (*Sus scrofa*) and domestic cattle are the ungulate prey found.

METHODS

Field methods

A total of 105.5 km of dirt trails in the STR were numbered at 500 meter contiguous intervals, termed sections, and walked systematically by two observers to search for the presence of tracks and signs of carnivores. Presence of leopard, dhole, sloth bear, tiger, jungle cat and palm civet tracks were noted. The tracks of these species were the ones most commonly seen on the trails. Monitoring was done either in the morning or in the evening. Sections checked on one day were not checked again on the same day. Only fresh tracks were counted. Species were marked as present if a minimum of one fresh track of that species was found within the section. It was again marked as present in the next section even if the same individual had walked from the previous section. Data were collected in the summer and winter for three years. The period from November to February was considered to be winter, while summer was from March to June. Over the three years, 211 sections were monitored 5294 times totally. These were used to quantify co-occurrence of the carnivore species. Co-occurrence between two species took place if tracks of both the species were found in the same section on the same sampling occasion. Of the 211 sections, 113 sections were monitored between 5 and 59 times each over all summers and again over all winters. These 113 sections were used to calculate the mean frequency of use for each carnivore species. Over the three years, the intensively checked sections were monitored a mean of 20.0 (S.E. 1.18) times in summer and 23.26 (S.E. 1.4) times in winter. An index of prey availability for 54 sections of the trails was calculated by vehicle transects along the trail to obtain an encounter rate of prey (number/km).

Analytical methods

Change in occurrence over time: An index of population abundance and activity is the average amount of use per section over the years. The mean proportion of times the sections were used in each season over three years was calculated, along with bootstrapped confidence intervals, to estimate the trend in occurrence over time. All calculations were done with Simstat v2.5 (Peladeau 2005).

Competitive structuring: If some species tend not co-occur with others, and this pattern holds true on an average over many sites, then it would suggest a competitive structuring in the community. The co-occurrence pattern is compared to a null model of simulated randomized co-occurrence patterns to see if it is significantly different from them. The C-score has been recommended as a robust index of co-occurrence (Stone and Roberts 1990). It quantifies the average amount of co-occurrence between all unique species of an assemblage. It calculates the average number of checkerboards, i.e. a 0,1 and 1,0 pattern between two species, for all species in the community. The number of checkerboards is given by the formula:

$$CU = (r_i - S)(r_j - S), \qquad (3\text{-}1)$$

where CU is the number of checkerboards, r_i is the number of sections with species i, r_j is the number of sections with species j and S is the number of shared sites. The C-score is then calculated as the average number of checkerboards across all species. The significance of the C-score is assessed by randomizing the 0,1 matrix many times while keeping the row and column totals fixed. If the observed C-score is significantly higher than that obtained by randomization, then there is evidence for competitive structuring. A C-score was calculated for each season. Instead of presence-absence of species, the data collected were the use or non-use by the species at that occasion. The C-Scores were calculated using the program EcoSim version 7.72 (Gotelli and Entsminger 2001), using the fixed row-fixed column option.

Differences in use of sections: The encounter rate of prey was the number of cervids and langur per kilometer. Cervids comprised of chital, sambar and muntjac. The encounter rate was arcsine transformed. Students-t test between used and unused sections by leopards and dholes was performed to test for differences in the means of these transformed variables in both seasons for leopards but summer only for dhole, due to sample size constraints.

Use of sections by leopards and dholes: A Kendals tau-C correlation coefficient was also calculated over all sections, to see if there was a correlation between the rank use of sections by leopards and dholes, indicating concordance in habitat use. Sections were then divided into four groups for two species according to degree of use by each species: the top 20 percent were termed ‘high use’, the next 20 percent were ‘medium use’, the remaining used sections were ‘low use’ and the ones that were never used were ‘no use’ sections. Similarity of use of the sections by the two species was tested for independence by a chi-square contingency table (Zar 1984). If habitat selection by the two species is not independent, then high use, medium use, low use and unused sections by leopards would tend to be similarly used by dholes, and vice versa, and the null hypothesis of independence would be rejected. The average proportion of times dhole tracks were found in each section for all use categories by leopards was calculated along with their bootstrapped bias-corrected confidence intervals. This was repeated for leopard tracks in all use categories by dholes. The data were pooled over all the years and the analyses were done for summer and winter separately.

Avoidance between leopards and dholes: In the absence of any spatial interaction between the two species, we can calculate the proportion of sections in which the tracks of leopards and dholes should be found together at the same time, given the probability of finding either of them alone. If leopards and dholes are avoiding each other, we would expect to find that the proportion of sections with tracks of both the species at the same sampling instance would be significantly less than that expected given this expected proportion. A Z-test for proportions (Zar 1984) was done to see if the ratio of the proportions is significantly less than one. If it is less than 1, we can say that the two species are found together less than that expected by chance, and may be avoiding each other. If the dholes avoid leopards, then lesser proportion of tracks together than expected would be found in leopard 'high use' sections than in other sections. Similarly, if leopards avoid dholes, we would expect lesser proportion of tracks together in dhole 'high use' sections.

RESULTS

Proportion of dhole tracks found per sampling occasion per section declined from 24 percent to 7 percent over the three years. The decline was continuous for the first two years, before recovering in the last year. Mean proportion of leopard tracks were less variable between years, except for season summer 2, where they declined drastically. The mean proportion of times tracks were present in each section per sampling occasion is given in Figure 3-1.

The cervid encounter rate, measured as the number of sambar, chital and muntjac individuals seen per kilometer, as well as langur encounter rate (measured as number of langur per km) was significantly lower in leopard-present than in leopard-absent sections in winter season (Table 1a). Dhole-used sections, analysed only for the summer season, showed did not show a significant difference from dhole-unused sections with respect to encounter rate of prey.

The presence of competitive structuring was ascertained by the C-score index (Table 3-2). C-scores were not more than expected by random chance when jungle cat and palm civet were also taken into consideration. When only the large carnivores were considered, some competitive structuring seemed to be present amongst tiger, leopard, dhole and sloth bear in winter, larger C-scores being obtained than expected by the null model. The data were subsampled to reduce spatial autocorrelation by randomly removing all but one section from all series of continuous occurrences. C-scores were not found to be higher than random after this was done (observed C-score 20169, mean randomized C-score 20174, p=0.44).

There was no significant correlation between the ranked use of sections by leopard and dhole, the confidence limits on the Kendall's tau C correlation coefficient overlapped zero (Table 3-3). This indicates that the degree of use of sections by one species has no bearing on the degree of use by the other.

The null hypothesis of independence of use by the two species of the number of high, medium, low and unused sections failed to be rejected in both the seasons, using the chi-square contingency test. Leopards and dholes used the sections independently (Table 3-4 and 3-5). The proportion of dhole tracks found in the different categories of use by leopards was not significantly different from each other in both the seasons

(Figure 3-2). Similarly the proportion of leopard tracks found in the different categories of use by dholes also overlapped completely (Figure 3-3).

For leopard-used sections, table 3-6 shows the number of sections with leopard and dhole tracks found separately, tracks of both species found together, and sections with tracks of neither species. A Z-value of greater than 1.96 or less than –1.96 would indicate significance at an alpha level of 0.05. The overall ratio of observed to expected is not significantly different from one. Only in the low-used sections in summer do we find more sections with tracks of both species simultaneously than expected. Combined over all sections, for each season the pattern seems to be that the sections with tracks of both species together are found in the same proportion (the ratio is nearly equal to 1) as that expected given independent use. The same pattern holds true in the dhole-used sections (Table 3-7).

Discussion

Both leopards and dholes have a tendency to walk long distances along trails. This results in a high degree of spatial autocorrelation in the occurrence data from contiguous sections. Spatial autocorrelation inflates type I error (Legendre 1993; Segurado et al. 2006) and so the conclusion of lack of dependence between use by leopards and dholes would only be strengthened if autocorrelation was reduced.

The decreasing pattern of tracks in dholes is a cause of worry. Canid populations have been known to be vulnerable to disease subjecting them to risk of extinction (Burrows et al. 1994). The reduction in leopard tracks in one season 'summer 2' could have been due to mortality amongst the resident population, leaving gaps in territories. Personal observation suggests that this may have been the case. At least four individually identified leopards were not photographed during and after this season. Two were large cubs and may have dispersed. It is possible that the two adults died, and that filling the gap by other leopards took some time. This has been noted for leopards in Chitwan (Seidensticker et al. 1990).

Numerous studies have shown that large predators are found at higher densities in prey rich landscapes (Karanth et al. 2004; Marker and Dickman 2005). This need not be true at smaller scales, where escape behavior by prey could result in predator-prey abundances being negatively correlated (Sih 1984; Rose and Legget 1990). Prey encounter rates, both for cervids and for langur, were higher in sections where leopards were not found than in sections where leopard tracks were present. This avoidance pattern was not seen for dholes, where there was no significant difference.

C-scores were higher than expected only in winter for the four large carnivores. which suggests that competitive structuring and subtle patterns of avoidance, if present, are more likely to break down in summer. In summer habitat selection for all carnivores is likely to be more influenced by the presence of water and shade than by the presence of competitors.

The lack of correlation, either negative or positive, in use of sections indicates that while leopards and dholes used the same spatial extent, the amount of activity within that spatial extent differed for the two species. In both summer and winter, the degree of use of the sections by one species was independent of the degree of use by the other species. This was true both of leopard-used sections as well as for dhole-used sections, as indicated by the chi-square contingency tests. The mean proportion of occurrence of leopard tracks per section was not different in different dhole used categories, and the same pattern held true for dholes with respect to leopard use categories for both the seasons. All this indicates that spatial avoidance between the two species is not taking place at the 500 m scale of sampling.

The tracks of both the species were found together in the same section per sampling occasion in the same proportion as could be expected given their occurrence in the habitat. Since only fresh tracks were considered, the tracks considered together by both the species in a section could at most have been made 15 to 20 hours apart. We could not detect simultaneous use of the sections at a finer time scale. Given the spatial and temporal resolution of the sampling method, we can say that there seems to be no evidence of avoidance between the two species. Using different methods, Karanth and Sunquist (2000) came to the same conclusion that for tigers, leopards and dholes in a prey rich protected area like Nagarhole, the amount of prey, cover and tree densities might play a more important role than behavioral avoidance. In Satpura Tiger Reserve too, though with poorer prey density, there is no evidence of spatial exclusion between leopards and dholes.

Figure 3-1: Trend in proportion occurrence of leopard and dhole tracks over three years

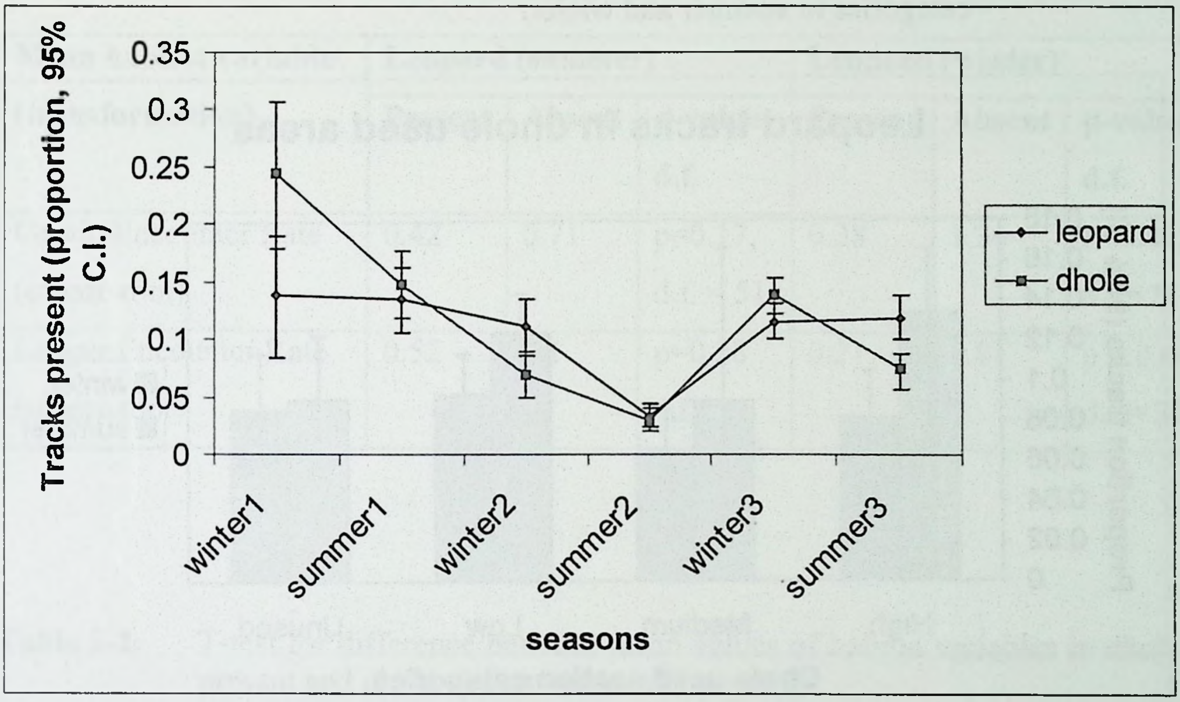

Figure 3-2: Mean proportion of dhole tracks per section in the four leopard-use categories in summer and winter

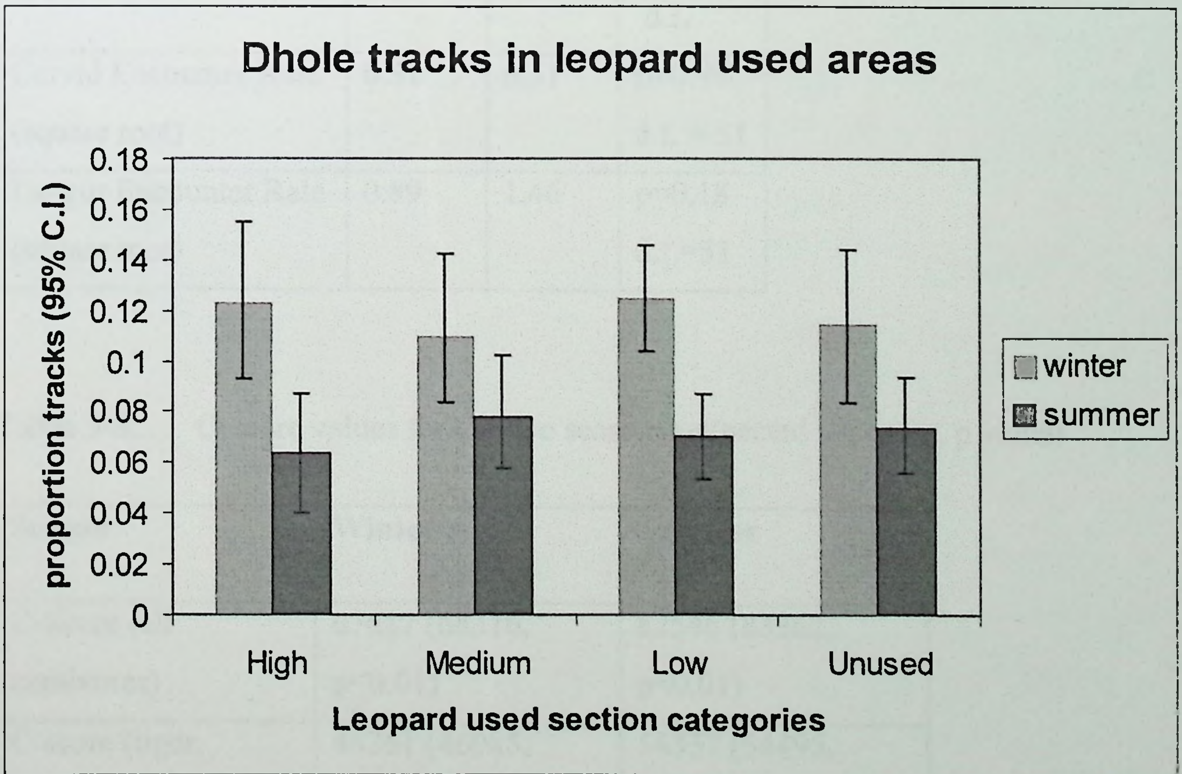

Figure 3-3: Mean proportion of leopard tracks per section in the four dhole-use categories in summer and winter.

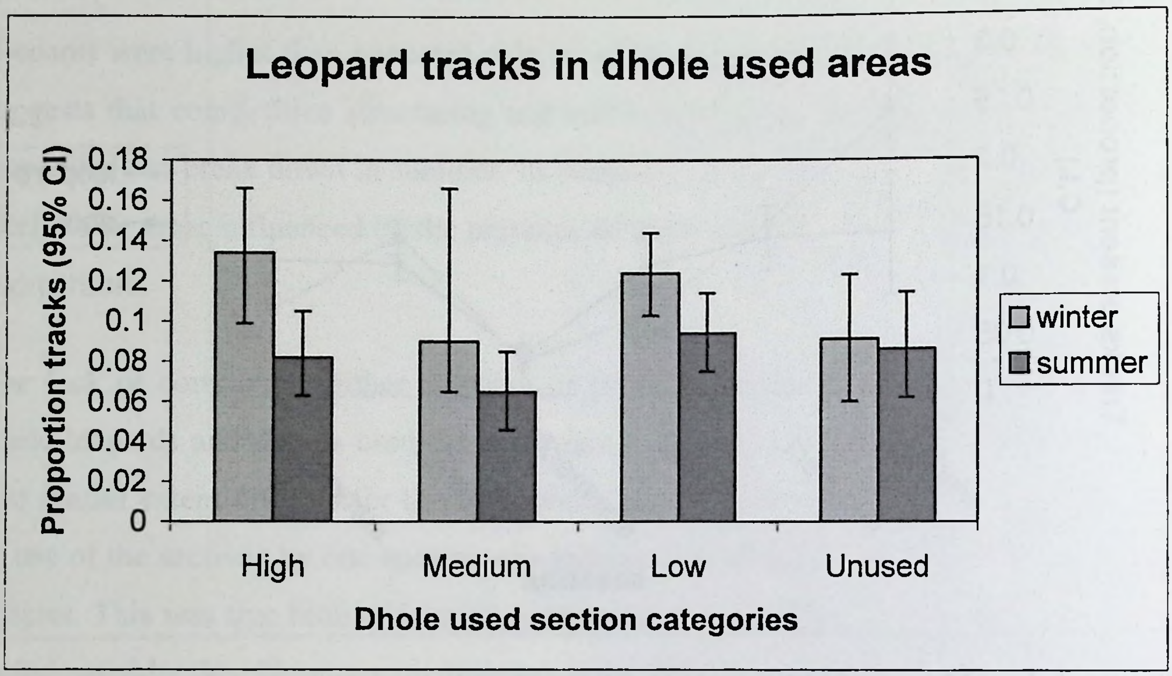

Table 3-1: T-test for difference between mean Encounter rates in leopard- present and leopard-absent sections

Mean habitat variable (transformation)	Leopard (summer)			Leopard (winter)		
	Present	**Absent**	**p-value, d.f.**	**Present**	**Absent**	**p-value, d.f.**
Cervid Encounter Rate (square root)	0.42	0.71	p=0.17, d.f. = 51	0.38	1.36	P<0.01, d.f.=28
Langur Encounter Rate (square root)	0.52	1.1	p=0.28 d.f.=51	0.21	0.81	p = 0.04, d.f.= 28

Table 3-2: T-test for difference between mean values of habitat variables in dhole-present and dhole-absent sections in summer

Mean habitat variable (transformation)	Dhole (summer)		
	Present	**Absent**	**p-value, d.f.**
Cervid Encounter Rate (square root)	0.51	0.51	p=0.99, d.f. = 51
Langur Encounter Rate (square root)	0.89	1.46	p=0.18 d.f.=51

Table 3-3: C-score values for the two seasons (expected C-scores, p value)

Season	**Winter**	**Summer**
C-Score (all carnivores)	67617 (68316, p<0.01)	82546 (83362, p<0.01)
C-score (tiger, leopard dhole, sloth bear)	46261 (46085, p=0.04)	54337 (54495, p=0.35)

Table 3-4: Correlation between dholes and leopard use of sections in winter and summer, (N= 113)

Winter	Kendall's tau (95% CI)
Winter	0.01 (-0.12-0.15)
Summer	0.04 (-0.18-0.09)

Table 3-5: Observed (and expected) use of sections by leopards and dholes in summer. Chi-square = 13.8, d.f.= 9, p>0.05)

	Summer	**Leopard**			
		High Use	Medium Use	Low Use	Unused
Dhole	**High Use**	5 (4.3)	4 (4.3)	5 (5.6)	8 (7.8)
	Medium Use	1 (4.3)	6 (4.3)	7 (5.6)	8 (7.8)
	Low Use	5 (6.2)	6 (6.2)	13 (8.2)	8 (11.3)
	Unused	11 (7.2)	6 (7.2)	4 (9.5)	16 (13.1)

Table 3-6: Observed (and expected) use of sections by leopards and dholes in winter. Chi-square = 9.05, d.f.= 9, p>0.05)

	Winter	**Leopard**			
		High Use	Medium Use	Low Use	Unused
Dhole	**High Use**	5 (4.3)	3 (4.3)	8 (7.4)	6 (6.0)
	Medium Use	3 (4.7)	7 (4.8)	6 (8.1)	8 (6.6)
	Low Use	11 (8.2)	7 (8.2)	17 (14.1)	7 (11.5)
	Unused	3 (4.9)	5 (4.9)	7 (8.2)	10 (6.9)

Table 3-7: Z-test for number of sections with tracks of leopards and dholes found together in different leopard-use categories

Season	**Use category**	**Sections with Leopard tracks only**	**Sections with Dhole tracks only**	**Sections with tracks of both species**	**Sections with tracks of neither species**	**Total Sections (N)**	**Ratio**	**Z - value**
Summer	High	85	24	3	311	423	0.53	-1.08
	Medium	71	42	4	472	589	0.68	-0.76
	Low	43	51	9	742	897	**2.37**	2.60
	Overall	201	120	16	1572	1909	1.034	0.13
Winter	High	101	36	17	277	431	1.17	0.61
	Medium	59	39	9	324	431	1.19	0.51
	Low	67	118	5	794	984	0.56	-1.39
	Overall	227	193	31	1395	1846	0.99	-0.05

Table 3-8: Z-test for number of sections with tracks of leopards and dholes found together in different dhole-use categories

Season	Use category	Sections with Leopard tracks only	Sections with Dhole tracks only	Sections with tracks of both species	Sections with tracks of neither species	Total Sections (N)	Ratio	Z-value
Summer	High	49	93	7	536	685	0.86	-0.43
	Medium	36	43	5	543	627	1.59	1.04
	Low	75	35	4	750	907	1.04	0.08
	Overall	166	173	16	1864	2219	1.03	0.13
Winter	High	43	88	11	261	403	0.83	-0.68
	Medium	36	69	7	324	476	0.94	-0.16
	Low	118	82	13	872	1065	1.15	0.50
	Overall	198	241	31	1474	1944	0.97	-0.19

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Chapter 4

Presence-only habitat suitability models for leopards (*Panthera pardus*) using field based and remotely derived variables at two spatial scales in Madhya Pradesh, India

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INTRODUCTION

Knowledge of the distribution and habitat requirements of a species are essential to formulate conservation strategies. While some species are considered habitat generalists, they are still vulnerable to habitat loss and fragmentation. These factors along with prey depletion and poaching are responsible for the decline of tiger (*Panthera tigris*) ranges across its distribution (Sunquist et al. 1999). It has been estimated that the tiger exists in only 7 percent of its historical range (Dinerstein et al. 2007). The leopard is another wide ranging large carnivore that is less susceptible to disturbance, is a generalist with respect to habitat requirements, and can survive on a wide range of prey species (Sunquist and Sunquist 2002). Unlike the tiger, which needs a high biomass of large sized prey (Karanth and Sunquist 1995), the leopard is able to survive on domestic dogs and rodents in the absence of wild prey populations (Edgaonkar and Chellam 2002). As the tiger population in India has declined, the leopard populations have also come under poaching pressure. There is a need to quantify habitat requirements and potential habitat availability for leopards in India. Good habitats for leopards can then be given conservation priority in protection and management.

Categorizing suitable leopard habitat requires information at multiple scales. First order selection (Johnson 1980) refers to the distribution of a species with respect to geographical space. Large scale species distribution models can be used to guide conservation strategies (Guisan et al. 2006; Hirzel et al. 2004; Mladenoff and Sickley 1998; Seoane et al. 2006). Techniques like logistic regression (Karlsson et al. 2007; Woolf et al. 2002) and Generalized linear models (GLM) (Austin 2007; Bustamante and Seoane 2004) use the information from multivariate measurements of habitat variables at locations with species presence and at locations where the species is absent (Guisan and Zimmermann 2000; Meynard and Quinn 2007). This information is used to derive a probability of species presence at each location. Though these methods are preferred when absence data are reliable (Brotons *et al.* 2004), logistic regression models are known to be sensitive to even low levels of non-detections (Gu and Swihart 2004). Leopards are not only rare and secretive, they are also crepuscular (Sunquist and Sunquist 2002) and without intensive effort there is a high likelihood of non-detections in areas where leopards are present contaminating the absence data. . The presence-only models are a way of dealing with this problem. This paper uses the environmental niche factor analysis (ENFA) (Hirzel et al. 2001), a presence only environmental habitat-envelope based method to create habitat suitability maps for the leopard in central India. ENFA has been used successfully to model the distributions and habitat suitability of a variety of taxa: dung beetles (Chefaoui et al. 2005), corals (Bryan and Metaxas 2007), reptiles (Santos *et al.* 2006), birds (Braunisch and Suchant 2007; Brotons et al. 2004; Olivier and Wotherspoon 2006; Reutter et al. 2003; Titeux et al. 2007), ungulates (Dettki et al. 2003; Traill and Bigalke 2007) and carnivores (Mestre et al. 2007).

The objectives of this paper are: 1.To develop predictive habitat suitability maps for leopards at various scales and evaluate their reliability. 2. To identify the environmental variables important in describing the habitat for this species 3. To quantify the extent and location of potential leopard habitat available for conservation action in south central Madhya Pradesh.

STUDY AREA

The extensive study area covers 52,971 sq km (Table 1) and is located across thirteen districts in south central Madhya Pradesh; it comprises about 18 percent of the state of Madhya Pradesh. Altitudes range from 215 to 1312 m. Annual rainfall for the state averages 1143 mm, with rainfall decreasing from the eastern part of the state to the west. The landscape is a matrix of forests, agriculture, villages and small and large towns. The main crops are wheat, soybean, sorghum, sugarcane and pulses. The forests are mainly teak dominated, dry and moist deciduous forests. The climate is cool in winter and very hot in summer, with temperatures ranging from 2-45 degrees Celsius. The largest river in region is the Narmada. The two main protected areas within the landscape are the Satpura and the Pench Tiger Reserves.

The intensive study site consisted of a 433 sq km area of moist and dry deciduous forests along with some teak plantations located inside the Satpura Tiger Reserve (STR). It was approximately in the center of the extensive study site. Topography ranged from relatively flat to very steep slopes and cliffs. Altitudes range from 300 to 1315 m. There are 7 small forest villages within its boundaries. Details of the intensive study are given in previous chapters.

METHODS

Data sources: In the STR study site, an encounter rate was calculated as the number of sightings per kilometer using all sightings of potential prey species. Potential prey species were chital (*Axis axis*), sambar (*Cervus unicolor*), langur (*Semnopithecus entellus*), wild pig (*Sus scrofa*), and a small prey category comprising of hare (*Lepus nigricollis*), peafowl (*Pavo cristatus*), red spurfowl (*Galloperdix spadicea*) and grey jungle fowl (*Gallus sonneratii*). Sightings were obtained from 20 straight line transects (630 km) and from vehicle transects using the dirt trail network (369.5 km). This encounter rate was then divided into 5 categories. The first category was 0 encounter rate, and the other 4 were based on equal quantiles (25^{th} , 50^{th} , 75^{th} and 100^{th}). Photos of prey from the camera trap stations were converted into a rate per trap night, and also similarly divided into 5 increasing categories based on equal quantiles. The two data sources (encounter rates and photo trap rates) were then assumed to be equivalent indices of prey abundance and were subsequently merged. Distance weighted interpolation of the categorical index was then done using the INTERPOL module of Idrisi (Eastman 2004) to obtain a prey map.

Sampling for evidence of leopard presence was done using kills, tracks, scrapes and camera-trap photos. All quantitative measures were degraded into presence absence measures to reduce biases introduced by different sampling efforts. Multiple instances of presence within a one hectare plot were combined to reduce spatial autocorrelation, which can lead to bias in precision estimates for habitat models (Diniz et al. 2003).

Secondary data were obtained from the Wildlife Institute of India. It was collected as part of a joint Wildlife Institute of India- Project Tiger initiative to monitor tiger populations in India in 2006 (Jhala et. al 2008). A total of 2582 beats were sampled (Figure 1). A 3 to 4 km long transect was located in each beat, and it was a walked a total of three times by the local forest guard in charge of the beat. The average size of the beat was 20 sq km. Data on anthropogenic pressure, presence of livestock signs, encounter rate of prey and sign of leopards was collected. Beat maps were digitized at WII and the centroid of each beat was used to approximate the location of leopard presences in the beat.

Data Processing: Ecogeographical variable (EGV) maps were created of prey encounter rates for sambar, nilgai (*Bosephalus tragocamelus*) and wild pig using the INTERPOL module of Idrisi. The encounter rate of leopard signs was converted to a binary variable of presences and probable absences. A buffer width of 3000 m was applied to create a 9 sq km patch of leopard presence pixels around each point. Female leopard home ranges are known to range from 6 to 30 sq km in Africa (Bailey 1993) and 17 sq km in Nepal (Odden and Wegge 2005), so 9 sq km was considered a conservative estimate of the area in which presence could be assumed in the forest beat. Only beats where some evidence of leopards was detected were retained for the analysis. All the beats where evidence of leopards was not detected were discarded from the dataset.

The elevation layer was obtained from the 90 m resolution DEMs created from the SRTM mission data by the CGIAR-CSI (http://srtm.csi.cgiar.org). Using Idrisi, a slope map and a ruggedness map (using the standard deviation of mean elevation in a 3 x 3 moving window) was created from the DEM.

The extensive study area encompassed parts of 6 Landsat ETM+ images. Georeferenced and orthorectified cloud free images dating between 2002 and 2004 were obtained from the Global Landcover Facility (www.landcover.org). Parts of the extensive study area found in each of these images were classified into four cover types: agriculture, bareground-urban, forest and water. These were then mosaicked together to obtain the land cover map. For the STR area 4 landcover types were delineated. These were : moist forest, dry forest, bareground/village, teak dominated forest and water. Spectral signatures for the classification supervision were obtained by using information from 473 vegetation plots in the Satpura Tiger Reserve, and with visual inspection of satellite imagery using Google Earth (http//:www.earth.google.com) for the extensive study area. Supervised classification was performed using FISHER classifier for both the study sites using the Idrisi GIS package. Using the CircAnn module of Biomapper, the boolean maps of each landcover type was converted to percent frequency in a 20 sq km circular moving window for the extensive study area and 1 sq km for the STR area. The models were made at two pixel resolutions: 1000 m for the extensive study area and 100 m for the STR study area. A list of all the EGVs for both the study areas is given in Table 2 and 3.

To observe the effect of pixel resolution on the accuracy of the models, the ENFA analysis was repeated at the 200m , 300m and 500m scales for the STR area, and at 1000m without the buffer, 2000m, 3000m and 5000m for the extensive study area.

Ecological modeling technique: The relationship between the distribution of leopard presence patches and a set of mapped ecogeographical variables was analyzed using ENFA. The program Biomapper v3.2 (Hirzel et al. 2006a) was used. Biomapper needs two types of data to calculate habitat suitability. The first is a map of locations where the species has been detected, and the next are a set of quantitative raster maps describing the environment as used by the species under investigation. This presence-only modeling technique describes the ecological niche of a species by computing uncorrelated factors from a comparison of values of eco-geographical variables in the entire study area and their values at the site where the species is known to be present. The first ENFA factor maximizes the absolute value of the marginality, defined as the standardized difference between the species mean and the global mean of each of the EGVs. The first factor explains how the species niche differs most from the available conditions. It explains all the marginality and some of the specialization. Specialization is defined as the ratio of the overall variance to the species variance for all the EGVs. It describes how restricted is the usage of the species of that variable compared to its availability. Details on the calculation of marginality and specialization are given in (Hirzel *et al.* 2002) The subsequent factors maximize the specialization. A high absolute value of the correlation of the variable with the specialization factor indicates that the species niche breadth is narrow with respect to that variable. There are as many factors as there are variables, but they successively explain a decreasing amount of the specialization. The number of factors used to calculate the habitat suitability was decided using Mac Arthur's broken-stick criterion (Hirzel *et al.* 2002) .

The habitat-suitability map was evaluated for its predictive accuracy by internal area adjusted frequency cross-validation (Fielding and Bell 1997). Leopard presences were geographically stratified and randomly partitioned into 10 sets. Nine partitions were used to compute a habitat suitability model and the left-out partition was used to validate it on independent data. This process was repeated 10 times, each time by leaving out a different partition. This process resulted in ten different habitat-suitability maps. Each map was reclassified into 4 bins, where each bin covered some proportion of the total study area (Ai) and contained some proportion of the left-out validation points (Ni).The area-adjusted frequency for each bin was computed as Fi = Ni /Ai. The expected Fi was 1 for all bins if the model was completely random. If the model is good, low values of habitat suitability should have a low F (below 1) and high values a high F (above 1) with a monotonic increase in between. The monotonicity of the curve was measured with a Spearman rank correlation on the Fi in a moving window, termed as the continuous Boyce Index (Boyce et al. 2002; Hirzel et al. 2006b). Validation of the models was also done using the Absolute Validation Index and the Contrast Validation Index. One criticism of the presence models is that they yield too optimistic results (Zaniewski et al. 2002). This problem was mitigated by using breaks in the predicted to expected ratio frequency curves to define 4 habitat classes (Hirzel et al. 2006). The map was then reclassified using the new bins into unsuitable, marginal, suitable and optimal habitat. Results

Effect of changing resolution: For the extensive study area the best model was at the 1000 m scale with buffer. It gave the highest continuous Boyce Index value. The coarsest resolution model was the most inaccurate. At a resolution of 5 km and moving window size of 225 sq km, the continuous Boyce Index reduced to 0.55. Changing the resolution did not change the AVI, CVI and the Boyce index much at all the other resolutions. For the STR area, the best model was the 100 m resolution with a moving window of 1 sq km, followed by the 200 m model. The effect of increasing the moving window scale degraded accuracy slightly. The 300 m and 500 m resolution models had lower Boyce index values (Table 4). The habitat suitability maps for the two areas were made from the best models.

Model validation: Overall the habitat suitability models for both STR and extensive study area were moderately accurate. They both showed similar values of AVI, indicating that the proportional accuracy in classifying presence points in the evaluation partition was similar for south central Madhya Pradesh and for Satpura Tiger Reserve.

CVI values were moderate, indicating that the model had some difficulty in discriminating between the suitability map and a purely random model. This is consistent with the generalist nature of the species. Both the continuous Boyce index values were high, which indicates good predictive power of both the models, but the larger scale model had better predictive power (Table 4). The predicted to expected frequency curves showed higher variance for good habitat than for bad habitat with both the models (Figure 3), the inflections in the curves were used to guide the selection of bins to reclassify the habitat suitability maps for the two areas (Figure 1 and 2).

Extensive study area: The marginality value was 1.25 and the tolerance value was 0.92 indicating that leopards were using conditions that were different from the mean environmental values, and that the leopard was more of a generalist in using a wide range from the EGVs. Seven factors were retained. The first factor accounted for 100 % of the marginality, while all 7 factors accounted for 100 % of the marginality and 80% of the specialization. The marginality coefficients showed that leopard habitat was more positively correlated with sambar distribution, terrain ruggedness and proportion of forests. It was less strongly correlated with altitude, slope, NDVI and nilgai and wild pig encounter rates. Leopard distribution was negatively correlated with presence of agriculture and urban-bare ground landcover types. Livestock presence, an indicator of human disturbance, was a weak negative correlate. The specialization factor indicated that the leopard used a restricted niche with respect to the availability of percentage frequency of urban-bare ground and agriculture, but not when compared with the availability of elevation, ruggedness and slope measured at the 1 km scale across the big study area (Table 5). The amount of suitable, marginal, unsuitable and optimal habitat in each district is given Table 7.

Satpura Tiger Reserve: The marginality value was 0.67 indicating that leopards were using conditions not too different from the mean environmental values. Tolerance was also relatively high (0.56), indicating that the leopard was found in areas that had a wide range of values of the EGVs. Four factors were retained, the first factor accounting for 100 % of the marginality. The four factors explained 79 % of the specialization. The marginality factor was strongly positively loaded with the coefficient for tassled cap 'greenness', an index of above ground biomass (Crist and

Kauth 1986) and percentage frequency of moist forests and teak dominated forest. It was also positively correlated with distance to water and the encounter rate of cervids (sambar and chital), wild pig and small-sized prey. The positive correlation with langur encounter rate was weak. Leopard presence was negatively correlated with elevation, slope and frequency of bare ground pixels. The negative loading with respect to distance from village was weak. The specialization factor indicated that elevation was used in a more restricted way than was available in the study area, as was the frequency of the moist, dry and teak forests (Table 6).

DISCUSSION

The change in resolution seemed to have a similar impact on models of both the areas. Coarse resolutions, 300m and 500 m for STR and 5 km for the extensive study area, degraded the accuracy of the models. The scale of the circular moving window for frequency of land use cover did not change accuracy appreciably, except for the very largest scale (225 sq km). The leopard is an adaptable species, being able to live in a wide variety of environmental conditions. This is reflected in the marginality and tolerance values for the model of the STR area, where almost all the area is potential leopard habitat. Habitat use by leopards in Satpura was strongly associated with moist and teak forests, as well as with most prey species, except the langur, with which it was only weakly associated. This is because more langur are seen in open areas, closer to villages, and along roads, rather than in denser forest areas (*pers obs*), perhaps as an anti-predatory strategy, and they do not comprise a large proportion of the leopard's diet in this area (chapter 1). Leopard presence had a weak negative association with the distance to villages. That means it was found closer to villages than average, though this tendency was weak. Unlike tigers, which are shy and prone to move away from disturbance, leopards are known to be bold and found in proximity to human habitats, visiting close to human inhabitation to prey on livestock (Odden and Wegge 2005). Though they are tolerant of human presence, they are not unaffected by disturbance, as the extensive study area model showed, with leopard habitat being negatively associated with bareground/urban landuse frequency. In Thailand leopard activity has been shown to be negatively correlated with distance from villages (Ngoprasert et al. 2007). Leopard habitat was negatively correlated with urban-bare ground and agriculture land cover types as also with livestock presence. At the large scale, good leopard habitat was seen to be more associated with terrain ruggedness, sambar prey availability and percentage of forested areas, and less associated with nilgai and wild pig prey availability. Both the latter species are known to be crop pests and able to live close to human inhabitation (Sekhar 1998), and this probably contributes to the observed pattern. Cougar (*Puma concolor*) abundance has also been shown to be affected by prey, ruggedness and forest cover at the landscape scale (Riley and Malecki 2001)

The larger spatial area model had a higher predictive accuracy than the smaller scale one as quantified by the higher continuous Boyce Index. (Table 4). This is possibly because the Satpura Tiger Reserve has less disturbance and is a less heterogeneous area given its smaller size. Given the high density of leopards in the area (chapter 3) and requiring large tracts of contiguous habitat (Marker and Dickman 2005), they probably move through and live in habitats that are not highly preferred, but are still inhabitable. Very few areas in the Reserve are likely to be completely unsuitable for leopards.

The habitat model was used to estimate the area occupied by various habitat categories in the 13 districts in south-central Madhya Pradesh (Table 7). 'Optimal' habitat was 5.2% of the study area, ranging from 0.5 to 8 percent of each district. As an absolute measure it can be said that approximately 11500 sq km of habitat is likely to support leopard populations. The districts with the most optimal habitat are Betul, Hoshangabad and Chhindwara. These districts are geographically adjacent to each other and constitute a compact block of about 2000 sq km of optimal habitat. The Satpura Tiger Reserve lies in Hoshangabad district and is already protected, but Betul and Chhindwara districts can be prioritized when allocating resources for leopard conservation efforts in Madhya Pradesh. In conclusion the ENFA model seems to work better at larger scales for a generalist species like the leopard. It is a useful tool to explore the characteristics of the leopards niche as well as to produce habitat suitability maps that can aid in conservation management.

Table 4.1. Districts and sampling effort in the extensive study area in south central Madhya Pradesh

District	Sampled Area (sq. km)	Number of transects	Transects with Leopard presence
Balaghat	419.9	50	0
Betul	10041.5	622	23
Bhopal	57.1	1	0
Chhindwara	11815.8	553	57
Dewas	1296.7	30	0
East Nimar	2104.4	100	8
Harda	3329.0	163	2
Hoshangabad	6734.1	351	111
Jabalpur	258.5	27	2
Narmsimhapur	4420.3	107	17
Raisen	3293.9	92	16
Sehore	3266.8	112	23
Seoni	5891.4	361	41

Table 4.2: List of EGVs with explanation and source for south central Madhya Pradesh

Eco geographical Variables	Explanation	Transformation	Source
Elevation	DEM in meters at 100m resolution, averaged to 1 km resolution.	None	SRTM data
Elevation standard deviation	Calculated with a moving window of 3x3 cells from DEM.	None	Calculated using Idrisi
Slope	Calculated from DEM	None	Calculated using Idrisi
NDVI	Calculated from bands 3 and 4 of Landsat ETM + imagery.	None	Calculated using Idrisi
Forest	Percentage frequency of cells with forests, urban/bareground and agriculture in a circular window area 25 sq km.	None	Supervised classification of Landsat ETM+ imagery to obtain landcover; frequency calculated using CircAn module of Biomapper.
Urban/bareground	Same as above	None	Same as above
Agriculture	Same as above	None	Same as above
Livestock	Distance weighted Interpolation of encounter rate (number seen/km) from line transects.	Square root	Calculated using INTERPOL module of Idrisi
Nilgai encounter rate (ER)	Same as above	Box-Cox	Same as above
Sambar ER	Interpolated encounter rate (number seen/km) from line transects.	Box-Cox	Same as above
Wild pig ER	Interpolated encounter rate (number seen/km) from line transects.	Box-Cox	Same as above
Distance to Water	Distance to the nearest water source in meters.	None	Calculated using DISTANCE module of Idrisi

Table 4.3 List of EGVs with explanation and source for the Satpura Tiger Reserve

Eco geographical Variables	Explanation	Transformation	Source
Cervid Encounter Rate (ER)	Interpolated encounter rate (number seen/km) from line transects and vehicle transects	Box-Cox	This study
Langur ER	Same as above	Box-Cox	This study
Wild pig ER	Same as above	Box-Cox	This study
Small Prey ER	Interpolated ER of jungle fowl, spur fowl, peafowl and black napped hare.	None	This study
Bare ground	Percentage frequency of cells with in a circular window of area 1 sq km	Box-Cox	Supervised classification of Landsat ETM+ imagery to obtain landcover; frequency calculated using CircAn module of Biomapper.
Dry forest	Same as above	Box-Cox	Same as above
Teak dominated forest	Same as above	None	Same as above
Moist forest	Same as above	Box-Cox	Same as above
Tassled cap 'greenness'	The first band of tassle cap transform using Landsat ETM + imagery.	None	Calculated using Idrisi
Elevation	DEM in meters at 100m resolution	Box-Cox	SRTM data
Slope	Calculated from DEM	Box-Cox	Calculated using Idrisi
Distance from village	Distance to the nearest village.	Box-Cox	Calculated using Idrisi
Distance to water	Distance from the nearest water source in meters	Box-Cox	Calculated using DISTANCE module of Idrisi

Table 4.4: Measures of evaluation for habitat models at different resolutions (with cross validated standard deviations). AVI measures proportional accuracy in classifying habitat. CVI measures the difference between the model and a random model. The Boyce index measures the correlation between habitat suitability values and the area adjusted frequency of presence points in the habitat map

Study Site	Model Resolution	Moving window (scale)	AVI	CVI	Continuous Boyce Index
STR	100 m	1 sq km	0.51 (0.11)	0.30 (0.11)	0.75 (0.18)
STR	100 m	54 sq km	0.48 (0.14)	0.33 (0.13)	0.69 (0.35)
STR	200 m	56 sq km	0.50 (0.19)	0.40 (0.19)	0.74 (0.25)
STR	300 m	52 sq km	0.49 (0.22)	0.34 (0.21)	0.36 (0.39)
STR	500 m	56 sq km	0.49 (0.17)	0.34 (0.16)	0.63 (0.26)
SC Madhya Pradesh	1000 m, with buffer	20 sq km	0.48 (0.12)	0.33 (0.11)	0.91 (0.13)
SC Madhya Pradesh	1000 m	21 sq Km	0.48 (0.15)	0.33 (0.14)	0.72 (0.32)
SC Madhya Pradesh	2000 m	84 sq km	0.50 (0.19)	0.35 (0.18)	0.78 (0.24)
SC Madhya Pradesh	3000 m	81 sq km	0.52 (0.11)	0.29 (0.10)	0.77 (0.17)
SC Madhya Pradesh	5000 m	225 sq km	0.48 (0.11)	0.20 (0.10)	0.55 (0.25)

Table 4.5: Correlation between ENFA factors and EGV for south central Madhya Pradesh. The percentages quantify the amount of specialization attributed to the factor. Factor 1 accounts for all the marginality

EGV	Factor1 (12%)$^{+}$	Factor 2$^{♦}$ (22%)	Factor3$^{♦}$ (12%)	Factor4$^{♦}$ (10%)	Factor5$^{♦}$ (9%)	Factor6$^{♦}$ (8%)	Factor7$^{♦}$ (7%)
Elevation	+	0	0	****	****	***	**
Elevation standard deviation	++++	0	0	*	0	*	0
Slope	++	0	0	0	0	0	0
NDVI	++	*	*****	***	***	*	**
Forest	+++++	*	****	***	*****	*****	*******
Bare ground/urban	--	********	****	***	***	**	***
Agriculture	----	*****	******	****	*****	******	*****
Livestock ER	-	*	*	***	0	****	**
Nilgai ER	+++	0	0	*	0	0	0
Sambar ER	++++	*	0	*	0	*	*
Wild pig ER	++	*	**	*****	*	**	**
Distance to water	0	*	0	**	***	*	**

$^{+}$For the marginality factor, the + symbol indicates that leopards presence was associated with values higher than average, and vice versa for -. The number of signs indicates the strength of the relationship. $^{♦}$ For the specialization factor, * indicates that leopards were found in narrower range of values than available. The number of * indicates the narrowness of the range. 0 indicates low specialization.

Table 4.6: Correlation between ENFA factors and EGV for Satpura Tiger Reserve: The percentages quantify the amount of specialization attributed to the factor. Factor 1 accounts for all the marginality

EGV	Factor1 (22%) [+]	Factor2 (42%) [♦]	Factor3[♦] (9%)	Factor4[♦] (6%)
Elevation	---	******	0	0
Slope	--	0	0	*
Langur ER	+	*	0	0
Cervid ER	++	0	0	0
Pig ER	++	0	0	0
Small-prey ER	+++	0	0	*
Tassled cap 'greenness'	++++	**	******	********
Teak Forest	+++	****	****	***
Moist Forest	+++	*****	*****	****
Dry Forest	---	****	*	**
Bare ground	----	*	***	***
Distance to water	+++	0	**	*
Distance to village	-	0	**	**

[+]For the marginality factor, the + symbol indicates that leopards presence was associated with values higher than average, and vice versa for -. The number of signs indicates the strength of the relationship. [♦] For the specialization factor, * indicates that leopards were found in narrower range of values than available. The number of * indicates the narrowness of the range. 0 indicates low specialization.

Table 4.7: Area (in sq km) under various categories in each district in south central Madhya Pradesh

District	Unsuitable	Marginal	Suitable	Optimal
Balaghat	118.3	210.6	86.2	5.0
Betul	5031.5	2387.9	1172.1	857.5
Bhopal	50.1	7.0	0	0
Chhindwara	5621.2	3528.2	1931.6	744.1
Dewas	776.2	288.8	166.5	66.2
East Nimar	1141.3	453.3	343.0	168.5
Harda	2187.3	490.4	415.2	238.7
Hoshangabad	3325.6	1577.5	1371.0	465.3
Jabalpur	38.1	172.5	28.1	20.0
Narmsimhapur	3265.4	638.8	303.9	215.6
Raisen	2464.1	535.5	282.8	14.0
Sehore	1590.6	882.5	583.7	212.6
Seoni	2951.5	1745.0	892.6	306.9

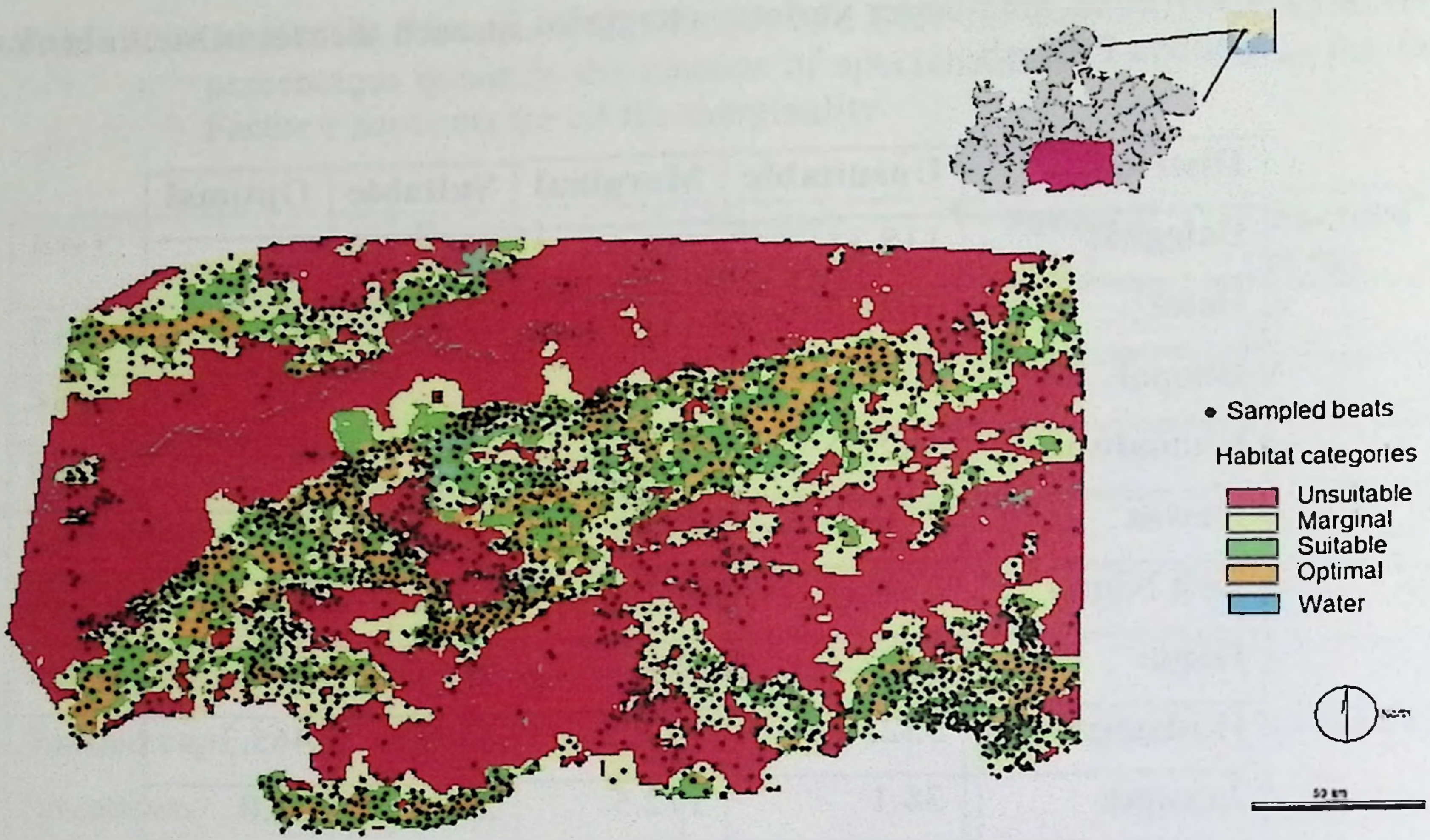

Figure 4.1: Leopard habitat suitability map for south central Madhya Pradesh.

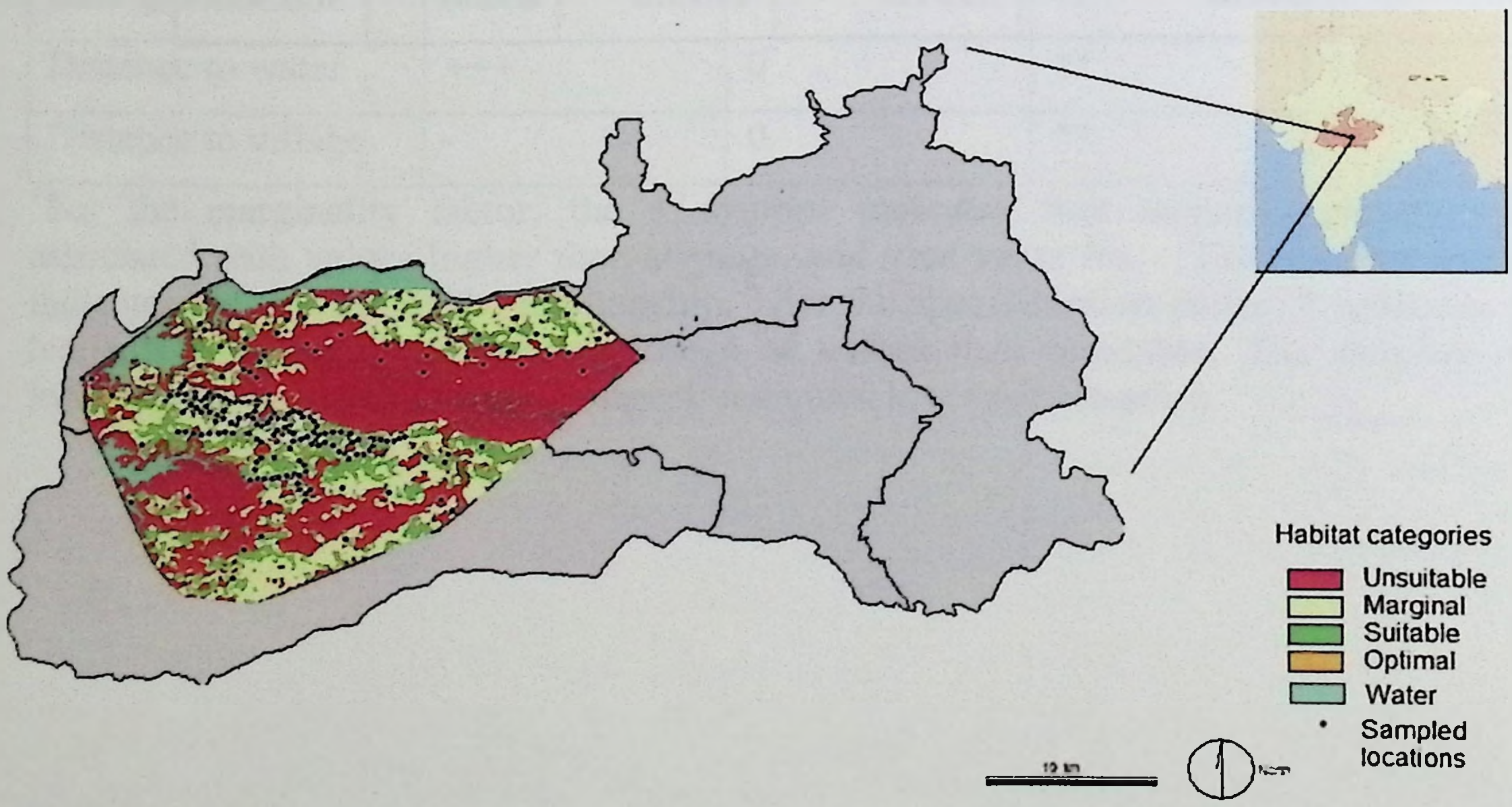

Figure 4.2: Leopard habitat suitability map for Satpura Tiger Reserve

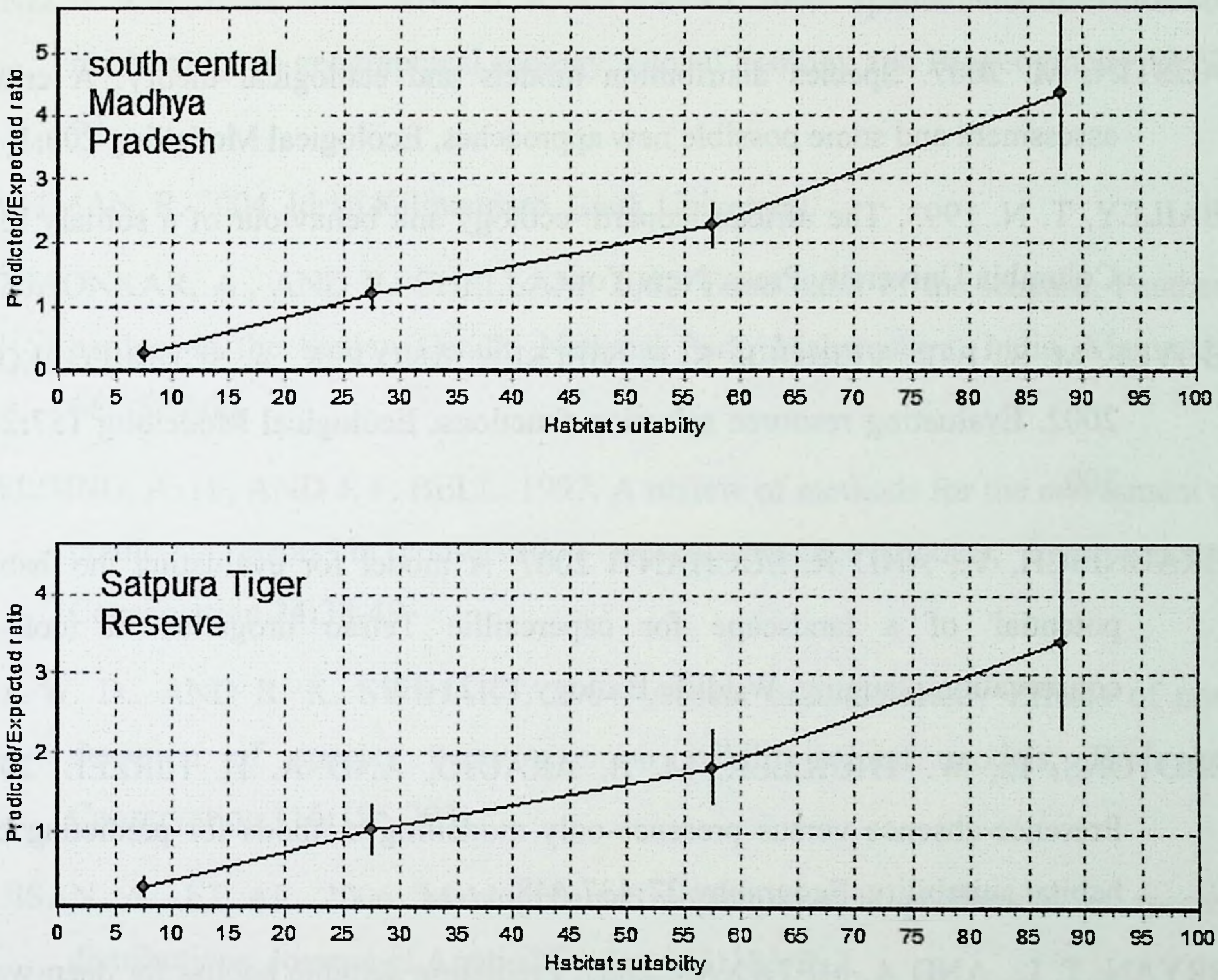

Figure 4.3: The predicted to expected frequency curves with habitat suitability values for both the models

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Chapter 5

Developing Species Specific Occurrence Models for Satpura Tiger Reserve

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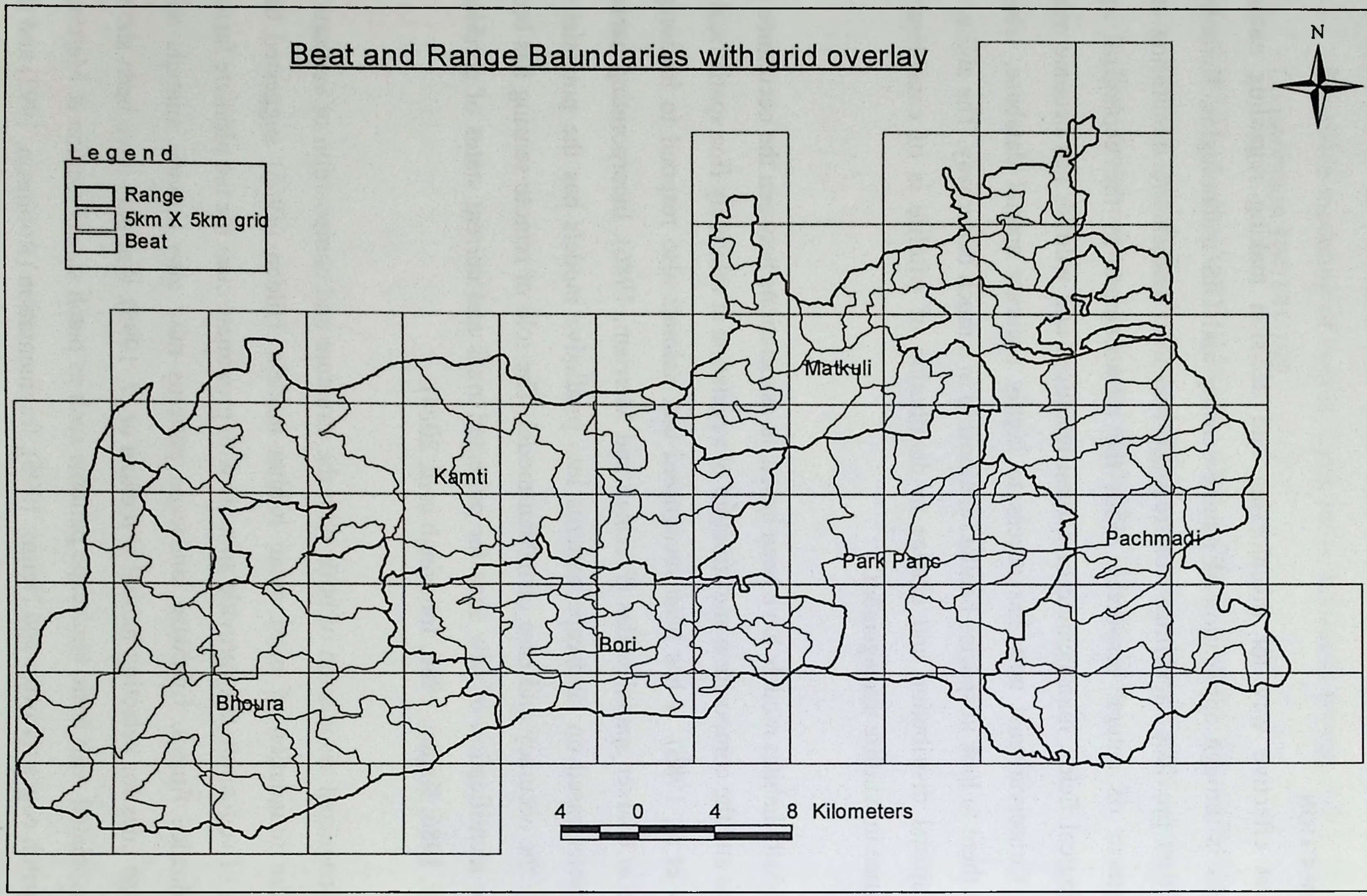
INTRODUCTION

The cost effective way for inventorying and decision making regarding natural resources is through application of remote sensing and GIS technologies. Remotely sensed data provides capabilities for frequent, real time assessment, monitoring and management of natural resources. With the advancement in the ecological and technological fields, management of natural resources and wildlife has become more robust. Conservationist now has access to highly accurate spatial database, which enables them to look at species-habitat relationship in a much better way. The ability to model spatial distribution and change in distribution of wildlife is of considerable importance in wildlife management.

Traditionally habitat models have been based on associations between the occurance of a species and the composition and structure of vegetation at relatively fine spatial scales (Verner et al, 1986). It has been recognized that animals also respond to landscape patterns at coarser spatial scales (Freeman and Merriam, 1986). Incorporating habitat associations based on landscape patterns into predictive models has the potential to improve the accuracy and ease of habitat model. The role of remote sensing has been vital for identification of new sites for protected areas and current status of corridors (Panwar, 1986; Kamat, 1986, Johnsingh *et al,* 2004).

Long recognized association of birds with the structure and composition of vegetation forms the foundation of most avian habitat models. Hilden (1965) suggested that patterns of vegetation may provide animals with proximate cues for the ultimate factors that influence fitness. Likewise landscape patterns may also provide animals with proximate cues for selecting habitat (Freeman *et al*, 1995). Animals have been shown to be associated with basic landscape patterns such as patch size (Freeman & Merriam, 1986), patch edges (Howrot and Neimi, 1996), fragmentation (Robinson, 1992) and the spatial arrangement of patches of vegetation (Hansen & diCastri, 1992)..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METHODS

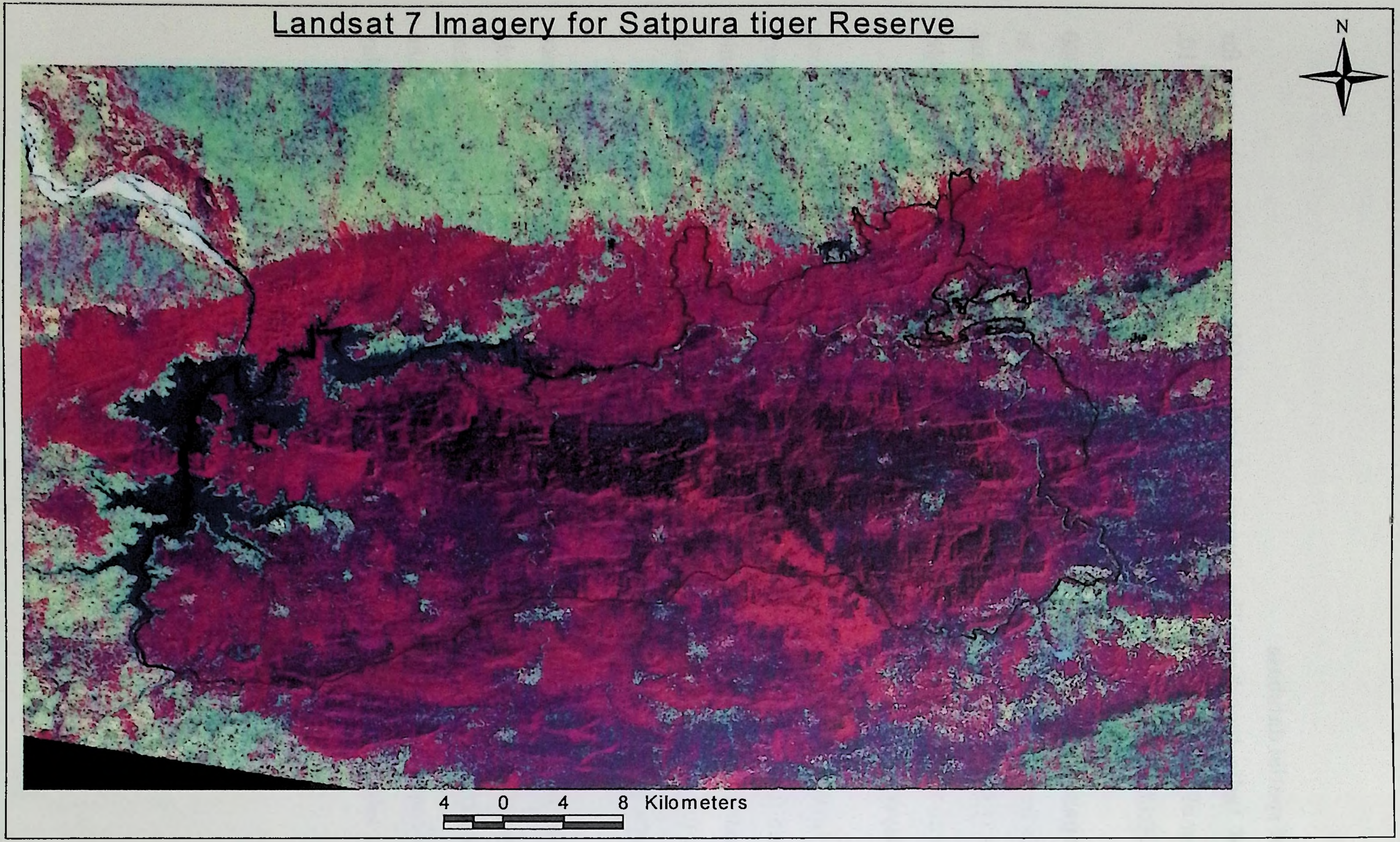
Sources of spatial database

Survey of India toposheets: The Survey of India (SOI) toposheets were used for preparation of baseline map of the study area are 55F14 and 15; and 55J 2, 3, 6, 7, 10, and 11(1:50,000 scale) (Fig 5.1& 5.2).

Forest Department Data: Compartment maps and beat maps at the scale of 1:50,000 were taken from Madhya Pradesh Forest Department and boundaries were digitized in ArcGIS 9 (ESRI Inc.) Landscape features like road network, drainage network and village locations were also digitized with the help of same sources at 1:50,000 scale. All these layers are used for the analysis phase directly or indirectly.

Satellite Imagery: False Colour composite (FCC) of Landsat 7, (10.1.2000) was downloaded from Global Land Cover Facility (GLCF) website (Fig 5.3). The imagery was geocoded using Survey of India (SOI) toposheets in Lambart Conformal Conic projection.We have used FSI forest cover data of 2004 for core area estimation. Details of this is described under generation of spatial database of this chapter.

Normalized Difference Vegetation Index (NDVI) data: The Normalized Difference Vegetation Index (NDVI) was used as surrogate for the vegetation cover in the study area. NDVI Composites are produced from multiple AVHRR daily observations that have been composited together to create a nearly cloud-free image showing maximum greenness. Global 10-day composites consist of data between April 1992 and May 1996.



Landsat 7 False Colour Composite showing Satpura Tiger Reserve

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

Where, $\rho_{nir} = R_{nir} / I_{nir}$ and $\rho_{red} = R_{red} / I_{red}$ (I signifies Incident and R signifies Reflected).

We generated mean and Co-efficient of variation in each 5km×5km grid.

The Shuttle Radar Topography Mission (SRTM) data: SRTM data is being used to generate a digital topographic mapSRTM data is being used to generate a digital topographic map of the Earth's land surface with data points spaced every 3 arc second for Earth's land surface (approximately 90 meters). The SRTM "finished" data meet the absolute horizontal and vertical accuracies of 20 meters (circular error at 90% confidence) and 16 meters (linear error at 90% confidence), respectively, as specified for the mission. This data is available at WII's GIS & RS lab.

Night light Data: The U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has a unique capability to perform low light imaging of the earth at night. The night light data was useful for monitoring human habitation, animal movement and fragmentation. This data is available at WII's GIS & RS lab.

Sampling for Carnivore sign: Forest guards are trained to search within those beats that have the maximum potential for large carnivore occupancy. The total minimum distance covered while searching for large carnivore signs was 15 km per beat (Jhala et al, 2004).

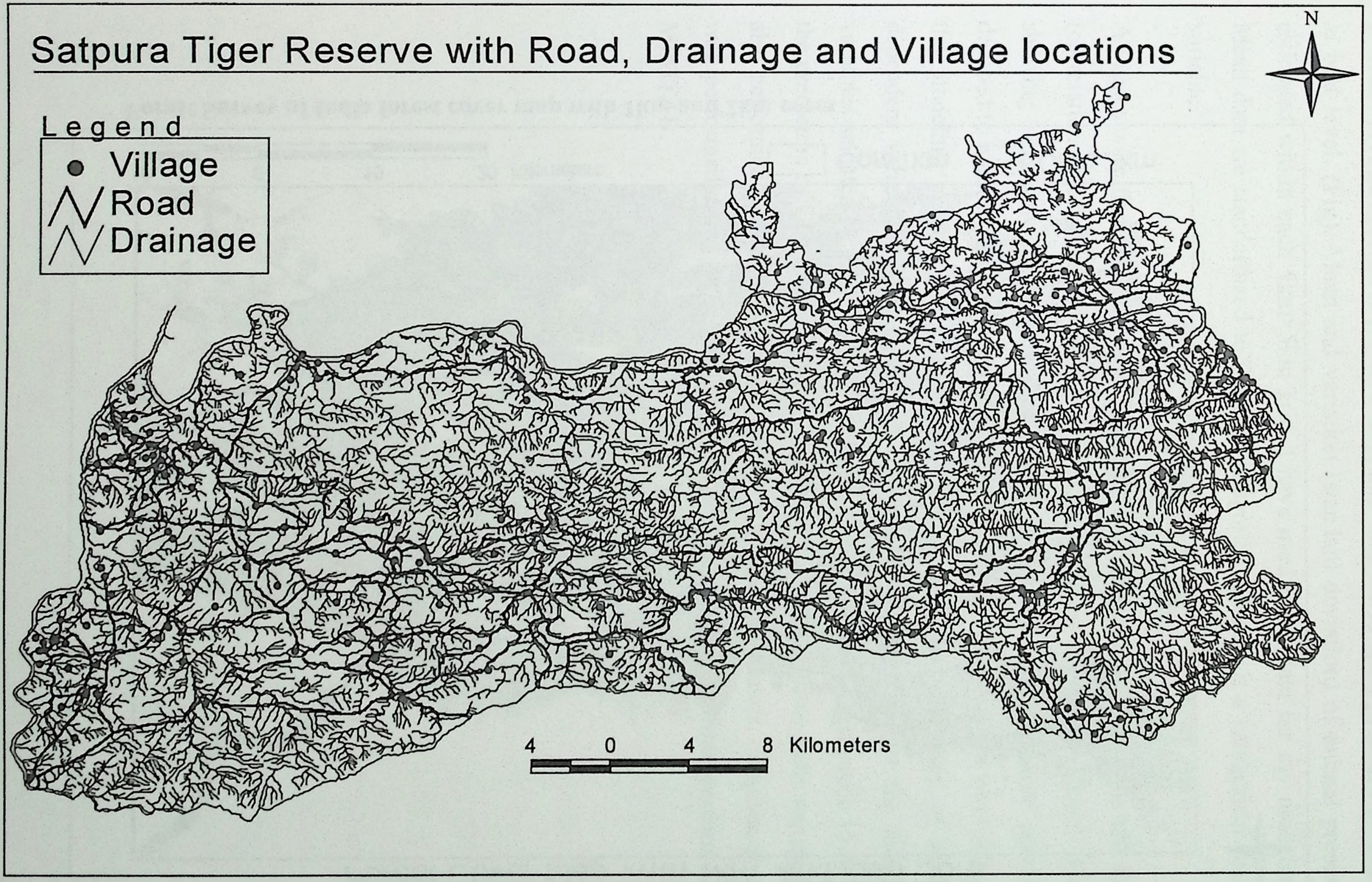
Sampling for ungulate encounter rates: With the helps of forest guards transect lines of a minimum of 2km and not exceeding 4km were marked. These transect lines were so made that it traversed through similar habitats as far as possible. Care was taken that a line transect must not locate near a busy road nor should it run parallel to river and other landscape features which may bias sightings of ungulate. GPS locations were taken as effectively as possible for the start and end points (Jhala et al, 2004).

Classification of vegetation : Vegetation was sampled at every 200m along the line transect (Jhala et al, 2004). For broad vegetation type 15m radius circular plots were laid. Five most dominant trees are noted within this plot. Five most dominant scrub species data was also collected. For ground flora and weed species 1m radius circular plots were made. Three most dominant grass species were recorded. Data was also collected on presence and absence of human disturbance like lopping, cuts etc.

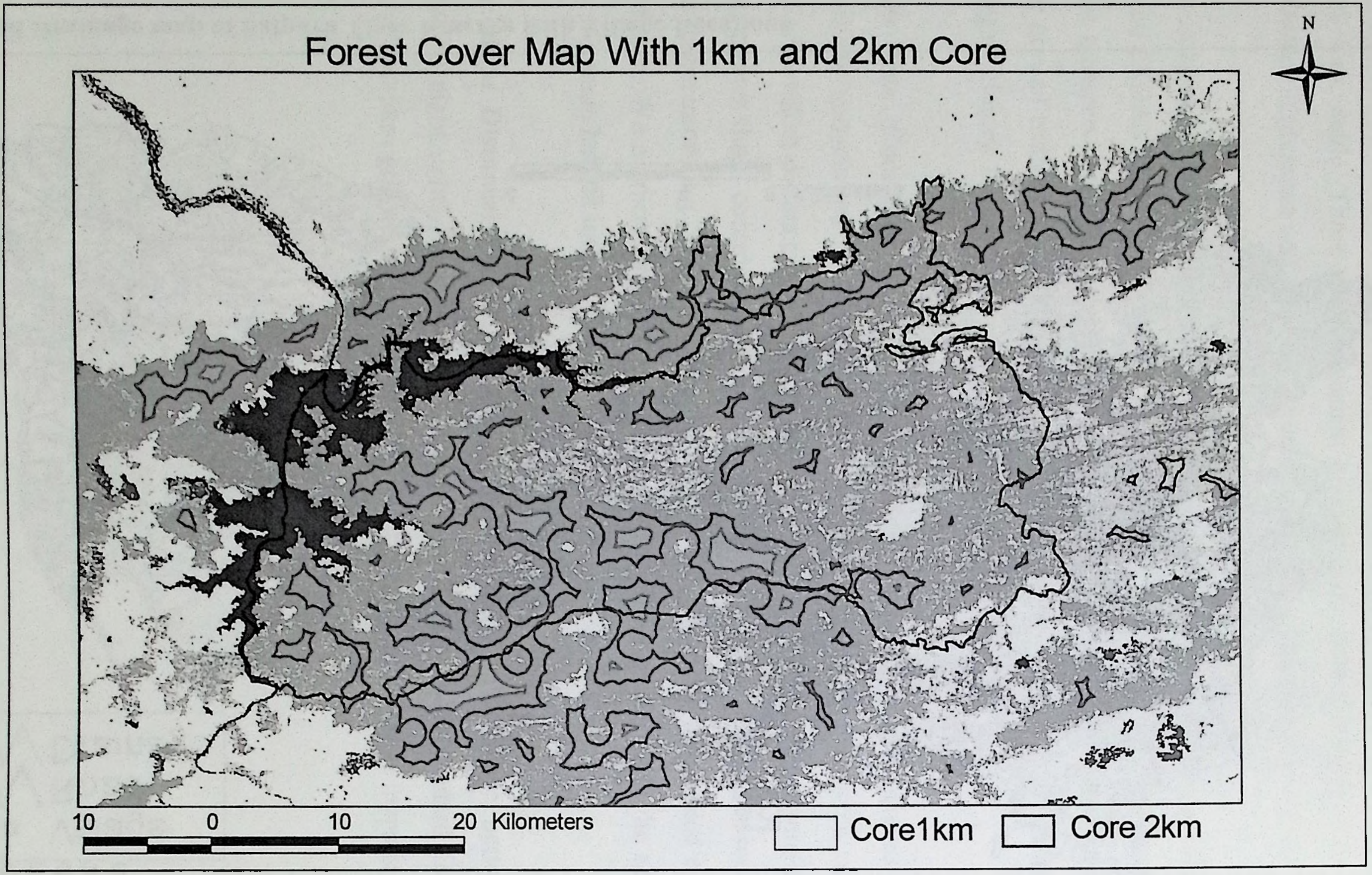
The imagery is classified with unsupervised unit algorithm into 40 classes with the help of the ERDAS (Leica Geosystems GIS & Mapping) software. The classes that results from unsupervised classification were based on clustering at one standard deviation. The ground truthing data of vegetation with GPS points was used for identifying and merging classes. Finally twelve classes were identified.

Core area : Core area (Fig 5.4) represents the interior area of patches which is relatively undisturbed by human disturbance. Core area integrates patch size, shape, and edge effect distance into a single measure. All other things equal, smaller patches with greater shape complexity have less core area. Most of the metrics associated with size distribution (e.g., mean patch size and variability) can be formulated in terms of core area. We extracted core as a forested area beyond two km from the edge of the forest-human habitat interface.

Euclidean Distance: Euclidean distance is calculated for Drainage network, road network, night lights, core and village locations The mean and standard deviation in each 5km×5km grid are extracted for all the three Euclidean distance maps in ArcView 3.2.



Road and Drainage map of Satpura Tiger Reserve with Village Locations



Forest Survey of India forest cover map with 1km and 2km cores

Estimation of animal abundance: For each animal species, encounter rate per km per beat is estimated from the field data. Then the beats are categorized into two classes presence (1) and absence (0). This data is then mapped to show presence-absence maps at beat level. (Fig). Mean and variation (standard deviation) of animal presence are estimated within each 5km×5km grid. I have used mean data for my modeling part. Mean data are standardized to 0 and 1 categories to make it a categorical dependent variable.

All cases were first filtered on the basis of sighting of individual species and the PCA (correlation Coefficient, varimax rotation) was run on the entire dataset. Variables showing very low loading on the rotated component matrices were successively dropped to reduce the noise in the dataset and ultimately 25 variables were selected for the modeling purpose. The animal presence derived data are used as categorical dependent variables. Each species was modeled separately against the independent variables selected by PCA. Logistic regression regression was performed to determine the predictors of Chital, Sambar and Leopard occurrence. Multilogistic regression was also performed to determine the predictors of leopard abundance. Logistic regression was performed using SPSS 12.0 and multilogistic regression was performed using MINITAB.

Result and Discussion

The vegetation was classified on the basis of Champion and Seth (1968) Classification system and landuse categories as per our need for modeling animal distribution.

a) Miscellaneous: It is one of the most dominant class in the study area (15.53%) and is distributed throughout the reserve, comes under Type 5A/c3 Southern Dry Mixed deciduous forest. This category is dominated by *Terminalia tomentosa*, *Terminalia belerica, Mangifera indica*, Syzigium cumini, *Anogeissus latifilia, Boswellia serrata* etc.

b) Teak: The most dominant class was found to be Teak (18.76%). Pure patches of teak can be seen where soil is sandy. It comes under the Type 3B/c1 Moist teak bearing Forest. This category is obviously dominated by *Tectona grandis* followed by *Terminalia tomentosa*, *Adina cardifilia*, *Lagerosrtoemia parviflora, Zizyphus xylopyra* etc. *Dendrocalamus strcitus*, *Helicteris isora*, *Lantana camara* forms the scrub layer.

c) Sal: It was a category restricted to a patch near Panchmari. (3%). This category represents the Type 5B/cl(c) Dry Peninsular Sal forest. *Shorea robusta, Chloroxylon swietenia, Madhuca indica* are the major tree species. The scrub layer is formed of *Dodonea viscose, Phoenix acaulis* etc.

d) Teak Mixed: This category is found in large proportions al over the reserve except some parts of Panchmari (12.27%). Type 5A/cl Dry teak bearing forest is represented by this category. *Lagerstroemia parviflola, Diospyros melanoxylon, Adina cardiflora* with *Shorea robusta* are dominant tree species.

e) Sal mixed: This category is only distributed to the north and eastern part of the reserve in the Panchmari area (6.57%). It also comes under the Type 5B/cl(c) Dry Peninsular Sal Forest. *Shorea robusta*, *Terminalia* sp., *Buchnania lanzan*, *Madhuka indica*, *Embellica officinalis* are the major tree species. *Dodonia viscosa*, *Holarrhaena antidysentrica*, *Phoenix acaulis* forms the scrub layer.

f) Bamboo: It can be seen evenly distributed throughout the study area with Teak, Sal and miscellaneous forests (2.31%). The main species of bamboo is *Dendrocalamus strictus. Bambusa polymorpha* occurs in some patches. Others are *Zizyphus* sp., *Hlictris isora* etc.

g) Riparian: Riparian forests occur along the deep and moderately deep streams and rivulets (3.76%). This type not clearly delineated on the image as they are extremely narrow in extent. It comes under 4E/R5- riparian Fringing Forest. *Terminalia arjuna, Syzyzium cumini, Mangifera indica* are the major tree species. At some places bamboos also grow in patches.

h) Scrub: It is distributed all over the reserve where biotic pressure is high (8.25%). Type 5 DS2 Dry Deciduous Scrub represents this category.

Lantana camara is the most dominant scrub of this area. Other than that Zizyphus spp are found in this areas. *Helicteris isora, Dodonia viscosa* are other dominant scrub species found here.

i) Grassland: These grasslands mainly occur on the Plateau and hill tops if they are moderately flat (16.66%). This type is associated with rocky outcrops. The main grass species are *Dichanthium ciliaris, Saccharam Spontaneum, Cymbopogon martinni*

j) Plantation: Plantation is mainly restricted to Bori Sanctuary (1.78%). Almost all the plantation consists of Teak except few which consist of Bamboo.

k) Agri-Habitation: There are lot of habitation and agricultural areas inside the reserve (4.51%).

l) Water body: In Satpura TR the biggest water body is the Tawa reservoir which is situated at the North-western side of the reserve. There are major rivers like Tawa and Denwa. This category occupies 6.6% of the area of the tiger reserve.

Animal Occupancy Probability Models

Chital occurrence was governed by the extent of vegetation types such as mixed Sal forest, Scrub and Teak forest (Fig 5.6). Sambar relates to vegetation, Miscellaneous forest, variation in NDVI (Forest density) as well as disturbance variables, namely distance from villages (Fig 5.6). Leopard occurrence is prinicipally goverened by the extent of core area and the abundance of prey, namely Sambar (Fig 5.6). The logistic model has performed well with 82, 76 and 82% correct classifications of observed distribution. Multilogistic regression was done to assess the predictors of leopard abundance in the Satpura Tiger Reserve. The extent of core area, variation in topography (elevation) distance from roads and villages were the principal predictors of leopard abundance suggesting disturbance can play an important role in producing patterns of leopard distribution and abundance. Gaur occurrence was correctly classified with 82.9% probability . The significant variable in the equation were teak, scrub, sal mixed. Nilgai was correctly classified with 72% probability. Barking Deer 68.3%, Wild Pig 65.9%, Livestock 79.3%, Tiger 80%, Sloth Bear 86% and Wild Dog 95% (Fig 5.6).

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I. Logistic regression for probability of occurrence of Chital

```
Classification Table for CHITALPA
The Cut Value is .50
                     Predicted
                   .00      1.00      Percent Correct
                    0  I     1
Observed          +-------+-------+
   .00       0    I  45   I    5  I   90.00%
                  +-------+-------+
   1.00      1    I   9   I   23  I   71.88%
                  +-------+-------+
                            Overall   82.93%
```

----------------- Variables in the Equation ------------------

Variable	B	S.E.	Wald	df	Sig	R
TEAKST	.7641	.3428	4.9693	1	.0258	.1645
SCRUB	1.3441	.4118	10.6526	1	.0011	.2809
SALMIXED	2.0135	.5127	15.4210	1	.0001	.3498
Constant	-.7565	.3197	5.5983	1	.0180	

		95% CI for Exp(B)	
Variable	Exp(B)	Lower	Upper
TEAKST	2.1470	1.0967	4.2033
SCRUB	3.8348	1.7108	8.5957
SALMIXED	7.4892	2.7416	20.4584

II. Logistic regression for probability of Sambar occurrence

```
Classification Table for SAMBERPA
The Cut Value is .50
                     Predicted
                   .00      1.00      Percent Correct
                    0  I     1
Observed          +-------+-------+
   .00       0    I  27   I   11  I   71.05%
                  +-------+-------+
   1.00      1    I   8   I   36  I   81.82%
                  +-------+-------+
                            Overall   76.83%
```

----------------- Variables in the Equation ------------------

Variable	B	S.E.	Wald	df	Sig	R
MISCFOR	-.7323	.3128	5.4814	1	.0192	-.1753
NDVICV	-2.1774	.5891	13.6613	1	.0002	-.3209
VILLEUCD	-1.0523	.3588	8.6035	1	.0034	-.2415
Constant	.1943	.2705	.5160	1	.4725	

		95% CI for Exp(B)	
Variable	Exp(B)	Lower	Upper
MISCFOR	.4808	.2605	.8876
NDVICV	.1133	.0357	.3596
VILLEUCD	.3491	.1728	.7053

III. Logistic regression for probability of Leopard occurrence

```
Classification Table for LEOPA
The Cut Value is .50
                   Predicted
                  .0      1.0      Percent Correct
                   0  I    1
Observed        +-------+-------+
   .0       0   I   26  I    6  I   81.25%
                +-------+-------+
   1.0      1   I    8  I   42  I   84.00%
                +-------+-------+
                         Overall    82.93%
```

------------------ Variables in the Equation ------------------

Variable	B	S.E.	Wald	df	Sig	R
STCOEUC	1.0721	.3730	8.2617	1	.0040	.2389
SAMBAR			16.9052	3	.0007	.3153
SAMBAR(1)	-9.0854	24.5112	.1374	1	.7109	.0000
SAMBAR(2)	-6.7810	24.5150	.0765	1	.7821	.0000
SAMBAR(3)	-5.4282	24.5332	.0490	1	.8249	.0000
Constant	8.2684	24.5080	.1138	1	.7358	

		95% CI for Exp(B)	
Variable	Exp(B)	Lower	Upper
STCOEUC	2.9214	1.4064	6.0685
SAMBAR(1)	.0001	.0000	8.283E+16
SAMBAR(2)	.0011	.0000	8.360E+17
SAMBAR(3)	.0044	.0000	3.352E+18

IV. Multi logistic regression for predicting leopard abundance

Ordinal Logistic Regression:

Logistic Regression Table

					Odds	95% CI	
Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Const(1)	1.1844	0.6055	1.96	0.050			
Const(2)	4.6017	0.9231	4.99	0.000			
Const(3)	7.356	1.131	6.50	0.000			
sambar							
1	-3.012	1.005	-3.00	0.003	0.05	0.01	0.35
2	-4.608	1.289	-3.58	0.000	0.01	0.00	0.12
3	-4.354	1.781	-2.44	0.015	0.01	0.00	0.42
SdevSRTM	-1.7691	0.8152	-2.17	0.030	0.17	0.03	0.84
MnRdEcld	2.249	1.025	2.19	0.028	9.48	1.27	70.71
villeuc	-1.7131	0.7179	-2.39	0.017	0.18	0.04	0.74
coeulkm	-2.649	1.246	-2.13	0.033	0.07	0.01	0.81

Log-likelihood = -59.329
Test that all slopes are zero: G = 89.244, DF = 34, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	190.076	209	0.822
Deviance	118.658	209	1.000

```
Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs          Number   Percent      Summary Measures
Concordant       2138     91.3%      Somers' D                   0.83
Discordant        199      8.5%      Goodman-Kruskal Gamma       0.83
Ties                6      0.3%      Kendall's Tau-a             0.58
Total            2343    100.0%

SdevSRTM= Std Deviation SRTM
MnRdEcld= Mean Road Eculidean distance
Villeuc=Mean Village Euclidean Distance
Coeulkm= Mean Core area Eculidean Distance within 1 km
```

V. Mean probability of leopard occurrence across ranges of Satpura Tiger Reserve

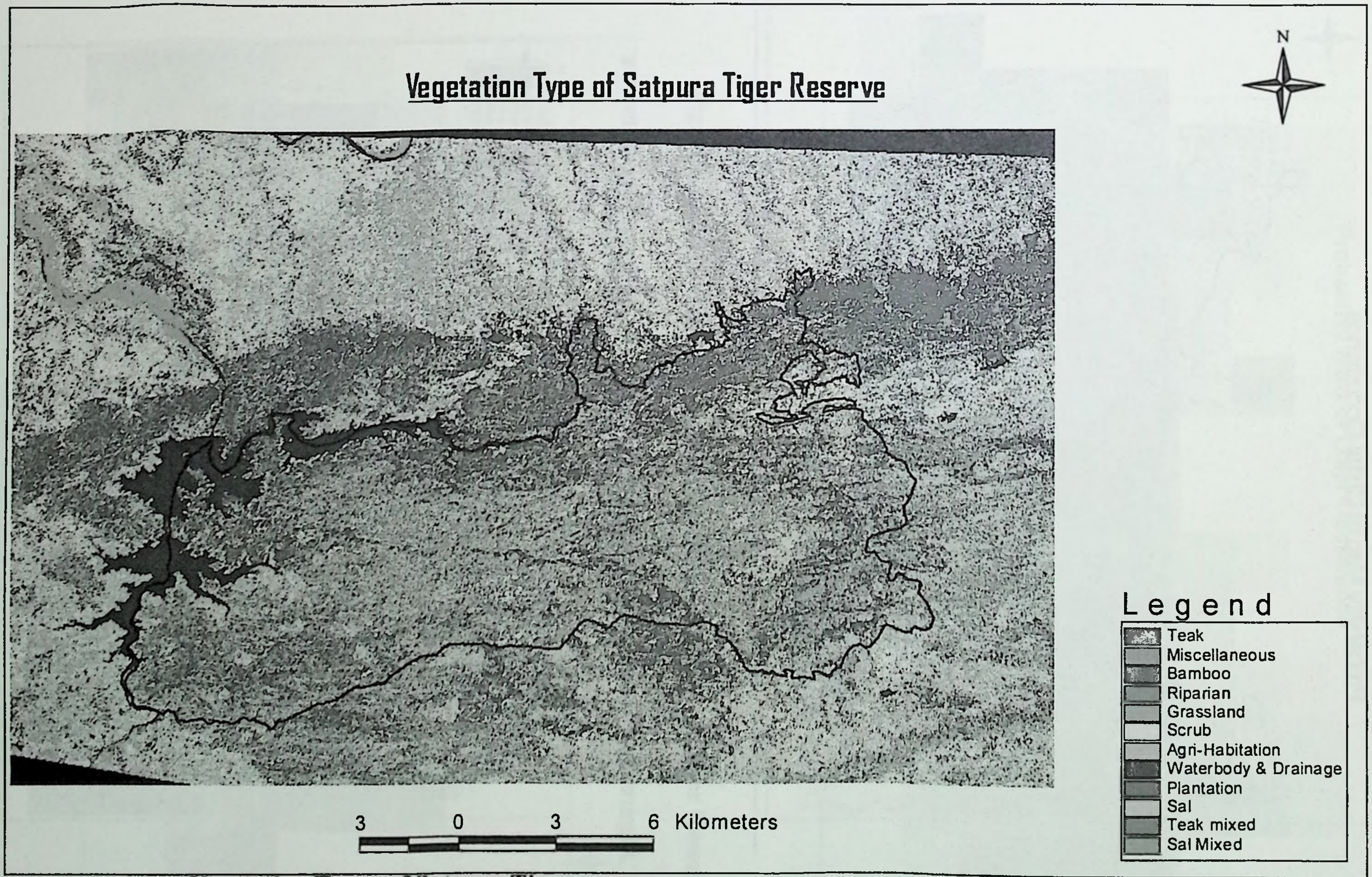
PROBABILITY OF LEOPARD OCCURRENCE					
RANGE	AREA	MIN	MAX	MEAN	STD DEV
Bhoura	316789504.00	0.3395	0.9879	0.8214	0.1841
Bori	152695152.00	0.4255	0.9879	0.8892	0.1411
Kamti	294153920.00	0.4220	0.9999	0.9057	0.1056
Matkuli	174950752.00	0.0324	0.9198	0.4889	0.2477
Pachmadi	274829568.00	0.0468	0.7504	0.2151	0.1191
Park	192483824.00	0.0824	0.9607	0.5679	0.3451

VI. Mean probability of Chital occurrence across ranges of Satpura Tiger Reserve

PROBABILITY OF CHITAL OCCURRENCE					
RANGE	AREA	MIN	MAX	MEAN	STD DEV
Bhoura	316789504.0	0.2823	0.9595	0.6964	0.1623
Bori	152695152.0	0.0043	0.9219	0.3634	0.3145
Kamti	294153920.0	0.0043	0.9595	0.3845	0.2792
Matkuli	174950752.0	0.0525	0.4445	0.2197	0.1111
Pachmadi	274829568.0	0.0154	0.8727	0.2737	0.2286
Park	192483824.0	0.0041	0.3754	0.0815	0.1109

VII. Mean probability of Sambar occurrence across ranges of Satpura Tiger Reserve

PROBABILITY OF SAMBAR OCCURRENCE					
RANGE	AREA	MIN	MAX	MEAN	STD DEV
Bhoura	316789504.00	0.3162	0.9999	0.7695	0.1558
Bori	152695152.00	0.3585	0.8528	0.6898	0.1332
Kamti	294153920.00	0.1325	0.9999	0.7649	0.1935
Matkuli	174950752.00	0.0099	0.8046	0.4558	0.1764
Pachmadi	274829568.00	0.0508	0.6453	0.4410	0.1667
Park Panc	192483824.00	0.0591	0.8238	0.5489	0.1984



Vegetation Types of Satpura Tiger reserve

Figure 5.6:Probability of occurrence of Chital in Satpura Tiger Reserve

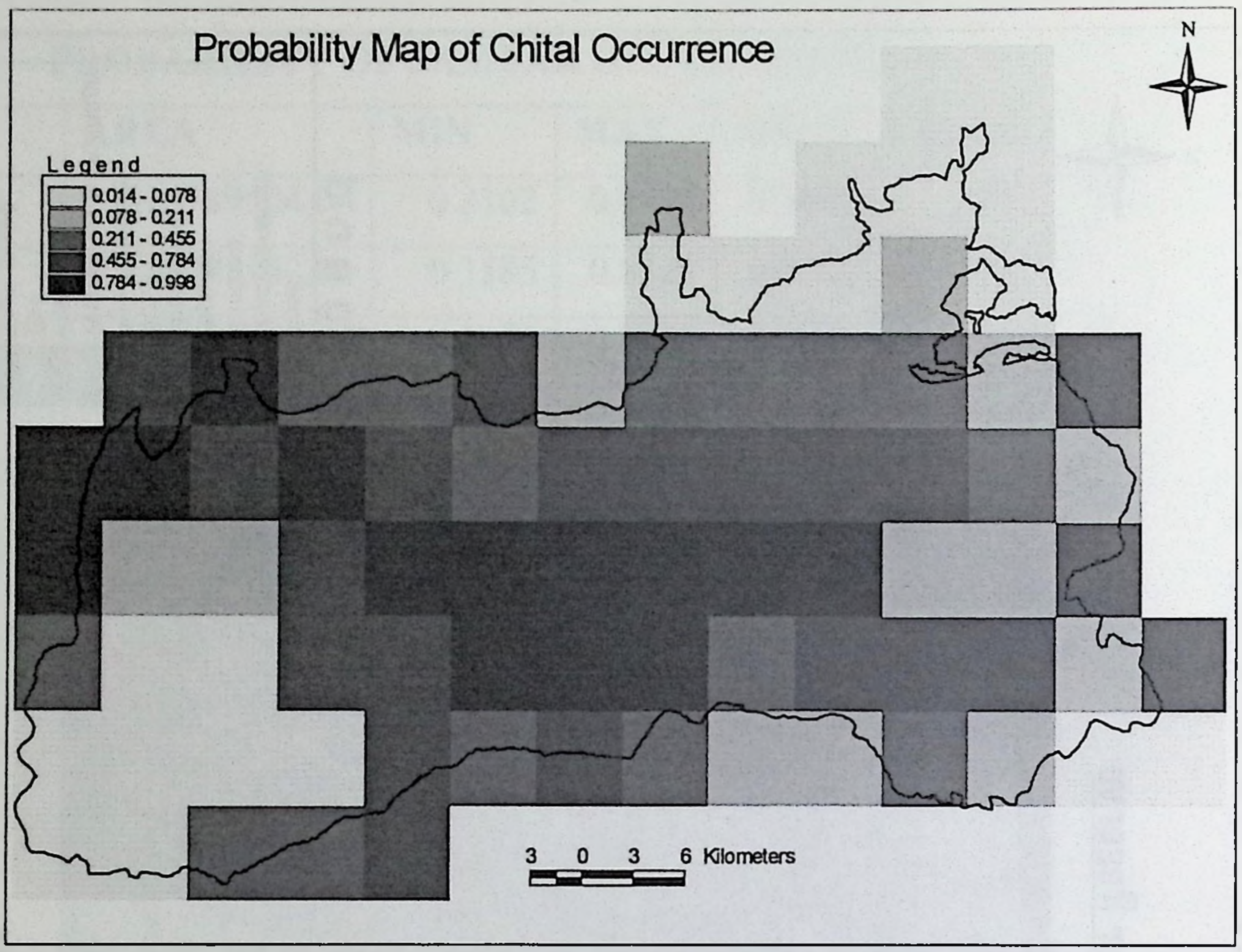


Figure 5.6:Probability of occurrence Sambar in Satpura Tiger Reserve

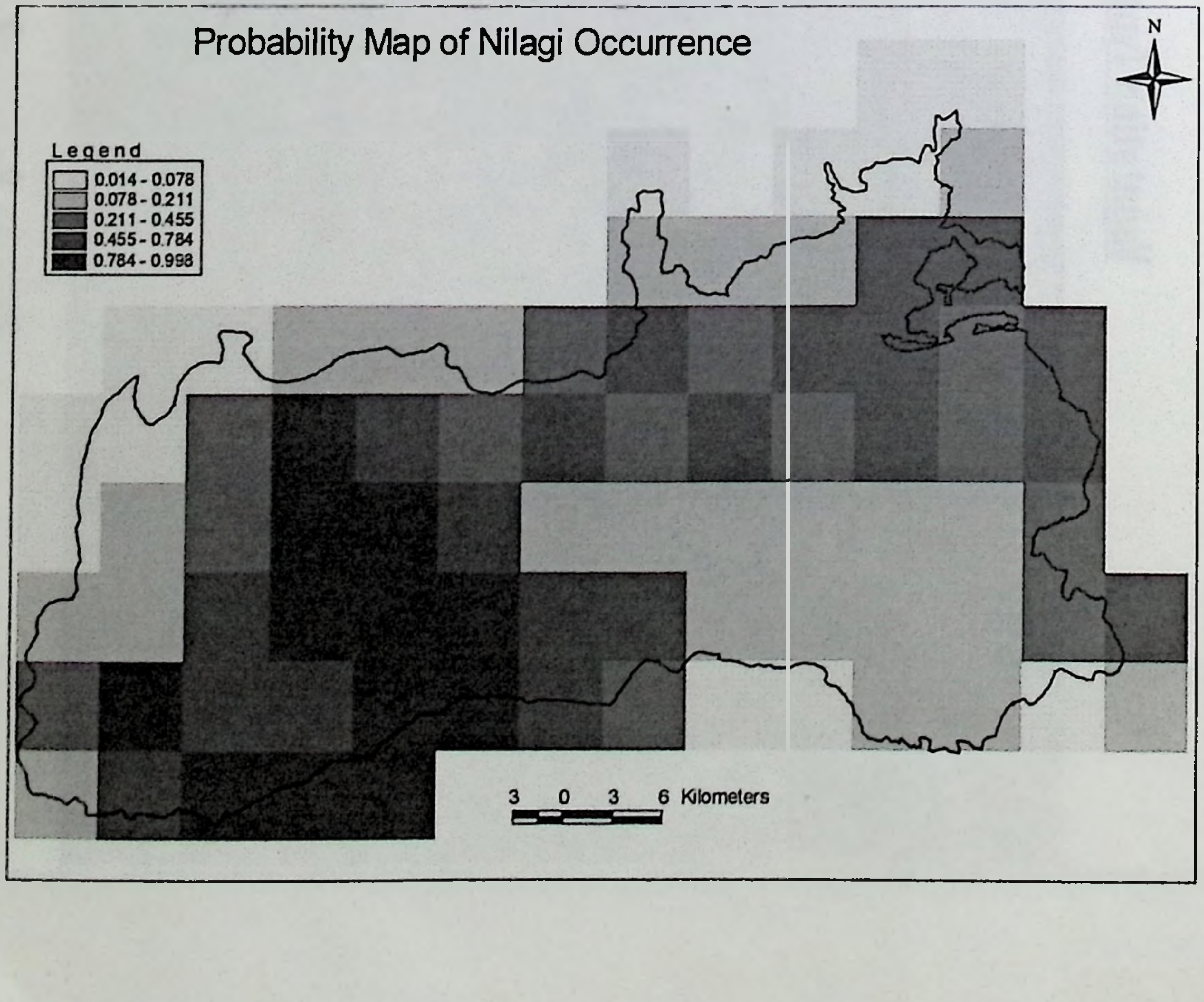


Figure 5.6:Probability of occurrence of Gaur in Satpura Tiger Reserve

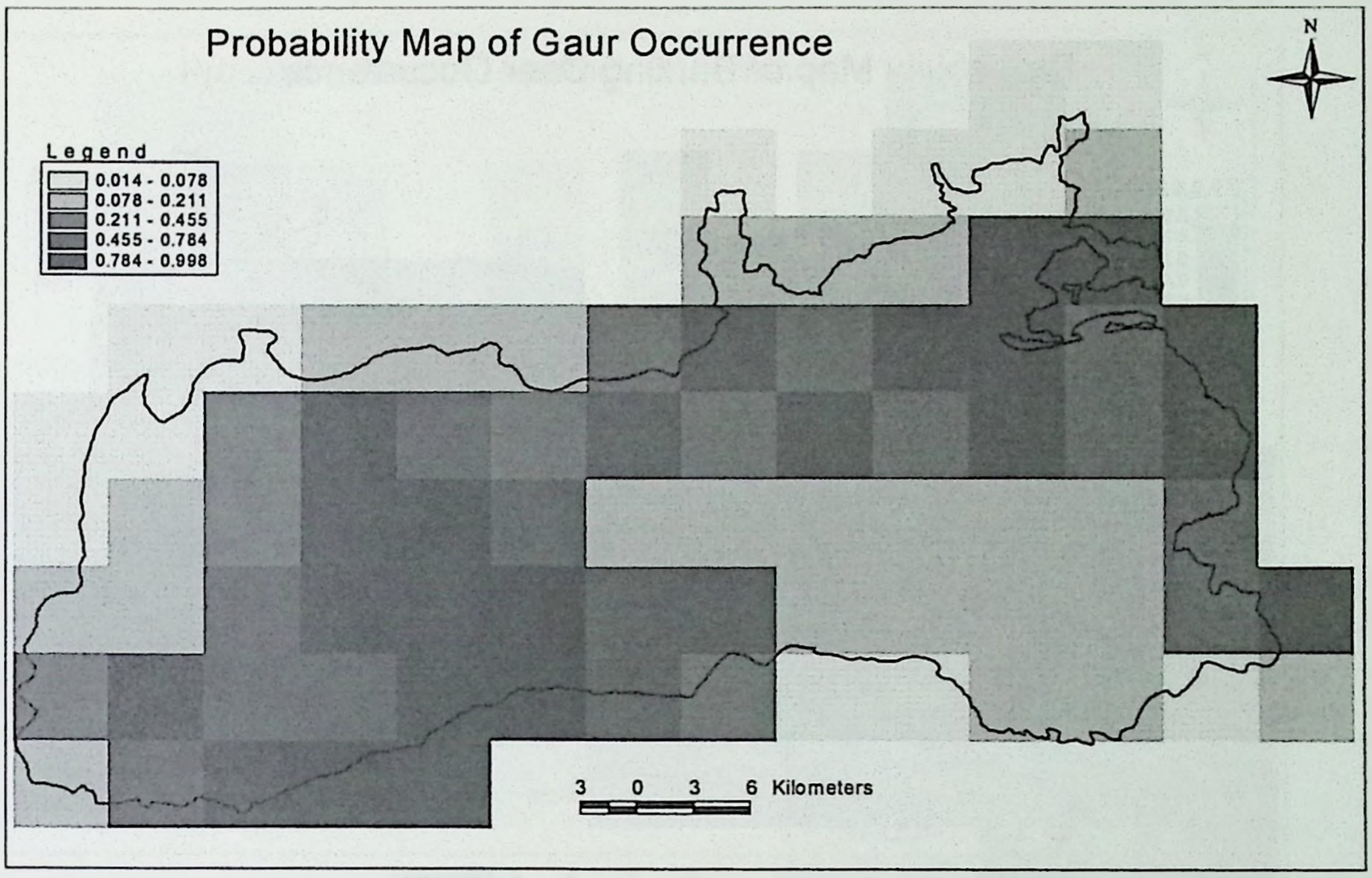


Figure 5.6:Probability of occurrence of Nilgai in Satpura Tiger Reserve

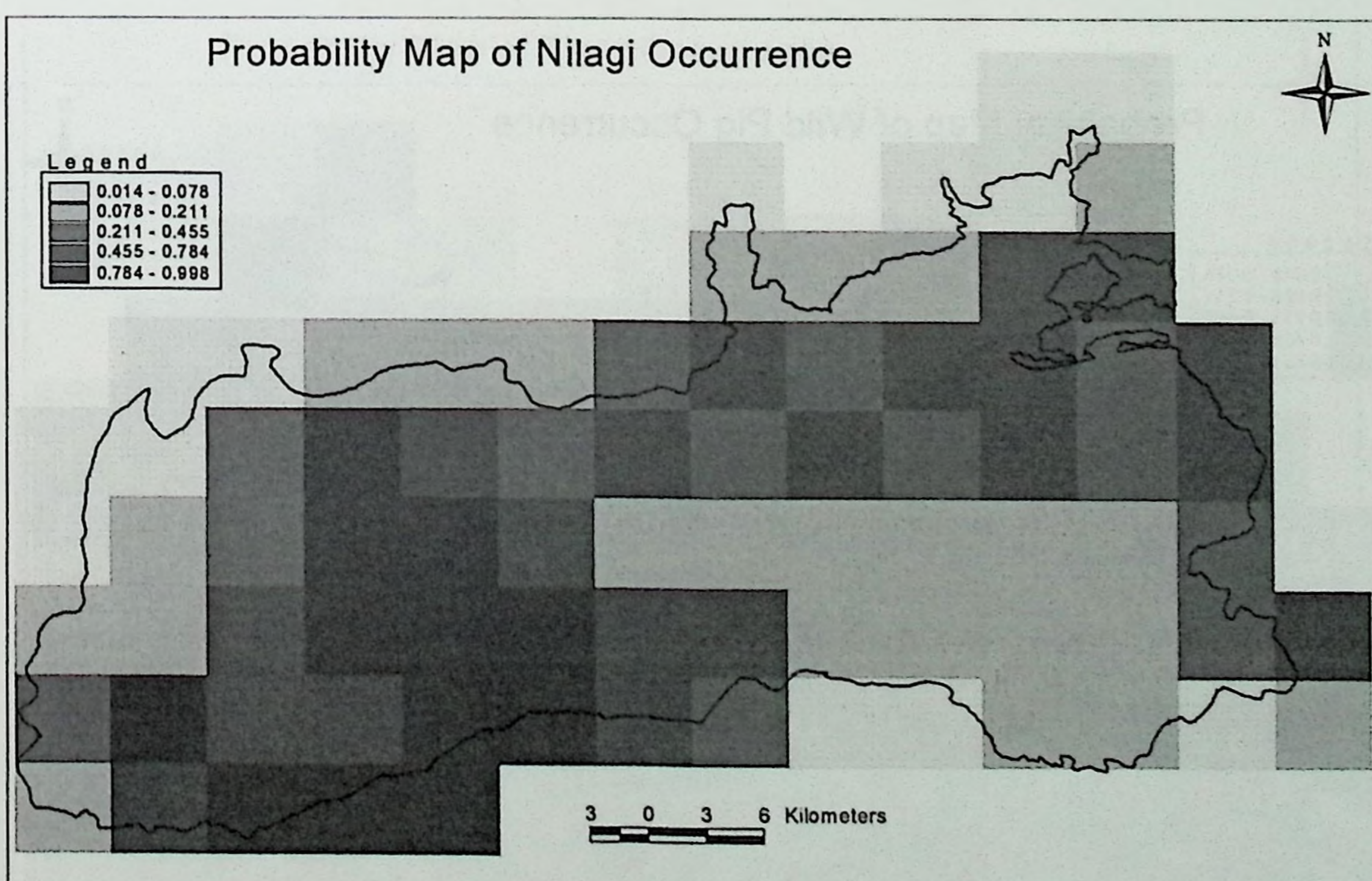


Figure 5.6:Probability of occurrence ofBarking Deer in Satpura Tiger Reserve

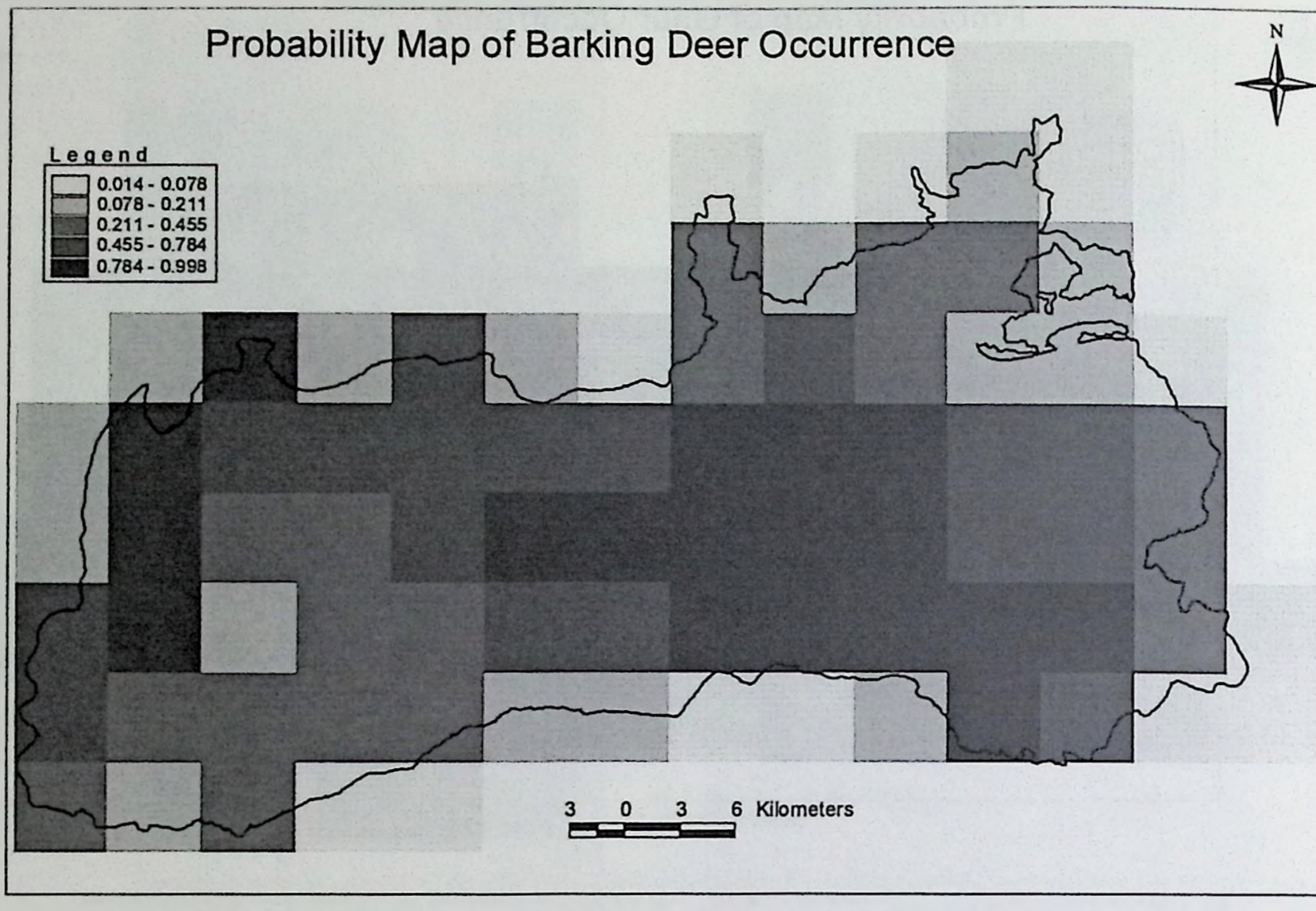


Figure 5.6:Probability of occurrence of Wild Pig in Satpura Tiger Reserve

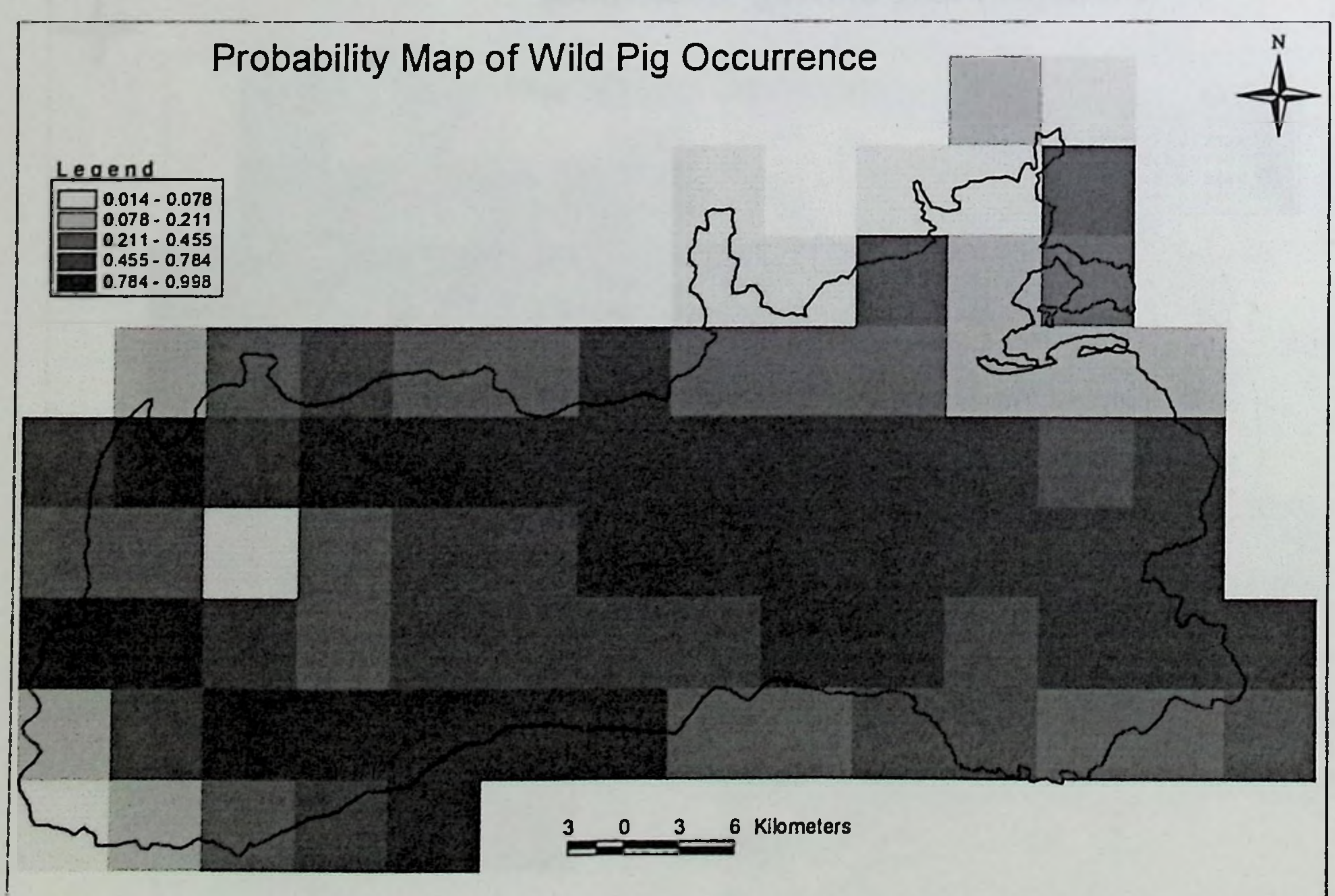


Figure 5.6:Probability of occurrence of Livestock in Satpura Tiger Reserve

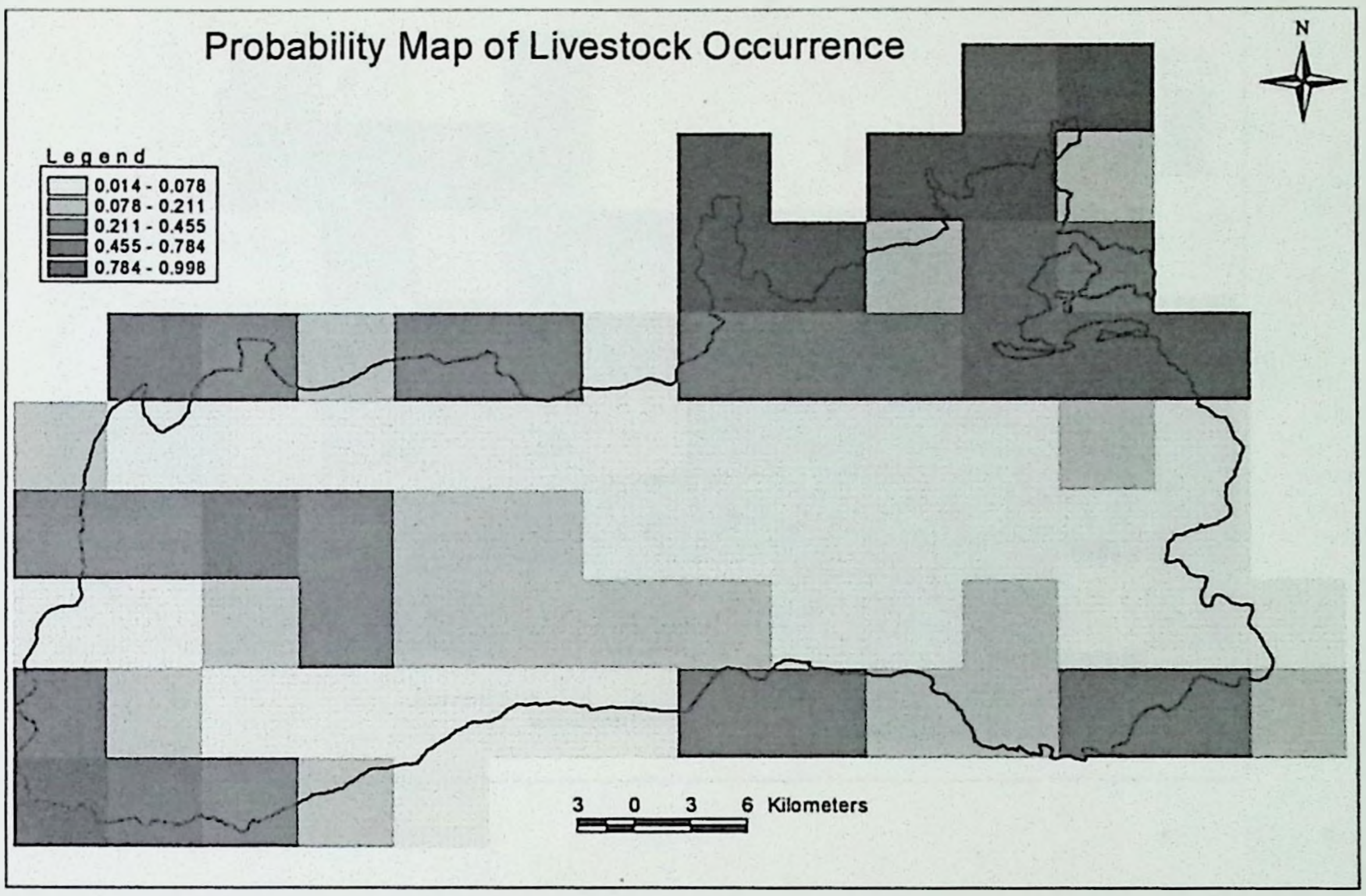


Figure 5.6:Probability of occurrence Tiger in Satpura Tiger Reserve

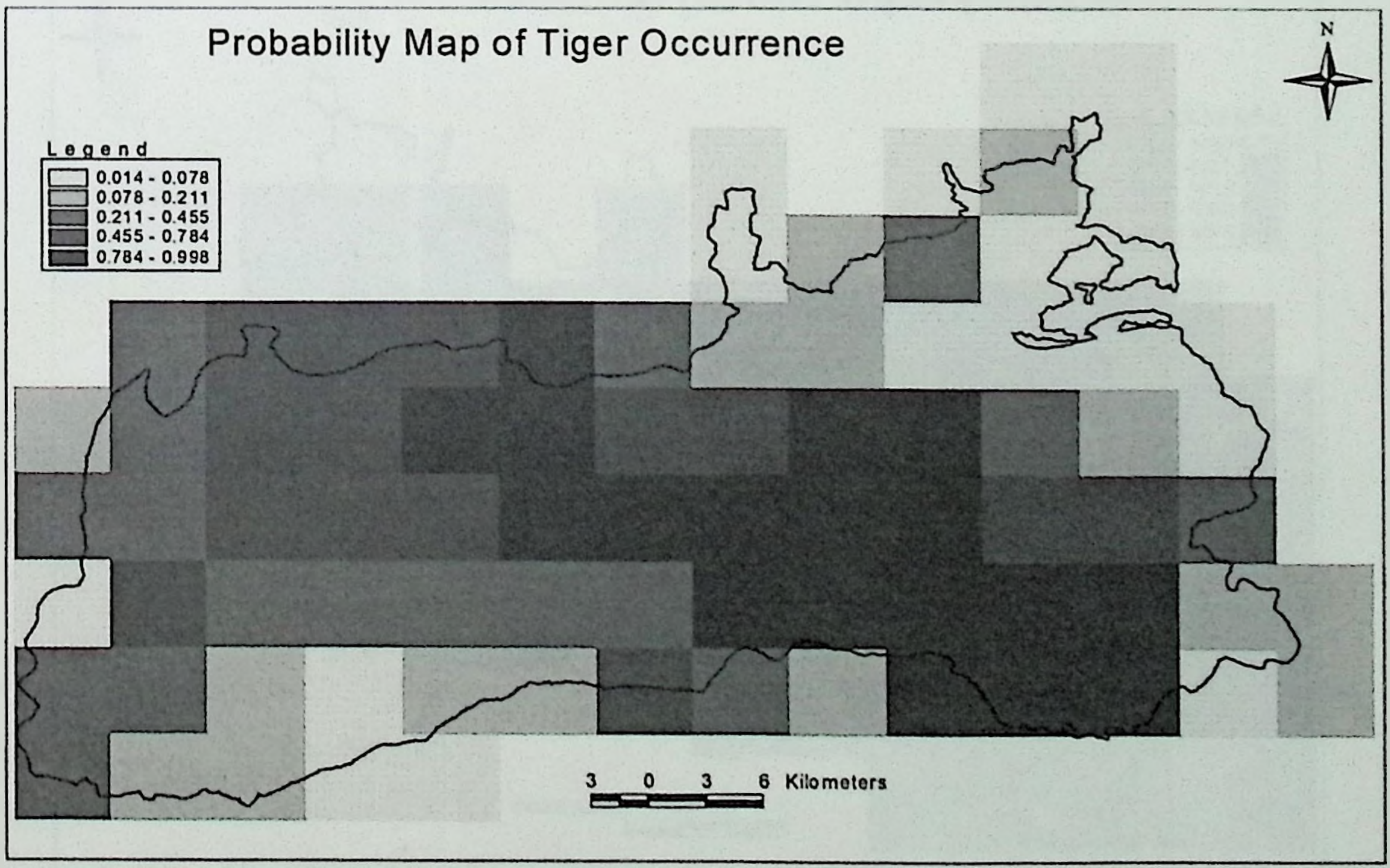


Figure 5.6:Probability of occurrence Sloth Bear in Satpura Tiger Reserve

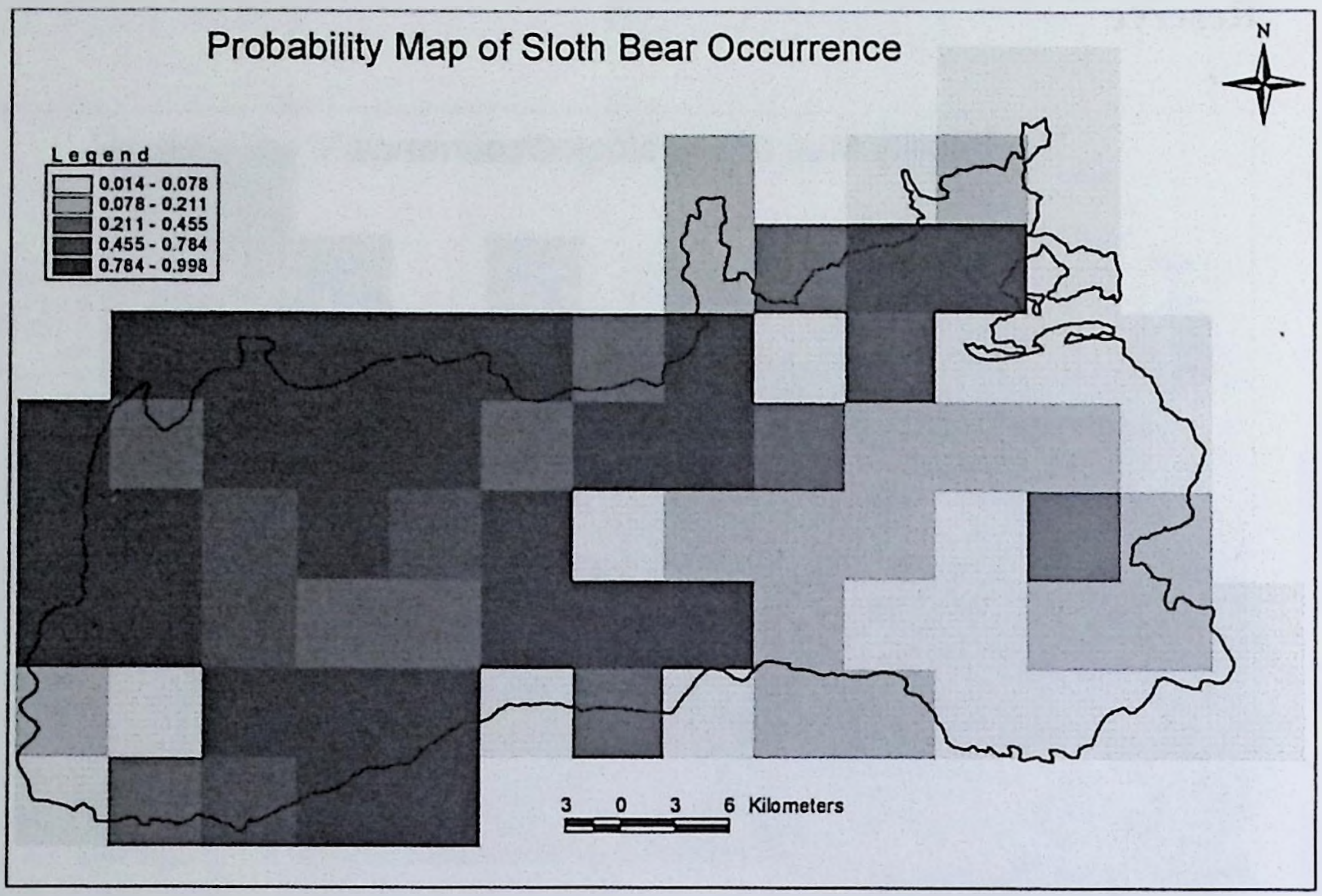


Figure 5.6:Probability of occurrence of Wild Dog in Satpura Tiger Reserve