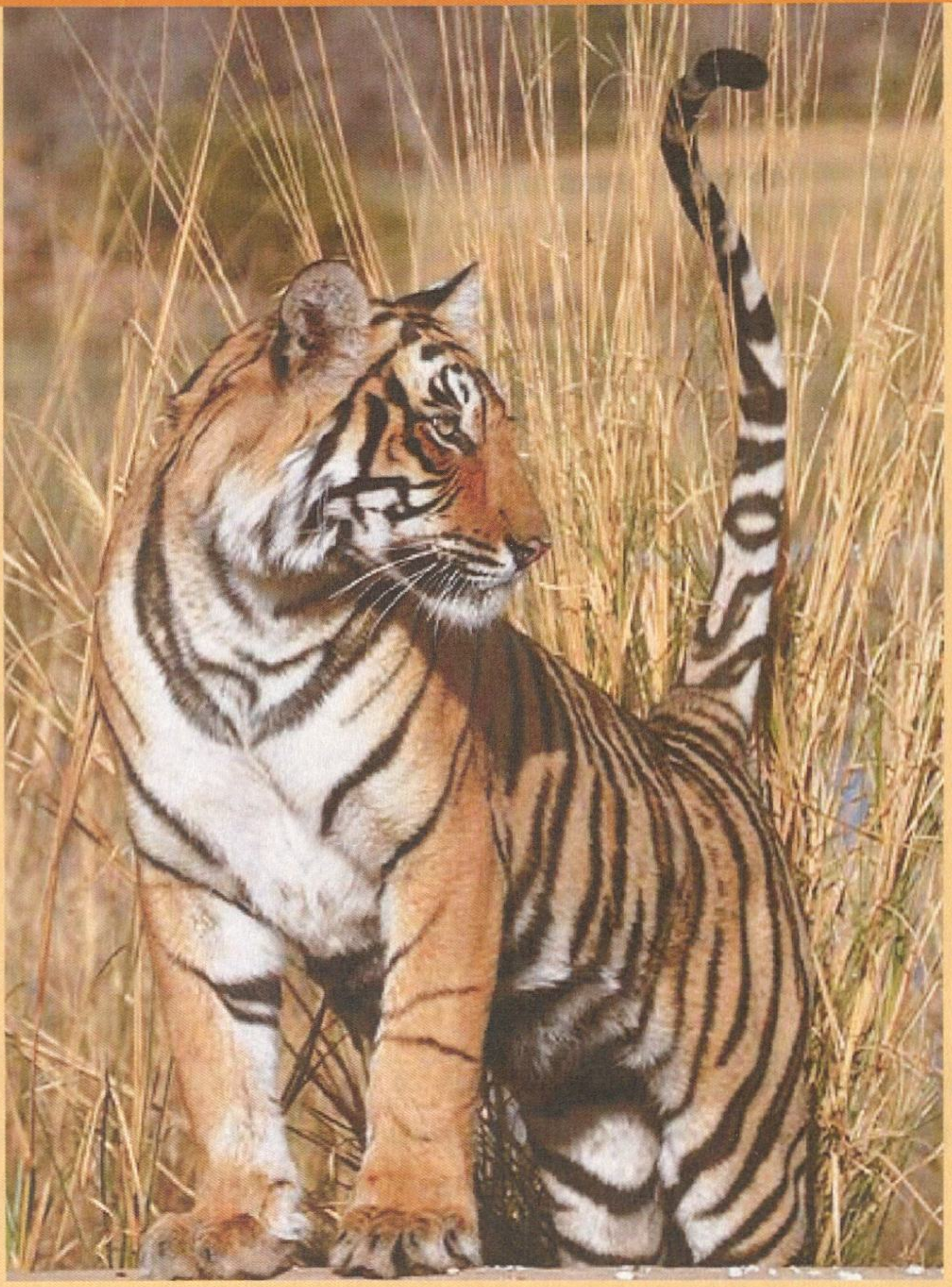
Ecology of Tigers in Pench Tiger Reserve, Madhya Pradesh and Maharashtra

FINAL REPORT



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Ecology of Tigers in Pench Tiger Reserve, Madhya Pradesh and Maharasta

Principal Investigators:

1. Dr. K.Sankar
Senior Reader
Wildlife Institute of India
Dehra Dun.

2. Mr. Qamar Qureshi
Reader
Wildlife Institute of India
Dehradun

3. Dr. Y. V. Jhala
Senior Reader
Wildlife Institute of India
Dehradun

4. Dr. Rajesh Gopal,
Director, Project Tiger, MoEF,
New Delhi

Researchers:

1. Aniruddha Majumder
Senior Research Fellow

2. Santanu Basu
Junior Research Fellow

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iii. Name of the investigator(s). Dr. K Sankar, Wildlife Institute of India.

Mr. Qamar Qureshi , Wildlife Institute of India

Dr. Y.V Jhala, Wildlife Institute of India)

Dr. Rajesh Gopal, National Tiger Conservation Authority, Government of India.

iv. Name of the research fellow(s): Mr. Aniruddha Majumder

Mr. Santanu Basu

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2) Ayan Sadhu. Diversity, Distribution, and Abundance of mesocarnivores in Pench Tiger Reserve, Madhya Pradesh India, M.Sc., Dissertation submitted to Forest Research Institute University, Dehradun, Uttarakhand.

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1) Aniruddha Majumder. Prey Selection, Food habits and Population Structure of Sympatric carnivores; tiger, leopard and dhole in Pench Tiger Reserve, Madhya Pradesh, India, Saurastra University, Rajkot, Gujrat, India (Awarded on July 2012).

2) Santanu Basu. Evaluation of Impact of Landscape Changes on Large Mammal Habitats in Pench Tiger Reserve, Madhya Pradesh, India, Saurastra University, Rajkot, Gujrat, India (Submitted).

xi. A copy of all publications and related materials should be appended in the final report.

1. Majumder, A., Basu, S., Sankar, K. and Qureshi, Q. (2009) Some observations on vultures in Pench Tiger Reserve, Madhya Pradesh. Journal of Threatened Taxa 1: 627– 628.

2. Majumder, A., Parida, A., Sankar, K. and Qureshi, Q. (2010) Utilization of food plant species and abundance of hanuman langurs (*Semnopithecus entellus*) in Pench Tiger Reserve, Madhya Pradesh, India TAPROBANICA, 02 (02): 105-108.
3. Majumder, A., Sankar, K., Qureshi, Q. and Basu, S. (2011). Food habits and temporal activity patterns of the Golden Jackal *Canis aureus* and the Jungle Cat *Felis chaus* in Pench Tiger Reserve, Madhya Pradesh, India. Journal of Threatened Taxa 3 (11): 2221–2225
4. Majumder, A., Sankar, K., and Sykes, B.R. (2011). Records of the Spot-bellied Eagle Owl *Bubo nipalensis* in Madhya Pradesh, India. BirdingASIA 15: 76.
5. Majumder, A., Qureshi, Q., Sankar, K., Basu, S. and Jhala, Y.V. (2011). Occupancy and abundance of dhole (*Cuon alpinus*) in Pench Landscape of Central India. Journal of the Bombay Natural History Society, 108(3): 158-162.
6. Majumder, A., Basu, S., Sankar, K., Qureshi, Q., Jhala, Y.V., and Gopal, R. (2012). Prey Selection, Food Habits and Temporal Activity Patterns of Sympatric Carnivores in Pench Tiger Reserve, Madhya Pradesh, Central India. Journal of Scientific Transactions in Environment and Technovation, 5(3):110-120.
7. Majumder, A, Basu, S., Sankar, K., Qureshi, Q., Jhala, Y.V., Nigam, P., Gopal, R. (2012). Home ranges of the radio-collared Bengal tigers (*Panthera tigris tigris* L.) in Pench Tiger Reserve, Madhya Pradesh, Central India, Wildlife Biology in Practices, 8(1): 36-49.
8. Majumder, A., Sankar, K., Qureshi, Q. (2013). Co-existence patterns of large sympatric carnivores as influenced by their habitat use in a tropical deciduous forest of Central India. Journal of Biological Research-Thessaloniki 19: 89 – 98.
9. Singh, R., Majumder, A, Qureshi, Q., Sankar, K, Goyal, S.P, Nigam, P. (2013). Inter-birth interval and Liter Size of Free Ranging Bengal tiger (*Panthera tigris tigris*) in India. European Journal of Wildlife Research, DOI 10.1007/s10344-013-0713-z

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List of Figures

List of Tables

List of Appendices

Executive Summary

Wildlife conservation planning *inter-alia* requires basic information on distribution and abundance of natural resources. Knowledge of presence or absence of wildlife species and their distribution across a landscape is critical for making sound wildlife management decisions. Carnivore and herbivore species play a pivotal role in maintenance of forest ecosystem equilibrium, as they help in shaping its structure, composition and also directly or indirectly affect other animals. However, efforts toward conservation and management of wildlife are often hampered due to non-availability of good quality data on species, habitats and sustainability of the habitats for different species. *In-situ* conservation of biodiversity requires multidisciplinary approaches sustained by a foundation of sound scientific and technological information. With this background, the present study aimed to map land use/land cover patterns and to assess spatial structure and configuration of landscape; structure and composition of vegetation types in landscape; and varies ecological aspects of tiger (*Panthera tigris*) in a Tropical Deciduous Forest of Central India from 2005 to 2013.

The study was carried out in Pench Tiger Reserve (PTR), Madhya Pradesh. The extent of the total area of PTR is 757.85 km² out of which Pench National Park (PNP) comprises 292.85 km² while Pench Mougli Sanctuary (PMS) covers 183 km² and surrounding reserved forest covers 229 Km², which are the parts of South Seoni forest division, South and East Chhindwara forest divisions. PNP and PMS forms the core of PTR while the reserved forest forms buffer. The Vegetation falls under Tropical dry deciduous and Tropical moist deciduous category.

Home ranges of three radio-collared Bengal tigers [one adult female (AF), one adult male (AM) and one sub-adult male (SAM)] were studied between March 2008 and December 2011. Using 100% Minimum Convex Polygon (MCP), the estimated home

ranges of AF (n= 750 locations), AM (n= 136 locations) and SAM (n= 739 locations) were 43 km^2, 55.1 km^2 and 52.2 km^2 respectively. Using 95% Fixed Kernel (FK), the corresponding figures were 32.1 km^2, 64.1 km^2 and 19.1 km^2. The core area of individual activity for each tiger, as determined by 65% FK, was 10.3 km^2 for AF, 20.3 km^2 for AM and 6.6 km^2 for SAM. The estimated overlap area between AM and AF using 95% FK was 19.2 km^2 (65%), whereas it was 15.4 km^2 (48%) between AF and SAM. The AF recruited three, four and five cubs in her 1^{st} (May 2008 and all died during post natal stage), 2^{nd} (October 2008) and 3^{rd} litter (October 2010) respectively. Minimum 44% of the original natal area was used by AF at the time of raising her 2^{nd} litter and 46% in her 3^{rd} litter. Though there was a gradual extension of the annual home range, as observed during the first two years (2008-2010), but the core activity area remained considerably the same for AF over the study period. The study revealed that a minimum of 25 to 30 km^2 undisturbed area was required for a breeding female in PTR where both the wild prey density (348.2/km^2) and biomass (12384.7 kg/ km^2) were found to be high with adequate ground cover for the successful raising of cubs up to the dispersal stage. Pench and its surrounding forested habitat need to be protected for the breeding and dispersing tiger population.

The available major habitat features of PTR were categorized into: 1) Land use and land cover, 2) Canopy cover and 3) Terrain or elevation types. The land use and land cover types of the intensive study area (410 km^2) were classified into six broader classes, based on unsupervised followed by supervised classification through ground validation: sub-mergence, riverine, miscellaneous, agriculture, barren land and *teak*-mixed forest using Satellite generated and digitized imagery of the area. Canopy types were divided into non forest (canopy cover <10%), open forest (between 10% and 40%), moderately dense forest (between 40% and 70%) and very dense forest (> 70%). Elevation types were sub-divided into two major categories: low (elevation between 350 m and 500 m) and high (elevation between 501m and 650 m). The Bonferroni confidence interval technique was used in conjunction with a chi-square goodness-of-fit test for both summer and winter between June 2006 and April 2011 to study habitat selection of tiger.

In winter, tiger utilized teak-mixed forest more than it's availability (++), utilized riverine and miscellaneous habitats in proportion to their availabilities (**); submergence, agriculture and barren lands were utilized less than their availabilities (--). In summer, tigers utilized riverine and submergence habitats more than their availabilities, utilized rocky or barren land and teak-mixed habitats in proportion to their availabilities and both agriculture and miscellaneous habitats were utilized less than their availabilities. In both winter and summer tiger utilized elevation between 501m and 650 m more than its availability. It was observed that, during winter, tiger used canopy cover between 70% and 100% in proportion to its availability, whereas canopy cover <10% (non-forest), 10% to 40% (open forest) and 40% to70% (moderately dense) were used less than their availabilities. In summer, tiger used canopy cover between 70% and 100% (very dense forest) more than its availability, whereas canopy cover < 10% (non-forest), 10% to 40% (open) and 40% to 70% (moderately dense) was used less than their availabilities. Protection of the habitat in Pench and surrounding areas is crucial for the survival of tigers in this landscape.

Prey species availability was estimated using line transect method in an intensive study area of 410 km² between January 2007 and June 2012. During this study forest beat was considered as sampling unit and line transects were laid on each beat (n=44) in the intensive study area. Forty four line transects which varied in length from 2 to 4 km and were walked during winter (total effort= 1016 km) and summer (total effort = 2852 km). Significant difference ($p<0.05$) was observed on visibilities of sighting distance of prey species between two seasons (summer and winter) and hence we estimated densities of major prey species such as chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Bosephalus tragocamelus*), gaur (*Bos gaurus*), wild pig (*Sus scrofa*) and common langur (*Semnopithecus entellus*) year wise separately (for winter 2007-

2010 and for summer 2007- 2012) and pooled or overall. Although barking deer (*Muntiacus muntjac*) and chousingha (*Tetraceros quadricornis*) were sighted on the line transects in both seasons (summer and winter) but their densities were not estimated because of low sample size. Prey species population was estimated using program Distance 6.0. Analysis was done following different detection functions to the observed data for estimation of densities. The best model was selected on the basis of lowest Akaike Information Criteria (AIC) values. Biomass of different prey species was computed by multiplying their mean densities (pooled for all years) with the body weight of respective species. Ten vehicle transect routes ranging from 2.7 to 13.6 km were monitored in each season (summer and winter) from 2007 to 2009. A total of 176.8 km was covered during winter and 214.5 km during summer to study the population structure and group size of five major wild ungulate species and common langur. Data on population structure and sex ratio of wild ungulates were pooled for two different seasons (winter and summer) for four years i.e. 2007, 2008, 2009 and 2010. Age and sex composition data of common langur was not collected due to difficulties in identifying different age/sex categories for this species.

Common langur was found to be the most abundant prey species both in winter and summer in the study area (73±7.6 SE/km² in winter and 10.7 ± 12.7 SE/km² in summer) followed by chital (50± 7.1 SE/km² in winter and 91.7±15.7 SE/km² in summer), sambar (6±0.5 SE/km² in winter and 9.5 ±0.7 SE/km² in summer), nilgai (2±0.5 SE/km² in winter and 2.8±0.7 SE/ km² in summer), wild pig (5.2±1.2 SE/km² in winter and 13.8±2.5 SE/km² in summer) and gaur (1.4±1 SE/km² winter and 3.3±0.9 SE/km² in summer). The estimated mean biomass for six potential prey species from line transect was 4894.4±1046.3 kg/km² in winter and 8885.5±1573.4 kg/km² in summer, where chital contributed maximum in both winter and summer followed by gaur in winter, sambar in summer, common langur, nilgai and wild pig in both summer and winter. Analysis of population structure data revealed that chital adult female was found to be most abundant (55.4% in winter and 57.7% in summer) followed by adult male (23.6% in winter and 17.2 % in summer), young (9.9 % in winter and 19.1% in summer), yearling female (6.7% in winter and 2.7% in summer) and yearling male (4.5% in winter and 3.2% in summer). Sambar adult female was found to be most abundant (49% in winter and 57.4% in summer) followed by adult male (21.3% in winter and 7.1% in summer), young (16.8% in winter and 23.5% in summer), yearling female (8.4% in winter and 5.6% in summer) and yearling male (4.5% in winter and 6.5% in summer). Nilgai adult female was found to be the most abundant (44.8% in winter and in summer 39.4%) followed by adult male (25.9% in winter and 30.9% in summer), young (24.1% in winter and 16% in summer), yearling male (3.4% in winter and 4.3% in summer) and yearling female (1.7% in winter and 9.6% in summer). Gaur adult female was found to be the most abundant (42.9% in winter and 30.4% summer) followed by young (25% in winter and 17.4% in summer), yearling male (16% in winter and 11.6% in summer) and yearling female (7.1% in winter and 23.2% in summer). In case of wild pig, adult female was found to be the most abundant (37.5% in winter and 44.4% summer) followed by adult male (31.3% in winter and 33.3% in summer) and young (31.3% in winter and 22.2% in summer).

The adult sex ratio (female: male) in case of chital during winter was 100:40 and adult female: fawn ratio was 100:20, whereas in summer these ratios were 100:30 and 100:30 respectively. In case of sambar the adult sex ratio was 100:40 and female: young (fawn) ratio was 100:30 in winter, whereas in summer these ratios were 100:10 and 100:30 respectively. In case of nilgai the adult sex ratio (adult female: adult male) was 100:60 in winter and 100:80 in summer, whereas adult female: young ratios were 100:50 in both winter and summer. In case of gaur adult sex ratio (adult female: adult male) was 100:20 in winter and 100:60 in summer whereas adult female: young ratio was 100:60 in both winter and summer. In case of wild pig, adult sex ratio (adult female: adult male) was 100:80 in both winter and summer, whereas adult female:young ratio was 100:80 in winter and 100:50 in summer. In case of chital, the estimated mean group size ± Standard Error or SE in winter was 4±0.3 and in summer was 9.8±0.25. In case of sambar, the estimated mean group size ± Standard Error or SE in winter was 2.2±1.3 and in summer it was 2.9±0.07. In case of nilgai, the estimated mean group size ± Standard Error or SE in winter was 2.1±1.4 and in summer it was 2.5±0.1. In case of wild pig, the estimated mean group size ± Standard Error or SE in winter was 5.7±2.2 and in summer it was 5.2 ±0.2. In case of gaur, the estimated mean group size in summer was 5.4±0.4, whereas the winter data of gaur was not assessed because of low sample size. In case of common langur, the estimated mean group size in winter was 6.7±0.5 and in summer it was 8.9±0.1.

Of the prey species found in tiger scats, chital constituted as major prey in terms of number (52.8% in winter and 62.7% in summer) followed by sambar (31.7% in winter and 18.6% in summer), common langur (5.7% in winter and 9.3% in summer), wild pig (6.2% in winter and 3.1% in summer), nilgai (0.4% in winter and 3.1% in summer), domestic cattle (0.2% in winter and 2.5% in summer), rodents (1.6% only in winter), gaur (0.6% in winter), hare (0.2% in winter), unknown birds (0.4%) and porcupine (0.6% in summer). In case of tiger scats, 96% contained single prey species and 4% contained two prey species in both winter and summer. Of the 292 tiger kills recorded, 127 were observed during winter and 165 kills during summer. Chital adult male contributed maximum in case of diet of tiger in both winter and summer (19.7% in winter and 33.3% in summer) followed by sambar adult female (tiger 14.2% in winter and 9.1% in summer), common langur (0.8% in winter and 1.2% in summer), peafowl (1.6% in winter), cattle (0.8%) and porcupine (0.6%) and gaur. In winter chital, sambar and gaur ($p<0.005$) were significantly consumed more than their availability by tiger, whereas common langur, wild pig and nilgai were less utilized in terms of individual density. In summer sambar, nilgai and chital were consumed more than their availability and wild pig and langur were less utilized. It was observed from kill study that during both summer and winter chital adult male were preferred by tiger as compared to their availability. The study revealed that tiger in PTR largely depended on wild ungulates rather than domestic livestock.

Health conditions of five potential prey species such as chital, sambar, nilgai, wild pig and gaur were evaluated during the study period based on bone marrow conditions. Of the 109 tiger kills, 42% was contributed by prey species with good health condition, 26.1% by medium health condition and 31.7% by poor health condition.

A study on population dynamics of tiger was carried out in the intensive study area between May 2006 and March 2013. The adult ($\geq$ 36 month) and sub-adult (18 to 36 month) tiger survival rate were studied using Camera Trap Mark Recapture (CTMR) technique whereas survival rate of tiger cubs ($\leq$ 12 month) was estimated following one radio-collared breeding tigress, CTMR and opportunistic sightings.

Overall tiger density ±SE/100 km² using Maximum Likelihood Spatial Explicit Capture Recapture method was 4.7 ±1.2 in 1st trapping year and 4.1±0.7 in last trapping year. The estimated survival rate of all tiger (n=66) was 0.66 (±0.04), whereas for all male tiger (n=22) it was 0.59 (±0.09), for all female tiger (n=44) it was 0.7 (±0.06), for adult male tiger (n=7) it was 0.83 (±0.07), for all breeding female tiger (n=14) 0.86 (±0.05) for sub-adult tiger (n=45) it was 0.57 (±0.29) and for cubs (n=52) it was 0.73 (±0.05). The estimated mean annual growth rate (±SE) for all tiger was 1.15 (± 0.11) followed by 1.23 ± 0.13 for all male, 1.17 ± 0.27 for all female, 1.1± 0.01 for adult male tiger and 0.98± 0.11 for all adult breeding female tiger population. The estimated mean recruitment (±SE) for all tiger population was 9.2±2.2 followed by 2.8±0.8 for all male tiger, 6.4±2.3 for all female tiger, 1.04±0.4 for adult male tiger and 1.2±0.2 for breeding female population. The sex ratio (Male : Female) was found to be female biased and more than 80% of overall recruitment was contributed by female tiger.

Other than high densities of principal prey species and availability of undisturbed breeding habitat, the strategy for breeding tigress adopted to protect her cubs from infanticide is found to be the important reason for high survival rate of cubs. Though incase of overall tiger population there was 2 % annual growth rate, it is the dispersal and recruitment of sub-adults in the population, contributed gradual fluctuation in annual growth rate, as resident adult tiger population remained almost same over the study period. The low survival rate of sub-adults in the study area may be also because of dispersing individuals. Long term monitoring of tiger population in Pench and its adjacent forest patches and habitat management of corridors connecting other meta-population structures of tiger in the Central Indian landscape is essential for long term survival of tiger.

In recent years, a critical approach to environmental sustainability has resulted in greater importance being given to scientific research into the causes and effects of land use and land cover changes. Direct causes of deforestation can be divided into three main groups: a) infrastructure extension, b) agricultural expansion and c) wood extraction. This study highlighted some key impact of landscape change due to different anthropogenic activities like dam construction, cattle grazing, wood extraction and by different demographic, economic and policy attributes. Landsat Satellite imageries of 1977, 1989, 1999 and 2009 were used for Land use/ land cover change (LULCC) analysis. The trajectory images from the four dates with 5 land cover classes for each date resulted into 1) Stable miscellaneous forest, 2) Stable teak-associated forest, 3) Stable open forest, 4) Stable water, 5) Stable Non-forest, 6) Teak to Miscellaneous, 7) Deforestation, 8) Reforestation, 9) Degradation, 10) Up-gradation. A series of non-redundant landscape metrics was applied to the present and historical classified land use/cover maps.

The overall trend corresponded to an absolute decrease in forest cover of about 11.1% of the forest surface present in 1977. This was due to the creation of hydroelectric dam in 1987 and deforestation. The forest surface showed a pronounced fragmentation in 1977 with a high number of patches and this fragmentation dramatically decreased in 2009, with a little exception of Miscellaneous forest which showed some increase in number of patches in last 10 years.

Creation of Totladoh hydroelectric dam in 1987 had caused a loss of 76.7 km^2 area of the landscape. Between the year 1999 and 2009, the observed deforestation and degradation rates were very low in the core area which might be because of the protection measures taken by the forest department. In the Middle area (within PA and within collection/extraction distance), though the deforestation rates went down in the last 10 years, an increase in degradation was observed in this category. In the Outside area, both deforestation and degradation were almost same over the years. The present study provided a direct comparison of the effects of strict protection on forest and land-cover changes and thus contributes to the forest management literature. The study area exemplifies a typical case of contrasting management regimes in an area protected for wildlife. This condition enabled us to examine the role of different protective management approaches in preserving forest cover. Due to very little forest management intervention for more than 30 years, one or two species that dominated forest stands (like Teak-associated forests) which were converted into mixed forest as shown by the increase in patch area but decrease in number of patches.

Uncontrolled extraction of forest resources in terms of fuel wood, fodder, NTFPs, agricultural expansions and utilization of forested lands for grazing left very less forested patch outside PTR where forests were heavily managed for harvesting of timber. While two date change trajectories showed decadal changes in forest covers as a result of changing forest policies, the overall change trajectory drew an overall change scenario experienced in the study area in the last 30 years. There were 50 tourism resorts that had come up after 1999 around the park. In the villages with these tourist resorts, degradation of forest had gone down between 1989 and 1999 but again increased after 1999. The opposite trend was found in deforestation. Most of these resorts maintained the theme to be a wildlife resort, so these resorts actually promoted to keep a forest cover to give the tourists wilderness feelings.

This study contributed to the land/forest cover change and socio-economic, biophysical and proximity factors affecting it. It was the first large scale forest cover change study in India for the entire Tiger Reserve and surrounding areas that investigated forest cover change and spatial variation within determinants by applying GWR. This study showed the importance of studying local spatial variation of forest cover in protected area gathering information at village level with a set of demographic, biophysical and proximity determinants. Finally, this study demonstrated the importance of GWR as a tool for exploring local spatial variation of forest cover change and reducing spatial autocorrelation. This instrument could be used for studies with focus on natural resources in human-dominated landscapes managed for wildlife to reveal information at local level, which could be otherwise neglected. It is suggested that a GWR study should investigate whether local spatial variation was due to the influence of determinants to a response variable, a step which was not often in use though we found it valuable and meaningful. GRW analysis explored the behavior of variables at a local level and revealed significant spatial variability among some of them. This represented a clear enhancement of the understanding offered by a global analysis, rather than obtaining an average coefficient for the entire area, an estimated coefficient for each point analysed was obtained. Furthermore, this method revealed certain aspects of the inter-relationships which did not emerge with traditional global specifications. This implied that the parameter estimates for this regression varied according to geographical location.

Therefore, the application of this method made it possible to study the spatial stability of the global model coefficients. It was found that the coefficients of many variables were spatially non-stationary and that the models produced using GWR describe the data significantly better than the global model (OLS). For both deforestation and degradation models in Geographically Weighted Regression, variation in number of households, variations in ST polulation, variation in literate population, variation in total irrigated land, distance from road and protectedness were selected.

The land use land cover prediction map by cellular automata markov model of 2019 had resulted in five classes i.e. Miscellaneous forest, Teak Associated forest, Open forest, Water and Agri-habitation. Miscellaneous forest had turned out to be the largest class.

Competition between human activities and wildlife is becoming more intense due to habitat destruction, leading to the decline of wildlife species. Effective wildlife conservation needs to reduce the friction between human and wildlife activities by identifying areas suitable for wildlife, and by reducing human intervention in these areas.

For this purpose, mapping of suitable habitat is very important for wildlife conservation and ecosystem management. The actual geographical distribution of species as Habitat Suitability (HS) map is the result of the analysis of species–environment relationships. Species distribution lies well within the optimal range of environmental factors. It is, therefore, useful for ecological modelers to design a methodological algorithm to compute HS by incorporating most of the environmental factors with presence–absence data or only with presence data to develop a more precise estimate. In the present study, chital, sambar, wild pig among the wild ungulate species and among large carnivores, tiger, leopard and wild dog were chosen for large mammal habitat suitability (HS) modeling.

In the present study, high positive marginality of chital, sambar and wild pig were found with tiger, leopard and wild dog. In spite of similar densities, carnivores like tiger, leopard and wild dog may co-exist since the ecological factors, such as adequate availability of appropriate-sized prey, dense cover and high tree densities may be the primary factors in structuring the predator communities of tropical deciduous forests. In the present study, the observed low marginalities among the carnivores showed less competition/affinity. The presence of all the study species (prey/predator) were negatively correlated with major human disturbance indicators such as lopping, cattle dung and wood cutting. This suggested that all these species avoided disturbed areas and preferred areas far from roads and villages. The extent of human presence could be attributed by the presence of 99 villages within 5 Km buffer of PTR. These villages exert immense pressure on forests as people here are mostly dependent on forest for fuel wood collection and grazing of livestock. Due to adequate protection and support from field staff, the overall specialisation of the human disturbance models of the carnivore species turned out to be the highest, which can be attributed as the conditions of human disturbances in PTR for carnivores are better than species interaction and resource geographical conditions. As predator distributions are guided by prey distributions, similarly presence of chital, sambar and wild pig distribution are influenced by forest canopies as observed in the present study. Miscellaneous and teak associated forests dominate in PTR. These forest types had shown greater association with all the study species. Water being one of the essential life support factor, contributed equally in all the HS models of the study species.

Though future predictions of HS are modeled only with few habitat classes, still they are powerful enough to enlighten future scenarios. In the given circumstance these predictions are over estimated as same species presence data sets of present day was used for the future scenarios. These results left enough space for validation or contradiction through many similar studies in future. All the study species showed decrease in suitable habitat.

The HS models provide a tool for the conservation and management planning of major carnivore and wild ungulate species in and around PTR. These models predicted the distribution and the extent of favorable species-specific habitats in the study area. This study provided not only factors governing species presence in PTR but also gave a clear idea of areas which needed urgent management interventions. Utmost care should be taken before any management intervention is planned in highly or moderately suitable areas as few of them may alter habitat quality for the study species. This study also provided good insight for future landscape changes which will help the managers to set priority areas for habitat improvement or restrict areas to deteriorate any further.

One hundred and fifty two km^2 is found highly suitable for tiger whereas, 254 km^2, 328 km^2 and 354 km^2 were found moderately suitable, low suitable and unsuitable respectively for tiger in Pench Tiger Reserve and its 5 km buffer. Most of the low suitable and unsuitable tiger habitats were found outside the Pench protected area (Pench National Park and Pench Wildlife Sanctaury) i.e. the habitat of buffer. As tiger is large ranging animal and they require large space to grow and dispersal, it is important to have suitable habitat for tiger in the buffer areas. So converting habitat from unsuitable to highly suitable for tiger is essential for their long term sustainance and growth in this landscape.

Overall, the study clearly suggested that effective wildlife conservation is necessary for the management of adjacent forest patches of the PTR for the long term survival of tiger in Pench landscape. PTR is connected with Kanha Tiger Reserve in north east and Pench Tiger Reserve, Maharastra in south and hence long-term monitoring of tiger using comparable scientific method is essential in these corridors.

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Contents

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Chapter 1
GENERAL INTRODUCTION

1. Introduction

Tiger *Panthera tigris* L. distribution has been reduced drastically over the last centaury, including the extinction of three of its subspecies (Bali tiger *P.l.balica*: Caspian tiger *P.t. virgata* and Javan tiger *P.t. sondaica*) and massive reduction in numbers of the rest (Sunquist *et al.* 1999). Though tiger has always attracted considerable attention, only a few scientific and long term research has been conducted on the ecology of tiger in India (Schaller 1967, Karanth 1993 and Chundawat *et al.* 1999). The paucity of information on the ecology of tiger has been highlighted in the Delhi declaration during the International Symposium on Tiger in 1993. Since late Sixties, when tiger's poor status in the wild was recognized, several conservation efforts were launched and a network of Protected Area (PA) exclusively for tiger was identified under the Project Tiger. Yet its status still remains highly threatened in India. The increasing human population, changing land use practices, soaring demands from our urban population and more recently fast expanding economic activity have started straining the delicate balance at which tiger survive. Tiger populations, in most of the protected areas in India face several major problems (Karanth 1993, Johnsingh 1983, Seidensticker 1976, Sunquist 1981, Karanth and Sunquist 1992 and Karanth and Stith, 1999). Inadequate size of the protected areas, tiger being a large territorial animal require large spaces and in small and isolated protected areas they frequently venture out and come in direct conflict and experience high mortality. Fragmentation and loss of habitat and its quality usually result in loss of prey availability. Inadequate prey base affect tiger's reproductive success and its survival. More recently poaching for commercial use is a serious threat to tiger population.

Thus increasing knowledge of their ranging pattern, dispersal, habitat use, food habits, prey selection and survivorship in both unfragmented and disturbed habitats will enable us to recognize the plasticity in the tiger's ability to use the available resources in various human-modified ecological systems.

Pench Tiger Reserve (PTR), which includes Pench National Park (PNP) and Pench Wildlife Sanctuary (PWS), along with Kanha Tiger Reserve constitutes one of the 11 level-I `Tiger Conservation Units' (TCU) in India classified by Wickramanayake *et al.*, (1998), where tiger has the highest possibility of survival. Pench is predominantly a dry deciduous system and a fewer studies on tiger ecology have been conducted in these habitats compared to those in tropical and subtropical moist deciduous forests and alluvial tall grasslands (Chundawat *et al.* 1999).

1.1 Taxonomy

Evidence for the evolution of the tiger comes from the fossil remains, as well as from the modern molecular phylogenies. A total of eight tiger subspecies are commonly recognised: Bengal tiger (*Panthera tigris tigris*), Sumatran tiger (*P. t. sumatrae*), Amur tiger (*P. t. altaica*), Indo-China tiger (*P. t. corbetti*), South China tiger (*P. t. amoyensis*), Caspian tiger (*P. t. virgata*), Javan tiger (*P. t. sondaica*) and Bali tiger (*P. t. balica*) (Luo *et al.*2004). Three of these, the Caspian, Javan and Bali tiger, went extinct in the last fifty years. The last Bali tiger was killed in 1937, the Caspian tiger became extinct in the 1950s and the last wild Javan tiger was seen in 1972. The wild South China tiger has not been directly observed since the 1970s and is now believed to be extinct in the wild too (Sunquist *et al.*1999).

1.2. Distribution

Tiger (Fig. 1.1) once ranged widely across Asia, from Turkey in the west to the eastern coast of Russia (Nowell and Jackson 1996). Over the past 100 years, tiger have disappeared from southwest and central Asia, from two Indonesian islands (Java and Bali) and from large areas of Southeast and Eastern Asia. Tigers have lost 93% of their historic range (Sanderson *et al.*2006) and are currently found in thirteen Asian range states: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Mayanmar, Nepal, Russia, Thailand and Vietnam. They may still persist in North Korea, although there has been no recent confirmed evidence. Currently tiger occur in the forested areas of 17 States in India (Qureshi *et al.*2006). The overall estimated occupancy of tiger in India was 81,881 for the year 2010 (Jhala *et al.*2010).

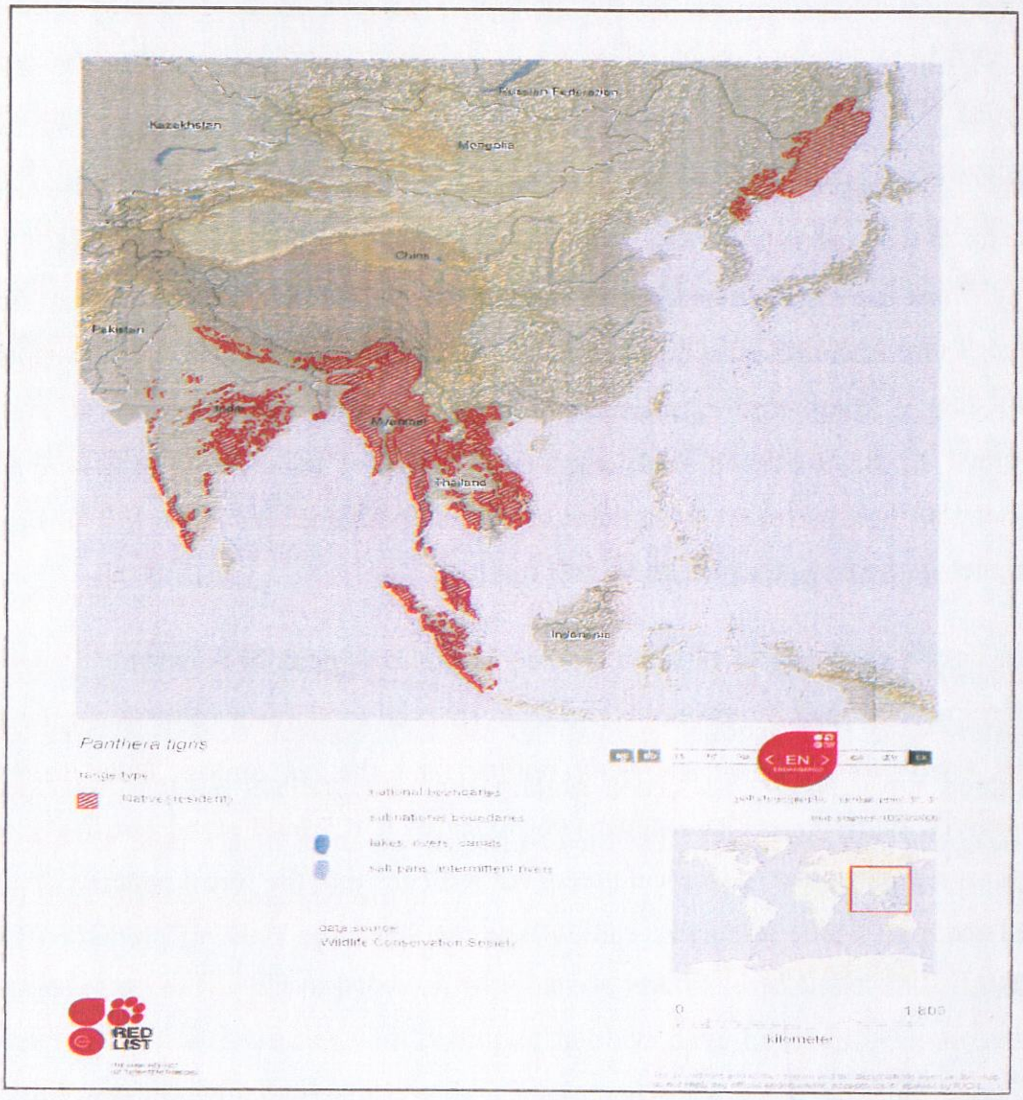

Fig.1.1. Global distribution of tiger (Source: IUCN Red List)

1.3 General morphology

Tiger is the largest of all living cats, an average Bengal tiger is about 3 meters from the tip of the nose to the end of the tail. Adult males weigh 200–260 kg (440–570 lb). Adult females are slightly smaller and lighter, weighing 100–160 kg (220–350 lb). Tiger from Sumatra and other Indonesian islands are smaller, darker and with shorter hair than tiger from more northern areas. Adult males in tropical areas are on an average 2.2 to 2.5 meters in total length (nose to tip of tail), which is about a half meter shorter than males from northern areas, and weigh only 100 to 140 kg. Adult females in tropical areas weigh 75 to 110 kg.

The tiger's coat pattern of black stripes against a dark gold background looks very conspicuous in a cage. In the wild, however, even in semi-open habitats, the striped coat seems to break up the body outline, and the cat almost fades from view. Similarly, its dark, golden orange coat looks as if it would stand out like a beacon against a background of tropical green, but it blends into the forest patterns of sunlight and shadow, which is perfect camouflage for this large stalking predator (Sunquist 2010).

1.4. Threats

The first threat to the survival of tiger came with the arrival of the British who brought in matchlocks and rifles as well as health care enabling people to conquer diseases. The resulting rapid increase in human population led to the clearing of vast tracts of forests. However the British also took several measures to protect forests, such as enactment of Forest Act of 1878 which highlighted the urgent need for saving forests and wildlife. Skin and bone of large cats have been used in traditional Chinese medicine where bones are crushed and used in anti-inflammatory drugs for treating rheumatism and arthritis. Hunting for fur is the biggest cause of decline of tiger. Habitat loss and poaching are important threats to the species survival (Kitchner 1999). One of the current tiger crises in India, the case in Sariska Tiger Reserve and Panna Tiger Reserve, where tiger have been wiped out due to poaching (Narain *et al.*2005, WII technical report 2009). Most of the tiger's range is being fragmented due management by cattle lifting and attacking humans (Corbett 1944, Rabinowitz and Nuttingham 1986, McDougal 1977, Seidensticker and Lumpkin 1996) due to fragmentation and over-hunting pressure on prey. The landscape has already lost a large part of its forest cover, and the remaining forests are threatened with ever increasing anthropogenic pressure (Rodgers and Panwar 1988, Qureshi *et al.*2006). Although tiger existed in large numbers during the last century, they are now being threatened due to habitat fragmentation, poaching for wildlife trade and decreasing prey populations (Karanth and Sunquist 1995, Jhala *et al.*2008). Tiger also perished from human persecution such as deliberate and accidental forest fire, trapping or snaring, poisoning and shooting (McDougal 1977, Karanth 1991). Only 7% of the original tiger habitat remains and conflict with humans poses a significant threat, which if unchecked, could reduce tiger populations beyond recovery (Karanth and Stith 1999, Sunquist *et al.*1999, Wang 2008).

1.5. Conservation status

Tiger have been the focus of substantial conservation effort and investment. Most of the range countries have developed or are developing national tiger conservation action plans. A unique international conservation body, the Global Tiger Forum, brings together tiger range state governments with other governments and NGO members (http://www.globaltiger.org/).

Tiger are included in CITES Appendix I, with ban on international trade, and all tiger range states as well as countries with consumer markets have banned domestic trade as well although implementation has been uneven, and some legal loopholes remain (Nowell 2007). The tiger is now listed as endangered on the International Union for Conservation of Nature (IUCN) Red List (2007). It is also included in Scheduled-I of the Wildlife Protection Act (1972), India.

1.6 *Justification of the study*

A detailed long-term study on ranging pattern, habitat use, prey selection, food habits, population dynamics and habitat suitability of tiger together has not been documented earlier in the central Indian landscape. Base line information on tiger and its prey species was collected in Pench National Park by Biswas and Sankar (2002). Intensive conservation efforts are required in these areas to ensure the long-term survival of tiger population. Pench Tiger Reserve, Madhya Pradesh, is one of the important habitats in Central India to study the tiger ecology and its management in the dry deciduous ecosystem. The adjoining forest tract in north and north east boundary of Pench provides crucial corridor linkage to Satpura and thus it is an important link between Satpura and Maikal populations of tiger. Management of tiger population requires information on the demography and on its ecology, which would require intensive monitoring. Radio-telemetry will help in gathering information and improve understanding about the reproductive success, dispersal pattern, habitat utilization, home ranges, movement and food habits of tigers and also on the extent and type of direct conflict (Sunquist 1981). Such information will be useful in targeting special management programmes for the critical tiger habitat.

1.7. *Objectives*

1 To study the ranging, movement and dispersal patterns of tigers.

2 To study the habitat use of tigers.

3 To study the food habits of tigers.

4 To assess the population of prey species of tigers.

5 To study population dynamics of tigers.

6 To prepare a habitat suitability map for tiger and its prey.

7 To suggest recommendations for the effective management of tiger population in Pench Tiger Reserve and adjoining areas.

1.8 *Organization of report*

The report is structured into ten chapters, each chapter consisting of an introduction of the topic, elaboration of methods and analysis used, results arrived at and discussion of the results and comparisons with earlier studies. Chapter 1 deals with the overall introduction of study species tiger, scope of the study and objectives of the study. Chapter 2 describes the study area, Pench Tiger Reserve, Madhya Pradehs. Chapter 3 deals with home range of tiger, Chapter 4 deals with habitat use by tiger, Chapter 5, deals with the prey species of tiger, their abundance and population structure. Chapter 6 describes prey selection and food habits of tiger. Chapter 7 covers population dynamics of tiger carnivores using different methods in the study area. Chapter 8 deals with the landscape changes and anthropogenic attributes and Chapter 9 deals with habitat suitability modeling of tiger, its co predator and their prey in the study area. Chapter 10 deals with overall conservation implications of this study.

Chapter 2

STUDY AREA

2.1 General

This study has been carried out in Pench Tiger Reserve (PTR), Madhya Pradesh which comprises of the Pench National Park (PNP), Pench Wildlife Sanctuary (PWS) and surrounding territorial forest. PTR is lying between 78° 55' E to 79° 35' E and 21° 40' N to 21° 57' N in the south-western region of Madhya Pradesh located on the Madhya Pradesh- Maharashtra border (Fig 2.1) and it comes under the biogeographic province 6A Deccan Peninsula- Central highlands (Fig 2.2) (Rodgers and Panwar 1988). It has a total area of 757.85 Km^2, which includes PNP (245.85 Km^2), PWS (183 Km^2) and surrounding reserved forest (229 Km^2), which are the parts of South Seoni forest division, South and East Chhindwara forest divisions. Pench river divides PTR into two blocks in east Seoni district and west Chhindwara district. It has 12 circles (Fig. 2.3) and 46 beats (Fig. 2.4) in total as its administrative layout. The State Government declared Pench Game Sanctuary (449.39 km^2) in 1977. In March 1983, the Government of Madhya Pradesh notified its intention to constitute an area of 292.85 Km^2 as Pench National Park, to be carved out of the pre-existing Pench Sanctuary area. The present Pench Tiger Reserve was included into the stream of the Tiger Reserves in 1992 as the 19th Tiger Reserve of India. The Pench River, from which the reserve derives its name, is the main source of water for PTR. On the southern end of Pench River a dam was constructed in 1987 to generate electricity and for irrigation purpose, resulting 54 Km^2 of submergence area in Madhya Pradesh side (Fig. 2.2).

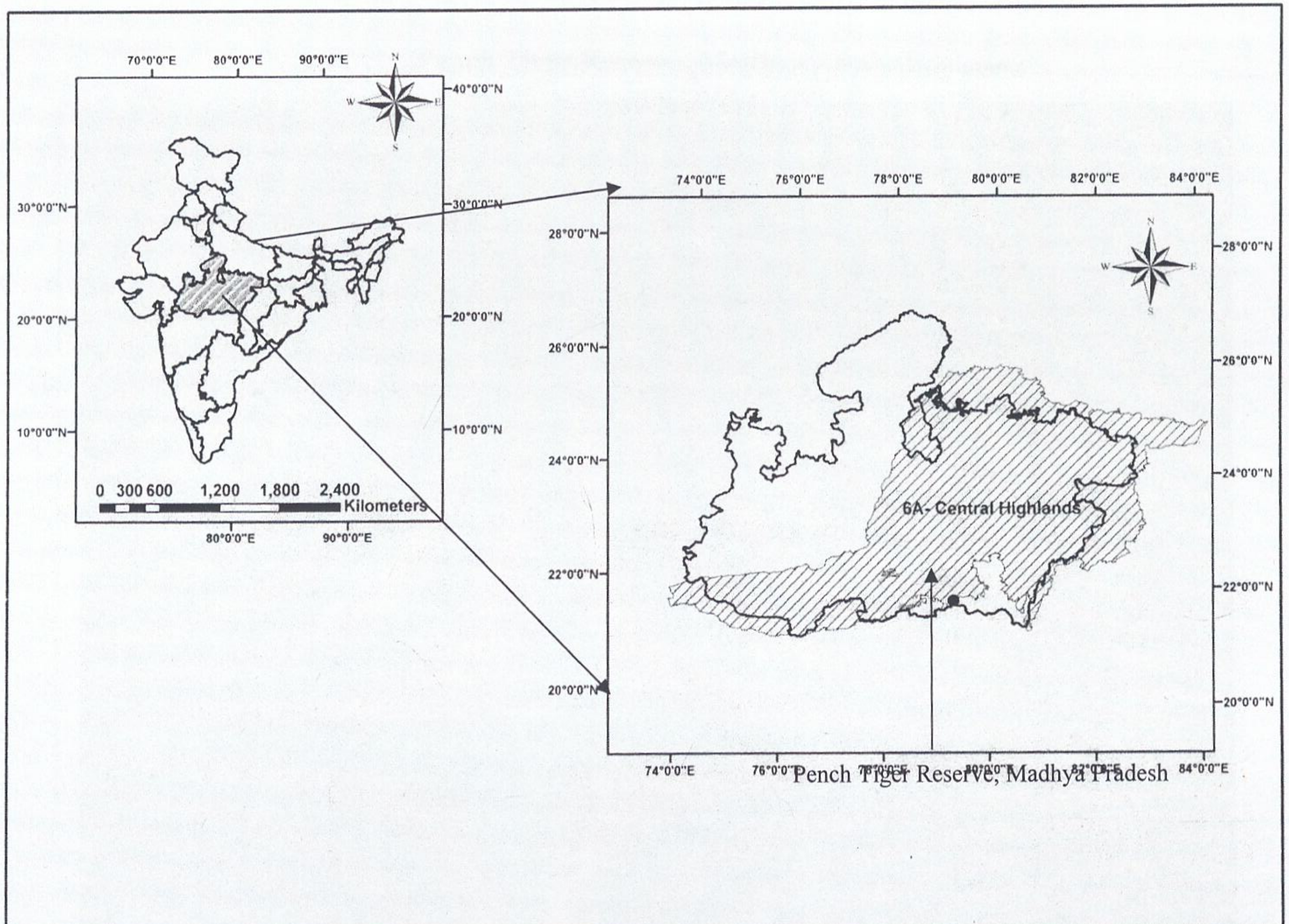

Fig 2.1 Location of Pench Tiger Reserve, Madhya Pradesh

Location of Pench Tiger Reserve, Madhya Pradesh

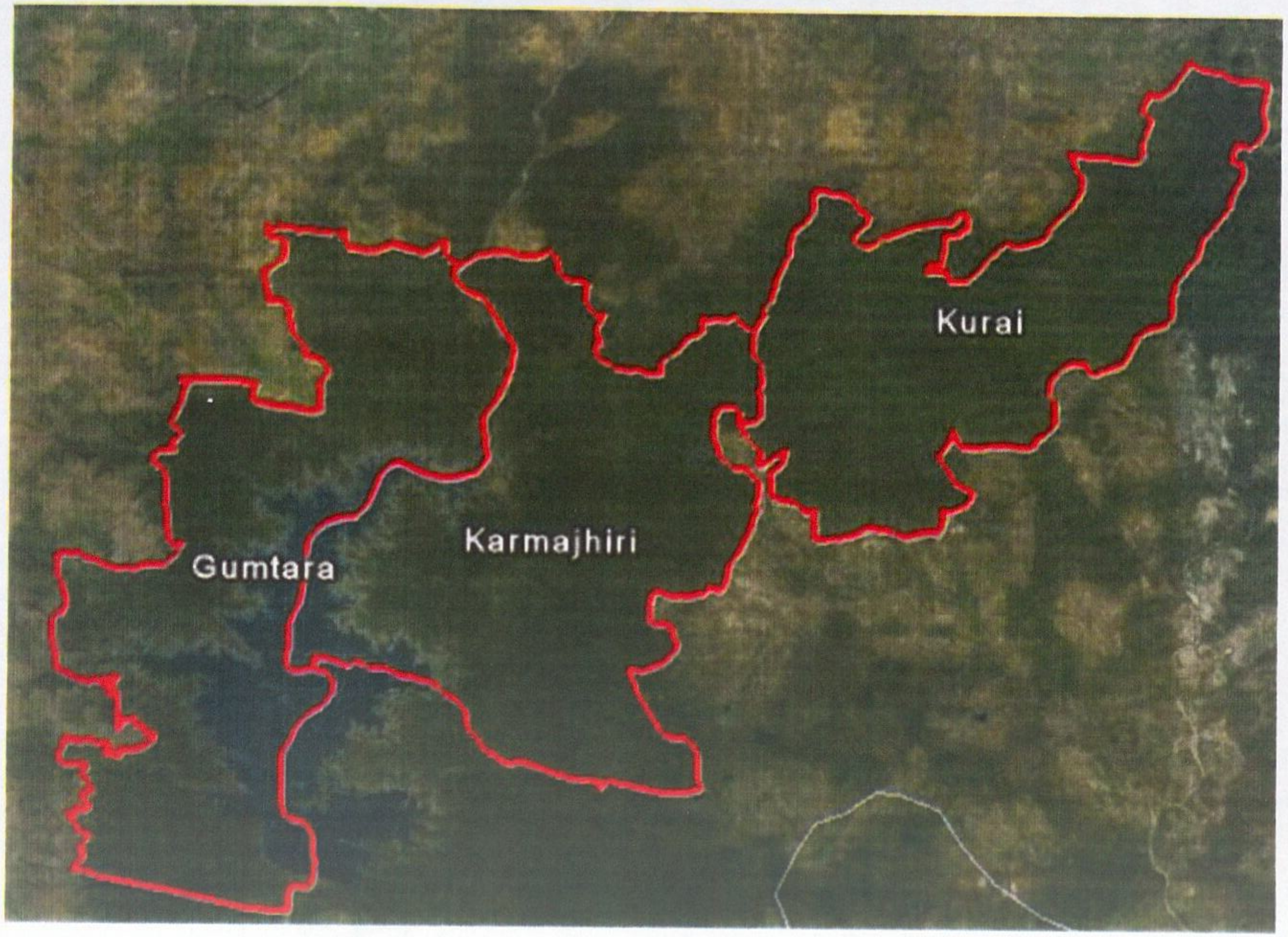

Fig 2.2 Forest ranges of Pench Tiger Reserve on Google earth image.

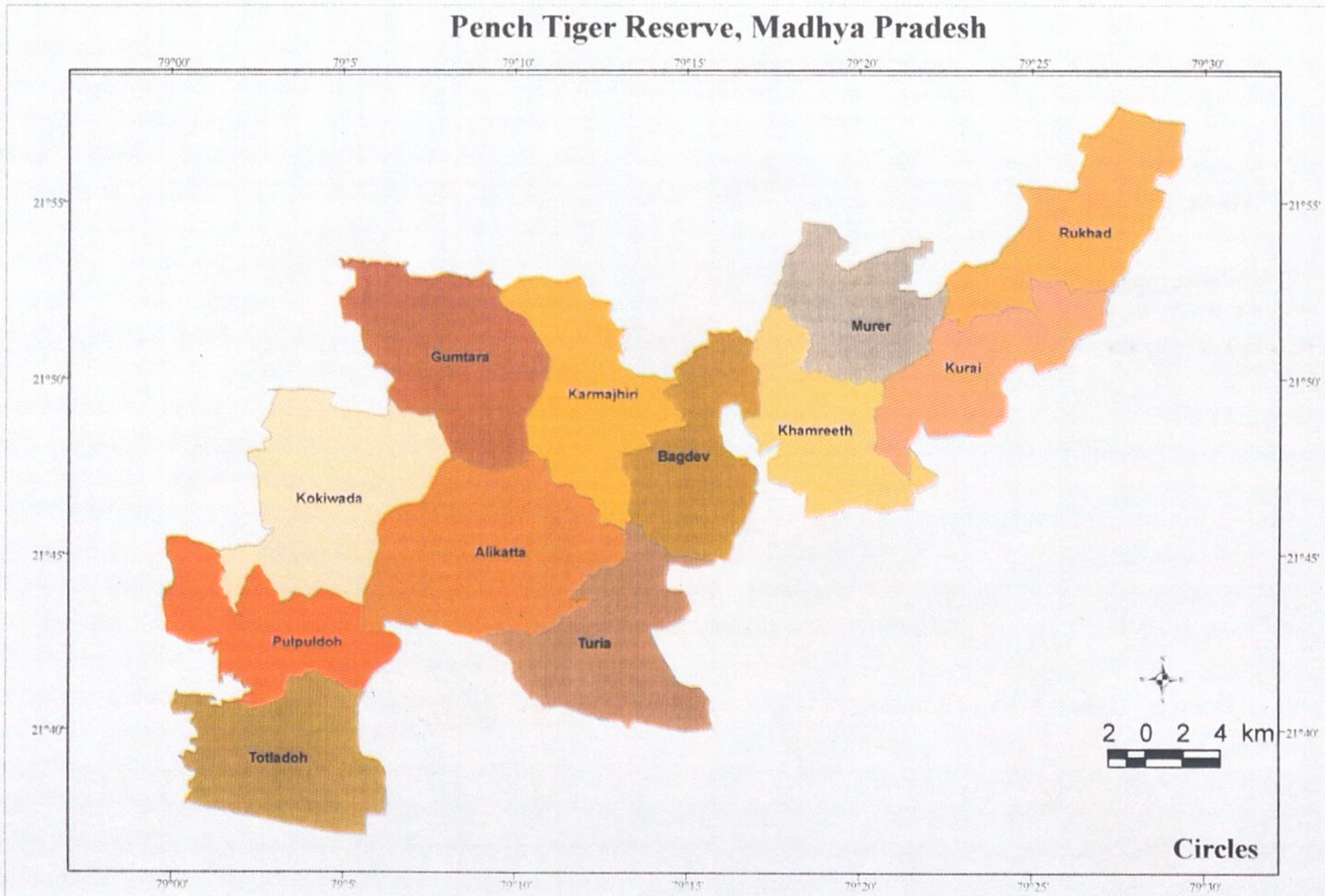

Fig 2.3 Forest circles of Pench Tiger Reserve

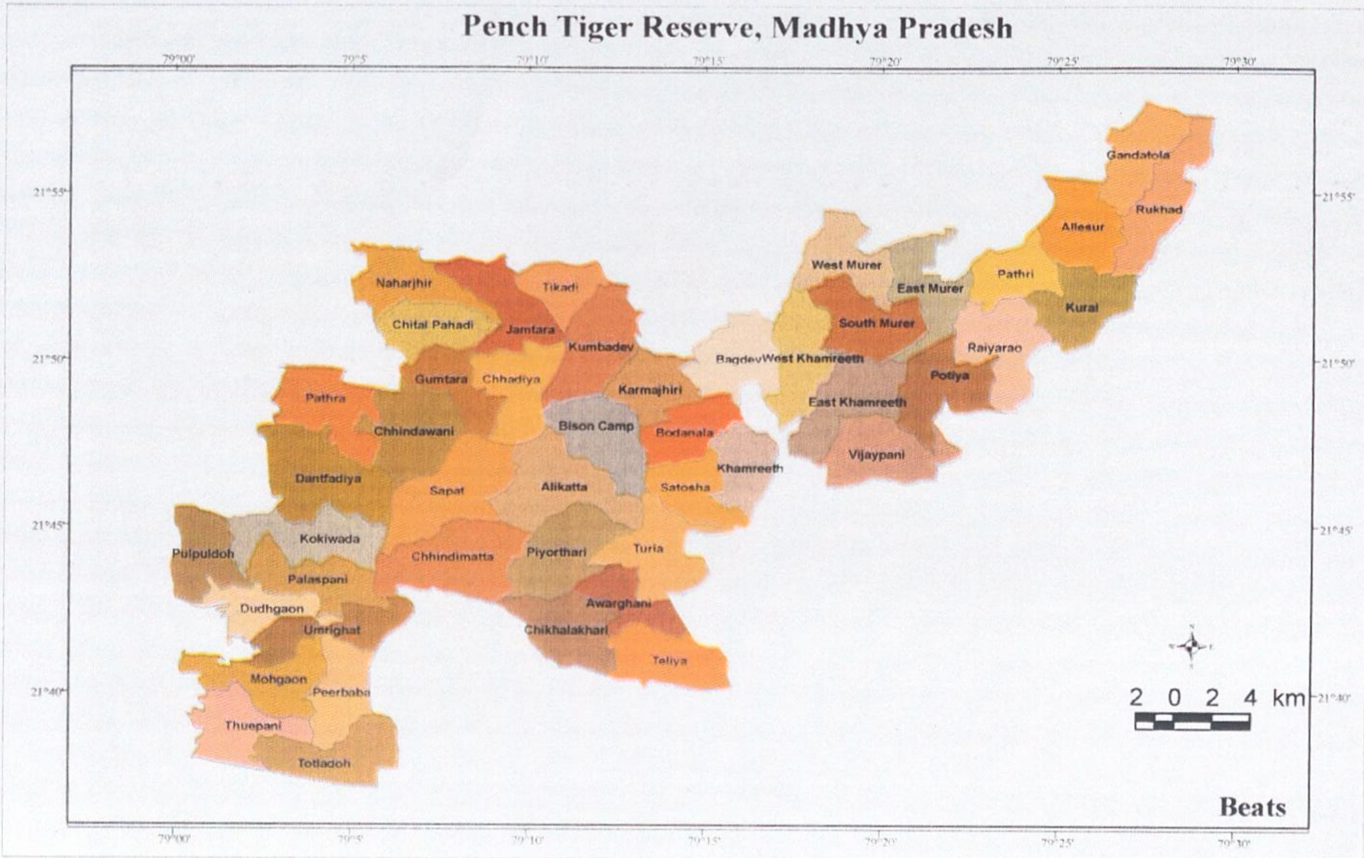

Fig 2.4 Forest beats of Pench Tiger Reserve

2.2 Background Information and Attribute

2.2.1 ***Terrain:*** Terrain is gently undulating and criss-crossed by seasonal streams and nullahs. The general slope of the area is from Southwest to Northeast. The mean altitude above mean sea level is 550 m. Among the hills or "matta" (hill in Local Gondi dialect) present in this area, Kalapahar is the highest with an altitude of 625 m. The hills have gradual to steep slopes with almost flat tops. Fig. 2.5 depicts details terrain outlay of PTR.

2.2.2 ***Soil:*** Sandy loam soil is the dominant soil type in all the gentle slopes and valleys of PTR resulted from the weathering of Granitic gneisses. Red soil is found in all elevated areas. Foothills with less tree cover and forest gap contains Kankar and saline soil. Alluvial soil is confined to the banks of the stream and Pench River. But according to the National Bureau of Soil Survey, Nagpur, there are 10 different soil types as shown in the table (Fig. 2.6) (Sankar et al. 2001).

Table. 2.1 Soil types and their percentage in Pench Tiger Reserve

Soil Type	Percentage
1. Loamy, mixed, isohyperthermic, Lithic Ustorthents, and Loamy, mixed, isohyperthermic, Lithic Ustropepts (6)	14.21
2. Fine, montmorillonitic, hyperthermic, Typic Haplusterts, and Loamy, mixed, hyperthermic, Typic Ustochrepts (48)	1
3. Loamy, mixed, hyperthermic, Typic Ustorthents and Clayey, mixed, hyperthermic, Lithic Ustothents (50)	29.82
4. Fine, montmorillonitic, hyperthermic, Vertic Ustochrepts and Clayey, mixed, hyperthermic, Typic Ustochrepts (79)	10.62
5. Fine, montmorillonitic, (Cal.), isohyperthermic, Typic Ustropepts and Fine, montmorillonitic, (Cal.), isohyperthermic, Typic Haplusterts (83)	0.00013
6. Loamy-skeletal, kaolinitic, isohyperthermic, Typic Ustropepts and Loamy, kaolinitic, isohyperthermic, Lithic Ustropepts (91)	17.4
7. Loamy, kaolinitic, isohyperthermic, Typic Ustropepts and Loamy kaolinitic, isohyperthermic, Lithic Ustropepts (107)	7.81
8. Fine, mixed, isohyperthermic, Typic Haplusterts and Fine, mixed,	0.61

isohyperthermic, Typic Ustropepts (108)	
9. Fine - loamy, kaolinitic, hyperthermic, Typic Ustochrepts and Fine, mixed, hyperthermic, Vertic Ustochrepts (113)	6.96
10. Loamy, kaolinitic, hyperthermic, Typic Ustortherns and Loamy, kaolinitic, hyperthermic, Typic Ustochrepts (137) :	10.13

2.2.3 ***Climate:*** There are four distinct seasons as follows:

Winter	-	November to February
Summer	-	March to June
Monsoon	-	July to August
Post-monsoon	-	September to October

- **Rainfall**: The monsoon generally begins in the middle of June and last up to September. The average annual rainfall ranged from 1300 mm to 1400 mm (Sankar et al.2001). This period accounts for about 90% of total annual rainfall. Pench experiences pre-monsoon showers in the month of April and May and Post-monsoon showers during month of September to November leaving the months December to March with no precipitation.
- **Temperature**: The temperature ranges between minimum of $9.1^{\circ}C$ (average) in winter to maximum of up to 40°-$45^{\circ}C$ in peak summer. Recorded minimum and maximum temperatures are $2.8^{0}C$ and $45^{0}C$ respectively (Sankar et al.. 2001).

2.2.4 Geology and geomorphology

Geo-morphologically PTR falls in the peninsular foreland of the peninsular division. The peninsula is Archean and Pre-Cambrian in formation (Mani 1974). This area is an extension of Satpura-Mahadeo-Maikal scraps. Nine different geological zones are found in PTR (Sankar et al.. 2001), viz. Gnisses (72.54%), Amphibolites (0.12%), Basalt (20.73%), Chorboali formation (1.82%), Lameta formation (1.7%), Lohangi formation (0.82%), Laterite (0.7%) and Manganese ore (0.17%) (Fig. 2.7 and Fig. 2.8)

2.2.5 Drainage

Most of the streams and nullahs in PTR are seasonal. The Pench river, lifeline for the area dries out in the month of April forms several puddles locally called "Kassa". In 1990, 54.51 Km^2 area was submerged due to the formation a reservoir which till date acts as the main water source of PTR. There are two small irrigation tanks namely Bodanala and Dudhgaon tank. As most of the areas are devoid of water in the peak summer months, the PTR management constructed several small ponds and artificial waterholes for wildlife.

2.3 Forest Types

Floristically, according to Champion and Seth (1968), the tiger reserve can be classified as

I) Tropical Moist deciduous Forest:

- i) TYPE 3B/C_{1c} Slightly moist teak forest

II) Tropical dry deciduous forests:

- i) TYPE 5A/C_{1b} Dry teak forest
- ii) TYPE 5A/C_3 Southern dry mixed deciduous forest

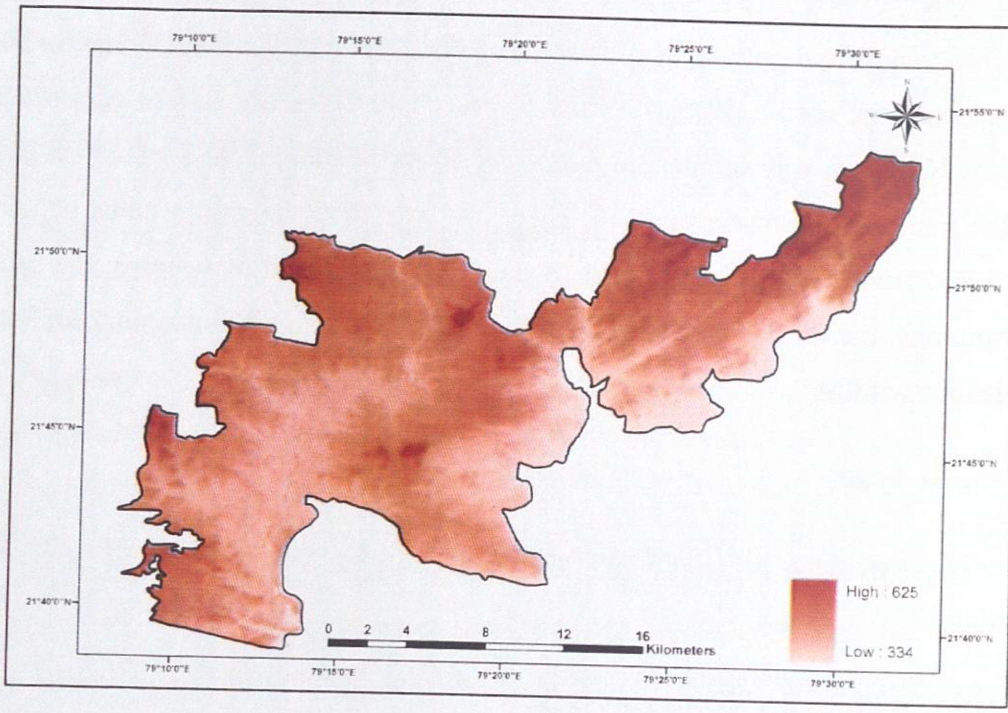

Fig 2.5 Digital elevation model of Pench Tiger Reserve, Madhya Pradesh

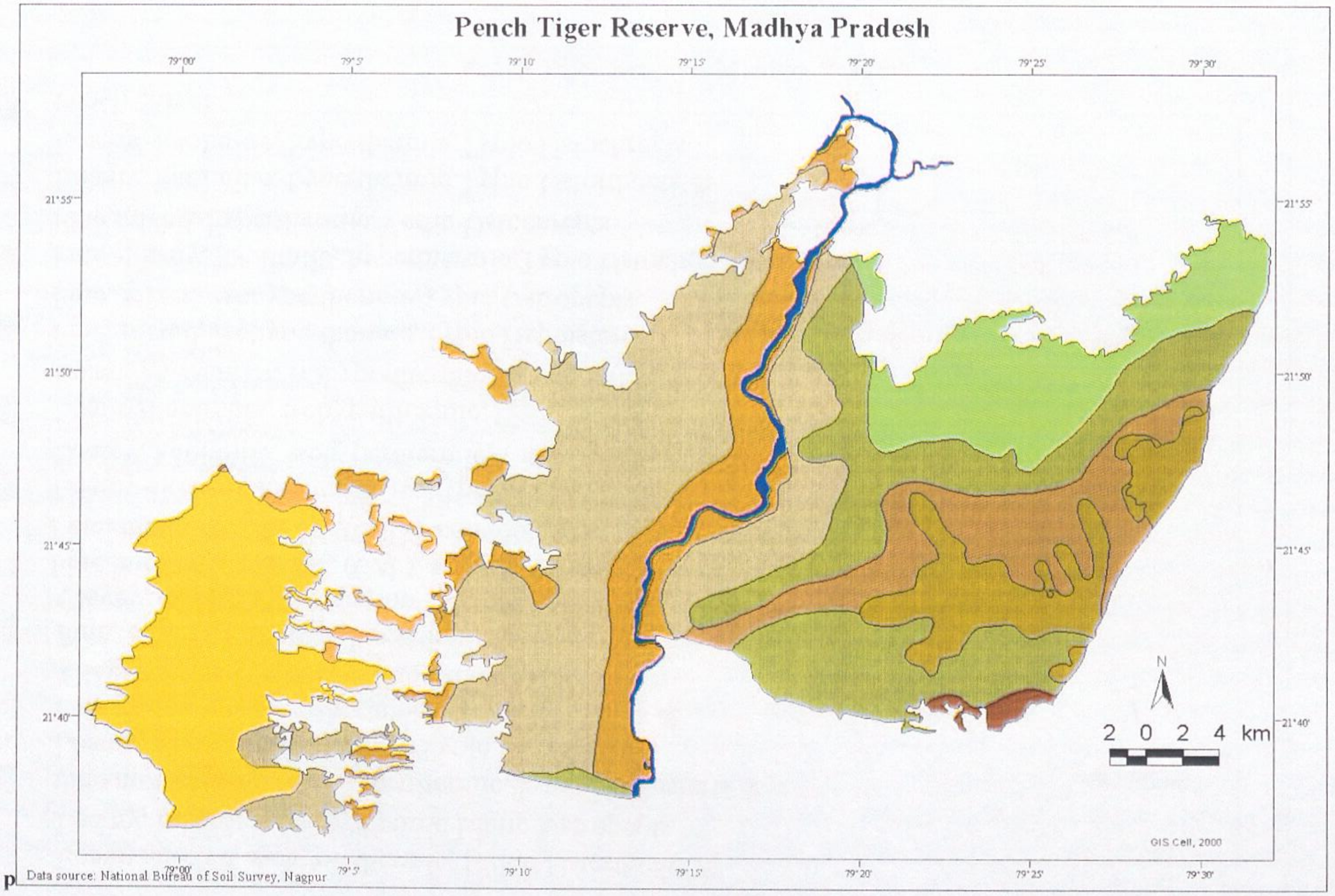

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Fig 2.6 Soil types of Pench Tiger Reserve (Sankar et al.2001)

Legend: Soil

6	Loamy, mixed, isohyperthermic, Lithic Ustorthents & Loamy, mixed, isohyperthermic Lithic Ustropepts
48	Fine,montmorillionitic,hyperthermic,Typic Haplusterts & Loamy, mixed, hyperthermic Typic Ustochrepts
50	Loamy, mixed ,hyperthermic, Typic Ustorthents & Clayey, mixed, hyperthermic Lithic Ustorthents
79	Fine, montmorillonitic, hyperthermic,Vertic Ustochrepts & Clayey, mixed, hyperthermic Typic Ustochrepts
83	Fine, montmorillonitic, (Cal.), isohyperthermic,Typic Ustropepts & Fine, montmorillonitic, (Cal.), isohyperthermic,Typic Haplusterts
91	Loamy-skeletal, kaolinitic, isohyperthermic, Typic Ustropepts & Loamy, kaolinitic, isohyperthermic, Lithic Ustropepts
107	Loamy-kaolinitic, isohyperthermic,Typic Ustropepts & Loamy, kaolinitic, isohyperthermic, Lithic Ustropepts
108	Fine, mixed, isohyperthermic,Typic Haplusterts & Fine, mixed, isohyperthermic,Typic Ustropepts
113	Fine -loamy, kaolinitic, hyperthermic,Typic Ustochrepts & Fine,mixed, hyperthermic,Vertic Ustochrepts
137	Loamy, kaolinitic, hyperthermic,Typic Ustorthents & Loamy, kaolinitic, hyperthermic,Typic Ustochrepts
10	Pench River

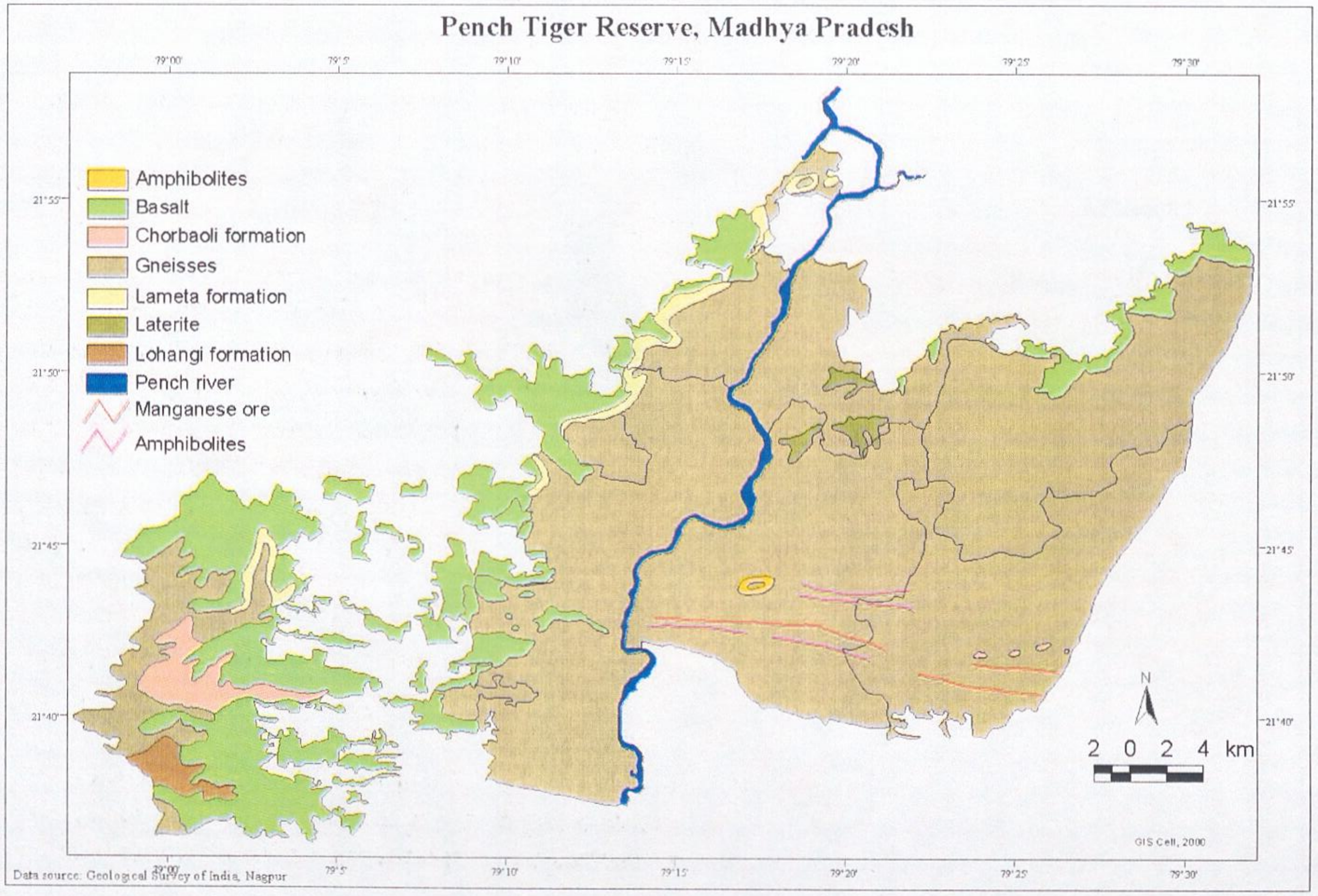


Fig 2.7 Geological types of Pench Tiger Reserve (Sankar et al. 2001)

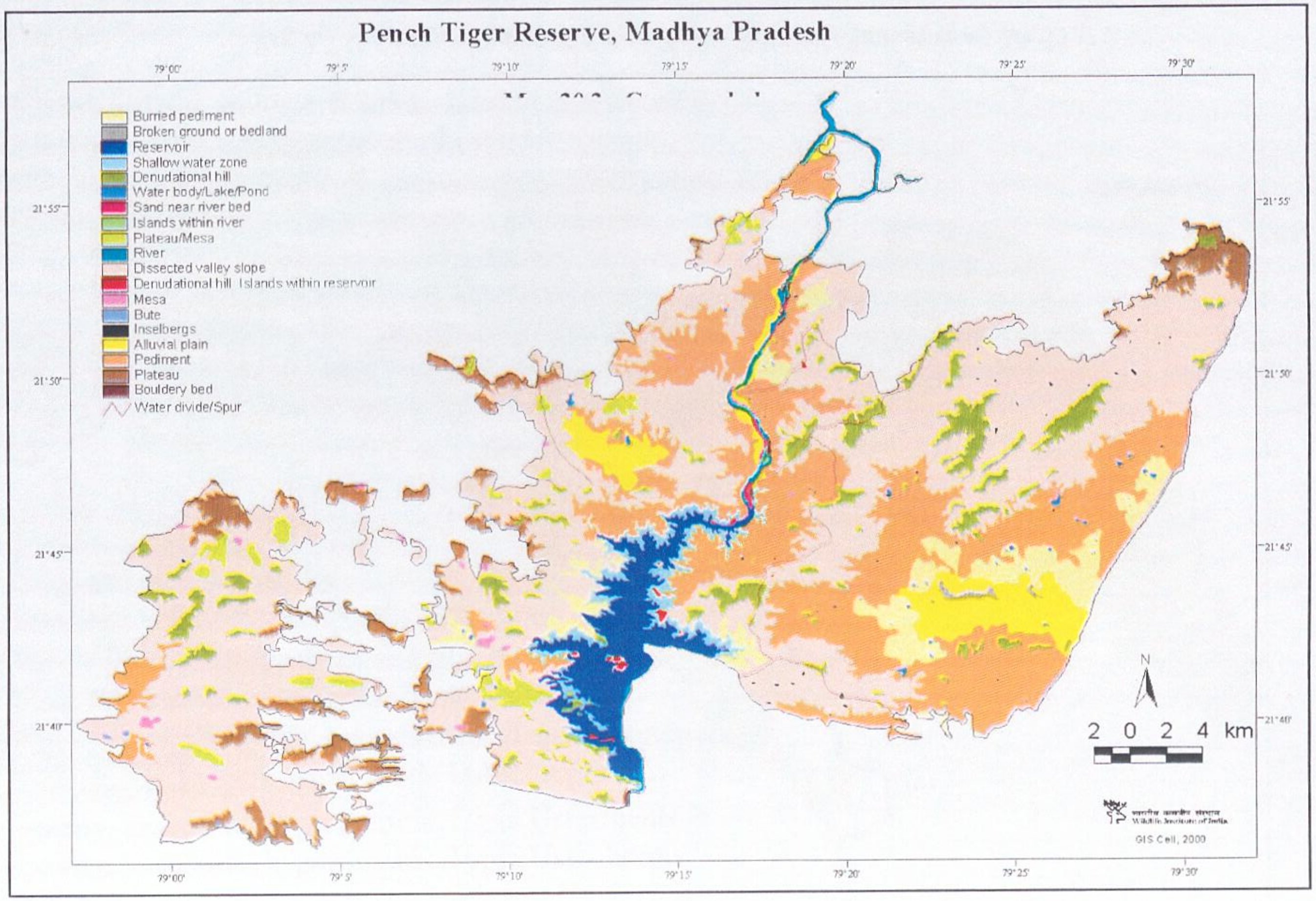


Fig 2.8 Geo-morphological types of Pench Tiger Reserve (Sankar et al.2001)

2.4 Flora

Teak (*Tectona grandis*) associated with *Madhuca indica, Diospyros melanoxylon, Terminalia tomentosa, Buchanania lanzan, Lagerostroemia parviflora, Ougeinia dalbergoides, Miliusa velutina* and *Lannea coromandelica* occur in more or less flat terrain. The undulating terrain and hill slopes have patches of mixed forest dominated by *Boswellia serrata* and *Anogeissus latifolia*. Species like *Sterculia urens* and *Gardenia latifolia* are found scattered on rocky slopes. Bamboo (*Dendrocalamus strictus*) patches occur in the hill slopes and along the streams. Some of the open patches of the park are covered with tall grasses interspersed with *Butea monosperma* and *Ziziphus mauritiana*. Evergreen tree species like *Terminalia arjuna, Syzygium cumini* and *Ixora parviflora* are found in riparian vegetation along the nullahs and river banks. *Cleistanthus collinus* occurs as dense dominant patches in some parts. The major shrub found in this area is *Lantana camara*. Dominant climber species are *Bauhinia vahlii* and *Butea superba*.

2.5. Fauna

Zoogeographically, PTR falls in Oriental realm. The large and medium sized carnivore fauna is represented by the tiger (*Panthera tigris*), leopard (*Panthera pardus*), dhole (*Cuon alpinus*) and golden jackal (*Canis aureus*). Jungle cat (*Felis chaus*), palm civet (*Paradoxurus hermaphrodites*), ratel (*Mellivora capensis*), small Indian civet (*Viverricula indica* Rasse), two species of mongoose *viz.* common mongoose (*Herpestes edwardsii*) and ruddy mongoose (*Herpestes smithii*) are the small carnivores. Wolf (*Canis lupus*) and Indian fox (*Vulpes bengalensis*) occur on the fringes and outside the protected area limits. Sloth bear (*Melursus ursinus*) is the only bear species found in this reserve (Sankar et al.. 2000).

Chital (*Axis axis*), sambar (*Rusa unicolor*), gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*), barking deer (*Muntiacus muntjac*) and chowsingha (*Tetraceros quadricornis*), are the wild ungulate species found in the study area. Chital, sambar, nilgai and wild pigs are found all over the Tiger Reserve. With the distribution of water governing their movement patterns to a great extent, gaur migrate down in large numbers from the hills during the dry season and occupy forests along the Pench river and other sources of water, and migrate back to the hill forests during the monsoon. Nilgai are found mostly in a few open areas, along forest roads, scrub jungles and fringe areas of the Reserve. Chousingha are more localized to the greatly undulating areas of the PTR. Barking deer are seen infrequently in moist riverine stretches. Chinkara (*Gazella bennetti*) are infrequently seen on the open areas bordering and outside the Buffer Zone of the Reserve (e.g. Turia, Telia, and Dudhgaon).

The common langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mulatta*) represents the primate fauna of the area. The Indian porcupine *Hystrix indica*, black-naped hare (*Lepus nigricollis*), flying fox (*Pteropus giganteus*), flying squirrel (*Petaurista petaurista*), three stripped squirrels (*Funambulus palmarum*) and Indian pangolin (*Manis crassicaudata*) also occur in PTR (Sankar et al.. 2000).

2.6 Fire

PTR, being a dry deciduous habitat experiences below canopy fires. These fires largely restricted to the shrub layer and result in the depletion of the ground layer and possess serious threat to the ground dwelling fauna. Park management burns roadsides as a control measure to accidental fire outbreak.

2.7 People and Protected Area

Mostly Gonds are the most prominent tribe in this part of the Central highlands. In early 17th century the Gonds are politically very active and ruled much of this tract (Rangarajan 1996). The lingual similarity between gonds and tamil folks of southern India bear the testimony that the gonds are a part of the same lineage as the Dravidians of the south India (Forsyth 1871). In the past, gonds inhabiting the interiors of the forest and hills are largely hunter gatherers while those in the fringes of the forest and in the foothills took to agriculture.

The principal tribe of the Dravidian family, the Gonds stand out among the various tribes of India, by their number, vast expanse and their historical importance. Although spread over Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Jharkhand, Maharashtra, Orissa and some parts of Assam, Tamil Nadu and Uttar Pradesh (Census of India 2011), the majority of Gonds are found today in Madhya Pradesh and

Chhattisgarh. In Madhya Pradesh, Gonds are concentrated in Satpura plateau (districts like Chhindwara, Betul, Seoni, Hoshangabad, Narsinghpur) and in Mandla district (Census of India 2011).

The Gonds are mainly agro-silvicultural community. While their forest dependence is high, the Gonds are mainly engaged in agriculture and a majority of them are either farm workers or daily wage laborers. In the hilly tracts most of the Gonds are landowners and cultivate their own land (Table 2.2).

Table 2.2 Occupational pattern of gonds in Madhya Pradesh

Total Worker	46.39
Cultivators	37.22
Agricultural Laborers	11.45
Agri-allied	4.94

(Source: Primary Census abstract, Census of India, 2001)

Of the various tribes of Madhya Pradesh, the Gonds are among the most educated, but still their literacy level was very low compared to other community. Literacy rates for male and female are 32.16 % and 10.73 % respectively with total literacy rate of 21.54 % (Primary Census abstract, Census of India 2001).

At present, there are 99 villages within five km radius of the periphery of the Pench Tiger Reserve. The total population of the villages stands to be 61000 with a livestock population of 36000 (present study).

2.8 Major Research conducted in Pench Tiger Reserve

Pench has a long history of research and studies conducted so far include both floral and faunal component of the park. In 1988, Dwivedi and Shukla described some ecological and behavioural aspects of the Indian Bison. Shukla (1990) studied ecological interaction between wild animals and vegetation in Pench Sanctuary and its surroundings. Rice (1991) had reported the distribution status of four horned antelope through a questionnaire survey. Jayapal (1997) carried out an intensive study on interaction between bird community and vegetation. Acharya (1997) carried out research on density of wild ungulates in this area. Shukla and Khare (1997) also studied ungulate population in the same year. Karanth and Nichols (1998) reported 4.1 (SE 1.31) tigers per 100 Km^2 in Pench National Park. Quli (1999) reported a significant decrease in tiger number between 1993 and 1995. Garshelis et al. (1999) reported low encounter of sloth bear in the study area. Sankar et al.(2001) studied gaur ecology in PTR. Ishtiaq and Rahmani (2000) tried to find Forest Owlet *Athene blewitti* in the areas where it was earlier reported but failed because of either due to human disturbance or thick ground vegetation. Pasha et al.(2000) reported 19 species of snakes in this area. Pasha et al. (2001) studied predation of gaur by tiger in PTR. Harshey and Chandra (2001) gave a comprehensive account of mammals during their study in Madhya Pradesh and Chhattisgarh. David (2002) conducted study on protected area management and human wildlife conflict interface around PTR. Biswas and Sankar (2002) revealed that Pench harbours very high prey density and tigers are mostly dependent on the wild ungulates rather than domestic livestock. In their study they found that chital (47.3%) along with sambar (14.5%) and wild pig (10.9%) constituted the major part of the tiger's diet. Pasha et al. (2002) reported debarking of Teak (*Tectona grandis*) by gaur during summer in Pench Tiger Reserve. Chandra et al. (2002) found 38 species of butterflies belonging to eight families during their study of which 14 species found to be rare. Chandra (2002) studied scarabaeid beetles of Pench Tiger Reserve. Karanth et al. (2004) reported Pench Tiger Reserve had comparatively higher prey density which can support more tigers. Pasha et al. (2004) reported 262 species of birds in this area. Areendran and Pasha (2004) reported presence of Indian wolf *canis lupus pallipes* in PTR. Gajbe (2004) found 21 genera of spiders in PTR. Cuthbert et al. (2006) reported absence of Egyptian vulture and just two individuals of red-headed vulture but Majumder et al. (2009) reported sightings of nine Egyptian and 12 red-headed vulture in the study area. Bhaskar (2007) carried out research on wild dog ecology in PTR. Bhattacharya and Shanker (2007) reported that the total wildlife Carrying Capacity (CC) of Pench National Park has declined by 18.53% due to the tourism activities. Ghuman (2009) studied vigilance behaviour of chital *Axis axis* and found that the behaviour decreases with increase in group size, decrease in density and increase in visibility. Large groups, adult males, fawns and adult females with fawns were found to be significantly more vigilant than females without fawns and yearling males in chital (Ghuman 2009). Chandra et al. (2009) studied species composition and diversity of Orthoptera and recorded 59 species belonging to 51 genera and 9 families. Family Acrididae was represented with 23 species in their study. Mascia and pailler (2010) reported proposed down-gradation of Protected area status of some parts of PTR due to the width expansion of National Highway 7. Pragatheesh (2011) studied the effect of human feeding on road mortality of Rhesus Macaque along 11 Km stretch of National Highway 7, which makes the boundary of Pench Mougli Sanctuary. Areendran et al. (2012) evaluated land use land cover patterns of PTR and surrounding areas between 1977 and 2006.

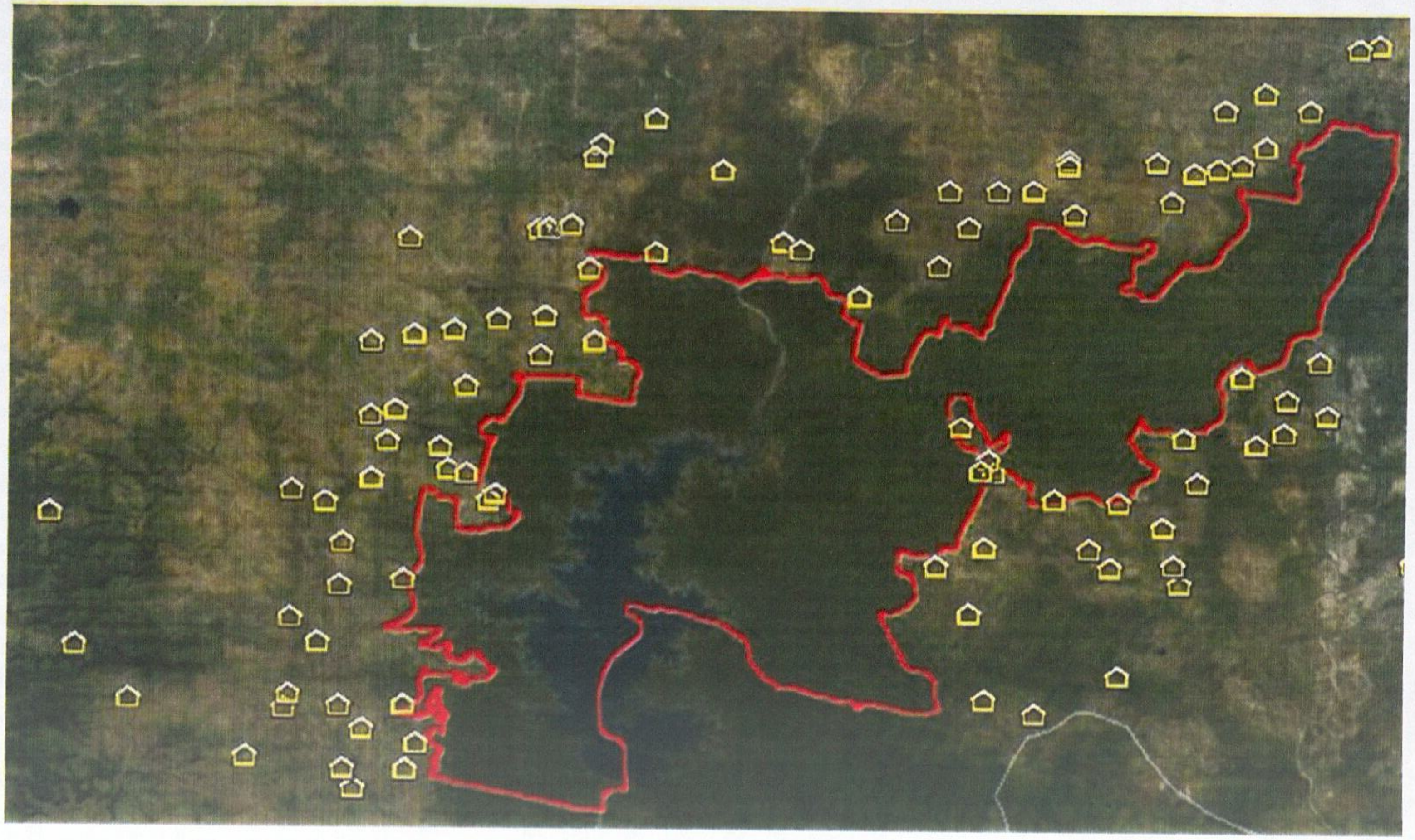


Fig. 2.9 Village locations within 5 Km radius of Pench Tiger Reserve on Google earth image

Chapter 3

HOME RANGE OF RADIO-COLLARED TIGER

3.1. Introduction

Home range is the area normally traversed by an individual animal or group of animals during activities associated with feeding, resting, reproduction, shelter-seeking and other factors important to an animal's survival (Burt 1943, Harestad and Bunnell 1979, Sandeson 1966). The ranging patterns and social behaviour of many mammals show distinct intersexual differences (Wilson 1975, Crook et al.1976). Female reproductive success is linked with an ability to exploit resources, whereas male reproductive success is governed by an ability to find and mate with females (Wilson 1975, Clutton-Brock 1989). Radio telemetry provides data on carnivore home range size and social organization, which can be used to derive, estimates of densities (Sunquist 1981, Smith et al.1987a, b, Quigley et al.1989, Soisalo and Cavalacanti 2006), habitat use (Eric et al. 2008, Jhala et al.2009) and survival rates (Trent et al. 1974, Kelly et al. 2008).

The tiger (*Panthera tigris* L.) is the largest of all felids found in diverse habitat types and show remarkable tolerance to the variation in altitude, temperature and rainfall regimes (Sunquist et al.1999). Being a large and charismatic carnivore, the tiger has attracted considerable attention in the conservation community the world over (Chundawat et al. 2002). In spite of this overwhelming care, the status of this predator has been deteriorating rapidly (Chundawat et al. 2002, Jhala et al.2008). Recently, this has reached more serious proportions than at any other time in the history of tiger conservation in India. A total of eight tiger subspecies are commonly recognised: Bengal tiger (*Panthera tigris tigris*), Sumatran tiger (*P. t. sumatrae*), Amur tiger (*P. t. altaica*), Indo-China tiger (*P. t. corbetti*), South China tiger (*P. t. amoyensis*), Caspian tiger (*P. t. virgata*), Javan tiger (*P. t. sondaica*) and Bali tiger (*P. t. balica*) (Luo et al.2004). Three of these, the Caspian, Javan and Bali tiger, went extinct in the last fifty years. The last Bali tiger was killed in 1937, the Caspian tiger became extinct in the 1950s and the last wild Javan tiger was seen in 1972. The wild South China tiger has not been directly observed since the 1970s and is now believed to be extinct in the wild too (Ronald et al. 2004).

In wild condition tiger can potentially hunt prey varying from the small mammals, medium-sized ungulates to the large bovids (Biswas and Sankar 2002), the preferred prey weighing between 60 and 250 kg (22). They are territorial and wide-ranging and the effective size of their territory is a function of the density and biomass of prey species in its habitat (Sunquist 1981, Smith 1993). Therefore, studies undertaken to address these issues on tiger are important because it can provide a better insight of tiger ecology and behavior. Radio-telemetry studies on tiger have been effectively used to address these questions (Sunquist 1981, Smith et al.1987a, Chundawat et al.2002, Karanth 1991, Seidensticker 1976, Smith 1993, Chundawat et al.1999, Goodrich et al. 2010). However, the fact those home ranges can vary widely within a species, which makes data transfer between study areas difficult (Herfindal et al.2005). It is therefore important to estimate site specific ranging patterns of tigers for better understanding, conservation and management. Our study area the Pench Tiger Reserve (PTR), Madhya Pradesh is one of the important source populations of tiger in the Central Indian landscape (Biswas and Sankar 2002). No detailed long-term study on ranging, recruitment and dispersal pattern of tiger has been documented earlier in this source population site. The present study was aimed to estimate the home ranges, recruitment and dispersal pattern of three radio-collared tigers in PTR.

3.2. Methods

Three tigers, one adult female (AF: T-15), one adult male (AM: T-2) and one sub-adult male (SAM: T-38), were radio-collared and monitored between March 2008 and December 2011 (Table 3.1) to understand the ranging and dispersal pattern of tigers. Although we had radio-collared one sub-adult male (T 31) on 11th of April 2007, we excluded the result from this analysis because the animal dropped it collars after 12 days of radio-collaring. The animals were radio-collared following immobilization with "Hellabrunn mixture" (125 mg xylazine + 100 mg ketamine/ml) (Hafner et al.1989). Initial dose depended on estimated body weight and sex of the animal and ranged from 2.5 ml for sub-adult to 2.75 ml for adult female and 3 ml for adult male. The estimated body weight of male, female and sub-adult were 200-220 kg, 140-150 kg and 100-120 kg respectively. Adult male however required supplementation and was administered a second injection of 1.2 ml. The drug mixture was remotely injected from the elephant back using Tele-inject projector (Model 4V.310). The induction time ranged between 26-36 minutes and effective handling time was 25-29 minutes. The drug combination induced reliable immobilization with good muscle relaxation and no significant alteration in physiological responses. The sedated animals were measured, weighed, radio-collared, and photographed. Individuals were aged using tooth wear, eruption, and body size, evidence of sexual development and previous births, and overall body condition. Both, Very High Frequency (Telonics ™) and Satellite radio-collars (Telonics ™ and Vectronics™) weighed less than 1% of the body weight of the tiger (Table 3.1). Yohimbine hydrochloride administered intramuscularly at a dose of 5 mg for every 50 mg of xylaxine (Seal et al. 1987) provided effective reversal for all the tigers and resulted in complete recovery that ranged from 10-28 minutes. The radio-collared tigers were radio-tracked and monitored either from the elephant back or by vehicle at different times of the day and night so as to record location data throughout the 24 hour period. During the study period, attempts were made to locate at least one and when possible two animals on daily basis following their signals. The located animals were 'homed in' from the elephant back at a distance between 50 and 75 m. Care was taken not to disturb tiger's natural behaviour or movement (Vattakaven et al. 2010). Once the animal was sighted, a hand-held Global Positioning System (GPS) was used to record the location with its coordinates. The actual sighting of each animal helped the accuracy of the GPS locations obtained for use in home-range analysis and also gave additional data on activity, behaviour and interaction with other tiger especially with cubs. These locations were also used in home range analysis taking only locations separated by a 6 hour interval in order to avoid auto correlation (White and Garrott 1990).

In addition, recruitment pattern of the AF was assessed with her home range during the cub-rearing period and compared with her own natal area. As AF was not radio-collared during her early growing stage (<2years), the locations of AF along with her mother were collected between May 2006 and June 2007 using Intensive Tiger Search Method (ITSM) (Sharma and Jhala 2010) and camera trapping (Jhala et al. 2008).

In total 80 pairs of camera traps were deployed (Fig. 3.4) in a systematic 2 km X 2 km grid (Jhala et al.2010) covering an area of > 410 km² during the study period. Individual tigers were identified from their unique stripe patterns (Karanth 1995). As studied by Sharma and Jhala (2010) in Kanha Tiger Reserve, Madhya Pradesh, an album of photographs of all the individual tigers operating in the study area was developed with a brief description of location–capture history including AM and AF and also to identify non collared mother of AF to study the natal area of AF. Using ITSM, tigers were located without affecting their natural movement between 6 am to 10 am from elephant back (n=3 elephants). Tiger pugmarks and alarm calls by prey species (chital, sambar, nilgai and common langur) were followed to locate the animal. In addition, we also collected information on tiger locations from forest beat guards, patrolling their individual beats (lowest administrative setup for any forest in India) on foot on a regular basis. Every GPS locations of tigers obtained from ITSM and camera traps were recorded and plotted on the map to estimate minimum home range.

Table 3.1. Home range estimates of three radio-collared Bengal tigers (*Panthera tigris tigris*) in Pench Tiger Reserve, Madhya Pradesh (March 2008- December 2011)

Tiger Id	Age-Sex	Body weight (kg)	Collaring period	Collar type	Collar weight (kg)	Number of location	Home Ranges in km²		
							100 % MCP	95% FK	65 % FK
T-15	Adult female	145	11/3/2008 to 31/12/2011	Very High Frequency (VHF) (Telonics ™)	0.763	750	43	32.1	10.3
T-2	Adult male	>200	1/1/2010 to 30/1/2010	Satellite and VHF (Telonics ™)	1.346	136	55.1	64.1	20.3
T-38	Sub-adult male	180	11/3/2010 To 30/8/2010	Satellite and VHF (Vectronics™)	1.324	739	52.2	19.1	6.6

MCP= Minimum Convex Polygon, FK= Fixed Kernel

The 100 % MCP method is the most widely used method (Harris et al.1990) and is also more useful for comparison with other relevant studies (Sunquist 1981, Smith et al.1987a, Seidensticker 1976, Chundawat et al.1999, Miquelle et al.1999, Karanth and Sunquist 2000). The FK is rated as one of the most robust and least biased estimator of home range and performs well even with small sample sizes, auto-correlated data and considers the shape of underlying utilization distributions (Renata and David 1987, Kernohan et al.2001, Worton 1989). The smoothing parameter of FK isopleths was chosen using the Least Square Cross Validation (LSCV) procedure (Kernohan et al.2001, Seaman et al.1999). The 95% fixed kernel method also takes care of exploratory movements and outlying fixes (White and Garrott 1990, Kernohan et al.2001, Mizutani and Jewell 1998). Thus, home ranges of all three tigers were estimated using both 95% FK and 100% MCP for the present study. In case of the AF, the annual home ranges for four consecutive years were also estimated using both MCP and FK method. The MCP (100%) method was used to estimate the minimum home range or natal area of the AF.

FK (%) isopleths versus the area of the home range were plotted and the point of inflexion of the home range curve was considered for the isopleth defining the core area of the home range (Miquelle et al.1999). Overlap comparisons were calculated using the 95% FK estimator. Percent overlap between adjacent home ranges was computed as the average proportion of overlap between two home ranges (Kernohan et al.. 2001, Mizutani and Jewell 1998).

Distance sampling by line transect method (Anderson et al.1979, Burnham et al.1980, Buckland et al.1993) was used to asses prey density and biomass around the den sites of collared female. In total 12 line transects were laid and walked early in the morning when animals found to be more active (Schaller 1967). Potential prey species of large carnivores were recorded during transect walk along with following parameters such as species, cluster size, animal bearing (with compass) and angular sighting distance (using laser range finder). The density of prey species was calculated using programme DISTANCE *Version 4.1* (Laake et al.. 1998).

3.3. Results

A total of 750 locations were collected from AF, 136 locations from AM and 739 locations from SAM (Table 3.1). GPS fixes were plotted on the map and home ranges were estimated using Hawths tool of Arc GIS 9.3 (White and Garrott 1990). The actual body weights of all three tigers were presented on Table 3.1. The 100% MCP ranges versus sample size plot showed an asymptote for the adult male and female confirming adequacy of sampling. The asymptote was reached at different sample sizes for individual animals during the study period (for AM between 115 and 120 from overall 136 locations and for AF between 460 and 465 from overall 750 locations) (Fig. 3.1). The sub-adult tiger ranges were found expanding and hence did not reach asymptote (Fig. 3.1). On an average, Fixed Kernel isopleth graphs for all three tigers showed an inflexion at 65% (Fig. 3.2), and this isopleth value was used as an estimate of the core area of home ranges for all three tigers. The estimated home range (100% MCP and 95% FK) of all three tigers was given in Table 3.1 and Fig. 3.3a and 3.3b. The core activity (65% FK) area of AF, as determined by 65% FK, was 7.1 km² for the 2nd litter and 5 km² for the 3rd litter (Table 3.1, Fig. 3.3a and 3.3b). The estimated overlap area between AM and AF (using 95% FK) was 19.2 km² (65%), whereas it was 15.4 km² (48%) between AF and SAM. As the collaring-period was not the same for both AM and SAM, their overlapped area was not assessed.

The estimated home range of AF using 100% MCP for the 1st year (March 2008 to February 2009, n=120) was 15 km² followed by 28 km² for the 2nd year (March 2009 to February 2010, n=110), 35 km² for the 3rd year (March 2010 to February 2011, n=390) and 23 km² for the 4th year (March 2010 to December 2011, n=130 locations).

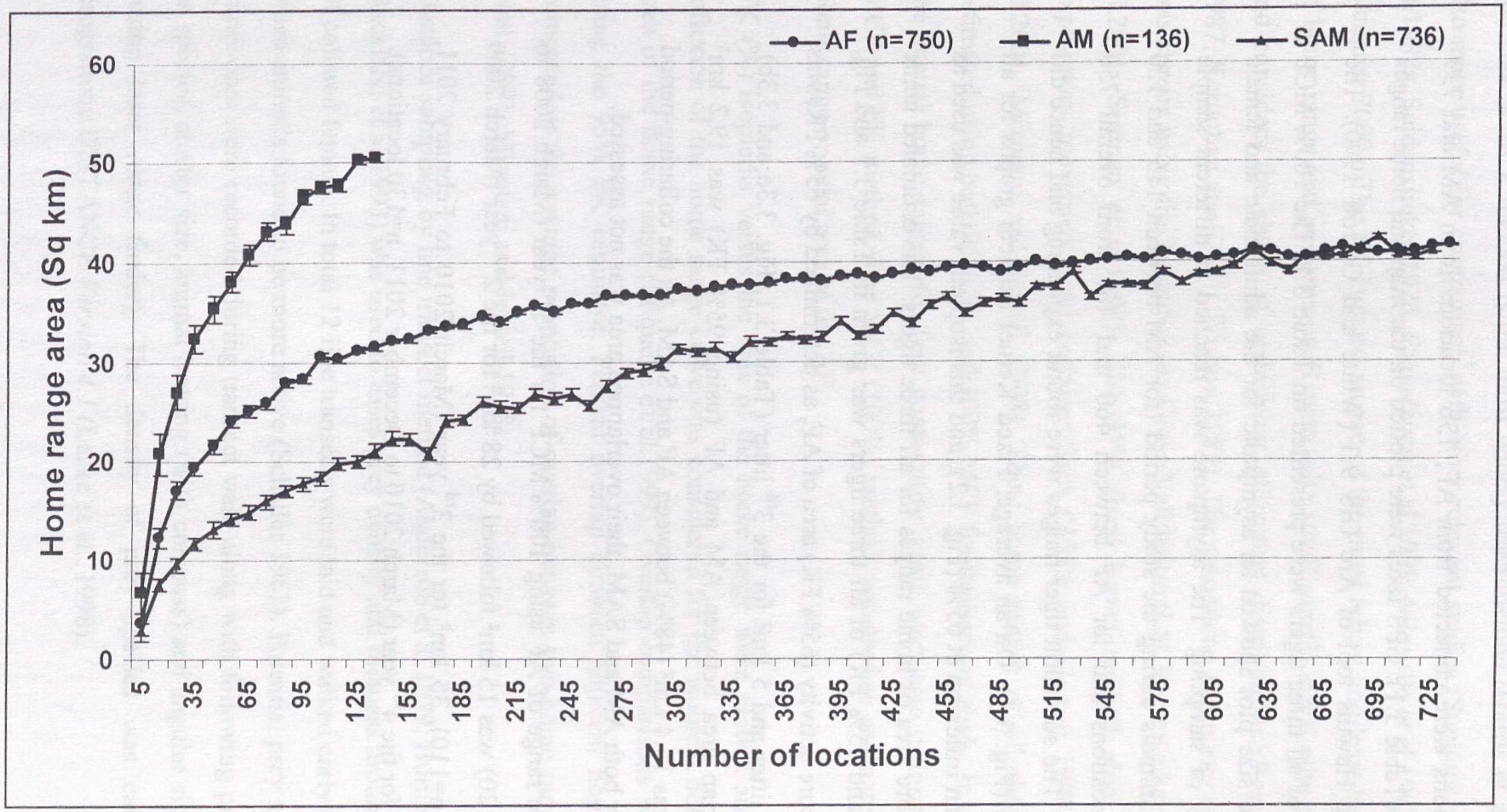


Fig. 3.1. 100% Minimum Convex Polygon home ranges (± Standard Error) of individual tigers obtained by cumulative sequential samples plotted versus number of cumulative locations showing adequacy of sampling effort for Adult Female (AF, total locations or n= 750), Adult Male (AM, n=136) and her Sub-Adult Male (SAM, n= 739) cub in Pench Tiger Reserve, Madhya Pradesh.

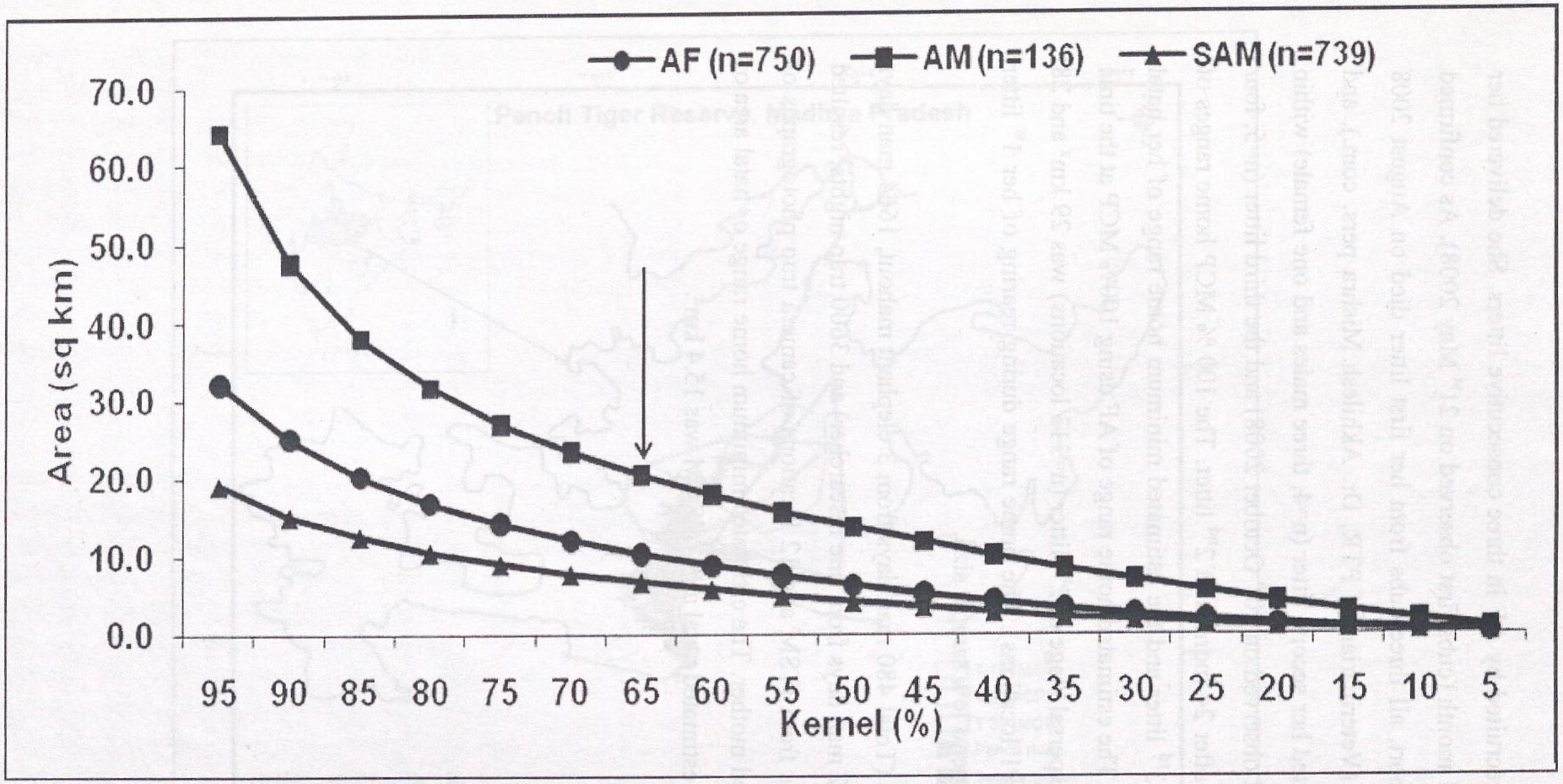


Fig. 3.2. Fixed Kernel (%) isopleths versus the area of the home range for defining the core area of the home range at point of inflexion (↓) for Adult Female (AF), Adult Male (AM) and Sub-Adult Male (SAM) in Pench Tiger Reserve (March 2008 and December 2011).

In total, 12 cubs were recruited by AF in three consecutive litters. She delivered her 1st litter at the age of 31 month (cubs first observed on 21st May 2008). As confirmed by the post-mortem report, all three cubs from her first litter died on August 2008 because of pneumonia (Veterinarian of PTR, Dr. Akhilesh Mishra pers. com.), and subsequently she recruited her second litter (n=4, three males and one female) within three months (cubs first observed on 20th October 2008) and the third litter (n=5, four females and one male) after 24 months of 2nd litter. The 100 % MCP home ranges of AF during the 2nd and 3rd litter and the estimated minimum home range of her natal area is shown in Fig. 4. The estimated home range of AF using 100% MCP at the time of raising cubs up to dispersal stage of 2nd litter (n=313 locations) was 29 km² and 28 km² for 3rd litter (n=291 locations). The home range during rearing of her 1st litter could not be assessed due to low sample size.

In total 2336 man days (Total 480 man days from 3 elephant mahout, 1664 man days from 8 beat guards, 192 man days from one researcher) and 3600 trap nights, resulted a total of 128 locations from ITSM and 12 locations of camera trap photographs of AF and her non collared mother. The estimated minimum home range or natal area of AF was 23.9 km². The estimated natal area of SAM was 15.4 km².

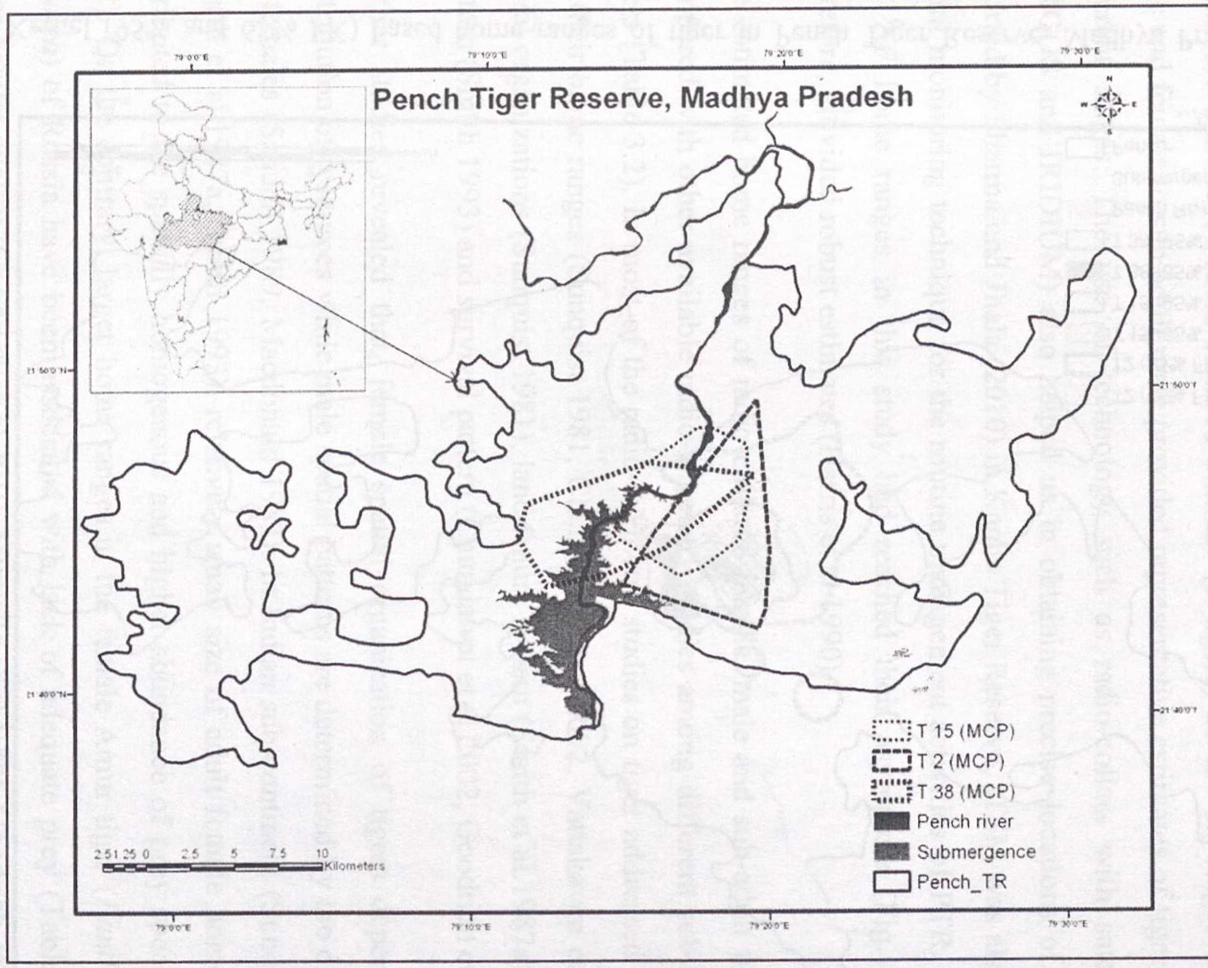


Fig. 3.3a. Minimum Convex Polygon (100%) based home ranges of tiger in Pench Tiger Reserve, Madhya Pradesh (March 2008- December 2011)

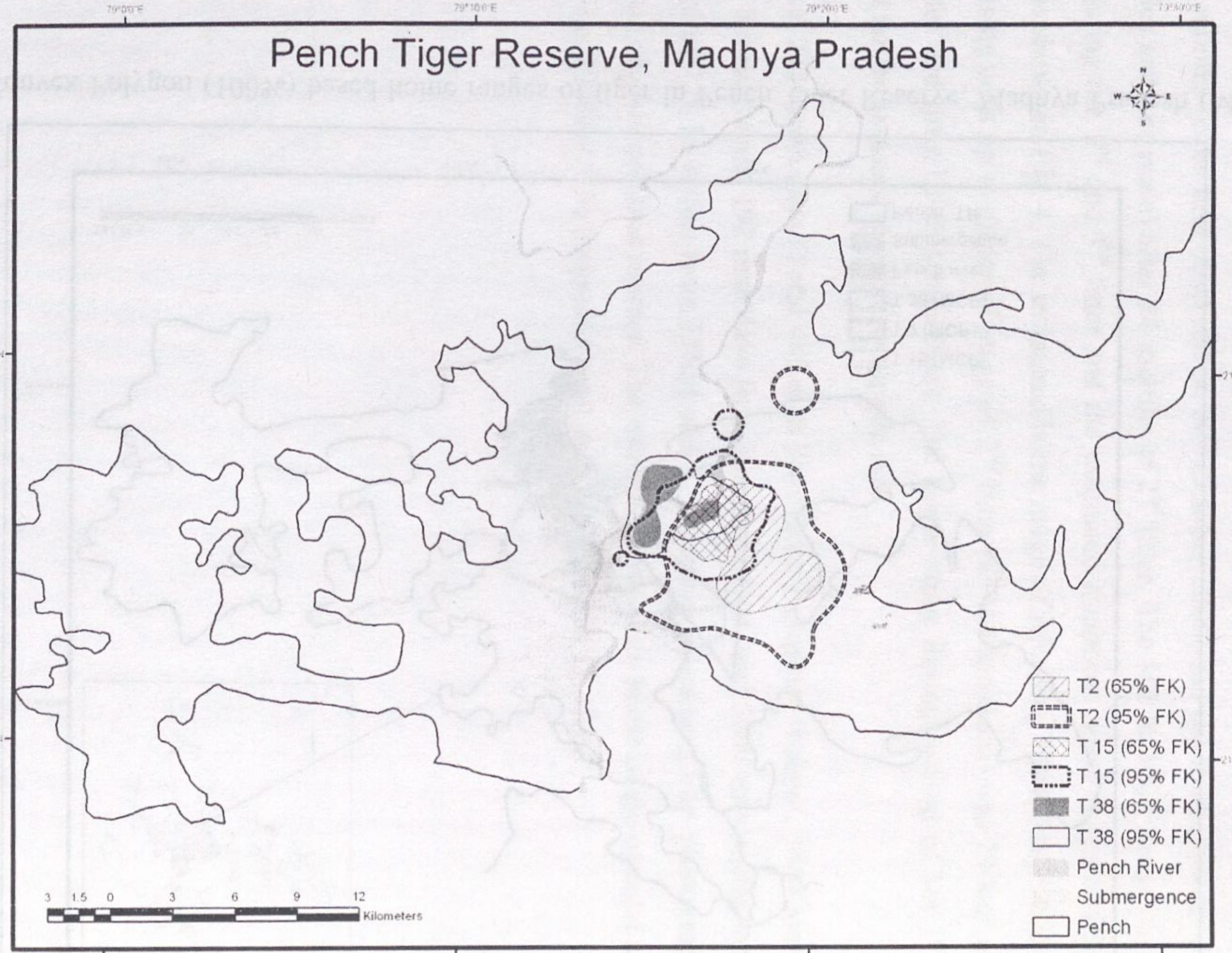


Fig. 3.3b. Fixed Kernel (95% and 65% FK) based home ranges of tiger in Pench Tiger Reserve, Madhya Pradesh (March 2008 to December 2011)

3.4. Discussion

Radio-telemetry is found more reliable to estimate home range of tiger, as they are elusive and nocturnal or move about the landscape using dense cover (Sunquist 1981, Smith et al.1987a, Chundawat et al.2002). However issues regarding sampling size have received less attention. The large number of radio-locations (n=1622) and a reasonable number of radio-collared animals (3 tigers) across all stages from adult male and female to sub adult male provided representative estimates of tiger ranges at different stages. The use of technology such as radio-collars with satellite link (ARGOS and IRIDIUM) also helped us in obtaining precise locations of tiger. As reported by Sharma and Jhala (2010) in Kanha Tiger Reserve, ITSM was also found a useful monitoring technique for the routine management activities of PTR. The AM and AF home ranges in this study had reached their asymptote (Fig. 3.1) and, therefore, provided robust estimates (Harris et al.1990).

The estimated home ranges of radio-collared female, male and sub-adult tigers were compared with other available radio-telemetry studies among different sub-species of tigers (Table 3.2). In most of the radio-telemetry studies on tiger addressed the issues on their home ranges (Sunquist 1981, Chundawat et al.2002, Vattakaven et al.2010), social organizations (Sunquist 1981), land tenure system (Smith et al.1987a) dispersal pattern (Smith 1993) and survival pattern (Chundawat et al.2002, Goodrich et al.2010).

Earlier studies revealed that, female spatial organization of tigers depend on the distribution of resources while male spatial patterns are determined by the distribution of females (Sandell 1989, Macdonald 1983). In Indian sub-continent (Sunquist 1981, Smith et al.1987a, Smith 1993), relatively small size of adult female home range is attributed to the spatially homogenous and higher abundance of prey species (Table 3.2). On the contrary, larger home ranges in the female Amur tiger (*Panthera tigris altaica*) of Russia have been associated with lack of adequate prey (Table 3.2) and poor habitat quality (Goodrich et al.2010, Miquelle et al.1999, Goodrich et al. 2005). Although prey biomass/km² in Sariska Tiger Reserve was very high as compared to other areas (Table 3.2), the reported annual home ranges of both the male (n=1) and females (n=2) were considerably larger since the re-introduced tigers explored larger areas during the initial period (Sankar et al.2010). The successful raising of all cubs by AF from her 2nd (n=4) and 3rd litter (n=5) to dispersal stage, suggested that all requirements for survival (as abundance of prey, cover for stalking and resting, no anthropogenic pressure and perennial water sources) were fulfilled in the study area. She used 44.3% (10.6 km²) of her original natal area for raising the 2nd litter and 46.4% (10 km²) area for raising the 3rd litter. The larger area beyond the original natal area, that was being used year-after-year by the radio-collared female (AF), was attributed to the philopatric nature of female tiger (Smith 1993). The sub-merged habitat was largely used by both the radio-collared breeding female and her non-collared mother during the cub-raising period and this may be attributed to the availability of major prey species, *i.e.* chital (> 60% of their diet composed of chital) and *Lantana* sp. as cover in and around the submerged habitat at Totladoh. The core activity (65% FK) area (Fig. 3.3a and 3.3b) was found to be smaller for the radio-collared breeding female (AF) during the first three months of recruitment and it was gradually expanded as the cubs grew up to about 12 months. Similar findings were also reported from Chitawan National Park, Nepal (Sunquist 1981, Seidensticker 1976, Smith 1993, McDougal 1977). In total, twelve den sites were used by the AF rearing her three litters (1st litter=3 den sites, 2nd litter=4 den sites and 3rd litter=5 den sites). All the dens were located in areas with no anthropogenic disturbance, Very Dense Forest cover (Fig. 3.4) and the estimated mean distance to the water source (i.e. back water or submergence of Pench river) was <250 m in all seasons. The estimated overall wild prey density around the den sites was 348.2/km² (chital 176.8/km², sambar 10.6/ km², common langur 144.5/km², nilgai 2.3/ km², wild pig 12.2/ km² and gaur 1.5/km²) with a total biomass of 12384.7 kg/ km² (Total effort 476.4 km). The reported overall female home ranges (Table 2) from five tiger reserves in India (Kanha - Sharma et al. (2010), Sunquist (2010), Nagarahole- Karanth and Sunquist (Karanth and Sunquist 2000, Karanth and Sunquist 1995), Ranthambore - Chakrabarty (2009), Jhala et al.(2010), Panna-Chundawat et al.(2002), Pench- Present study, Jhala et al.(2010) were compared with their respective tiger densities (Table 2). It was observed that the sizes of female (mean) home ranges are negatively related (Linear regression, $R^2 = 0.9116$) with overall tiger densities (Fig. 3.5a) *i.e* when the overall tiger density increases, the female home range size decreases.

A wide variation was observed in case of male home range sizes in different study areas (Table 3.2). Minimum home range (100% MCP) of the resident male tiger in Chitwan varied from 60 to 100 km² (Sunquist 1981). McDougal (1977) recorded a male home range of 90–105 km² (MCP) in Chitwan. Karanth and Sunquist (2000) recorded a home range (95% MCP) of 56.7 km² for an adult radio-collared male in Nagarhole, although the tiger had a 95% adaptive kernel home range of 98.8 km². Schaller (1967) recorded a minimum range of 78 km² for an adult territorial male and Panwar (1977) recorded a minimum range of 30–50 km² for the male in Kanha. Matyushkin (2012) estimated minimum ranges of 800–1000 km² for the male tigers in Russia. Miquelle et al. (1999) reported seasonal ranges of 235 to 238 km² for a male tiger in Russia. Goodrich et al. (2005) reported ranges of 299–614 km² for two translocated radio-collared males in Silkote-Alin in Russia, whereas the mean home range of six adult male tigers was 1,385 km² (95% MCP).

The home range size of male tiger may be influenced by various ecological factors. According to Chundwat et al.(2002), larger home ranges of radio collared male tiger in Panna may well be a response to the high spatial and temporal unpredictability of available resources. According to Priatna et al.(2012), the home range size of male tiger is not only determined by the abundance of prey species but also by the density of local tigers that already occupy the area as well as their social structure. Although there may not be sufficient data to compare (Table 3.2), we found an indication that size of male tiger (mean) home ranges are positively related with the size of female tiger (mean) home ranges (Fig. 3.5b). It was observed that the SAM home range remained smaller in its natal area (MCP home range 15.4 km²) and his home range expanded (MCP home range 52.2 km²) gradually during the dispersal stage. Similar findings were reported by Sunquist (1981) and Smith in Nepal (1993). Although the SAM's radio-collar ceased functioning after five months of deployment (Table 3.1), a long-term (January to May 2011) camera trap study, covering a larger area (> 410 km², 102 photographs of 23 individual tigers, 16 female and 7 male) confirmed the dispersal of this individual from its natal area.

Table 3.2. Estimates of mean home range sizes of different sub-species of tiger (*Panthera tigris*) in Nepal, Bangladesh, India, Indonesia and Russia

Place (Country)	Method	[1]MCP Home range in km^2			[2]Prey*		[3]Tiger Density/100 km^2	References
		AM (n)	AF (n)	SAM (n)	Density/km^2	Biomass(kg/km^2)		
Chitwan (Nepal) [a]	RT+CT	NA	9.3 (1)	NA	26	2933	3.7	[1,2]Seidesticker (1976), [3] Sunquist (1981)
Chitwan (Nepal) [a]	RT+CT	54.1(2)	16 (3)	44.7 (1)	59	2600	3.7	[1,2,3]Sunquist (1981, 2010)
Chitwan (Nepal) [a]	RT+CT	NA	20.7 (7)	NA	59	2600	3.7	[1]Smith *et al.*(1987a), [2],[3]Sunquist (1981, 2010)
Panna (India) [a]	RT+CT	188.6 (2)	42.2 (4)	NA	30.9	3100	6.9	[1,3]Chundawat *et al.*(2002), [2]Sunquist (2010)
Nagarahole (India) [a]	RT+CT	25.7 (1)	16.5 (1)	44.7 (2)	70	15094	11.9	[1,2,3] Karanth and Sunquist (2000,1995)
Sikhote-Alin (Russia) [b]	RT+SC	1385 (6)	390 (14)	NA	NA	400	0.6	[1]Goodrich *et al.*(2010), [2]Sunquist (2010), [3] Smirnov and Miquelle (1999)
Kanha (India) [a]	RT+CT	102 (2)	10.5 (4)	NA	57.3	3900	13	[1,3] Sharma *et al.*(2010), [2]Sunquist (2010)
Sariska (India) [a]	RT	168.6 (1)	202.4 (2)	NA	315.7	21618	NA	[1,2] Sankar *et al.*(2010)
Sunderban (Bangladesh) [a]	RT	NA	12.3 (2)	NA	41.8	998	4.3	[1] Barlow *et al.*(2011),[2,3] Khan (2004)
Sunderban (India) [a]	RT	NA	44 (1)	NA	NA	NA	NA	[1]Sharma *et al.*(2011)
Indonesia [c]	RT+CT	16 (1)	NA	NA	17.5	400	1.7	(Zoological Society of London 2003),

Place (Country)	Method	[1]MCP Home range in km²			[2]Prey*		[3]Tiger Density/100 km²	References
		AM (n)	AF (n)	SAM (n)	Density/km²	Biomass(kg/km²)		
								[2,3]Obrien *et al.*(2003)
Ranthambore (India)[a]	RT+CT	46.1(4)	20.1(2)	NA	69.3	6430	7	[1]Chakravarthi (2009),[2] Bagchi *et al.*(2003), [3]Jhala *et al.*(2010)
Indonesia[c]	RT	236 (4)	NA	NA	17.5	400	1.7	Priatna *et al.*(2012), [2,3]Obrien *et al.*(2003)
Pench (India)[a]	RT+CT	55.1 (1)	44 (1)	52.2 (1)	167.9	6238.1	3.6	[1]Present study, [2]Majumder *et al.*(2012), [3]Jhala *et al.*(2010)

RT (MCP) = Radio Telemetry, NA= Not Assessed/ Available, RT+CT= Radio-telemetry and Camera trap, TC= Track Count on Snow, * Large and medium body sized prey , [a]= Bengal tiger (*Panthera tigris tigris*), [b]= Amur tiger (*Panthera tigris altaica*), [c]= Sumatran tiger (*Panthera tigris sumatrae*). N.B. -All tiger den sities were estimated using ½ Mean Maximum Distance Moved or ½ MMDM Method (Efford 2004, 2009), [1]MCP= Minimum Convex Polygon.

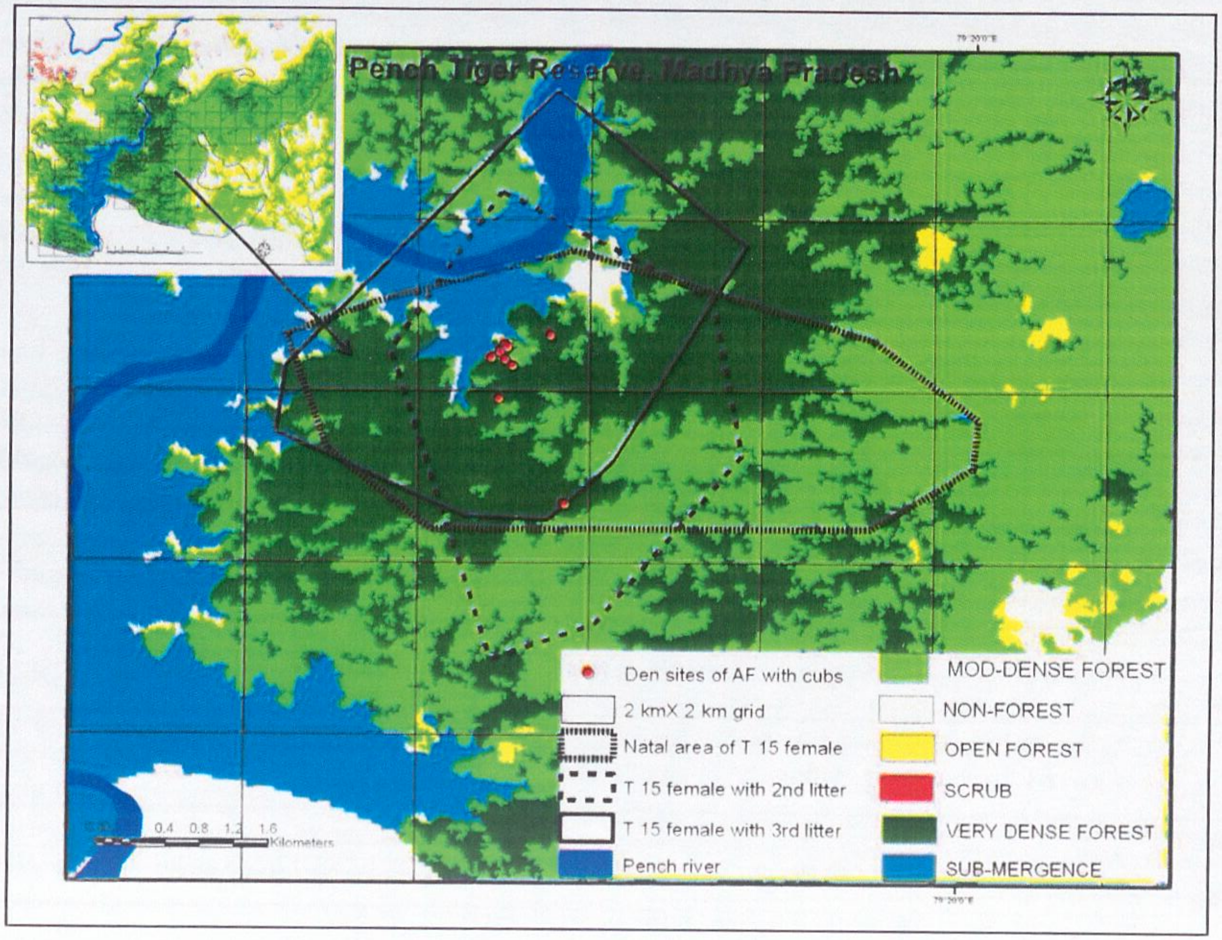


Fig. 3.4. Home range estimates (100% MCP) of two successive litters of a radio-collared female, their den sites (n=12) and her natal area (100% MCP) in Forest Cover Map of Pench Tiger Reserve, Madhya Pradesh (May 2006 to December 2011)

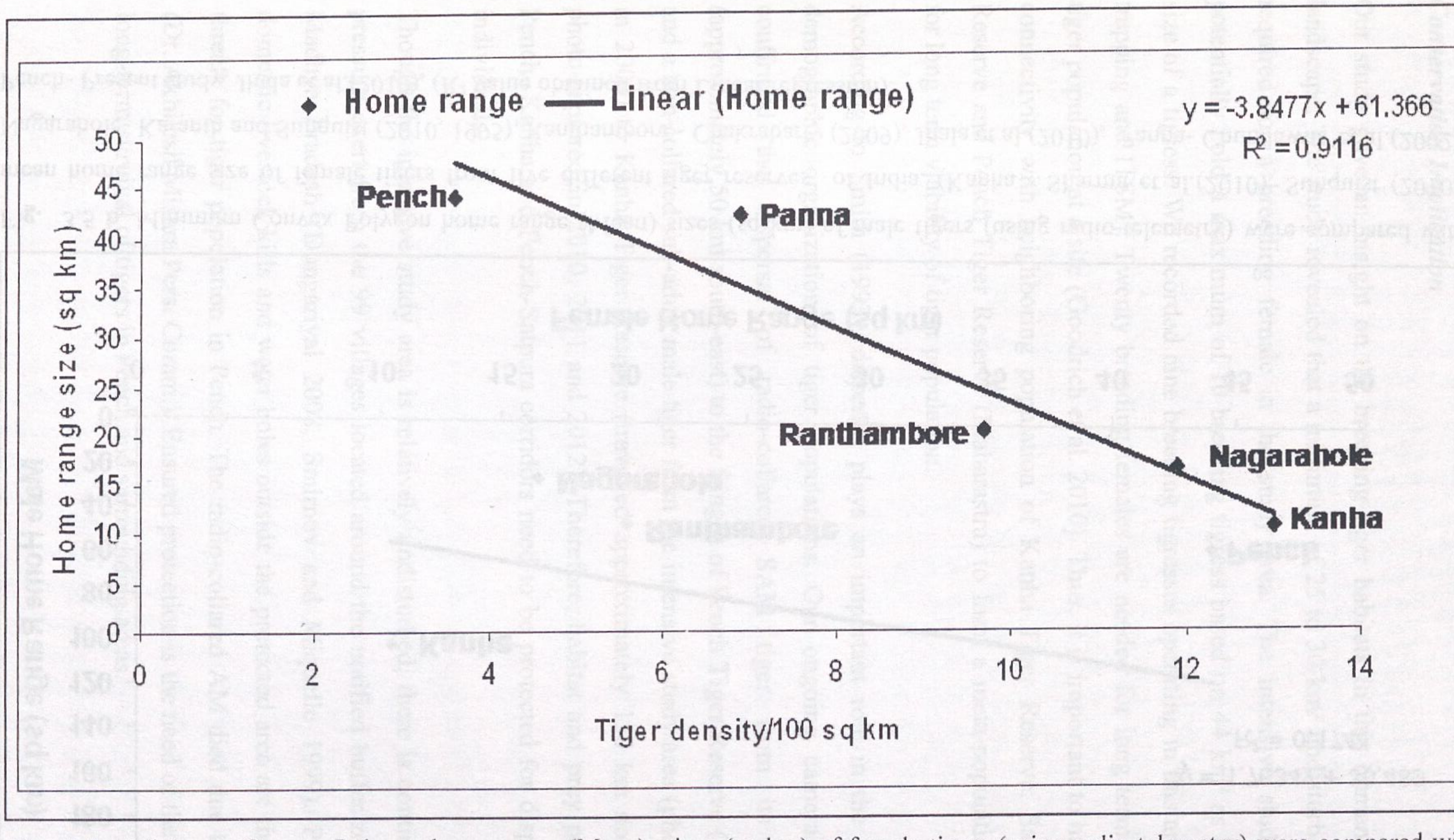


Fig. 3.5a. Minimum Convex Polygon home range (Mean) sizes (sq km) of female tigers (using radio-telemetry) were compared with available overall tiger densities/100 sq km (using camera trap) from five different tiger reserves of India, (Kanha - Sharma et al.(2010), Sunquist (2010), Nagarahole- Karanth and Sunquist (2010, 1995), Ranthambore - Chakrabarty (2009), Jhala et al.(2010), Panna- Chundawat et al.(2002), Pench- Present study, Jhala et al.(2010), (R^2 value obtained from Linear regression).

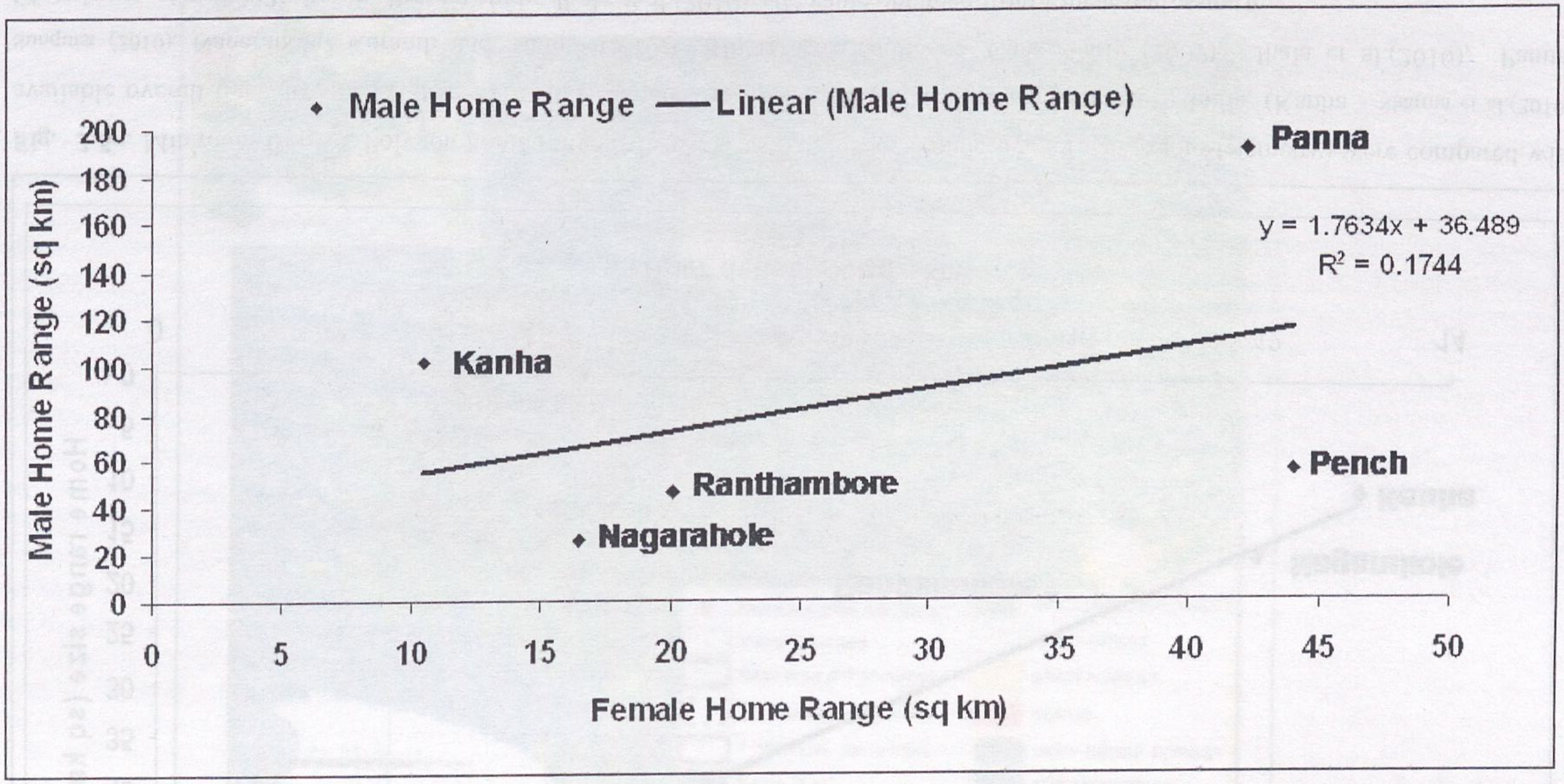


Fig. 3.5 b. Minimum Convex Polygon home range (Mean) sizes (sq km) of male tigers (using radio-telemetry) were compared with mean home range size of female tigers from five different tiger reserves of India, (Kanha - Sharma et al.(2010), Sunquist (2010), Nagarahole- Karanth and Sunquist (2010, 1995), Ranthambore - Chakrabarty (2009), Jhala et al.(2010), Panna- Chundawat et al.(2002), Pench- Present study, Jhala et al.(2010), (R^2 value obtained from Linear regression).

Conservation Implication

Our study gave an insight on the breeding tiger habitats in this human dominated landscape. The study revealed that a minimum of 25 to 30 km² undisturbed area was required for a breeding female in the study area. The intensive study area can potentially hold a maximum of 10 breeding tigress based on 44 km² as home range size of a tigress. We recorded nine breeding tigresses operating in this area (Camera trapping and ITSM). Twenty breeding females are needed for long term survival of tiger population at a site (Goodrich et al. 2010). Thus, it is important to have corridor connectivity with neighboring population of Kanha Tiger Reserve, Satpura Tiger Reserve and Pench Tiger Reserve (Maharastra) to form a meta-population structure for long term viability of tiger population.

According to Smith (1993), dispersal plays an important role in the genetic and demographic organization of tiger populations. Our ongoing camera trap study confirmed the dispersal of radio-collared SAM tiger from its natal area (approximately 50 km south-east) to the fringes of Pench Tiger Reserve (Maharastra) and a non-collared sub-adult male tiger from the intensive study area (photo-captured in 2006) to Kanha Tiger Reserve (travelled approximately 150 km north-east and photo-captured in 2010, 2011 and 2012). Therefore, habitat and prey population in Pench- Kanha and Pench-Satpura corridors need to be protected for dispersing tiger individuals.

Though the intensive study area is relatively undisturbed, there is continuous biotic pressure exert from the 99 villages located around the notified buffer zone of PTR, Madhya Pradesh (Dungariyal 2008, Smirnov and Miquelle 1999). Poisoning of domestic livestock kills and water holes outside the protected area are the two major threats for tiger population in Pench. The radio-collared AM died due to poisoning (Dr. Akhilesh Mishra Pers. Comm.). Ensured protection is the need of the hour for the long-term survival of tigers in Pench and surrounding areas.

Chapter 4

HABITAT USE BY TIGER

4.1 Introduction

Habitat loss and fragmentation are the main challenges in conservation and management of large carnivore worldwide (Peyton 1999). Habitat fragmentation can result in small, isolated populations which become increasingly vulnerable to extinction (Diamond 1986, Wilcove, 1987). Animals generally select habitats that satisfy their demands for food, water, and denning sites to optimize survival and reproduction (Boyce and McDonald 1999, Chamberlain et al.2002). Though, several hypotheses have been proposed to explain the coexistence patterns of tigers in forested habitat (Karanth and Sunquist, 1995), a comparison of habitat use by sympatric species allows an assessment of their interactions. Previous studies have indicated that habitat separation is the most common form of niche portioning in sympatric species of mammals (Brown and Lieberman 1973). Information on habitat use is thus crucial to understand the relationship between distribution and abundance of wildlife species (Tejeda-Cruz et al. 2009). This information can be helpful to assess not only habitat requirements of animals but also support sound wildlife management plans.

In India, tiger (*Panthera tigris*) was found utilizing a wide range of habitats (Johnsingh 1983, Karanth and Sunquist 1995, Edgaonkar, 2008, Jhala et al.2008, 2010). In tropical Asia, tigers inhabit forests of deciduous, evergreen, riverine, swamp and mangrove, showing incredible tolerance to variation in altitude, temperature and rainfall regimes. Conservation of habitat of tiger in the human dominated landscape of India is always been a challenging task for wildlife managers (Wikramanayaeke et al.1998) as their habitats have been fragmented because of various biotic pressure (Qureshi et al.2006, Jhala et al.2008). The reported occupancy of tiger in Central Indian landscape was 48610 km² in 2006 and 38056 km² in 2010 (Jhala et al.2010). With the decline of most of the tiger habitat from the central Indian Landscape (Qureshi et al.2006, Jhala et al.2010), there was an urgent need for adopting the effective practical methods to understand the seasonal utilization (winter and summer) patterns of different habitat resources by tiger. Utilization of major habitat resources at the population level by tiger was compared with the available habitat types (Manly et al.2004) in Pench Tiger Reserve (PTR), Madhya Pradesh. The study area has forest connectivity with PTR, Maharastra and forms one of the important conservation units for tigers in Central Indian Landscape (Qureshi et al.2006, Jhala et al.2010). A detailed long-term study on spatio-temporal utilization of major habitat resources by tiger has not been documented earlier in the central Indian landscape.

4.2. Methods

4.2.1. Utilisation of different land use, land cover and terrain types

Indirect (pugmark, scrape, fresh scats) evidences of tigers were collected from carnivore sign survey (Jhala *et al.*2005) between June 2006 and April 2011. Forest beats were considered as the lowest sampling unit for sign survey and three separate routes of each forest beats were walked early in the morning to record the signs and tracks of these three carnivores. Each search covered about 4 to 6 km distance in areas having the best potential for tiger presence. In total 44 beats from intensive study area were covered for data collection and a hand held Global Positioning System (GPS) was used to record all evidences.

All these locations were plotted on the classified land use and land cover map (Fig. 1) and elevation classes or Digital Elevation Model (DEM) map (Fig. 2) of the study area and the habitat variables for each point locations were extracted using program Arc Gis 9.3 (Singh 2011). Land use and land cover were categorized into six categories: sub-mergence, riverine, miscellaneous, agriculture, barren land and teak mixed forest, whereas terrain or elevation types were categorized as: elevation between 350 m and 500 m and elevation between 501 m and 650 m. Percentage of locations in each land use, land cover and terrain class were calculated as suggested by White and Garrot (1990) and Aebischer et al.(1993).

In accordance with the classification done by Forest Survey of India (www. fsi.org.in) the available canopy cover of PTR was classified into following four major categories:

1) Non-forest- Canopy cover <10%

2) Open forest- Canopy density between 10% and 40%.

3) Moderately dense forest- Canopy density between 40% and 70% above.

4) Very dense forest- Canopy density of 70% and above.

Elevation of entire intensive study area was classified into low (elevation between 350 m and 500 m) and high (elevation between 501 m and 650 m) categories.

4.2.2. Random points for available habitat resources

To select adequate available point locations for the present study, 500, 1000, 1500, 2000 and 2500 random points were generated within the 100% Minimum Convex Polygon (MCP) using Arc GIS 9.2 (Hosmer and Lemeshow, 2000, Singh, 2011). Fifteen hundred random points were found to be adequate to study habitat availabilities, as the curve was asymptote at this point.

4.2.3. Habitat selection by tiger

Point locations (%) of each utilized habitat resources by tiger in both winter and summer were compared with the available point locations (%) to study the habitat selection pattern (Neu *et al.*1974, Manly *et al.*2004). Confidence interval technique which involves the use of Bonferroni's Z' statistic (Neu *et al.*1974) was carried out to verify which habitat types were preferred. If the proportion available for a given habitat classes lies above or below the upper or lower boundary of the confidence interval then that vegetation is considered selected or avoided respectively. The indices "- -", "++" and "**" provided the basis for ranking the relative habitat preference by all three carnivores among different habitat categories (Table 4.1, 4.2 and 4.3).

4.3. Results

A total of 1303 and 2238 locations of tiger evidence were recorded in winter and summer respectively (Figs. 4.1, 4.2 and 4.3). The total effort for the present study was 1162 km in winter and 1674 km in summer. Significant difference (T-test, p=0.02) was found between summer and winter use of habitats by large carnivores. We pooled data of same seasons across years as there was no significant difference (T-test, p=0.09).

4.3.1. Land use and land cover

In winter, tiger utilized teak-mixed forest more than it's availability (++), utilized riverine and miscellaneous habitats in proportion to their availabilities (**), submergence, agriculture and barren lands were utilized less than their availabilities (--) (Table 4.1). In summer, tigers utilized riverine and submergence habitats more than their availabilities, utilized rocky or barren land and teak-mixed habitats in proportion to their availabilities and both agriculture and miscellaneous habitats were utilized less than their availabilities (Table 4.1).

4.3.2. Terrain

In both winter and summer tiger utilized elevation between 501m and 650 m more than its availability, leopards utilized elevation between 350 m and 500 m more than its availability and dhole used both of these terrain types in proportion to their availabilities (Table 4.2).

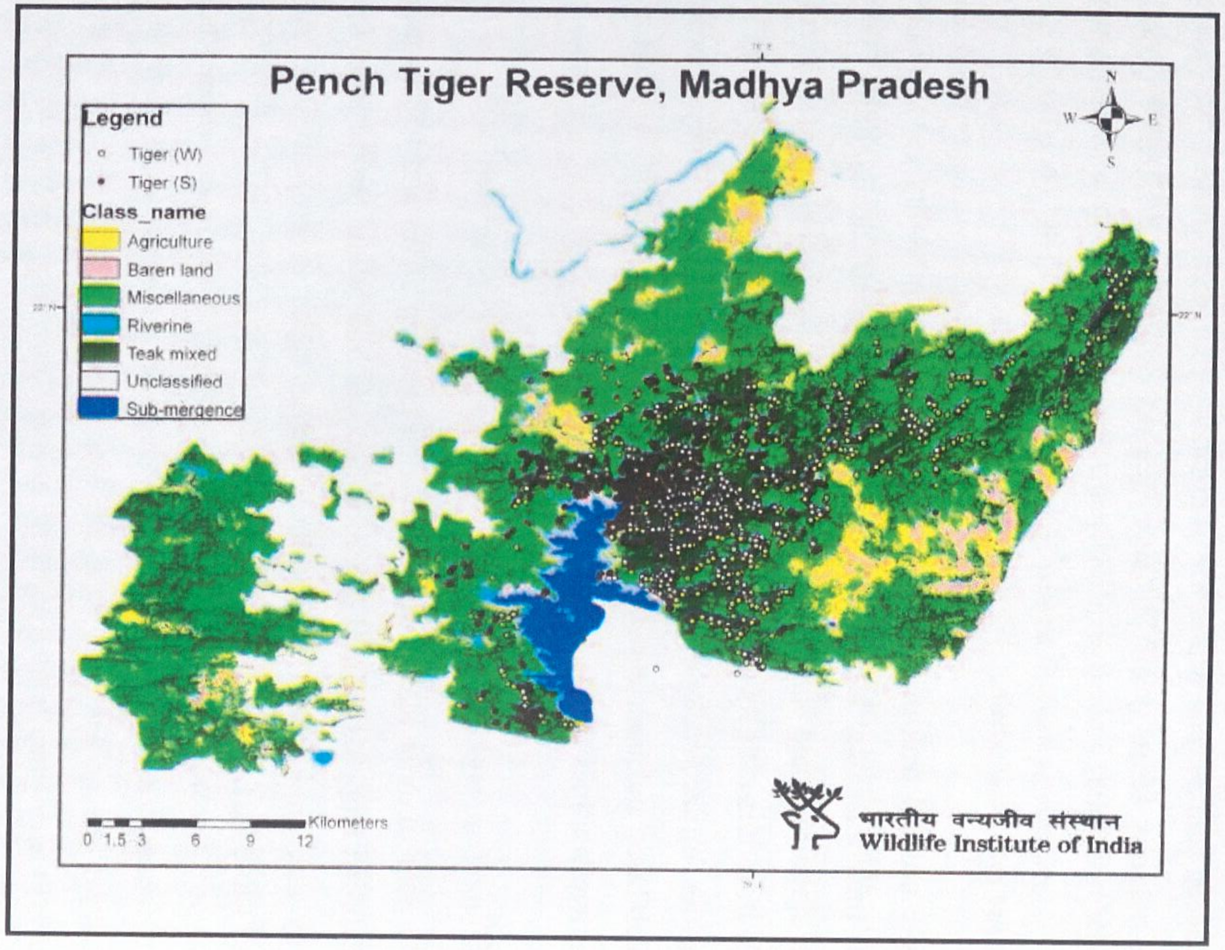


Fig 4.1. Distribution of tiger signs in different land use and land cover classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

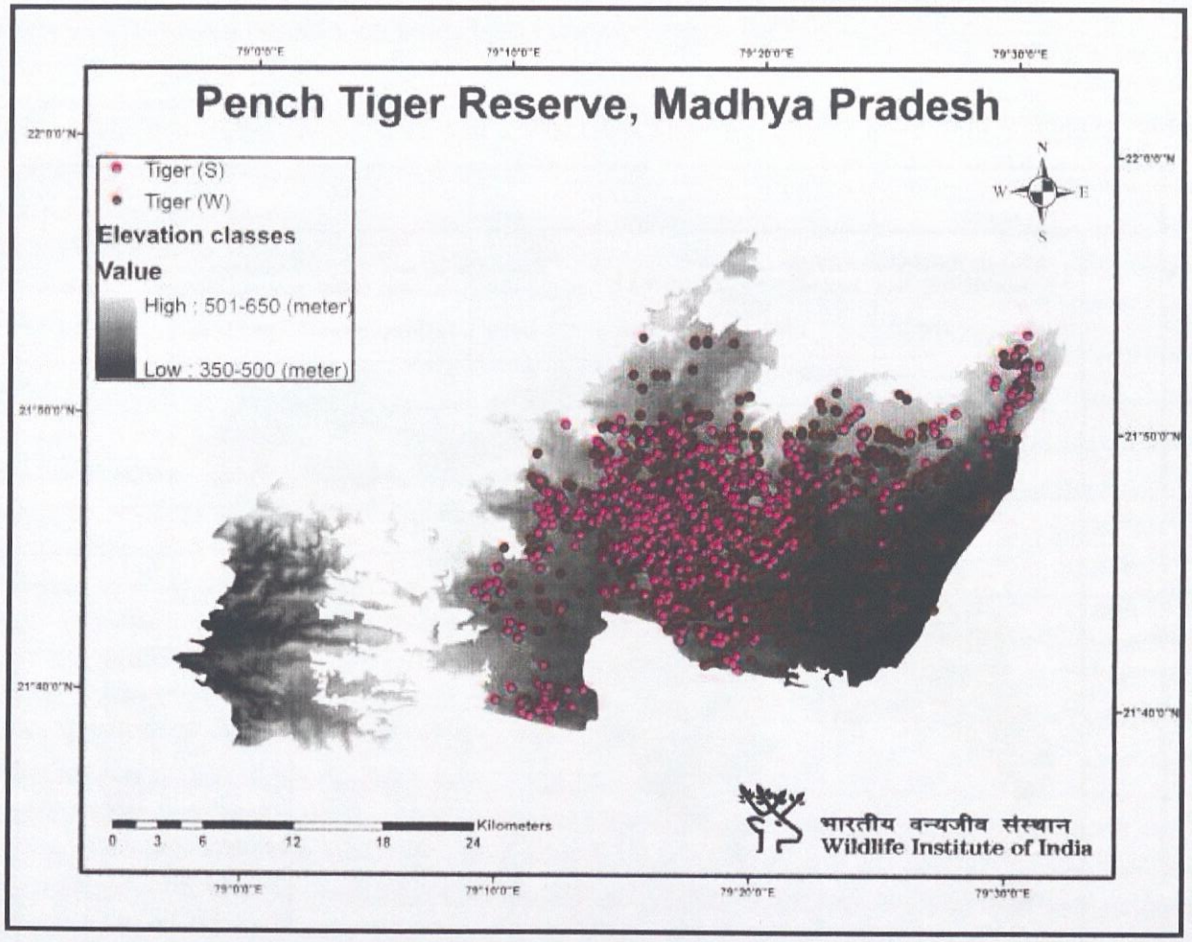


Fig. 4.2. Distribution of tiger signs in different elevation classes in Pench Tiger Reseprve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

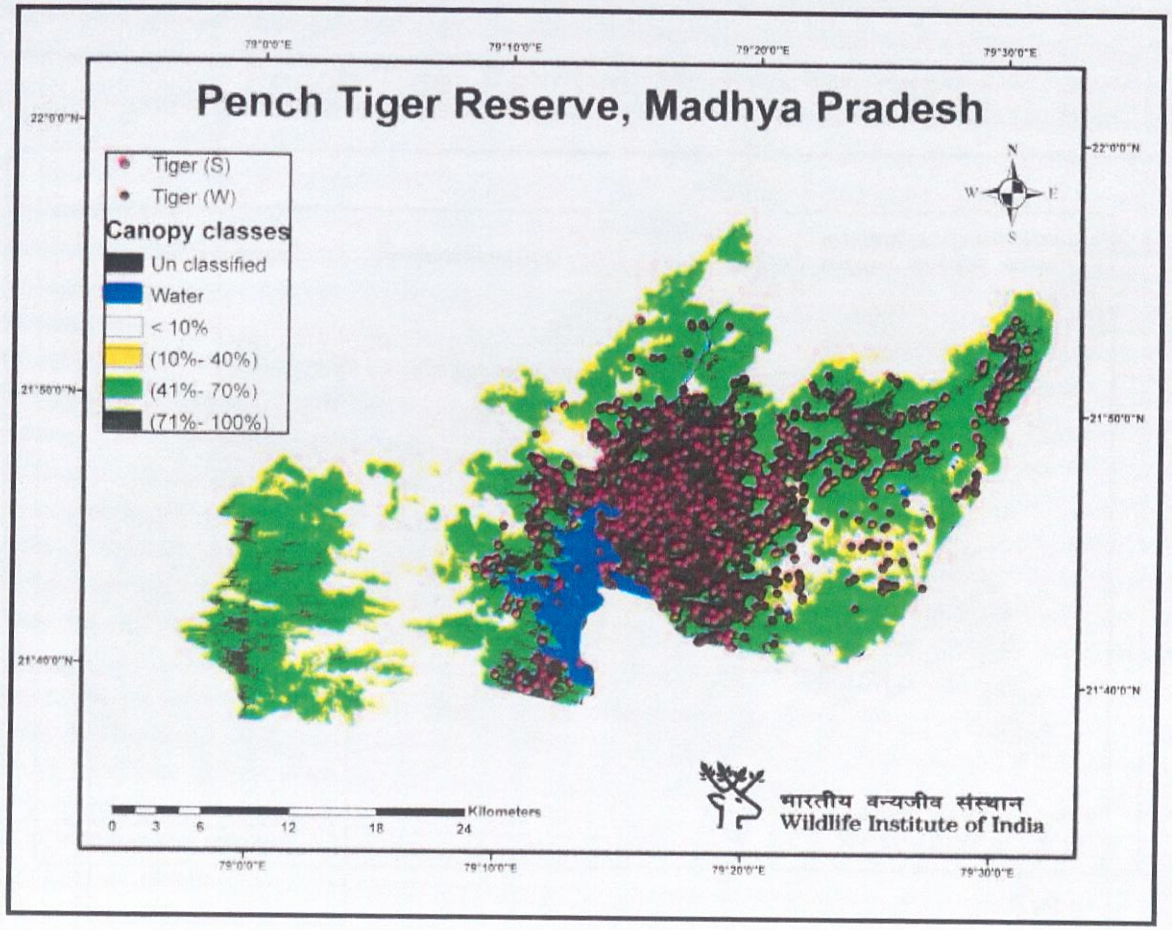


Fig.4.3. Distribution of tiger signs in different canopy classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

Table 4.1. Utilization of different land use and land cover types by tiger in winter and summer based on availability and utilization data in Pench Tiger Reserve, Madhya Pradesh between May 2006 and April 2011

Species	Landuse and landcover classes	No. of random points in each habitat	Proport-ion available	No. of carnivore signs in each habitat	Proport-ion used	Lower limit (W)	Upper limit (W)	Intensity of use	No. of carnivore signs in each habitat	Proport-ion used	Lower limit (S)	Upper limit (S)	Intensity of use
Tiger	Sub-mergence	36	0.031	5	0.004	-0.001	0.008	--	114	0.051	0.039	0.063	++
	Riverine	24	0.021	39	0.029	0.017	0.042	*	189	0.084	0.069	0.100	++
	Miscellaneous	429	0.375	455	0.349	0.314	0.384	*	721	0.322	0.296	0.348	--
	Agriculture	39	0.034	1	0.001	-0.001	0.003	--	3	0.001	-0.001	0.003	--
	Barren land	149	0.130	59	0.045	0.030	0.060	--	256	0.114	0.097	0.132	*
	Teak mixed	467	0.408	744	0.571	0.535	0.607	++	955	0.426	0.399	0.454	*

--used less than proportion available, * used in proportion to availability, + + used more than proportion availability (W) – winter and (S) – summer

Table 4.2. Utilization of different elevation types by tiger in winter and summer, based on availability and utilization data in Pench Tiger Reserve, Madhya Pradesh, between May 2006 and April 2011.

Species	Classes	DEM ranges in mtrs.	Number of Random points in each categories	Proportion of available categories	No. of carnivore signs in each categories	Proportion of used	Lower limit (W)	Upper limit (W)	Intensity of use	No. of carnivore signs in each categories	Proportion of used	Lower limit (S)	Upper limit (S)	Intensity of use
	Low	350-500	703	0.455	480	0.379	0.353	0.405	--	755	0.337	0.311	0.362	--
Tiger	High	501-600	843	0.545	786	0.621	0.595	0.647	++	1487	0.663	0.638	0.689	++

--used less than proportion available, * used in proportion to availability, + + used more than proportion availability (W) – winter and (S) – summer, mtrs- meters, DEM= Digital Elevation Model for Elevation types

Table 4.3. Tree canopy cover used by tiger in winter and summer based on availability and utilization data in Pench Tiger Reserve, Madhya Pradesh, between May 2006 and April 2011.

Species	Classes	Canopy density in(%)	Number of Random points in each canopy classes	Proportion of available canopy classes	No. of carnivore signs in each habitat	Proportion used	Lower limit (W)	Upper limit (W)	Intensity of use	No. of carnivore signs in each habitat	Proportion used	Lower limit (S)	Upper limit (S)	Intensity of use
Tiger	Non Forest	<10 %	136	0.115	76	0.067	0.049	0.086	--	50	0.031	0.020	0.042	--
	Open	10%-40%	67	0.057	16	0.014	0.005	0.023	--	6	0.004	0.000	0.008	--
	MDF	40%-70%	750	0.635	546	0.484	0.447	0.521	--	864	0.540	0.509	0.571	--
	VDF	70%-100%	229	0.194	490	0.434	0.398	0.471	**	679	0.425	0.394	0.456	++

MDF= Moderately Dense Forest, VDF= Very Dense Forest, --used less than proportion available, * used in proportion to availability, + + used more than proportion availability (W) – winter and (S) – summer.

4.3.3. Canopy classes

It was observed that, during winter, tiger used canopy cover between 70% and 100% in proportion to its availability, whereas canopy cover <10% (non-forest), 10% to 40% (open forest) and 40% to70% (moderately dense) were used less than their availabilities. In summer, tiger used canopy cover between 70% and 100% (very dense forest) more than its availability, whereas canopy cover < 10% (non-forest), 10% to 40% (open) and 40% to 70% (moderately dense) was used less than their availabilities (Table 4.3).

4.4. Discussion

The accuracy of habitat use estimates depends on how well the underlying assumptions were met. Tiger selectively utilized the habitat, and the pattern of selection differed among seasons. These seasonal differences suggested that habitat selection changed over time. The present study supported the findings of earlier studies in Indian sub-continent that tiger prefer dense forested habitats for their different biological activities (Seidensticker 1976, Biswas and Sankar, 2002, Edgaonkar, 2008, Jhala *et al.*2008). Tiger is a stealthy predator and stalk its prey from a certain distance before attacking (Hornocker, 1970, Seidensticker, 1976, Logan and Irwin, 1985). During the present study, evidences of tiger were mostly observed in teak-mixed and miscellaneous forests (>90%) in both summer and winter. The utilization of both teak mixed and miscellaneous forest more than their availabilities by tiger carnivores might be due to high abundance of sambar in these habitats. Acharya (1997) reported relatively higher heterogeneity both in tree composition and dense under storey found to be preferred habitat of sambar in the study area. The distribution of tiger evidences in hilly terrain (elevation 501-650 m) might be influenced by the distribution gaur in this habitat (Acharya, 1997). Tiger can potentially hunt on larger body sized prey species such as gaur (Ramesh, 2010, Majumder *et al.*2012). In PTR, especially during summer, tiger used riverine (8.4%) and submergence (5.1%) areas more (Table 4.1). This may be attributed to abundance of chital in both of these habitats (density 167/ km² from line transect). The fairly open canopy and availabilities of palatable grass species *Cynodon dactylon* probably attracted chital in both submergence (11.7 km²) and riverine habitats (12.5 km²). Thus, the habitat requirements of the prey combined with the prey preferences of tiger also influenced space use of large carnivores. Seidensticker (1976) found that, differences in use of habitat patches by tiger and leopard in Nepal was an important component of their ecological separation.

Another probable reason for tiger largely utilizing the submergence area may be due to the availability of dense bushes of *Lantana camara* along the Pench river bank which acts as cover for rearing cubs during their early growing stage (<2 years). The evaluation of denning sites (n=20) of four breeding female tigers (one radio-collared and three non collared) in the intensive study area showed that, they were found in high prey biomass area (pooled biomass of chital, sambar, nilgai, gaur, wild pig and common langur-9694.2 kg/km², total effort= 618.6 km using line transect method), with no anthropogenic disturbance and availability of water in all seasons (<200 m).

Tiger observed to avoid agricultural habitats present in the fringes of forest boundary (Table 4.1). As studied by Smith (1993) in Nepal, tiger probably used agricultural habitat during their dispersal from the natal area. Differences in habitat use, either temporally or spatially, have been recognized as behavioural characteristics that may promote survival of tiger (Partridge, 1978).

The study area offers a mosaic of ecological and habitat conditions, which effectively contributed to the maintenance of a rich assemblage of ungulates and primates in high numbers (Majumder *et al.*2012). This high prey base along with different habitat conditions in the study area is ideal for the sustenance and growth of tiger. Our study area Pench is connected with two other source-population sites of tigers i.e. Kanha Tiger Reserve and Satpura Tiger Reserve and forms one of the important units of meta-population structure of tiger in Central Indian Landscape (Qureshi *et al.*2006, Jhala *et al.*2010). Though the intensive study area is relatively undisturbed and no poaching of wild ungulates was recorded during the present study, there is continuous biotic pressure exert from the 99 villages located around the notified buffer zone of PTR, Madhya Pradesh (Qureshi *et al.*2006). Protection of the habitat in Pench and surrounding areas is crucial for the survival of tigers in this landscape.

Chapter 5
ESTIMATION OF PREY AVAILABILITY OF TIGER

5.1. Introduction

Conservation and management of an animal population requires reliable knowledge of the number of individuals in the area. Since ungulates make up the major part of tiger diet in various forests (Schaller 1967, Johnsingh 1983, Karanth and Sunquist 1995, Biswas and Sankar 2002, Bagchi et al.2003, Acharya et al.2007, Andheria et al.2007, Edgaonkar 2008, Ramesh 2010), understanding herbivore abundance therefore forms the basis for predator ecology studies. It is further supported by the logic that any effort towards conservation of tiger is preceded by an equal scale study on ungulate density estimation (Jhala et al.2008). It may also help in determining the capacity and suitability of different habitats to support the tiger. For long term survival of tiger it is important that the fundamental assumptions of established population estimation protocols for prey species do not compromise and should be scientifically institutionalized with the forest department. The ultimate aim is therefore to evolve a methodology that gives density estimates of prey population with acceptable accuracy and precision without requiring too much of resources or technical expertise in the study area.

5.2. Methods

5.2.1 Line transects

The line transects used in the presence study in PTR were established in 2005 and previously used for "Monitoring of tigers, co-predators, prey and their habitat" research project to estimate densities of prey species of tigers and its co-predators (Jhala et al.2005). During this study forest beat was considered as sampling unit and transects were laid on each beat (n=44) of the intensive study area. Forty four line transects which varied in length from 2 to 4 km (Fig. 4.1) were walked during winter (total effort= 1016 km) and summer (total effort = 2530 km). Student t-test (Zar 1984) showed significant difference ($p<0.05$) on visibilities of sighting distance of prey species between two seasons (summer and winter) hence we estimated densities of potential prey species such as chital, sambar, wild pig, nilgai, gaur and common langur from winter (2007 to 2010) and summer (2007 to 2012) line transect data separately (post stratified) and pooled or overall (season wise). Although barking deer and four horned antelope were sighted on the line transects in both seasons (summer and winter) but their densities were not estimated because of low sample size. Animal clusters were used as the analytical unit since individual data tends to underestimate true variance (Southwell and Weaver 1993). For each detection, the exact time, species, group size, group composition (age classes and sex, whenever possible) sighting angle and the sighting (radial) distance from the transect line were recorded. Transects were walked early in the morning in the first three hours after the sunrise when the animals are said to be most active (Schaller 1967).

Sighting angles were recorded using a see-through compass (Suunto KB 20). Sighting distances were measured accurately using a laser rangefinder (LRM 1500, Newcon Optik), thus preventing a bias in the density estimation process due to heaping (Buckland *et al.*1993). The best model was selected on basis of the lowest Akaike Information Criteria (AIC) (Burnham *et al.*1980, Buckland et al.1993).

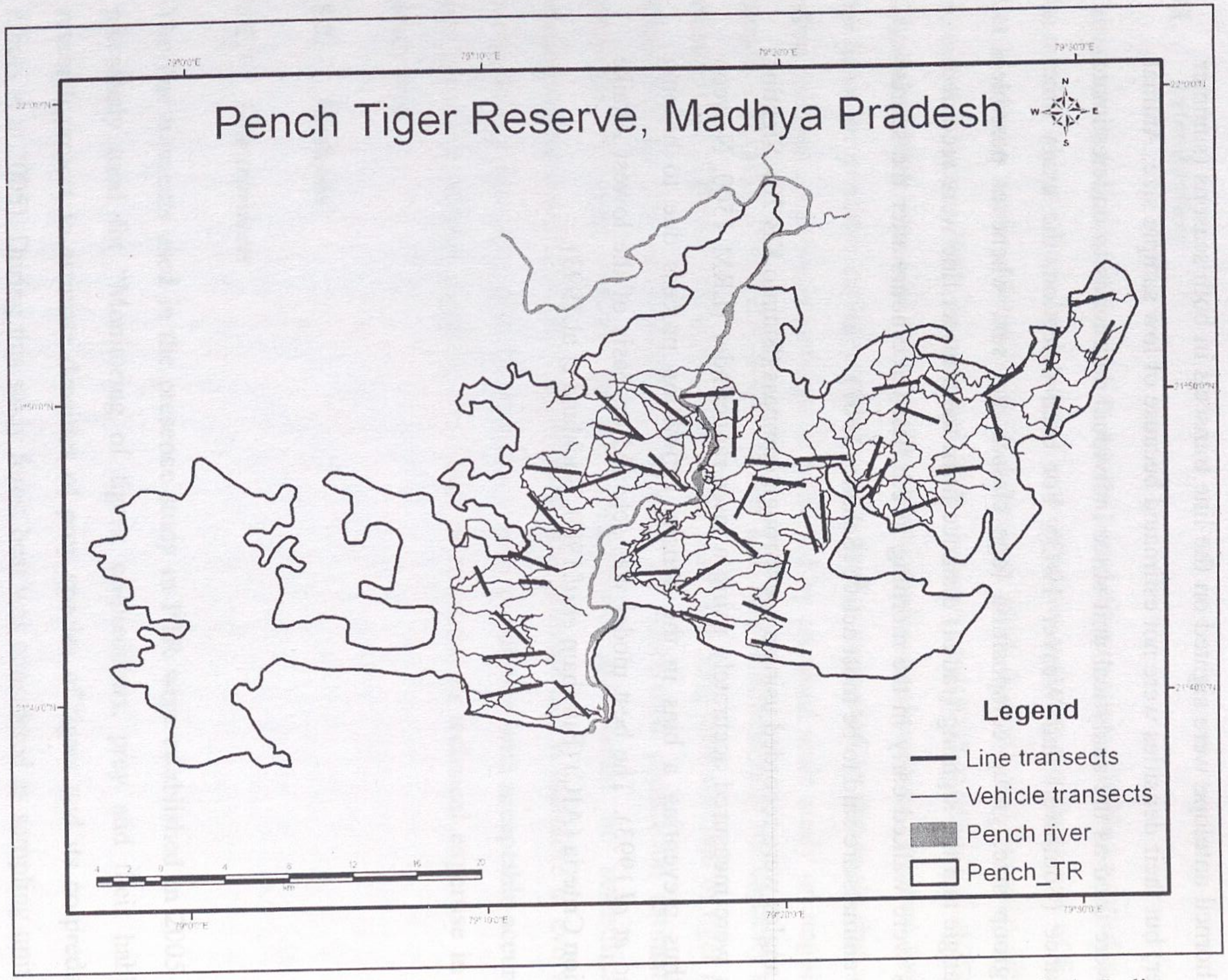


Fig. 5.1. Line transects and vehicle transects in Pench Tiger Reserve, Madhya Pradesh, India

5.3.2 *Vehicle transects*

Vehicle transects were used to estimate group size and composition of prey species of tiger in different part of India (Hirst 1969, Varman and Sukumar 1995, Ramesh 2010). Two observers monitored the transect route from a four wheel drive vehicle travelling at speeds less than 20 km/hr. The observers recorded on either side of the roads for sightings of prey species in early morning and late afternoon. The population structure and group size of five major wild ungulate species and common langur were recorded using vehicle-based road counts. Ten vehicle transect routes (Fig. 5.1) ranging from 2.7 to 13.6 km were monitored in each season (summer and winter) from 2007 to 2009. A total of 176.8 km was travelled during winter and 214.5 km for summer.

5.2.3. *Data analysis*

Line transects data were analyzed using program DISTANCE 5.0 (*Laake* et al.1993). The distribution of the data was first examined by assigning very small cutoff points to the distance intervals during the curve fitting, to detect evidences of evasive movements by the animals or heaping of data were truncated at suitable distances from the line. After choosing convenient cutoff points for the distance intervals, the best key function (with the appropriate adjustment term, where necessary) was selected using the criterion of lowest AIC (Akaike Information Criteria). The AIC is computed as AIC= -2 loge (£) + 2q, where loge (£) is the log likelihood function evaluated at the maximum likelihood estimates of the model parameters and q is the number of parameters in the model. AIC thus chooses the model with the best fit with the least terms (i.e. the most parsimonious model). The model selection was carried out only after the truncation and distance intervals were decided on since AIC cannot be used to choose between models that have different truncation distances (Buckland *et al.*1993).

Estimation of the variance associated with the mean density presented some difficulties since the theoretical variance estimated by program DISTANCE 5.0 is likely to be underestimated in biological populations, the underestimation in biological populations, may become more acute with species that are highly clumped.

Therefore, an over dispersion factor of 3, estimated to be a reasonable estimate for more biological populations (Buckland et al.1993, Burnham et al.1980) was applied.

To check the siginificant difference in densities between two different seasons, two sample T-test (with mean and SE) was done (Zar 1984) using program NCSS.

5.2.4. *Biomass estimation*

Earlier studies on ungulate densities in different parts of southern Asia (Karanth and Sunquist 1992, Khan *et al.*1996, Biswas and Sankar 2002, Jathanna 2001, Avinandan 2003, Acharya 2007, Ramesh 2010) stressed the need for extensive documentation of herbivore biomass of this region with standard census methodologies. Biomass of different prey species were computed by multiplying their estimated mean densities (pooled for all years) with the average body weight of respective species. Prey was categorized as small (5-30 kg), medium (31-175 kg), and large (176-1,000 kg) following Karanth and Sunquist (1992) and Sankar and Johnsingh (2002).

5.2.5. *Population structure of ungulates*

Living as a part of a group can increase foraging ability. The mean group size is a more sensitive measure of changes in group size due to the individuals remaining solitary or joining groups. An understanding of the structure and organization of a population is important for its long term conservation as it gives us information not only on the internal balance between various components (age and sex) of the population of a species, it also tells us how various components of a population interact with their environment (Pabla 1996).

McBridge (1976) suggested a structure for the study of social organization of animals. He stated that animal societies combine variations in only four structural features:

a) Species organize differently for periods of time, into social phases,

b) There are usually several types of individuals or classes (infants, juveniles, males and females) organized.

c) Animals normally aggregate into group characteristics of the species or they remain solitary, and

d) The group or individuals disperse in space in some regular patterns, such as territories or overlapping home ranges.

It was, however, not possible to analyze all the aspects of ungulate populations described by McBridge (1976), but many of his suggestions have been used. The population structure of a species is generally expressed as the proportion (ratio) of different age and sex classes and the changes that take place in these ratios under the influence of various ecological and intra-population factors (Schaller 1967). In any large sample of a population the two sexes are originally conceived in equal numbers although this parity may not persist until births because of prenatal mortality (Leopold 1933). Although some proportions of the sub adult and yearling population of some of the species are known to be capable of breeding (Graf and Nichols 1966, Schaller 1967), and a certain proportion of adults may not be actually breeding because of malnutrition or old age, in this analysis breeding population has been taken as synonymous with adult population, as both these factors may neutralize each other to some extent (Pabla 1996). Age classification of chital and sambar was followed by Schaller (1967), Sankar (1994) and gaur - Schaller (1967), Sankar et al. (2001). Age of female chital deer was categorized as follows, full grown > 30 kg as adults while < 30 kg as sub-adults. The male chital deer were classified into, adult (> 1 feet antlers) and sub-adult (spike and < 1 feet antlers). Fawns were considered if the size was equal to the height of the mother's belly. Gaur was classified into, adult males (shiny black coat with heavy horns sweeping sideways and upwards), sub-adult males (dark brown coat with a conspicuous dorsal ridge and small dewlap hanging below the chin, large drapes between the fore legs), yearlings (10-20 months old), adult females (smaller than adult males, pelage is dark brown with more upright horns corrugated inwards than in adult males), sub-adult females (50 - 75 % size of adult female lacking a conspicuous white stocking), female yearlings (light brown coat which were 25 to 50 percent size of sub-adult females), small calves (light brown coloured coat, approximately < 3 months old of < 30 kg), medium calves (light brown coloured coat of approximately 30 to 100 kg) and large calves (dark brown coloured coat which were half the size of yearling females). Male wild pigs were aged into adult males (well developed tushes and genital organs), sub-adult males (not well developed tushes and half the size of adult males), male yearlings (tushes not visible, genital organ and half the size of sub-adult males) and adult females (tushes not seen), subadult females (tushes not seen and half the size of adult females), female yearlings (half the size of sub-adult females). Piglets/stripper have brown coloured coat with black stripes on the dorsal region and are classified into small (half the size of large piglet and approximately <3 kg) and large (approximately 3-5 kg). Age and sex composition data on common langur could not be collected because of the difficulties in identifying different age/sex categories of this species in the field. Percentage of male and young ratio to 100 females was calculated from the group composition.

5.2.5.1. Group Size

Group size and group compositions are two important features of ungulate population which throws light on the ecology and adaptations of the species. Clutton Brock (1974) pointed out three principal advantages of group living:

a) Advantages related to defense or avoidance of predators.
b) Advantages related to finding or handling of food.
c) Advantages related to reproduction.

Data on group size and composition of prey species was estimated as suggested by Schaller (1967), Johnsingh (1983) and Karanth and Sunquist (1992). Average mean group size was estimated by taking the average of different group sightings and group size was classified into different class intervals for better interpretation between seasons. Observations on ungulates and primates from line transects and vehicle transects were pooled for two different seasons (winter and summer) of four years i.e. 2007, 2008, 2009 and 2010, to arrive at the population structure and grouping patterns of five ungulate species.

5.3 Results

5.3.1. Line transect

The effort and estimated individual prey species densities of chital, sambar, nilgai, wild pig, gaur and common langur for winter and summer (year wise and pooled) season using DISTANCE 5.0 are given below.

5.3.1.1. Chital

Chital or spotted deer was found to be the most abundant ungulate species in both winter and summer in the Intensive Study Area. Total number of observations for winter before truncation was 67 in 2007, 44 in 2008, 68 in 2009, 741 in 2010 and 920 in overall or pooled and truncating upto 150 m the observations was was 67 in 2007, 44 in 2008, 66 in 2009, 734 in 2010 and 911 in overall whereas for summer it was 61 in 2007, 40 in 2008, 242 in 2009, 929 in 2010, 588 in 2011, 700 in 2012 and 2560 in overall before truncation and after truncating upto 150 m it was 60 in 2007, 40 in 2008, 241 in 2009, 927 in 2010, 588 in 2011, 700 in 2012 and 2556 for overall observations. Half-normal cosine for both winter and summer were selected as the best fit estimator for computing effective strip width. The effective strip width for winter was 55.8 (SE ±1.4) m whereas for summer it was 51.7 (SE± 1.6) m. The density of chital was estimated to be 30 (SE±7.7)/ km² in winter 2007, 32 in winter 2008 (SE±10.1)/ km², 29.1 (SE±3.7)/ km² in winter 2009, 60 (SE±9)/ km² in winter 2010, and overall density in winter was 50 SE±7.1)/ km², whereas summer, it was 57 (SE ±18.7)/ km² in 2007, 40 (SE ±14.5)/ km² in 2008, 115 (SE ±20)/ km² in 2009, 70 (SE ±11.3)/ km² in 2010, 98.9 (SE± 13.4))/ km² in 2011, 150 (SE ±15.1)/ km² in and 91.7 (SE ±15.7)/ km² in overall summer (Table 5.1, Fig. 5.2a and 5.2b). Group densities of chital for summer and winter of 2007, 2008, 2009, 2010 and overall were presented in the Table 5.1.

Table 5.1. Densities of chital in Pench Tiger Reserve, Madhya Pradesh, during winter (2007 to 2010) and summer (2007 to 2012)

Parameters	Chital Winter					Chital Summer						
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	2011	2012	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	656	528	2350
Total Observations	67	44	68	741	920	61	40	242	929	588	700	2560
Truncated at	150					150						
Observation after Truncation	67	44	66	734	911	60	40	241	927	588	700	2556
Density ± SE	30±7.7	32±10.1	29.1±3.7	60±9	50±7.1	57±18.7	40±14.5	143±24.2	82±12.9	98.9±13.4	150±15.1	91.7±15.7
Group Density ± SE	7±1.8	6.8±1.9	3±0.8	8.9±1.2	7.8±1.1	9.6±2.8	5±1.5	15.6±2.4	9.6±1.4	8.6±1.1	12.8±1.1	10.2±1.5
Effective strip width	55.8±1.4					51.7±1.6						
AIC value	2023.7					5441.5						
Model+ Adjustment term	Half normal cosine					Half normal cosine						

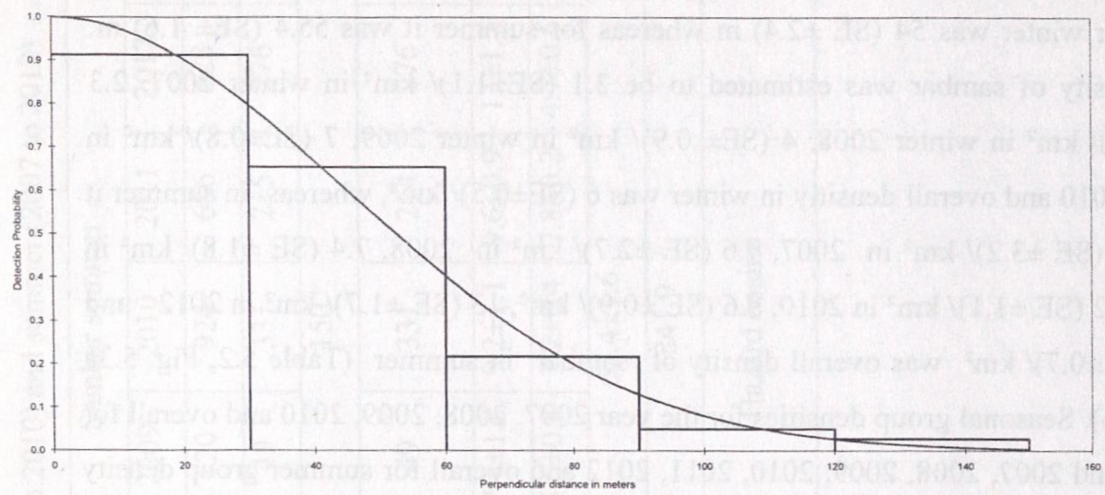


Fig. 5.2a. Probability of chital detections from line transect sampling (winter)

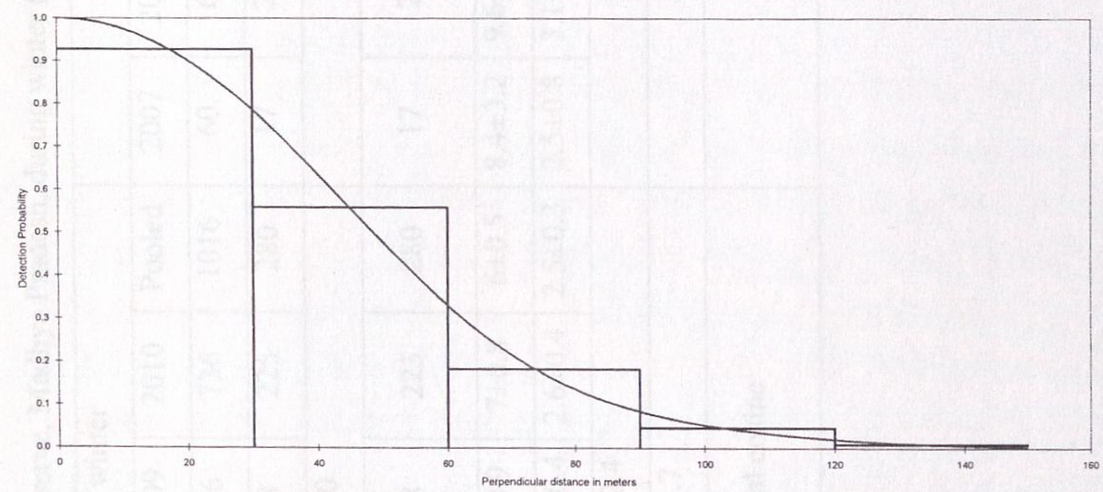


Fig. 5.2b. Probability of chital detections from line transect sampling (summer)

5.3.1.2. Sambar

The largest deer species found in PTR is sambar. Total number of observations for winter was in 17 in 2007, 10 in 2008, 28 in 2009, 225 in 2010 and 280 in overall or pooled and observations remained same after truncating upto 150 m. In summer, observation was 17 in 2007, 21 in 2008, 49 in 2009, 331 in 2010, 215 in 2011, 276 in 2012 and overall 909 before truncation and after truncating upto 150 m it was 17 in 2007, 21 in 2008, 49 in 2009, 321 in 2010, 214 in 2011, 276 in 2012 and 908 in overall. Half-normal cosine for winter and Hazard rate cosine for summer were selected as the best fit estimator for computing effective strip width. The effective strip width for winter was 54 (SE ±2.4) m whereas for summer it was 55.4 (SE± 1.6) m. The density of sambar was estimated to be 3.1 (SE±1.1)/ km² in winter 2007, 2.3 (SE±0.9)/ km² in winter 2008, 4 (SE± 0.9)/ km² in winter 2009, 7 (SE±0.8)/ km² in winter 2010 and overall densitiy in winter was 6 (SE±0.5)/ km², whereas in summer it was 8.4 (SE ±3.2)/ km² in 2007, 9.6 (SE ±2.7)/ km² in 2008, 7.4 (SE ±1.8)/ km² in 2009, 9.2 (SE ±1.1)/ km² in 2010, 9.6 (SE ±0.9)/ km², 13 (SE ±1.7)/ km² in 2012 and 9.5 (SE ±0.7)/ km² was overall density of sambar in summer (Table 5.2, Fig. 5.3a and 5.3b). Seasonal group densities for the year 2007, 2008, 2009, 2010 and overall for winter and 2007, 2008, 2009, 2010, 2011, 2012 and overall for summer group density were presented in Table 5.2.

Table 5.2. Densities of sambar in Pench Tiger Reserve, Madhya Pradesh, during winter (2007 to 2010) and summer (2007 to 2012)

Parameters	Sambar winter					Sambar summer						
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	2011	2012	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	656	528	2350
Total Observations	17	10	28	225	280	17	21	49	331	215	276	909
Truncated at	150					150						
Observation after Truncation	17	10	28	225	280	17	21	49	331	214	276	908
Density ± SE	3.1±1.1	2.3±0.9	4±0.9	7±0.8	6±0.5	8.4±3.2	9.6±2.7	7.4±1.8	9.2±1.1	9.6±0.9	13±1.7	9.5±0.7
Group Density ± SE	1.7±0.5	1.6±0.5	1.7±0.4	2.6±0.4	2.5±0.3	2.5±0.8	3.1±0.7	3.6±0.8	3.2±0.4	2.8±0.2	4.7±0.6	3.3±0.3
Effective strip width	54±2.4					55.4±1.6						
AIC value	618.7					1841.9						
Model+ Adjustment term	Half normal cosine					Hazard cosine						

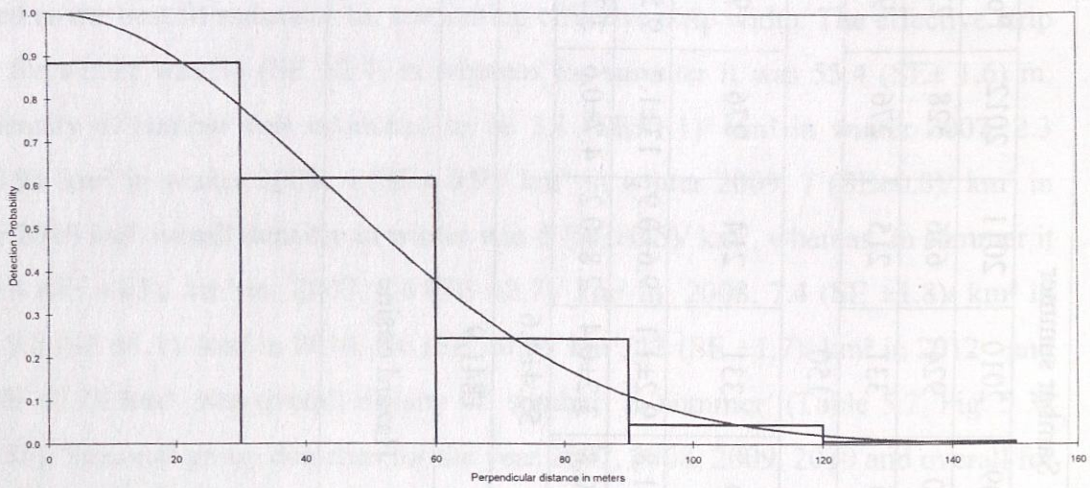


Fig. 5.3a. Probability of sambar detections from line transect sampling (winter)

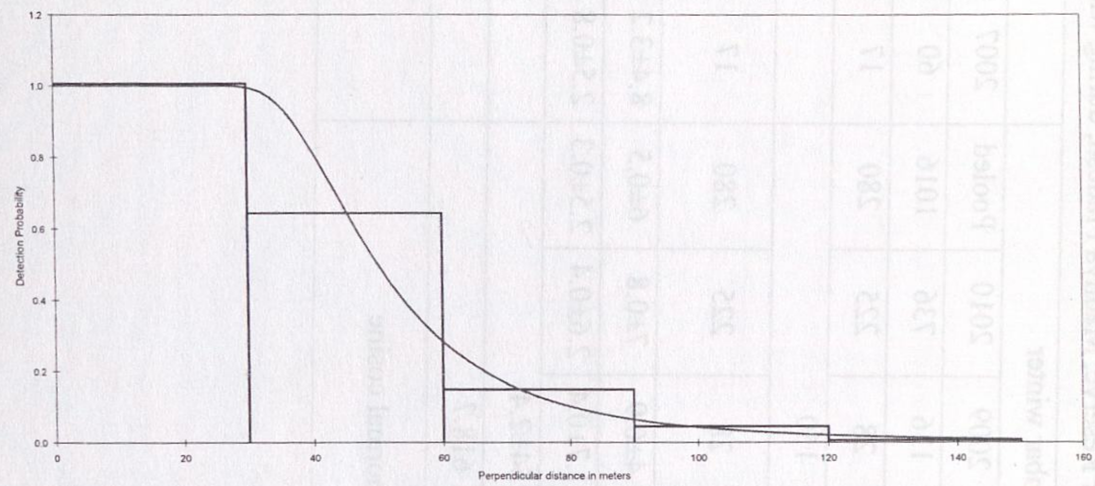


Fig. 5.3b. Probability of sambar detections from line transect sampling (summer)

5.3.1.3. Nilgai

Nilgai is the largest antelope species found in PTR. Total number of observations for winter was 2 in 2007, 4 in 2008, 6 in 2009, 83 in 2010 and 95 in overall or pooled and and truncating upto 150 m the observations remained same in 2007, 2008, 2009 and 81 in 2010 and 93 in overall whereas for summer it was 7 in 2007, 2 in 2008, 15 in 2009, 118 in 2010, 113 in 2011, 141 in 2012 and 396 in overall before truncation and after truncating upto 120 m observation remained same for the year 2007, 2008 and 2012, 14 in 2009 117 in 2010, 113 in 2011 and 394 for overall observations. Half-normal hermite polynomial for winter and Hazard rate for summer was selected as the best fit estimator for computing Effective Strip Width (ESW). The ESW for winter was 60.3 (SE ±5.6) m, whereas for summer it was 57.9 (SE± 2.8) m. The density of nilgai was estimated to be 0.3 (SE±0.2)/ km² in winter 2007, 1.1 (SE±0.5)/ km² in winter 2008, 3 (SE± 1.7)/ km² in winter 2009, 1.8 (SE±0.4)/ km² in winter 2010 and overall density in winter was 2 (SE±0.5)/ km², whereas in summer it was 2.5 (SE ±1.2)/ km² in 2007, 0.4 (SE ±0.3)/ km² in 2008, 2.1 (SE ±0.8)/ km² in 2009, 2.2 (SE ±0.3)/ km² in 2010, 4.3 (SE ±0.3)/ km² in 2011, 5.1 (SE ±0.7)/ km² in 2012 and 2.8 (SE ±0.7)/ km² was overall density of nilgai in summer (Table 5.3, Fig. 5.4a and 5.4b). Winter group densities for the year 2007, 2008, 2009, 2010 and summer group densities for the year 2007, 2008, 2009, 2010, 2011, 2012 and overall (pooled) were presented in Table 5.3.

Table 5.3. Densities of nilgai in Pench Tiger Reserve, Madhya Pradesh, during winter (2007 to 2010) and summer (2007 to 2012).

Parameters	Nilgai winter					Nilgai summer						
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	2011	2012	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	656	528	2350
Total Observations	2	4	6	83	95	7	2	15	118	113	141	396
Truncated at	150					120						
Observation after Truncation	2	4	6	81	93	7	2	14	117	113	141	394
Density ± SE	0.3±0.2	1.1±0.5	3±1.7	1.8±0.4	2±0.5	2.5±1.2	0.4±0.3	2.1±0.8	2.2±0.3	4.3±0.6	5.1±0.7	2.8±0.7
Group Density ± SE	0.2±0.1	0.6±0.3	0.6±0.2	0.9±0.2	0.8±0.1	1±0.3	0.3±0.2	0.9±0.2	1±0.1	1.4±0.1	2.3±0.3	1.2±0.2
Effective strip width	60.3±5.6					57.9±2.8						
AIC value	226.1					991						
Model+ Adjustment term	Half normal Hermite polynomial					Hazard rate cosine						

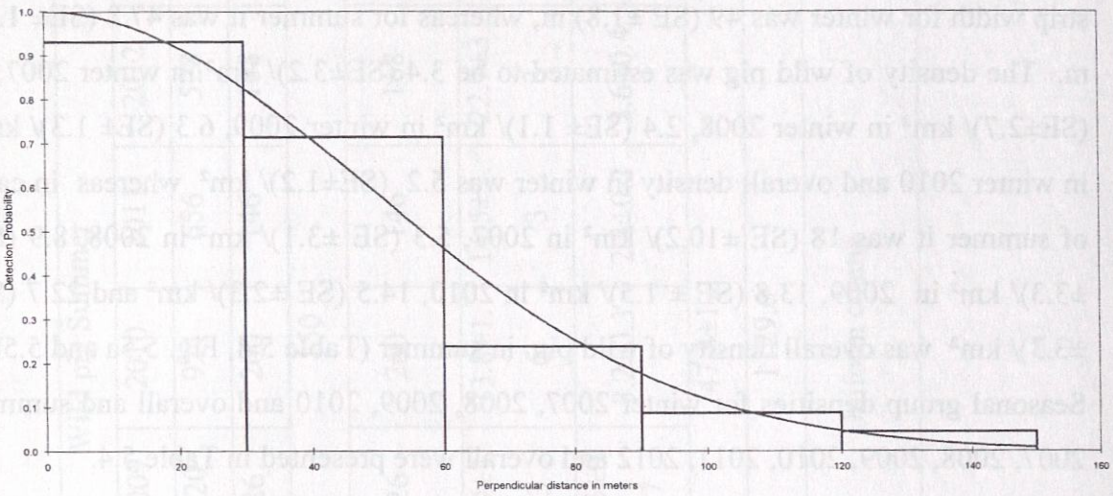


Fig. 5.4a. Probability of nilgai detections from line transect sampling (winter)

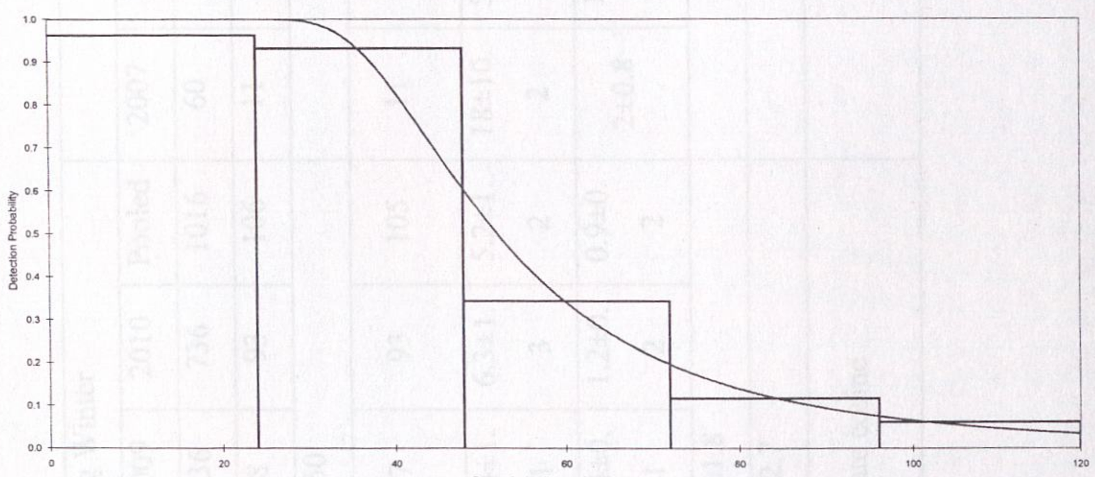


Fig.5.4b. Probability of nilgai detections from line transect sampling (summer)

5.3.1.4. Wild pig

Total number of observations for winter was 3 in 2007, 2 in 2008, 8 in 2009, 93 in 2010 and 106 in overall or pooled and and truncating upto 150 m the observations remained same in 2007, 2008, 2010 and 7 in 2009 and 105 in overall whereas for summer it was 11 in 2007, 8 in 2008, 26 in 2009, 260 in 2010, 146 in 2011, 168 in 2012 and 619 in overall before truncation and after truncating upto 150 m observation remained same. Hazard rate cosine for winter and Uniform cosine for summer were selected as the best fit estimator for computing effective strip width. The effective strip width for winter was 49 (SE ±1.8) m, whereas for summer it was 47.8 (SE± 1.2) m. The density of wild pig was estimated to be 3.4 (SE±3.2)/ km² in winter 2007, 3 (SE±2.7)/ km² in winter 2008, 2.4 (SE± 1.1)/ km² in winter 2009, 6.3 (SE± 1.3)/ km² in winter 2010 and overall density in winter was 5.2 (SE±1.2)/ km² whereas in case of summer it was 18 (SE ±10.2)/ km² in 2007, 5.3 (SE ±3.1)/ km² in 2008, 8.9 (SE ±3.3)/ km² in 2009, 13.8 (SE ± 1.5)/ km² in 2010, 14.5 (SE ±2.3)/ km² and 22.7 (SE ±3.3)/ km² was overall density of wild pig in summer (Table 5.4, Fig. 5.5a and 5.5b). Seasonal group densities for winter 2007, 2008, 2009, 2010 and overall and summer 2007, 2008, 2009, 2010, 2011, 2012 and overall were presented in Table 5.4.

Table 5.4. Densities of wild pig in Pench Tiger Reserve, Madhya Pradesh, during winter (2007 to 2010) and summer (2007 to 2012).

Parameters	Wild pig Winter					Wild pig Summer						
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	2011	2012	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	656	528	2530
Total Observations	3	2	8	93	106	11	8	26	260	146	168	619
Truncated at	150					150						
Observation after Truncation	3	2	7	93	105	11	8	26	260	146	168	619
Density ± SE	3.4±3.2	3±2.7	2.4±1.1	6.3±1.3	5.2±1.2	18±10.2	5.3±3.1	8.9±3.3	13.8±1.5	14.5±2.3	22.7±3.3	13.8±2.5
Group Density ± SE	0.4±0.2	0.3±0.1	0.4±0.1	1.2±0.2	0.9±0.2	2±0.8	1.4±0.5	2.5±0.7	3.2±0.3	2.4±0.2	3.6±0.4	2.5±0.3
Effective strip width	49±1.8					47.8±1.2						
AIC value	222.7					1129.6						
Model+ Adjustment term	Hazard rate cosine					Uniform cosine						

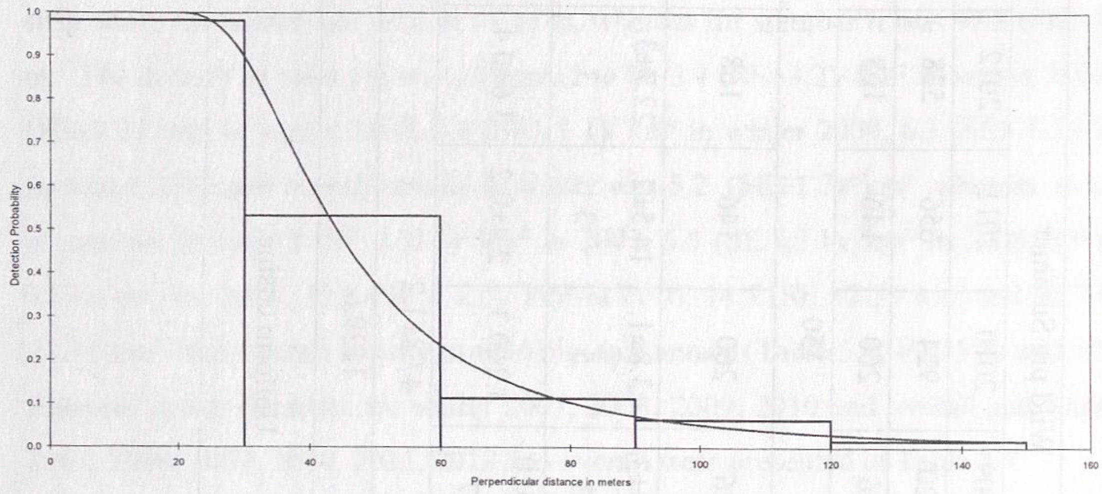


Fig. 5.5a. Probability of wildpig detections from line transect sampling (winter)

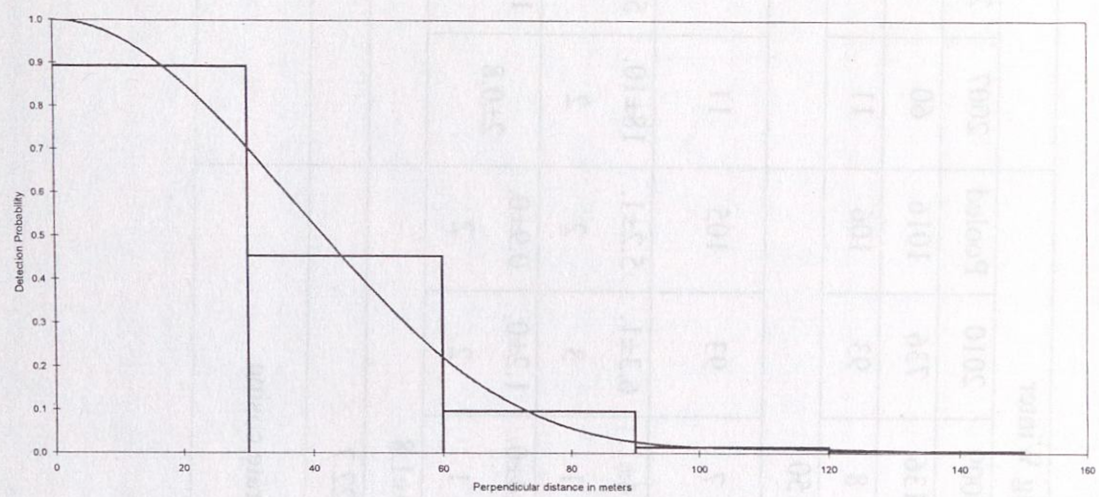


Fig. 5.5 b. Probability of wild pig detections from line transect sampling (summer)

5.3.1.5. Gaur

Gaur or Indian bison is the only mega herbivore species found in PTR. Total number of observations for winter was 5 in 2007, 1 in 2008, 2 in 2009, 26 in 2010 and 34 for overall or pooled and and truncating upto 100 m the observations remained same for all the years whereas for summer it was 0 in 2007, 3 in 2008, 0 in 2009, 38 in 2010, 32 in 2011, 50 in 2012 and 124 for overall. Half normal cosine for both winter and summer were selected as the best fit estimator for computing effective strip width.

The effective strip width for winter was 53.1 (SE ±7.1) m, whereas for summer it was 49.9 (SE± 3.3) m. The density of gaur was estimated to be 4 (SE±2.1)/ km² in winter 2007, 1.2 (SE± 0.4)/ km² in winter 2010 and overall density in winter was 5.4 (SE±1)/ km² whereas in summer it was 1.8 (SE ± 0.4)/ km² in 2010 , 3 (SE ± 1.3)/ km² in 2011, 5 (SE ± 1.2)/ km² in 2012 and 3.3 (SE ±0.9)/ km² was overall density of gaur in summer (Table 5.5, Fig. 5.6a and 5.6b). The density of gaur in winter 2008, 2009 and summer 2007, 2008 and 2009 was not assessed because of very low sample size. Seasonal group densities were assessed for the year 2007, 2010 and pooled in case of winter and 2010, 2011, 2012 and overall for summer (Table 5.5).

Table 5.5. Densities of gaur in Pench Tiger Reserve, Madhya Pradesh, during winter (2007 to 2010) and summer (2007 to 2012).

Parameters	Gaur Winter					Gaur Summer						
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	2011	2012	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	656	528	2530
Total Observations	5	1	2	26	34	0	3	0	38	33	50	124
Truncated at	100					150						
Observation after Truncation	5	1	2	26	34	0	3	0	37	32	50	122
Density ± SE	4±2.1	NA	NA	1.2±0.4	1.4±1	NA	NA	NA	1.8±0.4	3±1.3	5±1.2	3.3±0.9
Group Density ± SE	0.5±0.3	NA	NA	1.2±0.2	0.3±0.1	NA	NA	NA	0.4±0.07	0.5±0.1	0.9±0.1	0.6±0.1
Effective strip width	53.1±7.1					49.9±3.3						
AIC value	74.9					253.5						
Model+ Adjustment term	Half normal cosine					Half normal cosine						

NA- Not Assesed

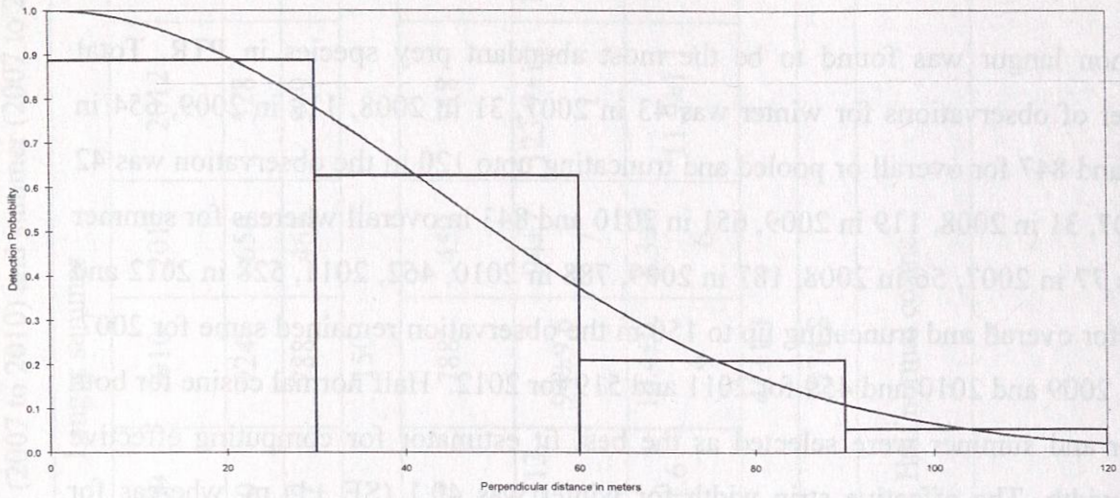


Fig. 5.6a. Probability of gaur detections from line transect sampling (winter)

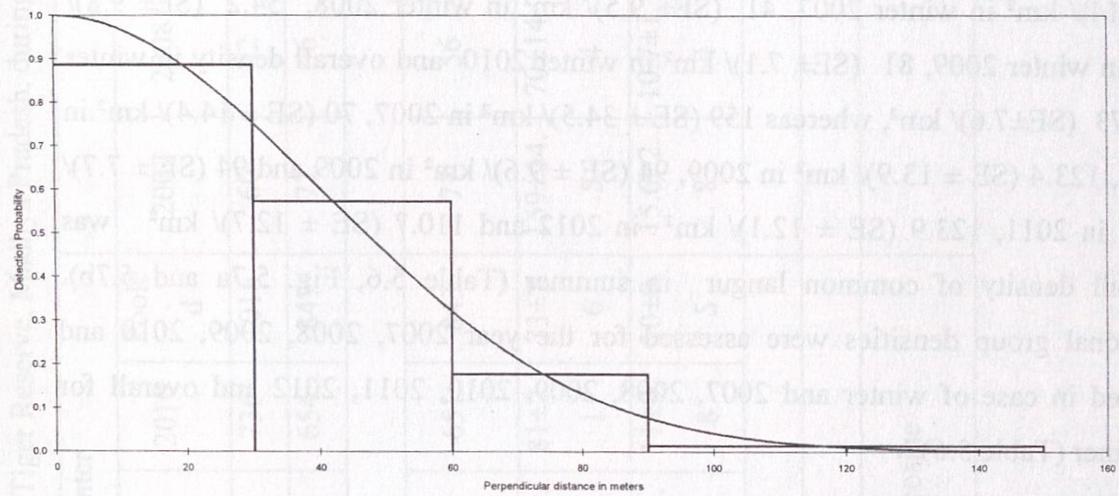


Fig. 5.6 b. Probability of gaur detections from line transect sampling (summer)

5.3.1.6. Common langur

Common langur was found to be the most abundant prey species in PTR. Total number of observations for winter was 43 in 2007, 31 in 2008, 119 in 2009, 654 in 2010 and 847 for overall or pooled and truncating upto 120 m the observation was 42 in 2007, 31 in 2008, 119 in 2009, 651 in 2010 and 843 in overall whereas for summer it was 77 in 2007, 56 in 2008, 187 in 2009, 788 in 2010, 462, 2011, 528 in 2012 and 2089 for overall and truncating up to 150 m the observation remained same for 2007, 2008, 2009 and 2010 and 459 for 2011 and 519 for 2012. Half normal cosine for both winter and summer were selected as the best fit estimator for computing effective strip width. The effective strip width for winter was 40.1 (SE ±1) m, whereas for summer it was 45 (SE± 1.1) m. The density of common langur was estimated to be 62 (SE±14)/ km² in winter 2007, 41 (SE± 9.5)/ km² in winter 2008, 54.2 (SE± 9.8)/ km² in winter 2009, 81 (SE± 7.1)/ km² in winter 2010 and overall density in winter was 73 (SE±7.6)/ km², whereas 159 (SE ± 34.5)/ km² in 2007, 70 (SE ± 14.4)/ km² in 2008, 123.4 (SE ± 13.9)/ km² in 2009, 94 (SE ± 9.6)/ km² in 2009 and 94 (SE ± 7.7)/ km² in 2011, 123.9 (SE ± 12.1)/ km² in 2012 and 110.7 (SE ± 12.7)/ km² was overall density of common langur in summer (Table 5.6, Fig. 5.7a and 5.7b). Seasonal group densities were assessed for the year 2007, 2008, 2009, 2010 and pooled in case of winter and 2007, 2008, 2009, 2010, 2011, 2012 and overall for summer (Table 5.6).

Table 5.6. Densities of common langur in Pench Tiger Reserve, Madhya Pradesh, during winter (2007 to 2010) and summer (2007 to 2012).

Parameters	Langur winter					Langur summer						
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	2011	2012	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	656	528	2530
Total Observations	43	31	119	654	847	77	56	187	788	462	519	2089
Truncated at	120					150						
Observation after Truncation	42	31	119	651	843	77	56	187	788	459	518	2085
Density ± SE	62±14	41±9.5	54.2±9.8	81±7.1	73±7.6	159±34.5	70±14.4	123.4±13.9	94±9.6	94±7.7	123.9±12.1	110.7±12.7
Group Density ± SE	6.1±1.1	6.7±1.2	10.3±1.7	11±0.8	10±0.5	15.6±2.8	10.7±1.4	19±1.6	10.4±0.9	8.3±0.6	11.9±1.1	12.6±1.6
Effective strip width	40±1					41±1.1						
AIC value	2036					3574.8						
Model+ Adjustment term	Half normal cosine					Half normal cosine						

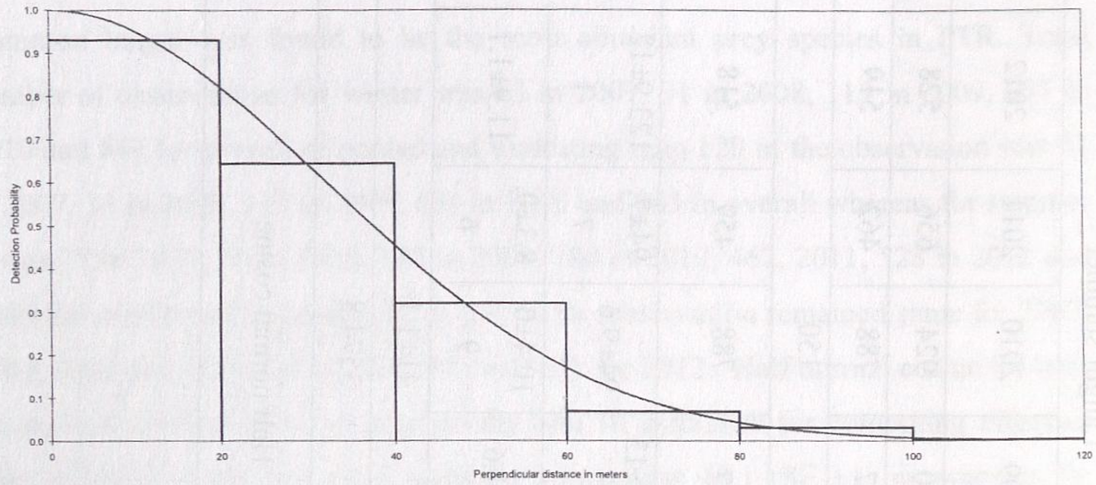


Fig. 5.7a. Probability of common langur detections from line transect sampling (winter)

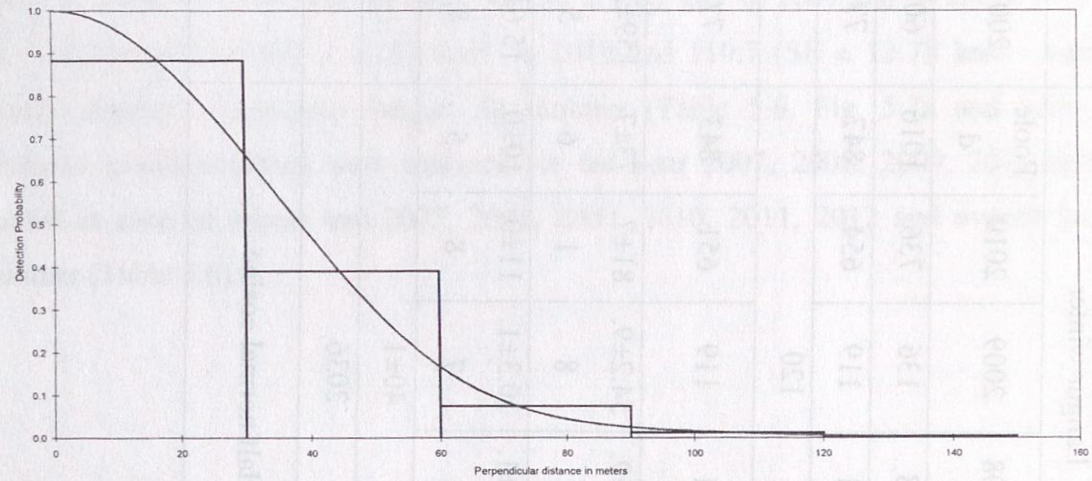


Fig. 5.7b. Probability of common langur detections from line transect sampling (summer)

5.3.2. Biomass estimation

The estimated mean biomass (on pooled densities) for six potential prey species from line transect was 4894.4 ± 1047 kg/ km^2 in winter and 8885.5±1573.4 kg/km^2 in summer where chital contributed maximum individual prey biomass in both winter and summer followed by gaur in winter, sambar in summer, common langur, nilgai and wild pig in both winter and summer (Table. 5.7).

Table 5.7. The estimated biomass of the prey species in Pench Tiger Reserve, Madhya Pradesh (2007 to 2012).

Species	Average body weight (Kg)	Biomass (W)	Biomass (S)
Chital	47	2350±334	4310.6±742.4
Sambar	134	804±67	1277.5±103.7
Nilgai	180	360±90	498±124
Gaur	450	630±450	1470±420
Wild pig	32	167±44.8	885.7±102.1
		4894.4±1046.3	8885.5±1573.4

D= Density, SE= Standard Error, Kg= Kilogram, Km = Kilometer * Karanth and Sunquist (1992), Sankar and Johnsingh (2002).

5.3.3. *Population structure*

The age and sex class distribution of five ungulate species in the study area for two different seasons (summer and winter) for four years (2007, 2008, 2009 and 2010) are given in Table 5.8. In case of wild pig only adult male, female and young ones were classified.

In total 1723 chital were recorded in winter (1053 on vehicle transect and 670 on line transect) and 6351 in summer (2822 on vehicle transect and 3529 on line transect) followed by sambar, 155 in winter (60 on vehicle transect and 95 on line transect) and 324 in summer (94 on vehicle transect and 230 on line transect), nilgai 58 in winter (31 on vehicle transect and 27 on line transect) and 94 in summer, gaur 156 in winter (122 on vehicle transect and 34 line transect) and 69 in summer (60 on vehicle transect and 9 on line transect) and 32 wild pig in winter (18 on vehicle transect and 14 on line transect) and 54 in summer (33 on vehicle transect and 21 on line transect). In case of chital adult female were observed maximum (%) in both winter (55.4%) and summer (57.7%) followed by adult male (23.6% in winter and 17.2 % in summer), young (9.9 % in winter and 19.1% in summer), yearling female (6.7% in winter and 2.7% in summer) and yearling male (4.5% in winter and 3.2% in summer). In case of sambar, adult female were observed maximum (49% in winter and 57.4% in summer) followed by adult male (21.3% in winter and 7.1% in summer), young (16.8% in winter and 23.5% in summer), yearling female (8.4% in winter and 5.6% in summer) and yearling male (4.5% in winter and 6.5% in summer). Incase of nilgai, adult female was observed maximum in both winter (44.8%) and in summer (39.4%) followed by adult male 25.9% in winter and 30.9% in summer, young 24.1% in winter and 16% in summer, yearling male 3.4% in winter and 4.3% yearling male in summer and yearling female 1.7% in winter and 9.6% in summer. In case of gaur, adult female were observed maximum in both winter 42.9% and 30.4% in summer followed by young 25% in winter and 17.4% in summer, yearling male 16% in winter and 11.6% in summer, adult male 9 % in winter and 17.4% in summer and yearling female 7.1% in winter and 23.2% in summer. In case of wild pig, adult females were observed maximum in both winter (37.5%) and summer (44.4%) followed by adult male 31.3% in winter and 33.3% in summer and young 31.3% in winter and 22.2% in summer.

Table 5.8. Proportions of different age and sex classes among different ungulate species in Pench Tiger Reserve, Madhya Pradesh (2007 to 2010)

	Winter						Summer					
Species	**Obs**	**AM**	**YM**	**AF**	**YF**	**YG**	**Obs**	**AM**	**YM**	**AF**	**YF**	**YG**
Chital	1723	23.6	4.5	55.4	6.7	9.9	6351	17.2	3.2	57.7	2.7	19.1
Sambar	155	21.3	4.5	49.0	8.4	16.8	324	7.1	6.5	57.4	5.6	23.5
Nilgai	58	25.9	3.4	44.8	1.7	24.1	94	30.9	4.3	39.4	9.6	16.0
Gaur	156	9.0	16.0	42.9	7.1	25.0	69	17.4	11.6	30.4	23.2	17.4
Wild pig	32	31.3	--	37.5	--	31.3	54	33.3	--	44.4	--	22.2

Obs= Total number of observations of particular species, AM= Adult Male, YM= Yearling Male, AF= Adult Female, YF= Yearling Female, YG= Young

The observed sex ratio was found to be skewed towards females in case of prey species such as chital, sambar, nilgai, gaur and wild pig (Table 5.9). The sex ratio (adult Female: adult Male) in case of chital during winter was 100:40 and adult female: fawn ratio was 100:20, whereas in summer these ratios were 100:30 and

100:30. Incase of sambar the adult sex ratio was 100:40 and female: young (fawn) ratio was 100:30 in winter whereas in summer these ratios were 100:10 and 100:30 respectively. Incase of nilgai the adult sex ratio (adult male: adult female) was 100:60 in winter and 100:80 in summer, whereas adult Female: young ratios were 100:50 for both winter and summer. Incase of gaur adult sex ratio was 100:20 in winter and 100:60 in summer, whereas adult female: young ratio was 100:60 in both winter and summer. In case of wild pig, adult sex ratio was 100:80 in both winter and summer, whereas adult female: young ratio was 100:80 in winter and 100:50 in summer.

Table 5.9. Seasonal variation in age-sex ratios among different ungulate species in Pench Tiger Reserve, Madhya Pradesh (2007 to 2010).

	Winter			Summer		
Species	**Obs**	**AF:AM**	**AF:Y**	**Obs**	**AF:AM**	**AF:Y**
Chital	1723	100:40	100:20	6351	100:30	100:30
Sambar	155	100:40	100:30	324	100:10	100:30
Nilgai	58	100:60	100:50	94	100:80	100:50
Gaur	32	100:20	100:60	69	100:60	100:60
Wild Pig	156	100:80	100:80	54	100:80	100:50

Obs= Total number of observations, AF= Adult Female, AM= Adult Male, Y= Young

Group size distributions of the ungulate species and common langur in the study area are presented in Table 5.10 to 5.15.

Table 5.10. Group size of chital in Pench Tiger Reserve,Madhya Pradesh for winter (2007 to 2010) and summer (2007 to 2012).

Year	Winter (%in each group size class)						Summer (%in each group size class)					
	Obs	1	2-3	4-10	11-30	30+	Obs	1	2-3	4-10	11-30	30+
2007	67	31.3	37.3	26.9	4.5	--	61	23.0	19.7	39.3	16.4	1.6
2008	44	13.6	40.9	36.4	9.1	--	40	22.5	27.5	30	12.5	7.5
2009	47	21.3	31.9	38.3	4.3	4.3	242	12.8	28.5	38.8	16.9	2.9
2010	742	13.9	26.4	41.8	15	3	929	9.3	19.1	43.3	23.7	4.7
2011	NA	NA	NA	NA	NA	NA	588	2.4	10.9	45.1	36.1	5.6
2012	NA	NA	NA	NA	NA	NA	700	6.4	14.7	45.1	28.4	5.3
Overall	898	15.3	28.3	40.5	13.5	2.4	2560	7.8	17.0	43.5	26.8	4.9

--not observed during the sampling period, Obs- total numbers of animal classified, N A- Not Assessed

In case of chital, the seasonal group size varied from 1 to 32 individuals during winter and from 1 to 120 during summer. In both summer and winter the medium group size i.e group comprised of 4-10 chital was found almost stable whereas solitary individual numbers decreased over the study period (Table 5.10). Amongst the overall chital population it was observed that larger group size i.e. group composed of 11-30 chital and more than 30 chital, were found maximum in summer than in winter. In case of chital, the estimated mean group size ± Standard Error or SE in winter was 4± 0.3 and in summer it was 9.8±0.25.

Table 5.11. Group size of sambar in Pench Tiger Reserve,Madhya Pradesh for winter (2007 to 2010) and summer (2007 to 2012).

Year	Winter (%in each group size class)						Summer (%in each group size class)					
	Obs	1	2-3	4-10	11-30	30+	Obs	1	2-3	4-10	11-30	30+
2007	17	58.8	35.3	5.9	--	--	17	17.6	52.9	29.4	--	--
2008	10	50	40	10	--	--	21	19.0	52.4	23.8	4.8	--
2009	28	32.1	46.4	21.4	--	--	49	40.8	44.9	14.3	--	--
2010	225	28.9	51.1	19.6	0.4	--	331	23.9	54.7	19.9	1.2	0.3
2011	NA	NA	NA	NA	NA	NA	215	16.7	46.0	36.7	0.5	--
2012	NA	NA	NA	NA	NA	NA	276	25.0	47.1	27.9	0.0	--
Overall	280	31.8	49.3	18.6	0.4	--	909	23.2	49.7	26.3	0.7	0.1

--not observed during the sampling period, Obs- total numbers of animal classified, N A- Not Assessed

In case of sambar, the overall seasonal group size varied from 1 to 5 individuals in winter and from 1 to 41 in summer. Alike chital, in case of sambar the medium group size i.e group size of 2-3 was found almost stable over the study period (Table 5.11). In case of sambar, the estimated mean group size ± Standard Error or SE in winter was 2.2±1.3 and in summer it was 2.9±0.07.

Table 5.12. Group size of nilgai in Pench Tiger Reserve,Madhya Pradesh for winter (2007 to 2010) and summer (2007 to 2012).

Year	Winter (%in each group size class)						Summer (%in each group size class)					
	Obs	1	2-3	4-10	11-20	30+	Obs	1	2-3	4-10	11-30	30+
2007	2	50.	50	--	--	--	7	28.6	42.9	28.6	--	--
2008	4	50	50	--	--	--	2	50	50	--	--	--
2009	6	16.7	50	33.3	--	--	15	80	6.7	13.3	--	--
2010	83	49.4	36.1	13.3	1.2	--	117	37.6	44.4	17.9	--	--
2011	NA	NA	NA	NA	NA	NA	112	18.8	48.2	33	--	--
2012	NA	NA	NA	NA	NA	NA	141	40.4	40.4	18.4	0.7	--
Overall	95	47.4	37.9	13.7	1.1	--	394	34.8	42.6	22.3	0.3	--

--not observed during the sampling period, Obs- total numbers of animal classified, N A- Not Assessed

In case of nilgai, the seasonal group size varied from 1 to 5 individuals in winter and from 1 to 13 in summer. On line transect, they were not found forming group size more than 30 individuals and they mostly formed medium group size i.e. groups size of 2-3 in both seasons during the study period (Table 5.12). The estimated mean group size ± Standard Error or SE in winter was 2.1±1.4 and in summer it was 2.5±0.1.

Table 5.13. Group size of wild pig in Pench Tiger Reserve, Madhya Pradesh for winter (2007 to 2010) and summer (2007 to 2012).

Year	Winter (%in each group size class)						Summer (%in each group size class)					
	Obs	1	2-3	4-10	11-30	30+	Obs	1	2-3	4-10	11-30	30+
2007	3	66.7	--	--	33.3	--	11	9.1	27.3	36.4	27.3	--
2008	2	--	50	--	50	--	8	50	37.5	12.5	--	--
2009	7	57.1	28.6	14.3	--	--	26	46.2	7.7	34.6	11.5	--
2010	93	34.4	19.4	34.4	11.8	--	260	35.8	20.8	33.1	10.4	--
2011	NA	NA	NA	NA	NA	NA	146	24.0	29.5	27.4	19.2	--
2012	NA	NA	NA	NA	NA	NA	168	24.4	18.5	39.3	17.3	0.6
Overall	105	36.2	20.0	31.4	12.4	--	619	30.0	22	33.3	14.5	0.2

--not observed during the sampling period, Obs- total numbers of animal classified, N A- Not Assessed

In case of wild pig, the seasonal group size varied from 1 to 28 individuals in winter and from 1 to 37 in summer. Medium group size i.e. group size of 2-3 wild pigs was found stable in both seasons over the study period (Table 5.14). The estimated mean group size ± Standard Error or SE in winter was 5.7±2.2 and in summer it was 5.2 ±0.2.

Table 5.14. Group size of gaur in Pench Tiger Reserve,Madhya Pradesh for winter (2007 to 2010) and summer (2007 to 2012).

Year	Winter (%in each group size class)						Summer (%in each group size class)					
	Obs	1	2-3	4-10	11-30	30+	Obs	1	2-3	4-10	11-30	30+
2007	5	--	60	40	--	--	0	--	--	--	--	--
2008	1	--	--	100	--	--	3	33.3	33.3	33.3	--	--
2009	3	66.7	0.0	33.3	--	--	--	--	--	--	--	--
2010	26	38.5	26.9	26.9	7.7	--	38	5.3	28.9	52.6	13.2	--
2011	NA	NA	NA	NA	NA	NA	33	21.2	18.2	42.4	18.2	--
2012	NA	NA	NA	NA	NA	NA	50	30.0	16	44	10	--
Overall	35	34.3	28.6	31.4	5.7	0.0	124	20.2	21	46	12.9	--

--not observed during the sampling period, Obs- total numbers of animal classified, N A- Not Assessed

In case of gaur, the seasonal group size varied from1 to15 individuals in winter and from 1 to 29 in summer. In both seasons, solitary individuals they were found maximum (more than 30%) during the study period (Table 5.14). In case of gaur, the estimated mean group size in summer was 5.4±0.4, whereas the winter data of gaur was not assessed because of low sample size.

Table 5.15. Group size of langur in Pench Tiger Reserve,Madhya Pradesh for winter (2007 to 2010) and summer (2007 to 2012).

Year	Winter (%in each group size class)						Summer (%in each group size class)					
	Obs	1	2-3	4-10	11-30	30+	Obs	1	2-3	4-10	11-30	30+
2007	43	2.3	16.3	51.2	30.2	--	77	10.4	22.1	37.7	29.9	--
2008	31	3.2	29.0	41.9	25.8	--	56	25	16.1	46.4	12.5	--
2009	119	13.4	22.7	61.3	2.5	--	187	16	21.9	49.2	12.8	--
2010	654	14.7	17.6	46.2	21.4	0.2	788	8.2	16.1	45.1	28.9	1.6
2011	NA	NA	NA	NA	NA	NA	462	1.5	6.1	46.5	44.4	1.5
2012	NA	NA	NA	NA	NA	NA	519	5.2	12.9	47	34.1	0.8
Overall	847	13.5	18.7	48.4	19.4	0.1	2089	52.2	13.8	46	31.8	1.1

--not observed during the sampling period, Obs- total numbers of animal classified, N A- Not Assessed

In case of common langur the seasonal group size varied from 1 to 23 individuals in winter and from 1 to 60 in summer. In both summer and winter they largely formed group size of 4-10 (more than 40%) during the study period (Table 5.15). The estimated mean group size in winter was 6.7±0.5 and in summer it was 8.9±0.1.

5.4. Discussion

5.4.1. Prey density and biomass

The accuracy of density estimates depends on how well the underlying assumptions were met. Line transects have been used widely to estimate populations of carnivore prey (Biswas and Sankar 2002, Bagchi *et al.*2003, Harihar 2005, Ramesh 2010). Since deriving prey species densities and biomass is essential in studies pertaining to predator ecology (Karanth and Sunquist 1995), line transect sampling in conjuncture with distance sampling methods are used. In most studies prey species estimates are derived for the entire protected area in concern (Karanth and Nichols 1998, 2000). During the present study the data was gathered using a laser rangefinder and compass to estimate the bearing and distance respectively to the animal group along the line transects for accurate data collection. Detections near the line, as shown by the low chi-square values for the first distance interval, were as expected for each model for all species. There was no evidence of heaping or a sharp drop-off indicating evasive movement in response to the observer for most species. Though this aids in arriving at estimates of densities for the entire area, no importance was given to the inherent variations in animal abundances and distribution. Since most species distributions are governed by various environmental variables, it is important to understand these sources of variation and estimate populations accordingly (Ramesh 2010).

Studies in PTR have used habitat of forest beats as the source of variation in animal distributions (Jhala *et al.*2008). Thus stratifying the area based on different habitat types helps to arrive at better ecological estimates of prey species densities.

The study area is dominated by fairly open canopy, mixed forest with considerable shrub cover interspersed with small open grassy patches. This condition of high habitat heterogeneity probably favoured the observed high density of browser and grazer (Eisenberg and Seidensticker 1976) such as sambar and chital respectively. The grass patches (*Cynodon dactylon*) found along the inundated areas of the Pench reservoir offered favourable feeding grounds for wild pig and chital during summer. As there is no village inside the intensive study area, competition for food between domestic livestock and wild ungulates was not observed during the present study. This undisturbed availability of food source of food resources may be attributed to the high abundance of wild ungulates in PTR.

Chital

Among all major ungulates chital by far were the most numerous of the prey species in PTR. This species dominates the landscape in Pench in terms of sheer numbers and biomass. Except for the hill-tops, they are found almost everywhere in the Reserve, forming huge aggregations in the green grassy patches sprouting from the receding waters of the reservoir. No significant difference in pooled densities of chital between summer and winter (p=0.3) was observed. The miscellaneous forest type, with moist-deciduous vegetation and gaps in the canopy had lots of grass. It was the favoured forest type for chital, demonstrated by their high densities in both seasons.

Sambar

There was a difference in pooled densities of sambar between winter and summer. Though they favoured dense forest patches (Biswas and Sankar 2002), the wide spread distribution of artificial water through hand pumps, operational in different parts of the study area during summer, may affect sambar distribution to some extent.

Nilgai

Nilgai because of the habitat they used were poorly represented on line transects in the study area, their population might have been underestimated. They mostly used open areas and relocated village sites (Biswas and Sankar 2002). No significant seasonal ($p>0.05$) difference was observed in densities of nilgai during the study period.

Wild pig

Wild pig showed seasonal variation in densities obtained. The palatable winter crops like wheat (*Triticum aestivum L*), corn (*Zea mays L.*), soyabean (*Glycine max (L.) Merr.*), chick peas (*Cicer arietinum L*) and yellow split peas (*Pisum sativum L.*) might have attracted them to move towards village habitation outside the study area during summer, whereas the availability of grass (*Cynodon dactylon* L.) a nutritious forage during late winter and early summer months along the banks of Pench river might have influenced their congregation in summer.

Gaur

Gaur, the largest of the wild cattle is more of a forest dwelling species, but also needs open grassy patches for foraging (Schaller 1967, Eisenberg and Seidensticker 1976, Biswas and Sankar 2002). Like nilgai, gaur also poorly represented on line transects and their density figures are probably underestimated. In the study area, they occurred in the areas along the water sources during summer were they were sighted frequently close to roads during the early morning and evening during winter and summer which probably led to their low sightings on the line transects.

Langur

Common langur was the most abundant prey species in the study area. This is attributed to the availability of food resources throughout the year in the study area (Majumder *et al.*2010).

Monitoring changes in densities of major prey species of tiger during study period

On comparing densities (± standard error or SE) of prey species during the study period in winter (Fig. 5.8a), it was evident that incase of chital, densities did not differ in first three years i.e 2007, 2008 and 2009 but differed in 2010. Incase common langur, densities (± SE)/ km²) did not differ between winter 2007 and 2008, 2008 and 2009 but there was a marginal difference between 2009 and 2010 (Fig. 5.8a). In case of sambar, nilgai, and wild pig, densities (± SE)/ km²) did not differ significantly (*p* >

0.05) over the period (Fig. 4.8a). In summer, sambar, nilgai and wild pig densities did not differ significantly (> 0.05) over the period (2007 to 2010) but a gradual fluctuation was observed in densities (± SE)/ km²) of chital and common langur over the period (Fig. 5.8b). The population of chital had shown an increasing trend from the year 2010 to 2012.

These changes in densities over the years might be because of various ecological factors. Sample sizes of gaur and nilgai found to be low except for the year 2010 because of their low detection on the line transects for the years 2007, 2008 and 2009. A long term ecological study is the need of the hour in PTR on these prey population covering their recruitment pattern and growth rate using comparable scientific methods.

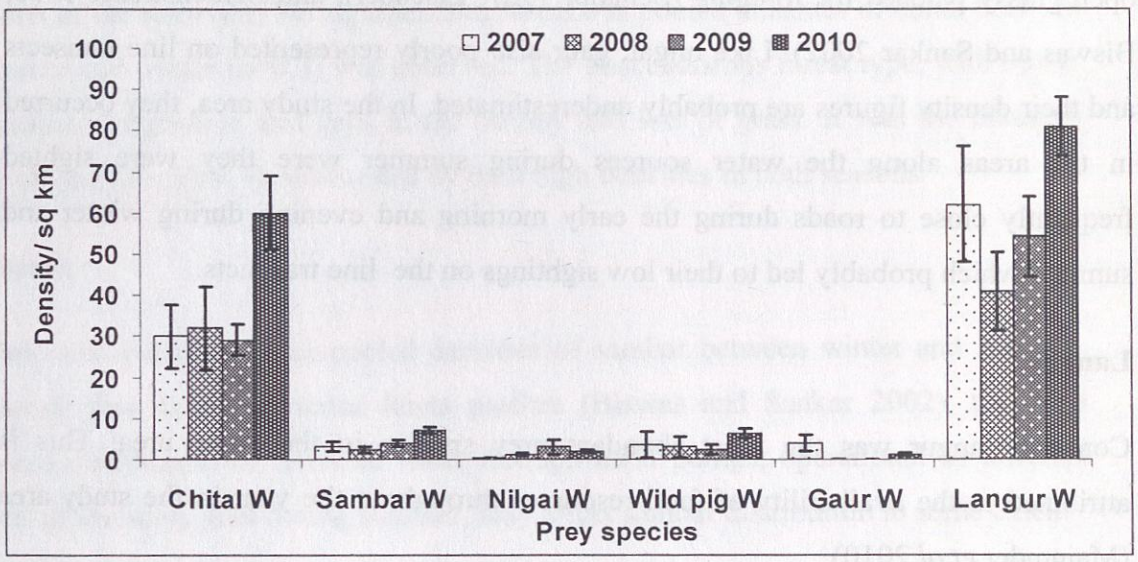


Fig. 5.8a Comparative densities (± SE)/ km² of major prey species of large carnivores in Pench Tiger Reserve during winter (2007 to 2010)

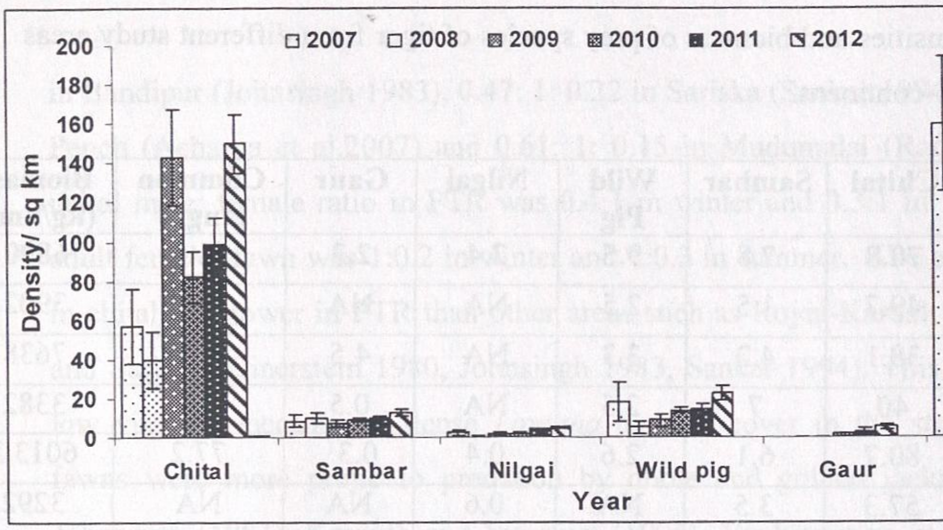


Fig.5.8b. Comparative densities (± SE)/ km² of major prey species of tiger in Pench Tiger Reserve during summer (2007 to 2012).

Biomass estimation

Since high prey biomass correlates to higher chances of survival of predator populations (Carbone and Gittleman 2002), such areas of high prey biomass need to be protected to ensure the survival of the species. The present study estimated overall (pooled both winter and summer) prey biomass of 6,890 kg/km^2 which is the fourth largest estimate of prey biomass density in the country followed by Sariska Tiger Reserve (Sankar et al.2010), Mudumalai Tiger Reserve (Ramesh 2010) and Nagarhole Tiger Reserve (Karanth and Nichols 1998) (Table 5.16). In Central and west Indian landscape, Pench harboured the third largest estimate of prey biomass after Sariska Tiger Reserve and Ranthambore Tiger Reserve. The reported chital and common langur density (pooled both winter and summer) in PTR is the highest in Indian Sub-continent (Table 5.16).

Table 5.11. Densities and biomass of prey species of tiger from different study areas in the Indian sub-continent.

Location	Chital	Sambar	Wild Pig	Nilgai	Gaur	Common langur	Biomass (kg/km^2)
Present study*	**70.8**	**7.8**	**9.5**	**2.4**	**2.3**	**81.5**	**6890**
Kanha[1]	49.7	1.5	2.5	NA	NA	NA	3902
Nagarahole[1]	38.1	4.2	3.3	NA	4.5	NA	7638
Bandipur[2]	40	7	2.5	NA	0.5	7.5	3382
Pench[3]	80.7	6.1	2.6	0.4	0.3	77.2	6013.3
Gir[4]	57.3	3.5	NA	0.6	NA	NA	3292
Bhadra[5]	4.5	0.9	NA	NA	1.5	22.6	1244.8
Bardia[6]	29.7	NA	4.2	5.0	NA	NA	2842
Chitwan[7]	17.3	2.9	5.8	NA	NA	NA	2933
Kaziranga[1]	NA	NA	2.6	NA	NA	NA	4252
Ranthambore[8]	31	17.2	9.8	11.3	NA	21.7	6429.8
Chilla[9]	56.2	24.2	6.1	4.3	NA	NA	6878.2
Bori-Satpura[10]	5.4	4.0	1.8	1.6	0.8	28.3	1721.8
Mudumalai[11]	55.3	2.8	0.4	NA	11.4	25.9	8365.2
Sariska[12]	46.7	26.2	19.5	15.4	NA	22.8	10072.8

[1] – Karanth and Nichols 1998 , [2] - Johnsingh 1983 , [3] – Biswas and Sankar 2002 , [4] – Khan *et al.*1996, [5] – Jathanna 2001 , [6] – Dinerstein 1979 , [7]– Seidensticker 1976b , [8] – Bagchi *et al.*2003 , [9] – Harihar 2005 , [10] – Edgaonkar 2008 , [11] Ramesh *et al.*2009 , [12] Sankar *et al.*2010 *- Present study (Overall density and biomass i.e. sum of winter and summer of prey species in PTR). NA= Data not available.

5.5.2. *Population structure of prey species*

Living as a part of a group can increase foraging ability. Schaller (1967) and Eisenberg and Lockhart (1972) reported that chital and sambar do not remain in permanent social groups. Group composition of chital was observed to change frequently during feeding periods (Dinerstein1980).

Chital male: female sex ratio was 0.77: 1 in Hawaii (Graf and Nichols 1966), 0.69: 1in Corbett and 0.70: 1 in Kanha (Schaller 1967), 0.72: 1.0 in Nagarahole (Karanth and Sunquist 1992) and 1: 0.2 in Gir (Khan et al.1996). The average male: female: fawn ratio was 0.57: 1: 0.53 in Royal-Karnali Bardia (Dinerstein 1980), 0.66: 1: 0.49

in Bandipur (Johnsingh 1983), 0.47: 1: 0.22 in Sariska (Sankar 1994), 0.50: 1: 0.27 in Pench (Acharya et al.2007) and 0.61: 1: 0.15 in Mudumalai (Ramesh 2010). The chital male: female ratio in PTR was 0.4:1 in winter and 0.3:1 in summer where as adult female: fawn was 1:0.2 in winter and 1:0.3 in summer. The average fawn ratio in chital was lower in PTR than other areas such as Royal-Karnali Barida, Bandipur and Sariska (Dinerstein 1980, Johnsingh 1983, Sankar 1994). This is may be due to low visibility because of dense *Lantana camara* cover in the study area or chital fawns were more prone to predation by dhole and golden jackal as reported by Johnsingh (1983), Karanth and Sunquist (1995), Venkatraman *et al.*(1995), Sankar and Acharya (2004) and Majumder *et al.*(2011). Chital sex ratio (male: female) in PTR was skewed towards females and similar findings were reported by other studies (Graf and Nichols 1966, Schaller 1967, Dinerstein 1980, Johnsingh 1983, Karanth and Sunquist 1992, Khan et al.1996, Ramesh 2010).

In PTR, the observed sambar male: female ratio was 0.40: 1 in winter and 0.1:1 in summer. The observed sambar low male ratio might be due to selective predation by tiger on male sambars as reported in other studies (Johnsingh 1983, Schaller 1967, Karanth and Sunquist 1992). In south Asian ungulates, solitary habits, proneness to injuries from intra-specific aggression, lack of antlers during rut, and dispersal behaviour have been considered as some of the factors which make males more vulnerable to selective predation (Johnsingh 1983, Schaller 1967, Karanth and Sunquist 1992). Sambar male: female sex ratio of present study can be comparable with Mudumalai 0.29: 1 (Ramesh 2010), Kanha 0.27: 1 (Schaller 1967), Mudumalai 0.11: 1 (Varman and Sukumar 1993), Sariska 0.22: 1 (Sankar 1994), Pench 0.22:1 (Acharya et al.2007), Gir, 0.5: 1 (Khan et al.1996), Wilpattu 1.2: 1 (Eisenberg and Lockhart 1972), Texas, 102: 1 (Richardson 1972), Florida, 0.73: 1 (Flynn et al.1990) and Ranthambore, 0.83: 1 (Bagchi et al.2008). In Kanha, sambar fawns were seen from April to December and the peak fawning period was observed in May and June (Schaller 1967). The female: fawn ratio in sambar was 1: 0.27 in Texas (Richardson 1972), 1: 0.41 in Bandipur (Johnsingh 1983), 1: 0.22 in Florida (Flynn et al.1990), 1: 0.12 in Mudumalai (Varman and Sukumar 1993), 1: 0.27 in Sariska (Sankar 1994), 1: 0.1 in Gir, (Khan et al.1996) and 1: 0.3 in Pench (Acharya et al.2007). The overall gaur male: female ratio was 0.2:1 in winter and 0.6:1 in summer, which was similar as reported in Mudumalai (0.42: 1) (Ramesh 2010), Kanha (0.38:1) (Schaller 1967), Parambikulam (0.45: 1) (Vairavel 1998), Tadoba (0.47: 1) (Dubey 1999) and Pench (0.6: 1) (Sankar et. al. 2001). The female: calf ratio was 1:0.6 in winter and 1:0.6 in summer, which is comparable to an earlier study in Pench (1:0.24) (Sankar *et al.*2001), Mudumalai (1:0.26) (Ramesh 2010), Kanha (1:0.46) (Schaller 1967) and Parambikulam (1: 0.16) (Vairavel 1998).

The male: female ratio of wild pig in PTR (0.8:1 in winter and 0.8:1 in summer) was found higer than Mudumalai (0.64: 1) (Ramesh 2010) and Nagarahole (0.53: 1) (Karanth and Sunquist 1992).

Schaller (1967) and Eisenberg and Lockhart (1972) reported that chital and sambar do not remain in permanent social groups. Group composition of chital was observed to change frequently during feeding periods (Dinerstein 1980). Smaller group sizes in forest habitats are presumably a consequence of food being more dispersed and scattered throughout the habitat (Jarman 1974, Mishra 1982, Johnsingh 1983, Karanth and Sunquist 1992, Ramesh 2010). Sartaj *et al.*(2010) reported that chital group size was more in open areas. Chital group size may vary from 1 to 150 individuals or more depending upon circumstances (De and Spillit 1966, Schaller 1967, Eisenberg and Lockhart 1972, Krishnan 1972, Fuchs 1977, Balasubramaniam *et al.*1980). Mishra (1982) reported a higher percentage of chital group size between 5 and 10 individuals with a mean group size of 7.5 in Chitawan National Park. Chital group size in Karnali - Bardia (Dinerstein 1980) varied from 1 to 91 individuals with a mean group size of 10.7, while in Sariska, chital group size varied from 1 to 88 individuals with mean group size 7.8 ± 8.3 (Sankar 1994). Barrette (1991) reported that chital group size varied from 2 to 125 individuals in Wilpattu with a mean group size of 6. In sambar, group size was small, numbering fewer than 6 individuals (Jerdon 1874, Schaller 1967). The characteristic social unit in sambar is one hind and one fawn or one hind, one yearling and one fawn (Schaller 1967, Kelton 1981, Downes 1983). Family groups usually travel in a single file led by the adult female (Kelton 1981). Lewis *et al.*(1990) recorded that during the rut, dominant stags were frequently seen with hinds and occasionally with other stags who may challenge the dominant stag for breeding rights. In PTR, smaller group size of 1-5 individuals of sambar comprised >70 percent in their population throughout the year. Similar findings were reported in Mudumalai (Ramesh 2010). Eisenberg and Lockhart (1972) commented that water holes are places where sambar populations come together in late evenings to form temporary aggregations before dispersing for food. Johnsingh (1983) also recorded large association of sambar near water holes and feeding sites in Bandipur. In Sariska, drought affected the reproductive rate of sambar in summer and resulted in low fawn ratio (Sankar 1994). In case of gaur group size the findings in PTR is comparable with Mudumalai (Ramesh 2010) (group size was 1- 42), an earlier study in Pench (Sankar et al.2001) (group size 2 – 19), with Kanha (Schaller 1967) (groups size 2 – 40) and Jaldapara (Bhattacharyya et al.1997) (group size 1 – 70).

In case of wild pig, the present study was comparable with Mudumalai (Ramesh 2010), where a maximum of 29 wild pigs were observed and Bandipur (Johnsingh 1983) where a maximum of 32 wild pigs were observed. The basic social group in wild pigs includes one or more females and their last litters (Chauhan 2004). Johnsingh (1983) also made similar observation in Bandipur. Wild pig peak oestrous activity has been recorded during the wetter months i.e. November and December in Sri Lanka (Santiapillai et al.1982). The reproductive activity in pigs tends to be seasonal and positively correlated with the relative availability of food or climatic factors (Chauhan 2004). On one occasion a mother was seen with 10 piglets in PTR.

The largest group of gaur (n>15) mostly frequented grassland areas close to water sources in the morning and evening in the study area. The abundance of food resources played a major role in grouping of the folivorous langur. A combination of factors is responsible for their high abundance in PTR. First they were found to be less preferred by large carnivore species found in the study area as compared to their availability (Biswas and Sankar 2002). Second, the study area is dominated by fairly open canopy, mixed forest with considerable shrub cover interspersed with small open grassy patches. Population of common langur is also subjected to extreme seasonality, with great fluctuations in climate and vegetation between summer and winter seasons (Newton 1987). Although, the study area is mostly tropical dry deciduous forest (Champion and Seth 1968), not all plant species loose their leaves at the same time. Many plant species are in their deciduous phase in some parts of the study area while others remain in leaf. Therefore, regular availabilities of food resources in the study area for common langur helped to recruit them though out the year in PTR (Majumder et al.2010).

PTR, thus offers a mosaic of ecological and habitat conditions, which effectively contributed to the maintenance of a rich assemblage of ungulates and primates in high densities.

Chapter 6
PREY SELECTION AND FOOD HABITS OF TIGER

6.1. Introduction

Acquisition of food is a fundamental component of every organism's existence (Miqulle et al.1996). Predators are crucial elements of the ecosystem for maintaining and shaping the structure of the communities by regulating the prey population and maintaining the biodiversity of the ecosystems (Glasser 1979). Canids and felids have specialized to become the most successful top predators in many terrestrial ecosystems. Information on their feeding ecology contributes substantially to the understanding of their behavioural ecology (Mills 1992). Prey availability and distribution can influence prey selection and hunting success (Acharya et al.2007), as well as activity patterns and spatial distribution (Henschel and Skinner 1990). Wide diversity, high abundance and regular presence of predators are sure signs of a broad range of prey species and of sustained biodiversity within ecosystems generally (Wilson 1993).

Although tiger can potentially hunt prey varying from small mammals to the largest of the bovids, the mean weight of species hunted is around 60 kg. This is obtained predominantly from deer species, which contribute up to 75% of the prey biomass requirement of the tiger in most parts of its range (Sunquist et al.1999).

The identification of food remains found in faces is the most common method for analyzing carnivore food habits. This method has been found to be useful for constructing a basic description of a carnivore diet, particularly where other types of observation are impossible, or where time does not permit detailed observations. Since more obvious characters of prey consumed are lost in the process of mastication and digestion, during faecal analysis investigators thus have to depend entirely on hard, indigestible parts of the prey-such as hair, claw, feathers, teeth and bones. Larger bones and teeth are generally fragmented, and are of little use, but hairs suffer little in the process of digestion and retain many identifiable features (Oli 1993). The identification of remains, in particular hair, have been reliably used in dietary studies of a wide range of mammalian carnivores like tiger (Schaller 1967, Seidensticker 1976a, Sunquist 1981, Johnsingh 1983, Biswas and Sankar 2002, Sankar and Johnsingh 2002, Bagchi et al.2003, Harihar 2005, Andheria et al.2007)

Though analysis of scat is a widely accepted method to understand carnivore diet, it cannot truly represent the age, sex and health conditions of the prey species and therefore study of kills made by predator should also be resorted to as a complementary technique. Owing to that, both analysis of scat and kills of prey species were undertaken to study the dietary pattern of tiger in PTR.

6.2. Methods

6.2.1. *Collection of scats*

Scats of tiger were collected opportunistically as well as systematically along animal and man made trails and dirt roads in the study area. Scats of the tiger were identified by the shape of their scats and also by other secondary evidences such as pugmark and scrapes. Scats of tiger have a lower degree of coiling and relatively larger distance between two successive constrictions within a single piece of scat. The felid scats were larger, stickier in consistency, and deposited on grass alongside tracks, foot paths or roads, or between the wheel tracks of motorable roads (Johnsingh 1983, Karanth 1993). 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 (Farrell et al.2000).

Scats which could not be identified were excluded from the analysis. The scats were collected in plastic bags and for each scat, the following information was noted: scat Id, condition of scats (fresh/old), date, place and GPS locations. This collection procedure was carried out in two seasons, winter (November to February) and summer (March to July).

6.2.2. *Analysis of scats*

All collected scat samples were oven dried at 60 °C for 48 hours. Each scat was then broken down and washed under running water by using a sieve. The scat contents were then teased apart with forceps and undigested prey remains such as hair, bones, skin, claws, hooves, mandible, quills and vegetable material were separated. All the different prey remains were examined macroscopically to identify the prey species (Grobler and Wilson 1972). In addition, hair remains in scat samples were microscopically examined for identifying species based on cuticle and medullary patterns (Mukherjee et al.1994a, b, Bahuguna et al.2010). Bird and rodent taxa were not identified to species level.

6.2.2.1. Preparation of reference slides

For the purpose of identification of the hair samples a reference collection was built that included hair from the following species- chital, sambar, nilgai, wild pig, gaur, common langur, black-napped hare, domestic cattle, four horned antelope and barking deer. These were prepared using slides from the collection of Wildlife Institute of India laboratory as well as by the collection of hair samples from predated animals in PTR.

6.2.2.2. Identification of hairs in scats

Undigested hair from the prey remains found in individual scats were taken and washed in water, dried in blotting paper and then dipped in 1:1 ethyl alcohol solution and kept for 30 minutes. The strands of hair were then dried in blotting paper. After that, 20 strands of hair were randomly selected from each sample and cuticular imprints were prepared following Mukherjee et al. (1994 a,b). To examine the medullary characteristics of hair, permanent slides were prepared as suggested by Brunner and Coman (1974). Prey hairs were identified by comparing with reference slides that were prepared earlier.

6.2.2.3. Whole mount for medullary patterns

Clean, individual strands of hair were placed on clean microscopic slide, mounted with DPX and microscopically studied (Bahuguna et al.2010).

6.2.2.4. *Examination of cuticular characteristics*

Gelatin solution was prepared by mixing gelatin powder in boiling water and a few drops of methylene blue were added to it. A thin smear of this gelatin solution was applied on a clean microscopic slide. Clean, dry hair was placed on the slide, some with the lower shaft region overhanging and some with the tip overhanging the edge of the slide and allowed to dry (Oli 1993). The hair was then gently removed by holding individual strand of hair with the help of fine forceps and the cuticular imprints were studied under microscope (Bahuguna et al.2010).

6.2.2.5. *Microphotography*

Microphotographs of representatives' whole mount (medulla) and cuticular imprints were taken at standard magnification (400X) by using Leica DMLB microscope with digital micro photographic attachment (Fig. 6.1).

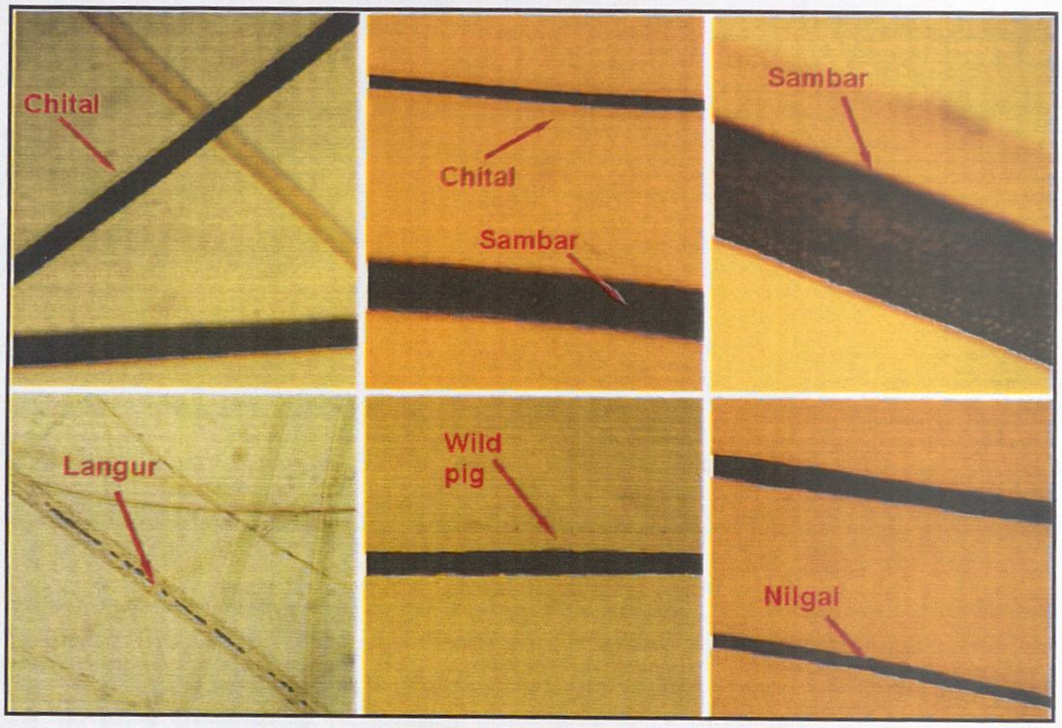


Fig. 6.1. Microphotography of medullar structure of hairs of different prey species of tiger.

6.2.3. *Sample size adequacy*

To check for the stability of percent frequency of occurrence in the diet, all scats for eachcarnivore species were randomized season wise and boot strapped 999 times with the help of program ESTIMATE S (Colwell 2005, Sankar et al.2010).

6.2.4. *Data analysis*

The presence of all identifiable items were recorded and their frequency of occurrence is expressed as a percentage of the total number of scat samples analyzed (Schaller 1967, Johnsingh 1983, Karanth and Sunquist 1995, Biswas and Sankar, 2002, Bagchi et al.2003, Andheria et al.2007, Ramesh et al.2009, Sankar et al.2010).

6.2.4.1. Estimation of Prey Selectivity

Frequencies of the identifiable prey remains in the scat do not tell us about the actual proportion of prey type eaten. This is more so when the prey types vary in size to a considerable degree. Smaller prey species produce digested material (i.e. hair) due to higher body surface to mass ratio. Hence, intake of smaller body sized prey induces relatively more amount of scat production per unit mass of prey consumed leading to an over estimation of smaller prey species in the diet of carnivores (Ackerman et al.1984, Jethva and Jhala 2003). Correction factor developed by Ackerman et al.(1984), from feeding studies on cougar (*Felis concolor*) was used for tiger to estimate the relative proportion of biomass of prey consumed. Application of this regression equation for tiger involves assuming similar carcass utilization and comparable digestive system of cougars with tiger (Karanth and Sunquist 1995).

Prey selectivity by tiger was estimated for each prey species by comparing their availability and utilization data. The expected proportion of scats in the environment (i.e. availability) was calculated using the following equation (Karanth and Sunquist 1995).

$fi = \{ (di / dt) * \lambda i / \Sigma \ \{ (di / \Sigma \ di \text{ --} dn) * \lambda i \}$, where

fi= Expected scat proportion in the environment.

di= Density of i th species

Σ di---dn= sum of density of all species.

$\Lambda i = X/Y$ = The average number of collectible scat produced by tiger from an individual of i th prey species.

X = Average Body weight of the species

$Y = 1.980 + 0.035 X$. (for tiger)

Y=Kg of prey consumed per field collectible scat (Ackerman et al.1984, Jethva and Jhala 2003).

Multinomial likelihood ratio test was used for prey selection (Chesson 1978, Manly et al.1972, Reynolds and Aebischer 1991, Link and Karanth 1994, Karanth and Sunquist 1995). The exact variability of prey items in scats is not known and in order to account for that sensitivity analysis was done by changing coefficient of variance from 10 to 40% (Link and Karanth 1994). Program SCATMAN (Link and Karanth 1994) was used to do multinomial test and sensitivity analysis by bootstrapping data 1000 times. To understand the effect of body weight, prey dispersion and group size on prey selection, partial correlation was done, controlling for prey availability.

6.2.5. Kills

Kills made by tiger was recorded opportunistically. Only fresh kills were recorded. Prime indicators of the presence of kills were the persistence of predators in the vicinity, the calls of jungle crows (*Corvus macrorhynchos*) and hovering or descending vultures (*Gyps sps*). The location of the kills was usually identified by the sighting of the feeding carnivores or scavengers, by the odour of the decomposing carcass and occasionally, by the signs of dragging of the carcass by the tiger. For identification of predators, both direct and indirect evidences (pugmarks, canine mark on neck of prey species and scrape mark) were used. In case of each kill, prey species, age and sex were recorded. Since prey distribution and abundance varies seasonally, winter and summer season's diets and prey selection of tiger was compared between these seasons and focused on frequency of occurrence of prey remains. The age-sex

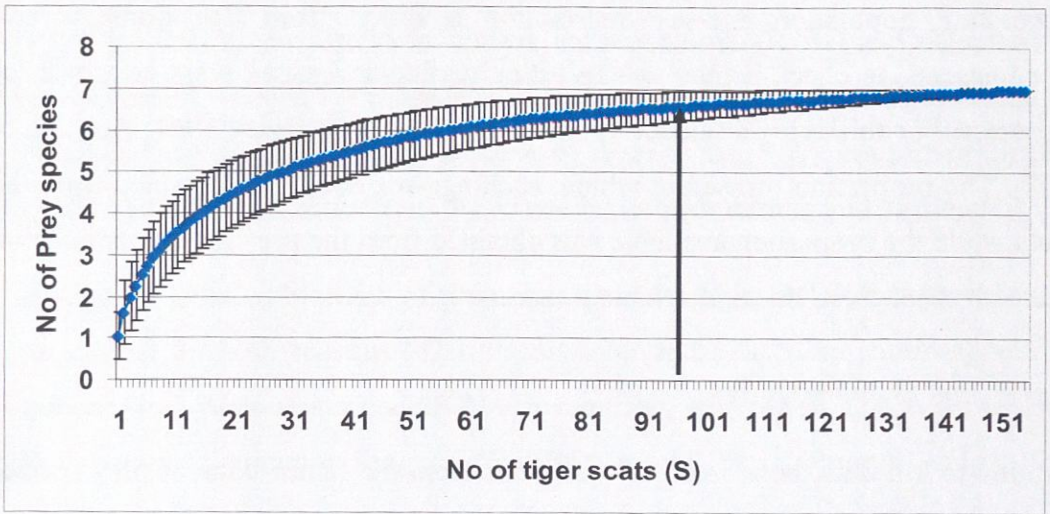


Fig. 6.2. Scat sample stabilization curve for summer diet of tiger in Pench Tiger Reserve (March-July, between 2007 and 2010).

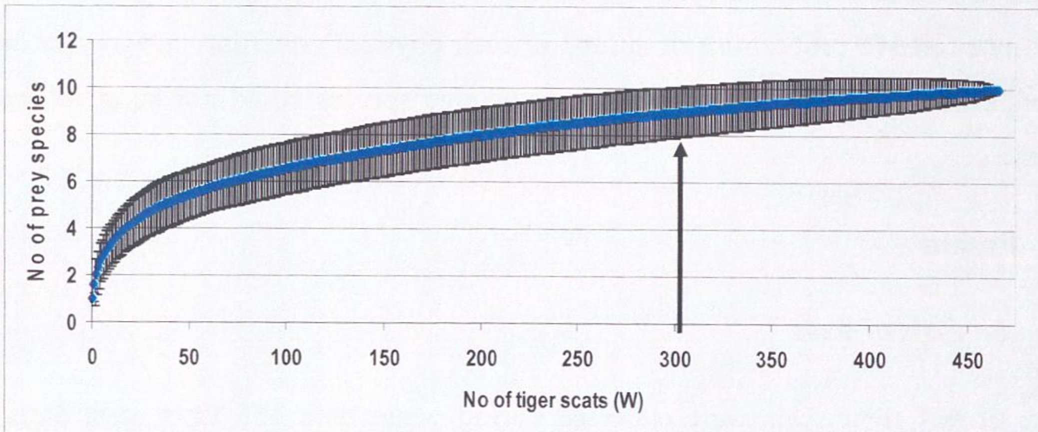


Fig 6.3. Scat sample stabilization curve for winter diet of tiger in Pench Tiger Reserve (November- February, between 2006 and 2010).

The scat analysis revealed the presence of ten prey species in the diet of tiger in winter and seven prey species in summer (Table 6.1). Of the prey species found in tiger scats, (Table 6.1) chital contributed maxium in terms of number (52.8% in winter and 62.7% in summer) followed by sambar (31.7% in winter and 18.6% in summer), common langur (5.7% in winter and 9.3 % in summer), wild pig (6.2% in winter and 3.1% in summer), nilgai (0.4% in winter and 3.1% in summer), domestic cattle (0.2% in winter and 2.5% in summer), rodents (1.6% only in winter), gaur class distribution of each major prey species in the kill data was compared with the corresponding population age-sex distribution recorded from line transects and vehicle transects, to check if tiger was selecting particular age-sex class categories of prey species. For this Ivlev's selectivity index (PI) was used (Ivlev 1961, Acharya et al.2007). The proportion utilised in which, each age-sex used was obtained from the kill data while the proportion available was obtained from the prey species population structure obtained from line and vehicle transects.

6.2.5.1. Health condition of prey species

In addition to kill data, bone marrow conditions from the femur bone of prey species were recorded to understand their health conditions. If femur marrow fat of predated prey species is examined, the physical condition of the prey can be categorized as good, medium and poor (Karanth and Sunquist 1995) and accordingly the relative proportions of kills in each category were recorded during the present study on kills of tiger. Since relative proportions of animal in each physical condition category in the prey populations were unknown, selectivity of prey species could not be quantified using indices.

6.3. Results

6.3.1. Analysis of scats

A total of 467 tiger scats were collected during winter and 155 tiger scats during summer.

Out of 155 tiger scats, analysis of 91 to 100 tiger scats were found adequate to stabilize the dietary spectrum of tiger in summer (Fig. 6.2) and out of 467 tiger scats, 300 to 310 scats were found adequate in winter (Fig. 6.3).

(0.6% in winter), hare (0.2% in winter), unknown birds (0.4%) and porcupine (0.6 % in summer). No attempt was made to identify the species of rodents, birds and reptiles observed in the scats of tiger. In case of tiger scats, 96% contained single prey species and 4% contained two prey species in both winter and summer.

In terms of relative biomass of prey consumed by tiger, chital contributed maximum for overall for both seasons (42.1 % in winter and 52.8 % in summer) followed by sambar (46.5 % in winter and 28.8 % in summer), wild pig (4.2 % in winter and 4.8% % in summer), common langur (3% in winter and 5% in summer), nilgai (0.7 % in winter and 6% in summer), cattle (0.4% in winter and 4.8% in summer), gaur (2.4% only in winter), hare (0.09% only in winter), rodents (0.7% in winter) and porcupine (0.3% only in summer) (Table 6.3).

Table 6.1. Tiger diet (n = 467 in winter and n = 155 in summer) and relative biomass contribution of different prey species as shown by scat analysis in Pench Tiger Reserve, Madhya Pradesh (November 2006 to July 2010).

Prey	RAPS (W)	RAPS (S)	Avg wt	FO (W)	PFOW)	FO (S)	PFO (S)	CF	RIC (W)	RIC (S)	Ivlevs W	Ivlevs S
Chital	0.38	0.36	47	257	52.88	101	62.73	3.6	0.42	0.53	0.073	0.177
Sambar	0.04	0.05	134	154	31.69	30	18.63	6.7	0.46	0.29	0.828	0.721
Nilgai	0.01	0.01	180	2	0.41	5	3.11	8.3	0.01	0.06	-0.319	0.691
Wild pig	0.05	0.07	32	30	6.17	5	3.11	3.1	0.04	0.02	0.053	-0.471
Common langur	0.50	0.50	8	28	5.76	15	9.32	2.3	0.03	0.05	-0.897	-0.810
Gaur	0.01	0.01	450	3	0.62	0		17.7	0.02		0.405	0.0000
Hare			2.1	1	0.21	0	0.00	2.1				
Cattle			180	1	0.21	4	2.48	8.3				
Rhodent			0.5	8	1.65	0	0.00	2.0				
Porcupine			10	0	0.00	1	0.62	2.3				
Bird				2	0.41	0	0.00					

RAPS (W) and (S) = Relative Abundance of Prey Species in winter and summer, Avg. wt. = Average body weight, FO (W) and (S) = Frequency of occurrence of prey species in scats in winter and summer, PFO (W) and (S) = Percentage frequency of occurrence of prey species in winter and summer, CF= Correction factor for tiger.

6.3.2. Prey selectivity- Scats

In winter, chital, sambar and gaur were significantly consumed ($p<0.005$) more than their availabilities by tiger, common langur, wild pig and nilgai were less consumed whereas in summer sambar, nilgai and chital were significantly consumed more than their availabilities and wild pig and langur were less consumed (Table 6.2). The individual level prey selectivity by tiger was ranked in the following order in winter: sambar> gaur >chital >wild pig >nilgai> common langur and in summer: sambar>nilgai>chital>wild pig>langur (Fig. 6.4).

Table. 6.2. Preference of prey species by tiger in Pench Tiger Reserve based on availability of individuals and utilization from analsys of scats (November 2006 to July 2010)

Carnivores	Prey species	Winter			Summer		
		Unadjusted p-value	**Adjusted p-value± SE 10% cv**	**Adjusted p-value± SE 40% cv**	**Unadjusted p-value**	**Adjusted p-value± SE 10% cv**	**Adjusted p-value± SE 40% cv**
Tiger	Chital	0.0001	0.0001±0.0001	0.0004±0.0001	0.000	0.001±0.0001	0.001±0.0001
	Sambar	0.0001	0.0001±0.0001	0.0001±0.0001	0.002	0.002±0.0001	0.004±0.0002
	Nilgai	0.0001	0.0005±0.0001	0.0011±0.0001	0.928	0.923±0.0046	0.925±0.0047
	Wild pig	0.0640	0.0824±0.0012	0.1291±0.0061	0.078	0.082±0.0006	0.098±0.002
	Langur	0.0010	0.0001±0.0001	0.0001±0.0001	0.001	0.0001±0.0001	0.001±0.0001

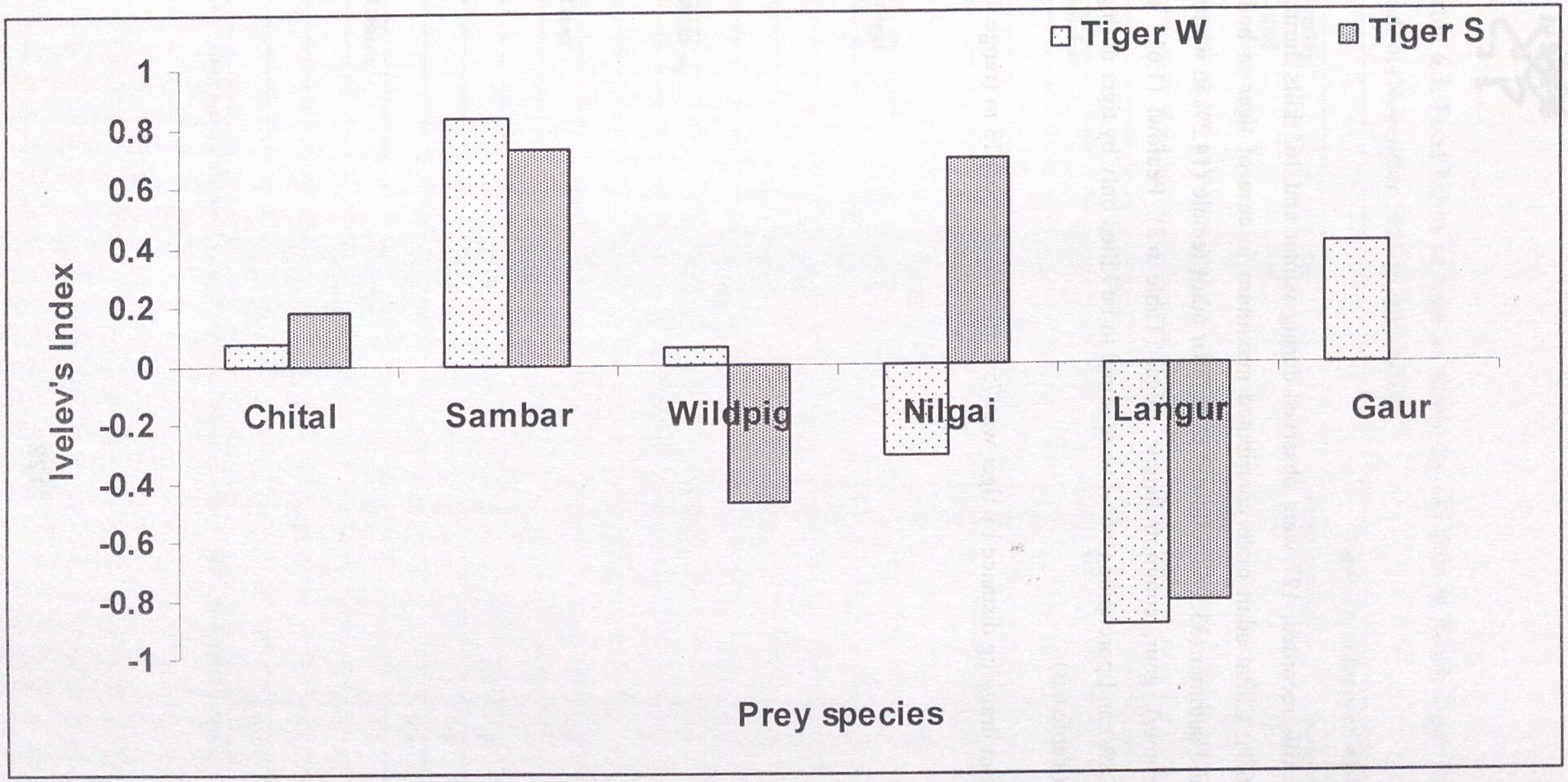


Fig. 6.4. Prey selection of tiger as shown by scat analysis in Pench Tiger Reserve, Madhya Pradesh in winter (November- February, between 2006 and 2010).

6.3.5. *Kills*

Of the 292 tiger kills recorded, 127 were observed during winter and 165 kills during summer (Table 6.3). Chital adult male contributed maximum in case of tiger in both winter (19.7%) and summer (33.3%) followed by sambar adult female (14.2% in winter and 9.1% in summer), gaur, common langur, nilgai (Table 6.3). Peafowl (1.6% in winter), cattle (0.8%) and porcupine (0.6%) were found to be killed only by tiger during the study period (Table 6.3).

The observed mean dragging distance by tiger was 75 ± (Standard error) 13 m (range 0-1500 m).

Table 6.3. Food habits of tiger as shown by kill data in Pench Tiger Reserve, Madhya Pradesh (November 2006 to July 2010).

		Tiger (% frequency of occurrence)	
Species	**Age**	**Winter (n=127)**	**Summer (n=165)**
Chital	AM	19.7	33.3
	AF	7.1	7.3
	SAM	1.6	2.4
	SAF	1.6	2.4
	Young	3.1	4.2
Sambar	AM	15.0	4.8
	AF	14.2	9.1
	SAM	0.8	1.2
	SAF	0.8	0.6
	Young	3.1	1.8
Nilgai	AM	9.4	6.1
	AF	2.4	1.8
	SAM	1.6	0
	SAF	0.8	0
	Young	1.6	1.2
Wild pig	AM	8.7	7.9
	AF	1.6	1.2
	Young	0.8	0
Gaur	AM	0.8	6.1
	AF	0.8	2.4
	SAM	0	3.0
	SAF	0	0.6
	Young	1.6	0.6
Others	Langur	0.8	1.2
	Peafowl	1.6	0
	Cattlle	0.8	0
	Porcupine	0	0.6

AM- Adult male, AF- Adult female, SAM= Sub-adult Male, SAF= Sub-adult Female

6.3.5.1. Prey selectivity- Kills

It was observed that during both summer and winter, chital adult male were preferred by all three carnivores as compared to their availabilities. The index of selection of prey species in different age classes by tiger was ranked in the following order in winter: chital adult male>sambar adult male>nilgai adult male>sambar adult female> wild pig adult male> chital young>chital adult female>sambar young>gaur adult male>nilgai young>nilgai adult female>wild pig adult female>gaur young. In summer, the order of prey selectivity was: sambar adult male>chital adult male>gaur adult male>wild pig adult male>nilgai adult male>sambar adult female>gaur adult female>chital young>nilgai adult female>sambar young>nilgai young>chital adult female>gaur young. (Fig 6.5).

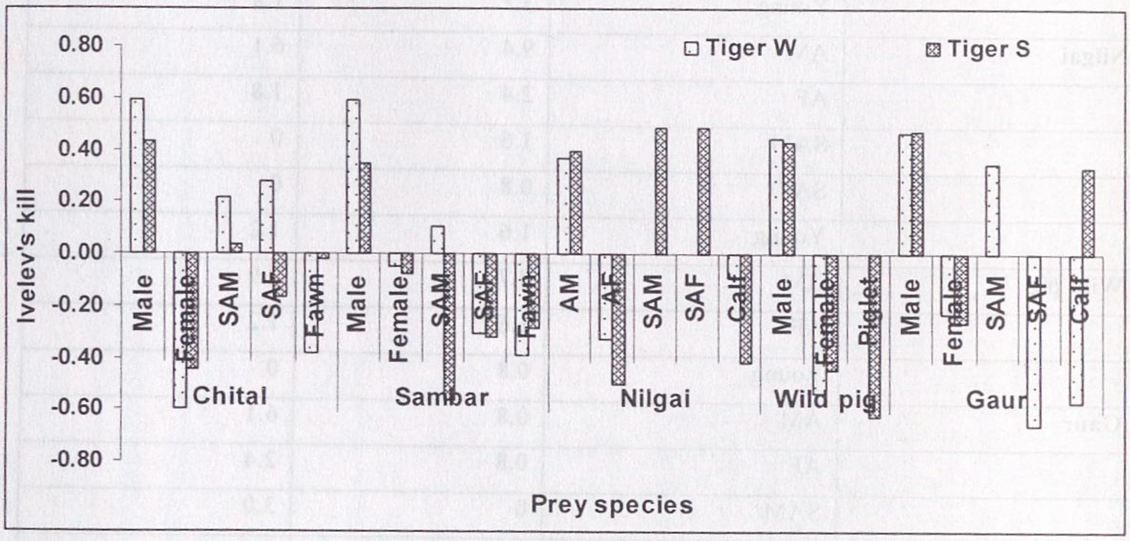


Fig. 6.5. Prey selection of tiger, as shown by kill data in Pench Tiger Reserve, Madhya Pradesh in winter (November- February, between 2006 and 2010) and summer (March-July, between 2007 and 2010).

6.3.5.2. Health condition of kills

Health condition of five potential prey species such as chital, sambar, nilgai, wild pig and gaur were evaluated during the study period based on evaluation of bone marrow conditions. Of the 109 tiger kills, 42% was contributed by prey species with good health conditions, 26.1% by medium health condition and 31.7% by poor health condition (Table 6.4).

Table 6.4. Proportion (%) of prey animals in different physical condition categories killed by predators

Predator	Prey (numbers)	Good%	Medium%	Poor%
Tiger (n=109)	Chital (n=57)	40.4	22.8	36.8
	Sambar (n=32)	50	28.1	21.9
	Nilgai (n=13)	38.5	15.4	46.2
	Wild pig (n=7)	57.1	14.3	28.6
	Gaur (n=4)	25.0	50	25.0
	Overall prey species	42.2	26.1	31.7

6.4. Discussion

The data was found sufficient in the present study to document the food habits of tiger. The analysis of scats and kills confirmed that tiger killed mainly large and medium body sized prey. In addition, tiger utilized negligible amount of small-sized prey (Table 6.8). Tiger showed significant level of preference towards utilization of prey species ($p < 0.05$). It largely depended (>90%) on principle prey species such as sambar, chital, gaur, wild pig and langur.

Previous studies on diet of tiger showed that diets of large carnivores are very similar when prey species are abundant (Schaller 1967, Johnsingh 1983, Sunquist and Sunquist 1989, Karanth and Sunquist 1995, Andheria et al.2007, Ramesh 2010). Environment pattern changes seasonally and annually leading to fluctuate levels of inter-specific competition. The ability of the tiger to hunt prey ranging from rodent to gaur indicates that tiger takes a much wider spectrum of food resources.

6.4.1. Analysis of scats

In terms of biomass consumed, chital was found to be the important prey of tiger (42.1% in winter and 52.9% in summer). Though tiger in the study area fed on 11 prey species, chital and sambar constituted 88.6% winter and 81.8% respectively in summer diet of tiger. The sambar and chital were found to be the important prey species for tigers in Bandipur and Nagarhole (Karanth and Sunquist 1995, Johnsingh 1992, Andheria et al.2007). The ability of the tiger to hunt prey ranging from rodent to gaur indicates that tiger utilizes a much wider spectrum of food resources. These evidences suggest that tiger can prey on broader size ranges of prey due to their prey handling capabilities (Gittleman 1985).

The recent studies have concluded (Karanth and Sunquist 1995) that prey biomass is the most important prerequisite for long term survival of large carnivore populations. The adaptabilities of tiger in using different techniques for hunting and obtaining food showed that overall, tiger is not restricted by sizes or types of prey, but can adapt to changing conditions assessing biomass available from very small prey (eg. invertebrates, hare, rodents and birds) to prey that weigh several times their own body weight (eg. gaur).

6.4.2. Analysis of Kill

During this study, among the total tiger kills recorded, the predation is male-biased in sambar, chital and gaur. Similar findings were reported in other studies (Johnsingh 1983, Karanth and Sunquist 1992). In South Asian ungulates, solitary habits, proneness to injuries from intra-specific aggression and dispersal behaviour have been considered as some of the factors that make males more vulnerable to selective predation (Johnsingh 1983, Karanth and Sunquist 1992, Schaller 1967). This male biased predation may be also attributed to the presence of large size antlers in deer that may hamper their navigation through thick bushes and solitary habits during the rut (Johnsingh 1983, Ramesh 2010). The solitary behaviour of males increases their individual probability of encountering predators and keeping them away from group vigilance which make them more vulnerable to predation (Childress and Lung 2003). Wild pig being an aggressive prey can retaliate viciously when attacked by predators but the piglets are vulnerable to predation. Adult wild pig was preyed by tiger on two occasions and piglets were killed by leopard and dhole on three occasions during the study period. Karanth (1993) also observed male-biased tiger predation on wild pig. The influence of predation on young and old animals and animals in poor condition is important in population dynamics of prey species.

No significant (Two sample T test with mean and Standard Error) seasonal difference was observed while Mean Prey Body Mass consumed by tiger (p= 0.58) (Table 6.5). Our results also supported the prediction of both Griffiths (1975) and Karanth and Sunquist (1995) that vertebrate predators would be selective energy maximizers in prey rich habitats, but would be non selective number maximizers where large prey were scarce. The findings (Table 6.8) were also related to the foraging theory which suggested that tiger may select species containing the most profitable prey by the ratio of energy gain to handling time (Scheel 1993).

Table 6.5. Descriptive statistics for the mean body mass data (kg) of prey killed by tiger, as determined from its kill records in Pench Tiger Reserve, Madhya Pradesh (January 2007-June 2010) (n = number of kill records) (Min- Minimum, Max- Maximum, SE- Standard Error).

Predator type (Season)	n	Mean Prey Body Mass± SE (kg)	Median (kg)	Range of Prey Mass Min-Max (kg)	Prey: predator body mass
Tiger (Winter)	123	150.8±10.9	70	15-745	0.89:1
Tiger (Summer)	162	161.4±13.05	70	20-745	0.95:1

6.4.3. Heath condition of prey species

Among each of the prey species predated by predators in Pench during the present study, more than 40% of tiger diet composed of prey species with good health conditions. Karanth and Sunquist (1995) reported that 13 to 23% of the prey species kills in Nagarahole was of poor health condition and rest of them was from good to medium health conditions. Ramesh (2010) reported, more than 95 % of kills of tiger in Mudumalai Tiger Reserve was in good health condition.

6.5. Conservation implication

The study on dietary pattern of tiger based on both kill (Karanth and Sunquist 1995, Present study) and scats (Andheria et al.2007, Johnsingh 1983, Karanth and Sunquist 1995, Majumder et al.2012, Ramesh 2010, Wang and MacDonald 2009) revealed that chital and sambar, the two cervid deer species contributed maximum to their diet in Indian sub-continent. Overall conservation of these two species of cervids is therefore essential for long term sustenance and growth of tiger population in this tropical deciduous forest.

Though the intensive study area is relatively undisturbed and no poaching of wild ungulate was recorded during the present study, there is continuous biotic pressure exert from the 99 villages located around the notified buffer zone of PTR, Madhya Pradesh (Qureshi et al.2006). The locals are predominantly tribal (62%) belonging to Gond and Baiga community and depending on animal meat as a supplement of protein content (Sankar et al.2001, Dungariyal 2008). As tiger densities are dependent on their available prey densities (Karanth et al.2004), ensured protection is the need of the hour for the population and habitat of wild ungulates to conserve tiger in Pench and its surrounding areas.

Chapter 7
POPULATION DYNAMICS OF TIGER

7.1. Introduction

Tiger, the largest of all living cats and Asia's largest predator is also serving as flagship species in the forest of Indian Sub-continent (Schaller 1967, Sunquist 1981, Seidensticker 1976, Jhala et al. 2010). Although tiger existed in large numbers during the last century in India (Qureshi et al. 2006), the population of tiger are now being threatened due to habitat fragmentation, poaching for wildlife trade and decreasing prey populations (Karanth and Sunquist 1995, Jhala et al. 2008). Therefore it is necessary to strict a balance between the socio-economic demands of growing human population with large areas of habitat adequate to support source population of tigers in any human dominated landscape of India. As the landscape becomes more fragmented by human activities, the proximity and accessibility of humans to natural areas will increase and augment tiger-human conflict. Such conflicts are often assessed in terms of the direct threats to the dynamics of the wild tiger population (survival and reproduction). In any carnivore population dynamics study, it is essential to know how individuals are surviving over the period (Karanth et al. 2006). In India, the lack of baseline data on tiger population dynamics has prevented biologists and wildlife managers from identifying, quantifying and addressing suspected negative impacts (Karanth et al. 2006, Jhala et al. 2010). An estimate of survival pattern of large carnivore is also challenging. Major challenge is to monitor the tiger populations over the period, as they are elusive and nocturnal or disperse over large areas (Seidensticker 1976). Typically, tiger range widely and occur infrequently over large parts of their home range (Sunquist 1981). Their population densities are usually low and making direct observation methodologies unreliable. Estimates based on track observations are failure prone and unreliable (Karanth 1995, 1999).

Although, demographic patterns of carnivore can be estimated using radio-telemetry (Mowat et al. 1996, Kelly et al. 1998), the technique is constrained by the small number of animals that can be tagged simultaneously, the uncertainties about how many individuals are not tagged, and the high costs and efforts involved (Karanth 1995). The major drawback of scat-DNA based population dynamics is high cost and need of skilled technician and advanced laboratories (Kohn et al. 1999).

The increasing popularity of remote photography in wildlife research has led to the development of a large variety of equipment and methods (Kucera and Barrett 1993). Since individual tiger are readily identifiable using the stripes on the body (Schaller 1967, McDougal 1977, Karanth 1995, Franklin et al. 1999), Karanth (1995) developed and implemented a method of photographic capture-recapture analysis to aid estimate and monitor tiger population demography in India (Karanth et al. 2006) and Nepal (Barlow et al. 2009).

Various statistical methods have been used by wildlife biologists to estimate survival rate of species as such as Cormack-Jolly-Seber (CJS), Kaplan Meier (K-M) known fate models (Kaplan and Meier 1958) and Pollock's robust design (Pollock 1982).

Pench Tiger Reserve (PTR) is one of the important source population's of tigers in central Indian landscape (Jhala et al. 2008). Our study aimed to estimate various aspects of tiger population dynamics such as densities, age-sex ratios, survival pattern, growth rate and recruitment pattern in PTR between May 2006 and March 2013. Pollock's robust design was used in this present study to estimate survival rate of tiger as robust design's two levels of sampling allow for finer control over the relative precision of each parameter (Cooch and White 1995).

7.2. Methods

The sampling design and statistical framework used in this study were based on camera trap mark-recapture (CTMR) as followed in various studies (Karanth, 1995, Karanth et al.2006, Jhala et al. 2011).

7.2.1. Study design and equipments: Active and passive infrared-triggered camera traps were used for the present study. Active infrared trail monitoring system consisted of two units: a transmitting unit that sends an infrared beam, and a receiving unit which is set across the target area. A picture is taken when the infrared beam is broken. Passive infrared systems are single units that use heat and motion detector to trigger the camera. We used widely available film camera system in active infrared trail monitoring system for session 1 to session 6, i.e. session 1 to session 6 and Infrared Digital camera system for session 7 i.e year 2013.

A pair of camera traps was deployed in a systematic 2 km X 2 km grid and the minimum distance between two camera locations varied between 1.5 and 2 km (Sharma et al. 2010, Sharma and Jhala 2010). The 151 sq km was covered in session 1 at 2006 (n=36 camera traps), 274 sq km in session 2, 3 and 6 i.e. 2008, 2009 and 2012 (n= 52, 50 and 59 camera traps respectively), 410 sq km in session 4, 5 and 7 i.e. 2010, 2011 and 2013 (n=80, 81 and 87 camera traps respectively) (Table 7.1 and Fig. 7.1, 7.2 and 7.3 respectively). Camera trapping devices were placed one opposite to another to photograph simultaneously both flanks of an animal. To eliminate mutual flash interference, the two cameras were not positioned directly facing each other. To minimize bias in the identification process, all tiger photographs were examined independently. Each photograph of an individual represented a capture occasion. Individual identification of tiger was done based on examination of the position and shape of stripes on the flanks (Schaller 1967, McDougal 1977, Karanth 1995, Jhala et al. 2008), limbs and forequarters and tail (Schaller 1967, McDougal 1977, Karanth 1995). The sex of the tiger was identified by its relative body size and genitalia as suggested by Karanth (1995). To increase the accuracy while identifying the sex of individual tigers, we monitored each camera trap site on a regular basis and pugmarks were traced from Pugmark Impression Pad (PIP) and compared with track size in combination with the particular spatial arrangement of toes relative to the pad of each foot (Sharma 2001). In addition, we also collected ground information of tiger age and sex classes from "homing in" of radio-collar individuals (n=4, 1 adult female, 1 adult male, 2 sub-adults) and opportunistic sighting as suggested by Barlow et al. (2009) and Sharma and Jhala (2010) by both foot patrolling and camp elephant. Information on tiger cubs was collected following one radio-collared tigress, CTMR and intensive monitoring.

As poor recaptures can affect population estimation (Sharma 2005), we camouflaged all cameras properly to avoid trap shyness. We frequently moved cameras ± 100 m from original camera trap locations to reduce instances of trap shyness and increase the probability of capture.

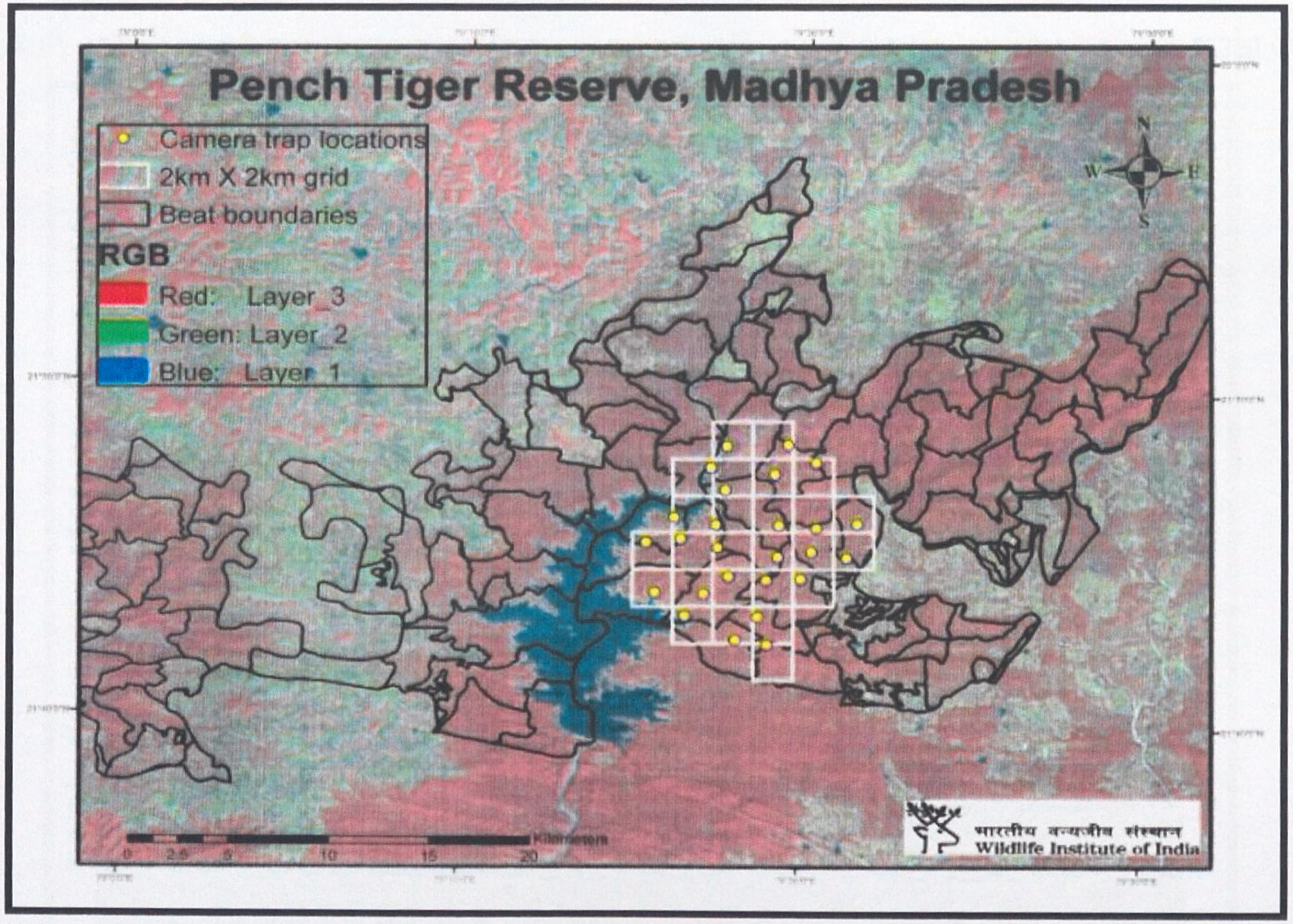


Fig 7.1 Map showing grid wise camera trap locations in Pench Tiger Reserve, Madhya Pradesh (Session 1)

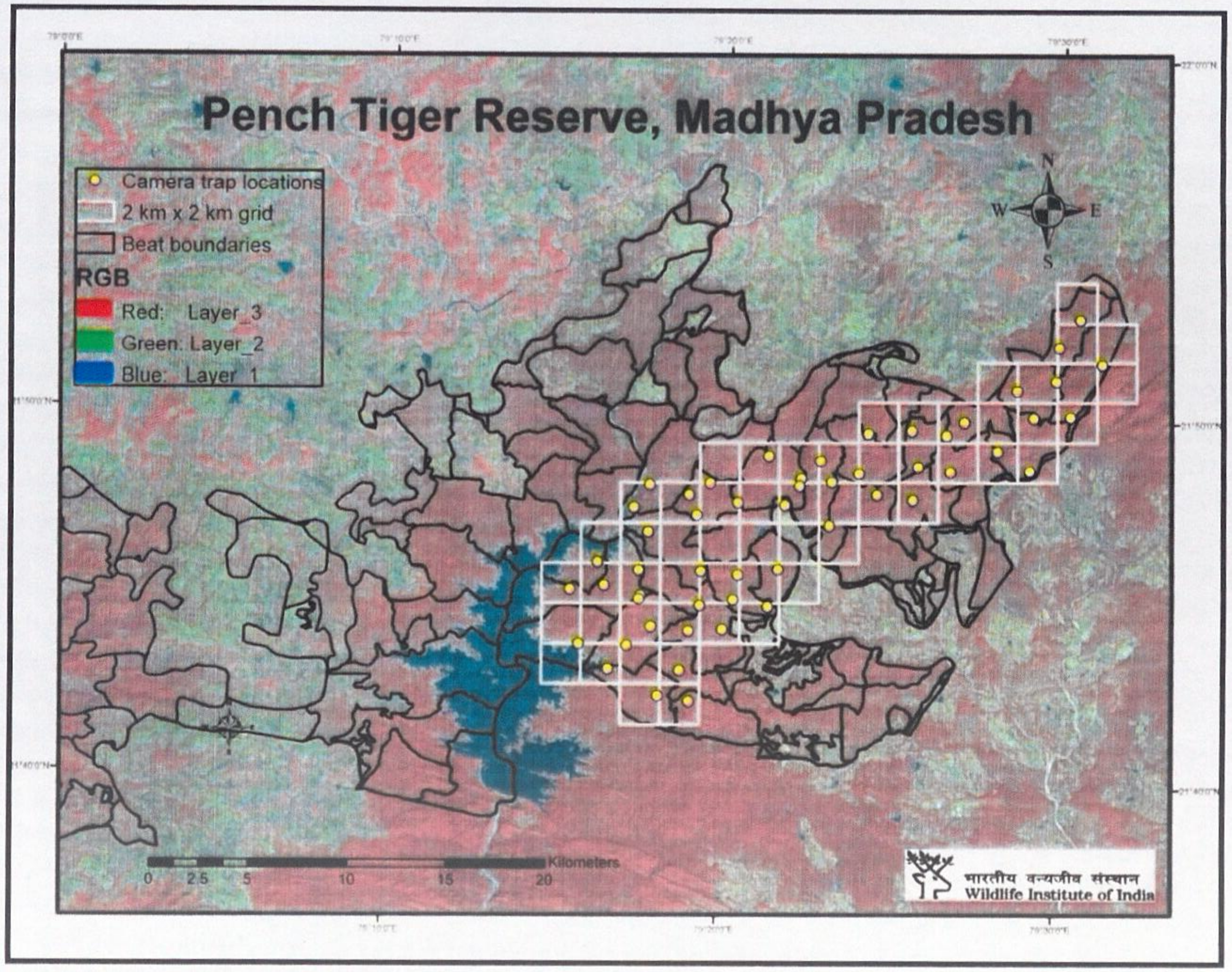


Fig 7.2 Map showing grid wise camera trap locations in Pench Tiger Reserve, Madhya Pradesh (Session 2, 3 & 6)

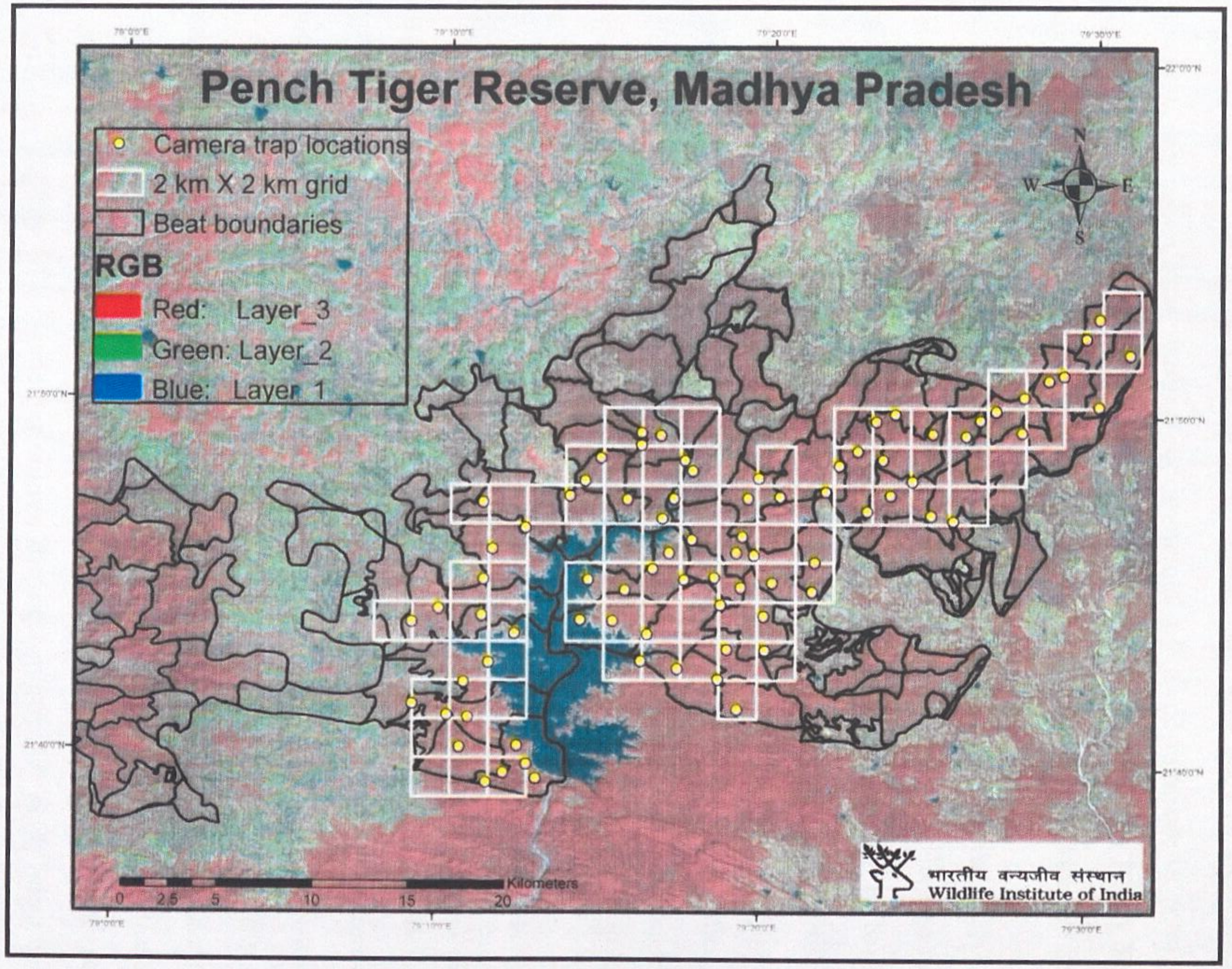


Fig 7.3. Map showing grid wise camera trap locations in Pench Tiger Reserve, Madhya Pradesh (Session 4, 5 & 7)

7.2.2. *Age sex categories:* An understanding of the organization of a population is important for its long term conservation as it gives us information not only on the internal balance between various components (age and sex) of the population of a species, but also how various components of a population interact with their environment (Pabla 1996). In accordance with Karanth and Stith (1999), Barlow et al. (2009), following age-sex categories of tiger was assessed for the present study.

1) Overall tiger - It includes male and female tiger of all age classes, 2) All male - It includes both adult (>36 month) and sub-adult male (>15 to 36< month), 3) All female - It includes both adult (>36 month) and sub adult female (>15 to 36< month), 4) Adult male- It includes only those adult male tigers found with established territories ≥ 2 years in the study area, 5) Breeding female- The female tiger either photo captured with cubs or encountered with cubs during opportunistic sightings 6) Sub-adult tiger- It includes only those male and female tiger captured once throughout the trapping session even not encountered during opportunistic sighting, and 7) Cubs = It includes age class of tiger ≤ 12 months.

7.2.3. *Statistical analysis:* The capture probabilities was investigated by assessing the discriminant function model selection statistics for the four likely models (Otis et al. 1978) for tiger data: Mo (constant capture probability), Mh (capture probability heterogeneous among individuals), Mbh (behavioral response in capture probability with heterogeneity among individuals), and Mtbh (capture probability affected by secondary sampling period, trap response, and heterogeneity). Accordingly, the overall X matrix was analyzed to estimate the survival rates for the entire study period and also for each primary sampling period in the study area. In X matrix format, '1' indicates capture of a particular animal during a particular sampling occasion, while '0' indicates that the animal was not captured during particular sampling occasion. Program DENSITY ver. 4.5 was used for density estimation of tiger under both ½ Mean Mode Distance Moved (½ MMDM) and Maximum Likelihood Spatially Explicit Capture-Recapture model (MLSECR) (Efford 2004, Jhala et al. 2010). For computing densities of tiger, model fit estimators as Half normal cosine and Uniform cosine were tested with various combination of models under M (h) Jacknife, M (O) null, M (b), Mbh, Mt and M th. The density was estimated from best fitted model based on the lowest AIC value.

Population closure test: To validate the closure assumption, the capture history data was analyzed using Program CT or Closure Test in each secondary period. The low P value in closure test suggests that there is addition or loss in the population i.e. population is not closed (Stanley and Burnham 1999).

Sex ratio of tiger

The present population estimation study was of a short duration, considering the life span of tiger (Sunquist 1981, Smith 1993), tiger >1.5 month old was considered at the time of estimation of sex ratio.

Estimation of survival rate of tiger

Pollock's (1982) recommendation for the robust design was a two-stage analysis: 1) Abundance was to be estimated using closed-population models with capture history data across secondary periods within each primary period and 2) Survival was then to be estimated by combining data across secondary periods to indicate whether or not an animal had been caught at least once during a primary period, and then analyzing the resulting capture histories using open models across all primary periods (Karanth et al. 2006). The study consisted of 7 "primary periods" or sessions of sampling covering 8 years. As reported by Karanth et al. (2006), the tiger population was expected to be open to gains and losses between these primary periods. There were multiple "secondary sampling periods" within each primary period, and the population was assumed to be closed to gains and losses among these secondary periods, an assumption that we tested. As larger area was covered (Table 7.1), various model combination of time variant (t) and constant (.) with temporary immigration (g′), temporary emigration (g″) and survival rate (s′) of tiger were tested under Mo, Mh, Mb, Mbh, Mt, Mth and Mtbh models to estimate survival rate of tiger. Among all model combination best fitted model was selected based on the lowest AIC value.

Since all new born cubs were monitored continuously for at least 12 months since their birth during the study period by following their mother, the cubs survival rate was estimated using known fate model (Kaplan-Meier, 1958). Program MARK *ver* 6 was used for data analysis.

Population growth rate: Population growth rate of tiger was estimated using the equation, growth rate (λ) = N_{t+1}/N_t where N_{t+1} is the estimated abundance of year two and N_t is the estimated abundance for year one (Karanth et al. 2006, Mondol et al. 2012).

Recruitment: Recruitment of tiger was estimated using the equation, recruitment (B_t) = (Abundance of period 2 or N_{t+1}) - (Abundance of period 1 or N_t X Survival rate of period 1 or S_t) (Karanth et al. 2006, Mondol et al. 2012). Two sampled T test from mean and standard error was performed using program NCSS to study significant difference of tiger densities over the period (Zar, 1984).

7.3. Results

7.3.1. Sampling effort : The overall (2006-2013) trapping effort for 742 days from trapping station varied between 36 and 87 amounted to total 47384 trap nights and documented a total of 771 photographs (328 male photographs, 433 female photographs and 58 unidentified photographs) (Table 7.3).

Table 7.1. Characteristics of camera trap efforts used during the sampling period in Pench National Park, Madhya Pradesh (May 2006 to March 2013)

Session	Period	MCP (sq km)	Total no of CT	Total Number of Trap days	Total Trap nights
1	27-5-06 to 31-7-06	151	36	65	2376
2	23-1-08 to 28-5-08	274	52	127	6604
3	17-1-09 to 15-6-09	274	50	150	7500
4	1-2-10 to 30-6-10	410	80	150	12000
5	29-12-10 to 17-4-11	410	81	110	9020
6	6-2-12 to 28-4-12	274	59	82	4838
7	16-12-12 to 12-2-13	448	87	58	5046
Total				742	47384

MCP= Minimum Convex Polygon, CT= Camera Trap

Table 7.2. Test for population closure and model selection statistics based on tiger photographic capture history data in Pench National Park, Madhya Pradesh (May 2006 to March 2013).

Year	Test for addition to the population (*p* value)	Test for losses from the population	Categories	M(O)	M(h)	M(b)	M(bh)	M(th)	M(tb)	M(tbh)
2006	0.07	0.42	Male	0.88	1	0.46	0.32	0.32	0.28	0.6
			Female	1	0.79	0.3	0.58	0.41	0.28	0.6
			Overall	1	0.88	0.19	0.24	0.52	0.07	0.61
2008	0.6	0.07	Male	1	0.95	0.42	0.65	0.32	0.45	0.72
			Female	0.87	0.97	0.89	1	0.51	0.74	0.87
			Overall	0.81	0.95	0.94	1	0.47	0.72	0.69
2009	0.07	0.06	Male	1	0.84	0.32	0.58	0.35	0.32	0.65
			Female	1	0.92	0.45	0.69	0.38	0.45	0.7
			Over all	1	0.95	0.32	0.54	0.43	0.35	0.63
2010	0.08	0.07	Male	1	0.94	0.51	0.75	0.4	0.49	0.76
			Female	0.86	0.92	0.99	1	0.35	0.82	0.76
			Over all	1	0.88	0.64	0.94	0.54	0.47	0.93
2011	0.46	0.06	Male	1	0.95	0.4	0.63	0.32	0.45	0.68
			Female	0.92	1	0.59	0.53	0.4	0.46	0.76
			Over all	0.95	1	0.74	0.51	0.54	0.61	0.89
2012	0.06	0.72	Male	0.69	1	0.9	0.6	0.2	0.86	0.39
			Female	1	0.89	0.44	0.68	0.2	0.37	0.68
			Over all	1	0.9	0.64	0.89	0.36	0.47	0.88
2013	0.18	0.2	Male	0.91	0.93	1	0.64	0.31	0.98	0.86
			Female	0.92	1	0.49	0.54	0.29	0.45	0.62
			Over all	0.14	1	0.92	0.05	0.2	0.59	0.73

([1] =Low P value suggests that there is addition or loss in the population i.e. population is not closed, [2] = Higher value i.e. value 1 or close to 1 considered for best fitted model)

During the study period, monitoring of one radio collar tigress and following eight non radio-collared breeding tigresses opportunistically and also from camera trap amounted information on 62 cubs (15 cubs from one radio collared breeding tigress and 47 cubs from eight non radio-collared tigress). Out of 62 cubs, information of 52 cubs was used to estimate survival rate of cubs under known fate model.

The statistical test for population closure using program CT accepted the closure assumption for all sampling occasions i.e. 2006, 2008, 2009, 2010, 2011, 2012 and 2013 (Table. 7.2).

The model fit is better with higher number (>0.8 to 1<) of parameters being estimated for the present study. Though best model selected by program CAPTURE inbuilt in program MARK was M (O) for most of the time, the jackknife estimator in model M (h) was used to arrive at an estimate of *N* for the purpose of calculating survival rate of tiger in each category (Table 7.2).

Population and density estimates of tiger: The estimated population and densities/ 100 sq km of male, female and overall tigers were presented in Table 7.3.

In **2006,** the estimated overall tiger population was 17±2.6 (p-hat = 0.06) under M (h) Jackknife model. The estimated male tiger population under M (h) model was 3±0.01 (p-hat = 0.2). The female tiger population was 13.9±2.5 (p-hat = 0.04) under M (h) Jacknife model. The estimated over all tiger density under ½ MMDM (Mean Maximum Distance Moved) method was 11.6±2.2/100 km² under M (h) Jackknife model. The estimated density of male tiger using the same method was 1.3±0.7 for M (h) model, whereas the estimated density of female tiger under M (h) Jackknife model was 10 ± 0.2/100 km². The Effective Trapping Area or ETA (½ MMDM) for overall tiger population it was 151.4 km², for male it was 192.4 km² and for female it was 137.5 km². The overall tiger density under MLSECR method was 4.7 ±1.2/100 km² for M (h) jackknife models. Estimated density of male tiger using same method was 1.3 ±0.7 /100 km² for M (h) Jackknife model, whereas for female tiger it was 5.2±1.7/100 km² in M (h) Jackknife models.

In **2008**, the estimated overall tiger population was 22.1±4.4 (p-hat = 0.02) under M (h) Jackknife model. The estimated male tiger population was 6.6±2.6 (p-hat = 0.05) under M (h) Jackknife model. The estimated female tiger population was 12±0.9 (p-hat = 0.02) under M (h) Jackknife model.

The estimated density using ½ MMDM method for over all tiger population was 4.8±1.3 /100 km² under M (h) Jackknife model. The estimated male tiger density was 0.9±0.4/100 km² under M (h) Jackknife model. The estimated density of female tiger was 2±0.2/100 km² under M (h) Jackknife model. The ETA for overall tiger population was 556.7 km², male tiger was 721.4 km² and female tiger was 587.1 km². The estimated density obtained from MLSECR method for overall tiger population was 2.5±0.6/100 km² for both of these models whereas the estimated density for male tiger was 1±0.2/100 km² under M (h) jackknife model. Estimated density of female tiger using same method was 1.7±0.5/100 km² under M (h) Jackknife model.

In **2009,** the estimated overall tiger population under M (h) model was 21.1±2.4 (p-hat = 0.02). The estimated male tiger population was 8.2±2.6 (p-hat = 0.02) under M (h) model. The estimated female tiger population was 13.5±5.9 (p-hat = 0.01) under M (h) Jackknife model.

The estimated over all density of tiger under ½ MMDM method was 5.5±1.9/100 km² under M (h) Jackknife models. The estimated density of male tiger using the same method was 1.9±0.7/100 km² under M (h) model. The estimated female tiger density under M (h) Jackknife model was 2.7±1.2/100 km². The ETA (½ MMDM) for overall tiger population was 491.2 km², for male it was 421.9 km² and for female it was 495.1 km².

The estimated density of tiger under MLSECR method was 4.4±1.2/100 km² under M (h) Jackknife models. The estimated density of male tiger using the same method was 1.6±0.7/100 km² under M (h) model. The estimated density of female tiger using the same method was 1.9±0.7/100 km² under M (h) Jackknife model.

In **2010,** the estimated overall tiger population under M (h) model was 31.4±4.9 (p-hat =0.05). Male tiger population was 8.2±2.6 (p-hat = 0.03) under M (h) model. The estimated female tiger population was 20.8±4.2 (p-hat = 0.01) under M (h) model.

The estimated tiger density for overall tiger population in **2010** using ½ MMDM method was 4.4±0.8/100 km² under M (h) model. In case of male tiger the estimated density using the same method was 1±0.4/100 km² under M (h) model. The estimated female density was 3.1±0.7/100 km² under M (h) Jackknife model. The ETA (½ MMDM) was 719.6 for overall, 794.1 km² for male and 667.5 km² for female tiger population. The estimated density using MLSECR method for overall tiger population was 3.4±0.8/100 km² under M (h) model. The estimated density of male tiger using the same method was 1±0.1/100 km² under M (h) Jackknife model. The estimated density of female tiger using the same method was 3.7±1.2 /100 km² under M (h) Jackknife model.

In **2011,** the estimated overall tiger population was 26.9±3.9 (*p*-hat = 0.03) under M (h) model. The estimated male tiger population was 9±2.1 (*p*-hat = 0.04) under M (h) Jackknife model. The estimated female tiger population was 17.3±3.3 (*p*-hat = 0.03) under M (h) Jackknife model.

The estimated density using ½ MMDM method for overall tiger population was 2.9±0.2 /100 km² under M (h) model. The estimated density of male tiger using same method was 1±0.2/100 km² under M (h) Jackknife model. The estimated density of female tiger using the same method was 1.9±0.2 /100 km² under M (h) Jackknife model. The ETA was 881.6 km² for over all tiger population, 841.7 km² for male tiger population and 881.6 km² for female tiger population.

The estimated density using the MLSECR method for overall tiger population was 3.2±0.1/100 km² under M (h) model. The estimated density of male tiger population using the same method was 0.8±0.3 under M (h) Jackknife model. The estimated MLSECR density of female tiger was 2.6±0.1/100 km² under M (h) Jackknife model.

In **2012,** the estimated overall tiger population was 23.6±3.9 (*p*-hat = 0.03) under M (h) model. The estimated male tiger population was 3±0.03 (*p*-hat = 0.04) under M (h) Jackknife model. The estimated female tiger population was 14±1.4 (*p*-hat = 0.02) under M (h) Jackknife model.

The estimated density using ½ MMDM method for overall tiger population was 3.9±0.1 /100 km² under M (h) model. The estimated density of male tiger using same method was 0.7±0.04/100 km² under M (h) Jackknife model. The estimated density of female tiger using the same method was 2.2±0.7 /100 km² under M (h) Jackknife model. The ETA was 570 km² for over all tiger population, 517.9 km² for male tiger population and 597 km² for female tiger population.

The estimated density using the MLSECR method for overall tiger population was 4.3±1.1 /100 km² under M (h) model. The estimated density of male tiger using same method was 0.6±0.08/100 km² under M (h) Jackknife model. The estimated density of female tiger using the same method was 2.3±0.4 /100 km² under M (h) Jackknife model.

In **2013,** the estimated overall tiger population was 38.9±2.5 (p-hat = 0.12) under M (h) model. The estimated male tiger population was 11±0.1 (p-hat = 0.04) under M (h) Jackknife model. The estimated female tiger population was 27.9±2.5 (p-hat = 0.02) under M (h) Jackknife model.

The estimated density using ½ MMDM method for overall tiger population was 5.1±0.4 /100 km² under M (h) Jackknife models. The estimated density of male tiger using same method was 1.7±0.5/100 km² under M (h) Jackknife model. The estimated density of female tiger using the same method was 4.1±0.4/100 km² under M (h). The ETA was 763.5 km² for over all tiger population, 678.7 km² for female tiger population and 944 km² for male tiger population. The estimated density under MLSECR method for overall tiger was 4.1±0.7/100 km² under M (h) models. The estimated density of male tiger population using the same method was 0.9±0.2 under M (h) Jackknife models. The estimated MLSECR density of female tiger was 4.2±1.9 /100 km² under M (h) Jackknife models.

All estimated results in detail (2006 to 2013) of tiger population are given in Table 7.3a.

Table 7.3a. Population and density (100/km^2) estimation of tiger in Pench Tiger Reserve, Madhya Pradesh (May 2006 to March 2013)

Year	Unidentified photographs	Parameters	N	No of Capture	p-hat	Population ±SE	ETA 1/2 MMDM (sq km)	Density (1/2 MMDM)	Model fit	Density (ML-Dens)	M L Sigma (m)
		Model			M (h)	M (h)		M (h)		M (h)	
2006	4	Male	3	48	0.18	3±0.01	192.4	1.6±0.5	Half normal	1.3±0.7	3039±594.6
		Female	11	42	0.04	13.9±2.5	137.5	10±0.2	Half normal	5.2±1.7	2155.3±343.4
		Over all	14	90	0.06	17±2.6	151.6	11.6±2.2	Half normal	4.7±1.2	2708.4±328.4
2008	6	Male	6	33	0.05	6.6±2.6	721.4	0.9±0.4	Half normal	1±0.2	4101.9±536.8
		Female	12	38	0.02	12±0.9	587.1	2±0.2	Half normal	1.7±0.5	2858.5±458.9
		Over all	18	71	0.02	22.1±4.4	556.7	4.8±1.3	Half normal	2.5±0.6	3769.3±379.2
2009	5	Male	8	18	0.015	8.2±2.6	421.9	1.9±0.7	Half normal	1.6±0.7	2446.5± 612.4
		Female	9	18	0.01	13.5±5.9	495.1	2.7±1.2	Half normal	1.9±0.7	1543±360
		Over all	17	45	0.011	21.1±2.4	491.2	5.5±1.9	Half normal	4.4±1.2	2027.1±344.1
2010	4	Male	8	38	0.031	8.2±2.6	794.1	1±0.4	Half normal	1±0.1	3603±1318.1
		Female	15	27	0.01	20.8±4.2	667.5	3.1±0.7	Half normal	3.7±1.2	4658.8±2043.6
		Over all	23	65	0.05	31.4±4.9	719.6	4.4±0.8	Half normal	3.4±0.8	4049.5±1063.7
2011	7	Male	7	39	0.04	9±2.1	841.7	1±0.2	Half normal	0.8±0.2	3690.7±513.7
		Female	16	59	0.03	17.3±3.3	881.6	1.9±0.2	Half normal	2.6±0.1	3114±343.7
		Over all	23	99	0.03	26.9±3.9	881.6	2.9±0.2	Half	3.2±0.1	3332.5±295.5

Year	Unidentified photographs	Parameters	N	No of Capture	p-hat	Population ±SE	ETA 1/2 MMDM (sq km)	Density (1/2 MMDM)	Model fit	Density (ML-Dens)	M L Sigma (m)
		Model			M (h)	M (h)		M (h)		M (h)	
									normal		
2012	8	Male	3	11	0.04	3±0.03	517.9	0.6±0.08	Half normal	0.7±0.04	2663.1±676.45
		Female	13	32	0.02	14±1.4	597	2.3±0.4	Half normal	2.2±0.7	3584.1±568.1
		Over all	16	43	0.02	23.6±3.9	570	4.3±1.1	Half normal	3.9±0.1	3365.1±488.6
2013	24	Male	11	141	0.16	11+0.1	944	1.7+0.15	Half normal	1±0.2	4288.9±255.1
		Female	25	217	0.11	27.9+2.5	678.7	4.1±0.4	Half normal	3.1±0.6	2222.8±102.5
		Over all	36	358	0.12	38.9±2.5	763.5	5.1±0.4	Half normal	4.1±0.7	3178.2±124.8

MMDM- Mean Maximum Distance Moved, MLSECR- Maximum Likelihood Spatially Explicit Capture-Recapture, ETA-Effective Trapping Area, m=meter, km=Kilometer,± Standard Error, N= Number of individual tigers

Sex ratios (male: female) of tiger:

The male: female sex ratios in the study area between 2006 and 2013 is given below (Table 7.3b)

Table 7.3b Adult sex ratios (Male:Female) in tiger between 2006 and 2013

Year	Male:Female
2006	1:2.5
2008	1:2.0
2009	1:1.4
2010	1:1.9
2011	1:2.3
2012	1:3.0
2013	1:2.3

7.3.2. Survival rate of tiger: Though various time constant (.) and variant (t) model combinations have been tested with survival rate of tiger, only best five models on each sex and age categories were shown in this paper (Table 7.4). Survival rates (± SE) in various categories were described according to the best fitted model (Table 4). The estimated survival rate of all tiger (n=66) was 0.66 (±0.04), whereas for all male tiger (n=22) it was 0.59 (±0.09), for all female tiger (n=44) it was 0.7 (±0.06), for adult male tiger (n=7) it was 0.83 (±0.07), for all breeding female tiger (n=14) it was 0.86 (±0.05) for sub-adult tiger (n=45) it was 0.57 (±0.29) and for cubs (n=52) it was 0.73 (±0.05) (Table 7.5).

Table 7.4. Model selection statistics for robust design analysis of tiger (overall, male, female, residential male and female) capture data from Pench National Park, Madhya Pradesh (May 2006 to March 2013).

Category	Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
Overall tiger	{s(.)g'(0)=g"(0)cg=pg(t)N(t)}	1238.836	0	0.57022	1	11	1207.0618
	{s(t)g'(.)g"(.)cg=pg(t)N(t)}	1240.505	1.6684	0.2476	0.4342	31	1163.4883
	{s(.)g'(.)g"(.)cg=pg(t)N(t)}	1241.135	2.2985	0.18069	0.3169	13	1205.0694
	{s(.)g'(t)=g"(t)cg=pg(t)N(t)}	1250.807	11.9703	0.00143	0.0025	27	1183.2708
	{s(.)g'(t)g"(t)cg=pg(t)N(t)}	1257.565	18.7285	0.00005	0.0001	22	1201.566
All Male	{s(.)g'(0)=g"(0)cg=pg(.)N(t)}	428.3064	0	0.64626	1	6	373.1241
	{s(.)g'(.)=g"(.)cg=pg(.)N(t)}	430.0828	1.7764	0.26587	0.4114	7	372.6092
	{s(.)g'(.)g"(.)cg=pg(.)N(t)}	432.382	4.0756	0.08422	0.1303	8	372.5703
	{s(t)g'(.)=g"(.)cg=pg(.)N(t)}	439.1513	10.8449	0.00285	0.0044	12	369.4898
	{s(t)g'(.)g"(.)cg=pg(.)N(t)}	441.7029	13.3965	0.0008	0.0012	13	369.4466
All female	{s(.)g'(0)=g"(0)cg=pg(.)N(t)}	868.7664	0	0.45351	1	11	816.9951
	{s(.)g'(.)=g"(.)cg=pg(.)N(t)}	868.9858	0.2194	0.4064	0.8961	12	814.9833
	{s(.)g'(.)g"(.)cg=pg(.)N(t)}	871.2379	2.4715	0.1318	0.2906	13	814.9832
	{s(t)g'(.)g"(.)cg=pg(.)N(t)}	876.7782	8.0118	0.00826	0.0182	18	808.9362
	{s(.)g'(t)g"(t)cg=pg(.)N(t)}	887.8644	19.098	0.00003	0.0001	22	810.3415
Adult male tiger	{s(.)g'(0)=g"(0)cg=pg(.)N(t)}	1033.9	0	0.59191	1	15	1080.58
	{s(.)g'(.)=g"(.)cg=pg(.)N(t)}	1035.218	1.3176	0.30629	0.5175	16	1079.6317
	{s(.)g'(.)g"(.)cg=pg(.)N(t)}	1037.421	3.521	0.10178	0.172	17	1079.5509
	{s(.)g'(t)g"(t)cg=pg(.)N(t)}	1054.947	21.0472	0.00002	0	30	1065.6061
	{s(t)g'(t)g"(t)cg=pg(.)N(t)}	1070.304	36.4041	0	0	36	1065.2275
Breeding tigress	{s(.)g'(0)=g"(0)cg=pg(.)N(t)}	1033.9	0	0.59191	1	15	1080.58
	{s(.)g'(.)=g"(.)cg=pg(.)N(t)}	1035.218	1.3176	0.30629	0.5175	16	1079.6317
	{s(.)g'(.)g"(.)cg=pg(.)N(t)}	1037.421	3.521	0.10178	0.172	17	1079.5509
	{s(.)g'(t)g"(t)cg=pg(.)N(t)}	1054.947	21.0472	0.00002	0	30	1065.6061
	{s(t)g'(t)g"(t)cg=pg(.)N(t)}	1070.304	36.4041	0	0	36	1065.2275
Sub-adult tiger	{s(.)g'(.)g"(.)cg=pg(t)N(t)}	383.6397	0	0.89492	1	13	162.3935
	{s(.)g'(0)=g"(0)cg=pg(t)N(t)}	389.4525	5.8128	0.04893	0.0547	12	170.869
	{s(.)g'(0)g"(0)cg=pg(t)N(t)}	389.4525	5.8128	0.04893	0.0547	12	170.869
	{s(t)g'(.)g"(.)cg=pg(t)N(t)}	394.6181	10.9784	0.0037	0.0041	17	162.0553
	{s(t)g'(.)=g"(.)cg=pg(t)N(t)}	394.7137	11.074	0.00352	0.0039	16	165.0848

S= Survival rate, g' or Gamma'= Immigration rate, g" or Gamma"= Emigration rate, pi= Probability of mixture, pg = Capture probabilities in group, cg= Recapture probabilities in group, (.)= Time constant or invariant, (t) = Time variant, (0) = Fixed

Table 7.5. Estimated survival rate, mean annual growth rate and mean recruitment of tigers in Pench Tiger Reserve, Madhya Pradesh (May 2006 to March 2013)

Parameters	All tiger (n=66)	All Male (n=22)	All Female (n=44)	Adult male (n=7)	Breeding female (n=14)	Overall Sub-adult (n=45)	Cubs (n=52)
Method for survival rate estimate	PRD	PRD	PRD	PRD	PRD	PRD	K-M
S'+SE	0.66±0.04	0.59±0.09	0.7±0.06	0.83±0.07	0.86±0.05	0.57±0.29	0.73±0.05
Growth rate (λ) ±SE 2nd and 3rd year	0.9±0.09	1.25±0.09	0.78±0.18	2±0.01	1.11±0.12	--	--
3rd and 4th year	1.14±0.11	1.4±0.01	1.23±0.3	0.67±0.01	1.12±0.04	--	--
4th and 5th year	1.01±0.1	0.86±0.01	1.11±0.24	1±0.01	1±0.01	--	--
5th and 6th year	0.99±0.14	0.67±0.15	1.11±0.28	0.75±0.01	0.67±0.14	--	--
6th and 7th year	1.72±0.12	2±0.45	1.6±0.33	1.07±0.01	0.97±0.19	--	--
Mean annual growth rate (λ) ±SE	1.15±0.11	1.23±0.13	1.17±0.27	1.1±0.01	0.98±0.11	--	--
Average Recruitment ±SE	9.2±2.2	2.8±0.8	6.4±2.3	1.04±0.4	1.2±0.2	--	--

(S'= Survival rate ± Standard Error, PRD- Pollock's Robust Design, K-M- Kaplan- Meier's known fate model, λ= Mean annual growth rate-- Not assessed)

7.3.4. Growth rate and recruitment pattern: Though sampling area varied as per the availabilities of camera traps, but we maintained the same trapping area for estimation of annual growth rate. Trapping period 2nd to trapping period 7th was only considered to estimate growth rate and recruitment. Though for estimating survival rates of tiger, survival constant model i.e. S (.) was found to be the best fitted model, time variant models i.e. S (t) were used while estimating growth rate and recruitment of tiger for the present study. The estimated mean annual growth rate (±SE) for all tiger was 1.15 (± 0.11) followed by 1.23 ± 0.13 for all male, 1.17 ± 0.27 for all female, 1.1± 0.01 for adult male tiger and 0.98± 0.11 for all adult breeding female tiger population (Table 7.5).

The estimated mean recruitment (±SE) for all tiger population was 9.2±2.2 followed by 2.8±0.8 for all male tiger, 6.4±2.3 for all female tiger, 1.04±0.4 for adult male tiger and 1.2±0.2 for breeding female population (Table 7.5).

7.4. Discussion

The tiger density in the study area did not differ ($P > 0.05$) between 2nd and 7th trapping period. No significant differences ($P>0.05$) was observed between tiger density from the last or 7th trapping year and an earlier study in the same study site (Karanth et al. 2004) using same (1/2 MMDM) methods which indicated a stable population in the study area.

Majumder et al. (2012) reported overall biomass of principal prey species (chital, sambar, nilgai, gaur, wild pig and common langur) in Pench as 6890 (kg/ km²). Using the equation developed by Hayward et al. (2007) for African lion (*Panthera leo*) i.e. $y = -2.158 + 0.377x$, where X= $\log_{10}$ prey biomass and y=$\log_{10}$ predator density, we found that predicted density for tiger in the study area is 4.14/100 km² whereas actual tiger density is (Pooled ½ MMDM density from 2nd to 6th trapping year ± SE) 4.4±0.1/100 km². So it can be concluded that tiger density in the study area reached its carrying capacity as per their available principal prey biomass.

The overall tiger density in PTR can be comparable with tiger densities of two other teak dominated tropical deciduous forest of central Indian Landscape i.e. with

Melghat (3.04±0.75/100 km²) and Tadoba (5.29±1.11/100 km²) while it was found higher than Satpura (2.7±1.2/100 km²) and Nagarjuna Sagar-Srisailam (1.5±0.3/100 km²) (Jhala et al. 2010).

Though all tigers typically show a 1:1 sex ratio at birth (Seifert 1985) , the overall female biased sex ratio as observed in the present study may be due to the philopatric nature of female tiger and dispersal of male tiger from the natal area. Similar finding was reported by Smith (1993) in Nepal. VanderWall et al. (2009) also reported many solitary species tolerate female offspring remaining in their territory (Waser & Jones 1983, Zedrosser et al. 2007), even sharing their original territory with their offspring (Rogers 1987).

Survivorship and reproductive success of tiger

Overall estimated survival rate of tiger in the present study can be comparable with the estimated survival rate of tiger in Nagarahole Tiger Reserve i.e. 0.77±0.05 (Karanth et al. 2006). The survival rate of breeding female of the study area can be comparable with adult survival rate (0.81±0.1) of female Amur tiger (*Panthera tigris altaica*) in Russia (Goodrich et al. 2008). The overall recruitment (Mean ± SE) of tiger in the study area can be comparable with the overall recruitment pattern of tiger (7±3) in Nagarahole Tiger Reserve (Karanth et al. 2006).

There were various possible factors observed for high survival rate of tiger cubs (73%) other than high densities of principal prey species and undisturbed habitat near breeding den (Majumder et al. 2012b). Breeding tigress might adopt a strategy to protect her cubs from infanticide, utilizing different temporal activity period with female without cubs and transient male tigers. The high survival rate of resident male (more than 80%) might have influenced the high survival rate of cubs in the study area. Though adult male tiger is largely a solitary felid (Schaller 1967, Sunquist 1981), according to Cavalcanti and Gese (2009), "A species may be considered solitary, but an individual may eventually meet with conspecifics". Barlow et al. (2009) observed that loss of resident males increases cub mortality substantially through infanticide and temporarily limits the supply of individuals available for replacing residents who die.

Of the cubs found survived in Pench for more than 12 months (n=39), 86% were observed up to transient stage (≥18 month-36 month≤) and 14% was up to adult stage (> 36 month). The transient male showed significant differences (P>0.001) in temporal activity pattern (Fig. 3) with resident adult male which may probably reduce intra-specific competition. No records of tiger death due to territorial fighting during the study period supported our aforesaid finding.

The overall growth rate of tiger population in the present study can be comparable with the study in Nagarahole (Karanth et al. 2006). Though there was an increase in the overall tiger population with 2 % annual growth rate in the study area, it is the dispersal and recruitment of sub-adults in the population, largely contributed to the gradual fluctuation in growth rate, as resident adult tiger population remained almost constant over the period (Fig. 7.4). A high survival rate (89%) of breeding female in the study area is important for the conservation of tiger in this landscape as sub-adult or transient survival rate was found to be low (11%) during the study period. Karanth et al. (2006) reported that high breeder survival rate ensures a population which can persist even with low juvenile and transient. Chapron et al. (2008) also reported that the low survival rate of dispersers is tolerable if survival rate of adult breeding female is high.

The high prey density in the study area (Majumder et al. 2012a) appeared to be critical for sustaining an overall stable adult tiger population in the study area which is in accordance with the other available survival studies of solitary felids in India by Karanth et al. (2006). As, carnivore densities are positively correlated with prey biomass (Silver et al. 2004, Carbone & Gittleman 2002), a high level of prey availability may cause an increase in the presence of adult animals and may also increase reproduction and survival of breeding individuals within the population. It can be expected that the proximity of larger forest continuity to high tiger population have greater chance for their long-term survival in this landscape.

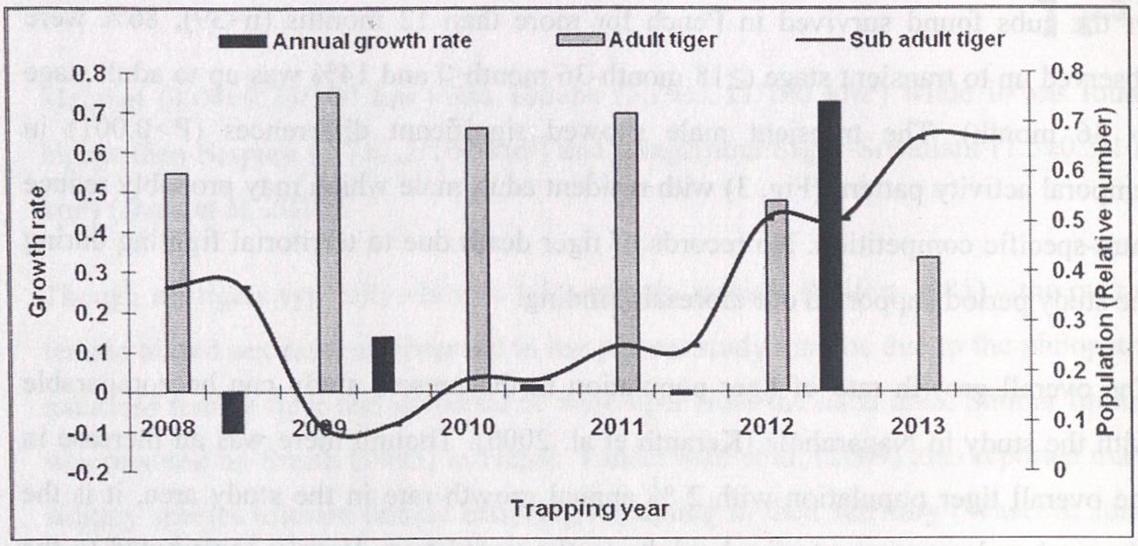


Fig. 7.4. Overall growth rate of tiger was compared with adult and sub-adult population in Pench National Park (May 2006 to March 2013)

Conservation implications

Conserving large carnivores in any human dominated landscape of India is a daunting task for forest managers. In the Indian sub-continent most of the forested habitat is fragmented and connected by narrow corridors (Jhala et al. 2010). As dispersal is essential for maintaining genetic connectivity within the tiger population (Goodrich et al. 2008, Miquelle et al. 1999), it is of serious concern for managers when dispersing individuals move out from any protected area to poorer habitat. Majumder et al. (2012b) reported dispersal of one radio-collared and one non collared transient male form Pench to adjacent forest patches and our present Camera Trap study also revealed fluctuation in overall growth rate of tigers because of dispersal of transients.

Another major problem in the study area is that, tigers are surviving with small population size and operating at carrying capacity. According to Jhala et al. (2010) in any landscape a minimum of twenty breeding females are needed for long term survival of tiger population whereas in Pench presently nine breeding females are operating and can hold a maximum of ten breeding females based on radio-telemetry studies (Majumder et al., 2012b). According to Harmon & Braude (2010) "Population size is extremely important in evaluating conservation priorities for a species and small populations are at risk of going extinct because of both environmental and demographic stochasticity and genetic drift. It is most important to take timely and effective action for small populations that are at great risk if the population is to continue to exist (Servheen 1998). Though the intensive study area is relatively undisturbed and favorable for breeding tigresses, there is continuous biotic pressure exert from 99 villages located around the notified buffer zone of PTR, Madhya Pradesh (Majumder et al. 2012b). Therefore, it is important to have corridor connectivity with neighboring population of Kanha Tiger Reserve, Satpura Tiger Reserve and Pench Tiger Reserve (Maharastra) to form a meta-population structure for long term viability and survival of tiger population. Recent study showed that tiger meta-population in this landscape has high genetic variation and very low genetic subdivision (Sharma et al. 2012). These important corridors may ensure constant emigration and immigration to reduce the chances of genetic drift or inbreeding in the Pench tiger population.

Chapter 8

LANDSCAPE CHANGE AND ANTHROPOGENIC ATTRIBUTES

8.1 Introduction

In recent years, a critical approach to environmental sustainability has resulted in greater importance being given to scientific research into the causes and effects of land use and land cover changes. Some of this work has been supported by the Land-Use and Land Cover Change (LULCC) project of the International Geosphere–Biosphere Programme (IGBP) and International Human Dimensions Programme (IHDP) on Global Environmental Change, which for more than a decade has made significant contributions to an analysis of the changes occurring in the territory (Lambin and Geist 2006).

Although the causes behind these changes are diverse, above all in the case of forest cover, they can nevertheless be organized into two large groups: a) proximate causes and b) underlying causes (Lambin 1997). The former constitute activities and actions which directly affect land use, such as wood extraction or road construction, whilst the latter comprise the root causes of these, such as demographic, economic, technological, institutional and cultural factors (Geist and Lambin 2001, Verburg et al.2004).

In most of the forested landscape of Southern Asia, identifying key drivers of forest change becomes even more difficult due to the long history of human occupation and use of these forests. In the recent past, a number of studies in India have focused on the impacts of human settlements on protected areas (PAs). These studies fall into two categories, those based primarily on ground measurements of vegetation across a human-use gradient (Barve et al.2005, Kumar and Shahabuddin 2005, Karanth et al.2006, Shahabuddin and Kumar 2006, 2007) and others that rely on some remotely sensed data from one, two or three date satellite data to assess changes over space and/or time (Barve et al.2005, Ostrom and Nagendra 2006, Robbins et al.2007).

According to Angelsen and Kaimozwitz (1999), the first step when analyzing the causes is to identify the agents involved in the processes of change, that is to say, the sources of deforestation. Among the primary sources identified are colonization programs, the spread of agricultural and cattle rearing activities, excessive commercial wood extraction and illegal logging (Morán and Galleti 2002). In recent years, various empirical studies have been carried out in order to identify those factors most frequently related to the loss of forest cover (Angelsen and Kaimozwitz 1999, Nelson et al.2001). In practice, many of these factors interact, leading to a complex web of relationships between the causal factors of change and their processes, as well as human behavior and organization (Verburg et al.2004).

Direct causes can be divided into three main groups: a) infrastructure extension, b) agricultural expansion and c) wood extraction (Fig. 8.1). The first group comprises infrastructures such as roads, tracks, human settlements and hydroelectric dams which are responsible for the flooding of large extensions of forest. In the second group, a shift in land use towards agricultural and cattle rearing activities is the most frequent cause. Fire is another factor with a close connection with forest cover changes in India specially in the North-Eastern region are converted to other uses through slash-and-burn techniques. The third group also plays an important role in the loss of forest cover, and depends to a large extent on local and national regulations, on government vigilance and the flow of capital.

Indirect causes comprise the factors which lead to or underlie direct causes, and can be divided into five large groups: a) demographic factors, b) economic factors, c) technological factors, d) policy and institutional factors and e) cultural factors (Fig. 8.1). In terms of scale, indirect causes may function directly at a local level and indirectly at national or even global level (Geist and Lambin 2001), although some authors have indicated that establishing a clear correlation between forest cover loss and indirect causes is more difficult than establishing the same for direct causes (Kaimowitz and Angelsen 1998).

The demographic factors influencing loss of forest cover are basically those related to population growth, density and spatial distribution, in addition to certain migratory processes. Meanwhile, the principle economic factors are commercialization and market growth, accessibility of regional and national markets, and the rising price of wood and certain agricultural products, with the latter leading to deforestation in order to cultivate the product. Indices related to poverty and marginalization, low standards of living and unemployment also have a significant influence in some regions.

There are two opposing sides to policy and institutional factors. On the one hand, there are official policies such as subsidies, credit and insurance for agro-forestry production, legislation concerning forestry and environmental issues, and other, more influential, policies such as the colonization and development programs officially promoted by government (Fig. 8.1) departments. On the other hand, tacit policies, such as corruption and even the particular interests of political parties also contribute to the process of deforestation. As for cultural factors, some of these are related to marginalized groups which, in the case of India, usually mean indigenous tribal people. Lastly, there is another group of factors associated with forest cover loss processes which are located somewhere between direct and indirect causes. The most common of these factors are those related to the characteristics of the land itself, such as its quality and suitability for agricultural production of some kind, or its topography and altitude, but they can also be associated with natural hazards such as drought, flooding, naturally-occurring forest fires and plagues, or social hazards such as infiltration or terrorist activities, the displacement of refugees and economic crises, among others.

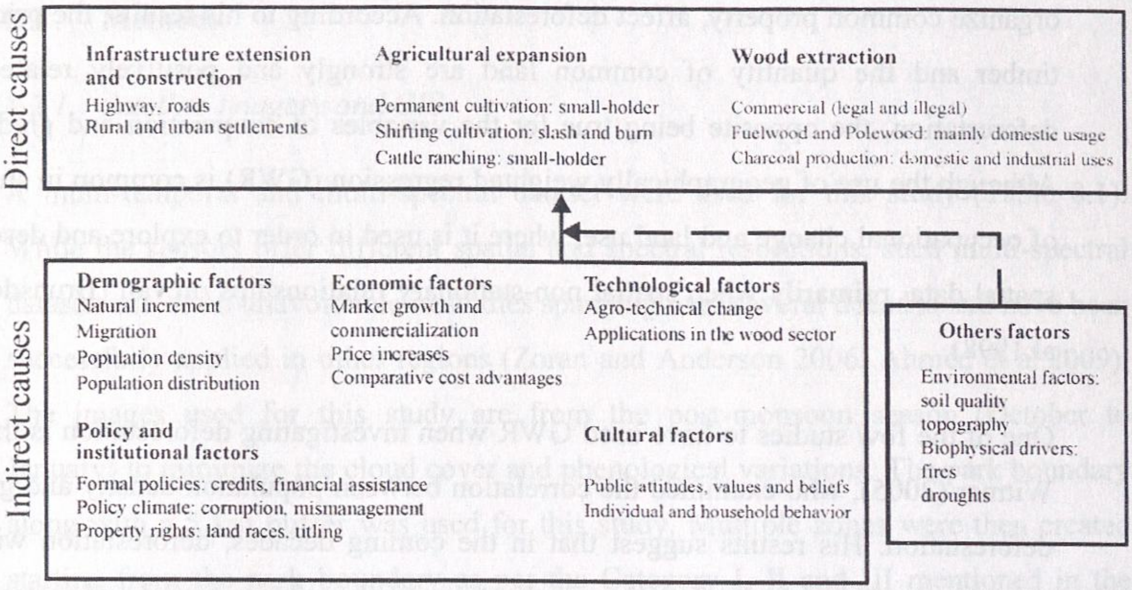


Fig. 8.1 Causes of deforestation (Source: Geist and Lambin 2001)

In recent years, a large body of researchers had analysed and modeled the changes of occupation and land use using quantitative methods. It has been demonstrated, for example, that agent-based models (ABM) are a useful tool for studying the environment (Bousquet and Le Page 2004, Hare and Deadman 2004). ABM have been applied to simulate the impact of human decisions on land use and land cover change (Brown et al.2004, Evans et al.2001, Hoffman et al.2002, Ligtenberg et al.2001, Loibl and Toetzer 2003, Parker et al.2003), and the deforestation of tropical forests (Huigen 2002, Lim et al.2002, Manson 2002, Manson and Evans 2007). Also multilevel models working on different temporal and spatial scales have been developed (Pan and Bilsborrow 2005, Overmars and Verburg 2006, Walsh et al.2001).

Deininger and Minten (1996) have shown how factors such as bank loans, the price of timber and poverty rates are closely and positively related to deforestation processes nationally, whereas technical assistance, protected natural areas and the indigenous population are negatively related. For their part, Blackman et al.(2008) have investigated the factors which lead to deforestation in the woodland of the southern sierra in Oaxaca, Mexico. According to their results, proximity and some variables related to land tenancy best account for deforestation patterns in the area. Alix-García (2007) has studied how cooperation from communities and the way communities organize common property, affect deforestation. According to his results, the price of timber and the quantity of common land are strongly and positively related to deforestation, the opposite being true for the variables of cooperation and gradient. Although the use of geographically weighted regression (GWR) is common in studies of occupational change and land use, where it is used in order to explore and describe spatial data, primarily when spatial non-stationary relationships prevail (Brunsdon et al.1998).

One of the few studies to have used GWR when investigating deforestation is that of Witmer (2005), who examined the correlation between population density and global deforestation. His results suggest that in the coming decades, deforestation will be more intense in tropical Africa than in the Amazon. In order to model and understand the reasons and driving forces behind the loss of forest cover in and around Pench Tiger Reserve (PTR), a method of quantitative analysis was applied which facilitated global and local understanding of the processes leading to this loss in four different areas of forest cover between the years 1999 and 2009, and which took account of the complex interaction of biophysical, socioeconomic, cultural and political factors.

This study highlighted some key impact of landscape change due to different anthropogenic activities like dam construction, cattle grazing, wood extraction and by different demographic, economic and policy attributes. Lack of long-term historical data in all the aspects mentioned above had limited this study scale both temporally and spatially. For this study GWR was used because unlike the "classic" methods it considers the location of the phenomenon studied. It is important to highlight that this study does not seek any causal depth in its models, but is rather concerned to provide an approach to and a description of relationships that occur spatially. It is therefore necessary to recognize that this technique has its shortcomings, especially those related to the significant levels of local coefficients, multi-collinearity and spatial autocorrelation (Griffith 2008, Wheeler and Tiefelsdorf 2005).

8.2 Methods

8.2.1 Satellite Imagery and GIS

A multi-temporal and multi-spectral dataset were used for this study (Table 8.1). While the sensors offer different spatial and spectral resolutions, such multi-spectral datasets are often unavoidable in studies spanning over several decades and have been successfully applied in other regions (Zoran and Anderson 2006, Ahmed et al.2009). The images used for this study are from the post-monsoon season (October to January) to minimize the cloud cover and phenological variations. The park boundary along with a 5 km buffer was used for this study. Multiple zones were then created starting from the park boundary as per the Category I, II and III mentioned in the earlier chapter up to the required buffer limit of 5 Km. We used this buffer-zone approach to understand the role of distance from the park boundary in the land cover changes. This study involves comparisons of land cover changes of a park and its surrounding matrix.

Table 8.1 Details of satellite imagery used in the study

Satellite	Sensor	Year of accusation	Resolution	Data source
Landsat	MSS	1977	60 m	http://earthexplorer.usgs.gov
Landsat	TM	1989	30 m	http://earthexplorer.usgs.gov
Landsat	ETM+	1999	30 m	http://earthexplorer.usgs.gov
Landsat	TM	2009	30 m	http://earthexplorer.usgs.gov

8.2.2. Image pre-processing

Image pre-processing was carried out in ERDAS Imagine 9.0 software package. Geometric rectification was carried out on all the Landsat images using the 1:50000 Survey of India (SOI) toposheets and nearest neighbor resampling algorithm, with root mean square (RMS) error of less than 0.5 pixels (<15 m) via image-to-image registration. Radiometric calibration and atmospheric correction were carried out to correct for sensor drift, differences due to variations in the solar angle and atmospheric effects (Green et al.2005).

8.2.3 Image classification

A hybrid approach was used to classify the images. First, an unsupervised classification method with ISODATA clustering was used to generate preliminary classes. Then similar classes were merged based on spectral signatures and training samples collected during May 2007 to June 2008. Finally, we defined five land cover classes – Teak associated forest, Miscellaneous forest, Open forest, Non-forest (agri-habitation and cleared forest) and water (reservoir, small ponds, and rivers) based on distinct spectral signatures and used those signatures for supervised classification with the minimum distance to means classification algorithm. Accuracy testing was performed using 460 training samples. Previous compartment history data was used as a historical record on land use/cover along with the training samples. The overall classification accuracy was over 91% with a kappa value of 0.87. Each image was classified following the same method, rather than applying signatures from one date back in time.

8.2.4 Change detection

For this analysis Idrisi Andes (© Clark Labs) was used. Regression analysis was done on every set of NDVIs to estimate the time frame when maximum change in green leaf biomass occurred in the study area. Post-classificatiion change detection is a widely used pixel based change detection method (Jensen et al.1995), where two (or more) classified images are compared using a change detection matrix. For this study, two date image trajectory images (1977-1989, 1989-1999, 1999-2009) were generated for PTR and three buffer categories from PTR. In order to maintain the spatial compatibility, the classified MSS image was artificially down-scaled to 30 m before performing the change trajectory analysis. The trajectory images from the four dates with five land cover classes for each date resulted many possible change trajectories. Since interpretation of these trajectories may be confusing, we further collapsed these trajectories into eleven categories namely 1) Stable miscellaneous forest, 2) Stable teak-associated forest, 3) Stable open forest, 4) Stable water, 5) Stable Non-forest, 6) Teak to Miscellaneous, 7) Deforestation, 8) Reforestation, 9) Degradation and 11) Up-gradation. The category "Deforestation"in this study means any of the three vegetative cover classes when converted to "Non-forest". "Reforestation" was exactly opposite condition of that. "Degradation" means when "Miscellaneous" or "Teak-associated forest" were converted into "Open forest" and similarly "Upgradation" was reverse of that.

8.2.5 *Calculation of landscape metrics*

A series of non-redundant landscape metrics was applied to the present and historical classified land use/cover maps. Landscape metrics have long been used in similar studies and they allow the objective description of the temporal patterns of landscape change (Turner et al.2001). Forest landscape composition was quantified by means of the area covered by each class (CA, Class Area). Landscape structure was assessed by means of patch-based metrics such as the total and per class number of patches, shape-based metrics, size-based metrics and edge-based metrics (Haines-Young and Chopping 1996). The number of patches (NumP) is a useful measure to evaluate the weight of landscape configuration in large ecological processes (McGarigal and Marks 1995). In order to analyse patch shape we used the area weighted mean shape index (AWMSI) that measures the average patch shape, weighted on patch shape size. Specifically, larger patches are weighted more heavily than smaller patches in calculating the average patch shape for the considered class or landscape (McGarigal and Marks 1995). Area weighted mean patch size and patch size standard deviation (PSSD) were used as size-based metrics (McGarigal and Marks 1995). Edge metrics were used in order to analyse habitat loss and forest fragmentation (Bender et al.1998). Statistics representing the amount of edge or degree of edge effect, like total edge (TE) was estimated.

8.2.6 *Anthropogenic driving forces of landscape change*

Direct and indirect causes comprise the factors which lead to or underline direct causes, and can be divided into four large groups: a) demographic factors, b) economic factors, c) technological factors and d) policy and institutional factors

Some of the direct and indirect causes had been measured for this study. In the year of 1987 a hydroelectric dam was constructed in PTR, as a result a large forest land was lost under water. The loss was a direct cause of infrastructural development which was estimated.

Through a structured questionnaire survey respondents were asked about the distance travelled by them for collecting fuel wood, NTFPs and livestock grazing from each village. Though historical data on these were lacking, as people traditionally maintain a path or course while going to collect fuel wood, NTFPs or livestock grazing, this study tried to look into whether there were any notable detrimental impact like deforestation and forest degradation within the buffered distances (average distances gathered from questionnaire survey for fuel wood and NTFP collection and livestock grazing) around those villages. After buffering, area was merged with the PTR boundary which resulted into three zones 1) Core zone (Only inside PTR), 2) Middle area (Inside both PTR and extraction distance buffer) and 3) Outside area (Only in extraction distance buffer). This process was carried out for fuel wood and NTFP collection. After 2001, Forest department had raised Cattle Proof Walls (CPW) in certain places where there was a possibility of village livestock going inside PTR for grazing. So at the present scenario there is no livestock grazing inside PTR. There might be some old routes or areas which were affected by grazing but due to lack of historical data, analysis was done only in the areas outside PTR.

In the year 1977 Pench got a Wildlife Sanctuary status and then 1983 it became National Park. It became 19th Tiger Reserve of India in 1992. These changed protection and conservation policies in PTR in terms of new legislations, more man power to look after and obviously more funds to keep the pace. To gather information on changes in the landscape due to changes in the policies on preservation and conservation under the Wildlife Protection Act 1972, reforestation, upgradation, deforestation and degradation of forest were estimated among landscapes inside and outside PTR. Different Categories namely i) Core (PTR), ii) Category I (within 1 Km of PTR), iii) Category II (1 Km to 2 Km from PTR) and Category III (2 Km to 5 Km from PTR) were used to evaluate the status of land use/cover type with the help of landscape metrics which gave in depth critics on landscape health over the years.

To access the impact of increase in price of land and importance of area, five villages Turia, Awarghani, Teliya, Kohka and Kuppitola where all the tourist resorts are situated, were selected. Deforestation and degradation were estimated in this region for the study period.

In GWR 1:50,000 scale digital maps produced by the SOI were used for the purposes of reference. To find the possible factors that were related to loss of forest cover, an exhaustive search was made of geographic and statistical information including data of 2001 Population census which had demographic and economic factors for all the 99 villages of Seoni and Chhindwara Districts around PTR. Using these variables, an analysis using Pearson's correlation coefficient was carried out in order to measure the extent of association between explanatory variables. As a result, thirteen uncorrelated independent variables with highest explanatory power were finally selected (Table 8.2). In accordance with the classification proposed by Geist et al.(2006) and previous studies on the subject, the variables were organized into three large groups: a) socioeconomics, b) biophysical and c) proximity.

After an exploratory analysis, overall deforestation and degradation were selected as dependent variables. These dependent variables were then transformed into percentage values reflecting the proportion of forest cover in 1999. Losses of less than 1 ha were considered irrelevant to this study as it was the minimum detectable unit.

To calibrate the models, Spatial Analysis in Macroecology 4.0 (SAM 4.0) software (Rangel et al.2010) was used. Two models were calibrated individually, and were taken as the dependent variables. In addition, this software offers results in parameters such as coefficient of determination, AICc and the adjusted R^2 from both the "global regression" using the classic Ordinary Least Squares (OLS) method as well as the local regression (GWR) method. Moreover, it was decided to compare the adjusted R^2 of both methods as ways of selecting the models which best explain variance in the data. As a methodological option, the proposal was to apply GWR in this study, which would offer an estimate for each parameter in each village.

Table 8.2 List of independent variables used in the model

Variables	Description
Socioeconomic	
VAR_NO_HH	Variation in number of household (2001-2009)
VAR_TOT_P	Variation in total population (2001-2009)
VAR_P_SC	Variation in total Scheduled cast population (2001-2009)
VAR_P_ST	Variation in total Scheduled tribe population (2001-2009)
VAR_P_LIT	Variation in number of Literate (2001-2009)
VAR_FRM_HH	Variation in number of farmer household (2001-2009)
VAR_WRK_HH	Variation in number of worker household (2001-2009)
VAR_TOT_IR	Variation in total Irrigated land (2001-2009)
Biophysical	
PROTECT	Percentage of pixels in protected natural areas
SLOPE10	Percentage of pixels in with slope less than 10%
SLOPE20	Percentage of pixels in with slope between 10% and 20%
Proximity	
EUC_ROAD	Mean euclidean distance from major public transporting roads

8.2.7 Future Land use land cover prediction by Cellular Automata- Markov model

A Markov chain is a stochastic process that consists of a finite number of states of a system in discrete time steps and some known transition probabilities pij, where pij is the probability of that particular system moving from time step i to time step j. For example, for a system composed of multiple land covers, the state of a particular cell at time step i denotes the type of land cover of that particular cell at time step i, which might change (or remain the same) in the next time step j. The transition probability denotes the probability of each class changing to every other class (or remaining the same) from time step i to time step j. With Markov chain analysis, future land cover can be modeled on the basis of the preceding state, that is, a matrix of actual transition probabilities between states can be used to predict future changes in the landscape from current patterns (Brown et al.2000). Cellular automata is a dynamic and spatially explicit modeling approach that encompasses five components – (a) a space composed of discrete cells, (b) a finite set of possible states associated to every cell, (c) a neighborhood of adjacent cells whose state influences the central cell, (d) uniform transition rules through time and space, and (e) a discrete time step to which the system is updated. A combination of Markov and cellular automata approaches has been shown to improve models describing complex natural patterns (Marshall and Randhir 2008, Fan et al. 2008, Peterson et al.2009). The modeled landscapes were generated using the software IDRISI, the Andes version. The MARKOV module of the software analyzes a pair of land cover images and outputs a transition probability matrix, a transition area matrix, and a collection of conditional probability images. The transition probability matrix is a text file that records the probability of each land cover category changing to every other category. The transition areas matrix is a text file that records the number of pixels that are expected to change from each land cover type to each other land cover type over the specified number of time units. The conditional probability images report the probability of each land cover type to be found at each pixel after the specified number of time units. These images are calculated as projections from the later of the two input land cover images. The CA MARKOV module then utilizes the transition area matrix and a base-image to model future landscapes. In addition, the CA MARKOV module integrates the spatial information based on the conditional probability images, where the CA model changes a particular pixel from one land cover class in time step i to another class in time step j based on the state of the local neighborhood. In other words, the CA model utilizes a collection of the conditional probability images (also known as the suitability images) to start an iterative process of relocating the pixels to the proximity of the same land cover class until it meets the area predicted by the Markov model for each land cover class. For this study, land cover maps (30 m resolution) from 1999 and 2009 as input maps in a CA-MARKOV model to predict Land cover for 2019 with the assumption that the pre-1999 drivers acting on the landscape are the only drivers guiding post-1999 changes. The transition probabilities for 2009 were calculated by the MARKOV module based on the transitions between 1999 and 2009. The CA MARKOV module then used these transitions to predict spatial patterns for 2019 using the 2009 image as the base-image.

8.3 Results

8.3.1 Multiple year Image classification

As a result of hybrid classification approach, the study area was classified into five land use/cover classes for all the time series: 1) Miscellaneous, 2) Teak-associated forest, 3) Open forest, 4) Water and 5) Non-forest. Percentage representation of each category in each time series was given in Table 8.3.

Table 8.3 Percentage occurance of different land use / cover types in different years

Land use/cover classes	**1977 (%)**	**1989 (%)**	**1999 (%)**	**2009 (%)**
Miscellaneous	18	23.5	27.4	37.6
Teak-associated	40.7	30.4	27.3	17.7
Open	13	17.9	10.2	10.5
Non-forest	28.2	27.9	29.5	30.9
Water	0.1	2.3	7.6	7.3

8.3.2 Spatial and temporal land use/cover change trajectories

Regression analysis between 1977 and 1989, 1989 and 1999 and 1999 and 2009 using NDVI maps showed a significant change in the green biomass with R^2 varying from 0.6 to 0.74 (Fig 8.2, 8.3 and 8.4).

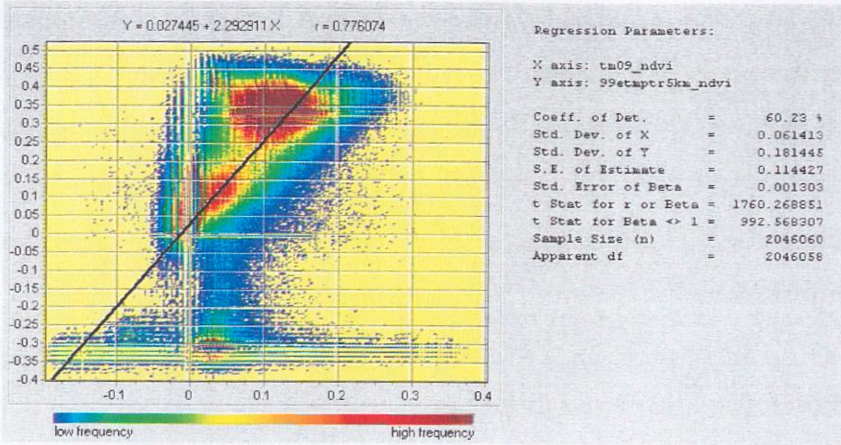


Fig 8.2 Regression analysis between 1999 and 2009

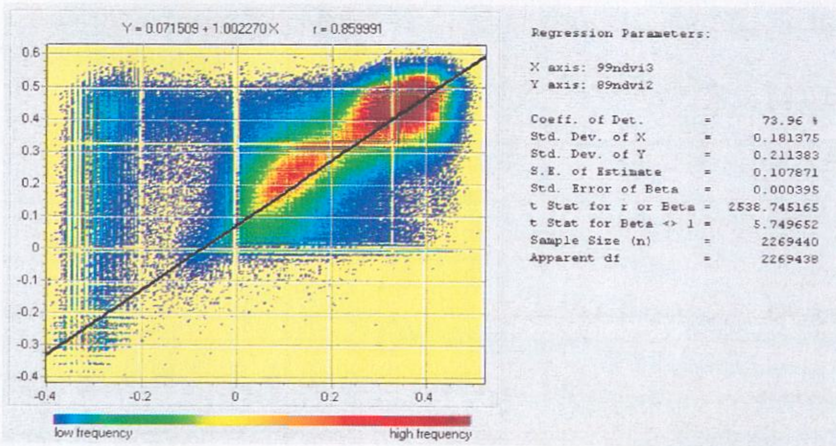


Fig 8.3 Regression analysis between 1989 and 1999

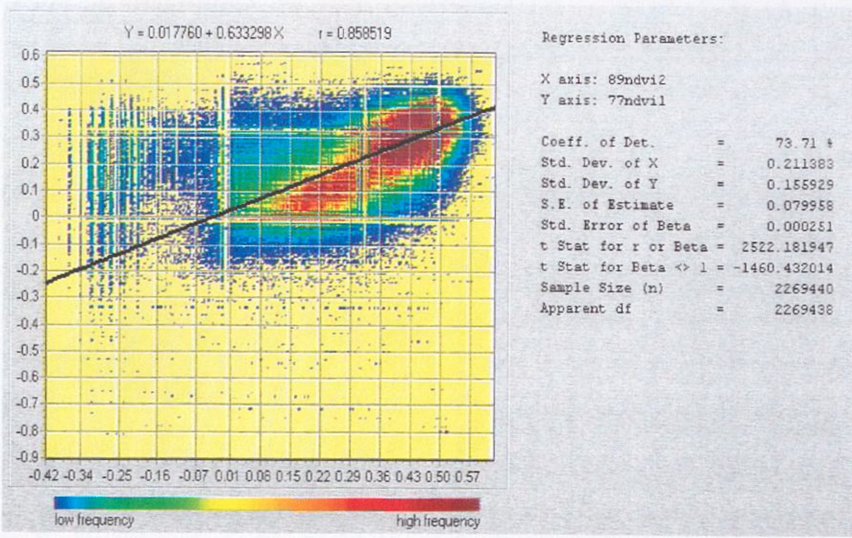


Fig 8.4 Regression analysis between 1977 and 1989

The two-date change trajectories reveald a distinct spatiotemporal pattern of forest-cover changes (Fig. 8.5, 8.6 and 8.7). As outlined in Table 8.4, PTR suffered notable deforestation before 1999, which became negligible in later years. While the proportion of stable miscellaneous forest consistently increased throughout the study period, post-1989 witnessed greater stability. In addition to stable land use/cover types, ''deforestation'' and ''reforestation'' classes, two-date change trajectories provided information on unique forest transition dynamics, namely "Teak to Miscellaneous", "Upgradation", "Degradation" (Table 8.4), which mainly represent rotational forests showing various forest transition pathways.

Table 8.4 Percentage representation of two date change trajectories

Land use/cover	1977 -1989 (%)	1989 -1999 (%)	1999 – 2009 (%)
Stable* Miscellaneous forest	10.4	17.1	18.7
Stable Teak-associated forest	19.5	14.5	10.2
Stable Open forest	7.1	7.1	7.2
Stable Water	0.1	2.2	7.7
Stable Non-forest	21.6	23.3	26.5
Reforestation	7.7	2.6	2.5
Teak to Miscellaneous	13.9	9.3	14.5
Upgradation	4.4	6.2	1.8
Deforestation	12.4	17.3	9.3
Degradation	6.9	6.4	7.6

* Stable means in both previous and later date, area belongs to same LULC

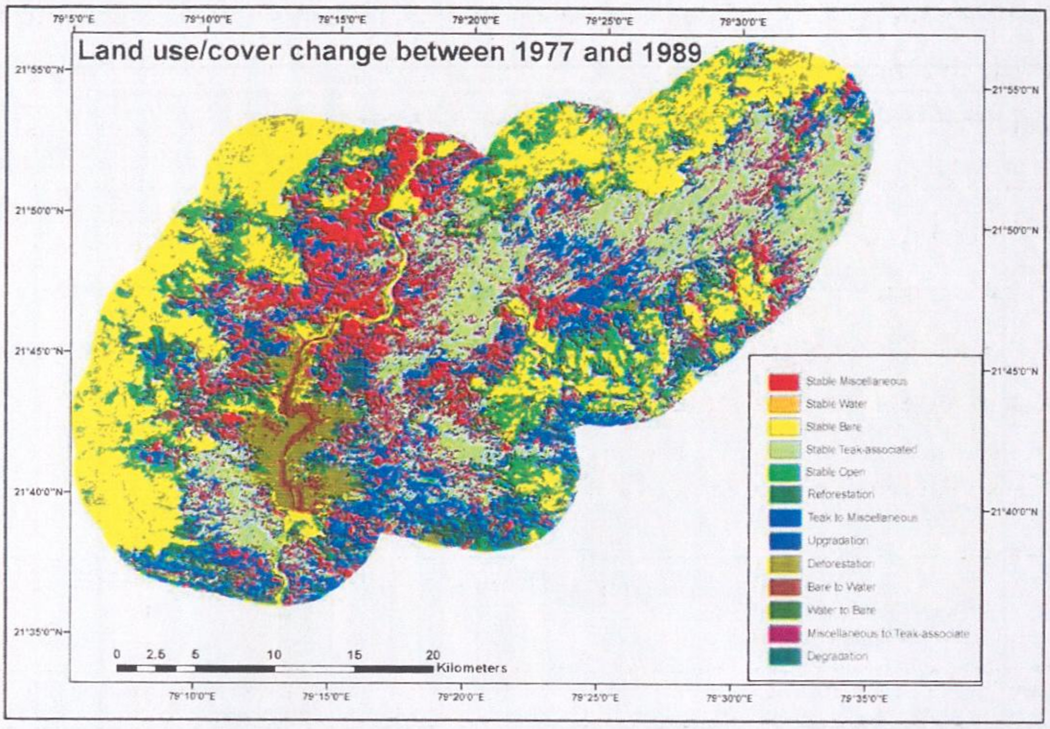


Fig 8.5 Land use/cover change between 1977 and 1989 in Pench Tiger Reserve

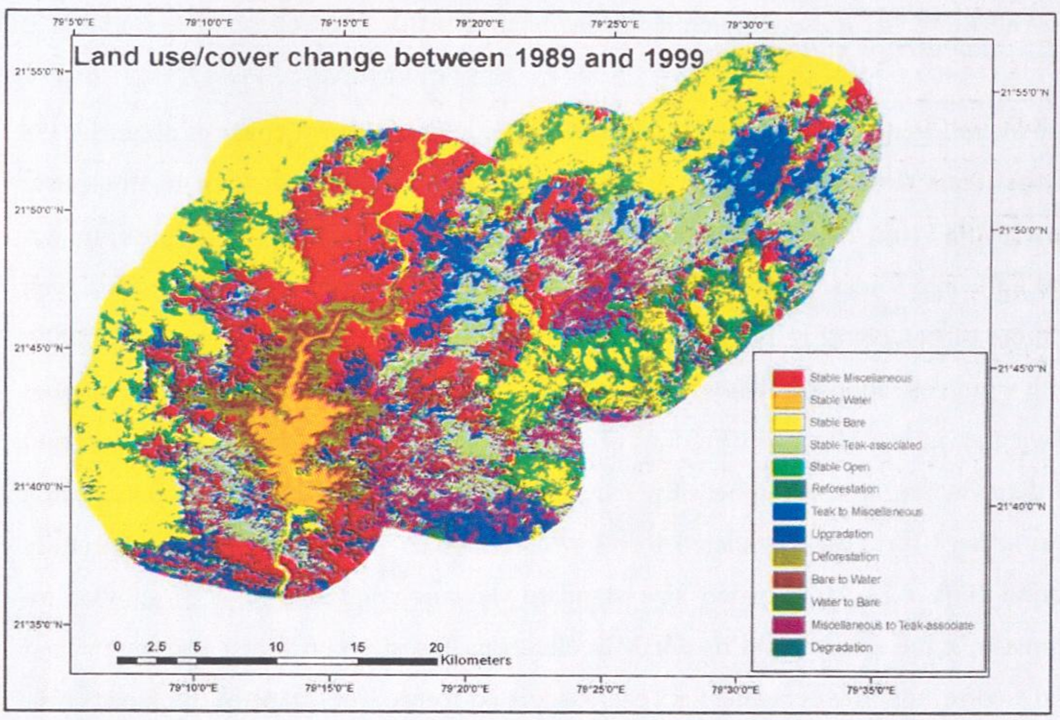


Fig 8.6 Land use/cover change between 1989 and 1999 in Pench Tiger Reserve

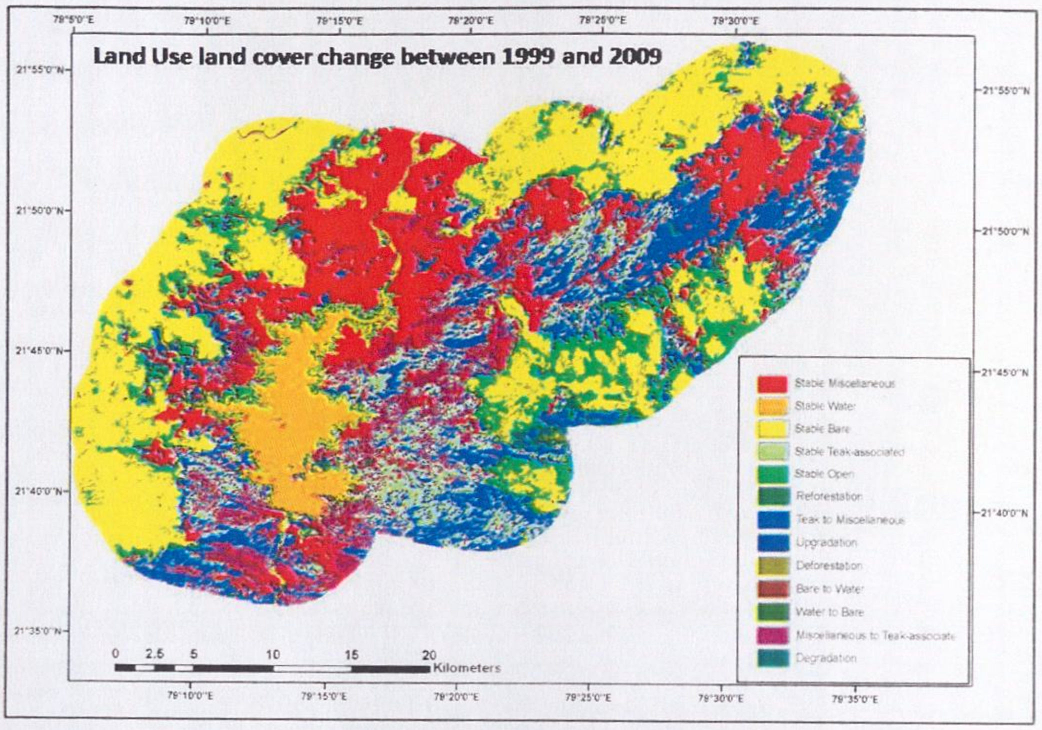


Fig 8.7 Land use/cover change between 1999 and 2009 in Pench Tiger Reserve

8.3.3 Landscape pattern indices

The overall trend corresponded to an absolute decrease in forest cover of about 11.1% of the forest surface present in 1977. This was due to the creation of hydroelectric dam in 1987 (impact of dam was discussed later in details) and deforestation (Fig. 8.5 and 8.6). The forest surface showed a pronounced fragmentation in 1977 with a high number of patches (Fig. 8.7) and this fragmentation dramatically decreased in 2009, with a little exception of Miscellaneous forest which showed some increase in number of patches in last 10 years. (Fig.8.6). The general trend of decrease in forest area and of the reduction in the number of patches was reflected by the increase in mean patch size, except for Teak-associated forest which showed fluctuations during the study period (Fig. 8.8). The patch size standard deviation index (Fig. 8.9) showed an increase in the size variability for Miscellaneous forest, open forest and baren land and a corresponding decrease for Teak-associated forest. The shape of the forests also changed in a clear way, with an increase of AWMSI (area weighted mean shape index) for the Miscellaneous and Open forest (Fig. 8.10), while Non-forest areas showed constant decrease and Teak- associated forest in the first part decreased and increased at last. In general, an increase in the geometric complexity of forest patch shapes was observed. The investigation of the total edge length showed a substantially similar trend in total edge (TE) between 1977 and 2000 (Fig. 8.13), with a decrease of TE in all land use/cover types except TE for Miscellaneous forest.

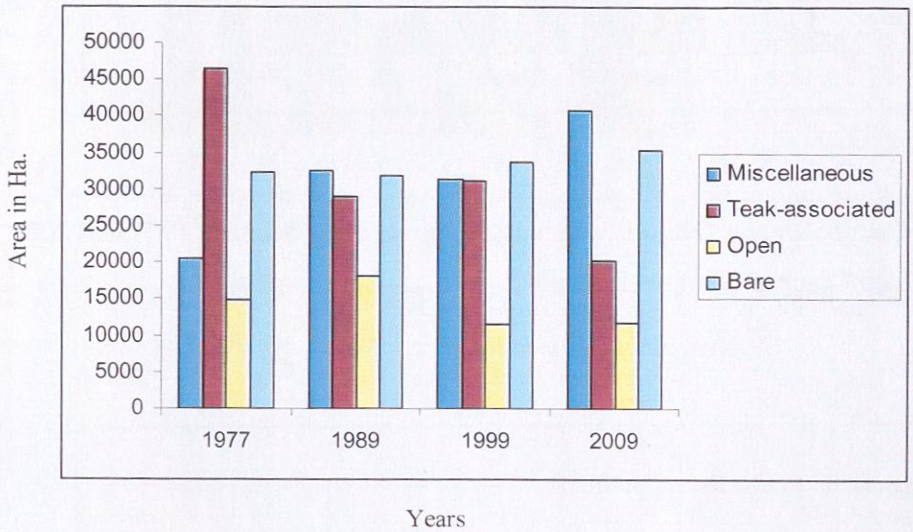


Fig. 8.8 Area (Ha) occupied by different land use/cover class between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

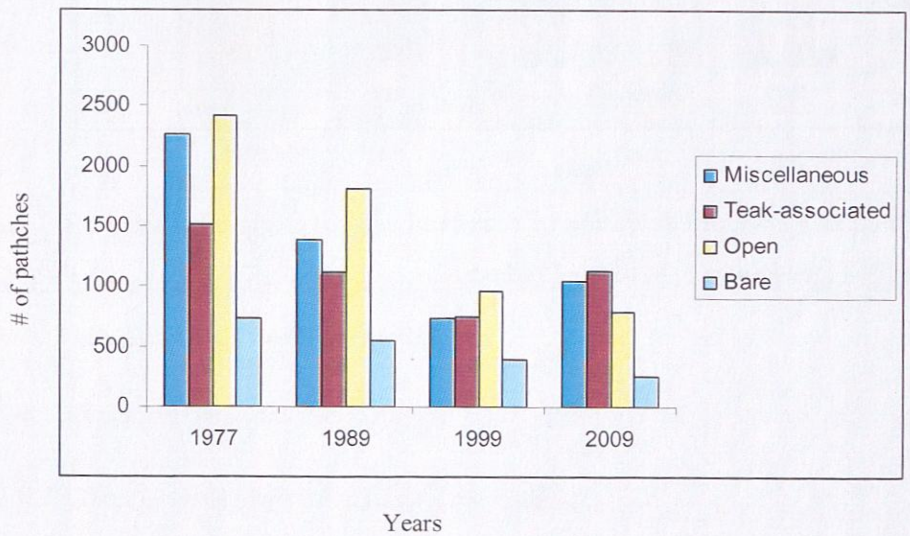


Fig. 8.9 Number of patches found in each land use/cover class between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

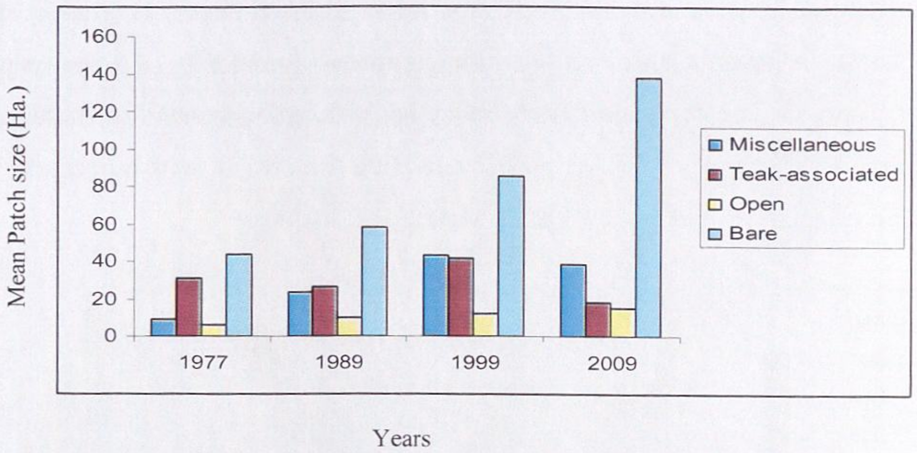


Fig. 8.10 Mean patch size (Ha) of each land use/cover class between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

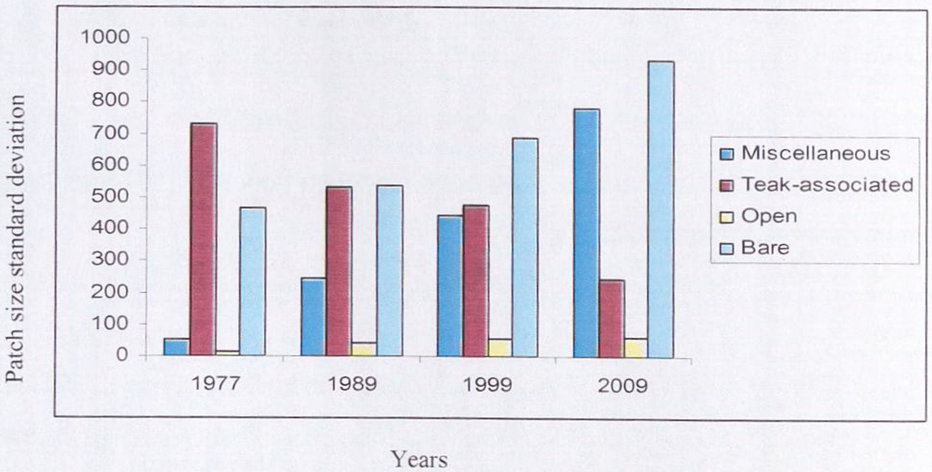


Fig. 8.11 Patch size standard deviation of each land use/cover class between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

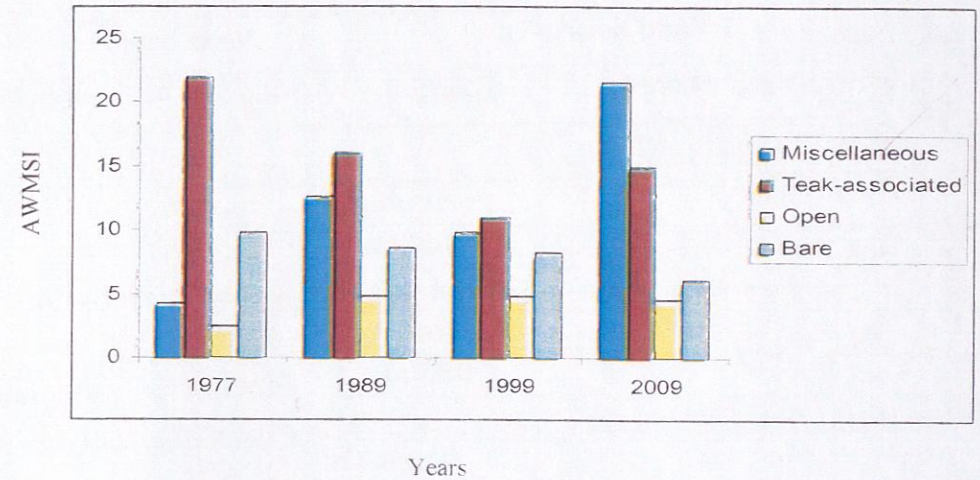


Fig. 8.12 Area weighted mean shape index (AWMSI) of each land use/cover class between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

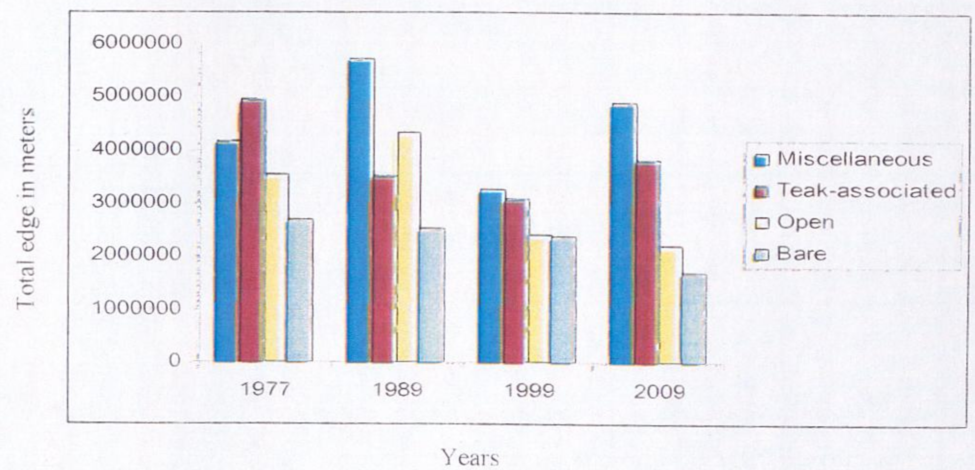


Fig. 8.13 Total edge (m) of each land use/cover class between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

8.3.4 Anthropogenic driving forces of landscape change

8.3.4.1 Direct cause: Infrastructural development:

Creation of Totladoh hydroelectric dam in 1987 had caused a loss of 76.7 km^2 area of the landscape. Loss of area in different land use/cover classes is given in the Table 8.5.

Table 8.5 Loss of different forest area due to the creation of hydroelectric dam

Land use/cover	**Area(Km^2)**
Miscellaneous Forest	27.4
Teak-associated Forest	17.5
Open Forest	12.7
Non-Forest	21.2

8.3.4.2 Landscape Changes due to Cattle grazing, Fuel wood collection and NTFP extraction:

Average distance moved by villagers by each target villages was measured on the basis of questionnaire survey for the 30 sampled villages for cattle grazing, fuel wood and NTFP extraction (Table 8.6).

Table 8.6 Average distances traveled by villagers for different purposes

Category	Range	Village	Distances(Km)		
			Fuel wood collection	Livestock grazing	NTFP collection
Category-I	Bichua	**Kokiwara**	1	1	1
	Bichua	**Dodhgaon**	2.6	2.1	2.2
	Gumtara	**Pathra khurd**	2.3	2	2
	Gumtara	**Gumtara**	2.9	2.6	2.9
	Khawasa	**Karmajhiri**	2	2.6	1.9
	Khawasa	**Turia**	4	2	3.9
	Kurai	**Khamrith**	1.8	2.1	1.8
	Kurai	**Pindkapar**	3.9	1.9	2
	Rukhad	**Murer**	2.2	1.5	2
	Rukhad	**Patarai**	2.9	3.3	3.2
Category-II	Bichua	**Mohgaon khurd**	4.2	3.7	3.7
	Bichua	**Surrewani**	4.4	3.5	4
	Gumtara	**Thota raiyat**	3.8	4	3.8
	Gumtara	**Patri**	3.2	2.5	4.1
	Khawasa	**Durgapur**	1.5	3	1.7
	Khawasa	**Sarahiri**	2.8	3.2	2.8
	Kurai	**Vijaypani II**	3.3	3.5	3.3
	Kurai	**Mohgaon (Yadav)**	4	1.75	2.2
	Rukhad	**Tewni**	7.2	7.8	3.1
	Rukhad	**Airma**	7	3.6	4.8
Category-III	Bichua	**Antra**	8.3	4	7.6
	Bichua	**Khamarpani**	7.9	5	7.1
	Gumtara	**Davajhir**	4.4	2.6	4
	Gumtara	**Rampuri**	7.1	3.5	4.3
	Khawasa	**Pachdhar**	4.4	5	2.2
	Khawasa	**Kothar**	7	4.4	4.9
	Kurai	**Harduli**	2.2	2.8	2.8
	Kurai	**Pipariya**	4.4	4.1	3.6
	Rukhad	**Niwari**	7.7	7.2	4.6
	Rukhad	**Mohgaon sadak**	7.8	6.2	7.6
	Bichua	**Antra**	8.3	4	7.6

The major amount of deforestation in the core area (with PA and outside collection/extraction distance) between 1977 and 1989 and between 1989 and 1999 were due to the formation of Totladoh reservoir which has resulted an increase in the area of submergence in respective years (Table 8.7 and 8.8). Between the year 1999 and 2009, the observed deforestation rates were very low in the core area which might be because of the protection measures taken by the forest department. In the Middle area (within PA and within collection/extraction distance), though the deforestation rates went down in the last 10 years, an increase in degradation was observed in this category (Table 8.7 and 8.8). In the Outside area (Outside PA and within collection/extraction distance), both deforestation and degradation were almost same over the years (Table 8.7 and 8.8).

Table 8.7 Deforestation and degradation within fuel wood collection distances

Category	1977-1989		1989-1999		1999-2009	
	Deforest - ation (Km^2)	**Degrad - ation (Km^2)**	**Deforest - ation (Km^2)**	**Degrad - ation (Km^2)**	**Deforest - ation (Km^2)**	**Degrad - ation (Km^2)**
Core	13.05	4.59	10.62	0.08	0.44	1.1
Middle area	1.92	4.17	7.60	2.72	0.53	3.17
Outside	7.64	7.07	8.48	7.39	6.66	4.83

Table 8.8 Deforestation and degradation within NTFP collection distances

Category	1977-1989		1989-1999		1999-2009	
	Deforest - ation (Km^2)	**Degrad - ation (Km^2)**	**Deforest - ation (Km^2)**	**Degrad - ation (Km^2)**	**Deforest - ation (Km^2)**	**Degrad - ation (Km^2)**
Core	11.33	4.44	9.99	0.32	0.40	1.17
Middle area	1.80	4.23	7.43	2.88	0.57	3.40
Outside	8.06	4.86	8.93	7.73	7.11	7.06

When we analysed deforestation and degradation of forest within the livestock grazing distances, similar kind of trends were found (Table 8.8). Historical records which were lacking, could have offered a better explanation in this regard.

Table 8.9 Deforestation and degradation within grazing distances between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

Loss	1977-1989	1989-1999	1999-2009
Deforestation (Km^2)	8.10	9.00	7.04
Degradation (Km^2)	4.75	7.89	4.59

8.3.4.3 Impact of increase in protection policy on landscape change:

The reforestation was higher inside PTR than outside throughout the study period. Past 20 years result (Table 8.10) showed almost no reforestation in the landscape outside PTR. Similar trend prevails for upgradation also. As indicated earlier, the higher deforestation rates during 1977-1989 and 1989- 1999 inside PTR were because of the formation of reservoir and increase in extent. The deforestation and degradation rates were almost similar for outside areas over the years (Table. 8.9).

Table 8.10 Reforestation, Upgradation, Deforestation and Degradation inside (Core) and outside PTR between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

	1977-1989		1989-1999		1999-2009	
Change category	**Core**	**Outside**	**Core**	**Outside**	**Core**	**Outside**
Reforestation* (Km^2)	7.38	2.76	3.55	0.85	2.70	0.19
Upgradation# (Km^2)	7.19	3.92	7.26	4.27	1.85	1.82
Deforstation$ (Km^2)	6.06	8.40	7.47	7.69	0.49	7.41
Degradation£ (Km^2)	4.32	8.25	1.74	4.36	2.40	4.19

* Later date has forest over non-forest on the previous date. # Open forest in the previous date converted to either Mixed or Teak-mixed forest on the later date. $ later date is non-forest in places of forest on the earlier date. £ Mixed or Teak-Mixed forest on the earlier date converted into open forest on later date.

According to Class area (CA), Miscellaneous forests showed constant increase in inside PTR, Category I and Category II and Teak- associated forest showed constant decrease (Fig. 8.12a , 8.13a and 8.14a) but in Category III both the forests registered decrease (Fig. 8.15a). For Teak associated forest inside PTR, since the Total edge (TE) increased (Fig. 8.12b) and Mean Patch Area (MPA) decreased (Fig. 8.12c), the Number of Patches (NP) must have increased in this area. Miscellaneous forest showed increase in TE and MPA in all categories (Fig. 8.12b, 8.12c, 8.13b, 8.13c, 8.14b, 8.14c, 8.15b and 8.15c). In Category I, II and III, Teak associated forest showed decrease in TE (Fig. 8.13b, 8.14b and 8.15b) with a decrease in MPA (Fig. 8.13c, 8.14c and 8.15c) which means that there was decrease in NP. As there was very less open forest inside PTR, they represented similar trend for all the landscape metrics over the years (Fig. 8.12a, 8.12b, 8.12c, 8.12d). CA, TE and MPA of Open forests increased from Category I to category III (Fig. 8.13a, 8.13b, 8.13c, 8.14a, 8.14b, 8.14c, 8.15a, 8.15b and 8.15c) indicating an increase in the NP over the years. Area Weighted Mean Shape Index (AWMSI) for Miscellaneous forest, Teak-associated forest and Open forest constantly decreased from Inside PTR to Category II but suddenly increased in Category III (Fig. 8.12d, 8.13d, 8.14d and 8.14d).

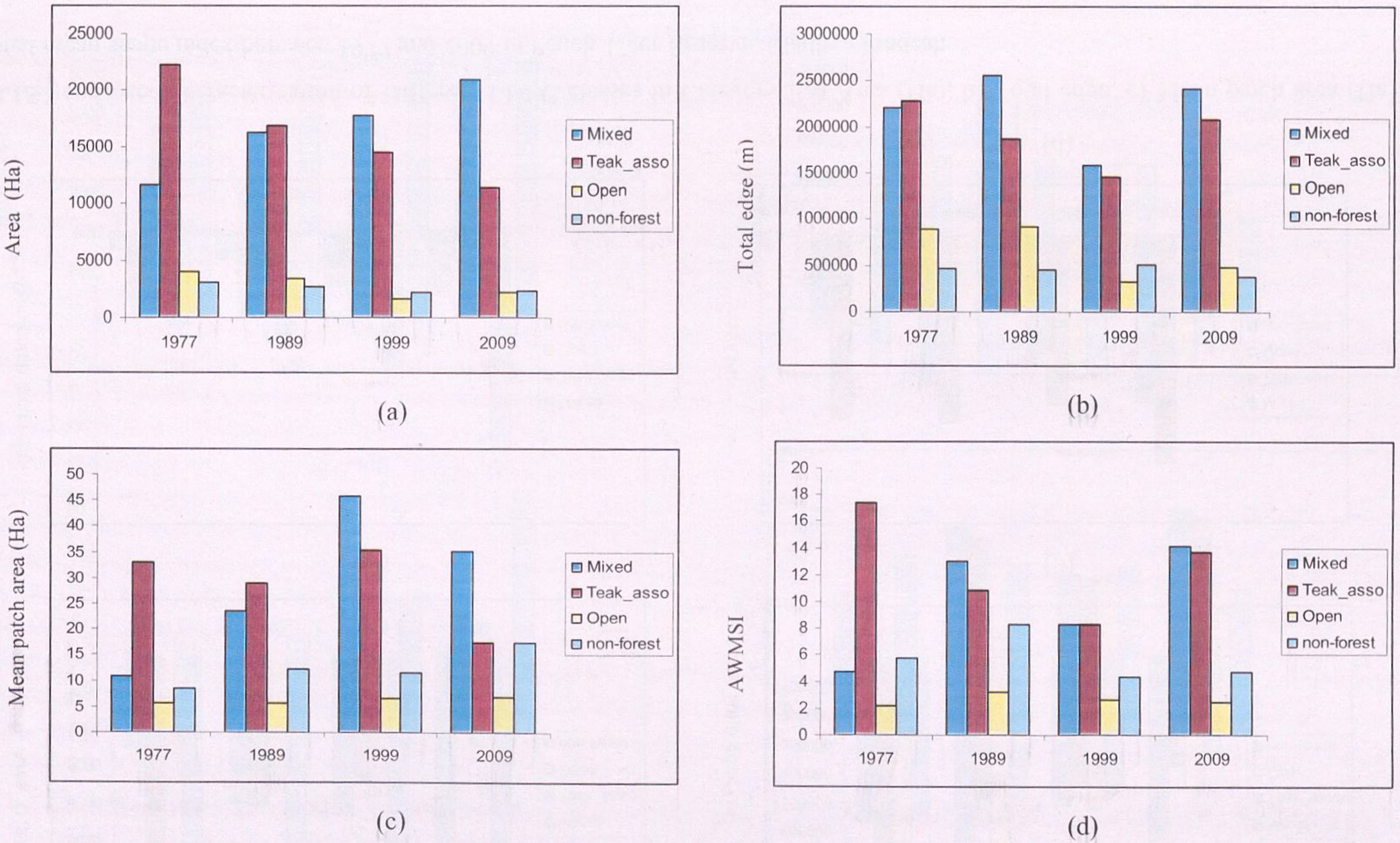
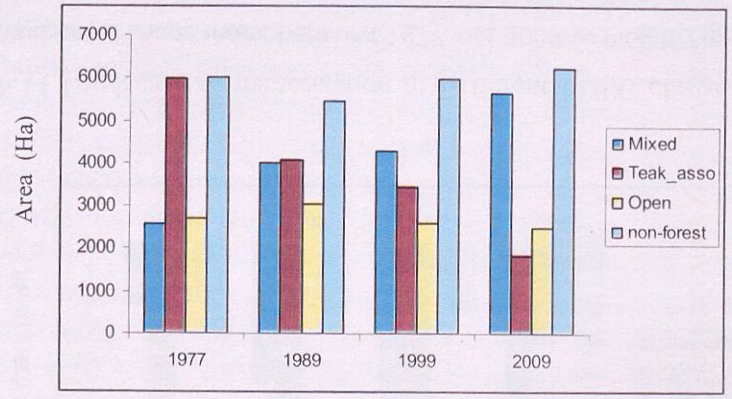
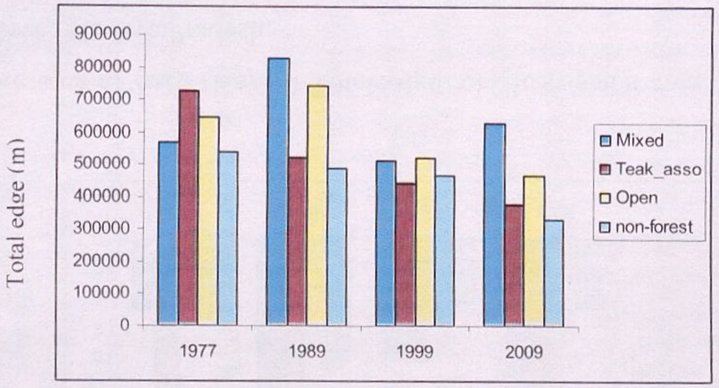


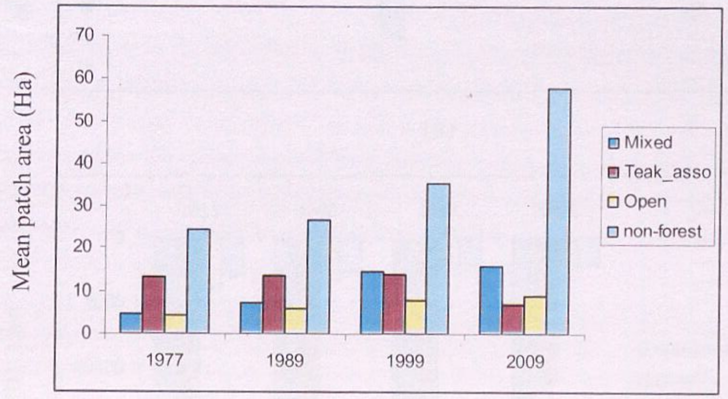
Fig. 8.14 Landscape characterization of Different LULC classes in core area a) Area (Ha), b) Total edge, c) Mean patch area (Ha), d) Area weighted mean shape index between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh



(a)



(b)



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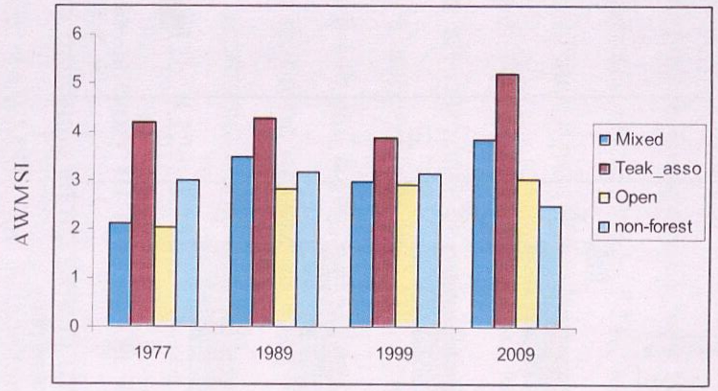


(d)

Fig. 8.15 Landscape characterization of Different LULC classes in Category I a) Area (Ha), b) Total edge, c) Mean patch area (Ha), d) Area weighted mean shape index between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

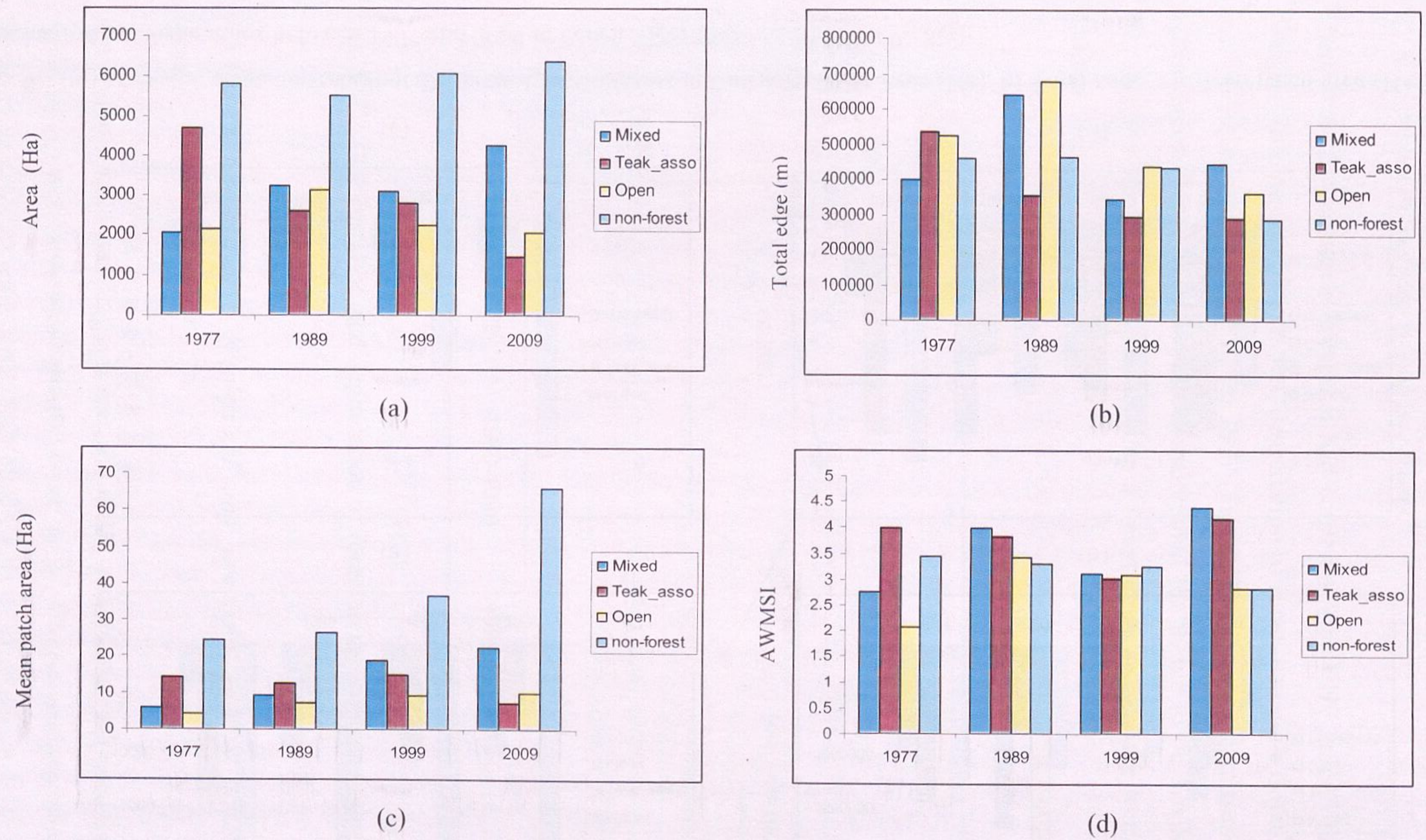
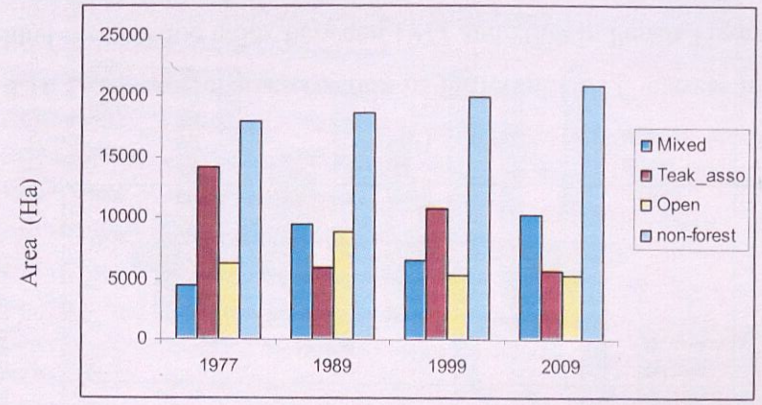
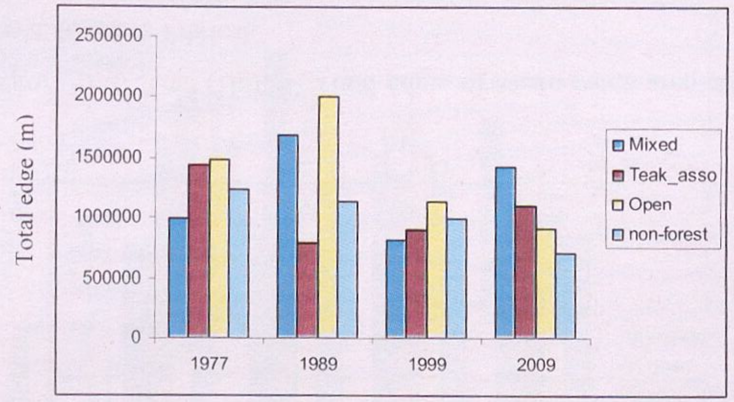


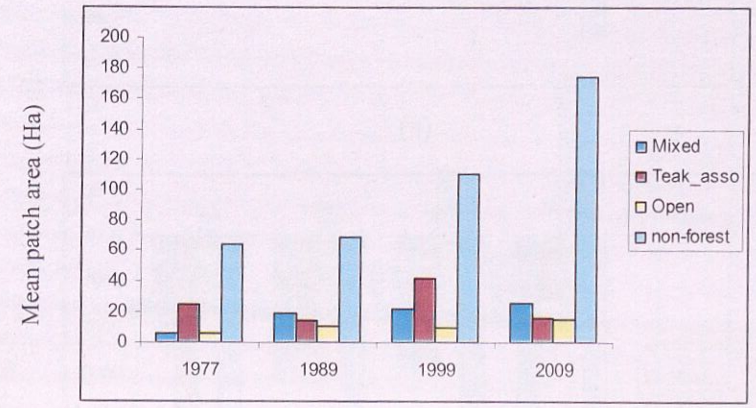
Fig. 8.16 Landscape characterization of Different LULC classes in Category II a) Area (Ha), b) Total edge, c) Mean patch area (Ha), d) Area weighted mean shape index between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh



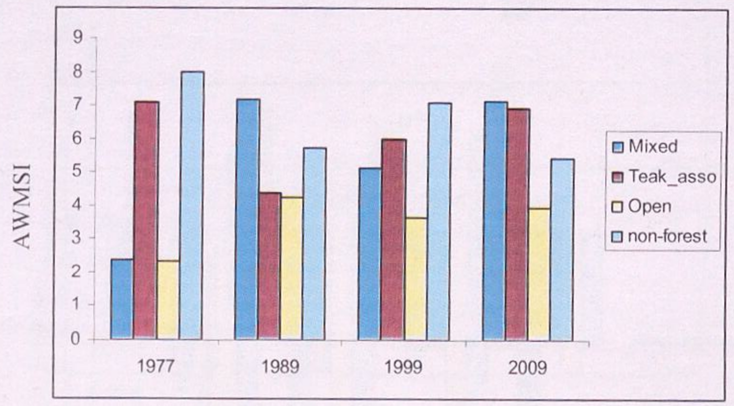
(a)



(b)



(c)



(d)

Fig. 8.17a Landscape characterization of Different LULC classes in Category III a) Area (Ha), b) Total edge, c) Mean patch area (Ha), d) Area weighted mean shape index between 1977 and 2009 in Pench Tiger Reserve, Madhya Pradesh

8.3.4.4 *Impact of increase in tourist resorts:*

There were 50 tourism resorts that had come up after 1999 around the park. In the villages with these tourist resorts, degradation of forest had gone down between 1989 and 1999 but again increased after 1999 (Fig. 8.17b). The opposite trend was found in deforestation. Most of these resorts maintained the theme to be a wildlife resort, so these resorts actually promoted to keep a forest cover to give the tourists wilderness feelings.

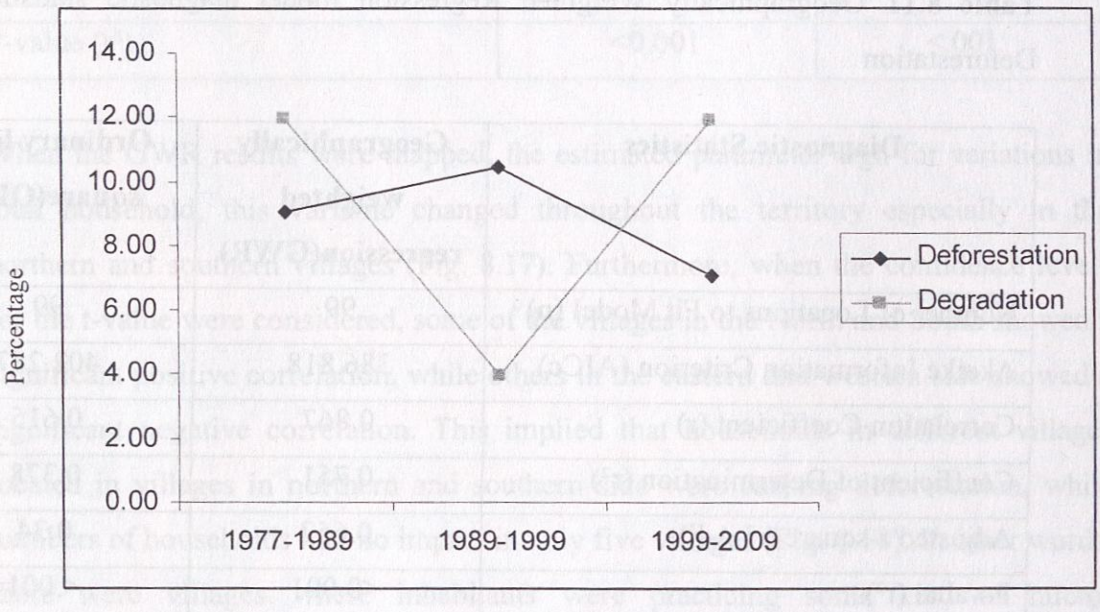


Fig. 8.17b Deforestation and degradation of forest in the villages with tourist resorts

8.3.4.5 *Social-economic, biophysical and proximity factors affecting landscape change*

For Deforestation and Degradation, the GWR results of fitted model (based on least AICc value) were given in Table 8.11 and 8.12. The parameters selected in both the models (least AICc) were VAR_NO_HH, VAR_P_ST, VAR_P_LIT, VAR_TOT_IR, EUC_ROAD AND PROTECT. With GWR, there was a local linear equation for each feature in the dataset. The equation was weighted so that nearby features had a larger influence on the prediction of yi than features that were farther away. Hence it was not appropriate to compute p-values for each coefficient in every one of the local linear equations. Moreover, the increases in adjusted R^2 confirmed that GWR-adjusted models in both the cases explain considerably better the variance of the data to global models (Table 8.10 and 8.11). The GRW models attained an adjusted value of 65%, which is 31% points more than the global model in case of deforestation where as in case of degradation model its 65 % with a 55% points difference than the global model. Other studies reviewed using the same techniques provided results with differences of more than 20% (Clement et al. 2009).

Table 8.11 Geographically Weighted Regression model diagnostic statistics for Deforestation

Diagnostic Statistics	**Geographically weighted regression(GWR)**	**Ordinary least square(OLS)**
Number of Locations to Fit Model (n)	99	99
Akaike Information Criterion (AICc)	386.818	402.287
Correlation Coefficient (r)	0.867	0.615
Coefficient of Determination (r^2)	0.751	0.378
Adjusted r-square (r^2 Adj)	0.652	0.34
P-value (r^2)	<0.001	<.001

Table 8.12 Geographically Weighted Regression model diagnostic statistics for Degradation

Diagnostic Statistics	Geographically weighted regression (GWR)	Ordinary least square (OLS)
Number of Locations to Fit Model (n)	99	99
Akaike Information Criterion (AICc)	458.15	499.339
Correlation Coefficient (r)	0.866	0.392
Coefficient of Determination (r^2)	0.75	0.135
Adjusted r-square (r^2 Adj)	0.652	0.102
P-value (r^2)	<0.001	<.001

When the GWR results were mapped, the estimated parameter sign for variations in total household, this variable changed throughout the territory especially in the northern and southern villages (Fig. 8.17). Furthermore, when the confidence levels for the t-value were considered, some of the villages in the North and South showed a significant positive correlation, while others in the eastern and western side showed a significant negative correlation. This implied that households in different villages located in villages in northern and southern side were causing deforestation, while numbers of households had no impact in only five villages (Fig. 8.18). In other words, there were villages where inhabitants were practicing some kind of micro-deforestation in order to secure energy supplies, but the difference was that while in some villages the impact of this activity was reflected in deforestation, in others this activity had no direct impact. In those villages which were closer to the communication network and had LPG facilities, the relationship was found negative. It was likely that energy was not obtained solely from fuel wood collection, in contrast, villages where the relationship was found positive, areas were far from LPG distribution network. It would not be right to compare the bio-gas units present in the villages as most of them were non-functional during the study. For the same parameter (VAR_TOT_HH) in the model of degradation, the impact of northern villages were far more than the southern villages (Fig. 8.29 and 8.30) which in turn showed that there was more dependency solely on fuel wood extracted from the forests. The factors which determine proximity to major communication roads (EUC_ROAD) contributed similarly in both the models of deforestation and degradation. As southern and northern villages were far from major roads showed more significant deforestation and degradation than other areas (Fig. 8.25, 8.26, 8.37 and 8.38). Being situated in two tribal districts of Madhya Pradesh, Gond tribes predominates this area. Southern and South-western villages exhibit higher Scheduled tribe population. Villagers in this area were getting good work opportunity either from tourist resorts or from winter capital of Maharashtra, Nagpur due to its proximity. Thus these villages specially those in the south-western region had high positive relation with both deforestation and degradation for the variable Var_P_ST (Fig. 8.19, 8.20, 8.31 and 8.32). Good number of labour families was present in these villages without agricultural lands which probably resulted in a lower per capita irrigated land available in these villages compared to other areas. These villages resulted significant deforestation and degradation for the factor VAR_TOT_IR (Fig. 8.23, 8.24, 8.35 and 8.36) which represented variations in the irrigated land. People here were more dependant on seasonal labour works rather than agriculture thus involving them into more forest utilization to generate secondary income for their households. There was more number of literates in Chhindwara district than Seoni. The variable Var_P_LIT in both the models showed more significant deforestation and degradation in the villages of district Seoni because of lack of literacy. Earlier in this chapter, I presented how deforestation and degradation had happened from protected areas to distant places. The factor PROTECT showed similar kind of trend in a significant way for the models of deforestation and degradation. Distant villages from PTR showed more parameter estimate for deforestation while for the model of degradation though the level of significance decreased as we move further from the protected area but all the villages had higher significance than the deforestation models suggesting that villages closer to the protected area might not be affecting deforestation but they had good contribution on forest degradation (Fig. 8.27, 8.28, 8.39 and 8.40).

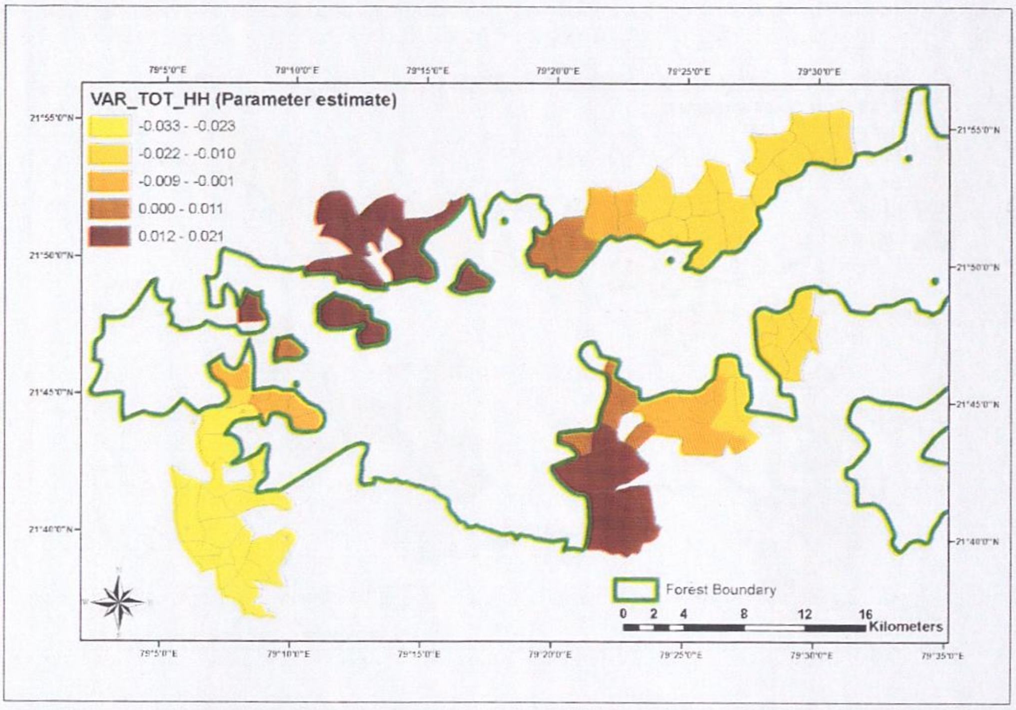


Fig. 8.17c Spatial distribution of parameter estimate of the variation in total household in deforestation model

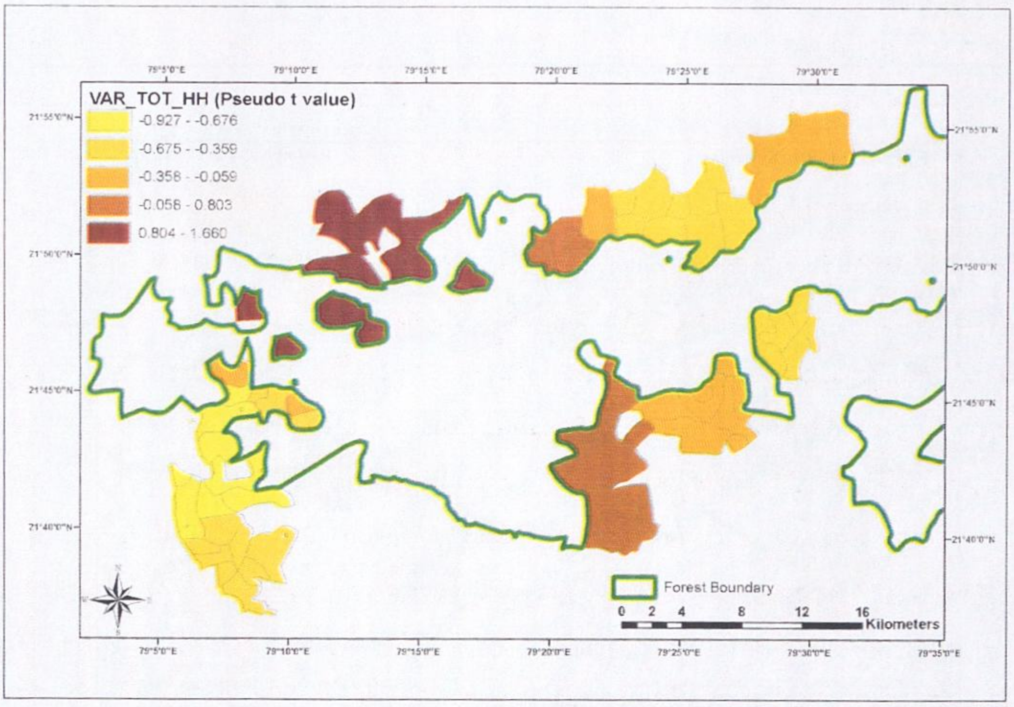


Fig. 8.18 Spatial distribution of pseudo t-values of the variation in total household in deforestation model

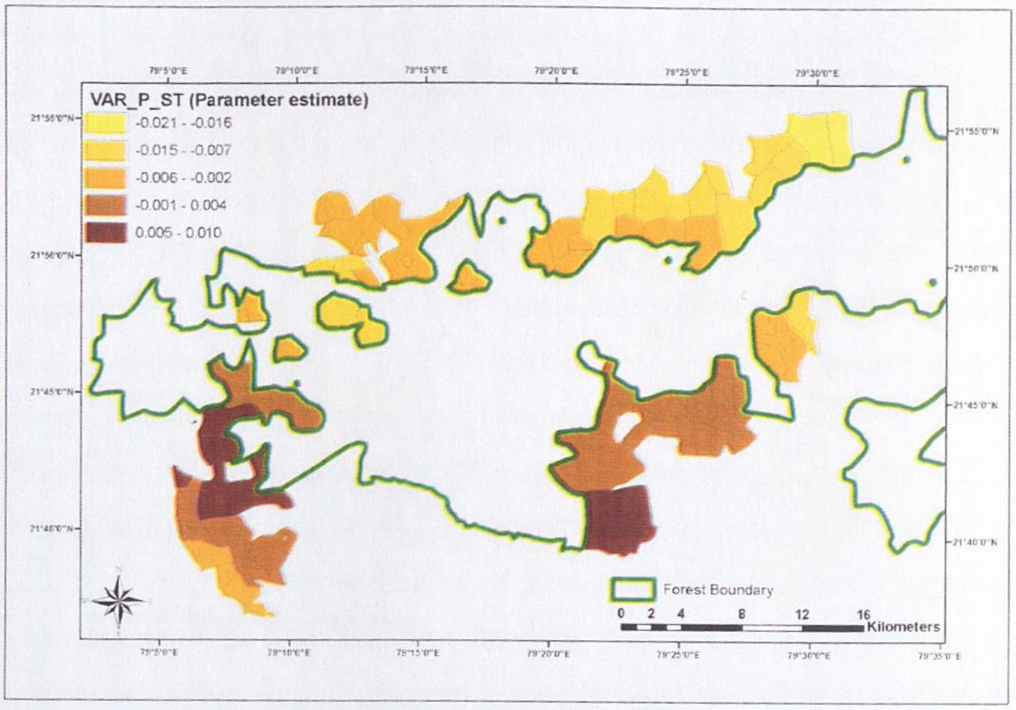


Fig. 8.19 Spatial distribution of parameter estimate of the variation in Scheduled Tribe population in deforestation model

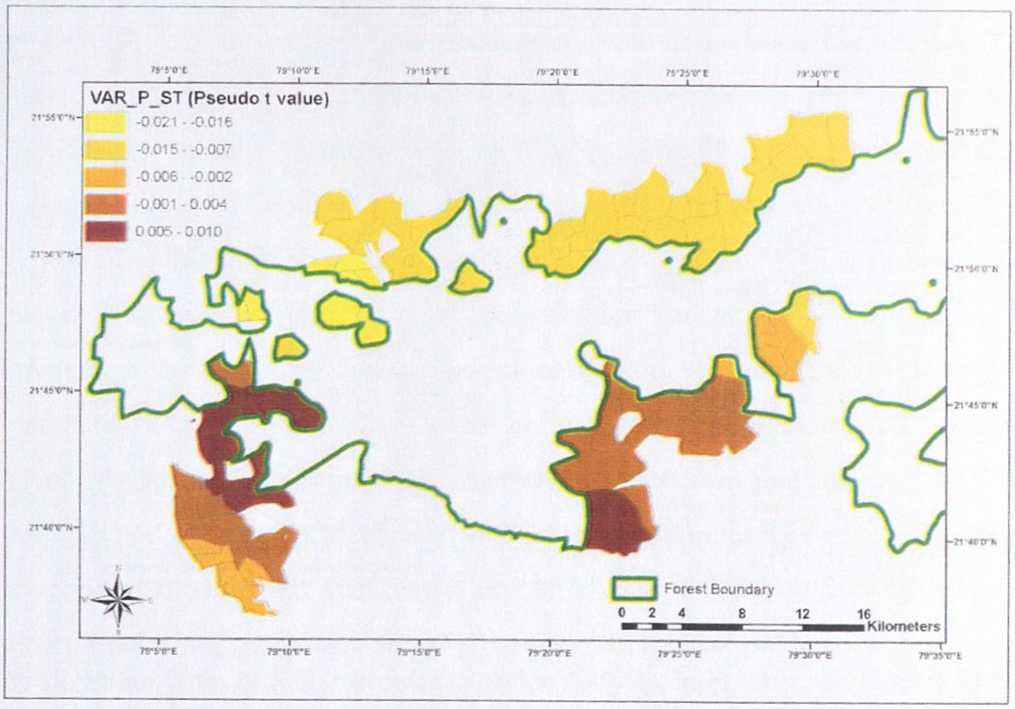


Fig. 8.20 Spatial distribution of pseudo t-values of the variation in Scheduled Tribe population in deforestation model

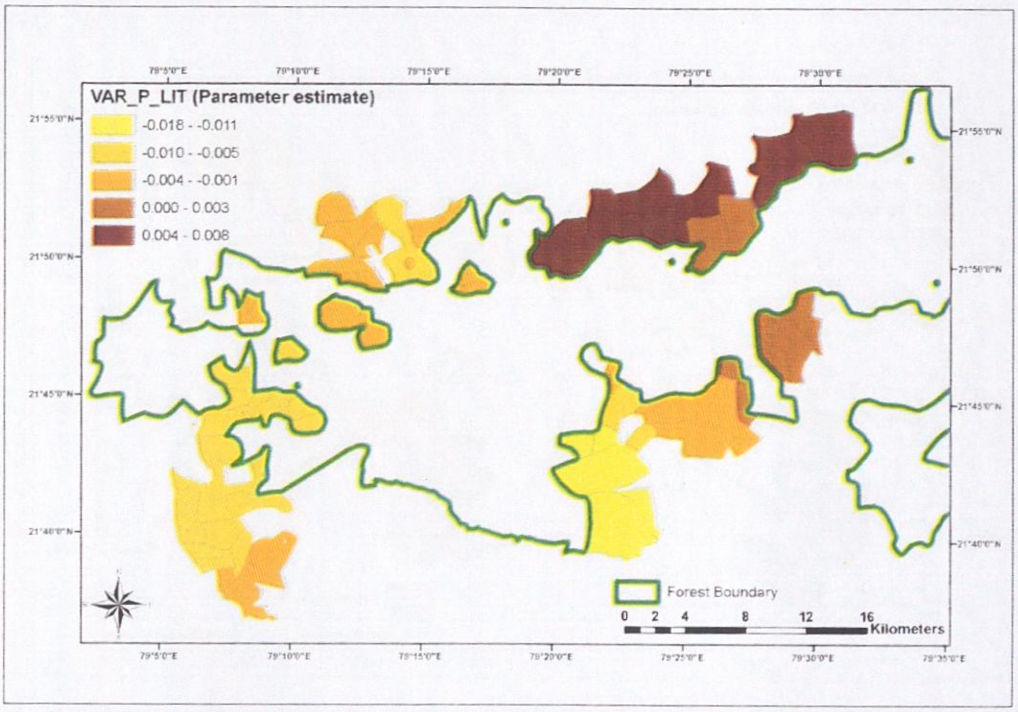


Fig. 8.21 Spatial distribution of parameter estimate of the variation in literate population in deforestation model

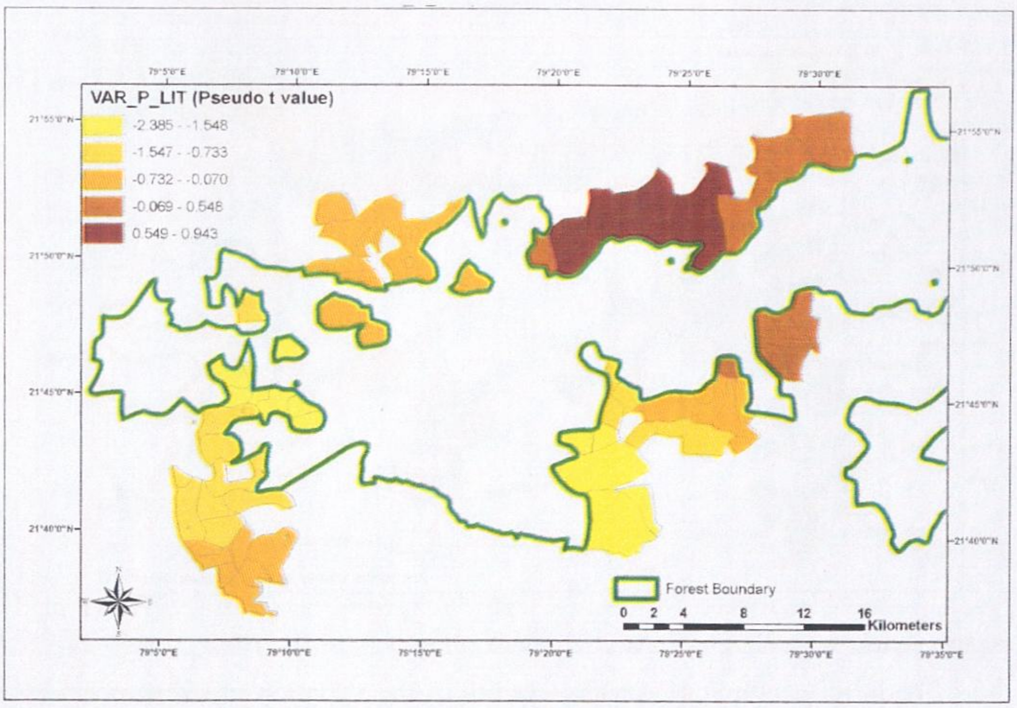


Fig. 8.22 Spatial distribution of pseudo t-values of the variation in literate population in deforestation model

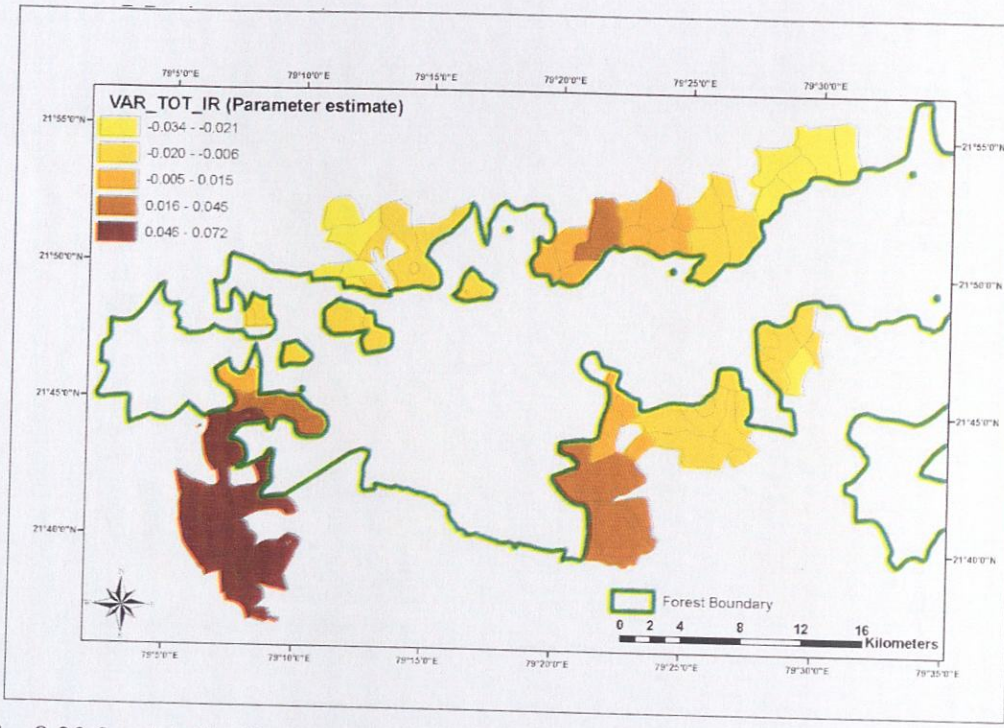


Fig. 8.23 Spatial distribution of parameter estimate of the variation in irrigated land in deforestation model

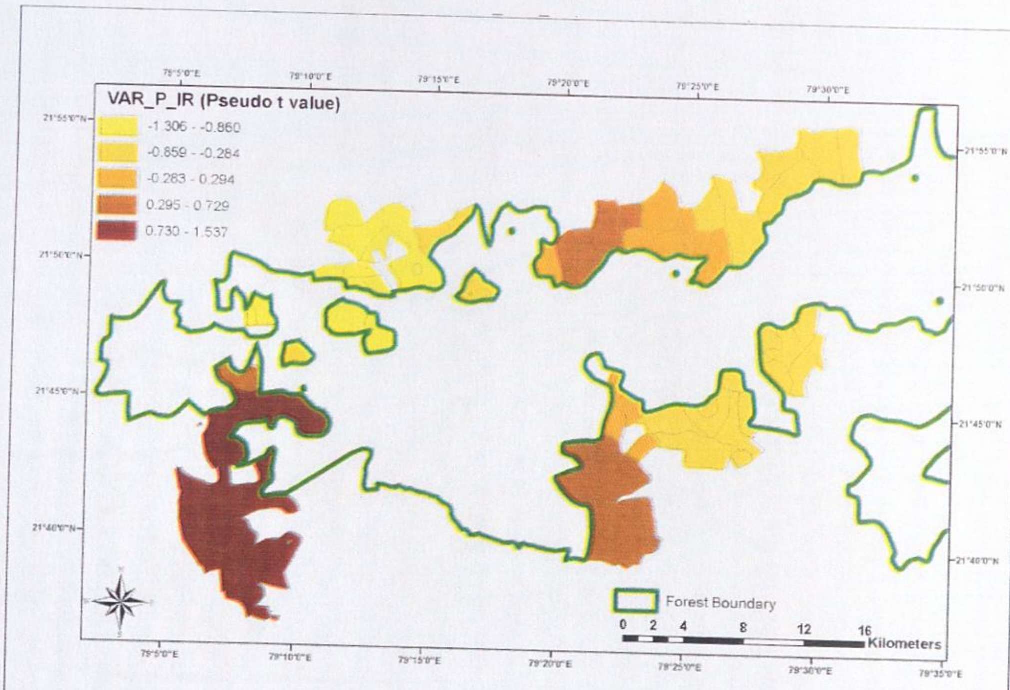


Fig. 8.24 Spatial distribution of pseudo t-values of the variation in irrigated land in deforestation model

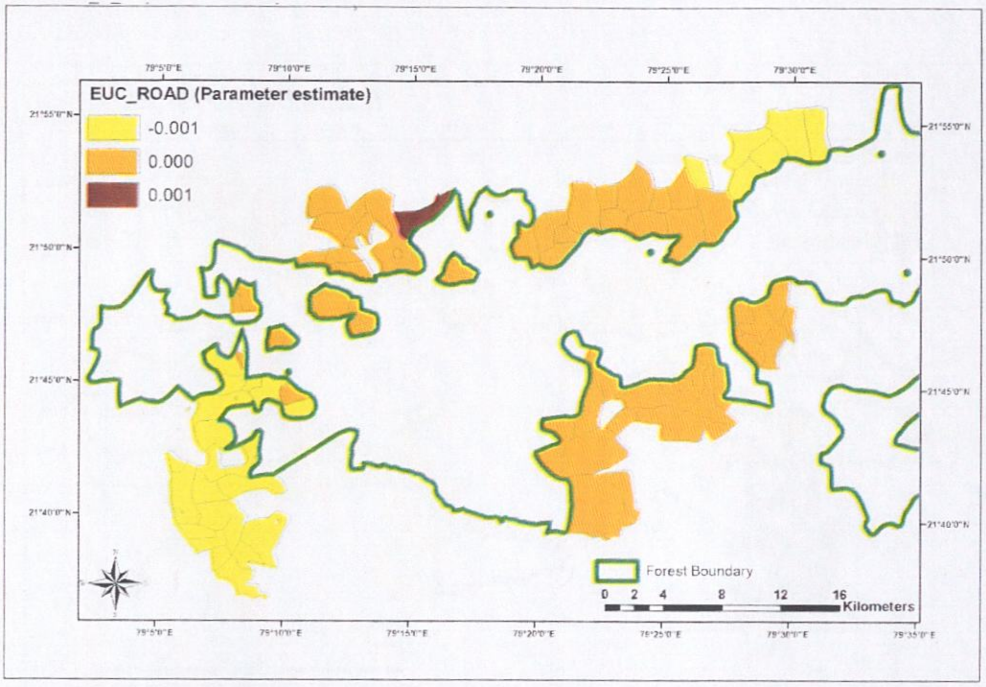


Fig. 8.25 Spatial distribution of parameter estimate of the distance from major roads in deforestation model

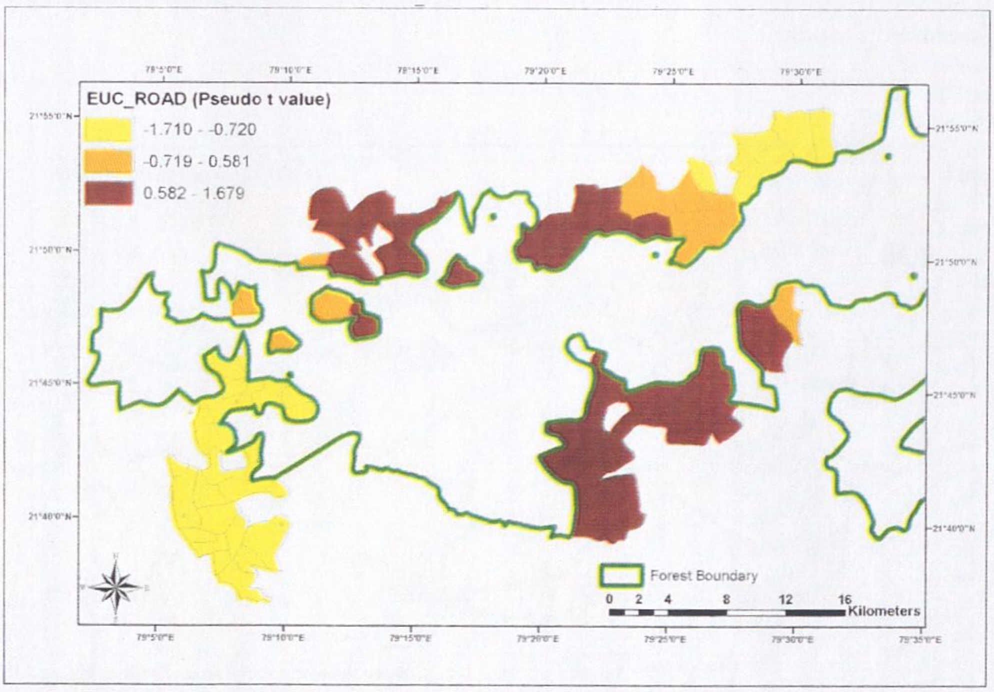


Fig. 8.26 Spatial distribution of pseudo t-values of the distance from major roads in deforestation model

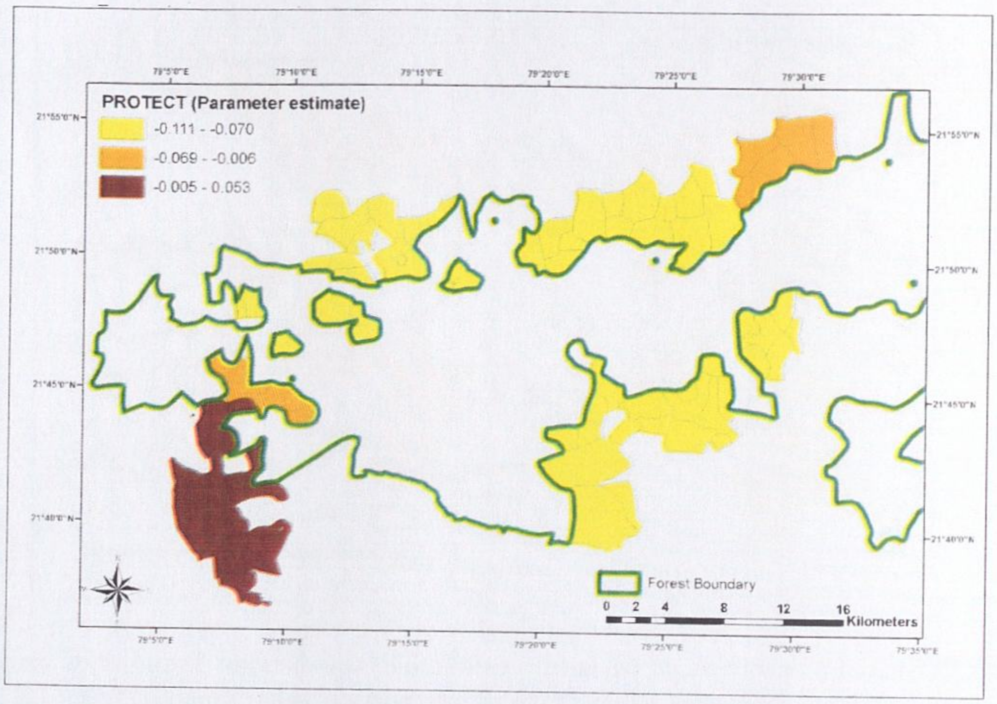


Fig. 8.27 Spatial distribution of parameter estimate of the distance from protected area in deforestation model

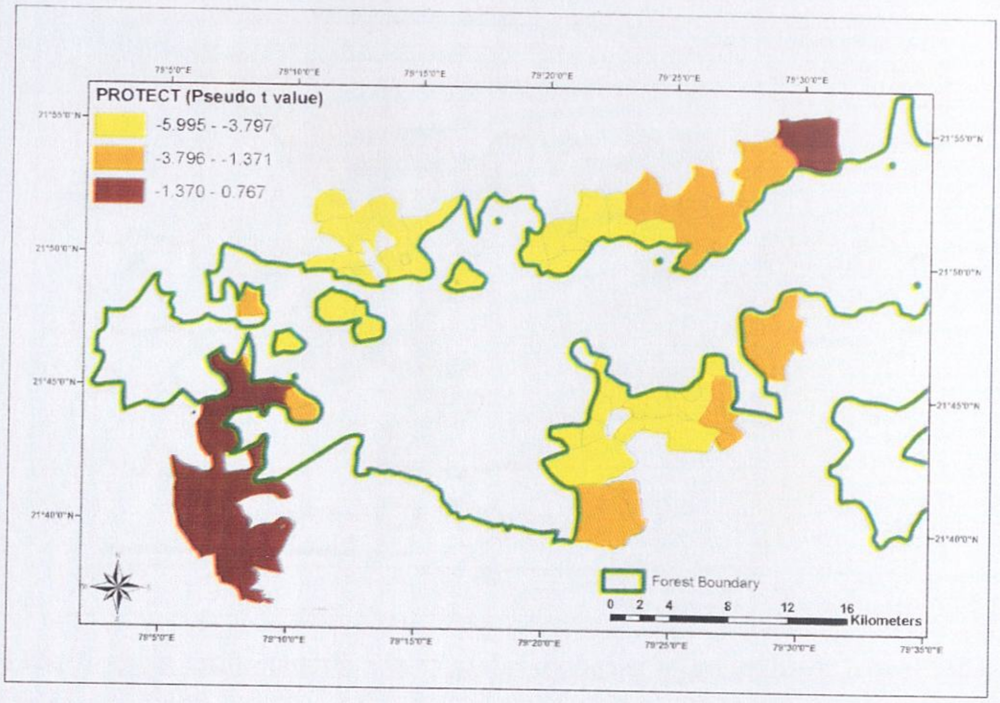


Fig. 8.28 Spatial distribution of pseudo t-values of the distance from protected area in deforestation model

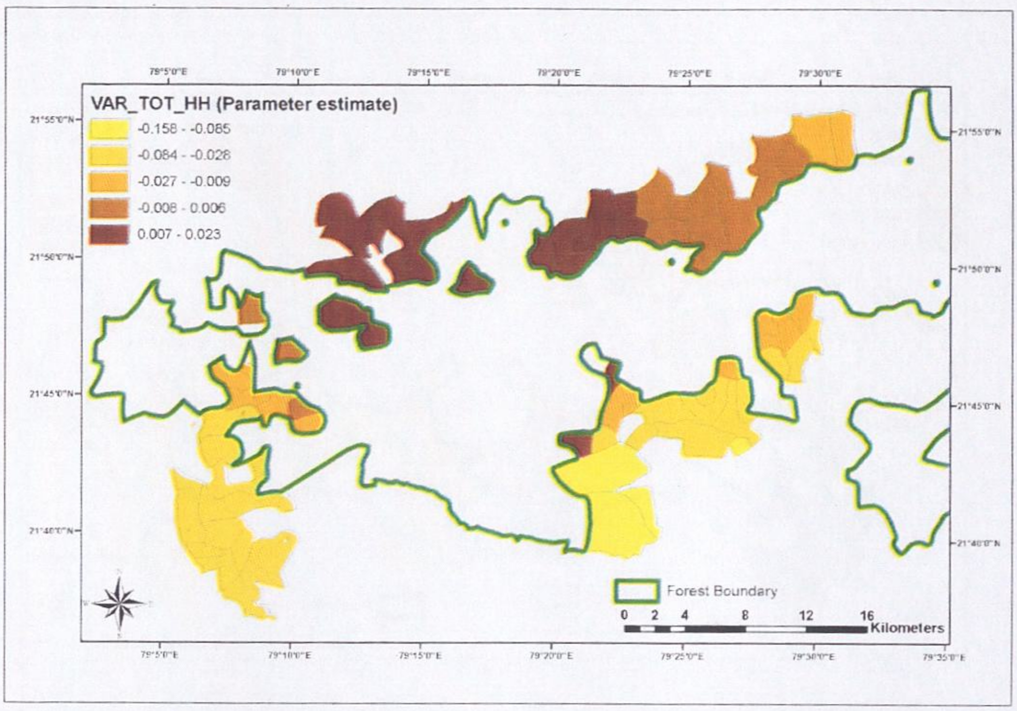


Fig. 8.29 Spatial distribution of parameter estimate of the variation in total household in degradation model

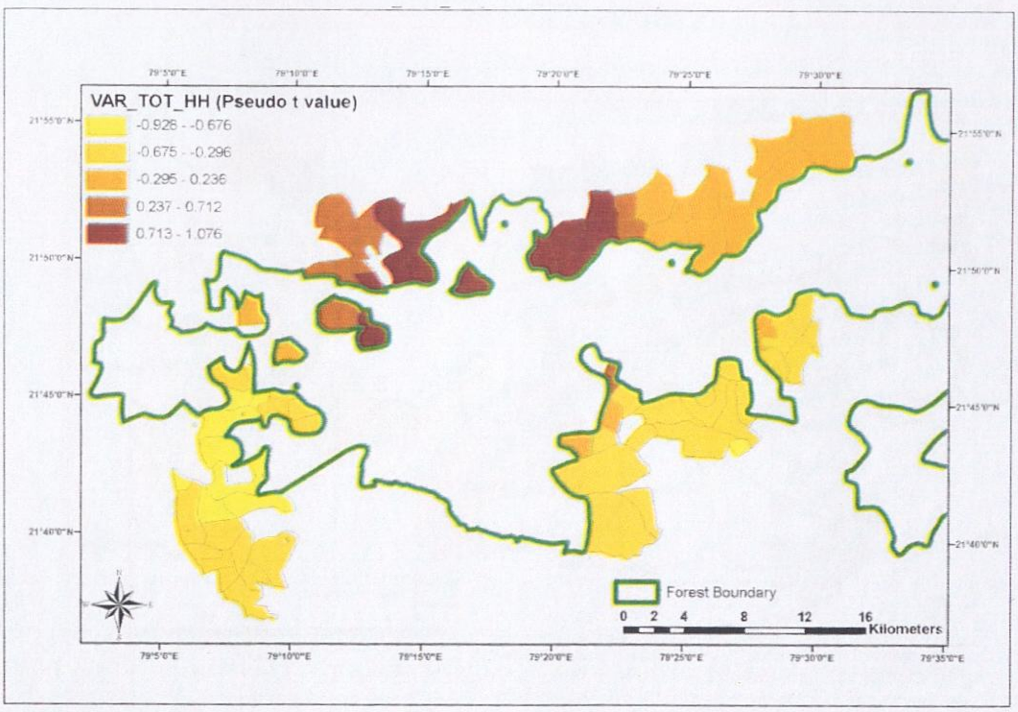


Fig. 8.30 Spatial distribution of pseudo t-values of the variation in total household in degradation model

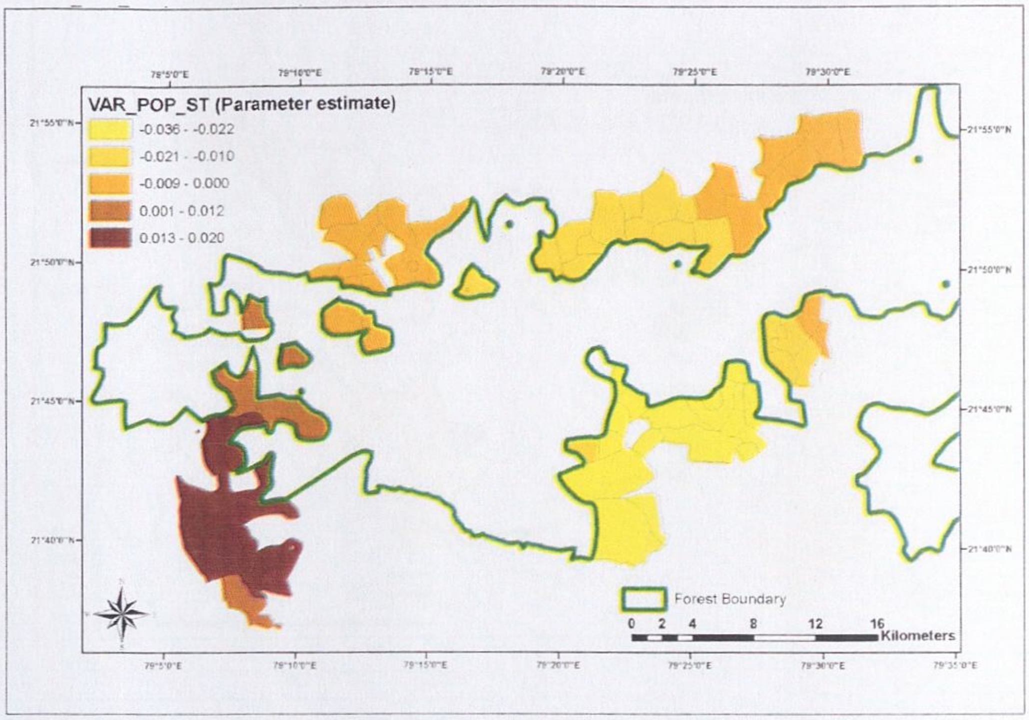


Fig. 8.31 Spatial distribution of parameter estimate of the variation in Scheduled Tribe population in degradation model

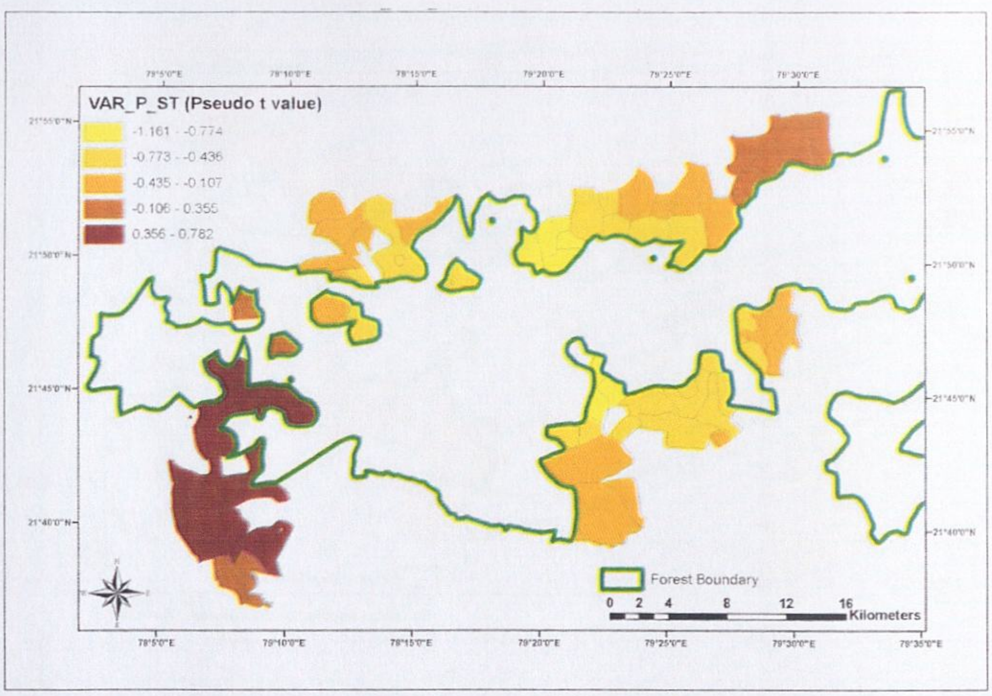


Fig. 8.32 Spatial distribution of pseudo t-values of the variation in Scheduled Tribe population in degradation model

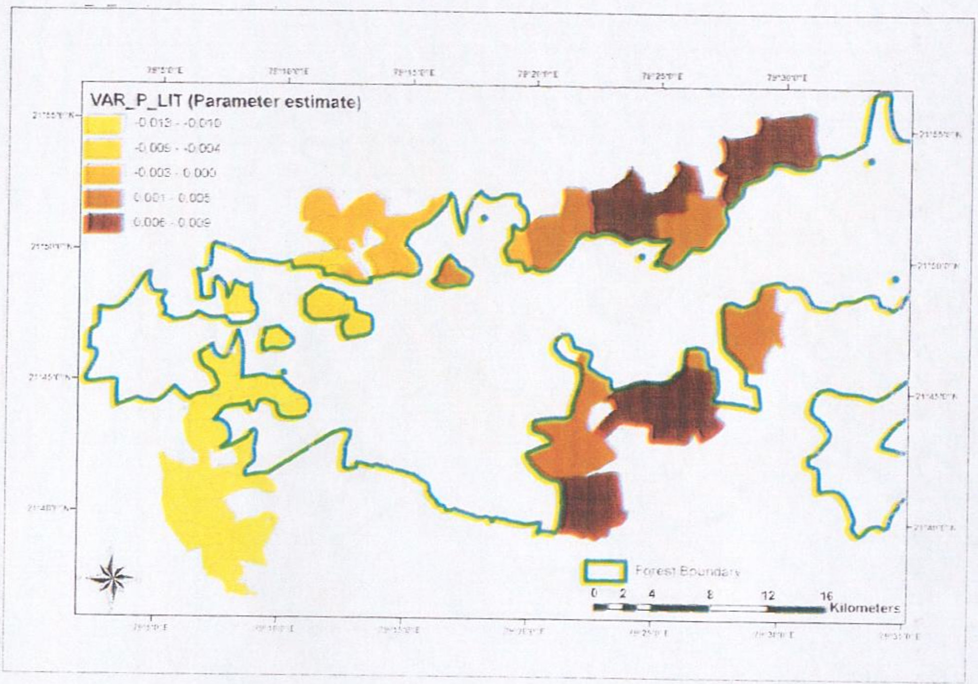


Fig. 8.33 Spatial distribution of parameter estimate of the variation in literate population in degradation model

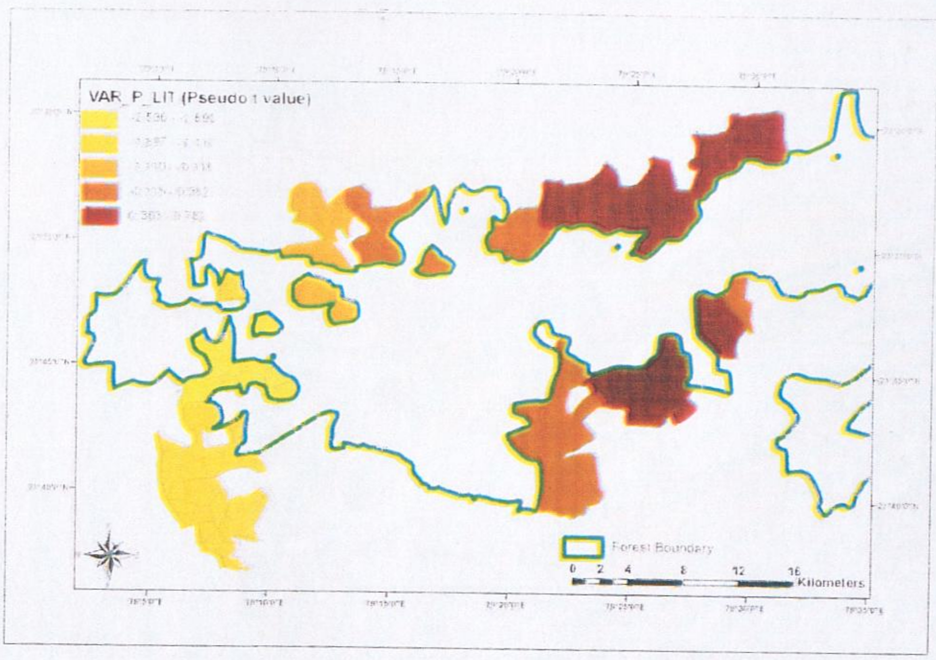


Fig. 8.34 Spatial distribution of pseudo t-values of the variation in literate population in degradation model

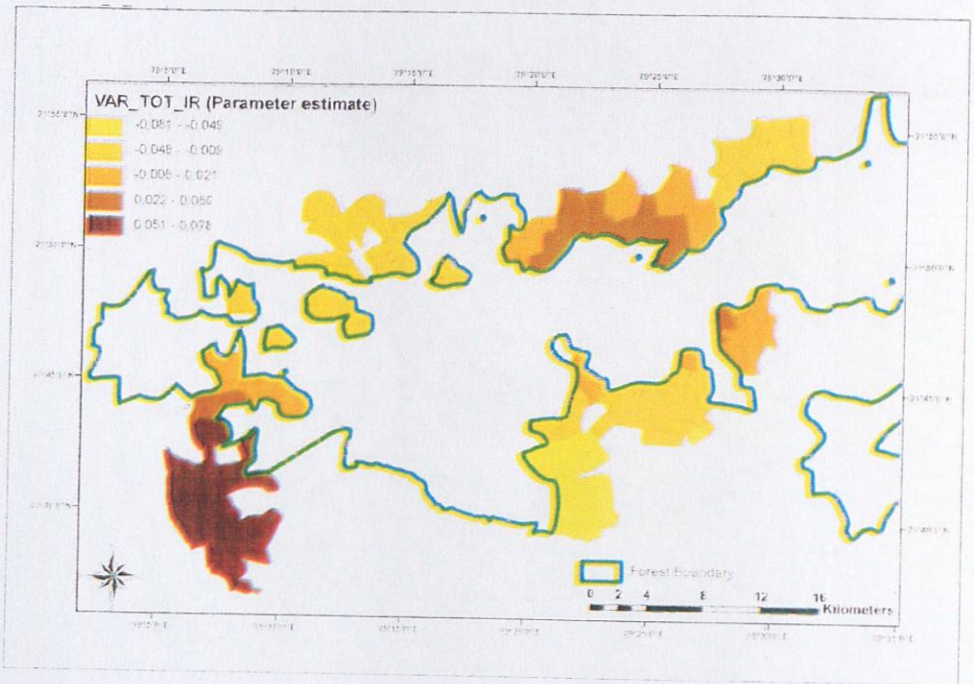


Fig. 8.35 Spatial distribution of parameter estimate of the variation in irrigated land in degradationmodel

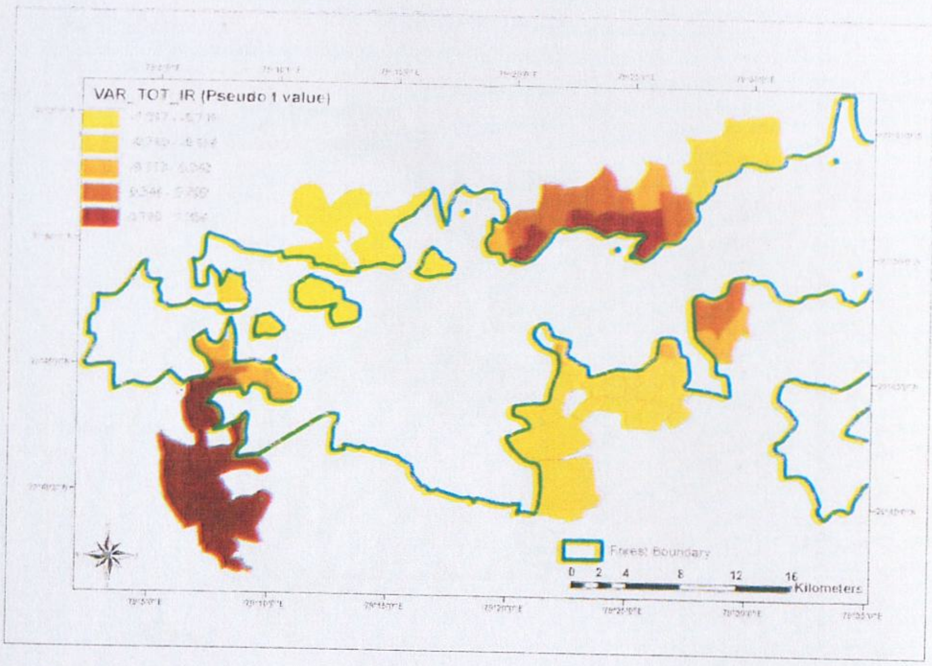


Fig. 8.36 Spatial distribution of pseudo t-values of the variation in irrigated land in degradation model

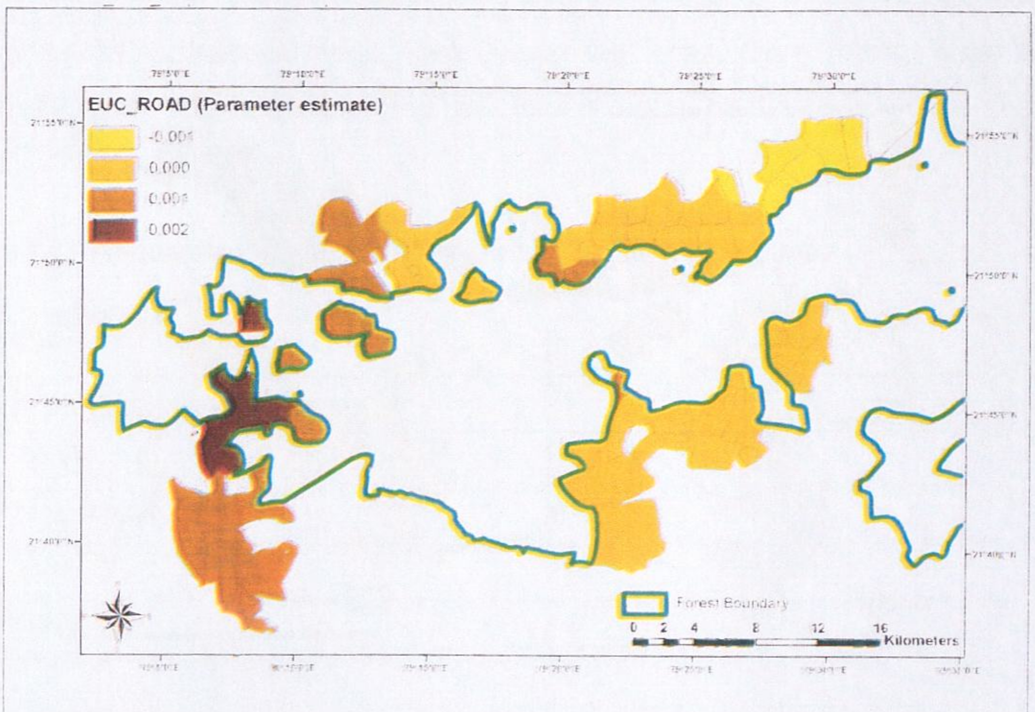


Fig. 8.37 Spatial distribution of parameter estimate of the distance from major roads in degradation model

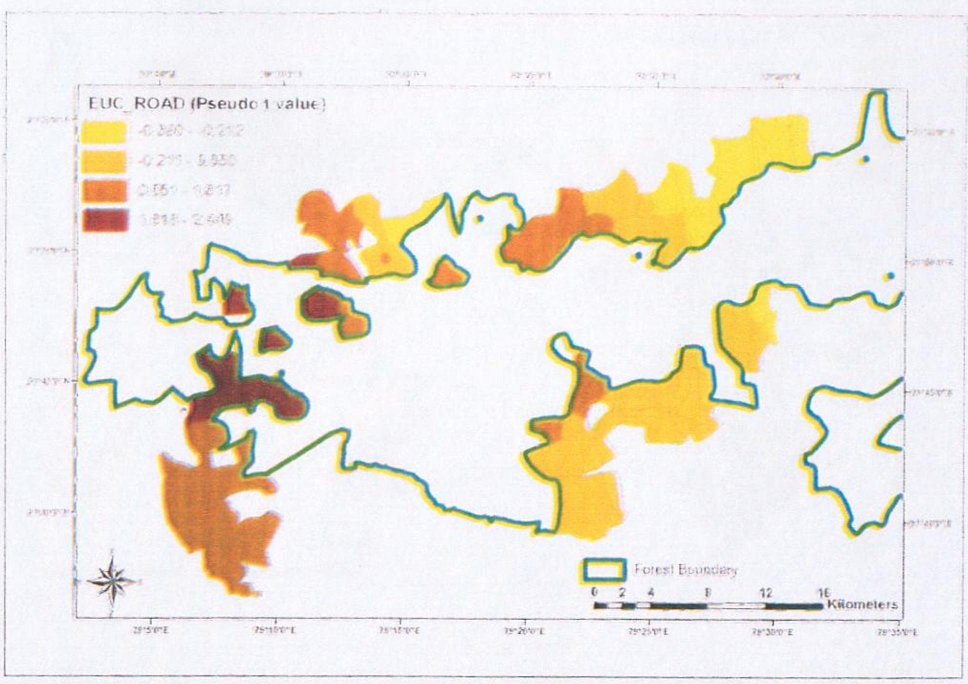


Fig. 8.38 Spatial distribution of pseudo t-values of the distance from major roads in degradation model

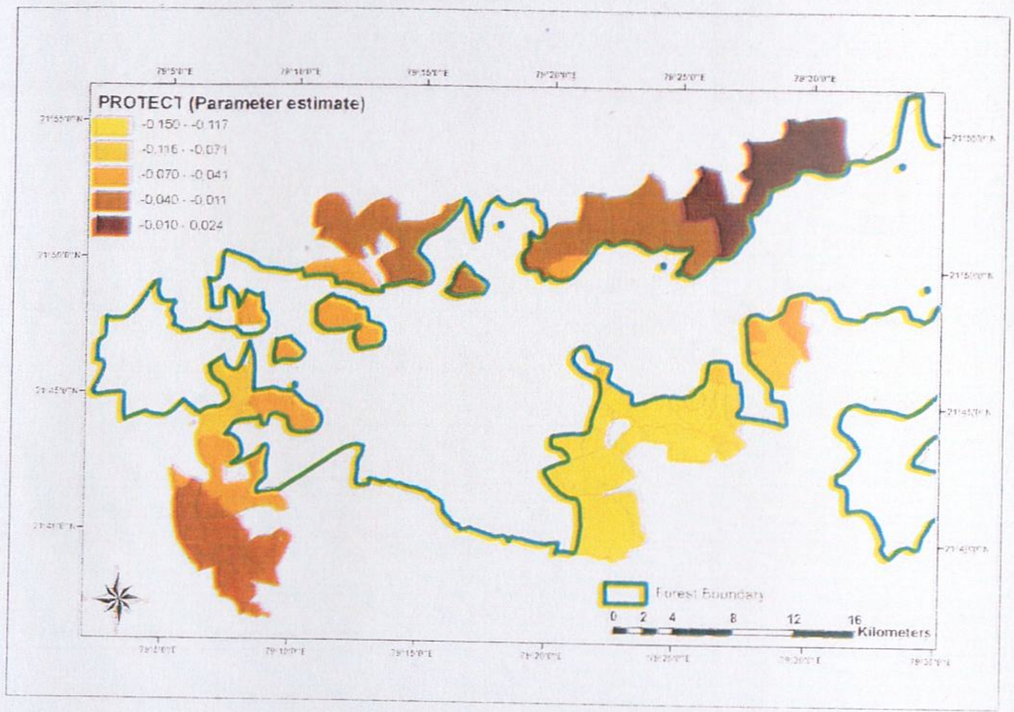


Fig. 8.39 Spatial distribution of parameter estimate of the distance from protected area in degradation model

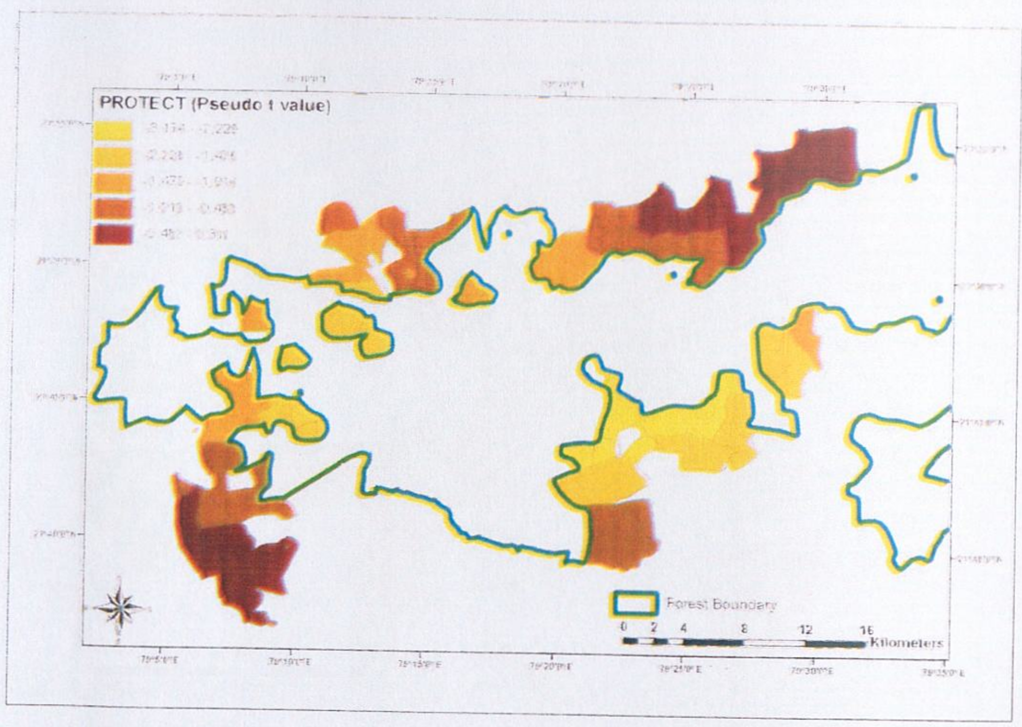


Fig. 8.40 Spatial distribution of pseudo t-values of the distance from protected area in degradation model

8.3.4.6 Land use land cover prediction by cellular automata model

The land use land cover prediction map of 2019 (Fig. 8.41) had resulted in five classes i.e. Miscellaneous forest, Teak Associated forest, Open forest, Water and Agri-habitation. Miscellaneous forest had turned out to be the largest class (Table 8.13).

Table 8.13 Area under various classes in predicted 2019 LULC map

Class	Area (Km^2)
Miscellaneous Forest	413.3
Water	58.9
Non-forest	387.5
Teak	192.5
Open	128.4

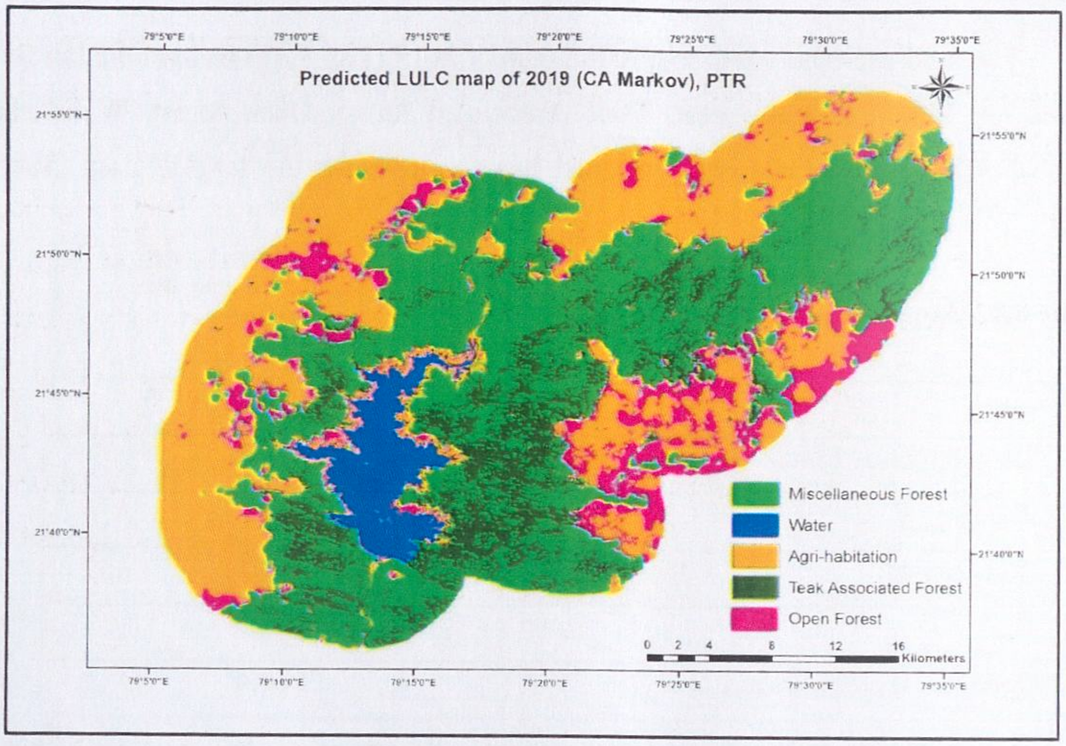


Fig. 8.41 Predicted LULC map of 2019 by CA Markov model in and around Pench Tiger Reserve, Madhya Pradesh

8.4 Discussion

Preceded by a global trend of tropical deforestation in the 1980s, many tropical countries witnessed a decline in deforestation rates (FAO 1993 and 2006) with a select few even exhibiting net reforestation (Lugo and Helmer 2004, Rudel 2005, Arroyo-Mora et al.2005). In the Indian subcontinent in particular, the expansion of forest protection and plantations have led to reforestation (Salam et al.2000, Lamb and Gilmour 2003). The present study provided a direct comparison of the effects of strict protection on forest and land-cover changes and thus contributes to the forest management literature. The study area exemplifies a typical case of contrasting management regimes in an area protected for wildlife. This condition enabled us to examine the role of different protective management approaches in preserving forest cover. While we expected to see maintained and/or regenerated forest cover within the park as a result of protection, we also expected greater forest loss over time outside the park, as suggested by many case-studies in the tropics (DeFries et al.2005). Part of our findings supported other studies showing the effectiveness of parks in maintaining forest cover (Bruner et al.2001). The findings of the present study had captured the dynamics of those government policies well in terms of protective measures. While the protected area (PA) status of the park became effective from 1977, it still continued to suffer notable forest loss until 1999 especially, in the buffer areas of the park which had continued pressure from the surrounding villages (mainly grazing, NTFP and fuel wood collection). This pre-1999 forest loss and post-1999 forest-cover recovery within the PA could be attributed to the 1983 notification of National Park and 1992 notification of Tiger Reserve by which felling and other timber management activities were banned inside PA, exhibiting the importance of national-level policies in favor of conservation of tiger landscapes.

The present study used NDVI standard normal deviate as a proxy of vegetation health and productivity. NDVI standard normal deviate image differences for the stable forest class showed a decrease in vegetation productivity (Fig. 8.2, 8.3 and 8.4) in later years. This degradation could potentially be due to several factors, e.g. grazing, changes in tree species richness, stand density and canopy cover as a result of felling or plantation activities (Pelkey et al.2000, Gillespie et al.2009).

Due to very little forest management intervention for more than 30 years, most of the one or two tree species dominated forest stands (like Teak-associated forests) were converted into mixed forest as shown by the increase in patch area but decrease in number of patches (Fig. 8.6 and 8.7). Uncontrolled extraction of forest resources in terms of fuel wood, fodder, NTFPs, agricultural expansions and utilization of forested lands for grazing left very less forested patch outside PTR where forests were heavily managed for harvesting of timber. While two date change trajectories showed decadal changes in forest covers as a result of changing forest policies, the overall change trajectory drew an overall change scenario experienced in the study area in the last 30 years. The stable forest classes were notably greater than that in any other change classes (Table 8.4). The stable barren class mainly denoted agri-habitational land in this area, which in totally situated outside PTR. The stable water class might be attributed partly to the presence of the Totladoh reservoir in the later images and partly to the precipitation variability resulting in more water in some images. The effect of the dam construction was also evident in the deforestation class, especially within the PA (Fig. 8.5 and Table 8.4). While restoration and upgradation trends were considerably lower in this area, deforestation and degradation trends were interestingly high. The study reported loss of 18.9% forest cover between 1977 and 1989, which was mostly due to the construction of hydroelectric dam and continuous increase in demands of people. The dominance of non-forest land covers in the northern, western and southern boundaries of the park related to the presence of villages in vicinity of the park which were dependent on the forest for fuel wood collection, cattle grazing and other minor forest products.

Villagers travelled most for collection of fuel wood (Mean 4.07 km, SE 0.35) compared to grazing and NTFP collection (Mean 3.28 km, SE 0.24 and Mean 3.3 km, SE 0.23 respectively). It was evident that both deforestation and degradation of forest inside the core area were negligible in the post 1999 period. In the middle area which comes under protected area and extraction radius though deforestation is negligible, registered almost similar trend in degradation of forested areas which could be interpreted as continuous resource extraction process even places inside PA. Its beyond the scope of this study to say which village was contributing how much for this kind of changes but in depth study along the boundary of PTR would definitely prove worthy in improving the quality of the forest. The India Eco-development project (1996-2001) funded by United Nation Development Programme (UNDP), aimed at involving forest dependent communities in sustainable forest management. Among all the villagers that fall within 5 km buffer around PTR, 99 villages were targeted under this project. This new participatory management regime was expected to reduce extraction and grazing pressure on the protected area as well as surrounding buffer by reducing forest dependence for fuel wood (through supply of bio-gas and LPG) and controlled grazing on marked pasture. Yet, researchers and scientists had continually been skeptical about the degree of true participation of the communities and intension of forest officials and public sectors to engage the local people in conservation efforts. Woodman (2002) pointed out that the antecedent conditions for the India Ecodevelopment Project were not conductive in the study area because of a lack of experience of such projects and lack of trust between the parties and thus transmission of project ideas, ethos and methodology was severely limited, partially due to resistance to change from both villagers and forest departments. Nevertheless, the concept of involving local people in conserving forest was appealing and with true implementation holds the promise of successful and potentially sustainable forest management.

While two-date change trajectories showed decadal changes in forest covers as a result of changing forest policies, the overall change trajectory drew an overall change scenario experienced by the study area in the last 30 years. While deforestation and degradation were negligible in PA in post 1999 period, reforestation and upgradation trends are quite interesting in pre 1999 period also stabilized in the post 1999 (Table 8.9). Outside forested areas showed considerable deforestation and an alarming degradation in post 1999 (Table 8.9). It could be visualized as good protection and management strategies in the post 1999 period almost stabilized changes in the forest inside PA whereas outside forests had higher degradation rates due to imposed ban and strict legislation on cutting trees.

While this study design did not allow us to identify the casual factors of this degradation, this difference in forest quality was important and will hopefully lead to more detailed ecological studies in this region. The differences in forest coverage in and around PTR, Madhya Pradesh most likely reflect the difference in degree of protection.

This study contributed to the land/forest cover change and socio-economic, biophysical and proximity factors affecting it. It was the first large scale forest cover change study in India for entire Tiger Reserve and its surrounding that investigates forest cover change and spatial variation within determinants by applying GWR. This study showed the importance of studying local spatial variation of forest cover in a protected area gathering information at village level with a set of demographic, biophysical and proximity determinants. Finally, this study demonstrates the importance of GWR as a tool for exploring local spatial variation of forest cover change and reducing spatial autocorrelation. This instrument could be used for studies with focus on natural resources in human-dominated landscapes managed for wildlife to reveal information at local level, which could be otherwise neglected. A GWR study should investigate whether local spatial variation was due to the influence of determinants to a response variable, a step which was not often in use though we found it valuable and meaningful. GRW analysis explored the behavior of variables at a local level and revealed significant spatial variability among some of them. This represented a clear enhancement of the understanding offered by a global analysis, rather than obtaining an average coefficient for the entire area, an estimated coefficient for each point analysed was obtained. Furthermore, this method revealed certain aspects of the inter-relationships which did not emerge with traditional global specifications. This implied that the parameter estimates for this regression varied according to geographical location. Therefore, the application of this method made it possible to study the spatial stability of the global model coefficients. It was found that the coefficients of many variables were spatially non-stationary and that the models produced using GWR describe the data significantly better than the global model (OLS).

India has a network of 660 protected areas that includes 99 national parks covering an area of 39,048km^2 (1.19% of the country) (National Wildlife Database, 2009). This network was created to help conserve a significant part of the country's biodiversity. The basic approach of park management in India has been exclusionary based on the assumption that permanent human settlement within or in near vicinity of the park degrades the ecosystem through resource extraction, which has been supported by several case studies (Barve et al.2005, Karanth et al.2006, Davidar et al.2007). In the present study, the park suffered from less deforestation after it was declared a national park. The actual scenario, even in the absence of the intervention, could have been something different than that predicted in this study. We attempted to capture the trend of changes in land use/ land cover and predicted future conditions in the landcape. With continuous increase in human population, forests in India are not only experiencing multiple fold increase in pressure but changing in much faster rate than anticipated in all tropical countries.

Chapter 9
HABITAT SUITABILITY MODELING

9.1 Introduction

Competition between human activities and wildlife is becoming more intense due to habitat destruction, leading to the decline of wildlife species. Effective wildlife conservation needs to reduce the friction between human and wildlife activities by identifying areas suitable for wildlife, and by reducing human intervention in these areas. For this purpose, mapping of suitable habitat is very important for wildlife conservation and ecosystem management. The actual geographical distribution of species as Habitat Suitability (HS) map is the result of the analysis of species–environment relationships (Dormann et al. 2007). Species distribution lies well within the optimal range of environmental factors (Kormondy 2003). It is, therefore, useful for ecological modelers to design a methodological algorithm to compute HS by incorporating most of the environmental factors with presence–absence data or only with presence data to develop a more precise estimate.

Ecological background and habitat definition are essential knowledge for HS modelling. Within the trophic levels of the food web in an ecosystem, organisms differ from each other in terms of population sizes, in terms of their roles as producer, prey, competitor, predator, etc., and also in terms of other biotic interactions. Species affect each other directly or indirectly depending on their relationship. Data based on field observation automatically include ecological autocorrelation among species (Betts et al.2006, Dormann et al.2007, Lichstein et al.2002) and must reflect species relationships and interactions. The availability of ecological components in terms of the quality and quantity of both physical factors and chemical conditions, on the other hand, determines the distribution pattern of plants, animals and microbes (Pirot et al.2000).

The 'ecological niche' is an important concept in HS modelling. It has been developed on the basis of the relationship between a species and its environment. Earlier scientists preferred an autecological and physiological approach to the niche (Austin 1992), while later writers focused more on trophic levels or food web theory (Guisan and Thuiller 2005). The ecological niche concept was first introduced by Grinnell (1917), who argued that every species has its own physiological, morphological and behavioral profile, which makes it suitable to occupy particular spaces offered by nature. Elton (1927) described niche as an integration of the interactions of species with their biotic environment in terms of food and enemies, excluding abiotic factors (Meyer 2007). Hutchinson (1957), on the other hand, developed the concept of niche as the sum of all environmental factors acting on the organism, the niche is thus defined as a region of a *n*-dimensional hypervolume. He also mentioned that under constant conditions, competitive relationships reduce the size of the fundamental niche to the size of a realized niche (Pulliam 2000, Meyer 2007). According to Dennis et al.(2003), niche is: (1) the place or living space, where an organism lives, (2) a place comprising a set of resources, consumables and utilities for the maintenance of an organism, (3) a form of behavior that appears to be essentially innate (Robinson and Bolen 1984), and which leads to the selection of an appropriate habitat in which an animal is most likely to survive and reproduce. The availability of resources and utilities such as food, shelter, concealment, and refuge constitutes the carrying capacity of a suitable site (Capen et al.1986, Caughley and Sinclair 1994, Phumiphakphun 1999, Schamberger and O'Neil 1986, Titeux 2006). Tolerance (Scalet et al.1997) is another inherent factor of species, which has an influence on their distributive capacity (Whittaker et al.1973).

Environmental factors can be divided into two main groups: (1) environmental requirements of species under the influence of limiting factors, (2) environmental impacts on species such as disturbances and perturbations affecting environmental systems (Guisan and Thuiller 2005).

Williams (2003) categorized HS models based on the original data of species into (1) presence–absence models and (2) presence models, and explained further that species data are employed extensively in habitat modeling and that most modeling methods use statistical tools, particularly multiple regressions. Guisan et al. (2006) argued that ecological modeling can be improved by including individual species' distribution as a bottom-up approach. They also proposed how to make better predictions of biogeography, and determined a framework to predict HS more efficiently by: (1) linking to ecological theory, (2) using existing data and already generated information, (3) incorporating spatial technique, (4) including ecological and environmental interactions, (5) evaluating the errors and uncertainties of the process and (6) predicting distribution of communities.

The issue was that we did not know why certain species occur in certain places, and we did not know which environmental factor had an influence on the presence of species in each location. Environmental parameters (EnvPs) such as physical factors, biological factors (Guisan and Thuiller 2005, Guisan and Zimmermann 2000, Williams and Araujo 2000) and human factors have always been put into the model at the same time to analyze HS either through presence–absence models such as Generalized Linear Modeling (GLM) (McCullagh and Nelder 1989), Discriminant Function Analysis (Davis 1986), Generalized Additive Modeling (GAM) (Hastie and Tibshirani 1986), Artificial Neural Networks, and Classification and Regression tree (CART) or other presence models such as Maximum Entropy Method (MaxEnt) (Phillips et al.2006) and especially, Ecological Niche factor analysis (ENFA model). Greaves et al. (2006), for instance, used GLM for estimating HS of the New Zealand long-tailed bat (*Chalinolobus tuberculata*) with six EnvPs, and obtained a correct classification rate value of 0.56, and predictive power values of 0.45 and 0.1 for presence and absence, respectively. Cassinello et al. (2006) used ENFA with 31 EnvPs for estimating HS of aoudad (*Ammotragus lervia*) obtained a correct classification rate value of 0.6, etc. Both of the studies excluded environmental categorization and species–human interaction factors in HS modeling.

Based on the assumption that species must be affected by each feature in terms of their behavior, movement and activities, HS modeling incorporating all EnvPs at the same time, may result in lower predicting power. Environmental impacts and trophic effects (Arditi et al.2005) such as competition, predation and other ecological interactions (Pulliam 2000, Titeux 2006) as well as perturbations by humans (Guisan and Zimmermann 2000, Guisan and Thuiller 2005), however, have not been incorporated into modeling to a comparable extent, despite the fact that they play an extremely important role in determining HS. In this study, these factors were incorporated into HS modeling for complete ecological modeling.

9.1.1 Chital:

Chital is an endemic species of south Asia, occurring in India, Sri Lanka, Nepal and Bangladesh (Prater 1934, Schaller 1967). They are found in a variety of forest types in India viz. dry deciduous, moist deciduous, thorn and mangrove forests. The introduced chital population in Andaman Islands is found in evergreen forests. Chital are known to feed on more than 160 species of plants (Schaller 1967, Johnsingh and Sankar 1991). Schaller (1967) showed that grass/herb formed the bulk of the feed of chital, while Mishra (1982) considered chital primarily a grazer. Sankar (1994) found that chital was a grazer as long as green grasses were available (monsoon and post-monsoon seasons), but switched over to fallen leaves, flowers and fruits in winter. Chital form one of the important preys of top carnivores as is evident from studies in Kanha (Schaller 1967), Bandipur (Johnsingh 1983), Rajaji National Park (Johnsingh et al.1993), Sariska (1994), Pench (Biswas and Sankar 2002) and Ranthambore (Bagchi et al.2003).

9.1.2 Sambar:

Sambar (*Rusa unicolor*) is the largest deer species native to South and South-East Asia. Adult sambar stags weigh between 225 and 320 kg. It has an exceedingly wide geographical distribution that includes India, Myanmar, Sri Lanka, extending through the Malay countries, and eastward to the Philippines and beyond (Prater 1971). Within India sambar occur in the tropical thorn forests of Gujarat and Rajasthan, in the moist deciduous forests throughout peninsular India, in the pine and oak forests at the Himalayan foothills, and in the evergreen and semi-evergreen forests of north-eastern India. Sambar had been observed to feed on more than 139 species of plants (Schaller 1967, Johnsingh and Sankar 1991). Sambar would graze or browse depending upon the forage available at any given point of time. The estimated annual home range of sambar stags was nearly 15 km^2, whereas that of hinds was nearly 3 km² (Sankar 1994). The preference of sambar for heavy cover has already been recorded (Schaller 1967, Johnsingh 1983). Sambar predation is mainly by tiger, leopard and dhole (Schaller 1967, Johnsingh 1983, Karanth and Sunquist 1995, Sankar 1994, Biswas and Sankar 2002, Bagchi et al.2003). Sambar are predominantly forest-dwellers, favouring the cover of trees, venturing out into the open mainly at night, and late at dusk or early dawn. They usually rest the whole of the daylight hours (Schaller 1967).

9.1.3 Wild Pig:

Wild pigs are ungulates native to Eurasia. The wild pigs occupy a wide variety of habitats, from semi-desert to tropical rain forests, temperate woodlands, grasslands and reed jungles, and often venturing into agricultural land to forage (Prater 1971). They are omnivorous, living on crops, roots, tubers, fruits and carrion. The stomach and fecal matter analysis indicated that vegetable matter, fruits, seeds, roots and tubers, constituted about 90% of the diet (Prater 1971, Spitz 1986). Wild pigs form an important part in the diets of tiger, leopard and dhole.

9.1.4 Tiger:

Tiger is the largest Felid classified into nine subspecies including three extinct ones. Tigers once ranged widely across Asia, from Turkey in the west to the eastern coast of Russia. Over the past 100 years, they have lost 93% of their historic range, and have been extirpated from southwest and central Asia, from the islands of Java and Bali, and from large areas of Southeast and Eastern Asia. Today, they range from the Siberian taiga to open grasslands and tropical mangrove swamps. The remaining six tiger subspecies have been classified as endangered by IUCN. The global population in the wild is estimated to number between 3,062 to 3,948 individuals, with most remaining populations occurring in small pockets that are isolated from each other. Major reasons for population decline include habitat destruction, habitat fragmentation and poaching (Chundawat et al.2011). The extent of area occupied by tigers is estimated at less than 1,184,911 km² (457,497 sq mi), a 41% decline from the area estimated in the mid-1990s (Sanderson 2006). Tiger habitats will usually include sufficient cover, proximity to water, and an abundance of prey. Bengal tigers live in many types of forests, including wet, evergreen, the semi-evergreen of Assam and eastern Bengal, the mangrove forest of the Ganges Delta, the deciduous forest of Nepal, and the thorn forests of the Western Ghats. In the wild, tigers mostly feed on larger and medium sized animals. Sambar, chital and wild pig are the favoured prey of tiger in India.

9.1.5 Leopard:

The leopard is a member of the Felidae family and the smallest of the four "big cats" in the genus *Panthera*. The leopard was once distributed across eastern and southern Asia and Africa, from Siberia to South Africa, but its range of distribution has decreased radically because of hunting and loss of habitat. There are nine sub-species recognized by IUCN (Hanschel 2011, Uphykina et al. 2001). It is now chiefly found in sub-Saharan Africa, there are also fragmented populations in the Indian subcontinent, Sri Lanka, Indochina, Malaysia, Indonesia, and China (Hanschel 2011). Leopards live mainly in grasslands, woodlands, and riverine forests. They are usually associated with savanna and rainforest, but leopards are exceptionally adaptable: in the Russian Far East, they inhabit temperate forests where winter temperatures reach a low of −25 °C (−13 °F) (Uphykina 2001). Major prey species for leopard are chital, sambar and wild pig.

9.1.6 Dhole or Indian Wild Dog:

The dhole or Indian Wild Dog is a species of canid native to South and Southeast Asia. The dhole is a highly social animal, living in large clans which occasionally split up into small packs to hunt. It primarily preys on medium-sized ungulates, which it hunts by tiring them out in long chases, and kills by disemboweling them. Prey species for dholes in India include chital, sambar, muntjac, mouse deer, wild pig, cattle, goats and common langur (Achariya 2007, Durbin et al.2011). Dholes are primarily diurnal hunters, hunting in the early hours of the morning. In some areas, dholes are sympatric to tigers and leopards. Competition between these species is mostly avoided through differences in prey selection, although there is still substantial dietary overlap observed (Karanth and Sunquist 1995). Dholes once ranged throughout most of South, East and Southeast Asia, extending from the Tien Shan and

Altai Mountains and the Primorsky Krai southward through Mongolia, Korea, China, Tibet, Nepal, India, and south-eastwards into Myanmar and Indochina, Thailand, Malaysia, Sumatra and Java (Hunter 2011). Dhole inhabits forest, forest grassland mosaic and montane scrublands from peninsular India to Eastern Himalaya.

9.2 Methodology

Chital, sambar, wild pig among the herbivore species and among carnivores, tiger, leopard, wild dog were chosen for large mammal habitat suitability (HS) modeling. Very few sightings of gaur restricted us to do habitat suitability modeling for this species. The ENFA model was applied to analyze the study species HS.

9.2.1 ENFA model:

The ENFA model was designed on the basis of Hutchinson's niche concept (Hutchinson 1957), which focuses on presence only data. It is widely accepted because it does not need absence data which often are not available or difficult to sample, even if the sampling is systematic. Absence data, however, seem to reflect closer links with unsuitable habitat (Jimenez-Valverde et al.2007, Tole 2005). Hirzel et al.(2002) explained that absence data may be arranged into two types: (1) species are absent from suitable habitat because they cannot be detected and (2) species are absent from habitat that is truly unsuitable. ENFA compares the Environmental parameters (EnvPs) of species distribution and global distribution. The ecological niche of a species is normally a subset of its global distribution. Hirzel et al.(2002) have determined the following two parameters: (1) the difference of mean between species distribution and global distribution, called "marginality", which is shown in Eq. (9.1):

$$M = \frac{|mG - mS|}{1.96\sigma G} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9.1)$$

M is the marginality for a species expressed by the fact that the species mean differs from the global mean. *mG* is the mean of global distribution. *mS* is the mean of species distribution. *σG* is the variance of the global distribution. The ratio between variance of global distribution and species distribution, called "specialisation", which is shown in Eq. (9.2). The specialisation of a species is expressed by the fact that the species variance is lower than the global variance. Specialisation indicates how restricted the species' niche is in relation to the study area (Hirzel et al.2002):

$$S = \frac{\sigma G}{\sigma S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9.2)$$

S is the specialisation of a species and σ*S* is the variance of species distribution. Eqs. (9.1) and (6.2) is given here mainly to explain the principle of ENFA. For overall marginality of all EnvPs, ENFA is computed in Biomapper as:

$$M = \sqrt{\frac{\sum_{i=1}^{v} m_i^2}{1.96}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9.3)$$

The coefficient *mi* of the marginality factor expresses the marginality of a species for each EnvP in units of variance from the global distribution. Along the *mi*, Hirzel et al.(2002) explain that the signs (minus and plus) of the coefficients indicate whether the suitable habitat is found above or below the average value of each EnvP. *M* is the marginality of all EnvPs. The large value of *M* indicates that species range is different from average condition of all EnvPs. ENFA also calculated overall specialisation in Biomapper as

$$S = \sqrt{\frac{\sum_{i=1}^{v} (\sigma_{Gi} / \sigma_{Si})^{-}}{v}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

S is in range from1 to infinity, with the niche becoming narrower as *S* increases (Bryan and Metaxas 2007). σ*Gi* is variance of the global distribution of EnvP *i* while σ*Si* is variance of the species distribution of EnvP *i*. *v* is the number of EnvPs. The ENFA model uses raster grid maps containing continuous values of EnvPs. The specialisation factors were produced as uncorrelated factors by maximizing the ratio of variance of global distribution and of species distribution (*S*). These specialization factors were constructed by alternately removing and restoring each EnvP (Hirzel et al.2002), until all EnvPs were extracted. This process is similar to PCA (principal component analysis). HS maps build on a count of all cells of species distribution that are situated as far as or farther apart from the median than the cells of each specialisation factor. This count is normalized in such a way that the suitability index ranges from 0 to 100 (Estrada-pena et al.2006, Hirzel et al.2002, Zaniewski et al.2002). The suitability of any cell of global distribution is calculated from its situation relative to the species distribution on all selected specialisation factors, which were selected as first few factors. ENFA takes 100% of the marginality, as well as some proportion of specialisation factors into account for computing the HS index. Biomapper 3.2 (Hirzel et al.2004) as a GIS-statistic program was designed to process according to the ENFA concept in order to facilitate the generation of HS maps (Zaniewski et al.2002).

9.2.2 Dataset of wildlife species, human activities/visitations and human-induced events

Three to five km carnivore sign survey (Jhala et al.2008) (total effort = 252 km) for major carnivore species (tiger, leopard, wild dog) by recording their signs (pugmark, scat, scrape, rake, direct sighting) and two km line transects for major wild ungulate species (chital, sambar, wild pig) were walked (total effort = 168 km) in all 43 beats of the study area (Fig. 9.0) , which had been collected during 2007-2009 in PTR in winter (November to February). Data on carnivore signs and wild ungulate sightings were converted to encounter rates per kilometer. These encounter rates were mapped at beat level. Data on human disturbance signs such as signs of lopping, wood cutting, number of trails and livestock dung were collected in 10 m radius plots at every 400 m on the line transects. These data was also mapped at beat level. The distribution map of tiger, leopard, wild dog, chital, sambar, wildpig were prepared in ArcGIS 9.2 (ESRI Inc.) by using GIS technique and was transformed to Boolean map in Idrisi based on 1 km X 1 km square pixels covering PTR and its five km buffer.

9.2.3 Dataset of environmental parameters

GIS layers such as beat boundary, streams and roads were digitized from Survey of India (SOI) toposheets. These GIS layers were generated to produce the EnvP maps as environmental variables. The EnvPs were arranged based on similarity of mechanisms and, in addition to that, on species–human interactions (Guisan et al. 2006). Three main features were categorized. Altogether 35 EnvPs, which consist of 18 geographical and resource parameters, 11 human disturbance and 6 species interaction parameters (Table 9.1). All EnvPs, to serve as input into ENFA model, must be in the form of quantitative maps, which contain continuous values such as slope and elevation. Therefore, qualitative maps like vegetation types were generated and transformed into Boolean maps in Idrisi. Distance measurement was applied to produce parameter maps by using Euclidian distance. All EnvP maps must be prepared in the form of idrisi format.

Table 9.1 Details of variables used in different habitat suitability models

Variables in species Interaction model	**Variables in geographical-resource model**
Chital encounter rate	Percentage High canopy
Sambar encounter rate	Percentage Medium canopy
Wild pig encounter rate	Percentage Low canopy
Tiger encounter rate	Percentage No canopy
Leopard encounter rate	Percentage Agriculture
Wild dog encounter rate	Percentage *Cliestanthus colinus*
Variables in human disturbance model	Percentage Miscellaneous forest
Lopping signs	Percentage Open forest
Cattle dung	Percentage Riverine forest
Livestock seen	Percentage Submergence
People seen	Percentage Teak dominated forest
No. of Trails	Percentage Teak-lagerstromia forest
No. of Wood cutting signs	Percentage Teak-mixed forest
Distance from road	Elevation
Distance from village	Slope
	Distance from water

9.2.3.1 Species interaction

This feature has been added to HS modelling to include the effect of perturbations by other species (Guisan et al.2006). It is generally not used as input for habitat modeling because of the lack of data on other species in a study site. This feature was categorized into two groups: encounter rates of competitor species and encounter rates of predator/prey species. Parameters for this feature were generated by dividing PTR and its five Km buffer into 1 km X 1 km fishnet grids. GIS technique was used to analyze the species encounter data.

9.2.3.2 Human disturbance factors

This feature influences species through disturbances and pressures, causing the animals to retreat to interior places. Human factors include (1) human disturbance signs, (2) distance to villages and (3) distance to roads. Data on human disturbance signs like signs of lopping, wood cutting, grass- bamboo cutting, number of human trails, livestock dung and people seen were collected in 10 m radius plots at every 400 m on the line transects laid in every beat for ungulate encounter rate estimation. These data was also mapped at beat level. The mean value was extracted by the same 1 km X 1 km square pixels.

9.2.3.3 Geographical and resource features

This feature has been used early in habitat modeling. It describes the landscape characteristics and their effect on the movement and the geographical region of a species. This study has defined geographical features as follows: (1) Elevation and slope generated ASTER GDEM 30 m resolution data downloaded from http://www.gdem.aster.ersdac.or.jp/ , (2) Distance to waterhole: Euclidean distance function was used to generate this geo-parameter, (3) Land use/cover classes and forest density classes and (4) Normalized Difference Vegetation Index: this was generated from Infra red (IR) and near IR bands of the multi-spectral Landsat TM satellite imagery.

9.2.4 HS map by model averaging:

HS mapping for target species was done in two steps to produce HS map: (A) Using ENFA model to produce 3 HS maps by separate niche analysis according to the three sets of features, i.e. species interaction features, geographical and resource feature and human disturbance features (model 1–model 3). Marginality and specialisation were computed separately for each model. This method is the key point for HS analysis according to the influence of each feature. Each HS map indicates and provides suitable habitat in the form of (1) geographical/resource region where species prefer to live, (2) region for species to retreat from human disturbances and (3) preference/avoidance for species due to interaction with other species. (B) The next step was model averaging (model 4) which was performed to include all EnvPs by averaging the HS values of model 1 to model 3 as 3-dimensional hypervolumes of HS according to the three features by using the marginality of three HS as an axis. This model can explain the relationship between niche and species distribution according to Pulliam (2000), who proposed four theoretical models by interpreting 2-dimensional environments: (1) the *fundamental niche* of Grinell, where species occupy a suitable area and are absent in unsuitable areas, (2) the *realized niche* of Hutchinson, where competition may lead to species being absent from a suitable area, (3) the source–sink dynamic whereby conditions for a species to satisfy its requirements are favorable or sufficient in the source habitat, and unfavorable or insufficient in the sink habitat, (4) the dispersal limitation situation in which a species can sometimes be absent from suitable habitat.

9.2.5 Model evaluation

The approaches of model 1 and model 3 performed with ENFA differed from each other methodologically with respect to the manner of inputting the EnvPs. Model 4 is the result of integrating the average HS values of model 1–model 3. All HS maps contain the probability values of HS between 0 and 100. All the models were compared. The Absolute Validation Index (AVI) and the Contrast Validation Index (CVI), which is provided in Biomapper, were used to evaluate all result models. CVI can be calculated by AVI-AVI0 when AVI0 (AVIzero) is the proportion of all pixels with HS > 50, with the CVI always lower than the AVI. A good model should have a high value of both AVI and CVI in the sense that AVI should have value >0.6 and CVI > 0.3 (Hirzel et al.2004).

9.2.6 Habitat classification

The HS map of different species was classified into four habitat types: highly suitable habitat (HS values >60), moderate suitable habitat (40 <HS values <=60), low suitable habitat (20 <HS values <=40) and unsuitable habitat (HS values are <=20). Suitable habitat contains most of the essential conditions of the three EnvP features, and is sufficient for species to survive and to reproduce. The suitability values decrease from moderate suitable to low suitable and to unsuitable habitat until some essential conditions are no longer sufficient for species.

9.2.7 Predicted HS of different species with cellular automata model predicted land use land cover

ENFA was used to predict future habitat suitability of tiger, leopard, wild dog, chital, sambar and wild pig. Predicted 2019 land use land cover map was used in these models. To compare the changes in different suitability classes between present and 2019 HS, present model was also run with 2009 land use land cover map only.

9.3 Results

8.3.1 HS model for Chital:

Incorporating the presence data of chital (*n* = 530), has resulted in the three HS map (model 1 to model 3) for species interaction, human disturbances and geographical–resource factors respectively (Fig. 9.1-6.3). The proportion of explainable information in model 1 to 3 is 89%, 95% and 84% respectively. The overall marginality (*M*) for model 1 to 3 are 0.75, 0.56 and 1.23 respectively and the overall specialisation (*S*) are 0.94, 2.36 and 1.345 respectively. This indicates that chital preferred habitat that is different from the average conditions in PTR, and that chital requires a quite specific range of habitats. Positive sign of marginality means that chital preferred higher average than the global mean. Accordingly, chital preferred to stay nearly with sambar (0.779) and wild pig (0.59) (Table 9.2). Chital did not preferred areas with high lopping (-0.268), high cattle presence (-0.212) and high human disturbance in terms of wood cutting (-0.316).

Table 9.2 Marginality and Specialisations of different variables in HS models of Chital

Chital species Interaction model (Model 1)

Variables	Marginality	Specialisation1	Specialisation2	Specialisation3
Leopard encounter rate	-0.043	-0.999	-0.006	0
Wild dog encounter rate	0.098	-0.001	-0.034	0.058
Tiger encounter rate	0.184	0.001	-0.981	0.032
Sambar encounter rate	**0.779**	-0.036	0.151	-0.612
Wild pig encounter rate	**0.59**	-0.024	0.113	0.788

Chital human disturbance model (Model 2)

Lopping	-0.268	0.13	-0.983	0.693
Cattle dung	-0.212	0.11	-0.019	0.216
Livestock seen	-0.015	-0.172	0.002	-0.454
People seen	0.04	0.03	0.043	0.471
Trail	0.233	0.055	0.005	0.01
Wood cutting	**-0.316**	0.059	0.006	0.025
Distance from road	**0.485**	0.603	-0.147	-0.187
Distance from village	**0.702**	0.755	0.097	0.096

Chital geographical-resource model (Model 3)

Agriculture	-0.207	0.058	0.015	0.118
High canopy	**0.313**	0.022	-0.017	0.032
Medium canopy	**0.428**	0.051	0.029	0.045
Low canopy	**0.321**	0.331	-0.048	0.675
No canopy	0.029	-0.007	0.007	-0.066
Cliestanthus colinus	0.072	0.003	0.001	0.003
Elevation	**0.307**	-0.826	-0.195	-0.173
Miscellaneous forest	0.267	0.044	0.018	0.128
Open forest	0.111	0	0.011	-0.005
Riverine forest	-0.012	0.003	-0.014	-0.012
Slope	-0.147	-0.338	0.364	0.522
Submergence	0.087	0.016	0.019	0.024
Teak dominated forest	**0.411**	0.094	0.01	-0.012
Teak-lagerstromia forest	0.172	0.013	0.01	-0.062
Teak-mixed forest	0.269	-0.026	0.012	-0.024
Distance from water	0.133	0.273	0.907	-0.407

Chital preferred areas away from road (0.485) and village (0.702). It avoided agricultural areas (-0.207). It had no bias towards any canopy density area but preffered teak-dominated forest (0.411). Pench has undulating terrain. Chital though preferred elevated areas (0.307) but avoided steep slope (-0.147) to a certain limit. The large numbers of specialisation were found on leopard encounter (-0.999 on Spec.1), sambar (-0.612 on spec. 3), wildpig (0.788 on spec.3), lopping on spec. 2 (-0.983) and spec. 3 (0.693), distance from road (0.603 on spec.1) and distance to village (0.755 on spec.1), low canopy in spec.1 (0.331) and spec. 3 (0.675), slope in spec.1 (-0.338), spec.2 (0.364) and spec.3 (0.522), distance from water in spec.2 (0.907) and in spec.3 (-0.407). This showed that the distribution of chital could deviate from optimal values with respect to these parameters (Hirzel et al.2002). ENFA was performed again to produce HS maps of chital according to each categorized environmental parameters (EnvPs) (model 1 to model 3, see Fig. 9.1 to

9.3). The M and S were also computed. The M of model 1 to model 3 was 0.746, 0.566 and 1.228 respectively, while the S are 0.939, 2.366 and 1.345 respectively (Table 9.2). The HS map which was created by inputting only geographical and resource features (M= 1.228) differred from the average geographical conditions of PTR. The difference was the largest of M when compared with M of other condition such as species interaction (M=0.746) and human disturbance (M=0.566). On the other hand, S indicated that conditions for chital in PTR for resource and geographical features (S = 1.228) were better than species interaction (S = 0.939) and human disturbance conditions (S = 2.366). M and S of each model reflected the size of suitable habitat in different aspects. The integrated-ENFA model (model 4) includes all EnvPs by model averaging (model 1 to model 3) as presented in the HS map in Fig. 9.4. The averaging model did not receive the M and S similar to general ENFA model. However, model 4 needed model 1 to model 3, as the background on explainable information.

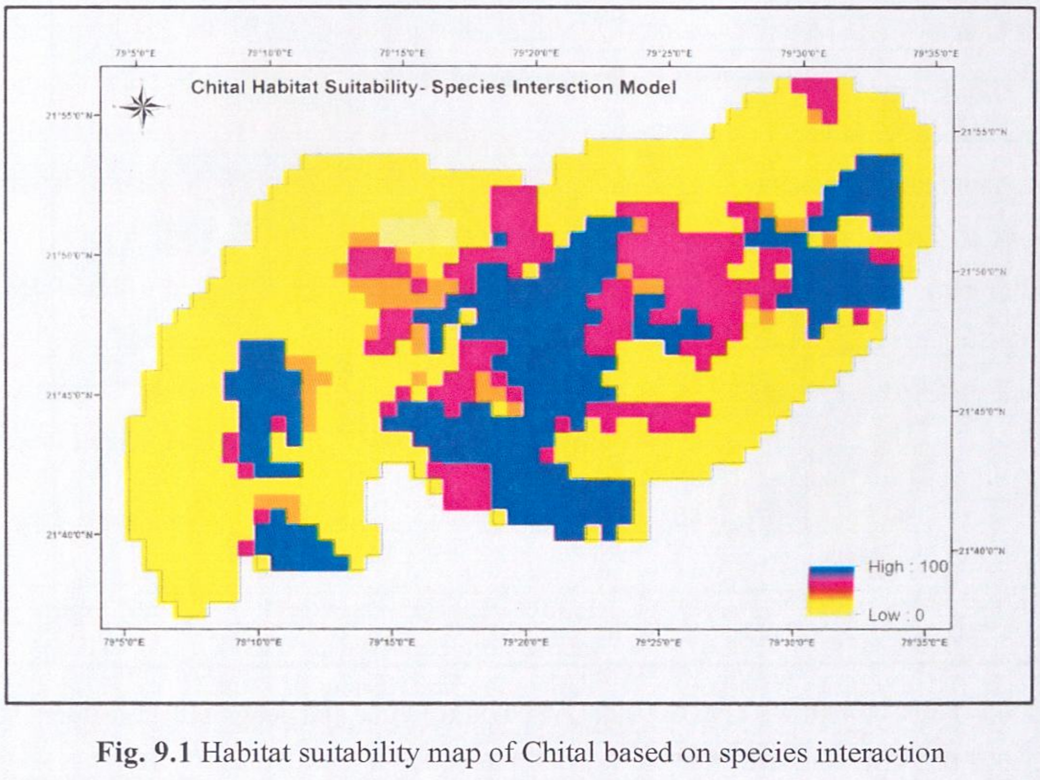


Fig. 9.1 Habitat suitability map of Chital based on species interaction

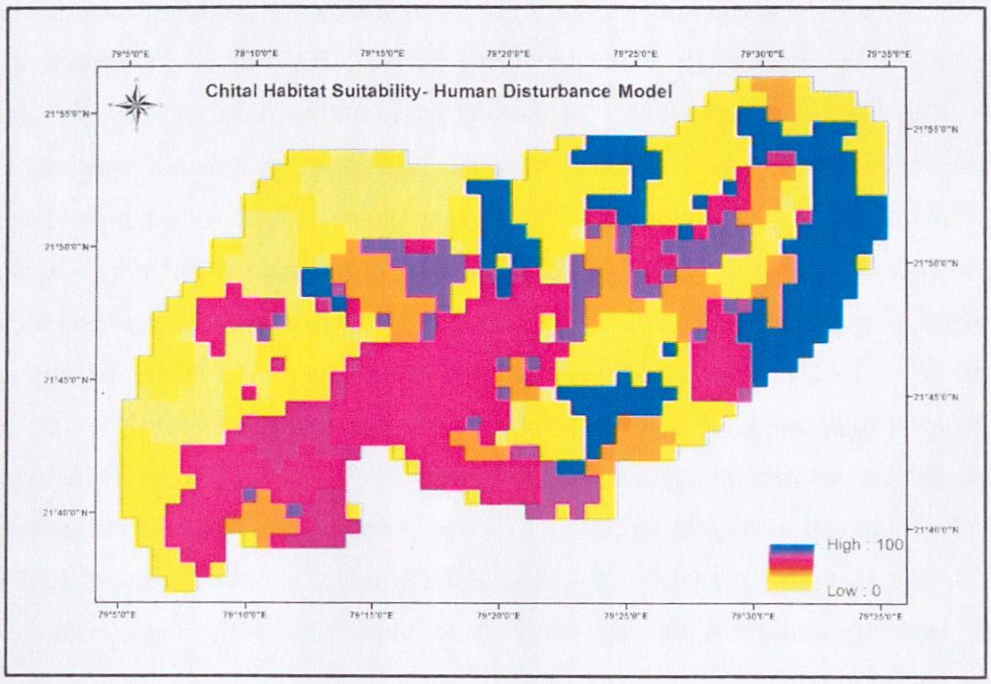


Fig. 9.2 Habitat suitability map of Chital based on Human disturbance

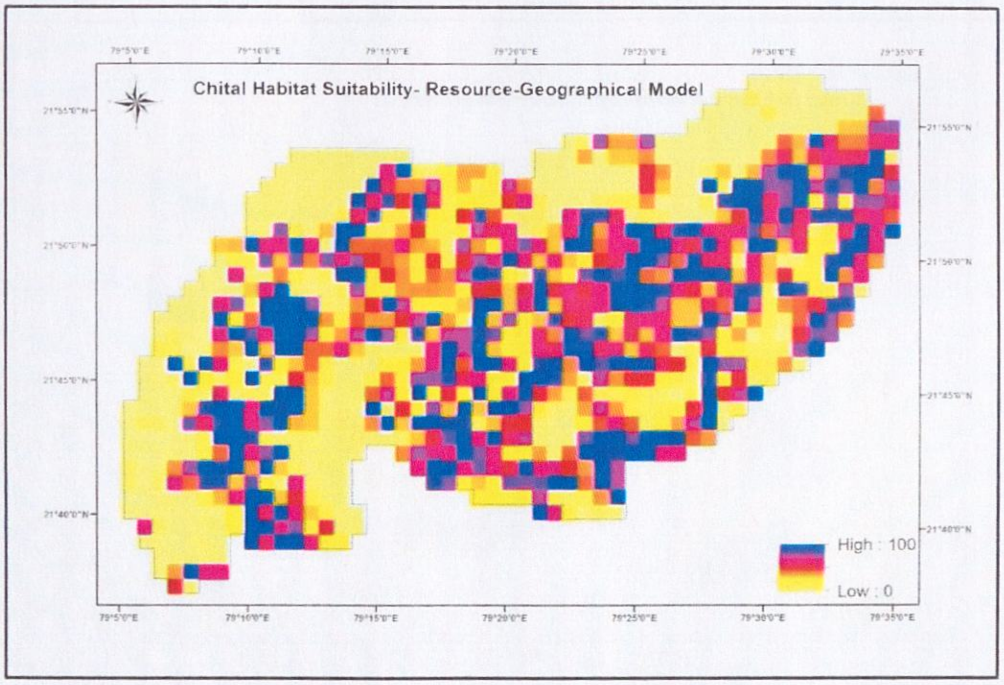


Fig. 9.3 Habitat suitability map of Chital based on resource and geographical features

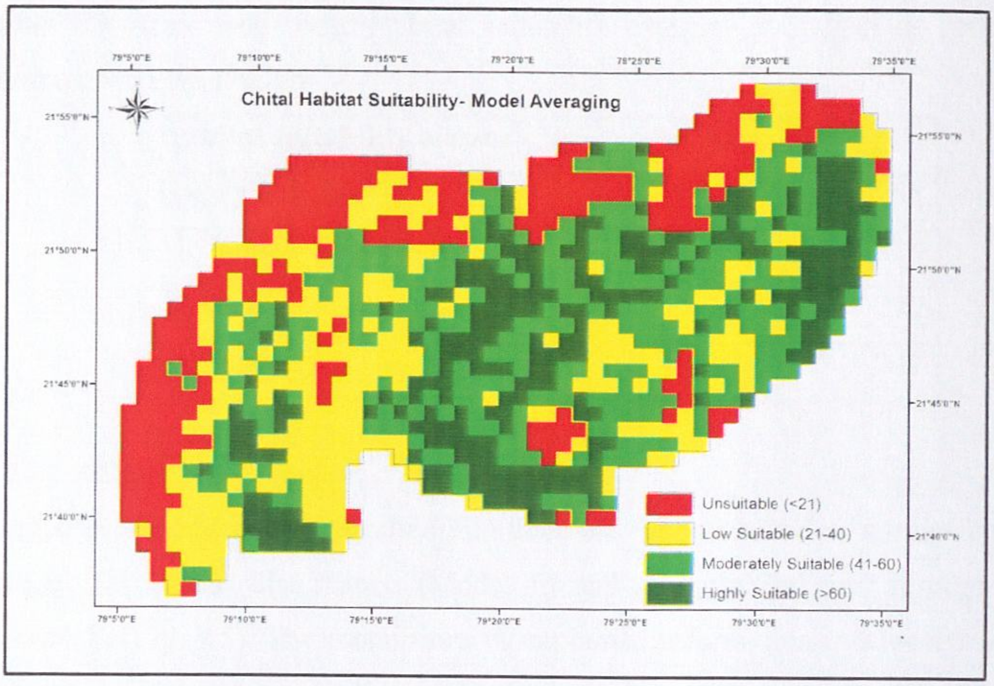


Fig. 9.4 Habitat suitability map of Chital based on model averaging

The chital HS model validation results (Table 9.3) showed that Model 4 attains the highest value of AVI and CVI with 0.715 and 0.399. The other models: i.e. Species interaction (model 1), human disturbance model (model 2) and geographical-resource model (model 3) attained AVI with 0.675, 0.609 and 0.602 respectively and attained CVI with 0.367, 0.32, and 0.378 respectively. Therefore, the validating test showed that model 4 has the highest values of AVI and CVI, and matches better than other models. The area under highly suitable, moderately suitable, low suitable and unsuitable classes for chital are 256 Km^2, 270 Km^2, 315 Km^2 and 256 Km^2 respectively (Table 9.4). \

Table 9.3 Summary of validating model of all HS models for chital

Model No.	Habitat Suitability Model	AVI	AVI0	CVI
1	Chital Species Interaction Model	0.675	0.308	0.367
2	Chital Human Disturbance Model	0.609	0.289	0.32
3	Chital Resource-geographical Model	0.602	0.224	0.378
4	Chital Model Averaging	0.715	0.316	0.399

AVI (prop. of validation cells with HS > 50), AVI0 (Prop. of all cell with HS > 50), CVI (CVI =AVI−AVI0)

Table 9.4 Area under each Habitat suitability category for chital in Pench Tiger Reserve, Madhya Pradesh

Habitat suitability classes	Area (Km^2)
Highly Suitable	256
Moderately suitable	315
Low suitable	270
Unsuitable	247

9.3.2 *HS model for Sambar:*

Sambar presence (n= 503) resulted into three HS models based on species interaction (Model 5), human disturbance (Model 6) and geographical and resource factors (Model 7) (Fig. 9.5). The proportions of explained information in Model 5 to 7 were 80%, 95% and 83% respectively. *M* for model 5 to 7 was 0.756, 0.572 and 1.3 respectively and overall *S* were 0.693, 2.442 and 1.397 respectively. Positive marginality indicated that sambar preferred habitat higher than the global mean i.e. better than average condition in PTR. Similarly sambar shared habitats with chital (0.764) and wild pig (0.614). Predator species had almost no significant impact on sambar habitat preference.

Table 9.5 Marginality and Specialisations of different variables in HS models of Sambar

Sambar Species Interaction model (Model 5)

Variables	Marginality	Specialisaion1	Specialisation2	Specialisation3
Chital encounter rate	**0.764**	-0.742	0.109	0.134
Leopard encounter rate	-0.059	0.546	0.774	-0.977
Wild dog encounter rate	0.101	-0.03	-0.02	-0.019
Wild pig encounter rate	**0.614**	-0.386	0.027	-0.164
Tiger encounter rate	0.157	0.038	-0.623	0

(Model 6)

Sambar human disturbance model

Variables	Marginality	Specialisation1	Specialisation2	Specialisation3
Lopping	-0.265	0.796	-0.949	0.092
Cattle dung	-0.225	0.08	-0.032	0.27
Livestock seen	-0.1	-0.107	-0.001	-0.674
People seen	-0.053	0.031	0.064	0.64
Trail	0.155	0.027	0.012	-0.002
Wood cutting	**-0.397**	-0.035	-0.008	0.034
Distance from road	**0.429**	0.36	-0.26	-0.208
Distance from village	**0.708**	0.465	0.163	0.102

Sambar Geographical-resource model (Model 7)

Agriculture	-0.087	-0.133	0.424	0.477
High canopy	0.272	-0.007	0.014	0.083
Medium canopy	**0.382**	-0.052	0.118	0.094
Low canopy	**0.358**	-0.372	-0.028	0.505
No canopy	-0.036	0.037	-0.14	-0.245
Cliestanthus colinus	0.051	-0.005	0.001	-0.004
Elevation	0.27	0.888	-0.695	0.193
Miscellaneous forest	**0.343**	-0.085	-0.083	-0.075
Open forest	0.035	0.002	0.022	0.072
Riverine forest	0.006	-0.007	-0.004	0.232
Slope	0.294	0.042	0.023	-0.113
Submergence	0.02	-0.026	0.037	0.056
Teak dominated forest	**0.382**	-0.088	0.113	-0.064
Teak-lagerstromia forest	0.278	0.004	0.022	-0.037
Teak-mixed forest	0.254	0.017	0.025	-0.063
Distance from water	0.274	-0.181	0.53	-0.561

Sambar prefered undisturbed habitat (Lopping: -0.265, Cattle dung: -0.225, wood cutting: -0.397) and areas away from villages (0.708) and road (0.429). It also

Sambar prefered undisturbed habitat (Lopping: -0.265, Cattle dung: -0.225, wood cutting: -0.397) and areas away from villages (0.708) and road (0.429). It also preferred medium (0.382) and low canopy (0.358) areas in PTR as most of the area is covered by these two classes. Similarly it preferred Miscellaneous (0.343) and Teak dominated forests (0.382). Large numbers of specializations were found in chital encounter rate (-0.742 on spec.1), leopard encounter rate (spec.1: 0.546, spec.2: 0.774, scpec.3: -0.977), wild pig in spec.1 (-0.386), tiger encounter rate in spec.2 (-0.623), lopping (spec.1: 0.796, spec.2: -0.949), distance from village on spec.1 (0.465), agriculture (spec.1: 0.424, spec.2: 0.477), low canopy on spec.3 (0.505), elevation (spec.1: 0.888, spec.2: -0.695), distance from water (spec.2: 0.53, spec.3: -0.561). Sambar HS could deviate from its optimum value with respect to these parameters. Three HS maps (Fig. 9.5-8.7) were produced by ENFA. The overall *M* was 0.756, 0.572 and 1.3 respectively and *S* were 0.693, 2.442 and 1.397 respectively for model 5 to 7. Similarly like chital, models for sambar also showed that Geographical and resource features (Model 7) were better than other two models as per *S* of the respective models. The final HS map (Fig. 9.8) was created by model averaging (Model 5- to 7).

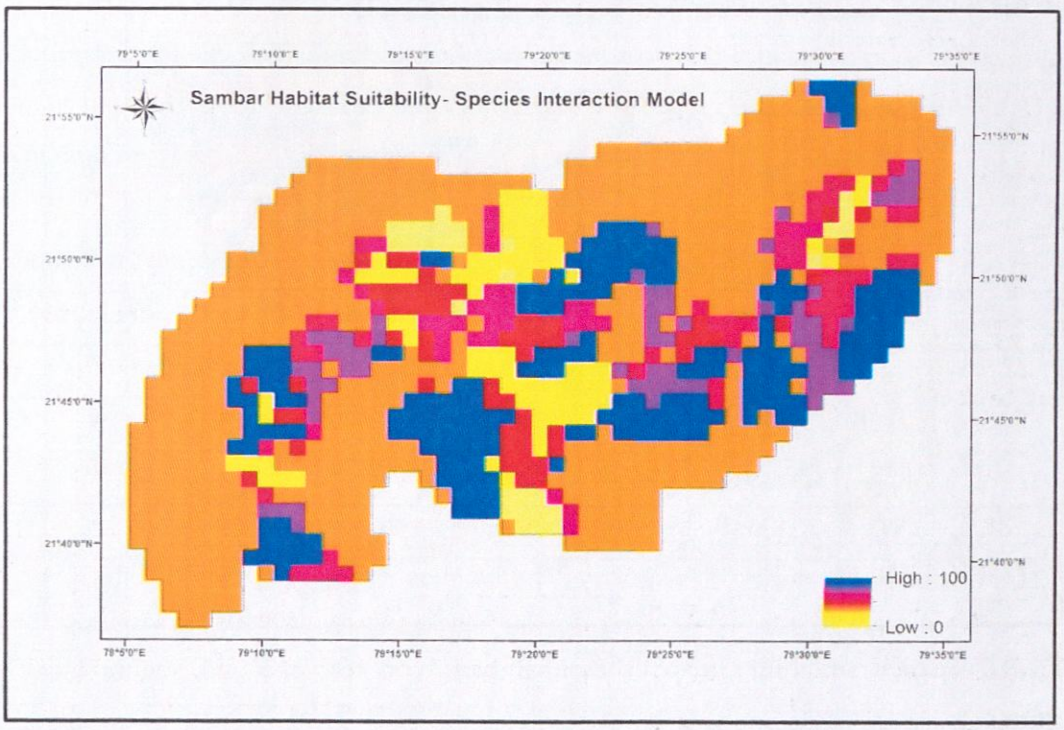


Fig. 9.5 Habitat suitability map of Sambar based on species interaction

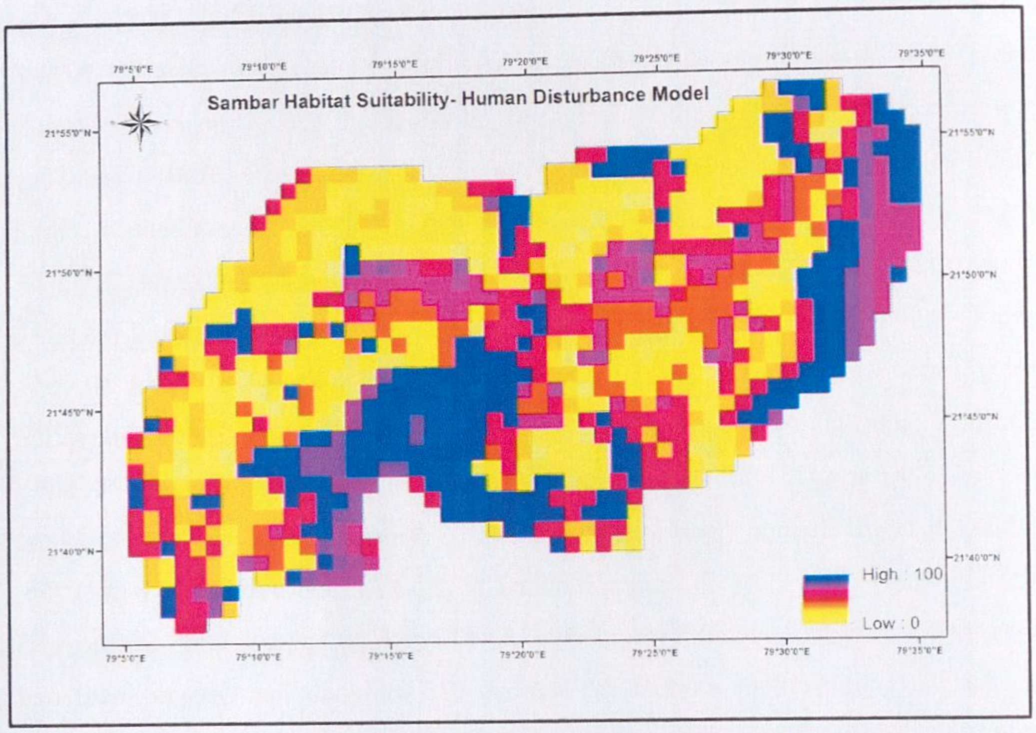


Fig. 9.6 Habitat suitability map of Sambar based on Human disturbance

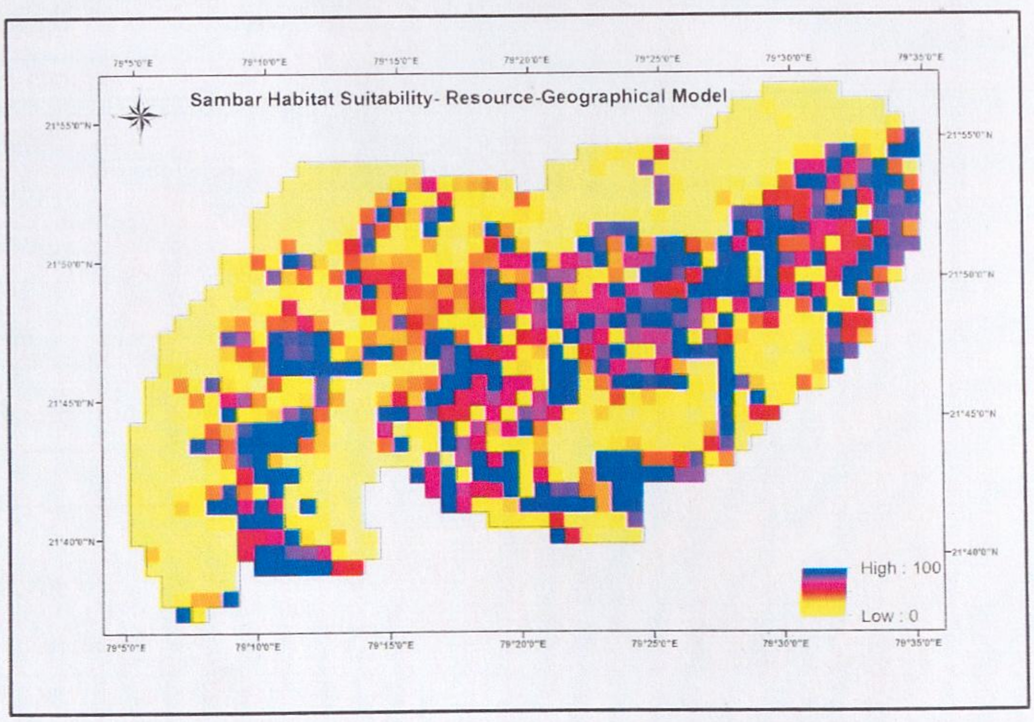


Fig. 9.7 Habitat suitability map of Sambar based on resource and geographical features

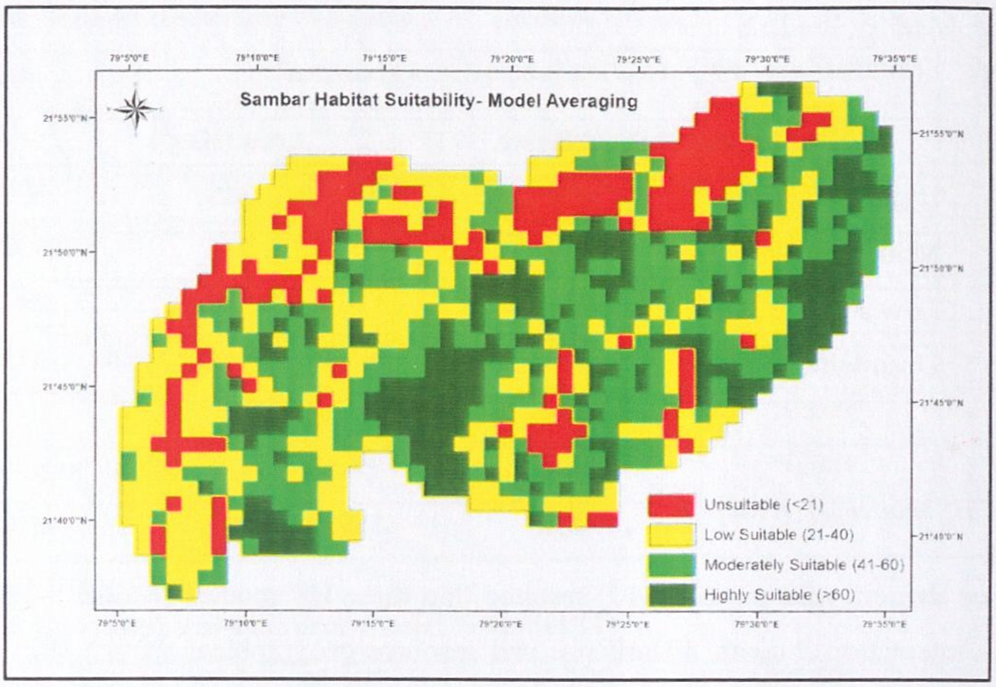


Fig. 9.8 Habitat suitability map of Sambar based on model averaging

Model 8 attained highest value of AVI and CVI of 0.689 and 0.382 respectively, compared to AVI (0.644, 0.619 and 0.635) and CVI values (0.355, 0.317 and 0.33) of model 5-7 (Table 9.6). This showed that model 8 was the best fit model. The area under highly suitable was 245 Km^2, moderately suitable 348 Km^2, low suitable 317 Km^2 and unsuitable 178 Km^2 respectively for sambar in PTR (Table 9.7).

Table 9.6 Summary of validating model of all HS models for Sambar

Model No.	Habitat Suitability Model	AVI	AVI0	CVI
5	Sambar Species Interaction model	0.644	0.289	0.355
6	Sambar Human Disturbance Model	0.619	0.302	0.317
7	Sambar Resource-geographical model	0.635	0.305	0.33
8	Sambar model averaging	0.689	0.307	0.382

AVI (prop. of validation cells with HS > 50), AVI0 (Prop. of all cell with HS > 50), CVI (CVI =AVI−AVI0)

Table 9.7 Area under each Habitat suitability category for sambar in Pench Tiger Reserve, Madhya Pradesh

Habitat suitability classes	Area (Km^2)
Highly Suitable	245
Moderately suitable	348
Low suitable	317
Unsuitable	178

9.3.3 HS model for Wild pig:

Presence data of wild pig (n= 417) resulted into three HS models (Model 9-11) for species interaction, human disturbance and resource-geographical factors (Fig. 9.9-8.11). The proportions of explained information in these three models were 80%, 97% and 81% respectively. Overall M in these models was 0.761, 0.616 and 1.33 respectively and S in these models was 0.707, 2.916 and 1.32 respectively. This indicated that resource and geographical features were found to be more suitable for wild pig than other features in PTR. Positive signs of M indicated that Wild pig preferred higher average of EnvPs than the global mean.

Table 9.8 Marginality and Specialisations of different variables in HS models of Wild Pig

Wild Pig Species Interaction model (Model 9)

Variables	Marginality	Specialisation1	Specialisation2	Specialisation3
Chital encounter rate	**0.743**	0.029	-0.13	0.66
Leopard encounter rate	-0.034	0.999	-0.006	-0.002
Sambar encounter rate	**0.634**	0.02	0.406	-0.722
Tiger encounter rate	0.171	-0.004	-0.903	-0.207
Wild dog encounter rate	0.122	-0.001	-0.057	0.021

Wild Pig human disturbance model (Model 10)

Variables	Marginality	Specialisation1	Specialisation2	Specialisation3
Lopping	-0.24	-0.626	-0.919	0.99
Cattle dung	-0.165	-0.076	-0.005	-0.006
Livestock seen	-0.241	0.059	-0.253	-0.064
People seen	-0.239	0.013	0.258	0.066
Distance from road	**0.334**	-0.511	-0.137	0.089
Trail	0.016	-0.028	0.009	-0.002
Distance from village	**0.645**	-0.579	0.081	-0.051
Wood cutting	**-0.522**	-0.04	0.005	-0.006

Wild Pig Geographical-resource model (Model 11)

Agriculture	-0.108	-0.129	0.501	-0.381
High canopy	0.246	-0.012	0.02	0.028
Medium canopy	**0.372**	-0.039	0.041	-0.167
Low canopy	0.35	-0.274	0.179	0.579
No canopy	-0.051	0.016	-0.158	0.053
Cliestanthus colinus	0.064	-0.005	0.003	0
Elevation	0.267	0.89	-0.652	0.236
Miscellaneous forest	0.297	-0.047	0.003	0.136
Open forest	0.026	-0.004	0.021	-0.046
Riverine forest	0.003	0.006	-0.009	0.091
Slope	0.292	0.028	-0.029	-0.203
Submergence	0.036	-0.02	0.064	0.014
Teak dominated forest	**0.422**	-0.124	0.02	-0.564
Teak-lagerstromia forest	**0.303**	-0.002	0.014	-0.025
Teak-mixed forest	0.274	0.015	-0.014	-0.11
Distance from water	0.261	-0.31	0.509	0.179

Wild pig preferred areas with chital (0.743) and sambar (0.634) presence. It also preferred areas distant from road (0.334), distant from village (0.645), less wood cutting areas (0.522), areas with medium canopy (0.372), teak dominated forest (0.422) and teak Lagerstroemia forest (0.303). Large numbers of specializations were located in chital encounter rate (0.66 on spec.3), leopard encounter rate (0.999 on spec.1), sambar encounter rate (0.406 on spec.2), tiger encounter rate (-0.903 on spec.2), lopping (spec.1: -0.626, spec.2: -0.919, spec.3: -0.99), distance from road (-0.511 on spec.1), distance from village (-0.579 on spec.1), agriculture (spec.2: -0.501, spec.3: -0.381), low canopy (0.579 on spec.3), teak dominated forest (-0.564 on spec. 3) and distance from water (spec.1: -0.31, spec.2: 0.509). Any change in these observed factors is likely to affect the HS of wild pig in PTR.

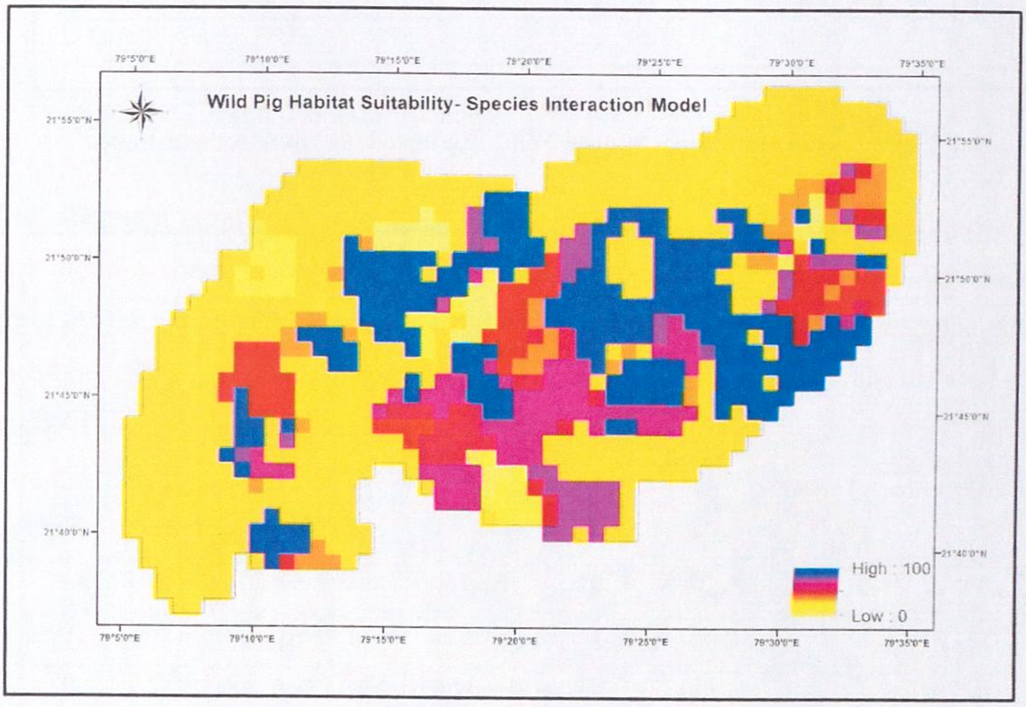


Fig. 9.9 Habitat suitability map of Wild Pig based on species interaction

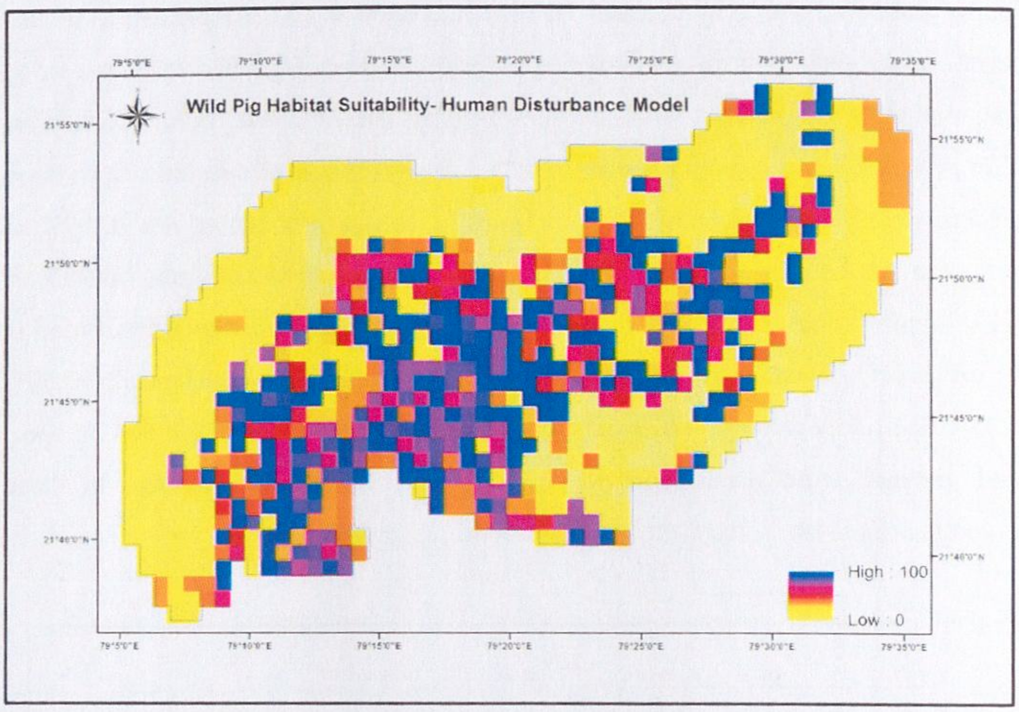


Fig. 9.10 Habitat suitability map of Wild Pig based on Human disturbance

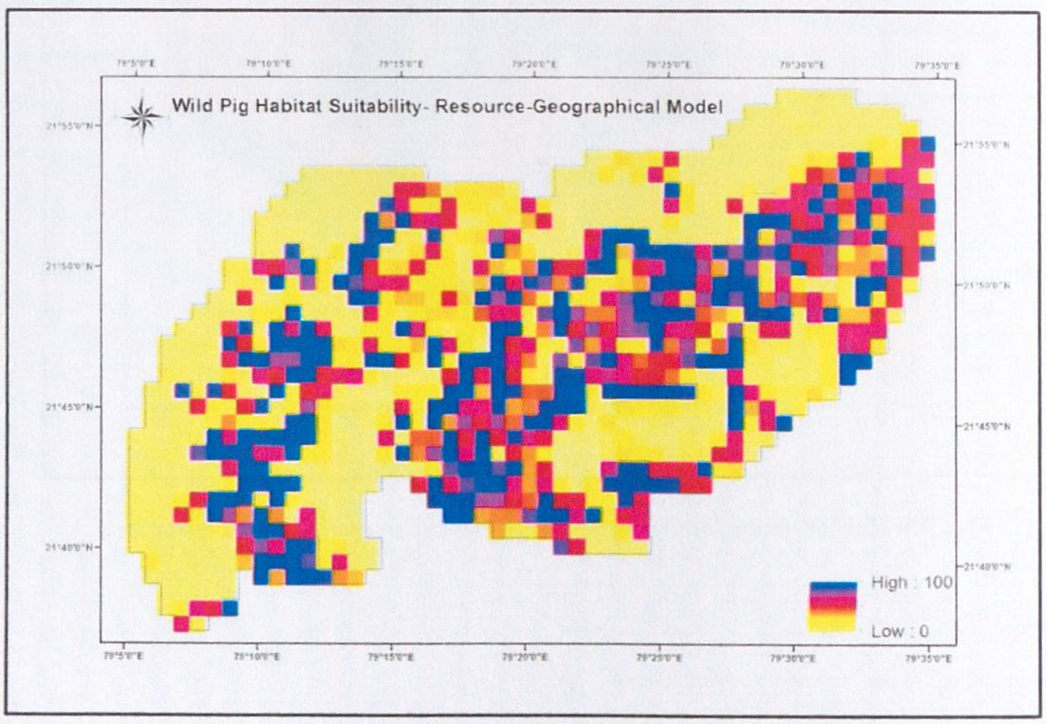


Fig. 9.11 Habitat suitability map of wild pig based on resource and geographical features

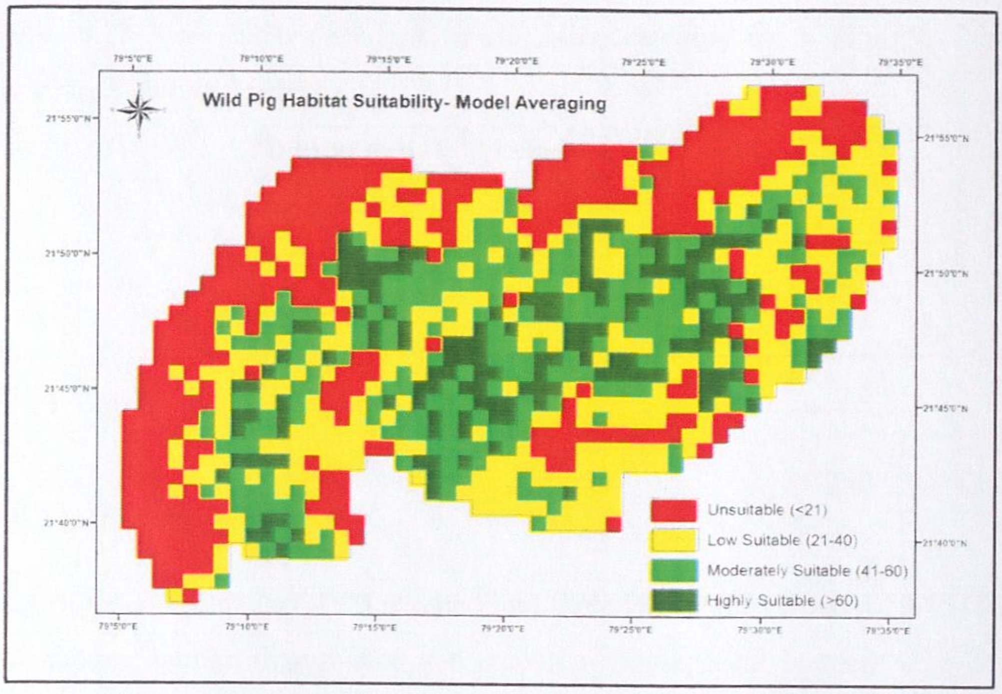


Fig. 9.12 Habitat suitability map of wild pig based on model averaging

The integrated HS model (model 12) was developed by model averaging (Fig. 9.12). This model attained highest AVI (0.645) and CVI (0.34) values when validated (Table 9.9). Areas under highly suitable, moderately suitable, low suitable and unsuitable categories were 160 Km^2, 251 Km^2, 328 Km^2 and 349 Km^2 respectively for wild pig in PTR (Table 9.10).

Table 9.9 Summary of validating model of all HS models for wild pig

No.	Habitat Suitability Model	AVI	AVI0	CVI
1	Wild Pig Species Interaction model	0.609	0.288	0.321
2	Wild Pig Human Disturbance Model	0.607	0.291	0.316
3	Wild Pig Resource-geographical model	0.611	0.287	0.324
4	Wild Pig model averaging	0.645	0.305	0.34

AVI (prop. of validation cells with HS > 50), AVI0 (Prop. of all cell with HS > 50), CVI (CVI =AVI−AVI0)

Table 9.10 Area under each Habitat suitability category for wild pig in Pench Tiger Reserve, Madhya Pradesh

Habitat suitability classes	Area (Km^2)
Highly Suitable	160
Moderately suitable	251
Low suitable	328
Unsuitable	349

9.3.4 *HS model for Tiger:*

Tiger presence data (n= 452) resulted into three HS models (model 13-15) for species interaction, human disturbance and resource-geographical features (Fig. 9.13-9.15). The proportions of explainable information in these models were 85%, 96% and 91% respectively. Overall *M* were 0.89, 0.636 and 1.402 respectively and *S* were 0.938, 2.87 and 2.017 respectively. This indicated that tiger preferred habitat that were different from average conditions of PTR and it required very specific range of habitat. This difference was found largest for geographical-resource features (*M* = 1.402). On the other hand, *S* indicated that conditions for tiger in PTR for human disturbance (*S*=2.87) was better than species interaction (*S*=0.938) and geographical-resource features (*S*=2.017).

Table 9.11 Marginality and Specialisations of different variables in HS models of Tiger

Tiger Species Interaction model (Model 13)

Variables	Marginality	Specialisation1	Specialisation2	Specialisation3
Chital encounter rate	**0.59**	-0.021	0.633	-0.599
Leopard encounter rate	-0.03	-1	-0.001	-0.003
Sambar encounter rate	**0.526**	-0.017	-0.772	-0.221
Wild dog encounter rate	0.093	0	0.032	0.132
Wild pig encounter rate	**0.604**	-0.014	0.048	0.758

Tiger human disturbance model (Model 14)

Lopping	**-0.226**	-0.46	-0.99	-0.701
Cattle dung	-0.092	-0.039	0.039	0.017
Livestock seen	**-0.336**	0.113	-0.097	0.489
People seen	**-0.333**	-0.02	-0.019	-0.518
Trail	-0.073	-0.044	0	-0.009
Wood cutting	**-0.493**	-0.046	0.006	0.005
Distance from raod	**0.33**	-0.507	-0.089	0.007
Distance from village	**0.6**	-0.716	0.021	-0.016

Tiger Geographical-resource model (Model 15)

Agriculture	-0.109	-0.061	-0.359	-0.473
High canopy	0.232	-0.027	-0.01	0.019
Medium canopy	**0.368**	-0.041	-0.015	-0.172
Low canopy	**0.358**	-0.516	-0.134	0.355
No canopy	-0.048	-0.009	0.088	0.059
Cliestanthus colinus	0.057	-0.006	-0.004	0
Elevation	0.265	0.843	0.755	0.1
Miscellaneous forest	**0.301**	-0.068	-0.014	0.088
Open forest	0.054	0.004	-0.01	-0.034
Riverine forest	0.033	-0.024	0.022	0.03
Slope	0.293	0.047	-0.009	-0.149
Submergence	0.03	-0.001	-0.04	0.025
Teak dominated forest	**0.416**	-0.087	-0.104	-0.545
Teak-lagerstromia forest	**0.319**	0.013	-0.008	-0.005
Teak-mixed forest	0.279	0.03	0.008	-0.094
Distance from water	0.249	0.027	-0.512	0.517

Tiger preferred habitats with chital (0.59), sambar (0.526) and wild pig (0.604) presence. It avoided areas with high human disturbances (Livestock seen: -0.336, people seen: -0.33, wood cutting: -0.493). It preferred distant areas from road (0.33) and distant areas from villages (0.6), medium (0.368) and low (0.358) canopy areas, miscellaneous forest (0.301), teak dominated forest (0.416), Teak Lagerstroemia forest (0.319). Large numbers of specializations were observed in chital encounter rate (0.633 on spec.2), sambar encounter rate (-0.722 on spec.2), wild pig encounter rate (0.758 on spec.3), lopping (spec.1: -0.46, spec.2: -0.99, spec.3 -0.701), livestock seen (0.489 on spec.3), people seen (-0.518 on spec.3), distance to road (-0.507 on spec.1), distance to village (-0.706 on spec.1), agriculture (spec.2: -0.359, spec.3: 0.473), low canopy (spec.1: -0.516, spec.3: 0.355), teak dominated forest (-0.545 on spec.3) and distance to water (spec.2: -0.512, spec.3: 0.517). Tiger HS may deviate from its optimal value with respect to these parameters.

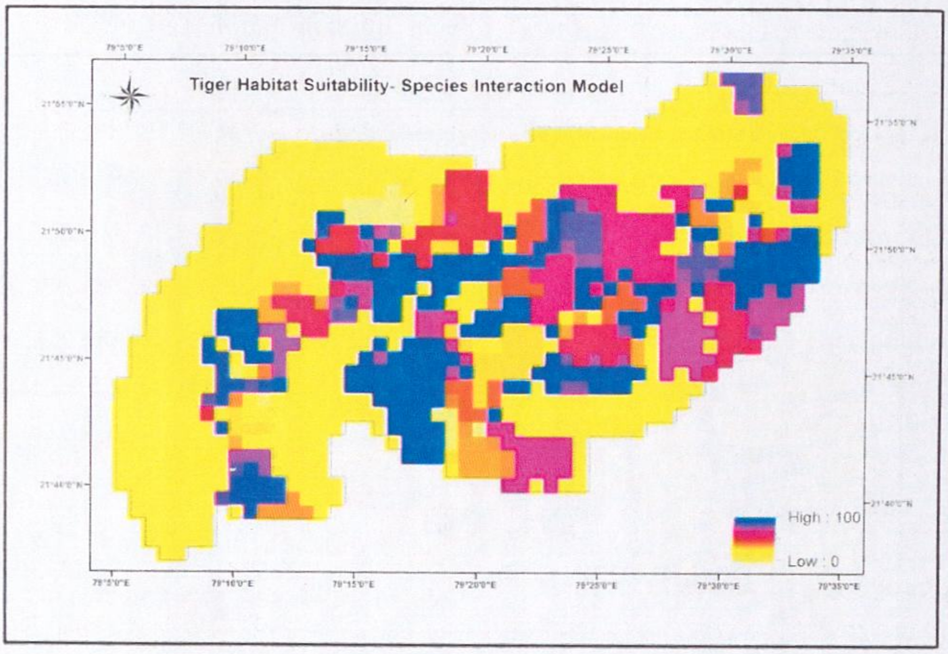


Fig. 9.13 Habitat suitability map of Tiger based on species interaction

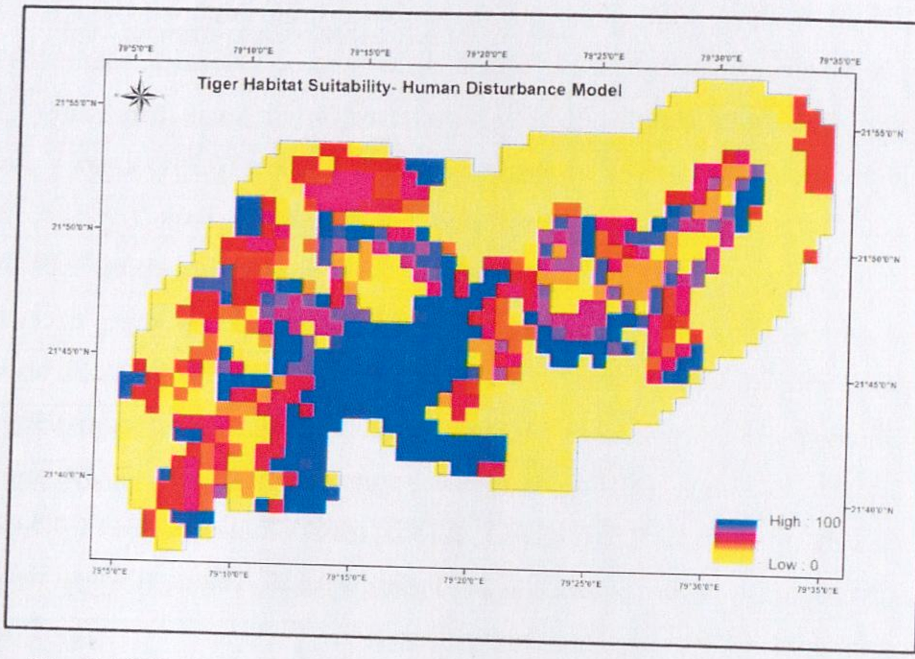


Fig. 9.14 Habitat suitability map of Tiger based on Human disturbance

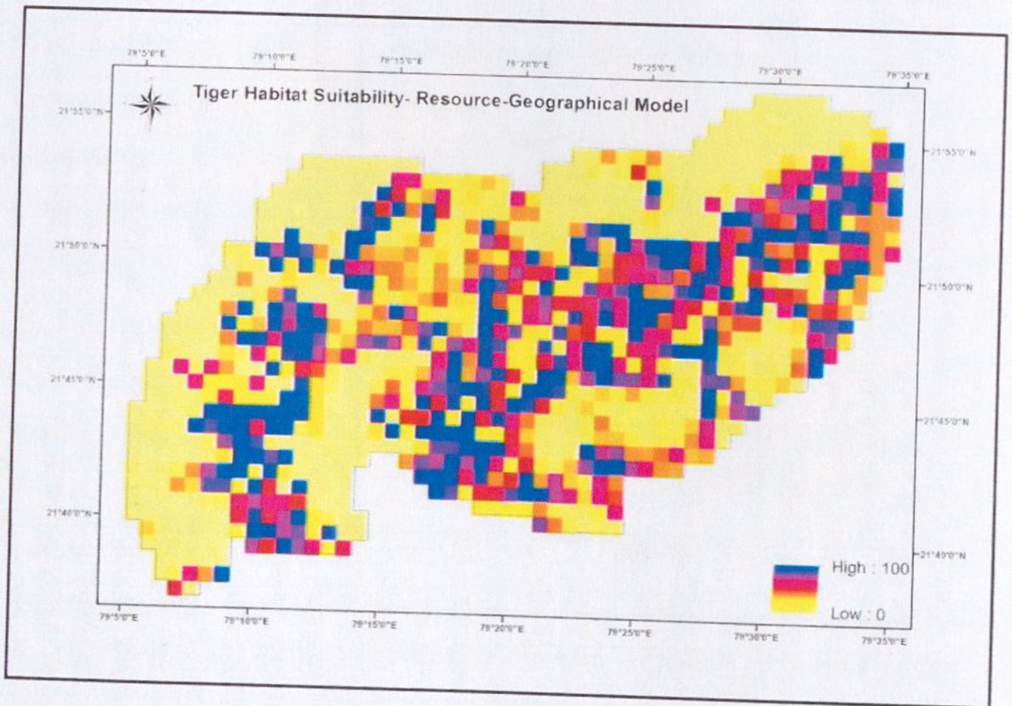


Fig. 9.15 Habitat suitability map of Tiger based on resource and geographical features

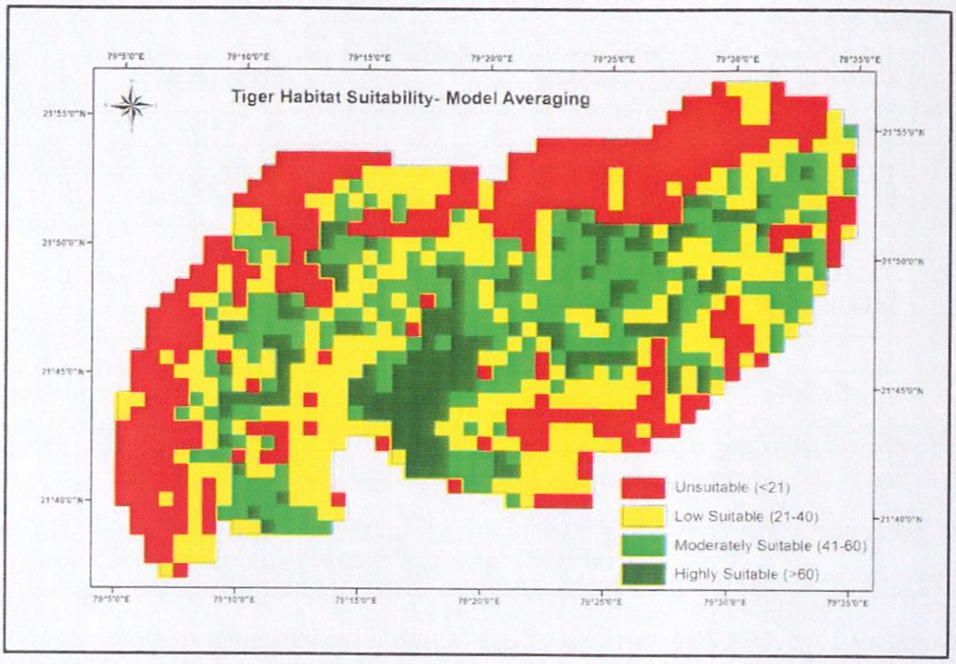


Fig. 9.16 Habitat suitability map of Tiger based on model averaging

Model 16 (Fig. 9.16) was created by model averaging from model 13 to 15. All the models were tested for validation. The AVI and CVI values of model 16 were 0.666 and 0.353 respectively (Table 9.13) which were higher than the AVI (model 13: 0.634, model 14: 0.624, model 15: 0.645) and CVI values (model 13: 0.328, model 14: 0.313, model 15: 0.347). The areas under highly suitable, moderately suitable, low suitable and unsuitable classes were 152 Km^2, 254 Km^2, 328 Km^2 and 354 Km^2 respectively for tiger in PTR (Table 9.14).

Table 9.12 Summary of validating model of all HS models for Tiger

No.	Habitat Suitability Model	AVI	AVI0	CVI
1	Tiger Species Interaction model	0.634	0.306	0.328
2	Tiger Human Disturbance Model	0.624	0.311	0.313
3	Tiger Resource-geographical model	0.645	0.298	0.347
4	Tiger model averaging	0.666	0.313	0.353

AVI (prop. of validation cells with HS > 50), AVI0 (Prop. of all cell with HS > 50), CVI (CVI =AVI−AVI0)

Table 9.13 Area under each Habitat suitability category for Tiger in Pench Tiger Reserve, Madhya Pradesh

Habitat suitability classes	Area (Km^2)
Highly Suitable	152
Moderately suitable	254
Low suitable	328
Unsuitable	354

9.3.5 HS model for Leopard:

Leopard presence data (n= 437) had resulted in the creation of three HS models (model 17 -19) for species interaction, human disturbance and resource-geographical features (Fig. 9.17-6.19). Proportions of explainable information of these models were 79%, 965 and 88% respectively. *M* for these models were 0.753, 0.647 and 1.359 and *S* were 0.791, 3.037 and 1.681 respectively. Leopard preferred higher average of EnvPs than the global mean. A condition for leopard in PTR for human disturbances was found to be better than species interaction and resource-geographical features.

Table 9.14 Marginality and Specialisations of variables in HS models of leopard

Leopard Species Interaction model (Model 17)

Variables	Marginality	Specialisation1	Specialisation2	Specialisation3
Chital encounter rate	**0.566**	-0.063	-0.631	-0.663
Sambar encounter rate	**0.521**	-0.497	0.727	-0.06
Wild dog encounter rate	0.1	0.095	-0.022	0.112
Wild pig encounter rate	**0.616**	0.281	-0.089	0.697
Tiger encounter rate	0.138	0.813	0.255	-0.244

Leopard human disturbance model (Model 18)

Lopping	-0.065	0.068	0.025	-0.392
Cattle dung	-0.292	-0.709	0.696	-0.143
Livestock seen	-0.292	-0.319	-0.718	-0.003
People seen	0.26	-0.585	0.007	0.779
Trail	**-0.603**	-0.045	-0.009	0.009
Wood cutting	-0.087	0.002	-0.011	0.035
Distance from road	**0.483**	-0.213	-0.013	-0.44
Distance from village	**0.391**	-0.033	0.009	-0.155

Leopard Geographical-resource model (Model 19)

Agriculture	-0.116	0.029	0.387	0.332
High canopy	0.223	0.025	0.015	-0.027
Medium canopy	**0.364**	0.03	0.009	0.133
Low canopy	**0.36**	0.454	0.155	-0.578
No canopy	-0.05	0.024	-0.106	-0.038
Cliestanthus colinus	0.059	0.005	0.005	-0.001
Elevation	0.262	-0.874	-0.745	-0.19
Miscellaneous forest	0.291	0.07	0.013	-0.112
Open forest	0.046	-0.005	0.007	0.038
Riverine forest	0.03	0.013	-0.037	-0.057
Slope	0.287	-0.071	0.009	0.222
Submergence	0.034	0.003	0.05	-0.027
Teak dominated forest	**0.429**	0.11	0.096	0.589
Teak-lagerstromia forest	**0.315**	-0.01	0.008	0.003
Teak-mixed forest	0.287	-0.023	-0.013	0.121
Distance from water	0.252	0.063	0.496	-0.265

Leopard preferred habitats with chital (0.566), sambar (0.521) and wild pig presence (0.616). It preferred areas with less human trails (-0.603), distant areas from road (0.483), distant areas from villages (0.391), medium (0.364) and low canopy areas (0.36), Teak dominated forest (0.429) and Teak Lagerstroemia (0.315) forests. Optimal HS of leopard is expected to deviate with respect to following parameters,

chital encounter rate (spec.2: -0.631, spec.3: -0.663), sambar encounter rate (0.497 on spec.1), wild pig encounter rate (0.697 on spec.3), lopping (-0.392 on spec.3), cattle dung (spec.1: -0.709, spec.2: 0.696), livestock seen (spec.1: -0.319, spec.2: -0.718), people seen spec.1: -0.585, spec.3: 0.779), agriculture (spec.2: 0.387, spec.3: 0.332), low canopy (spec.1: 0.454, spec.3: -0.578), Teak dominated forest (0.589 on spec.3) and distance to water (0.496 on spec.2).

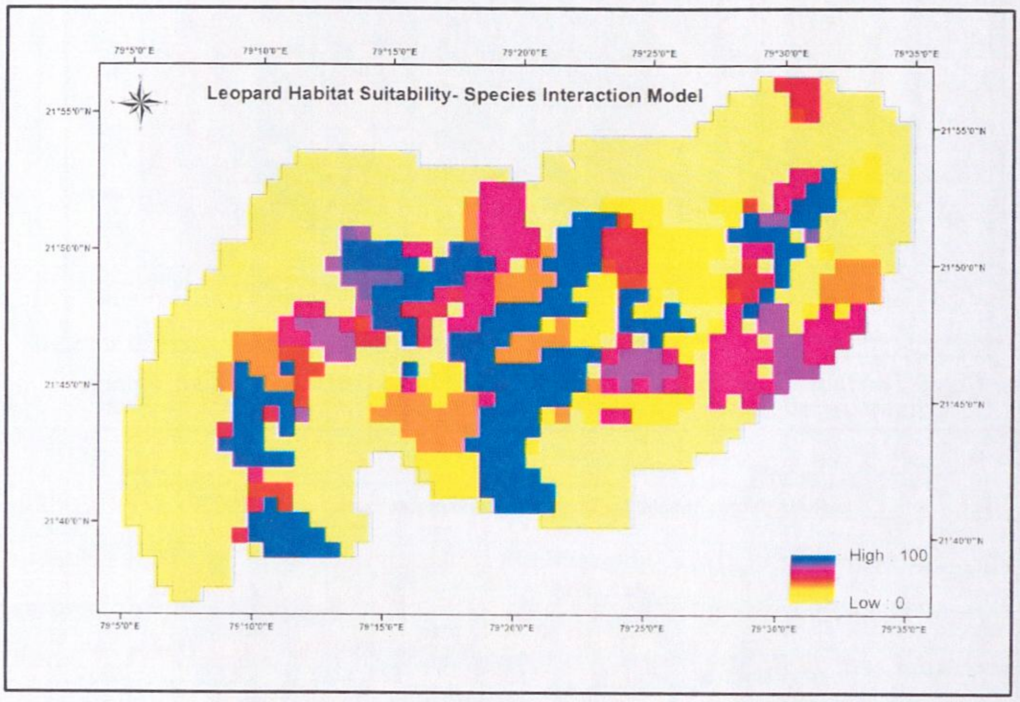


Fig. 9.17 Habitat suitability map of Leopard based on species interaction

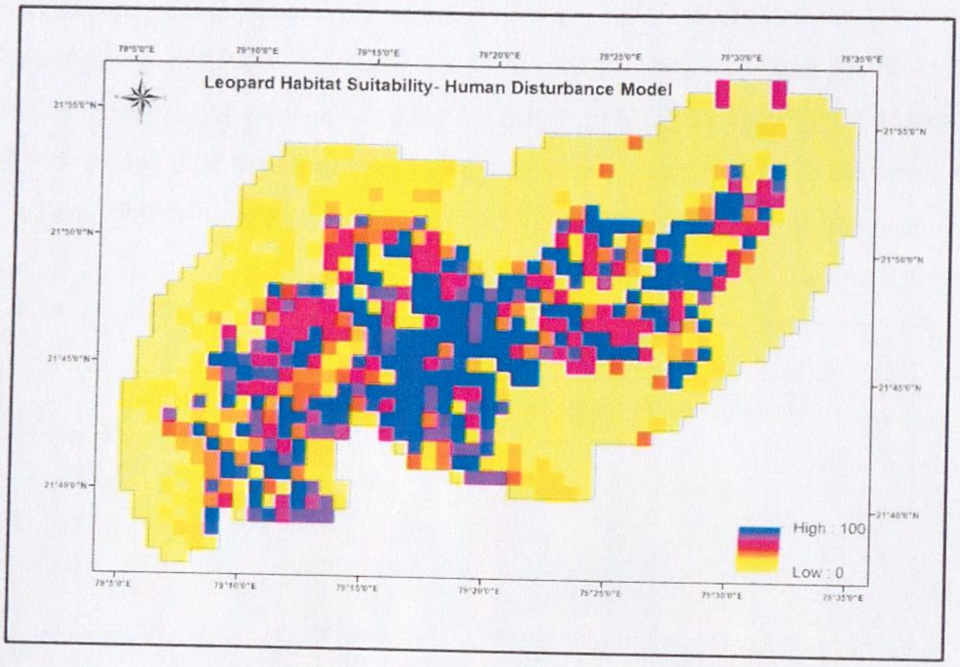


Fig. 9.18 Habitat suitability map of Leopard based on Human disturbance

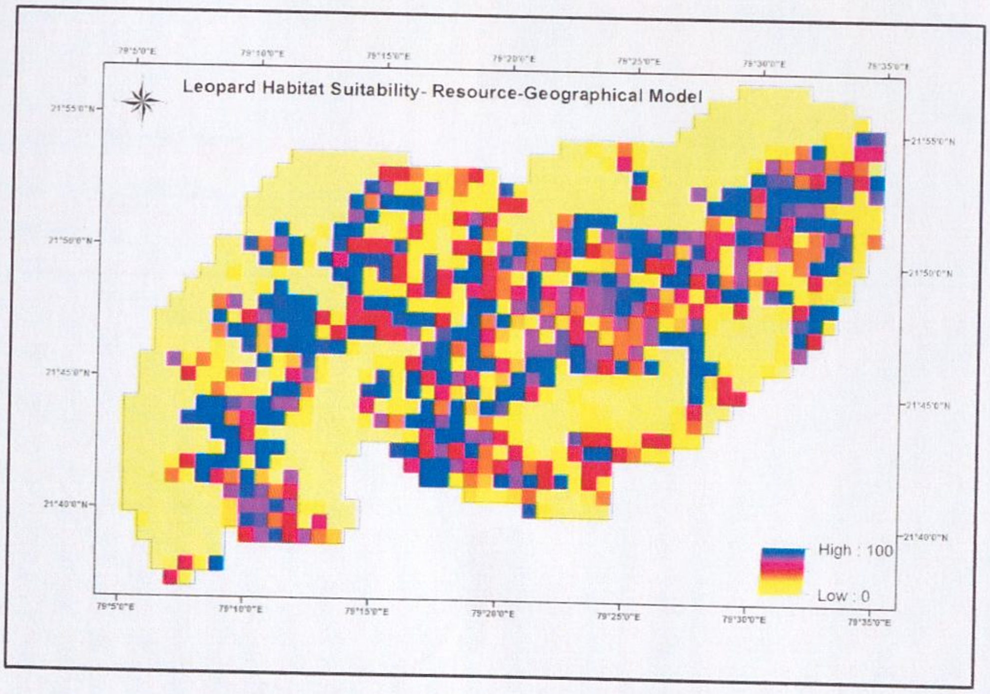


Fig. 9.19 Habitat suitability map of Leopard based on resource and geographical features

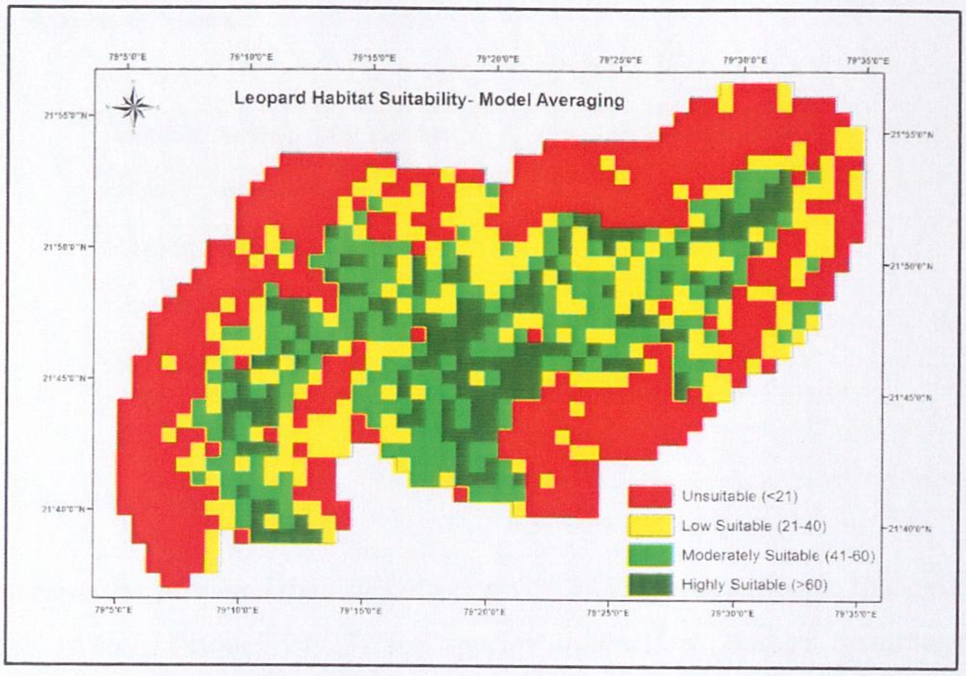


Fig. 9.20 Habitat suitability map of Leopard based on model averaging

Model 20 (Fig. 9.20) was generated by model averaging of model 17 to model 19. Validation of model 20 gave highest AVI (0.699) and CVI (0.392) (Table 9.16) values compared to other models (AVI: 0.653, 0.645 and 0.608 respectively, CVI: 0.35, 0.308, 0.327). The areas under highly suitable, moderately suitable, low suitable and unsuitable were 167 Km^2, 211 Km^2, 233 Km^2 and 477 Km^2 respectively for leopard in PTR (Table 9.17).

Table 9.15 Summary of validating model of all HS models for Leopard

No.	Habitat Suitability Model	AVI	AVI0	CVI
1	Leopard Species Interaction model	0.653	0.286	0.367
2	Leopard Human Disturbance Model	0.645	0.325	0.32
3	Leopard Resource-geographical model	0.608	0.23	0.378
4	Leopard model averaging	0.699	0.307	0.392

AVI (prop. of validation cells with HS > 50), AVI0 (Prop. of all cell with HS > 50), CVI (CVI =AVI−AVI0)

Table 9.16 Area under each Habitat suitability category for Leopard in Pench Tiger Reserve, Madhya Pradesh

Habitat suitability classes	Area (Km^2)
Highly Suitable	167
Moderately suitable	211
Low suitable	233
Unsuitable	477

9.3.6 HS model for dhole:

Incorporating the presence data of wild dog (n= 241) had resulted in the creation of three HS models (model 21-23) for species interaction, human disturbance and resource-geographical features (Fig. 9.21-8.23). In these models, the proportions of explainable information were 91%, 95% and 88% respectively. Overall *M* was 0.853, 0.629 and 1.38 and overall *S* were 1.61, 2.952 and 1.835 respectively. This indicated that though the difference between the mean and the global distribution was found to be highest in resource-geographical feature model but conditions for wild dog in PTR was best in terms of human disturbance compared to other two.

Table 9.17 Marginality and Specialisations of different variables in HS models of wild dog

Wild Dog Species Interaction model (Model 21)

Variables	Marginality	Specialisation1	Specialisation2	Specialisation3
Leopard encounter rate	-0.014	-1	-0.002	0.002
Chital encounter rate	**0.631**	-0.01	-0.721	0.132
Sambar encounter rate	**0.478**	-0.01	0.421	0.676
Wild pig encounter rate	**0.584**	-0.005	0.503	-0.55
Tiger encounter rate	0.18	0.003	-0.223	-0.472

Wild Dog human disturbance model (Model 22)

Lopping	-0.232	-0.652	-0.982	-0.948
Cattle dung	-0.14	-0.086	0.088	-0.028
Livestock seen	**-0.296**	0.062	-0.039	-0.133
People seen	**-0.291**	0.081	-0.085	0.198
Trail	-0.205	-0.028	0.005	0.007
Wood cutting	**-0.46**	-0.03	0.009	0.009
Distance from raod	**0.32**	-0.538	-0.13	-0.176
Distance from village	**0.631**	-0.515	0.048	0.115

Wild Dog Geographical-resource model (Model 23)

Agriculture	-0.102	0.077	0.319	-0.446
High canopy	0.24	0.017	0	0.067
Medium canopy	**0.368**	0.027	0.033	-0.092
Low canopy	**0.362**	0.422	0.013	0.262
No canopy	-0.025	0.008	-0.094	0.014
Cliestanthus colinus	0.005	-0.001	0.003	0.016
Elevation	0.271	-0.884	-0.736	-0.157
Miscellaneous forest	**0.303**	0.078	0.009	-0.062
Open forest	0.028	-0.007	0.018	0.035
Riverine forest	0.035	0.006	-0.021	0.062
Slope	0.261	-0.036	0.033	0.073
Submergence	0.053	0.009	0.044	0.02
Teak dominated forest	**0.419**	0.127	0.096	-0.503
Teak-lagerstromia forest	**0.301**	-0.009	0.015	-0.017
Teak-mixed forest	**0.301**	-0.028	0.011	-0.12
Distance from water	0.262	0.093	0.577	0.642

Wild dog preferred habitat with chital (0.631), sambar (0.478) and wild pig (0.584), areas with less livestock (-0.296), people (-.0.291), areas with less wood cutting (-0.46), distant areas from road (0.32) and village (0.631), areas with medium (0.368) and low canopy (0.362), miscellaneous forest (0.303), teak dominated forest (0.419), teak lagerstroemia forest (0.301) and teak mixed forest (0.301). Optimal HS of wild dog is expected to deviate with respect to following parameters, chital encounter rate (-0.721 on spec.1), sambar encounter rate (spec.2: 0.421, spec.3: 0.676), wild pig encounter rate (spec.2: 0.503, spec.3: -0.55), lopping (spec.1: -0.652, spec.2: -0.982, spec.3: -0.948), distance from road (-0.538 on spec.1), distance from village (-0.515 on spec.1), agriculture (spec.2: 0.319, spec.3: -0.446), low canopy (0.422 on spec.1) and distance from water (spec.2: 0.577, spec.3: 0.642).

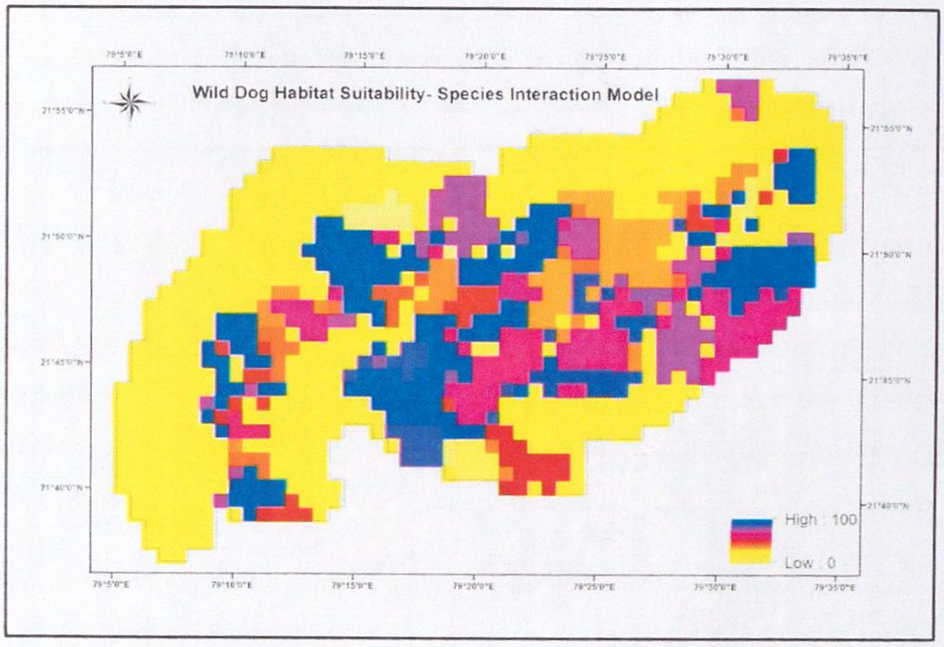


Fig. 9.21 Habitat suitability map of Wild Dog based on species interaction

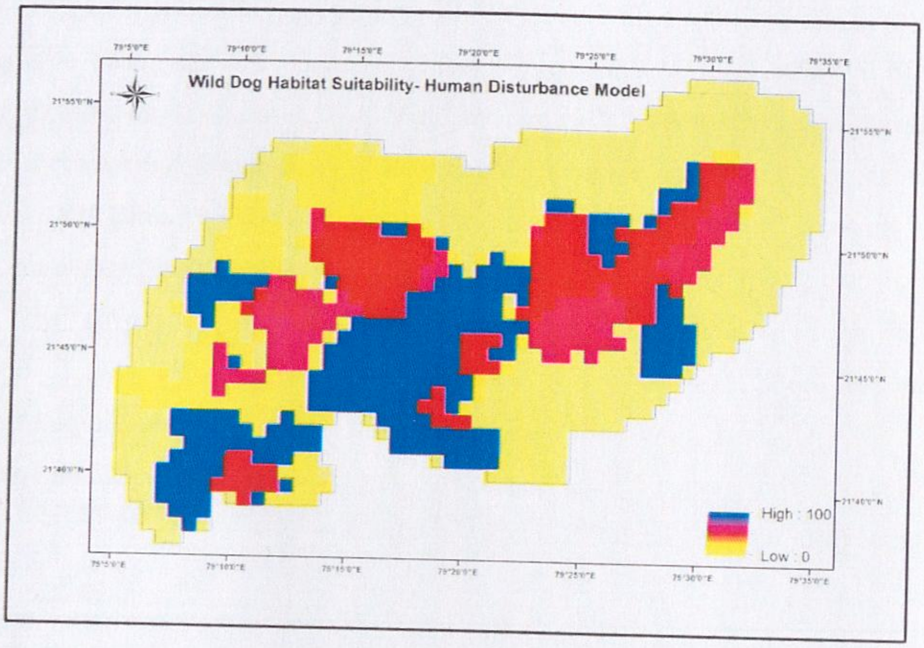


Fig. 9.22 Habitat suitability map of Wild Dog based on Human disturbance

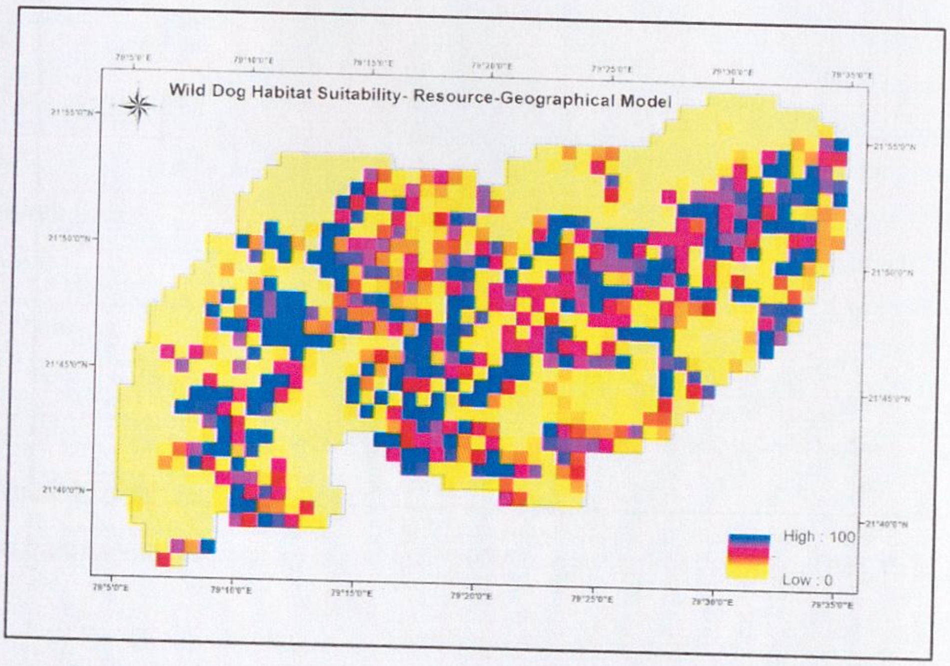


Fig. 9.23 Habitat suitability map of Wild Dog based on resource and geographical features

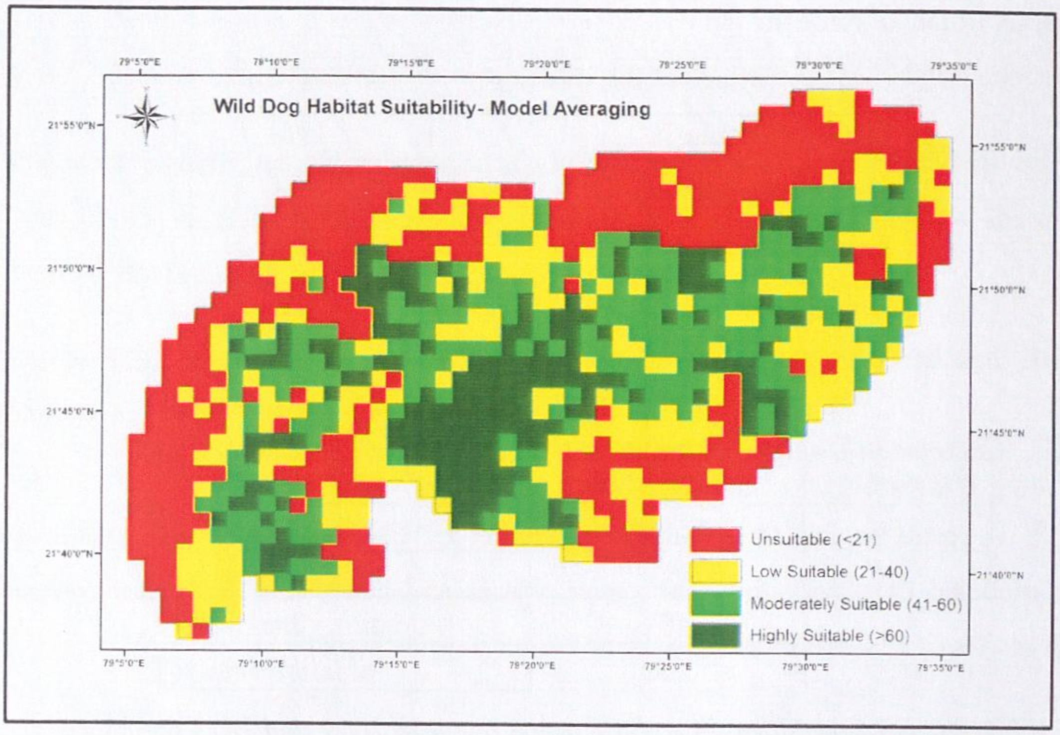


Fig. 9.24 Habitat suitability map of Wild Dog based on model averaging

Model 24 (Fig. 9.24) was generated by model averaging of model 21 to model 23. Validation of model 24 gave highest AVI (0.688) and CVI (0.376) (Table 9.19) values compared to other models (AVI: 0.664, 0.631 and 0.602 respectively, CVI: 0.361, 0.344, 0.305). The areas under highly suitable, moderately suitable, low suitable and unsuitable were 192 Km^2, 249 Km^2, 279 Km^2 and 371 Km^2 respectively for wild dog in PTR (Table 9.20).

Table 9.18 Summary of validating model of all HS models for wild dog

No.	Habitat Suitability Model	AVI	AVI0	CVI
1	Wild dog Species Interaction model	0.664	0.303	0.361
2	Wild dog Human Disturbance Model	0.631	0.287	0.344
3	Wild dog Resource-geographical model	0.602	0.297	0.305
4	Wild dog model averaging	0.688	0.312	0.376

AVI (prop. of validation cells with HS > 50), AVI0 (Prop. of all cell with HS > 50), CVI (CVI =AVI−AVI0)

Table 9.19 Area under each Habitat suitability category for wild dog in Pench Tiger Reserve, Madhya Pradesh

Habitat suitability classes	Area (Km^2)
Highly Suitable	196
Moderately suitable	249
Low suitable	272
Unsuitable	371

9.3.7 *Changes in Habitat suitability with present and predicted land cover*

A result on habitat suitability modeling by ENFA, presented in this section was modeled only with few land cover classes and hence they were not compared with results of ENFA models discussed earlier in this chapter.

9.3.7.1 Predicted suitability area comparison between 2009 and 2019 for chital

A significant decrease was visible for highly suitable areas for chital in 2019 compared to 2009 in the study area (Table 9.22). Decrease in high suitable areas and increase in moderate suitable area showed degradation of habitat suitability for chital. Similarly results registered decrease in low suitable area and increase in unsuitable areas for this species.

Table 9.20 Area Comparison of habitat suitability classes between 2009 and 2019 for chital in Pench Tiger Reserve, Madhya Pradesh

Class	2009 (Km^2)	2019 (Km^2)
Unsuitable	509	522
Low suitable	141	129
Moderately suitable	108	157
Highly suitable	330	280

9.3.7.2 Predicted suitability area comparison between 2009 and 2019 for sambar

For sambar there was an increase in the highly suitable area observed between 2009 and 2019 but moderately and low suitable areas decreased with an increase in unsuitable areas in PTR (Table 9.23).

Table 9.21 Area Comparison of habitat suitability classes of 2009 and 2019 for sambar in Pench Tiger Reserve, Madhya Pradesh

Class	2009 (Km^2)	2019 (Km^2)
Unsuitable	403	451
Low suitable	229	202
Moderately suitable	171	126
Highly suitable	285	309

9.3.7.3 Predicted suitability area comparison between 2009 and 2019 for wild pig

For wild pig, there were decreases in high suitable, moderately suitable and low suitable areas, observed between 2009 and 2019 in PTR. However the unsuitable area for wild pig in the study area increased (Table 9.24).

Table 9.22 Area Comparison of habitat suitability classes between 2009 and 2019 for wild pig in Pench Tiger Reserve, Madhya Pradesh

Class	2009 (Km^2)	2019 (Km^2)
Unsuitable	524	563
Low suitable	147	138
Moderately suitable	140	122
Highly suitable	277	265

9.3.7.4 Predicted suitability area comparison between 2009 and 2019 for tiger

For tigers also highly, moderate and low suitable areas decreased in 2019 with an increase in unsuitable area (Table 9.25).

Table 9.23 Area Comparison of habitat suitability classes between 2009 and 2019 for Tiger in Pench Tiger Reserve, Madhya Pradesh

Class	2009 (Km^2)	2019 (Km^2)
Unsuitable	518	556
Low suitable	156	147
Moderately suitable	133	121
Highly suitable	281	264

9.3.7.5 Predicted suitability area comparison between 2009 and 2019 for leopard

For Leopard, the predicted model actually showed increase in the suitable areas both highly and low, but decrease in moderately suitable and unsuitable areas for leopard in PTR (Table 9.26).

Table 9.24 Area Comparison of habitat suitability classes of 2009 and 2019 for leopard in Pench Tiger Reserve, Madhya Pradesh

Class	2009 (Km^2)	2019 (Km^2)
Unsuitable	596	577
Low suitable	89	121
Moderately suitable	142	121
Highly suitable	261	269

9.3.7.6 Predicted suitability area comparison between 2009 and 2019 for wild dog

For wild dog, the predicted model showed decrease in all the suitability classes and increase in unsuitable area in PTR between 2009 and 2019 (Table 9.27).

Table 9.25 Area Comparison of habitat suitability classes of 2009 and 2019 for wild dog in Pench Tiger Reserve, Madhya Pradesh

Class	2009 (Km^2)	2019 (Km^2)
Unsuitable	524	563
Low suitable	147	138
Moderately suitable	140	122
Highly suitable	277	265

9.4 Discussion

Each one of the three HS maps can provide ecological information on major mammalian species according to its favorite area in the sense of favorable resources, sufficiency of undisturbed areas and less competition between species. The species distribution is accordingly influenced by each feature. This is in agreement with the relationship between species distribution and niche as proposed by Pulliam (2000). The distributions of different species and of human activities/visitation and of human-induced events in each habitat type can delineate the places of competition, predation, immigration and re-colonization (Guisan and Thuiller 2005) by other species as well as the place(s) of pressure by humans. Since species can be found in unsuitable sites, one can say that the realized niche is sometimes larger than the fundamental niche (Pulliam, 1988).

9.4.1 Species preference

Past studies (Sankar et al.2001, Biswas and Sankar 2002, Karanth et al.2004, Majumder 2012) had reported high wild ungulate densities in PTR which comprised of chital, sambar and wild pig. Biswas and Sankar (2002) reported chital sambar and wild pig are main prey species of tiger in this area. In the present study, this fact is supported by high positive marginality of chital, sambar and wild pig with tiger. Similarly these wild ungulates had high positive marginality with leopard and wild dog. Karanth et al.(2004) found that in PTR, tiger density falls outside the 95% prediction intervals of prey density which can be interpreted that PTR could support more numbers of tigers in comparison to its prey density. Densities of tiger, leopard and wild dog in PTR as reported by Majumder (2011) were 3.6 (SE 1.5), 4.9 (SE 1.2) and 3.3 (SE 1.2) respectively per 100 Km^2. In spite of similar densities, carnivores like tiger, leopard and wild dog may co-exist since the ecological factors, such as adequate availability of appropriate-sized prey, dense cover and high tree densities may be the primary factors in structuring the predator communities of tropical forests (Karanth 2000). In the present study, the observed low marginalities among the carnivores showed less competition/affinity.

The presence of all the study species (prey/predator) were negatively correlated with major human disturbance indicators such as lopping, cattle dung, wood cutting. This suggested that all these species avoided disturbed areas and preferred areas far from roads and villages. The extent of human presence could be attributed by the presence of 99 villages within 5 Km buffer of PTR. These villages exert immense pressure on forests as people here are mostly dependent on forest for fuel wood and grazing of livestock. Due to adequate protection and support from field staff, the overall specialisation of the human disturbance models of the carnivore species turned out to be the highest, which can be attributed as the conditions of human disturbances in PTR for carnivores are better than species interaction and resource-geographical conditions. Despite a long history of concern for wild tigers, both their range and total number have collapsed: fewer than 3,500 animals now live in the wild, occupying less than 7% of their historical range (Sanderson et al.2006) and PTR could turn out to be a major source population of tigers in the Central Indian landscape. It is presumed that if tiger as a flagship species is conserved, it will in turn have positive impact on other major mammalian species conservation as well.

In this study, forest canopy played an important role for the presence of tiger, leopard and wild dog. Similar findings were reported by Karanth (2000) in Nagerhole Tiger Reserve. As predator distributions are guided by prey distributions (Karanth 2000), similarly presence of chital, sambar and wild pig distribution are influenced by forest canopies as observed in the present study. Miscellaneous and teak associated forests dominate in PTR. These forest types had shown greater association with all the study species. Water being one of the essential life support factor, contributed equally in all the HS models of the study species.

Though future predictions of HS are modeled only with few habitat classes, still they are powerful enough to enlighten future scenarios. In the given circumstance these predictions are over estimated as same species presence data sets of present day was used for the future scenarios. These results left enough space for validation or contradiction through many similar studies in future.

Chapter 10
CONSERVATION IMPLICATIONS

The findings of the present study will be useful in strengthening the conservation of tiger carnivores, their prey and habitat in the Pench Tiger Reserve in various ways.

- The present study generated baseline data as a model for long-term monitoring of tiger and its prey in the study area which should be effectively utilized for conservation of entire Pench landscape.

- Our study gave an insight on the breeding tiger habitats in this human dominated landscape. The study revealed that a minimum of 25 to 30 km² undisturbed area was required for a breeding female in the study area. The intensive study area can potentially hold a maximum of 10 breeding tigress based on 44 km² as home range size of a tigress. We have recorded nine breeding tigresses operating in this area (Camera trapping and ITSM). Twenty breeding females are needed for long term survival of tiger population at a site (2010). Thus, it is important to have corridor connectivity with neighboring population of Kanha Tiger Reserve, Satpura Tiger Reserve and Pench Tiger Reserve (Maharastra) to form a meta-population structure for long term viability of tiger population.

- The present study provided information on the demographic structure of potential prey species of tiger and its usefulness in understanding the dynamics of population growth and life history parameters, on the basis of which regular monitoring of prey – predators must be carried out on a long – term basis. Chital and common langur densities found to be highest and contributing fourth highest prey biomass-kg/km² in the Indian sub-continent.

- Our study revealed that the population of chital increased inside the Pench protected area in a gradual way over the years and hence it is expected that the existing and newly recruited chital population may disperse into adjacent forest patches of Pench protected area. The chital population was found very high in the submergence area of Pench river because of its favorable habitat i.e. fairly open canopy and presence of palatable *Cynodon dactylon* in both side of the Pench river. The highly abundant chital population may disperse from core to buffer areas if the habitat is managed for chital in buffer areas. As chital is the principal prey of large carnivores in Pench, the proposed translocation of chital by the Forest Department from Pench Protected Area to other protected area in Madhya Pradesh may be put on hold, and the buffer areas should be converted into suitable habitat for chital, by creation of more open patches and maintenance of grassland with palatable species such as *Cynodon dactylon*, *Chloris dolichostachya*, *Heteropogon contortus* and *Themeda quadrivalvis*. Also it is suggested that weed alike *Cassia tora*, *Parthenium* sp., and *Datura metel* eradication program in the sub-mergence areas of Pench river should be done on priority basis to make more grass land areas available for chital grazing. A long term study is recommended for the population and habitat assessment of tiger and its principal prey species in proposed buffer.

- Since the shrub cover is important for stalking predators, the *Lantana camara* eradication programme should be done only in patches, if desired on an experimental basis. The *Lantana* cover has been used by tiger for hiding kills and rearing cubs.

- One of the major problems in the study area is that, tigers are surviving in a small population size and operating at carrying capacity. According to Harmon and Braude (2010) "Population size is extremely important in evaluating conservation priorities for a species and small populations are at risk of going extinct because of both environmental and demographic stochasticity and genetic drifts. Therefore, it is important to have corridor connectivity with neighboring population of Kanha Tiger Reserve, Satpura Tiger Reserve and Pench Tiger Reserve (Maharastra) to form a meta-population structure for long term viability and survival of tiger population. These important corridors may ensure constant emigration and immigration to reduce the chances of genetic drift or inbreeding in the Pench tiger population.

- Though the intensive study area is relatively undisturbed and supports a high prey biomass for the sustenance and growth of tiger, there is continuous biotic pressure exert from the 99 villages located around the notified buffer zone of PTR, Madhya Pradesh which is found to be the major threat for dispersing tiger. Overall protection of tiger population in Pench and its adjacent forest patches and habitat management of tiger and its prey in these two corridors is essential for long term survival of tiger in the Central Indian landscape.
- In the present study, the park suffered from less deforestation after it was declared a National Park. The actual scenario, even in the absence of the intervention, could have been something different than that predicted in this study. We attempted to capture the trend of changes in land use/ land cover and predicted future conditions in the landcape.
- One hundred and fifty two km² is found highly suitable for tiger whereas, 254 km², 328 km² and 354 km² were found moderately suitable, low suitable and unsuitable respectively for tiger in Pench Tiger Reserve and its 5 km buffer. Most of the low suitable and unsuitable tiger habitats were found outside the Pench protected area (Pench National Park and Pench Wildlife Sanctaury) i.e. the habitat of buffer. As tiger is large ranging animal and they require large space to grow and dispersal, it is important to have suitable habitat for tiger in the buffer areas as well. So converting habitat from unsuitable to highly suitable areas for tiger is essential for their long term sustainance and growth in this landscape.

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Appendix 1

Line transect locations (n=44) in Pench Tiger Reserve, Madhya Pradesh

Transect	Transect Length (Km)	Starting Lat	Starting Long	Ending Lat	Ending Long
Kurai	2.8	N21° 48' 29.0"	E079° 28' 52.6"	N21° 49' 43.9"	E 79° 29' 18.2"
Raiya Rao	2.8	N21° 49' 46.6"	E079° 26' 56.2"	N21° 48' 16.4"	E 79° 27' 19.1"
Potia	2.8	N21° 47' 47.0"	E079° 26' 39.4"	N21° 47' 17.8"	E 79° 25' 09.3"
East Khamrit	2.8	N21° 46' 28.4"	E079° 22' 54.6"	N21° 47' 46.8"	E 79° 23' 36.9"
Vijaypani	2.8	N21° 45 54.7"	E079° 23' 42.2"	N21° 46' 27.3"	E 79° 25' 13.0"
West Khamrit	2.8	N21° 47' 09.7"	E079° 22' 49.3"	N21° 48' 31.7"	E 79° 23' 20.5"
South Murer	2.8	N21°49' 30.2"	E079° 23' 49.2"	N21° 48' 56.3"	E 079° 25' 16.9"
West Murer	2.8	N21°50' 19.2"	E079° 24' 39.3"	N21° 50' 04.7"	E 079° 23' 02.1"
East Murer	2.8	N21° 50' 28.6"	E079° 24' 45.7"	N21° 49' 33.8"	E 079° 26' 00.4"
Rukhad	2.8	N21° 52' 13.8"	E079° 31' 10.6"	N21° 50' 54.4"	E 079° 30' 24.2"
Alisor	2.8	N21°52' 01.8"	E079° 29' 19.0"	N21° 50' 36.1"	E 079 28' 59.3"
Patrai	2.8	N21° 50' 40.1"	E079° 28' 06.3"	N21° 49' 48.5"	E 79° 26' 46.4"
Gandatola	2.8	N21°52' 41.4"	E079° 29' 41.8"	N21° 53' 06.3"	E 079° 31' 09.7"
Bagdev	3.2	N21°44' 50.6"	E079°21' 17.7"	N 21°47' 47.4"	E079°20' 22.3"
Bodanala	3.2	N21°46' 57.7"	E079°20' 46.6"	N 21°47' 14.0"	E079°18' 57.3"
Khamrit	3.2	N21°45' 01.5"	E079°21' 24.9"	N 21°46' 42.5"	E079°21' 17.5"
Satosa	2.8	N21°44' 40.5"	E079° 21' 9.2"	N 21° 46' 04.4"	E079° 20' 42.2"
Turia	3.2	N21°44' 44.7"	E079°20' 10.2"	N 21°43' 10.3"	E079°19' 41.1"
Awarghani	2.8	N21°42' 25.5"	E079°20'06.9"	N 21°43' 8.4"	E079°18' 22.5"
Telia	3.6	N21°41' 47.3"	E079°18' 53.6"	N 21°41' 21.9"	E079°20' 55.1"
Chiklakhari	3.2	N21°42' 47.8"	E079°16' 29.9"	N 21°42' 18.9"	E079°17' 38.6"
Piorthari	3.2	N21°43' 34.4"	E079°16' 25.5"	N 21°44' 31.8"	E079°1' 04.2"
Chhindimatta	2.8	N21°44' 04.5"	E079°14' 52.6"	N 21°44' 07.9"	E079°16' 31.6"
Sapat	2.8	N21° 44' 47.8"	E079°14' 57.7"	N 21°45' 38.7"	E079°16' 21.9"
Alikatta	3.2	N21°45' 47.3"	E079°17' 43.5"	N 21°44' 39.6"	E079° 19' 07.1"

Transect	Transect Length (Km)	Starting Lat	Starting Long	Ending Lat	Ending Long
Bison Camp	2.8	N21° 45' 56.5"	E079° 19' 18.6"	N21° 46' 04.8"	E079° 19' 22.5"
Kumbhadev	4	N21°49' 48.2"	E079° 18' 24.4"	N21° 47' 53.7"	E 079° 18' 20.7"
Kumbhadev	4	N21°49' 48.2"	E079° 18' 24.4"	N21° 47' 53.7"	E 079° 18' 20.7"
Tikadi	3.2	N21°50' 02.5"	E079° 18' 24.3"	N21° 49' 58"	E 079° 16' 34.2"
Jamtara	4	N21°50' 18.6"	E079°15' 13.3"	N21°49' 01.0"	E079°16' 49.9"
Naharjhir	4	N21°50' 10.4"	E079°13' 12.9"	N21°50' 09.0"	E079°13' 22.0"
Chitalpahari	3.2	N 21 49' 01.6"	E079 13' 42.9"	N21 48' 37.2"	E079 15' 13.1"
Chendia	3.2	N 21 48' 04.7"	E079 15' 29.1"	N21 46' 49.4"	E079 16' 44.9"
Gumtara	3.2	N 21°47' 57.7"	E 079°14' 02.9"	N 21°47' 24.9"	E 079°15' 56.4"
Chindewani	3.2	N 21 46' 52.7"	E079 12' 58.2"	N21 47' 31.2"	E079 41.5' 42.6"
Pathara	3.6	N 21 47' 42.8"	E079 11' 19.9"	N21 47' 28.8"	E079 13.5' 12.9"
Datfaria	2.8	N21°46' 52.7"	E079°45' 32.6"	N21°45' 32.6"	E079°12' 34.5"
Kokiwara	2.8	N21°44' 48.4"	E079°10' 53.2"	N21°44' 13.2"	E079°12' 26.0"
Pulpuldoh	2	N 21° 43' 26.5"	E 079° 10' 048"	N 21° 44' 26.5"	E 079° 09' 37.7"
Doodhgaon-Umrighat	2.8	N21°42' 55.6"	E079°10' 16.3"	N21°41' 48.4"	E079°11' 24.1"
Mohgaon	4	N 21 41' 21.7"	E079 1.59' 15.0"	N21 41' 31.2"	E079 11.5' 8.5"
Palaspani	2	N21°43' 49.5"	E079° 12' 04.4"	N21°43' 54.4"	E079° 11' 04.8"
Totladoh	3.2	N 21 39' 24.2"	E079 13' 25.7"	N21 40' 55.8"	E079 12' 24.5"
Thuapani	3.6	N 21 40' 04.3"	E079 09' 44.0"	N21 40' 28.4"	E079 11' 51.8"

Appendix 2

Camera trap locations of Pench Tiger Reserve, Madhya Pradesh (December 2012- March 2013)

Sl No	CT ID	Place	Deg	Min	Sec N	Deg	Min	Sec E
1	K1	Jhandimatta	21	47	31.3	79	19	50.1
2	K2	Bansnala	21	48	2.1	79	19	50.4
3	K3	12 Mor	21	47	36.5	79	20	24.7
4	K4	Pania Billo	21	47	47.7	79	21	49.5
5	K5	Banderchua	21	48	27.8	79	22	12.4
6	K6	Raiakassa Gufa	21	48	32.3	79	17	42.4
7	K7	Sitaghat dub	21	47	29.4	79	17	8.3
8	K8	Patdeo	21	46	27	79	19	16.8
9	K9	Arjal pahari	21	45	56.4	79	19	38.9
10	K10	Joramunara	21	45	57.3	79	19	4.8
11	K11	1 no Lantana	21	45	56.5	79	17	1.5
12	K12	Dourikund nala	21	45	24	79	16	22.1
13	K13	Sapat purana camp	21	45	9.3	79	14	32.5
14	K14	Bijamatta line	21	44	52.9	79	15	41.9
15	K15	Gurluchattan chindimatta	21	43	49.9	79	16	3.6
16	K16	Gandsekia	21	44	1.6	79	15	19.8
17	K 17	Powerjhiria Talab	21	45	1.3	79	19	15.8
18	K18	Pipalnala	21	45	17.6	79	18	26.8
19	K 19	Kotwarjhori	21	44	56.8	79	18	0
20	K 20	Safed ghitikiri	21	43	37.4	79	17	51.2
21	K 21	Piorthodi pakdandi	21	43	40.4	79	16	24.8
22	K 22	Chiklakhari dub road	21	42	53.3	79	16	14.3
23	K 23	Chiklakhari dhwatirha	21	42	33.2	79	17	10
24	K 24	Garrha fata nala	21	42	25.2	79	18	35.1
25	K 25	Moyakatta	21	41	34.9	79	19	13.8
26	K 26	36 no Lantana	21	43	16.2	79	20	3.5
27	K 27	Data choupan talab	21	43	17.2	79	18	52.5
28	K 28	Seonnala	21	44	14.4	79	20	1
29	K 29	Baghin nala Tigadda	21	45	10	79	20	14.5
30	K 30	Khara nalla	21	44	56.1	79	21	28.1
31	K 31	Khamreet chougadda	21	45	46.6	79	21	32.4
32	K 32	60 meter reepta	21	47	54.9	79	20	24.5
33	K 34	Gurshalghat	21	48	31.4	79	19	14

Sl No	CT ID	Place	Deg	Min	Sec N	Deg	Min	Sec E
34	K 35	Jamunnala	21	49	52.9	79	18	27.4
35	K 36	Chendia ghat	21	50	8.5	79	17	28.7
36	K 37	Piorthodi kusum nala	21	43	53.6	79	16	24.5
37	G 1	Pipalnala chattan	21	49	0.7	79	16	6.9
38	G 2	Mahadebghat Sardamai	21	46	57	79	16	42
39	G 3	Mahulfata Imlimarg	21	49	22.3	79	15	27.3
40	G 4	Alikatta road Bagdeo	21	47	27.4	79	15	43.7
41	G 5	Dhawa Tirha	21	48	36.5	79	14	52.5
42	G 6	Golpahari Tirha	21	47	42.3	79	14	9.2
43	G 7	Barjhori Talab	21	49	51.9	79	15	45.9
44	G 8	Chital pahari camp	21	48	12.3	79	15	19.4
45	G 9	Chindwani Jhopri	21	47	22.3	79	13	29.7
46	G 10	Menjhori nala	21	45	57.7	79	11	35.6
47	G 11	Jetimarg base camp	21	45	9.7	79	11	31.7
48	G 12	Palaspani camp	21	44	5.3	79	11	17.9
49	G 13	Bagdeo ke pas	21	46	34.1	79	12	35.3
50	G 14	Sandalkassa camp	21	47	17.6	79	11	15.4
51	G 15	Koilasor camp	21	42	47.3	79	11	31.9
52	G 16	Kormatta camp	21	43	36.8	79	12	18.8
53	G 17	Bagharia nala	21	44	15.2	79	9	57.4
54	G 18	Pulpuldoh faldan	21	43	52.6	79	9	7.5
55	G 19	Jhiltola Ammmai	21	42	20	79	10	30.9
56	G 20	Kherwan chattan	21	41	14.3	79	10	16.5
57	G 21	Nalli Tekri	21	41	32.9	79	9	12.5
58	G 22	Sajdobri	21	41	11.3	79	10	56
59	G 23	Pirbaba dub road	21	40	24.2	79	12	28.2
60	G 24	Munjaljhori	21	40	20.2	79	10	42
61	G 25	Koliakamat nala	21	39	23.1	79	11	31.9
62	G 26	Bamnijhiria	21	39	53.7	79	12	46.8
63	G 27	Amadoh	21	39	48.5	79	12	3.6
64	G 28	Tendu mor	21	39	29.6	79	13	4
65	S 1	Alijhor	21	47	15.7	79	23	7.2
66	S 2	Gangerkund nala	21	47	43.6	79	23	50.3
67	S 3	Gaighat nala	21	48	7.9	79	24	29.4
68	S 4	Chindbarri camp	21	47	7.8	79	24	9.4
69	S 5	Purranbarra Tigadda	21	47	1.7	79	25	8.1

Sl No	CT ID	Place	Deg	Min	Sec N	Deg	Min	Sec E
70	S 6	Potia camp	21	47	8.8	79	25	46.7
71	S 7	Pandrier Talab	21	48	42.8	79	23	56.4
72	S 8	Murer Tisra Km	21	49	49.4	79	24	11.3
73	S 9	Rothia Nala	21	50	1.9	79	23	20.5
74	S 10	Toer talab	21	48	57.2	79	22	47.1
75	S 11	Dhakni tongi talab	21	49	54.3	79	25	51.1
76	S 12	Tuta pulia	21	49	49.7	79	26	33.4
77	S 13	Patrai Tigadda	21	50	10.8	79	27	1.8
78	S 14	Lavanguri Amlamor	21	50	35.9	79	27	54.6
79	S 15	Rinjhabarra	21	51	5.5	79	28	38.6
80	S 16	Alisor Talab watch tower	21	51	13.9	79	29	6.5
81	S 17	Bhiriban Tigadda	21	52	8	79	29	46.9
82	S 18	Gandhatola road	21	52	50.4	79	30	10.8
83	S 19	Renubai gate	21	51	50.9	79	31	7.8
84	S 20	Dudhia watchtower	21	50	20.8	79	30	12.3
85	S 21	Lamandoh Tigadda	21	49	28.1	79	28	5.5
86	S 22	Raiarao Pakdandi	21	49	34.5	79	27	33.8
87	S 23	Baraghat Talab	21	48	48.2	79	26	42.1

Some observations on vultures in Pench Tiger Reserve, Madhya Pradesh

Aniruddha Majumder[1], Santanu Basu[1], K. Sankar[2] & Qamar Quresh[1]

[1,2] Wildlife Institute of India, Chandrabani, P.O. Box # 18, Dehra Dun, Uttarakhand 248001, India
Email: [2] sankark@wii.gov.in (corresponding author)

Between October 2006 and June 2008 information on population, group size, habitat use and food habits of six species of vultures was collected in Pench Tiger Reserve (79°9'-79°22' 30"E & 21°38'-21°50'30"N) Madhya Pradesh. The Tiger Reserve comprises of Sanctuary, National Park and reserved forests. The total area of the Pench Tiger Reserve is $758km^2$. According to Champion & Seth (1968) the flora of Pench falls under tropical dry deciduous forest (Champion & Seth 1968). Based on ad-libitum observations, locations of vultures were recorded using Global Positioning System (GPS) from the entire Tiger Reserve. In addition, the number of individuals of each species, major vegetation type around 20m radius and the prey species on which vultures were found feeding were also noted on each observation.

In total 547 individuals belonging to six species of vultures were recorded. Of these, the Oriental White-backed or White-rumped Vulture (*Gyps bengalensis*) were found to be the most abundant (n=334) followed by Long-billed Vulture (*Gyps indicus*) (n=184), Red-headed or King Vulture (*Sarcogyps calvus*) (n=12), Egyptian Vulture (*Neophron percnopterus*) (n=9), Indian Griffon Vulture (*Gyps fulvus*) (n=5) and Cinereous Vulture (*Agypius monachus*) (n=3). The Indian Griffon and Cinereous Vulture were recorded only during winter (November-February) whereas the other four species were recorded throughout the year.

The number of individuals and percentage flock size of vultures is given in Table 1. A maximum of 28 individuals were recorded for white-backed vulture in a flock, where as the Long-billed Vulture had a maximum of 18 individuals in a flock. Multiple associations among different species of vultures were also recorded during study period (Table 2).

Vultures were largely found in riparian forest (70%) followed by miscellaneous forest (23%) and teak mixed forest (7%). White-backed and Long-billed Vulture nests were recorded on *Tectona grandis* and *Dalbergia paniculata* at four sites each in Gumtara, Alikatta, Chiklakhari and Chindwani. No attempts were made to study the nesting success of vultures. However fledglings of White-rumped Vultures were seen once during the study period.

In total 24 kills of Wild Ungulates (20 Chital, three Sambar and one Nilgai) were recorded. Of these, 16 kills were located due to vulture's activity. On ten occasions Jungle Crow (*Corvus macrorhynchos*) was found associated with vultures on the feeding grounds followed by Golden Jackal (*Canis aureus*) on five occasions and Wild Pig (*Sus scrofa*) on two occasions. During the study period two vultures, one each of White-backed and Long-billed were found dead in the study area. Post-mortem reports revealed that these were natural deaths (Akhilesh Mishra pers. com.). Since Pench harbours one of the highest prey-predator densities (Biswas & Sankar 2002) in central Indian landscape, vultures have better chance of survival on carnivore kills. It is suggested that the reported breeding sites of vultures in Pench need monitoring for the survival of chicks. Since the 1990s vulture populations especially the *Gyps* species across the Indian subcontinent have declined drastically (Gilbert et al. 2002; Prakash et al. 2003; Green et al. 2004). The findings of the present study showed encouraging results regarding the population of *Gyps* species in Pench

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Table 1. Number of individuals and percentage flock size recorded for six species of vultures in Pench Tiger Reserve (2006-2008)

Species	Number of flocks	Mean flock size	Number of individuals	Flock size in % 1	2-3	4-10	11-20	21-30
King vulture	11	1.5	12	91	9	—	—	—
White-backed vulture	66	14	334	11	50	26	11	3
Long-billed vulture	37	9	184	24	27	37	11	—
Egyptian vulture	4	1.5	09	50	50	—	—	—
Indian griffon vulture	3	1.5	05	33	66	—	—	—
Cinereous vulture	1	3	03	—	100	—	—	—

Table 2. Multiple associations among different species of vultures recorded in Pench Tiger Reserve (2006-2008)

Species associations	Number of occasions
Long billed - White Backed	15
White backed - Long billed - Egyptian	3
White backed - King Vulture	2
King Vulture - White backed - Long billed	3
King Vulture - White backed - Long billed - Egyptian - Indian Griffon	1
King Vulture - White backed - Long billed - Egyptian - Indian Griffon - Cinereous	1

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Utilization of food plant species and abundance of hanuman langurs (*Semnopithecus entellus*) in Pench Tiger Reserve, Madhya Pradesh, India

Utilization of food plant species and abundance of hanuman langurs (*Semnopithecus entellus*) were studied between January 2009 and August 2010 in Pench Tiger Reserve, Madhya Pradesh (78° 55' to 79° 35' E and 21° 8' to 22° N), India. This nature reserve is in the southern lower reaches of the Satpura Hill Range, on the southern border of Madhya Pradesh and covers an area of 758 km². According to Champion & Seth (1968) Pench Tiger Reserve is under both tropical dry and moist deciduous forest systems. Floristically, Pench is very rich and composed with 189 tree species, 138 shrubs, 452 herbs, 102 climbers, 10 epiphytes and parasites and 119 grasses and bamboos (Dungariyal, 2008). The year is broadly grouped into four major seasons: summer (March to June), monsoon (July to August), post monsoon (September to October) and winter (November to February). Temperature varies annually from 2 °C in winter to 49 °C in summer. The average rainfall is almost 1400 mm (Biswas & Sankar, 2002). Hanuman langur is listed as the least concern species in IUCN red list categories, CITES Appendix I and Schedule II in Wildlife Protection Act 1972 (India).

We studied the utilization of different food plant species by hanuman langurs opportunistically in the study area. Overall, different plant parts of 50 plant species (Table 1) were utilized by hanuman langurs during the study period.

Distance sampling by line transect method (Burnham *et al.*, 1980; Buckland *et al.*, 1993) was used to estimate approximate densities of hanuman langurs in the intensive study area (410 km²). We walked a total of 44 line transects in both summer and winter (total effort 752.8 km/season). Each transect was walked early in the morning (Schaller, 1967; Jhala *et al.*, 2008) and radial distance (using a laser range finder) and sighting angles (using a SUNTO compass) were recorded in each detection. DISTANCE version 5.0 was used to analyze the data. The results from line transects showed that densities of adult hanuman langurs were 73.8/km^2 (SE ± 6.4) during winter and 91.2/km^2 (SE ± 9.2) in summer (Table 2). Densities were multiplied by the study area (410 km^2) to obtain populations of hanuman langur in winter 30347 (SE ± 2637) and in summer 37532 (SE ± 3790). Average troop size was 7.1 in winter and 8.7 in summer.

On comparison with other studies of Indian sub-continent it is evident that Pench harbours a very high density of hanuman langur (Table 3). A combination of factors is responsible for their high abundance in Pench Tiger Reserve. First they were found to be less preferred by large carnivore species found in the study area as compared to their availability (Biswas & Sankar, 2002). Second, the study area is dominated by fairly open canopy, mixed forest with considerable shrub cover interspersed with small open grassy patches. The relationship (Newton, 1989) between troop of hanuman langur and axis deer (*Axis axis*) may be one of the major reasons in such type of habitat for their less predation as the axis deer population is also high in Pench Tiger Reserve (Biswas & Sankar, 2002). Although, the study area is mostly tropical dry deciduous forest (Champion & Seth, 1968), not all plant species loose their leaves at the same time. Many plant species are in their deciduous phase in some parts of the study area while others remain in leaf. The langurs debarked some selectively soft-bark species such as *Schleichera oleosa*, *Terminalia arjuna*, *Mitragyna parvifolia*, *Terminalia tomentosa*, *Lanea coromandelica*, *Boswellia serrata* and *Anogeissus latifolia*. We have opportunistically found that sometimes hanuman langurs sitting on ground were very fond of the dry seeds of the *Ougeinia dalbergioides* tree. We also found, strangely, that hanuman langurs utilized not whole plants, but some portion such as the leaf apex of *Butea monosperma*, mid vein of the leaf of *Terminalia* *tomentosa*, fruit apex of *Madhuca longifolia*, and fruit apex of *Syzygium cumini* in summer. We observed langurs taking fresh bark of trees mostly during summer as 'famine food' to overcome food scarcity. Therefore, regular availabilities of resources in the study area and their hardy and highly adaptive nature (Raemakers, 1980; Marsh, 1981; Isbell, 1983; Bennett, 1986; Newton, 1992) may have enabled them to recruit though out the year in Pench.

Table 1: Overall utilization of food plant species by hanuman langurs (*Semnopithecus entellus*) in Pench Tiger Reserve, between January 2009 and August 2010 (for plant type, T=tree; C= climbers; G=grass; S=shrub and for season, S=summer; W=winter)

no	Plant Species	Family	Plant type	Season	Plant parts utilized
1	*Terminalia arjuna*	Combretaceae	T	S	Young leaves and bark
2	*Syzygium cumini*	Myrtaceae	T	S	Young leaves and young flower
3	*Bahunia vahlii*	Leguminosae	C	S	Young flower
4	*Diospyros melanoxylon*	Ebenaceae	T	S & W	Ripe fruit and young leaves
5	*Buchnania lanjan*	Anacardiaceae	T	S	Young leaves, ripe and un ripe fruit
6	*Ficus infectoria*	Moraceae	T	S & W	Young leaves
7	*Schleichera oleosa*	Sapindaceae	T	S & W	Young leaves, ripe fruit and bark
8	*Lanea coromandelica*	Anacardiaceae	T	S & W	Young leaves, ripe fruit and latex
9	*Ficus bengalensis*	Moraceae	T	S	Young leaves and ripe fruit
10	*Ougeinia dalbergioides*	Leguminosae	T	S	Young leaves, flower, latex and dry seed
11	*Lantana camara*	Verbenaceae	S	S & W	Young leaves and young flower
12	*Soymida febrifuga*	Meliaceae	T	S	Young leaves
13	*Albizzia procera*	Leguminosae	T	S	Bark
14	*Madhuca longifolia*	Sapotaceae	T	S & W	Flower, young leaves, apex of un ripe fruit and bark
15	*Butea monosperma*	Leguminosae	T	S & W	Flower and young leaves
16	*Mangefera indica*	Anacardiaceae	T	S	Young leaves, flower and ripe fruit
17	*Semecarpus anacardium*	Anacardiaceae	T	S	Ripe fruit
18	*Ficus glomerata*	Moraceae	T	S & W	Young leaves
19	*Lagerstroemia purviflora*	Lythraceae	T	S & W	Young leaves
20	*Acacia catechu*	Leguminosae	T	W	Young leaves
21	*Cynodon dactylon*	Poaceae	G	W	Node and inter node, young leaves
22	*Tamarindus indica*	Leguminosae	T	S	Young leaves
23	*Miliusa velutina*	Annonaceae	T	S	Fruit, young leaves
24	*Zizyphus mauritiana*	Rhamnaceae	T	S	Ripe fruit
25	*Dalbergia paniculata*	Leguminosae	T	S	Young leaves
26	*Mitragyna parvifolia*	Rubiaceae	T	S & W	Young leaves and bark
27	*Bombax ceiba*	Bombacaceae	T	S & W	Flower
28	*Ficus religiosa*	Moraceae	T	S	Young leaves
29	*Aegle marmelos*	Rutaceae	T	S	Ripe fruit
30	*Zizyphus xylopyra*	Rhmanaceae	T	W	Young leaves and ripe fruit
31	*Bauhinia racemosa*	Leguminosae	T	W	Young leaves
32	*Cleistanthus collinus*	Phyllanthaceae	T	S & W	Young leaves
33	*Terminalia tomentosa*	Combretaceae	T	S & W	Young leaves
34	*Cordia myxa*	Boraginaceae	T	S	Ripe fruit
35	*Stereospermum chelonoides*	Bignoniaceae	T	S	Young leaves
36	*Casia fistula*	Leguminosae	T	S & W	Flower and ripe fruit
37	*Gardenia latifolia*	Rubiaceae	T	S	Flower, fruit and mature leaves
38	*Ixora parviflora*	Rubiaceae	T	W	Young leaves
39	*Heteropogon contortus*	Poaceae	G	S & W	Node and inter node
40	*Anogeissus latifolia*	Combretaceae	T	S & W	Young leaves and bark
41	*Chloroxylon swietenia*	Rutaceae	T	W	Young leaves
42	*Pterocarpus marsupium*	Leguminosae	T	S & W	Young leaves
43	*Alangium lamarckii*	Alangiaceae	T	S	Bark
44	*Boswellia serrata*	Burseraceae	T	S & W	Young leaves
45	*Sterculia urens*	Sterculiaceae	T	S	Latex
46	*Adina cordifolia*	Rubiaceae	T	S & W	Young leaves and ripe fruit
47	*Datura metel*	Solanaceae	S	S	Young leaves

48	*Chloris virgata*	Poaceae	G	W	Node and inter node
49	*Hardwickia binnata*	Leguminosae	T	S & W	Young leaves and bark
50	*Emblica officinalis*	Euphorbiaceae	T	S & W	Young leaves, ripe and unripe fruit

Table 2: Seasonal variation of densities, populations and troop sizes of hanuman langurs (*Semnopithecus entellus*) in Pench Tiger Reserve, Madhya Pradesh (January 2009 and August 2010)

Seasons	Observations	D±SE	Population± SE	Troop size %				
				1-10	11-20	21-30	31-40	41-50
Winter	610	73.8±6.4	30347 ± 2637	78.2	18.6	3	0.2	0
Summer	795	91.2±9.2	37532 ± 3790	69.6	23.8	4.9	1.3	0.5

D: Individual density, SE: Standard Error

Table 3: Densities of hanuman langurs compared with different study areas in the Indian sub-continent.

Location	Forest type	Density/km²
Bandipur[1]	Tropical dry deciduous	7.5
Pench[2]	Tropical dry and moist deciduous	77.2
Bhadra[3]	Tropical moist deciduous	22.6
Ranthambore[4]	Tropical thorn and dry deciduous	21.7
Bori-Satpura[5]	Tropical dry and moist deciduous	28.3
Mudumalai[6]	Tropical dry thorn, moist, dry deciduous and semi evergreen	25.9
Present study*	Tropical dry and moist deciduous	**82.5**

[1] – Johnsingh, 1983; [2] – Biswas and Sankar 2002; [3] – Jathanna, 2001; [4] – Bagchi *et al.*, 2003 ; [5] – Edgaonkar, 2008; [6] Ramesh *et al.*, 2009; * - Present study (Over all density).

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Aniruddha Majumder[1,2], Abinash Parida[1], K. Sankar[1] and Qamar Qureshi[1]
[1] Wildlife Institute of India, P.O, Box 18, DehraDun, 248001,Uttarakhand, India
[2] Email: aniruddha@wii.gov.in

Food habits and temporal activity patterns of the Golden Jackal *Canis aureus* and the Jungle Cat *Felis chaus* in Pench Tiger Reserve, Madhya Pradesh, India

Aniruddha Majumder [1], K. Sankar [2], Qamar Qureshi [3] & Santanu Basu [4]

[1,2,3,4] Wildlife Institute of India, P.O. Box 18, Dehradun, Uttarakhand 248001, India
Email: [1] aniruddha@wii.gov.in (corresponding author), [2] sankark@wii.gov.in, [3] qnq@wii.gov.in, [4] santanubasu2k6@gmail.com

The ability of ecologically similar species to coexist depends largely on the degree to which resources are limiting and how resources can be partitioned as the species become sympatric (Schoener 1974). Empirical studies dealing with mammalian carnivores showed that coexisting carnivores tend to have different dietary and activity patterns, indicating that it is a common phenomenon for coexisting species to have different niches (Maddock & Perrin 1993; Tatara & Doi 1994). In India, most of the studies on dietary and temporal activity patterns of carnivores have been carried out on large carnivores (Johnsingh 1983; Karanth & Sunquist 1995; Biswas & Sankar 2002; Andheria et al. 2007; Edgaonkar 2008; Ramesh et al. 2009) and very few studies were carried out on meso-carnivores (Sankar 1988; Mukherjee 1989; Balasubramanian & Bole 1993; Mukherjee et al. 2004; Aiyadurai & Jhala 2006).

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Food habits and temporal activity patterns of the Golden Jackal *Canis aureus* and the Jungle Cat *Felis chaus* were studied between January 2008 and June 2009 in Pench Tiger Reserve (PTR) ($79^0$09'-$79^0$22'E & $21^0$38-$21^0$50'N), Madhya Pradesh, central India. Pench Tiger Reserve connects Kanha with Satpura Tiger Reserve and forms a continuous forest patch in central India which offers one of the important habitats of large and meso-carnivores in the Indian subcontinent (Biswas & Sankar 2002; Qureshi et al. 2006; Acharya et al. 2007). The overall goal of the present study is (i) to determine the frequency of occurrence of different food items in the diet of these two meso-carnivores in PTR, (ii) to examine the implications of these diet profiles and temporal activity for understanding resource partitioning patterns and ecological sympatry among them in PTR.

The Pench Tiger Reserve comprises a national park (292km^2), a sanctuary (118km^2) and a reserved forest (348km^2) covering an area of the 758km^2. Vegetation in the area is broadly classified as having both tropical dry deciduous and tropical moist deciduous forests (Champion & Seth 1968). Teak (*Tectona grandis* L.) and its associated species in the area represent a transition from tropical dry deciduous to tropical moist deciduous forests. The terrain is undulating in most areas of the tiger reserve (Biswas & Sankar 2002). Pench experiences markedly seasonal climate with a distinct summer (March–June), monsoon (July–September) and winter (October–February) and receives a mean annual rainfall of c. 1400mm. The temperature ranged from 2^0C in winter to 49.5^0C in summer during the study period.

The Golden Jackal (body weight 8–11 kg) (Prater 1980; Giannatos 2004) ranges from northern Africa and extends across the middle-east to India. The species is included in CITES Appendix II and Schedule III in the Wildlife (Protection) Act 1972 of India. The Jungle Cat (body weight 5–6 kg) has established itself over a wide range from northern Africa through south-western Asia to India, Ceylon and Indo-China

(Prater 1980). It is included in CITES Appendix II and Schedule II of the Indian Wildlife (Protection) Act 1972. Apart from the Golden Jackal and the Jungle Cat, other carnivore species found in the study area are Tiger *Panthera tigris*, Leopard *Panthera pardus*, Dholes *Cuon alpinus*, Palm Civet *Paradoxurus hermaphrodites*, Ratel *Mellivora capensis*, Small Indian Civet *Viverricula indica*, Common Mongoose *Herpestes edwardsii* and Ruddy Mongoose *Herpestes smithii* (Biswas & Sankar 2002). Rodent species found in the study area are Indian Gerbil *Tatera indica*, Flat Haired Mouse *Mus platythrix* and Bush Rat *Golunda ellioti* (Dungariyal 2008).

The diets of the Golden Jackal and the Jungle Cat can be studied through scat analysis (Reynolds & Aebischer 1991; Mukherjee et al. 1994; Mukherjee et al. 2004). A total of 50 Golden Jackal scats and 85 Jungle Cat scats were collected wherever encountered from the intensive study area (292km^2). Scats were mostly collected on roads (65% Golden Jackal scats and 56% Jungle Cat scats), trails (19% Golden Jackal scats and 34 % Jungle Cat scats) and dry stream beds (16% Golden Jackal scats and 10% Jungle Cat scats). Jackal and Jungle Cat scats were identified by their size, shape and associated signs (Weaver & Fritts 1979; Green & Flinders 1981; Danner & Dodd 1982; Mukherjee et al. 2004). Scats, once collected from the field were washed and dried. Hair and prey remains were compared with reference slides and other body parts of different prey species available at the Wildlife Institute of India laboratory.

We used Pianka's index (Pianka 1973) for measuring diet overlap between predators.

$$O_{AB} = \Sigma pi_A * p_{iB} / (\Sigma p^2_{iA} p^2_{iB})^{1/2}$$

where, pi is the relative frequency of prey item i in the diet of species A and B. This index (O) ranges in value from 0 (indicating no overlap) and 1 (complete overlap).

Information on temporal activity pattern was obtained using camera traps (Gompper et al. 2006; Long et al. 2008). Fifty-two pairs of self-triggered analog cameras (DEER CAM ™) were deployed in each 2km x 2km grid in the intensive study area (21.07^0–21.08^{0}N & 79.02^0–79.5^{0}E), close to animal trails, between March and June for two successive years. Entire camera trap area (>250 km^2) covered a homogeneous teak-mixed and undulating habitat. The cameras had a 35mm lens, and recorded the date and time of each photograph. The camera delay we kept at a minimum (15 seconds) and sensor activity was set high. We maximized our effort to select the best site for deploying camera traps as per sign intensity of study species and no bait was used to attract the animals. Based on the exact time of the photo-capture for the total number of identified individuals of Golden Jackal and Jungle Cat were pooled into six time categories: 12:00–16:00 hr; 16:01–20:00 hr; 20:01–00:00 hr; 00:01–04:00 hr; 04:01–08:00 hr and 08:01–12:00 hr.

Student t-test (Zar 1984) showed no significant difference on both dietary (p=0.06) and activity pattern (p=0.08) of these two meso-carnivores between two seasons (summer and winter) so we pooled the data of both into one to analyze them for the present study. The analysis of scats revealed the presence of 10 prey species in the Golden Jackal and eight prey species in the Jungle Cat diets (Table 1). Rodents contributed the maximum in the diet of the two predators (40% in Golden Jackal and 63.6% in Jungle Cat). In Jackal scats, 86% contained single prey type, 12% contained two prey types and 2% contained three prey types. For Jungle Cat scats, 84.7% of the scats contained single prey type, 14.1% contained two prey types and 1.2% contained three prey types. The estimated dietary overlap between jackal and jungle cat was 0.9 (90%) (Table 2).

Table 1. Percentage frequency of food items recorded in scats of Golden Jackal and Jungle Cat in Pench Tiger Reserve, Madhya Pradesh.

Food item	No. of scats (Golden Jackal)	% frequency of occurrence	No. of scats (Jungle Cat)	% frequency of occurrence
Rodents	22	40	63	63.6
Langur *Semnopithecus entellus*	3	5.4	1	1
Hare *Lepus nigricollis*	6	10.9	11	11.1
Chital *Axis axis*	13	23.6	6	6.1
Sambar *Rusa unicolor*	1	1.8	2	2
Nilgai *Bosephalus tragocamelus*	2	3.6	0	0
Wild Pig *Sus scrofa*	1	1.8	1	1
Birds	2	3.6	7	7.1
Reptiles	4	7.2	8	8.1
Cattle	1	1.8	0	0

0 - Not present

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OCCUPANCY AND ABUNDANCE OF DHOLE (*CUON ALPINUS*) IN PENCH LANDSCAPE OF CENTRAL INDIA

ANIRUDDHA MAJUMDER[1,2], QAMAR QURESHI[1,3], KALYANASUNDARAM SANKAR[1,4], SANTANU BASU[1,5], YADAVENDRADEV V. JHALA[1,6]

[1]Wildlife Institute of India, P.O. Box # 18, Chandrabani, Dehradun 248001, Uttarakhand, India.
[2]Email: aniruddha@wii.gov.in
[3]Email: qnq@wii.gov.in
[4]Email: sankark@wii.gov.in
[5]Email: santanubasu2k6@gmail.com
[6]Email: jhalay@wii.gov.in

Occupancy and abundance of dhole was studied in the Pench landscape of Central India between 2006 and 2010. Royle-Nichols heterogeneity model was used for abundance estimation of dhole. The 4,300 sq. km area of the Landscape was divided into 10 km x 10 km grids (n=43), considering each grid size is larger than the home range size of an individual dhole.

Different forest routes on each grid were surveyed to collect indirect evidences (spoor, fresh scats, etc.) of dhole, and each search covered 5 km distance (total effort 3,720 km) during 2006. The average dhole pack size was 13.9 ±1.4 (Standard Error or SE). The estimated individual density of dhole in the Pench landscape was 3.3 ±1.2 (SE)/100 sq. km. Naïve or site occupancy of dhole was estimated using indirect evidences from the Intensive Study Area or ISA (410 sq. km), i.e., in Pench National Park (PNP) and Pench Wildlife Sanctuary (PWS) of Pench Tiger Reserve, Madhya Pradesh, between February and June 2006, 2007, 2009 and 2010. Sampling occasions (n=3) were same for all four years and total effort varied between 725 km and 750 km. The estimated naïve or site occupancy of dhole in ISA was 0.81 ±0.07 (SE) in 2006 followed by 0.96 ±0.15 in 2007, 0.52 ±0.08 in 2009 and 0.82 ±0.14 in 2010.

Our study revealed that occupancy of dhole is high inside the Pench Protected Area (i.e., PNP and PWS), but low and patchy outside. As dhole population is observed fragmented, linkage between the different Protected Areas in this landscape is crucial for its long term survival.

Key words: *Cuon alpinus*, Pench landscape, abundance, occupancy, central India

INTRODUCTION

With the decline of most large carnivore population worldwide (Nowell and Jackson 1996) there is always an urgent need for practical and accurate methods of estimating population numbers and monitoring trends (Caughley and Sinclair 1994). Estimates of abundance are extremely valuable for species conservation, yet determining the abundance of elusive and wide-ranging carnivores is difficult, but possible, especially for those that can be identified by individual marking, like Tiger *Panthera tigris* (Karanth 1995; Sharma *et al.* 2010; Jhala *et al.* 2011), Leopard *Panthera pardus* (Mondol 2006; Edgaonkar 2008; Harihar *et al.* 2009; Ramesh 2010), Jaguar *Panthera onca* (Soisalo and Cavalcanti 2006) and Cheetah *Acinonyx jubatus* (Marnewick *et al.* 2008). Kelly *et al.* (2008) assessed reliability of Puma *Puma concolor* identification by photo-trapping using double-blind observer identifications. They also reported that obvious and subtle markings (scar, cut marks and wounds) of the species can be compared from camera trap photographs if the photo quality is good. Carbone *et al.* (2001) used photographic rates to estimate densities of cryptic mammals, which require large sample size. Rowcliffe *et al.* (2008) also estimated animal density, without the need for individual recognition, from camera trapping rates by modelling the underlying detection process. Radio telemetry study was also used to estimate population of some large-bodied canids like Dhole *Cuon alpinus* (Acharya *et al.* 2007), Wolf *Canis lupus* (Mech 1977), Coyote *Canis latrans* (Andelt 1985). Radio-telemetry is constrained by the small number of animals that can be tagged simultaneously, the uncertainties about how many individuals are tagged, and the high costs and efforts involved (Karanth 1995). Kohn *et al.* (1999) estimated coyote population by genotyping faeces. Though this method may be more reliable for population estimation, because of its non-invasiveness (Miththapala 1996), the major drawback is high cost and need of skilled technicians and advanced laboratories (Kohn *et al.* 1999).

The only information on dhole abundance comes from a few protected areas in southern and central India (Johnsingh 1983, Karanth 1993, Venkatraman *et al.* 1995, Acharya *et al.* 2007). These estimates have not been obtained through systematic sample based survey methods, but on estimates of number of packs within the protected areas (derived using known home range areas and knowledge of mean pack sizes) (Durbin *et al.* 2004). Ramesh (2010) estimated population of Dhole using vehicle transect method.

As dholes are the least studied social carnivores in the Asian jungles (Acharya *et al.* 2007), the present study was carried out in the Pench landscape of central India, between June 2006 and June 2010, to estimate occupancy and abundance of dholes using reliable scientific methods.

MATERIAL AND METHODS

Study area

The study area, Pench landscape (4,300 sq. km) is one of the important conservation units for carnivores and its prey in the central Indian landscape (Jhala *et al.* 2010) (Fig. 1). According to Champion and Seth (1968) classification, the study area falls under tropical dry deciduous forest and tropical moist deciduous forest. It includes Pench Tiger Reserve, South Seoni Forest Division, South Balaghat Forest Division, East Chindwara Forest Division and South Chindwara Forest Division. This Landscape lies in the southern lower reaches of Satpura Hill ranges. According to the biogeographic classification of Rodgers and Panwar (1988), it lies in the Zone – 6E Deccan Peninsula Central Highland. The terrain is gently undulating and criss-crossed by small streams and nullahs, most of these are seasonal. The study area experiences markedly seasonal climate with a distinct summer (March-June), monsoon (July-September) and winter (October-February) and receives a mean annual rainfall of *c.* 1,400 mm. The temperature ranged from 2 °C in winter to 49.5 °C in summer. Pench Tiger Reserve (PTR), which includes Pench National Park (PNP) and Pench Wildlife Sanctuary (PWS), along with Kanha Tiger Reserve constitutes one of the 11 level-I Tiger Conservation Units (TCU) in India classified by Wickramanayake *et al.* (1998). The PNP and PWS were considered as the intensive study area (410 sq. km) for the present study. Apart from dhole the other carnivore species found in this landscape are tiger, leopard, wolf, jackal (*Canis aureus*), Striped Hyena (*Hyaena hyaena*), Indian fox (*Vulpes bengalensis*) and Jungle cat (*Felis chaus*). The wild ungulates found here are Chital (*Axis axis*), Sambar (*Rusa unicolor*), Nilgai (*Boselaphus tragocamelus*), Gaur (*Bos frontalis*), Barking Deer (*Muntiacus muntjak*), Chousingha (*Tetracerus quadricornis*), Wild Pig (*Sus scrofa*), Blackbuck (*Antilope cervicapra*) and Chinkara (*Gazella bennettii*) (Sankar *et al.* 2001; Dungariyal 2008; Jhala *et al.* 2010). The Common Langur (*Semnopithecus entellus*) and Rhesus Macaque (*Macaca mulatta*) represent the primate fauna of the area. The Indian Crested Porcupine *Hystrix indica*, Black-naped Hare (*Lepus nigricollis*), Indian Flying Fox (*Pteropus giganteus*), Red Giant Flying Squirrel (*Petaurista petaurista*), Three-striped Squirrel (*Funambulus palmarum*) and Indian Pangolin (*Manis crassicaudata*) also occur in this area. There are over 51,648 inhabitants in 107 villages and 60,000 livestock present around the notified buffer zone of PTR (Dungariyal 2008). The mean human population density is 112 ±9 (Standard Errror or SE) / sq. km and Gond tribes are the main inhabitants of this landscape (Qureshi *et al.* 2006; Jhala *et al.* 2010).

Methods

We used Royle-Nichols (Royle and Nichols 2003) heterogeneity model for abundance estimation of dhole. The key assumptions of the Royle-Nichols model are (1) the number of animals at a particular site follow a Poisson probability distribution for which lambda indicates the mean abundance across all sites, and (2) the probability of detecting animals at each site is related to the species specific capture probability 'r' and the site abundance (Ni).

Royle-Nichols heterogeneity model was used for larger data set (4,300 sq. km) for 2006 from 'Monitoring tiger, co-predator, prey and their habitat'- research project (Jhala *et al.* 2008). The parameter derived from larger study area was used to infer abundance of dhole in the intensive study area (410 sq. km). This larger study area was further sub-divided into 10 km x 10 km grids (n=43) (Fig. 1) and our assumption was that the grid size should be more than the home range size of a dhole pack. The average home range of dhole pack was 63 sq. km as reported by Acharya *et al.* (2007) in the same study area. Forest beats were considered as the lowest sampling unit for sign survey (Jhala *et al.* 2008) and three separate routes of each forest beat were walked early in the morning to record the signs and tracks of dhole. Each search covered 5 km having the best potential for dhole presence. Data collection was done covering 3,720 km. The site (naïve) occupancy (Mackenzie *et al.* 2002) of dhole population was estimated from beat wise (n=44) sign survey in the ISA in 2006, 2007, 2009 and 2010. Sampling occasions (n=3) were same for all the four years and total effort varied between 725 km and 750 km. The program PRESENCE ver. 3 was used for occupancy and abundance estimation (Jhala *et al.* 2010). T-test (Zar 1984) was used to evaluate temporal changes in occupancy.

RESULTS

The estimated occupancy of dhole in the overall landscape was 0.21 ±0.06 (SE). Detection probability was 0.74 ±0.09 (SE) and average dhole pack size was 13.9 ±1.4

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diet of tigers, eight prey species both in winter and summer diet of leopard diet where as nine prey species in winter and seven prey species were recorded in the diet of dhole (Table 3, 4 and 5). Of the prey species found in tiger scats (Table 3) chital constituted as major prey in terms of number (52.8% in winter and 62.7% in summer) followed by sambar (31.7% in winter and 18.6% in summer), common langur (5.7% in winter and 9.3 % in summer), wild pig (6.2% in winter and 3.1% in summer), nilgai (0.4% in winter and 3.1% in summer), domestic cattle (0.2% in winter and 2.5% in summer), rodents (1.6% only in winter), gaur (0.6% in winter), hare (0.2% in winter), unknown birds (0.4%) and porcupine (0.6 % in summer). In leopard scats (Table 4) chital contributed as major prey (55.5% in winter and 42.7% in summer) followed by common langur (16.4% in winter and 29.2% in summer), sambar (9.1% in winter and 6.7% summer), wild pig (8.2% in winter and 8.9% in summer), hare (3.6% in winter and 4.5% in summer), nilgai (2.7% in winter and 1.1% in summer), rodents (3.6% in winter and 2.3% in summer), unidentified birds (0.9% in winter and 2.3% in summer) and cattle (2.3% in summer). In dhole scats (Table 5) chital contributed maximum (57.4% in winter 61.5% in summer) followed by sambar (20.6% in winter and 17.5% in summer), common langur (8.6% in winter and 8.4 % in summer),

Table 3. Composition of tiger diet (n = 467 in winter and n = 155 in summer) and relative biomass contribution of different prey species in Pench Tiger Reserve, Madhya Pradesh (November 2006 to June 2010).

Prey	Avg. wt.	FO (W)	PFO (W)	FO (S)	PFO (S)	CF	Ivlev's Index (W)	Ivlev's Index (S)
Chital	47	257	52.88	101	62.73	3.6	0.0466	0.1908
Sambar	134	154	31.69	30	18.63	6.7	0.8499	0.6954
Nilgai	180	2	0.41	5	3.11	8.3	-0.3016	0.6550
Wild pig	32	30	6.17	5	3.11	3.1	-0.0747	-0.5019
Langur	8	28	5.76	15	9.32	2.3	-0.8921	-0.8211
Gaur	450	3	0.62	-	-	17.7	0.2657	-
Hare	2.1	1	0.21	-	-	2.1	-	-
Livestock	180	1	0.21	4	2.48	8.3	-	-
Unknown Rodent	0.5	8	1.65	-	0.00	2.0	-	-
Porcupine	10	-	-	1	0.62	2.3	-	-
Unknown Bird	-	2	0.41	0	0.00	-	-	-

Avg. wt. = Average body weight, FO (W) and (S) = Frequency of occurrence of prey species in scats in winter and summer, PFO (W) and (S) = Percentage frequency of occurrence of prey species in winter and summer, CF= Correction factor for tiger

Table 4. Composition of leopard diet (n = 107 in winter and n = 82 in summer) and relative biomass contribution of different prey species in Pench Tiger Reserve, Madhya Pradesh (November 2006 to June 2010).

Prey	Avg. wt.	FO (W)	PFO (W)	FO (S)	PFO (W)	CF	Ivlev's Index (W)	Ivlev's Index (S)
Chital	47	61	55.45	38	42.70	3.63	0.1835	0.1247
Sambar	134	10	9.09	6	6.74	6.67	0.6333	0.4418
Nilgai	180	3	2.73	1	1.12	8.28	0.6349	0.3802
Wild pig	8	9	8.18	8	8.99	2.26	0.1793	0.1037
Langur	450	18	16.36	26	29.21	17.73	-0.6611	-0.4336
Hare	2.1	4	3.64	4	4.49	2.05		
Livestock	180	0	0.00	2	2.25	8.28		
Unknown Rodent	0.5	4	3.64	2	2.25	2.00		
Unknown Bird	-	1	0.91	2	2.25			

Avg. wt. = Average body weight, FO (W) and (S) = Frequency of occurrence of prey species in scats in winter and summer, PFO (W) and (S) = Percentage frequency of occurrence of prey species in winter and summer, CF= Correction factor for leopard.

hare (7.2% in winter and 2.8% in summer), wild pig (2.4% in winter and 3.5% in summer), rodents (1.4 % in winter and 2.1% in summer) birds (1.4% in winter and 1.4% in summer), nilgai (2.1% in summer), cattle (0.7% in summer), porcupine and reptiles (0.5% both in winter). No attempt was made to identify the species of rodents, birds and reptiles in the scats of tiger, leopard and dhole. In case of tiger scats, 96% contained single prey species and 4% contained two prey species in both winter and summer. In leopard scats 97.2% contained single prey species and 2.8% contained two prey species in winter, 92.7% contained single prey species, 6.1 % contained two prey species and 1.2 % contained three prey species in summer. In dhole scats 95% contained single prey species and 5% contained two prey species in winter and 97% contained single prey species and 3% contained two prey species in summer.

In terms of relative biomass of prey consumed by tiger, chital contributed maximum (42.1 % in winter and 52.8 % in summer) followed by sambar (46.5 % in winter and 28.8 % in summer), wild pig (4.2 % in winter and 4.8% % in summer), common langur (3% in winter and 5% in summer), nilgai (0.7 % in winter and 6% in summer), cattle (0.4% in winter and 4.8% in summer), gaur (2.4% in winter), hare (0.09% in winter), rodents (0.7% in winter) and porcupine (0.3% in summer) (Table 3). In case of leopard, chital contributed maximum (55.6% in winter and 46.2% in summer) followed by sambar (16.7 % in winter and 13.4 in summer), common langur (6.2 % in winter and 2.8 % in summer), wild pig (7.01 % in winter and 8.3 % in summer), nilgai (6.2% in winter and 2.8% in summer), hare (2.06% in winter and 2.8% in summer), rodents (2.01% in winter and 1.3% in summer) and cattle (5.5 % in summer) (Table 4). In case of dhole, chital (54.5 % in winter and 57.01% in summer) contributed the maximum followed by sambar (31.8% % in winter and 26.4 % in summer), common langur (5.9 % in winter and 5.5 % in summer), wild pig (2.02 % in winter and 2.9 % in summer), nilgai (3.8 % in summer), hare (4.6 % in winter and 1.7 % in summer), cattle (1.3 % in summer), rodents (0.9 % in winter and 1.2 % in summer) and porcupine (0.3% in winter) (Table. 5).

Chital, sambar and gaur ($p>0.005$) were significantly consumed more than their availability by tiger where as common langur, wild pig and nilgai were less utilized in terms of individual density in winter where as in summer sambar, nilgai and chital were consumed more than their availability and wild pig and langur were less utilized. The individual level prey selectivity by tiger was ranked in the following order in winter: sambar> gaur>chital >wild pig >common langur and in summer, the order of prey selectivity was sambar>nilgai>chital>wild pig>langur (Fig. 3a and Fig. 3b). In case of leopard, nilgai, sambar, chital and wild pig were consumed more than their availability and common langur were less utilized in both winter and summer in terms of individual density. Index of selection at individual level prey species by leopard in winter was ranked as nilgai>sambar>chital>wild pig> common langur and in summer the order of prey

Table 5. Composition of dhole diet (n=199 in winter and n=139 in summer) and relative biomass contribution of different prey species in Pench Tiger Reserve, Madhya Pradesh (November 2006 to June 2010).

Prey	Avg. wt.	FO (W)	PFO (W)	FO (S)	PFO (S)	CF	Ivlev's Index (W)	Ivlev's Index (S)
Chital	47	120	57.4	88	61.54	0.83	0.1732	0.2268
Sambar	134	43	20.5	25	17.48	2.12	0.7881	0.6712
Nilgai	180	-		3	2.10	2.80	-	0.5074
Wild pig	32	5	2.4	5	3.50	0.61	-0.4142	-0.4007
Langur	8	18	8.6	12	8.39	0.25	-0.7906	-0.7986
Hare	2.1	15	7.2	4	2.80	0.17	-	-
Livestock	180	-	-	1	0.70	2.80	-	-
Unidentified Rodent	0.5	3	1.4	3	2.10	0.14	-	-
Porcupine	10	1	0.5	0	0	0.28	-	-
Unidentified Bird	-	3	1.4	2	1.40	-	-	-
Unidentified Reptile	-	1	0.5	0	0	-	-	-

Avg. wt. = Average body weight, FO (W) and (S) = Frequency of occurrence of prey species in scats in winter and summer, PFO (W) and (S) = Percentage frequency of occurrence of prey species in winter and summer, CF= Correction factor for dhole.

which includes Pench National Park and Pench Sanctuary, along with Kanha Tiger Reserve constitutes one of the 11 level-I Tiger Conservation Units (TCU) in India classified by Wickramanayake *et al.*, (1998) where tiger has the highest possibility of survival. Pench Tiger Reserve, Madhya Pradesh has forest connectivity with Pench Tiger Reserve Maharashtra in south and Kanha Tiger Reserve in north-west to form an important meta-population of tigers and its co-predators in India (Qureshi *et al.*, 2006). The reported occupancy of tiger, leopard and dhole was the highest in Central Indian landscape (48610 km², 117913 km² and 85962 km² respectively) as compared to other landscapes in India (Jhala *et al.*, 2008). Thus protection of the habitat along with regular monitoring of prey-predator population using comparable scientific methods is essential for Pench to emerge as one of the most important areas for sympatric carnivore conservation in central India.

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ORIGINAL PAPER

Home Ranges of the Radio-Collared Bengal Tigers (*Panthera tigris tigris* L.) in Pench Tiger Reserve, Madhya Pradesh, Central India

A. Majumder[1], S. Basu[1], K. Sankar[1,*], Q. Qureshi[1], Y.V. Jhala[1], P. Nigam[1], R. Gopal[2]

[1] Wildlife Institute of India, P.O. Box # 18, Chandrabani, Dehra Dun-248001, Uttarakhand, India.
[2] Member Secretary, National Tiger Conservation Authority, Government of India, New Delhi.
* Corresponding author: sankark@wii.gov.in, Phone +911352640112

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Abstract
Home ranges of three radio-collared Bengal tigers [one adult female (AF), one adult male (AM) and one sub-adult male (SAM)] were studied between March 2008 and December 2011 in Pench Tiger Reserve (PTR), Madhya Pradesh. Using 100% Minimum Convex Polygon (MCP), the estimated home ranges of AF (n= 750 locations), AM (n= 136 locations) and SAM (n= 739 locations) were 43 km^2, 55.1 km^2 and 52.2 km^2 respectively. Using 95% Fixed Kernel (FK), the corresponding figures were 32.1 km^2, 64.1 km^2 and 19.1 km^2. The core area of individual activity for each tiger, as determined by 65% FK, was 10.3 km^2 for AF, 20.3 km^2 for AM and 6.6 km^2 for SAM. The estimated overlap area between AM and AF using 95% FK was 19.2 km^2 (65%), whereas it was 15.4 km^2 (48%) between AF and SAM. The AF recruited three, four and five cubs in her 1st (May 2008 and all died during post natal stage), 2nd (October 2008) and 3rd litter (October 2010) respectively. Minimum 44% of the original natal area was used by AF at the time of raising her 2nd litter and 46% in her 3rd litter. Though there was a gradual extension of the annual home range, as observed during the first two years (2008-2010), but the core activity area remained considerably the same for AF over the study period. The study revealed that a minimum of 25 to 30 km^2 undisturbed area was required for a breeding female in PTR where both the wild prey density (348.2/km^2) and biomass (12384.7 kg/ km^2) were found to be high with adequate ground cover for the successful raising of cubs up to the dispersal stage. Pench and its surrounding forested habitat need to be protected for the breeding and dispersing tiger population.

Introduction

Home range is the area normally traversed by an individual animal or group of animals during activities associated with feeding, resting, reproduction, shelter-seeking and other factors important to an animal's survival [1, 2, 3]. The ranging patterns and social behaviour of many mammals show distinct intersexual differences [4, 5]. Female reproductive success is linked with an ability to exploit resources, whereas male reproductive success is governed by an ability to find and mate with females [4, 6]. Radio telemetry provides data on carnivore home range size and social organization, which can be used to derive, estimates of densities [7, 8, 9, 10, 11], habitat use [12, 13] and survival rates [14, 15].

The tiger (*Panthera tigris* L.) is the largest of all felids found in diverse habitat types and show remarkable tolerance to the variation in altitude, temperature and rainfall regimes [16]. Being a large and charismatic carnivore, the tiger has attracted considerable attention in the conservation community the world over [17]. In spite of this overwhelming care, the status of this predator has been deteriorating rapidly [17, 18]. Recently, this has reached more serious proportions than at any other time in the history of tiger conservation in India. A total of eight tiger subspecies are commonly recognised: Bengal tiger (*Panthera tigris tigris*), Sumatran tiger (*P. t. sumatrae*), Amur tiger (*P. t. altaica*), Indo-China tiger (*P. t. corbetti*), South China tiger (*P. t. amoyensis*), Caspian tiger (*P. t. virgata*), Javan tiger (*P. t. sondaica*) and Bali tiger (*P. t. balica*) [19]. Three of these, the Caspian, Javan and Bali tiger, went extinct in the last fifty years. The last Bali tiger was killed in 1937, the Caspian tiger became extinct in the 1950s and the last wild Javan tiger was seen in 1972. The wild South China tiger has not been directly observed since the 1970s and is now believed to be extinct in the wild too [20].

In wild condition tiger can potentially hunt prey varying from the small mammals, medium-sized ungulates to the large bovids [21], the preferred prey weighing between 60 and 250 kg [22]. They are territorial and wide-ranging and the effective size of their territory is a function of the density and biomass of prey species in its habitat [7, 23]. Therefore, studies undertaken to address these issues on tiger are important because it can provide a better insight of tiger ecology and behavior. Radio-telemetry studies on tiger have been effectively used to address these questions [7, 8, 17, 24, 25, 26, 27]. However, the fact those home ranges can vary widely within a species, which makes data transfer between study areas difficult [28]. It is therefore important to estimate site specific ranging patterns of tigers for better understanding, conservation and management. Our study area the Pench Tiger Reserve (PTR), Madhya Pradesh is one of the important source populations of tiger in the Central Indian landscape [21]. No detailed long-term study on ranging, recruitment and dispersal pattern of tiger has been documented earlier in this source population site. The present study was aimed to estimate the home ranges, recruitment and dispersal pattern of three radio-collared tigers in PTR.

Study area

The 758 km^2 area of PTR, Madhya Pradesh (79° 9' E to 79° 22' E and 21° 38 N' to 21°50' N) comprises of Indira Priyadarshini Pench National Park (PNP) (292 km^2), Mowgli Pench Wildlife Sanctuary (PWS) (118 km^2) and Reserved Forest (348 km^2) of Seoni and Chindwara Forest Circles. The intensive study was carried out in the critical tiger habitat or Core Area of PTR (410 km^2) i.e. PNP and PWS. Jhala *et al*. [29] reported a population of 23± 0.77 tiger in this intensive study area. The broadly classified forest types of PTR are tropical dry deciduous (5A/C$_{1b}$ and 5A/C$_3$) and tropical moist deciduous forests (3B/C$_{1c}$) [30]. Teak *Tectona grandis* L. and its associated species in the area represent a transition from the tropical dry deciduous to the tropical moist deciduous forests [31]. According to Forest Survey of India [www.fsi.org.in], the forest cover of the study area was classified into 1) Non-Forest (Canopy density < 10%), 2) Open Forest (Canopy density between 10% and 40%), 3) Moderately Dense Forest (Canopy density between 40% and 70%) and 4) Very Dense Forest (Canopy density > 70%), (Figure 4). Being located in the southern lower reaches of the Satpura range of hills, the terrain is undulating (350 m–650 m) in most areas of the tiger reserve [31].

The climate of PTR is sub-tropical and characterized by winter (October-February), summer (March-June) and monsoon (July-Sep¬tember) with a mean annual rainfall of 1400 mm. The temperature ranged from 2°C in winter to 49.5°C in summer during the study period. The River Pench is the main source of water, which flows, north to south, 74 km through the reserve. On its extreme south a dam was constructed. The draw-down area coming under the submergence of Totladoh (Pench) reservoir is 11.7 km^2 and covers 1.55% of PTR, Madhya Pradesh [31]. As summer approaches, these areas, from where the water gradually recedes downstream, become lush green meadows attracting high numbers of wild herbivores. Apart from tiger, the other carnivore species found in PTR are leopard (*Panthera pardus*), dhole (*Cuon alpinus*), jackal (*Canis aureus*) and jungle cat (*Felis chaus*). Palm civet (*Paradoxurus hermaphrodites*), ratel (*Mellivora capensis*), small Indian civet (*Viverricula indica*), two species of mongoose viz. common mongoose (*Herpestes edwardsii*) and ruddy mongoose (*Herpestes smithii*) are the small carnivores. Wolf (*Canis lupus*) and Indian fox (*Vulpes bengalensis*) occur on the fringes and outside the protected area limits. Sloth bear (*Melursus ursinus*) is the only bear species found in this reserve [31].

The wild ungulates found here are chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), gaur (*Bos gaurus*), barking deer (*Muntiacus muntjac*), chousingha (*Tetraceros quadricornis*) and wild pig (*Sus scrofa*) [21, 31]. There are over 51648 inhabitants, 36143 livestock in 99 villages around the notified buffer zone of PTR [32]. The locals are predominantly tribal (62%) belonging to Gond and Baiga community [32].

Methods

Three tigers, one adult female (AF: T-15), one adult male (AM: T-2) and one sub-adult male (SAM: T-38), were radio-collared and monitored between March 2008 and December 2011 (Table 1) to understand the ranging and dispersal pattern of tigers. The animals were radio-collared following immobilization with "Hellabrunn mixture" (125 mg xylazine + 100 mg ketamine/ml) [33]. Initial dose depended on estimated body weight and sex of the animal and ranged from 2.5 ml for sub-adult to 2.75 ml for adult female and 3 ml for adult male. The estimated body weight of male, female and sub-adult were 200-220 kg, 140-150 kg and 100-120 kg respectively. Adult male however required supplementation and was administered a second injection of 1.2 ml. The drug mixture was remotely injected from the elephant back using Tele-inject projector (Model 4V.310). The induction time ranged between 26-36 minutes and effective handling time was 25-29 minutes. The drug combination induced reliable immobilization with good muscle relaxation and no significant alteration in physiological responses. The sedated animals were measured, weighed, radio-collared, and photographed. Individuals were aged using tooth wear, eruption, and body size, evidence of sexual development and previous births, and overall body condition. Both, Very High Frequency (Telonics TM) and Satellite radio-collars (Telonics™ and Vectronics™ weighed less than 1% of the body weight of the tiger (Table 1). Yohimbine hydrochloride administered intramuscularly at a dose of 5 mg for every 50 mg of xylaxine [34] provided effective reversal for all the tigers and

Table 1: Home range estimates of three radio-collared Bengal tigers (*Panthera tigris tigris*) in Pench Tiger Reserve, Madhya Pradesh (March 2008 - December 2011).

Tiger Id	Age-Sex	Body weight (kg)	Collaring period	Collar type	Collar weight (kg)	Number of location	Home Ranges in km^2 100 % MCP	95% FK	65 % FK
T-15	Adult female	145	11/3/2008 to 31/12/2011	Very High Frequency (VHF) (Telonics ™)	0.763	750	44	32.1	10.3
T-2	Adult male	>200	1/1/2010 to 30/7/2010	Satellite & VHF (Telonics ™)	1.346	136	55.1	64.1	20.3
T-38	Sub-adult male	180	11/3/2010 To 30/8/2010	Satellite & VHF (Vectronics™)	1.324	739	52.2	19.1	6.6

MCP= Minimum Convex Polygon, FK= Fixed Kernel resulted in complete recovery that ranged from 10-28 minutes. The radio-collared tigers were radio-tracked and monitored either from the elephant back or by vehicle at different times of the day and night so as to record location data throughout the 24 hour period. During the study period, attempts were made to locate at least one and when possible two animals on daily basis following their signals. The located animals were 'homed in' from the elephant back at a distance between 50 and 75 m. Care was taken not to disturb tiger's natural behaviour or movement [35]. Once the animal was sighted, a hand-held Global Positioning System (GPS) was used to record the location with its coordinates. The actual sighting of each animal helped the accuracy of the GPS locations obtained for use in home-range analysis and also gave additional data on activity, behaviour and interaction with other tiger especially with cubs. These locations were also used in home range analysis taking only locations separated by a 6 hour interval in order to avoid auto correlation [36].

In addition, recruitment pattern of the AF was assessed with her home range during the cub-rearing period and compared with her own natal area. As AF was not radio-collared during her early growing stage (< 2 years), the locations of AF along with her mother were collected between May 2006 and June 2007 using Intensive Tiger Search Method (ITSM) [37] and camera trapping [18].

In total 80 pairs of camera traps were deployed (Figure 4) in a systematic 2 km X 2 km grid [18] covering an area of > 410 km^2 during the study period. Individual tigers were identified from their unique stripe patterns [38]. As studied by Sharma and Jhala [37] in Kanha Tiger Reserve, Madhya Pradesh, an album of photographs of all the individual tigers operating in the study area was developed with a brief description of location–capture history including AM and AF and also to identify non collared mother of AF to study the natal area of AF. Using ITSM, tigers were located without affecting their natural movement between 6 am to 10 am from elephant back (n=3 elephants). Tiger pugmarks and alarm calls by prey species (chital, sambar, nilgai and common langur) were followed to locate the animal. In addition, we also collected information on tiger locations from forest beat guards, patrolling their individual beats (lowest administrative setup for any forest in India) on foot on a regular basis. Every GPS locations of tigers obtained from ITSM and camera traps were recorded and plotted on the map to estimate minimum home range.

The 100 % MCP method is the most widely used method [39] and is also more useful for comparison with other relevant studies [7, 8, 24, 26, 40, 41]. The FK is rated as one of the most robust and least biased estimator of home range and performs well even with small sample sizes, auto-correlated data and considers the shape of underlying utilization distributions [42, 43, 44]. The smoothing parameter of FK isopleths was chosen using the Least Square Cross Validation (LSCV) procedure [43, 45]. The 95% fixed kernel method also takes care of exploratory movements and outlying fixes [36, 43, 46]. Thus, home ranges of all three tigers were estimated using both 95% FK and 100% MCP for the present study. In case of the AF, the annual home ranges for four consecutive years were also estimated using both MCP and FK method. The MCP (100%) method was used to estimate the minimum home range or natal area of the AF.

FK (%) isopleths versus the area of the home range were plotted and the point of inflexion of the home range curve was considered for the isopleth defining the core area of the home range [40]. Overlap comparisons were calculated using the 95% FK estimator. Percent overlap between adjacent home ranges was computed as the average proportion of overlap between two home ranges [43, 46].

Distance sampling by line transect method [47, 48, 49] was used to asses prey density and biomass around the den sites of collared female. In total 12 line transects were laid and walked early in the morning when animals found to be more active [50]. Potential prey species of large carnivores were recorded during transect walk along with following parameters such as species, cluster size, animal bearing (with compass) and angular sighting distance (using laser range finder). The density of prey species was calculated using programme DISTANCE *Version 4.1* [51].

Nagarahole- Karanth and Sunquist [41, 59], Ranthambore - Chakrabarty [60], Jhala *et al.* [29]; Panna-Chundawat *et al.* [17]; Pench- Present study, Jhala *et al.* [29]) were compared with their respective tiger densities (Table 2). It was observed that the size of female (mean) home ranges are negatively related (Linear regression, R^2= 0.9116) with overall tiger densities (Fig. 5a) *i.e* when the overall tiger density increases, the female home range size decreases.

A wide variation was observed in case of male home range sizes in different study areas (Table 2). Minimum home range (100% MCP) of the resident male tiger in Chitwan varied from 60 to 100 km² [7]. McDougal [61] recorded a male home range of 90–105 km² (MCP) in Chitwan. Karanth and Sunquist [41] recorded a home range (95% MCP) of 56.7 km² for an adult radio-collared male in Nagarahole, although the tiger had a 95% adaptive kernel home range of 98.8 km². Schaller [50] recorded a minimum range of 78 km² for an adult territorial male and Panwar [62] recorded a minimum range of 30–50 km² for the male in Kanha. Matyushkin [63] estimated minimum ranges of 800–1000 km² for the male tigers in Russia. Miquelle et al. [40] reported seasonal ranges of 235 to 238 km² for a male tiger in Russia. Goodrich et al. [54] reported ranges of 299–614 km² for two translocated radio-collared males in Silkote-Alin in Russia, whereas the mean home range of six adult male tigers was 1,385 km² (95% MCP).

The home range size of male tiger may be influenced by various ecological factors. According to Chundwat *et al.* [17], larger home ranges of radio collared male tiger in Panna may well be a response to the high spatial and temporal unpredictability of available resources. According to Priatna *et al.* [64], the home range size of male tiger is not only determined by the abundance of prey species but also by the density of local tigers that already occupy the area as well as their social structure. Although there may not be sufficient data to compare (Table 2), we found an indication that size of male tiger (mean) home ranges are positively related with the size of female tiger (mean) home ranges (Fig. 5b).

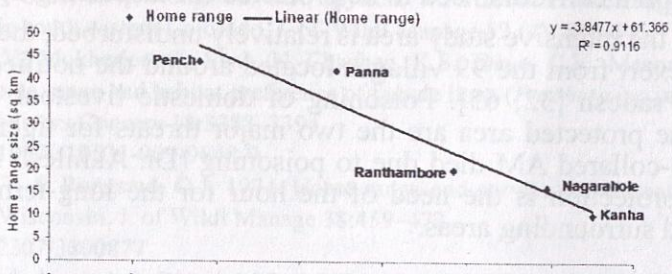

Fig. 5a: Minimum Convex Polygon home range (Mean) sizes (km²) of female tigers (using radio-telemetry) were compared with available overall tiger densities/100 km² (using camera trap) from five different tiger reserves of India, (Kanha - Sharma *et al.* [57], Sunquist [58]; Nagarahole - Karanth and Sunquist [41, 59], Ranthambore - Chakrabarty [60], Jhala *et al.* [29]; Panna - Chundawat *et al.* [17]; Pench - Present study, Jhala *et al.* [29]) (R^2 value obtained from Linear regression).

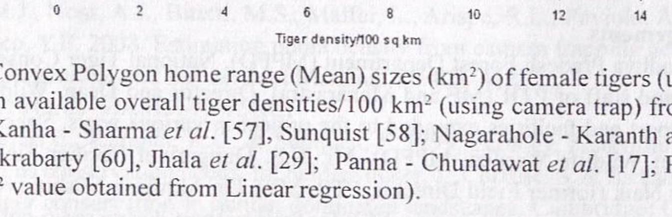

Fig. 5b: Minimum Convex Polygon home range (Mean) sizes (km²) of male tigers (using radio-telemetry) were compared with mean home range size of female tigers from five different tiger reserves of India, (Kanha - Sharma *et al.* [57], Sunquist [58]; Nagarahole - Karanth and Sunquist [41, 59], Ranthambore - Chakrabarty [60], Jhala *et al.* [29]; Panna - Chundawat *et al.* [17]; Pench - Present study, Jhala *et al.* [29]) (R^2 value obtained from Linear regression).

It was observed that the SAM home range remained smaller in its natal area (MCP home range 15.4 km²) and his home range expanded (MCP home range 52.2 km²) gradually during the dispersal stage. Similar findings were reported by Sunquist [7] and Smith in Nepal [25]. Although the SAM's radio-collar ceased functioning after five months of deployment (Table 1), a long-term (January to May 2011) camera trap study, covering a larger area (> 410 km², 102 photographs of 23 individual tigers; 16 female and 7 male) confirmed the dispersal of this individual from its natal area.

Conservation Implication

Our study gave an insight on the breeding tiger habitats in this human dominated landscape. The study revealed that a minimum of 25 to 30 km² undisturbed area was required for a breeding female in the study area. The intensive study area can potentially hold a maximum of 10 breeding tigress based on 44 km² as home range size of a tigress. We have recorded nine breeding tigresses operating in this area (Camera trapping and ITSM). Twenty breeding females are needed for long term survival of tiger population at a site [29]. Thus, it is important to have corridor connectivity with neighboring population of Kanha Tiger Reserve, Satpura Tiger Reserve and Pench Tiger Reserve (Maharastra) to form a meta-population structure for long term viability of tiger population.

According to Smith [25], dispersal plays an important role in the genetic and demographic organization of tiger populations. Our ongoing camera trap study confirmed the dispersal of radio-collared SAM tiger from its natal area (approximately 50 km south-east) to the fringes of Pench Tiger Reserve (Maharastra) and a non-collared sub-adult male tiger from the intensive study area (photo-captured in 2006) to Kanha Tiger Reserve (travelled approximately 150 km north-east and photo-captured in 2010, 2011 and 2012). Therefore, habitat and prey population in Pench- Kanha and Pench-Satpura corridors need to be protected for dispersing tiger individuals.

Though the intensive study area is relatively undisturbed, there is continuous biotic pressure exert from the 99 villages located around the notified buffer zone of PTR, Madhya Pradesh [32, 65]. Poisoning of domestic livestock kills and water holes outside the protected area are the two major threats for tiger population in Pench. The radio-collared AM died due to poisoning (Dr. Akhilesh Mishra Pers. Comm.). Ensured protection is the need of the hour for the long-term survival of tigers in Pench and surrounding areas.

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Five "key references", selected by the authors, are marked below (Three recommended (●) and two highly recommended (●●) papers).

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Co-existence patterns of large sympatric carnivores as influenced by their habitat use in a tropical deciduous forest of Central India

Aniruddha MAJUMDER, Kalyanasundaram SANKAR* and Qamar QURESHI
Wildlife Institute of India, P.O. Box # 18, Chandrabani, Dehradun-248001, Uttarakhand, India

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Habitat used by tiger, leopard and dhole was assessed between June 2006 and April 2011 in Central India. Indirect evidences (pugmark, scrape, scats) of these three large sympatric carnivores were collected from carnivore sign survey (total effort 1162 km in winter and 1674 km in summer) in each sampling unit [i.e. forest beat (n = 44) of the intensive study area (410 km²)]. A total of 1303 and 2238 locations of tiger evidence, 362 and 608 locations of leopard evidence and 264 and 324 locations of dhole evidence were recorded in winter and summer, respectively. Significant difference ($p = 0.02$) was found between summer and winter use of habitats by three large carnivores. We pooled data of same seasons across year as there was no significant difference ($p = 0.09$). All locations were plotted on the classified land use and land cover map and Digital Elevation Model maps and percentage of locations in each class was calculated. The utilized habitat locations were compared with randomly generated available habitat locations (n = 1500) for seasonal habitat selection. It was observed that all three carnivores selectively utilized different habitats. Significant seasonal habitat separation was observed between tiger, leopard and dhole while utilizing different land use and land cover types in both winter ($p = 0.0001$) and summer ($p = 0.01$) and terrain types in winter ($p = 0.001$). This may have allowed them to co-exist in the study area. Protection of the habitat in Pench and surrounding areas is crucial for the survival of large carnivores in this landscape.

Key words: Tiger, leopard, dhole, habitat use, spatial separation, Pench.

INTRODUCTION

Habitat loss and fragmentation are the main challenges in conservation and management of large carnivores worldwide (Peyton, 1999). Habitat fragmentation can result in small, isolated populations which become increasingly vulnerable to extinction (Diamond, 1986; Wilcove, 1987). Animals generally select habitats that satisfy their demands for food, water, and denning sites to optimize survival and reproduction (Boyce & McDonald, 1999; Chamberlain *et al.*, 2002). Though, several hypotheses have been proposed to explain the co-existence patterns of large carnivores in forested habitats (Karanth & Sunquist, 1995); a comparison of habitat use by sympatric species allows an assessment of their interactions. Previous studies have indicated that habitat separation is the most common form of niche partitioning in sympatric species of mammals (Brown & Lieberman, 1973). According to Marsh & Harris (2000), habitat separation between closely related species is one of the most common forms of co-existence. Schoener (1974) also considered habitat separation to be responsible for multispecies co-existence. Information on habitat use and habitat separation is thus crucial to understand the relationship between distribution and abundance of wildlife species (Tejeda-Cruz *et al.*, 2009). This information can be helpful to assess not only habitat requirements of animals but also support sound wildlife management plans (Morrison *et al.*, 2006).

In India, tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) were found utiliz-

* Corresponding author: tel.: ++0135-2640112, e-mail: sankark@wii.gov.in

ing a wide range of habitats (Johnsingh, 1983; Karanth & Sunquist, 1995; Edgaonkar, 2008; Jhala *et al.*, 2008, 2010). In tropical Asia, tigers inhabit forests of deciduous, evergreen, riverine, swamp and mangrove, showing incredible tolerance to variation in altitude, temperature and rainfall regimes. Leopards too, have the ability to adapt in different habitats and feeding on a variety of prey as well as they have the capacity of surviving in close proximity to humans (Hamilton, 1976). The factors which govern dhole habitats are prey abundance, water availability, interspersion of forests with grassy openings, minimum human disturbance and potential den sites (Johnsingh, 1985; Acharya *et al.*, 2007). Conservation of habitat of these sympatric carnivores in the human dominated landscape of India is always been a challenging task for wildlife managers (Wikramanayaeke *et al.*, 1998) as their habitats have been fragmented because of various biotic pressure (Qureshi *et al.*, 2006; Jhala *et al.*, 2008). The reported occupancy of tiger, leopard and dhole in Central Indian landscape in 2006 was 48610 km^2, 117913 km^2 and 85962 km^2, respectively, and 38056 km^2, 92786 km^2 and 71817 km^2, respectively, in 2010 (Jhala *et al.*, 2010).

With the decline of most of the large carnivore habitats from the central Indian landscape (Qureshi *et al.*, 2006; Jhala *et al.*, 2010), there was an urgent need for adopting the effective practical methods to understand the utilization patterns of different habitat resources by tiger, leopard and dhole. Seasonal (winter and summer) utilization of major habitat resources at the population level by each of these species was compared with the available habitat types (Manly *et al.*, 2004) in Pench Tiger Reserve (PTR), Madhya Pradesh. The study area has forest connectivity with PTR, Maharastra and forms one of the most important conservation units for large carnivores in central Indian landscape (Qureshi *et al.*, 2006; Jhala *et al.*, 2010). A detailed long-term study on spatio-temporal utilization of major habitat resources by three co-occurring large carnivores together has not been documented earlier in the central Indian landscape. The objectives of the present study were 1) to evaluate the seasonal utilization of different land use, land cover and terrain types by three large sympatric carnivores and 2) to evaluate the implications of seasonal habitat separation among the three large carnivores for their co-existence in this landscape.

MATERIALS AND METHODS

The study was conducted in Pench Tiger Reserve (PTR), Madhya Pradesh (79° 09′ E to 79° 22′ E and 21° 38 N′ to 21° 50′ N), India. The total geographical area of PTR (758 km^2) consists of Pench National Park (PNP), Pench Wildlife Sanctuary (PWS) and Reserved Forests. Both, PNP and PWS were considered as intensive study area (410 km^2). The terrain is undulating and the elevation ranged between 350 m and 650 m (Sankar *et al.*, 2001). There are three distinct periods; summer (March-June), monsoon (July-September) and winter (October-February). Mean annual rainfall was 1400 mm occurring largely in monsoon period. Temperature varies from a minimum of 1°C in winter to 45°C in summer (Sankar *et al.*, 2001). Vegetation is broadly classified into tropical dry deciduous and tropical moist deciduous forests (Champion & Seth, 1968). The Pench river, which is the major source of perennial water, is dammed downstream of the study area, leading to the inundation of 54 km^2 area of the National Park. A significant part of study area comes under sub-mergence habitat. The draw down area coming under the submergence of Totladoh reservoir (Pench Hydro-electric project) is 11.7 km^2 and cover 1.55% of PTR (Sankar *et al.*, 2001). As summer approaches, these areas, from where the water gradually recedes downstream, become lush green meadows attracting high numbers of wild herbivores. The miscellaneous forest type, more of a moist-deciduous forest and gaps in canopy had lots of grass (Acharya, 1997). This forest type constitutes major association of *Boswellia serrata*, *Anogeissus latifolia*, *Buchanania lanzan*, *Lannea coromandelica*, *Miliusa velutina*, *Bauhinia racemosa* and *Soymida febrifuga* (Dungariyal, 2008). In a teak-mixed forest, more than 75% vegetation type comprised of *Tectona grandis* followed by other species such as *Miliusa velutina*, *Terminalia tomentosa*, *Lagerstroemia parviflora*, *Bauhinia racemosa*, *Ougeinia oojeinensis*, *Grewia tiliaefolia* and bamboo (*Dendrocalamus strictus*) (Dungariyal, 2008).

Wild ungulates comprised of chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Bosephalus tragocamelus*), gaur (*Bos gaurus*), barking deer (*Muntiacus muntjac*), chousingha (*Tetracerus quadricornis*) and wild pig (*Sus scrofa*). Apart from tiger, leopard and dhole, other carnivore species in PTR are golden jackal (*Canis aureus*) and jungle cat (*Felis chaus*). Primate species found are common langur (*Semnopithecus entellus*) and Rhesus macaque (*Macaca mulatta*) (Biswas & Sankar, 2002). The Indian porcupine (*Hystrix indi-*

TABLE 1. Utilization of different land use and land cover types by tiger, leopard and dhole in winter (W) and summer (S) in Pench Tiger Reserve, Madhya Pradesh between June 2006 and April 2011

Species	Land use and land cover classes	No. of random points in each habitat	Proportion available	No. of carnivore signs in each habitat (W)	Proportion used (W)	Lower limit (W)	Upper limit (W)	Intensity of use	No. of carnivore signs in each habitat (S)	Proportion used (S)	Lower limit (S)	Upper limit (S)	Intensity of use
Tiger	Sub-mergence	36	0.031	5	0.004	–0.001	0.008	-	114	0.051	0.039	0.063	++
	Riverine	24	0.021	39	0.029	0.017	0.042	*	189	0.084	0.069	0.100	++
	Miscellaneous	429	0.375	455	0.349	0.314	0.384	*	721	0.322	0.296	0.348	-
	Agriculture	39	0.034	1	0.001	–0.001	0.003	-	3	0.001	–0.001	0.003	-
	Barren land	149	0.130	59	0.045	0.030	0.060	-	256	0.114	0.097	0.132	*
	Teak mixed	467	0.408	744	0.571	0.535	0.607	++	955	0.426	0.399	0.454	*
Leopard	Sub-mergence	36	0.031	0	0	0.000	0.000	-	3	0.005	–0.003	0.012	-
	Riverine	24	0.021	1	0.003	–0.001	0.007	-	6	0.009	–0.001	0.020	-
	Miscellaneous	429	0.375	167	0.461	0.422	0.500	++	252	0.414	0.362	0.467	*
	Agriculture	39	0.034	0	0	0.000	0.000	-	4	0.006	–0.002	0.015	-
	Barren land	149	0.131	9	0.024	0.013	0.037	-	25	0.041	0.020	0.062	-
	Teak mixed	467	0.408	185	0.511	0.472	0.550	++	318	0.523	0.470	0.576	++
Dhole	Sub-mergence	36	0.031	0	0	0.000	0.000	-	1	0.003	–0.005	0.011	-
	Riverine	24	0.021	4	0.015	–0.005	0.035	*	6	0.018	–0.001	0.038	*
	Miscellaneous	429	0.375	110	0.416	0.337	0.497	*	129	0.398	0.326	0.470	*
	Agriculture	39	0.034	0	0	0.000	0.000	-	2	0.006	–0.005	0.018	-
	Barren land	149	0.131	9	0.034	0.005	0.064	++	11	0.033	0.007	0.060	-
	Teak mixed	467	0.408	141	0.534	0.453	0.615	++	175	0.541	0.467	0.613	++

TABLE 2. Utilization of different terrain types (elevation classes) by tiger, leopard and dhole in winter (W) and summer (S) in Pench Tiger Reserve, Madhya Pradesh, between June 2006 and April 2011

Species	DEM ranges (m)	Number of Random points in each categories	Proportion of available categories	No. of carnivore signs in each categories (W)	Proportion of used (W)	Lower limit (W)	Upper limit (W)	Intensity of use (W)	No. of carnivore signs in each categories (S)	Proportion of used (S)	Lower limit (S)	Upper limit (S)	Intensity of use (S)
Tiger	350-500	703	0.455	480	0.379	0.353	0.405	-	755	0.337	0.311	0.362	-
	501-600	843	0.545	786	0.621	0.595	0.647	++	1487	0.663	0.638	0.689	++
Leopard	350-500	703	0.455	182	0.501	0.472	0.530	++	296	0.486	0.457	0.515	++
	501-600	843	0.545	181	0.499	0.470	0.528	-	313	0.514	0.485	0.543	-
Dhole	350-500	703	0.455	117	0.437	0.377	0.496	**	144	0.442	0.382	0.502	**
	501-600	843	0.545	151	0.563	0.504	0.623	**	182	0.558	0.498	0.618	**

TABLE 3. G-test statistics for seasonal spatial separation between tiger, leopard and dhole in Pench Tiger Reserve, Madhya Pradesh

G-test statistics	Land use and Land cover (Winter)	Land use and Land cover (Summer)	Terrain or elevation (Winter)	Terrain or elevation (Summer)
G-adjusted	29.04	21.7	17.735	1.8959
G-critical	12.6	18.3	9.487	9.487
p-value	0.0001	0.01	0.001	0.754
d.f.	6	10	4	4

habitats were utilized less than their availabilities (Table 1). Leopard utilized both teak-mixed and miscellaneous forest types more their availabilities and utilized rocky-barren land and riverine forest more than their availability, whereas utilized both submergence and agricultural land less than their availabilities in winter. In summer, leopard utilized teak-mixed forest more than it's availability and utilized miscellaneous forest in proportion to its availability, whereas riverine, agriculture land, barren land and submergence habitat types were less utilized (Table 1). Dholes utilized both barren land and teak-mixed forests more than their availabilities and utilized riverine and miscellaneous forest in proportion to their availabilities, whereas no dhole evidence was obtained from submergence and agricultural land in winter. In summer, dholes utilized teak-mixed forests more than it's availability and utilized riverine and miscellaneous forests in proportion to their availabilities, whereas barren land, agricultural land and submergence areas were utilized less than their availabilities (Table 1).

Terrain

In both winter and summer tiger utilized elevation between 501 m and 650 m more than its availability, leopards utilized elevation between 350 m and 500 m more than its availability and dhole used both of these terrain types in proportion to their availabilities (Table 2).

Seasonal habitat separation among sympatric carnivores

A significant difference (G-test) was observed by all three carnivores while utilizing different land use and land cover types in both winter ($p = 0.0001$) and summer ($p = 0.01$), terrain types in winter ($p = 0.001$) whereas no significant difference was observed while utilizing different terrain types in summer ($p = 0.75$) (Table 3).

DISCUSSION

The accuracy of habitat use estimates depends on how well the underlying assumptions were met. Large carnivore selectively utilized the habitat, and the pattern of selection differed among seasons. These seasonal differences suggested that habitat selection changed over time. The present study supported the findings of earlier studies in Indian sub-continent that large carnivore prefer dense forested habitats for their different biological activities (Seidensticker, 1976; Biswas & Sankar, 2002; Edgaonkar, 2008; Jhala *et al.*, 2008). Both tigers and leopards are stealthy predator and stalk their prey from a certain distance before attacking (Hornocker, 1970; Seidensticker, 1976; Logan & Irwin, 1985). During present study, evidences of all three species were mostly observed in teak-mixed and miscellaneous forests (together > 90%) in both summer and winter. The utilization of both teak mixed and miscellaneous forest more than their availabilities by all three carnivores might be due to high abundance of sambar in these habitats. Acharya (1997) reported relatively higher heterogeneity both in tree composition and dense under storey found to be preferred habitat of sambar in the study area. The distribution of tiger evidences in hilly terrain (elevation 501-650 m) might be influenced by the distribution of gaur in this habitat (Acharya, 1997). Although there is high diet overlap between tiger, leopard and dhole reported in the study area, some diet segregation amongst them is also observed (Majumder *et al.*, 2012). Tiger can hunt on larger body sized prey species such as gaur which is largely avoided by comparatively smaller body sized dhole and leopard (Ramesh, 2010; Majumder *et al.*, 2012). In PTR, especially during summer, tiger used riverine (8.4%) and submergence (5.1%) areas more as compared to leopard (0.5% only in summer) and dhole (0.3% only in summer) (Table 1). This may be attributed to abundance of chital in both of these habitats (density 167 individuals per km² from line transect). The fairly open canopy and availabilities of palatable grass species *Cynodon dactylon* probably attracted chital in both submergence (11.7 km²) and riverine habitats (12.5 km²). Though chital is also one of the major prey species for both leopards and dholes in the study area, majorly open riverine and submergence areas were less preferred by both of them to avoid inter-specific competition with comparatively larger body sized competitor; tiger. Thus, the habitat requirements of the prey combined with the prey preferences of each species also influenced space use of competing carnivores. Seidensticker (1976) found that, differences in use of habitat patches by tiger and leopard in Nepal was an important component of their ecological separation. Subtle differences in habitat use, possibly associated with avoidance, have also been documented between jaguar and puma in Peru (Emmons, 1987) and in Mexico (Aranda & Sánchez-Cordero, 1996). Avoidance can also magnify the effect of differential patch use (Ives & Dobson, 1987; Chesson & Rosenzweig, 1991). Our finding is also in accordance with the findings of several studies in African savannah where comparatively smaller body sized predators such as African wild dogs (*Lycaon pictus*) and hyenas (*Crocuta crocuta*) avoided the areas used by lions (*Panthera leo*) (Kruuk, 1972; Trikel & Kastberger, 2005; Webster *et al.*, 2012; Darnell, 2012). Durant (2000) also reported that Serengeti cheetahs (*Acinonyx jubatus*) employ avoidance behaviour to reduce the risks of agonistic encounters with lion and hyena. Moehrenschlager *et al.* (2007) found that kit foxes were able to successfully avoid coyotes within relatively small areas indicating that sometimes smaller competitors may be able to co-exist with larger competitors separating their habitats.

Another probable reason for tiger largely utilizing the submergence area may be due to the availability of dense bushes of *Lantana camara* along the Pench river bank which acts as cover for rearing cubs during their early growing stage (< 2 years). The evaluation of denning sites (n = 20) of four breeding female tigers (one radio-collared and three non collared) in the intensive study area showed that, they were found in high prey biomass area (pooled biomass of chital, sambar, nilgai, gaur, wild pig and common langur was 9694.2 kg km^{-2} with a total effort of 618.6 km using line transect method), with no anthropogenic disturbance and availability of water in all seasons (< 200 m).

All three sympatric large carnivore species were observed to avoid agricultural habitats present in the fringes of forest boundary (Table 1). As studied by Smith (1993) in Nepal, tiger probably used agricultural habitat during their dispersal from the natal area. The rocky or barren lands were preferred by dholes during winter and the reason for the same was attributed to denning and rearing pups as reported by Acharya *et al.* (2007).

Differences in habitat use, either temporally or spatially, have been recognized as behavioural characteristics that may promote co-existence (Partridge, 1978). Majumder *et al.* (2012) reported the variation in temporal activity patterns among these large carnivores in the study area may largely lie in utilization of prey resources in different times (hours) of a day (leopard being nocturnal, tiger crepuscular and dhole diurnal). Our study revealed that a significant seasonal spatial separation between these three sympatric carnivores may allow their co-existence in PTR, similar to the co-existence pattern of jaguar (*Panthera onca*) and puma (*Puma concolor*) in a mosaic landscape in the Venezuelan llanos (Scognamillo *et al.*, 2003). Many studies have also found that sympatric carnivores are able to co-exist by selecting different habitats (Seidensticker, 1976; Schaller & Crawshaw, 1980; Norton & Lawson, 1985; Konecny, 1989; Johnson *et al.*, 1996; Fedriani *et al.*, 1999).

Conservation implication

The study area offers a mosaic of ecological and habitat conditions, which effectively contributed to the maintenance of a rich assemblage of ungulates and primates in high numbers (Majumder *et al.*, 2012). This high prey base along with different habitat conditions in the study area is ideal for the sustenance and growth of these three large sympatric carnivores. Our study area Pench is connected with two other source-population sites of large carnivores, i.e. Kanha Tiger Reserve and Satpura Tiger Reserve, and forms one of the important units of meta-population structure of tiger, leopard and dhole in Central Indian Landscape (Qureshi *et al.*, 2006; Jhala *et al.*, 2010). The present study gave insight on multiple large predator co-existence patterns in this human dominated landscape. Though the intensive study area is relatively undisturbed and no poaching of wild ungulate was recorded during the present study, there is continuous biotic pressure exert from the 99 villages located around the notified buffer zone of PTR, Madhya Pradesh (Qureshi *et al.*, 2006). Protection of the habitat in Pench and surrounding areas is crucial for the survival of large carnivores in this landscape.

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*Interbirth interval and litter size of free-ranging Bengal tiger (*Panthera tigris tigris*) in dry tropical deciduous forests of India*

Randeep Singh, Aniruddha Majumder, Kalyanasundaram Sankar, Qamar Qureshi, Surendra Prakash Goyal & Parag Nigam

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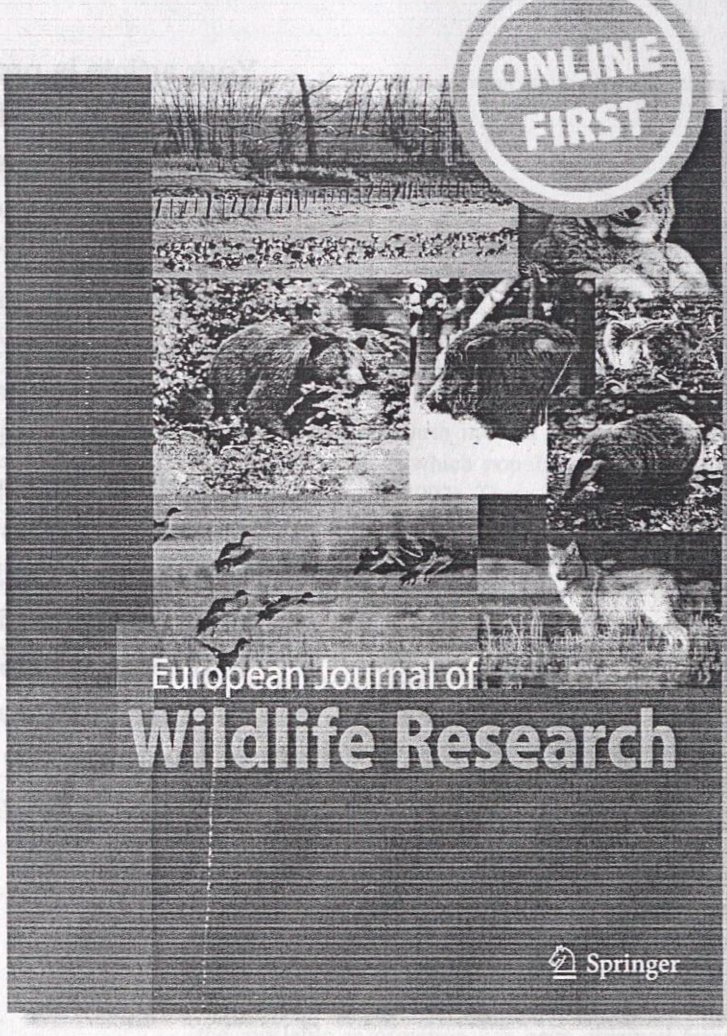

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ORIGINAL PAPER

Interbirth interval and litter size of free-ranging Bengal tiger (*Panthera tigris tigris*) in dry tropical deciduous forests of India

Randeep Singh · Aniruddha Majumder · Kalyanasundaram Sankar · Qamar Qureshi · Surendra Prakash Goyal · Parag Nigam

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Abstract We studied the interbirth interval (IBI) and litter size of the population of free-ranging Bengal tigers (*Panthera tigris tigris*) in dry tropical deciduous forests in Ranthambhore Tiger Reserve (RTR), Rajasthan, and Pench Tiger Reserve (PTR), Madhya Pradesh, between April 2005 and June 2011. Data on 15 breeding females in RTR and nine breeding females in PTR were collected using camera trapping, direct observation and radio-telemetry. The mean±standard error of IBI (months) in RTR was 33.4±3.7 and in PTR was 25.2±1.8. A significant difference was observed between the mean IBI of tigresses in RTR and those in PTR (df=9, *P*=0.04). The estimated mean litter size in RTR was 2.3±0.1 and that in PTR was 2.9±0.2. There was a significant difference between the litter size in RTR and that in PTR (χ^2=12.04, *P*=0.017, df=4). Since RTR and PTR are the important source populations of tigers in the Western and Central Indian landscapes, we propose that the tigers in these reserves be monitored, particularly for reproductive traits that are essential for understanding aspects of their population ecology.

Keywords Reproductive parameters · Breeding tigress · Cubs

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R. Singh · A. Majumder · K. Sankar · Q. Qureshi · S. P. Goyal · P. Nigam
Wildlife Institute of India, Post Box # 18, Dehradun, 248 001 Uttarakhand, India

A. Majumder (✉)
Department of Habitat Ecology, Wildlife Institute of India, Post Box # 18, Dehradun, 248 001 Uttarakhand, India
e-mail: aniruddha@wii.gov.in

Introduction

Reproductive success is a key to the survival of a species, and understanding the reproductive parameters of free-ranging large carnivores is crucial for assessing the reproductive output of their populations for effectively managing them in any human-dominated landscape (Kerley et al. 2003). Among the different reproductive parameters, the litter size and interbirth interval (IBI) are critical for estimating the rates at which populations of large cats might grow (Eizirik et al. 2002). These parameters are also important for determining the reproductive output of an identified source population, for population modeling and for estimating the viability of a population (Smith and McDougal 1991).

Among the felids, the tiger (*Panthera tigris*) is the largest. It is endangered throughout its range (Nowell and Jackson 1996). Despite several decades of national and international conservation efforts, the tiger population continues to decline (Nowell and Jackson 1996; Wikramanayeke et al. 1998; Seidensticker et al. 1999; Sanderson et al. 2006; Dinerstein et al. 2007). For any successful conservation efforts, an understanding of the reproductive parameters is crucial (Kerley et al. 2003), but these are poorly known for free-ranging Bengal tigers (*Panthera tigirs tigris*), and only a few studies have been undertaken in the Indian subcontinent (Sunquist 1981; Chundawat et al. 2002). Most of the available information has been obtained from captive animals (Sadleir 1966; Kleiman 1974; Seal et al. 1987).

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Information on some important parameters of the breeding biology, such as the mean interbirth interval (IBI) and litter size for tiger is limited in Indian subcontinent (Schaller 1967; Sunquist 1981; Smith and McDougal 1991; Smith 1993; Chundawat et al. 2002) and Russian Far East (Kerly et al. 2003). Throughout the range, tigers typically raise only first litter after they are approximately 2 years of age (Smith and McDougal 1991; Chundawat et al. 2002; Kerly et al. 2003). Current descriptions of geographic variations in the litter size and IBI of tigers are anecdotal and imply that there is a likely impact of climatic, ecological and habitat conditions on the demographic and reproductive characteristics of the tiger, i.e., the litter size and IBI. Thus, the present study examined the effects of micro-level climatic variations and prey densities on the litter size and IBI of Bengal tiger populations in two different deciduous habitats in India: 4B (Semi Arid Gujrat-Rajputana) in Ranthambhore Tiger Reserve (RTR) and 6A (Deccan Peninsula-Central Highlands) in Pench Tiger Reserve (PTR) (Rodgers and Panwar 1988).

Study area

We selected two study areas, viz. RTR and PTR, that differ in their climatic conditions at the micro-level as well as in their ecological attributes (Jhala et al. 2010).

(i) Ranthambhore Tiger Reserve (RTR): RTR is a tropical thorn forest and semi-arid region holding the western-most population of the tiger. This population is a unique genetic pool (Sharma et al. 2008) and has been designated a priority tiger conservation unit, level-III (TCU-III) (Wikramanayeke et al. 1998). RTR, situated in the south-eastern part of Rajasthan (25° 54′ N to 26° 12′ N and 76° 22′ E to 76° 39′ E), is an area of importance for biodiversity. It is a transition zone between the desert and peninsular India (Rodgers and Panwar 1988) and receives an average annual rainfall of 800 mm (Bagchi et al. 2003). The total area of the tiger reserve is 1,394 km^2, with the tiger population largely restricted to a core area of 392 km^2 which is our Intensive Study Area (ISA) in RTR. The vegetation of RTR corresponds to northern tropical dry deciduous forests and the northern tropical thorn forest (Champion and Seth 1968). The wild ungulate prey species of the tiger in RTR are the chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), chinkara (*Gazella gazella*), and wild pig (*Sus scrofa*).

(ii) Pench Tiger Reserve (PTR): PTR was designated as a high-priority tiger conservation unit, level-I (TCU-I) (Wikramanayeke et al. 1998). The total area of the tiger reserve (21° 38′ N to 21° 51′ N and 79° 09′ E to 79° 22′ E) is 757 km^2, including Pench National Park (PNP) (292 km^2), Pench Wildlife Sanctuary (PWS) (118 km^2) and reserved forest (347 km^2). The area receives an average annual rainfall of 1,400 mm and supports a tropical deciduous teak (*Tectona grandis*) forest type. The ISA in PTR was 410 km^2 in extent, i.e., it included PNP and PWS. The vegetation in the area is broadly classified as being both tropical dry deciduous and tropical moist deciduous forests (Champion and Seth 1968). The wild ungulate prey species of tigers in Pench are the chital (*A. axis*), sambar (*R. unicolor*), nilgai (*B. tragocamelus*), gaur (*Bos gaurus*), wild pig (*S. scrofa*), and muntjac (*Muntiaccus muntjac*) (Sankar et al. 2001; Majumder et al. 2012a).

Materials and methods

The tiger populations in RTR and PTR were monitored for reproductive traits from April 2005 to June 2011 using camera trapping, radio-telemetry, and intensive monitoring. Intensive monitoring was carried out in both RTR and PTR between April 2005 and June 2011 through direct and indirect evidence of tigresses with cubs. In PTR, camp elephants were also used to collect detailed information on breeding tigresses with cubs. Systematic camera trapping was carried out between April 2005 and June 2011 in RTR and between May 2006 and June 2011 in PTR. One radio-collared tigress in PTR was also monitored between March 2008 and June 2011 (Majumder et al. 2012b).

Data on litter size and interbirth interval (IBI) in RTR and PTR

Study design

In RTR, the study area was divided into 1 km^2 grids, and in total, 224 grids that covered 233 km^2 were selected, based on a reconnaissance survey and the presence of indirect signs (i.e., pugmarks, scats, and scrape marks) (Singh 2011). Pair of camera traps was deployed in each systematic grid. We used two types of remotely triggered camera trap (n=100) systems (active infrared and digital passive infrared) to take pictures of both the flanks of an animal. All camera traps were placed at a distance of 5 m from the center of the trail so as to get full-frame pictures of tigers. We deployed one camera trap on the either side of the road to maximize the capture probability (Wilson and Delahay 2001). As we had limited resources, the study area was further divided into three to four adjacent spatially separated blocks, and sampling was done phase-wise systematically.

Owing to the good network of roads, all the trapping sites were checked on a regular basis.

In PTR, pair of camera traps was deployed in a systematic 4 km^2 grid covering an area of 200 km^2. A total of 36 active and passive camera traps were deployed among the trap sites and placed opposite each other to get pictures of both flanks of tiger. The camera time delay was set at the minimum (6 to 60 s) to maximize the chances of capturing cubs with mothers (Majumder 2011).

Data collection on reproductive traits

The adult female tigers photo-captured in the two study areas were individually identified as suggested by McDougal (1977) and Karanth (1995) by the stripe patterns on their right and left flanks. As suggested by Sharma and Jhala (2010), an album of photographs of all the breeding tigers operating with cubs (indexed by age and sex) in the study area was developed. Each photograph was provided the date of capture and a brief description of the location. The identified females were assigned unique numbers. Data obtained from opportunistic sightings were also used to maximize the sampling efforts to record the number of cubs with a breeding female. We estimated the litter size by regular monitoring at the individual level through identified breeding females through (i) intensive monitoring, (ii) locating the pugmarks of cubs with a mother, and (iii) photo-capturing using a camera trap. Recording the actual litter size at birth in free-ranging elusive carnivores is difficult, and hence we do not have confirmed data on the litter size of the tiger at the time of birth. The litter size of tiger is noted when cubs are seen moving with their mothers (Smith et al. 1987). If any identified female tiger was photo-captured or sighted with cubs, the capture date was recorded, and the approximate date of birth of the cubs was estimated by subtracting 2 months from the first appearance of the cubs, as suggested by Smith et al. (1987). The IBI was estimated when the same female produced a second or third litter and was photo-captured or sighted with her cubs. Since our monitoring was intensive, it is likely that we did not miss any tigress in the study area in our long-term monitoring, except for animals that migrated.

Intensive monitoring of the tiger populations throughout the year, except during the rainy season, enabled us to identify the litter size and mortality of cubs. If the cubs were not photo-captured or found to be moving with their mothers (as confirmed by pugmarks) for more than 6 months, we assumed that the cubs were lost. We considered as a cub any tiger that was up to 12 months old, and we classified the cubs by size based on our continuous monitoring of radio-collared females with cubs in PTR.

Data analysis

The differences between litter size and IBI were compared using Student's t test (Zar 1984) and paired t test, assuming equal or unequal variances as appropriate (Sokal and Rohlf 2012). SPSS ver 16.0 was used for data analysis.

Results

Sampling efforts in RTR and PTR

A total of 12 occasions of camera trapping were carried out in the ISA during the study period (2005 to 2011), amounting to 33,340 trap nights. A total of 647 photographs of female tigers (71 photographs of females with cubs and 576 photographs of females without cubs) were obtained (Table 1). In addition, 79 females without cubs and 38 females with cubs were recorded through direct sightings (n=117).

In PTR, a total of five camera trap sessions (one in each of the years from 2006 to 2011, except for the year 2007), amounting to 20,880 trap nights, were conducted. A total of 202 photographs of female tigers (70 photographs of females with cubs and 132 photographs of females without cubs) were obtained (Table 1). In addition, we followed through radio-telemetry (n=750 locations) one breeding tigress that recruited 12 cubs in three litters between May 2008 and October 2010. Intensive monitoring of tigers in ISA yielded information on 30 distinct cubs from marked non-collared breeding tigresses (n=8).

Each female in the two areas was intensively monitored during the study period. The number of photographs obtained for each breeding individual ranged from 1 to 10 in RTR and from 1 to 9 in PTR (Table 1).

Litter size

A total of 22 litters were recruited by 15 breeding females during the study period in RTR (Table 1), and a total of 18 litters were recruited by 9 breeding females in PTR (Table 1). In RTR, there were 51 cubs from the 22 litters. The sex of 32 of these cubs was identified. In PTR, there were 52 cubs from the 18 litters, and the sex of 38 cubs was identified (Table 1). In both these study sites, a litter size of two cubs was observed most frequently (>47 %), followed by a litter size of three cubs (Fig. 1). The mean litter size in RTR was 2.3±0.12 (n=22, range=1–3), and it was 2.9±0.2 (n=18, range=2–5) in PTR. The mean litter size of RTR was significantly lower than that of PTR (df=17, P=0.02).

Table 1 Interbirth interval (IBI) of Bengal tiger (*Panthera tigris tigris*) in Ranthambhore and Pench Tiger Reserves from April 2005 to June 2011

Female ID	Litter no.	*n*	IBI (months)	Litter size (cubs)			
				Tot	M	F	UK
RFT-16	1	7	–	2	1	1	–
	2	2	24	3	–	3	–
RFT-15	1	2	–	2	2	–	–
	2	3	32	2	1	1	–
RFT-14	1	1	–	1	–	1	–
RFT-22	1	6	–	3	3	–	–
RFT-27	1	1	–	2	2	–	–
RFT-30	1	3	–	3	2	1	–
RFT-26	1	2	–	3	–	3	–
	2	4	45	3	–	–	3
RFT-31	1	2	–	2	–	–	2
	2	3	36	2	–	–	2
RFT-05	1	6	–	3	2	1	–
	2	2	48	2	–	–	2
RFT-04	1	10	–	2	1	1	–
RFT-13	1	7	–	2	1	1	–
	2	2	24	2	–	–	2
RFT-09	1	2	–	2	1	1	–
	1	2	–	2	2	–	–
RFT-11	2	1	25	3	–	–	3
RFT-08	1	1	–	2	–	–	2
RFT-19	1	2	–	3	–	–	3
Total	22	71	–	51	18	14	19
PFT-04	1	5	–	4	2	2	–
	2	3	19	4	2	2	
	3	2	24	2	–	–	2
PFT-07	1	9	–	4	2	2	–
	2	4	32	4	2	2	–
	3	5	23	4	–	–	4
	4	2	6	2	–	–	2
PFT-12	1	1	–	2	1	1	–
	2	4	29	2	–	–	2
PFT-15	1	3	–	3	1	2	–
	2	9	5	4	3	1	–
	3	7	24	5	1	4	–
PFT-16	1	2	–	2	–	–	2
	2	6	7	2	1	1	–
PFT-25	1	2	–	2	1	–	1
PFT-35	1	1	–	2	–	1	1
PFT-5	1	3	–	2	1	1	–
PFT-33	1	2	–	2	1	1	–
Total	18	70	–	52	18	20	14

n number of photographs, *Tot* total, *M* male, *F* female, *UK* unknown sex, *RFT* ranthambore female tigress, *PFT* Pench female tigress

Interbirth interval (IBI)

A significant difference was observed between the mean IBI of tigresses in RTR and those in PTR (df=9, P=0.04) (Fig. 2). The mean IBI in RTR was 33.4±3.7 months (range 24–65 months), and that in PTR was 25.2±1.8 months (range 19–32 months). In PTR, three females delivered cubs within 5–7 months after losing all cubs from an earlier litter.

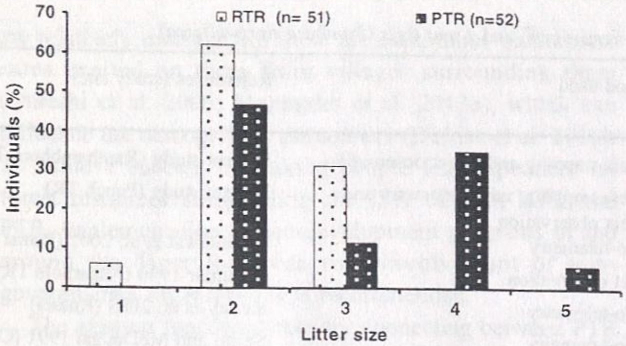


Fig. 1 Percent variations in litter size of different female tigers in Ranthambhore and Pench Tiger Reserves from April 2005 to June 2011

These instances were excluded from the IBI calculations. In RTR, one female recruited 45 months after the loss of cubs from an earlier litter during the study period.

Discussion

A limited number of studies have been carried out on the reproductive biology of free-ranging tigers in the Indian subcontinent (Sunquist 1981; Smith and McDougal 1991; Smith 1993; Chundawat et al. 2002) and in Russia (Kerley et al. 2003) (Table 2). The present study was a pioneer effort in which different reproductive parameters of tigers were compared in two source populations using comparable scientific techniques such as camera trapping, radio-telemetry, and studying pugmarks. The mean litter size of both PTR and RTR, documented in this study was comparable with those of Panna Tiger Reserve (mean litter size 2.3, n=12) (Chundawat et al. 2002), Chitwan National Park (mean litter size 2.9) (Smith and McDougal 1991) and Nagarhole Tiger Reserve (mean litter size 3, n=15) (Karanth et al. 2006) and that of the Amur tiger (mean litter size 2.4±0.6, range 1–4, n=16) (Kerley et al. 2003).

PTR has 20 rock caves for tiger breeding in the ISA, whereas in RTR, there are 15 caves found for tiger breeding in the ISA. Hence, we believe that the availability of safe rock caves may not have much influence on higher litter size in both study areas. The observed high litter size of tiger in PTR may be attributed to individual tiger's genetic ability.

The mean litter size of large felids such as the tiger (Sunquist 1981), leopard (*Panthera pardus*), African lion (*Panthera leo*), cheetah (*Acinonyx jubatus*), jaguar (*Panthera onca*), puma (*Puma concolor*), and snow leopard is positively correlated with the body weight (R^2=0.7, Fig. 3). However, the observed variation in IBI among the individuals of the two populations (Fig. 3) may be due to the presence of cubs with their mothers, as tigers are known to come into oestrus when a cub has either died or dispersed from its mother. The mean IBI of PTR was comparable with those found in Chitwan National Park, Nepal (21.6 months, n=7) (Smith and McDougal 1991), Panna Tiger Reserve (21.6 months, n=14) (Chundawat et al. 2002) and in Amur tigers (21.6 months) (Kerley et al. 2003), but the mean IBI in RTR (33.4 months, n=15) was higher than the values determined in any other studies on Bengal tiger (Table 2).

The longer IBI in RTR might be due to the influence of harsh climatic conditions during summer and the low annual precipitation (<800 mm, present study), compared with Panna (1,100 mm, Chundawat et al. 2002), PTR (1,400 mm, present study) and Chitwan National Park (2,150 mm, Smith and McDougal 1991). The limited data indicated that the IBI is negatively correlated with the average annual rainfall though not significant (Fig. 4). We compared the IBI and principal prey densities of four different sites in the Indian subcontinent and found no strong influence of the principal prey densities on the IBI (Fig. 4).

Conservation implications

Our study provided an insight into the reproductive biology of free-ranging Bengal tigers in two distinct bio-geographic zones. Both RTR and PTR support very high densities of wild prey (Bagchi et al. 2003; Majumder et al. 2012a), which is essential for the long-term sustenance of tigers and the growth of tiger populations. Though both the ISAs

Fig. 2 Percent variations in interbirth interval of different female tigers in Ranthambhore and Pench Tiger Reserves from April 2005 to June 2011

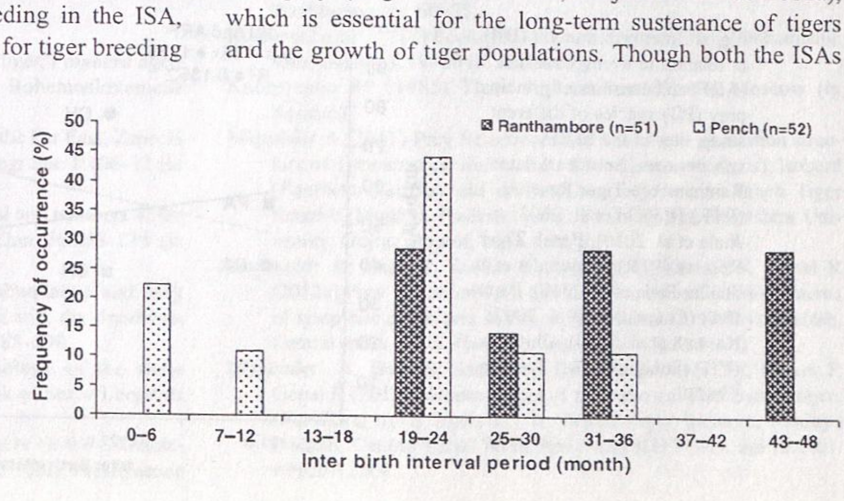


Table 2 Interbirth interval and liter size of Bengal tiger (*Panthera tigris tigris*) and Amur tiger (*Panthera tigris altaica*)

Subspecies	Mean litter size (cubs)	Interbirth interval (months)	Method used	References (study site)
Bengal	2.3	33.4	Camera trapping and direct observation	Present study (Ranthambhore TR)
Bengal	2.9	25	Camera trapping, radio-telemetry and direct observation	Present study (Pench TR)
Bengal	2.3	21.6	Radio-telemetry	Chundawat et al. 2002 (Panna TR)
Bengal	3		Direct observation	Sukumar 1990 (Nagarhole TR)
Amur	2.5	21.8	Radio-telemetry	Kerley et al. 2003 (Russia)
Bengal	2.98	21.6	Radio-telemetry	Smith and McDougal 1991 (Chitwan National Park, Nepal)
Amur	2.4	>36	Snow tracking	Abramov 1962, 1977 (Russia)
Amur	1.8	–	Snow tracking	Abramov 1965 (Russia).
Amur	2.4	–	Snow tracking	Kucherenko 1972, 1985 (Russia)
Amur		>36	Snow tracking	Matyushkin 1984 (Russia)
Amur	–	>36	Snow tracking	Salmin 1940 (Russia)
Amur	1.7	–	Snow tracking	Smirnov and Miquelle 1999 (Russia)
Amur	1.9	–	Snow tracking	Bragin 1989 (Russia)

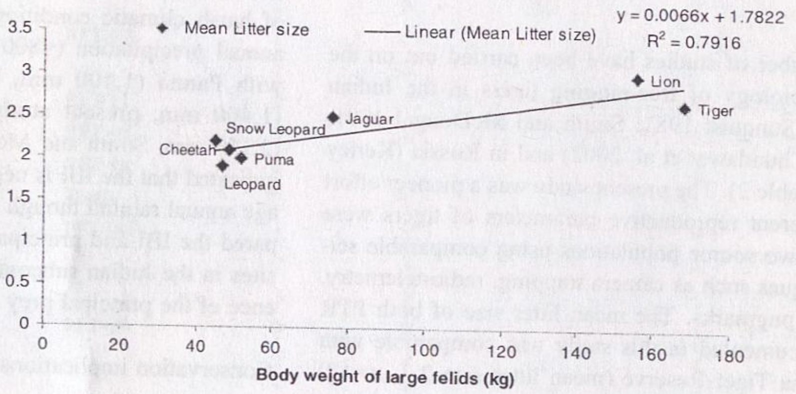
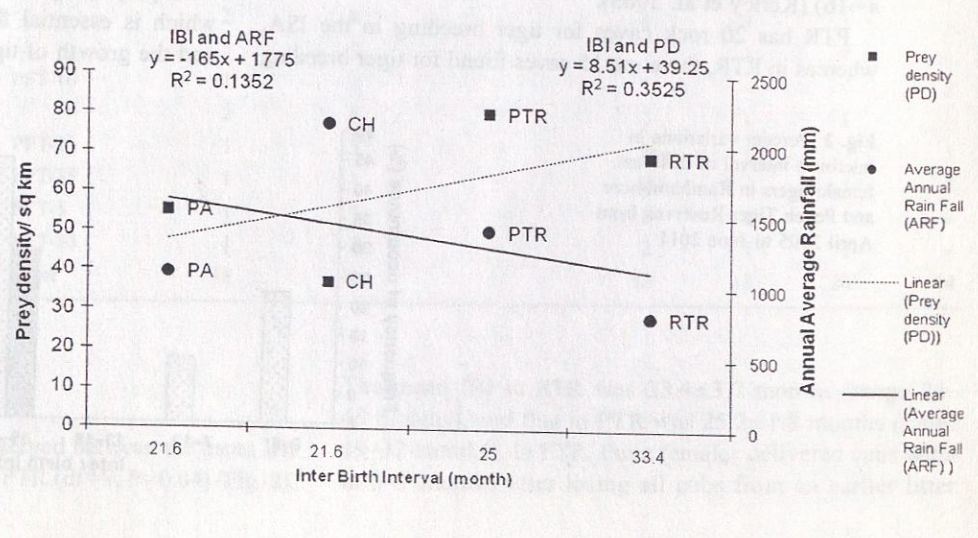


Fig. 3 Body weight (kilogram) in relation to mean litter size of different large felids. Source of data: tiger (Sunquist 1981 and mean of PTR and RTR), leopard (Carbone and Gittleman 2002; Friedmann and Traylor-Holzer 2008), lion (Radloff and Du Toit 2004; Schaller 1972), cheetah (Radloff and Du Toit 2004; Kelly et al. 1998), jaguar (Mondolfi and Hoogesteijn 1986; Carrillo et al. 2009), puma (Carbone and Gittleman 2002; Eaton and Verlander 1977), snow leopard (Shehzad et al. 2012; Blomqvist and Sten 1982)

Fig. 4 Interbirth interval (IBI) in relation to average rainfall (ARF) and densities of principal prey (PD) species of different study sites in the Indian subcontinent. Source of data: Ranthambore Tiger Reserve (RTR) (Bagchi et al. 2003; Jhala et al. 2010), Pench Tiger Reserve (PTR) (Majumder et al. 2012a; Jhala et al. 2010), Panna (PA) (Chundawat et al. 2002; Karanth et al. 2004), Chitwan (CH) (Sunquist 1981; Tamang 1982)



are relatively undisturbed, there are continuous biotic pressures exerted on them from villages surrounding them (Qureshi et al. 2006; Majumder et al. 2012b), which can influence the demographic parameters (Defries et al. 2010). To achieve success in making people less dependent on forest resources surrounding the ISA of both RTR and PTR, implementation of eco-development programs in and around the Tiger Reserves with involvement of non-governmental organizations is recommended.

The existing functional corridor connecting between PTR and neighboring population of Kanha Tiger Reserve, Satpura Tiger Reserve and Pench Tiger Reserve, Maharastra, needs to be maintained to form a meta-population structure for long-term viability and survival of tiger population in PTR. Since RTR does not have functional corridors at present with Kailadevi National Park, Kuno Wildlife Sanctuary, Ramgarh Bishdhari Wildlife Sanctuary and National Chambal Wildlife Sanctuary (Jhala et al. 2010), restoration of these corridors required for tiger dispersal is the need of the hour.

As RTR and PTR are the important source populations of tigers in the Western and Central Indian landscapes (Jhala et al. 2010), ensuring their protection and continuous monitoring of the tiger populations in these areas, particularly for reproductive traits, is crucial for their long-term survival as well as for gaining an understanding of aspects of population ecology.

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