PREY SELECTION, FOOD HABITS AND POPULATION STRUCTURE OF SYMPATRIC CARNIVORES: TIGER *Panthera tigris tigris* (L.), LEOPARD *Panthera pardus* (L.) AND DHOLE *Cuon alpinus* (PALLAS) IN PENCH TIGER RESERVE, MADHYA PRADESH (INDIA)

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By

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Certificate

This is to certify that the thesis titled "**Prey Selection, Food Habits and Population Structure of Sympatric Carnivores: Tiger *Panthera Tigris tigris*, Leopard *Panthera pardus* and Dhole *Cuon alpinus* in Pench Tiger Reserve, Madhya Pradesh (India)**" submitted for the award of degree of **Doctor of Philosophy** in Wildlife Science to Saurashtra University, Rajkot is a record of original and independent research work carried out by **Mr. Aniruddha Majumder** under our guidance. No part of this thesis has been submitted in part or full to any other University/Institution for the award of any degree and it fulfils all the requirements laid down by Saurashtra University.

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Executive Summary

A detailed long-term study on prey selection, food habits and population status of three sympatric large carnivores (tiger, leopard and dhole) was documented during the present study. In many protected areas upto date scientific information on this aspect remains negligible. To supplement the current basic information, the present study was conducted in Pench Tiger Reserve (PTR), Madhya Pradesh from May 2006 to April 2011.

The objectives of the study include estimating density, group size and composition of prey species of sympatric carnivores, food habits and prey selectivity of sympatric carnivores and to estimate the population of the sympatric carnivores.

Prey species availability was estimated using line transect method in an intensive study area of 410 km^2. During this study forest beat was considered as sampling unit and line 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 and were walked during winter (total effort= 1016 km) and summer (total effort =1168 km). Significant difference ($p<0.05$) was observed on visibilities of sighting distance of prey species between two seasons (summer and winter) and hence I 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*) for the year 2007, 2008, 2009, 2010 separately 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/km^2 in winter and 90 ± 8.2 SE/km^2 in summer) followed by chital (50± 7.1 SE/km^2 in winter and 71.1±11.1 SE/km^2 in summer), sambar (6±0.5 SE/km^2 in winter and 9 ±1.1 SE/km^2 in summer), nilgai (2±0.5 SE/km^2 in winter and 2.1±0.5 SE/ km^2 in summer), wild pig (5.2±1.2 SE/km^2 in winter and 12±1.5 SE/km^2 in summer) and gaur (1.4±1 SE/km^2 winter and 1.4±0.5 SE/km^2 in summer).

The estimated mean biomass for six potential prey species from line transect was 4894.4±1046.3 kg/km^2 in winter and 6705±1080 kg/km^2 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 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 in (24.1% in winter and 16% in summer), in 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 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 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 7.5±0.8. In case of sambar, the mean group size in winter was 2.2±1.3 and in summer was 3.1±0.3. In case of nilgai, the estimated mean group size in winter was. 2.1±1.4 and in summer was 1.9±0.3. In case of wild pig, the estimated mean group size in winter was 5.7±2.2 and in summer was 4.3±0.8. In case of gaur, the estimated mean group size in summer was 2.3±0.8, 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 was 7.4±0.6. The seasonal group size of chital varied from 1 to 32 during winter and from 1 to 203 during summer. In case of sambar, the seasonal group size varied from 1 to 5 in winter and from 1 to 12 in summer. In case of nilgai, the seasonal group size varied from 1 to 5 in winter and from 1 to 6 in summer. In case of gaur, the seasonal group size varied from 1 to 15 in winter and from 1 to 4 in summer. In case of wild pig, the seasonal group size varied from 1 to 28 in winter and from 1 to 14 in summer. In case of common langur the seasonal group size varied from 1 to 23 in winter and from 1 to 39 in summer.

Prey selection and large carnivore food habits were evaluated from November 2006 to June 2010 using scat and kill data. In total 469 tiger scats were collected during winter and 157 scats during summer, 107 leopard scats in winter and 82 scats in summer and 199 dhole scats were collected in winter and 139 scats in summer. Kills made by these three sympatric carnivores were recorded opportunistically. In total, 127 tiger kills were recorded during winter and 165 during summer. Thirty six leopard kills were collected during winter and 55 during summer and 32 dhole kills were collected during winter and 55 during summer. I compared the age-sex class distribution of each major prey species in the kill data with the corresponding population age-sex distribution recorded from line transects and vehicle transects, to find out if the sympatric carnivores were selecting a particular age-sex class of prey species.

The scat analysis revealed the presence of ten prey species in the diet of tiger in winter and seven prey species in summer; eight prey species both in the diet of leopard in winter and summer, whereas nine prey species in the diet of dhole in winter and seven prey species in summer. 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 leopard scats, chital contributed maximum (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, 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), 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 observed 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.

Of the 292 tiger kills recorded, 127 were observed during winter and 165 kills during summer; in case of leopard 36 kills were recorded during winter and 55 kills were recorded during summer, whereas 32 kills in winter and 55 kills in summer were recorded in case of dhole. Chital adult male contributed maximum in case of all three carnivores in both winter and summer (for tiger 19.7% in winter and 33.3% in summer, for leopard 33.33% in winter and 40% in summer and for dhole 21.9% in winter and 29.1% in summer) followed by sambar adult female (for tiger 14.2% in winter and 9.1% in summer, for leopard 1.8% in summer and for dhole 18.8% in winter and 5.5% in summer). Gaur contributed only in the diet of tiger. Common langur was predated maximum by leopard (11.1% in winter and 12.7% in summer) followed by tiger (0.8% in winter and 1.2% in summer). Peafowl (1.6% in winter), cattle (0.8%) and porcupine (0.6%) were found to be killed only by tiger during the study period.

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. In case of leopard, nilgai, sambar, chital and wild pig were significantly consumed (*p*=0.001) more than their availability and common langur were less utilized in both winter and summer in terms of individual density. Sambar and chital were significantly consumed (p= 0.001) more than their availability by dhole whereas wild pig and common langur were less utilized in winter and in summer sambar, nilgai and chital were utilized more than their availability and wild pig and common langur were less utilized in terms of individual density.

It was observed from kill study that during both summer and winter chital adult male were preferred by all three carnivores as compared to their availability.

The estimated dietary overlap as determined by scat analysis, between tiger and leopard was 91% in winter and 88% in summer, between tiger and dhole it was 97% in winter and 99% in summer and between leopard and dhole it was 96% in winter and 88% in summer. The overall dietary overlap between tiger and leopard was 89%, tiger and dhole was 98% and leopard and dhole was 92%.

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 conditions, 26.1% by medium health condition and 31.7% by poor health condition. Of the 59 leopard kills, 30.3% was contributed by prey species with good health condition, 24.2% with medium health condition and 53.1% with poor health condition. Of the 50 dhole kills, 29.2% was contributed by prey species with good health conditions, 10.1% with medium health condition and 60.8% with poor health conditions. The study revealed that these sympatric carnivores in PTR largely depended on wild ungulates rather than domestic livestock.

Remotely triggered ‘‘camera traps’’ were used in the intensive study area (410 km^2) to estimate populations of tiger and leopard; and whereas survey-based Royal Nichols heterogeneity model was used to estimate population of dhole. A pair of cameras was deployed in a systematic 2 km X 2 km grid during 2006, 2008, 2009, 2010 and 2011 and the minimum distance between one camera locations varied from 1.5 to 2 km. In total, 84 km^2 was covered in 2006 (Minimum Convex Polygon) followed by 218 km^2 in 2008, 239 km^2 in 2009, 357 km^2 in 2010 and 410 km ^{2} in 2011. 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. Each photograph of an individual represented a capture occasion. Identification of individual was done based on examination of the position and shape of stripes on the flanks for tiger and rossete pattern for leopard. Program MARK ver 6.0 was used for data analysis. Pollock's Robust design was used to estimate survival rate of tiger and leopard using the same program. The estimated overall tiger population as per the best fitted model was 12 ±0.3 (*p*-hat or capture probability was 0.07, under M (O) null model), 17±2.5 (*p*-hat = 0.07), 17±2.5 (*p*-hat = 0.03, under M (O) Null model), 18±3.3 (*p-hat* = 0.02, under M (B) l model) and 22±0.4 (*p*-hat = 0.08, under M(h) Jacknife model) for the year 2006, 2008, 2009, 2010 and 2011 respectively. The estimated over all tiger density under ½ MMDM (Mean Maximum Distance Moved) method was 9.5±1.2/100 km^2 (M (O) null model), 3.4±0.5/100 km^2 (M (bh) model), 3.6±0.5/100 km^2 and 3.5±0.5/100 km^2 both under M (O) Null model, 3.1±0.2/100 km^2 (under M (h) model) respectively for the year 2006, 2008, 2009, 2010 and 2011. The estimated tiger density under Maximum likelihood method (ML-Dens) was 4±1.2 /100 km^2 (M (O) null), 2.6±0.6/100 km^2 (M bh), 4.4±1.9/100 km^2 (M (O) null), 3.6±1.5/100 km^2 (M (O) null) and 2.5±0.7/100 km^2 (M (h) Jacknife) for those respective years. The Effective Trapping area was 151.6 km^2, 556.7 km², 491.2 km², 719.6 km² and 881.6 km² for the year 2006, 2008, 2009, 2010 and 2011 respectively.

The estimated overall leopard population as per the best fitted model was 10.1 ±2.8 (*p*-hat 0.04, M (h) jackknife model), 14±3.2 (*p*-hat = 0.04, M (bh) model), 16±2.1 (*p*-hat = 0.03, M (bh) model), 22±5.4 (*p-hat* = 0.05, M (h) jackknife model) and 39±24.1 (*p*-hat = 0.01, M (bh) model) for the year 2006, 2008, 2009, 2010 and 2011 respectively. The estimated over all leopard density under ½ MMDM (Mean Maximum Distance Moved) method was 7.5±2.6/100 km² (M (h) jacknife model), 2.3±0.6/100 km² (M (h) model), 6.4±2/100 km² (M (O) null model), 4.9±1.2/100 km² (Mbh model) and 10.6±3.2/100 km² (M bh model) respectively for the year 2006, 2008, 2009, 2010 and 2011. The estimated leopard density under Maximum likelihood model (ML-Dens) was 7.3±2.6/100 km² (M (O) null, 1.5±0.5/100 km² (M (bh) model), 8.5±5/100 km² (M (O) null and 9±4/100 km² (under M (O) null) for the years 2006, 2008, 2009 and 2011 respectively. The Effective Trapping area was 151.6 km², 556.7 km², 491.2 km² and 881.6 km² for the years 2006, 2008, 2009 and 2011 respectively.

Based on camera trap photographs, the estimated adult sex ratio (female: male) for tiger during 2006 (number of individual or n= 12) was 100:33 followed by 100:42 in 2008 (n= 17), 100:56 in 2009 (n=14), 100:60 in 2010 (n=16) and 100:47 in 2011 (n=22).

In case of leopard, the adult sex ratio during 2006 (number of individual or n= 10) was 100:100 followed by 100:38 in 2008 (n= 11), 100:88 in 2009 (n=15), 100:125 in 2010 (n=18) and 100:47 in 2011 (n=22).

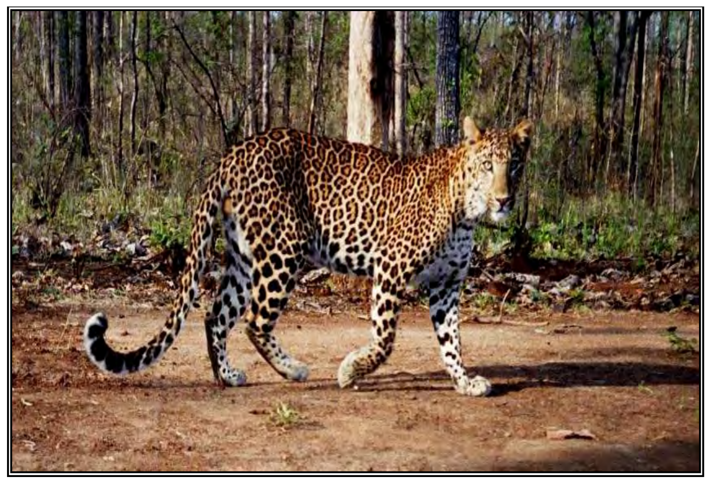
The estimated average abundance of dhole in the study area was 0.24± 0.08 (Standard Error or SE)/100 km². The estimated occupancy was 0.21± 0.08 (SE). Detection probability or r was 0.74± 0.09 (SE). The average or mean dhole pack size was 13.9± 1.4 (SE). The estimated individual density of dhole in the study area (multiplying average pack size of dhole with average abundance) was 3.3±1.2 /100 km^2.

According to best fitted model the estimated survival rate for overall tiger was 0.64±0.06, for male tiger was 0.54±0.12 and for female tiger was 0.67±0.08. In case of leopard estimated survival rate for overall leopard was 0.63±0.11, for male leopard was 0.76±0.13 and for female leopard was 0.42±0.16.

Spatio-temporal utilization of major habitat features by tiger, leopard and dhole and temporal activity patterns of these sympatric carnivores were studied in PTR. 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 to study habitat selection. There was a significant difference between tiger, leopard and dhole in terms of utilization of different vegetation types during winter (p = 0.0001) and summer (p = 0.01), different canopy classes in winter (p = 0.001) but no significant difference (p = 0.754) was observed in summer utilization of canopy cover, terrain types in both winter (p = 0.2) and summer (p = 0.08). The camera trap studies (n=52 pairs) revealed that both tiger and leopard showed two activity peaks, evening (18:01- 22:00 hrs) and early morning (02:01 – 06:00 hrs) and dhole had two activity peaks, morning (06.01-10.00hrs) and afternoon (14.01-18.00hrs).

The results highlighted both the potential and the difficulties involved in multispecies conservation planning as all three carnivores showed plasticity to remain in different forested habitat of PTR, segregating spatially with each other. This observed spatial segregation between these carnivores to reduce inter-specific competition may have influence in their co-existence in Pench. The study clearly suggested that effective wildlife conservation is necessary for the management of adjacent forest patches of the PTR, as the observed spatial variation in all three carnivores' among the different forested habitats may indicate continuous movements of those species even outside the Tiger Reserve. PTR is connected with Kanha Tiger Reserve in north east and Pench Tiger Reserve, Maharastra in south and hence long-term monitoring of these sympatric carnivores using comparable scientific method is essential.

Chapter 1



Chapter 1

GENERAL INTRODUCTION

1. Introduction

One of the important challenges for any sympatric carnivore studies is to understand their ecological separation (Seidensticker 1976a). Whether the separation is causally related to competitive interactions, due to stochastic effects, or to other structuring factors has however been the subject of some debate (Weins 1977; Schoener 1982). Utilization of available food resources by them and their spatio-temporal patterns of abundance are the windows into community ecosystem and evolutionary processes. As tertiary consumer, predator plays an important role in regulating prey species such as herbivores and omnivores (Carbone *et al*. 1999). Such predator-prey dynamics maintain the health and balance of ecosystems. The competitive exclusion principle in ecology has traversed a tortuous path from its inception in the ideas of Volterra (1926), Lotka (1932), and Gause (1935) to its present extension into the concepts of the community matrix, in which groups of species compete with one another (Vandermeer 1970; Wilbur 1972). Empirically, the importance of competition among sympatric carnivores has been difficult to assess due to the paucity of intensive field studies (Palomares and Caro 1999).

Generally, coexistence in carnivores appears to be facilitated by differences in body size (Kiltie 1984; Rosenzweig 1966). Since predator body size is usually correlated with the size of prey utilized (Hespenheide 1973; MacDonald 1980; McNab 1971; Rosenzweig 1966), body size differences often result in the segregation of predators along a continuous prey size resource axis. Character displacement in response to inter-specific competition has been invoked as one possible mechanism by which this segregation arises (Kiltie 1984; McNab 1971; Rosenzweig 1968).

Factors influencing large and medium sized carnivore prey choice in a tropical forest of India are a result of a complex interplay of various ecological parameters that often varies at the extremes of distribution of those species (Johnsingh 1983; Sunquist and Sunquist 1989; Karanth and Sunquist 1995). Our understanding of this phenomenon was far from complete (Sunquist and Sunquist 1989) and is urgently required for a highly endangered species like the tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) which inhabit diverse ecosystems. Thus increasing knowledge of their prey selection, competition, coexistence and survivorship in both unfragmented and disturbed habitats will enable us to recognize the plasticity in the predator's ability to use the available resources in various human-modified ecological systems. Competition of these three species may result in reduced fecundity, growth or energy stores of individuals and reduced density and /or an altered age structure at a population level (Dunham 1980; Korpimaki 1987; Petren and Case 1996). Therefore information on their ecological separation would be extremely important for conceiving better management strategies as well as contributing to our understanding of sympatric carnivore ecology in a tropical dry deciduous forest of India.

India is very rich in diversities of different large and medium sized carnivore. Of the 36 species of cats extant in the world, India has fifteen of them, including five of the large sized cats: the tiger, the lion (*Panthera leo persica*), the leopard, the snow leopard (*Uncia uncia*) and the clouded leopard (*Neofelis nebulosa*) (Edgaonkar and Chellam 1998).

Among dog, India has four species; dhole or Asiatic wild dog, golden jackal (*Canis aureus*), foxes - Bengal fox (*Vulpes bengalensis*) and red fox (*Vulpes vulpes*) and wolves as Tibetan wolf (*Canis lupus chanco*) and grey wolf (*Canis lupus*). Different forest types and their resource availability in India, helped to form different large and medium body sized carnivore associations as tiger, leopard and dhole in tropical moist, rain and dry deciduous forests; tiger, leopard and striped hyena (*Hyaena hyaena*) in tropical moist and dry-deciduous forests and lion and leopard in semi-arid forest.

1.1. Tiger

Tiger, the largest of all living cats and Asia's largest predator (Seidensticker and McDougal 1993), is widely considered to be one of the most charismatic species on Earth. Molecular phylogenies confirm the close relationship among the members of the genus *Panthera* and show that the tiger diverged more than two million years ago and before the divergence of the lion, leopard and jaguar (Collier and O'Brien 1985; Wayne *et al.* 1989). They are found in diverse habitat types including dry deciduous, moist deciduous, semi evergreen, wet evergreen, riverine, swamp and mangrove forests. They show remarkable tolerance to variation in altitude, temperature and rainfall regimes (Sunquist *et al*. 1999). Throughout centuries, tiger have been revered as a cultural icon over much of its range (Jackson 1999). They have been continually threatened by hunting, habitat loss, fragmentation of populations and most importantly, the depletion of its prey base (Karanth and Stith 1999). Despite extensive conservation efforts this iconic species continues to decline relentlessly across the world (Jhala *et al.* 2008).

1.1.1 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).

1.1.2 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).

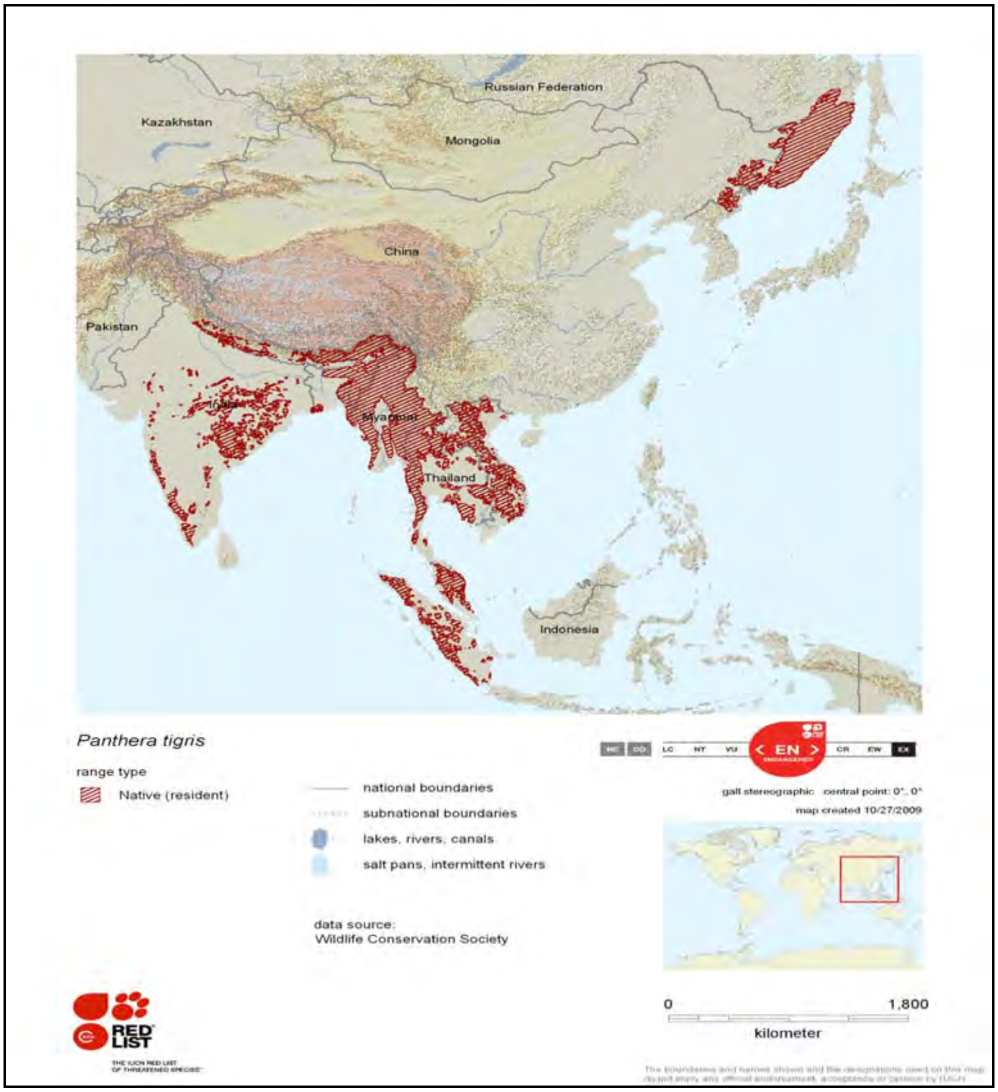


Fig.1.1. Global distribution of tiger (Source: IUCN Red List)

1.1.3 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).

1.1.4. 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 to population explosion. Sometimes large predators can give serious problems to the 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).

1.1.5. 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 of India 1972.

1.2 Leopard

Leopard is the most adaptable and widely distributed among all the big cats (Bailey 1993; Nowell and Jackson 1996). This species is known for its ability to use habitat edges and live close to human habitation (Seidensticker *et al*. 1990). Leopard shows plasticity in behavior as conditions changes (Daniel 1996). Leopard's ability to feed on a broad spectrum of prey makes them the most successful predator among big cats and its size gives it the advantage to feed on a variety of prey species ranging in size from a young buffalo to the smallest rodent (Eisenberg and Lockhart 1972; Santiapillai *et al*. 1982; Johnsingh 1982; Rabinowitz 1989; Seidensticker *et al*. 1990; Bailey 1993; Karanth and Sunquist 1995; Daniel 1996; Sankar and Johnsingh 2002). According to Patrick Hamilton (1976) leopard had the reputation of being one of the least studied of the large carnivores despite being the most abundant. The situation is hardly different even now, in the Indian context (Edgaonkar 2008). Most of the studies on leopard have been done in Africa (Bailey 1993; Bertram 1982; Hamilton 1976; Jenny 1996). The sparse information on leopard in the Indian subcontinent has mostly come from studies that focused on the tiger (Karanth and Sunquist 1995, 2000; Sunquist 1981) or the lion (Chellam 1993).

The studies on leopard in India gained momentum by 2000, addressing human-leopard conflicts (Edgaonkar and Chellam 1998; Goyal and Chauhan 2006), general ecology (Qureshi and Edgaonkar 2006) and population estimation (Mondal 2006; Edgaonkar 2008; Harihar *et al*. 2009).

1.2.1 Taxonomy

According to genetic analysis, nine subspecies are recognized, with all continental, African leopards attributable to the nominated form (Miththapala *et al*. 1996; Uphyrkina *et al*. 2001).

These include: *Panthera pardus pardus*: Africa, *Panthera pardus*: Arabia, *Panthera pardus saxicolor*: Central Asia, *Panthera pardus melas*: Java, *Panthera pardus kotiya*: Sri Lanka, *Panthera pardus fusca*: Indian sub-continent, *Panthera pardus delacourii*: south-east Asia into southern China, *Panthera pardus japonensis*: northern China, *Panthera pardus orientalis*: Russian Far East, Korean peninsula and north-eastern China.

1.2.2 Distribution

The leopard occurs (Fig. 1.2) across most of sub-Saharan Africa, as remnant populations in North Africa, and then in the Arabian Peninsula and Sinai/Judean Desert (Egypt/Israel/Jordan), south-western and eastern Turkey, and through Southwest Asia and Himalayan foothills. India, China and the Russian far East, as well as on the islands of Java and Sri Lanka (Nowell and Jackson 1996; Sunquist and Sunquist 2002). Leopard occurs widely in the forests of the Indian sub-continent, through Southeast Asia and into China, although they are becoming increasingly rare outside protected areas. They are not found on the islands of Borneo or Sumatra (Nowell and Jackson 1996). The overall estimated occupancy of leopard in India was 1,45,184 for the year 2010 (Jhala *et al.* 2010).

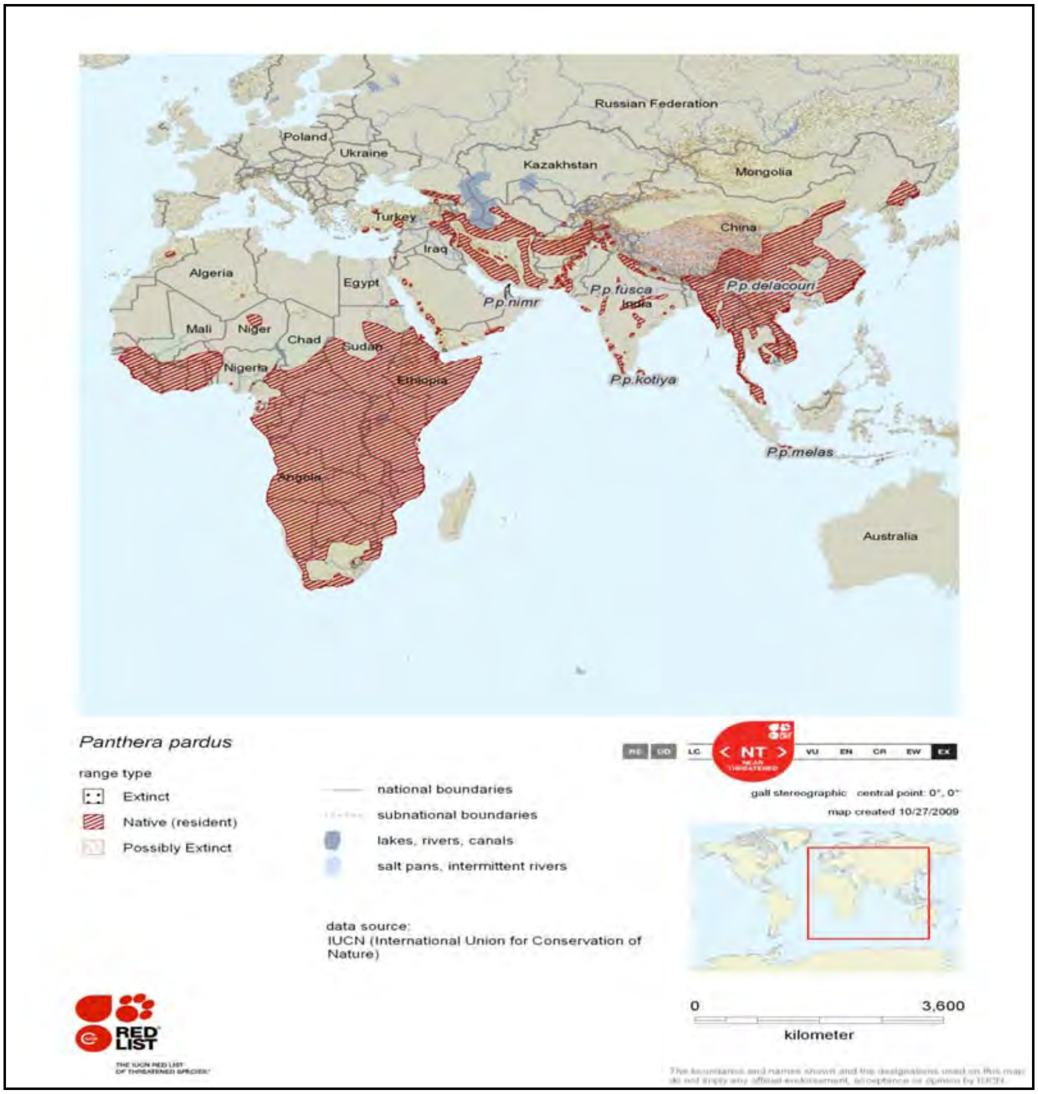


Fig.1.2. Global distributions of leopard (Source: IUCN Red List)

1.2.3 General morphology

The average total length is 7 ft (215 cm), female about 1 ft (30 cm) less. An exceptionally large male may reach 8 ft (245 cm). Weight 150 lb (68 kg), female about (50 kg) maximum. Average weights are 115 lb. (52 kg) for male and 85 lb. (39 kg) for female. There is much variation in size in various parts of India (Prater 1980). Leopard has a startlingly beautiful coat with black rosettes on a ground colour which shows individual variation in different habitats from grey to almost rusty brown (Daniel 1996).

1.2.4. Threats

The leopard is quite adaptable to different habitat and food requirements, being found in intensively cultivated and inhabited areas as well as near urban development (Nowell and Jackson 1996) which leads them to animal-human conflict. Leopard are found very often in villages to prey upon domestic animals and often encountered with man. Leopard are still found throughout most of their historic range, although their numbers have been significantly reduced over the last hundred years due to increasing human population expansion, habitat loss, hunting, and poaching by snares, traps, guns and poisoning. Leopard populations have become heavily fragmented and isolated (Uphyrkina *et al.* 2001). Loss of habitat is the most serious long-term threat to leopard and their prey. 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 and leopard survive (Wickramanayake *et al.* 1998).

1.2.5. Conservation status

Leopard is included in CITES Appendix I. Legal international traffic is limited largely to exports of skins and hunting trophies under a CITES Appendix I quota system by 13 African countries (2005 CITES quota is 2,590). In Africa, although leopard occur in numerous protected areas across their range, the majority of the population occurs outside of protected areas, necessitating a need for improved conflict mitigation measures (including livestock management, conflict resolution). In West Asia, leopard are essentially restricted to protected areas, many of which are too small to support viable populations, and need expansion through buffer zones and connectivity through corridors (Breitenmoser *et al.* 2006, 2007). Leopard is protected under national legislation throughout most of their range (Nowell and Jackson 1996). It is considered as near threatened in IUCN Red List and Scheduled-I species in Indian Wildlife (Protection) Act of India, 1972.

1.3 Dhole

The dhole or Asiatic wild dogs are one of the most remarkable carnivores in the Asian jungles. The term 'dhole' is reported to have an ancient Asiatic origin signifying "recklessness and daring" (Mivart 1890). Dhole is group-living canids, in many ways resembling with wolves (*Canis lupus*) and the African wild dogs (*Lycaon pictus*) in their life history traits (Johnsingh 1982). Like wolves, dhole run down their prey, biting as they chase, and feeding while the prey is still alive. As expected, this behavior has led to unjustified revulsion and calls for their extermination, and they have been highly persecuted in the past. Within peninsular India, dhole are encountered specifically in dense forests and thick scrub jungles (Krishnan 1972; Davidar 1974), making them difficult animals to find and to observe, unlike the wild dogs of the African savannah. The prime factors that determine dhole’s habitats are prey abundance, water availability, interspersion of forests with grassy openings, minimum human disturbance, and potential den sites (Johnsingh 1985). Dhole packs exhibit a remarkable degree of co-operation in hunting down prey. However, on rare occasions, hunting by lone individuals or a pair has been observed. Hunting strategies and methods may vary depending on hunting pack size, prey type, and habitat conditions. Dhole is predominantly diurnal in habit, hunting mainly in the mornings and evenings (Johnsingh 1983).

1.3.1 Taxonomy

According to Thenius (1954), the genus *Cuon* is post-Pleistocene in origin, once widespread across North America, Europe and Asia. Based on the numerical analyses of 90 morphological, ecological and behavioural characteristics of 37 canid species, Clutton-Brock *et al*. (1976) opined *Cuon* is more similar to *Canis*, *Dusicyon* and even *Alopex*, than to either *Speothos* or *Lycaon*. However, when only skull and dental characters are considered, *Cuon* resembles *Speothos* and *Lycaon* most. As suggested by Seal (1975), molecular genetic studies (Girman *et al*. 1993 for *Lycaon*; Gottelli *et al*. 1994 for *Canis simensis*) are required to get a true and conclusive picture of genetic and taxonomic affinities of these three species within Canidae. Recent molecular phylogenetic analyses (Wayne *et al*. 1997) have placed *Cuon* as an early divergent within the wolf-like canid group along with the grey wolf (*Canis lupus*), the coyote (*Canis latrans*), the Ethiopian wolf (*Canis simensis*), and some jackals (*Canis aureus, Canis mesomelas*).

Mivart (1890) split the genus *Cuon* into two species, *C. javanicus* and *C. alpinus,* on the basis of body size and molar dentition. Ellerman and Morrison-Scott (1966), however, recognised nine subspecies. According to Ginsberg and Macdonald (1990), currently there exist 11 subspecies, of which, three subspecies occur within India viz. *C. a. dukhunensis*, found in south of the river Ganga; *C. a. primaevus*, seen in Kumaon, Nepal, Sikkim and Bhutan; and *C. a. laniger*, occurring in Kashmir and Ladakh. *C. a. adustus*, a subspecies found in northern Myanmar, may distribute in adjacent parts within India. *C. a. infuscus* is the other subspecies found in Myanmar that may occur within Indian political boundary.

1.3.2 Distribution

The dhole have a geographical range (Fig. 1.3) stretching from Siberia in the north, India in the west, Java in the south, and China in the east (Fox 1984; Johnsingh 1985) (Fig. 1.3). Oddly, dhole occurs on the islands of Sumatra and Java, but not on those of Japan, Sri Lanka or Borneo (Pocock 1936; Ellerman and Morrison-Scott 1951). In effect, dhole is the most widespread canids of the Indian, the Indo-Malayan and the

Indo-Chinese sub-regions of the Oriental region. Currently however, dhole is either extinct or extremely rare in China (Haibin and Fuller 1996). Such a problem of rarity or extinction is evident from many other parts of their range. A major stronghold of the dhole still remains in the forests of south and central India, and probably Myanmar too (Johnsingh 1985).

The overall estimated occupancy of dhole in India was 1,07,958 for the year 2010 (Jhala *et al.* 2010).

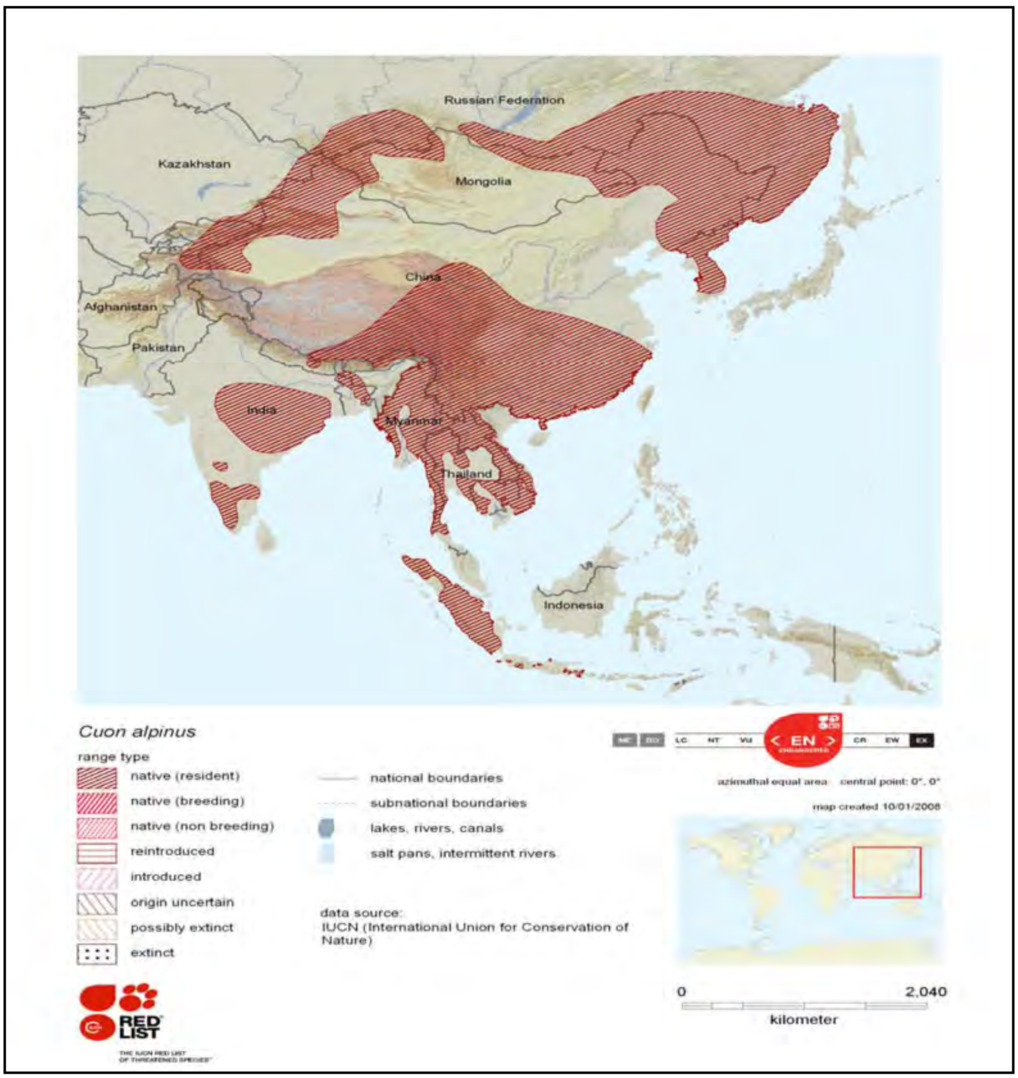


Fig. 1.3. Global distribution of dhole (Source: IUCN Red List)

1.3.3 General morphology

Adult males weigh between 15 and 20 kg, standing around 50 cm at the shoulder. The total body length comes to around 130 cm, including the 40-45 cm long tail. Females are slightly smaller than the males (Prater 1980). Dhole is more-or-less monomorphic, and it is not very easy to distinguish sexes.

The term 'wild dog' is in fact a misnomer, as dhole is genetically distinct from the true dogs. The ears are slightly rounded and furrier. The muzzle, viewed from the side, is slightly convex and shorter than typical dogs. The teeth on the lower jaw are fewer (six molars) than in typical dogs (seven molars), the last molar being absent. However, the teats in females are more numerous (12-14) than the typical dog number (i.e. 10) (Prater 1980). The coat colour is usually bright rust-red, pale ventrally. Some races however may have a duller pelage, tending to brownish-grey. Dhole pups are born with a sooty-brown coat, progressively turning russet-red with age (Fox 1971). Wagging of the tail, a sign of pleasure or happiness, typical of domestic dogs, is common in dhole too. Unlike domestic dogs, the tail is straight, usually held slightly lower than horizontal. The black tail is bushier than in wolves and jackals. In some individuals, the tail has a pronounced white or grey tuft of hair at the extreme tip (Brander 1923).

1.3.4. Threats

In India, dhole has been poisoned with strychnine (Burton 1899). The wide ranging dhole conflicts with human in the periphery of protected areas due to livestock lifting. Overgrazing and agricultural expansion has destroyed huge amounts of dhole habitat (Krishnan 1972; Cohen 1978; Fox 1984). The habitat loss and the elimination of prey species pose the greatest threats to the survival of the dhole. Diseases like Canine Distemper and Rabies, possibly spread by domestic dogs, are important threat to this species (Central Zoo Authority 2008). In the 1940s, a rabies epidemic resulted in villagers being bitten by rabid dhole and subsequently died in Biligirirangan Hills (Morris 1942). Other imposing major threats are stealing their kill by local folk, disturbing their den site and road accidents. The present range of dhole has been much reduced due to human activities.

1.3.5. Conservation status

Dhole have had a long history of persecution by humans (Fox 1984), particularly well documented in India, where bounties were arranged for killing them (Davidar 1968). Dhole is listed as 'threatened' according to the Wildlife (Protection) Act of India (1972) and 'vulnerable' by the IUCN (Appendix II of CITES). However, this status has been accorded to the species without taking into consideration the almost extinct status of some of the dhole sub-species and their uncharted distributions. Such information on their status, abundance, and distribution of sub-populations throughout their geographical range, especially in Myanmar, China and Russia, is vital for the conservation of this species.

1.4. Justification of the study

In India most of the studies on sympatric carnivores have been conducted in Western Ghat complex (Johnsingh 1983; Karanth and Sunquist 1995; Andheria *et al.* 2007; Ramesh 2010).

A detailed long-term study on prey selection, food habits and population status of three sympatric large carnivores together has not been documented earlier in the central Indian landscape. Even though prey selection and food habits of large carnivores have been studied but it was either for small time frame (Sujai 2004) or species specific (Schaller 1967; Biswas and Sankar 2002; Acharya *et al.* 2007; Edgaonkar 2008). In many of the well Protected Areas (PAs) of India, up to date scientific information on this aspect remains negligible. To supplement the current basic information, the present study was conducted in Pench Tiger Reserve from May 2006 to April 2011.

1.5. Objectives of the study

1. To estimate density, distribution, group size and composition of prey species of sympatric carnivores (tiger, leopard and dhole).
2. To study the food habits and prey selectivity of sympatric carnivores and
3. To estimate the population of sympatric carnivores.

1.6. Organisation of thesis

The thesis is structured into six 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 study species tiger, leopard and dhole, scope of the study and objectives of the study. Chapter 2 describes the study area, Pench Tiger Reserve, Madhya Pradehs. Chapter 3, deals with the prey species of large carnivores, their abundance and population structure. Chapter 4 describes prey selection and food habits of large carnivores. Chapter 5 covers population estimation of large carnivores using different methods in the study area. Chapter 6 deals with the spatio-temporal utilization of habitat resources by these sympatric carnivores in the study area, their spatial segregation and temporal activity patterns. A brief conservation implecation was also described in this chapter

Chapter 2

Chapter 2

STUDY AREA

2.1 General Locations

The study was conducted in Pench Tiger Reserve (PTR), Madhya Pradesh (79^0 9' E to 79^0 22' E and 21° 38 N' to 21°50' N). PTR (Fig. 2.1) includes the Pench National Park (PNP) and Pench Wildlife Sanctuary (PWS) along with buffer area of Seoni and Chhindwara districts**.** The intensive study area for the present study was PNP and PWS that covers an area of 410 km^2. The PNP has been named after a river, the Pench that meanders along the centre of the Park, bisecting it in almost two equal parts. This river forms a boundary between Seoni and Chhindwara districts and also between the state of Madhya Pradesh and Maharashtra. Pench Tiger Reserve is located 98 km north of Nagpur (Maharashtra) and 12 km from Khawasa (Madhya Pradesh) on National Highway No. 7.

The total area of the PNP is 292.8 km^2, out of which 145.2 km^2 lies is Seoni district and the remaining in Chhindwara district. The PWS has an area of 118.4 km^2. It is connected to Kanha Tiger Reserve by forest of Seoni, Balaghat and Mandla districts and southern side is contiguous with PTR of Maharastra.

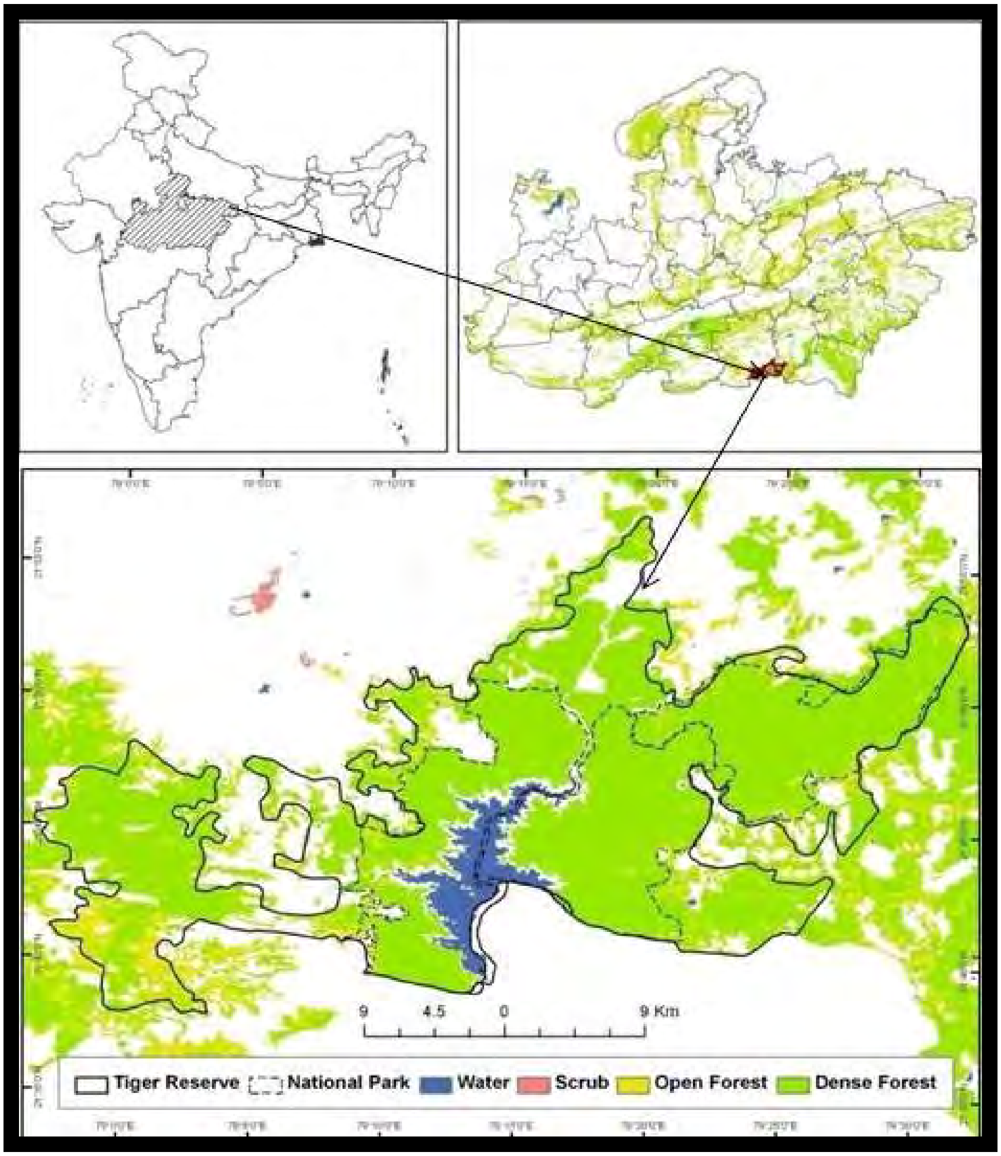


Fig. 2.1. Map showing Pench Tiger Reserve, Madhya Pradesh, India

2.2. Historical and legal status

This part of Central India has been a major attraction for naturalists and as well as game hunters. Descriptions of its natural wealth and richness appear in the writings dating back to 14th Century. Ain-i-Akbari and the references available on Deogarh Kingdom of the sixteenth century also give passing remarks on the wildlife of this area. During 17th Century the Gond rulers of this region cleared large tracts of forests for cultivation and dwellings. This onslaught continued up to 1818, through the rule by the Marathas and later, the British. It was not until 1862 that efforts were made to control the indiscriminate destruction of forest and the area was declared as reserved (Kumar 1989).

PTR has its own importance in the natural history of central India. Many eulogies of its natural beauty and richness in fauna and flora have appeared in numerous literatures dating back to the 17th century. Books, pertaining to 19th and early 20th century, by famous naturalists like Captain J. Forsyth (High lands of central India, 1871), R.A. Sterndale (Camp life in Seoni, and Mammals of India, 1887), Dunbar Brander (Wild animals in Central India, 1923) and Rudyard Kipling (Jungle book 1894) explicitly present the detailed panorama of nature's abundance in this tract of Satpura hill Ranges.

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

In 1977, an area of 449.4 km² was notified as the Pench Game Sanctuary, vide Madhya Pradesh State Forest Department Memo No. F/15/77-10 (3) Bhopal, dated 30.09.1977. In March 1983, Government of Madhya Pradesh notified its intention to constitute an area of 292.8 km² as PNP, to be carved out of the pre-existing Pench Sanctuary area vide notification No. 15/5/82-10(2) Bhopal dated 01.03.1983 (3). This was then the 19th Tiger Reserve of India under centrally sponsored scheme, Project Tiger vide Govt. of India, Ministry of Environment and Forests, Project Tiger's order No. 1-2/92-PT (Part II) dated 23 November 1992.

2.3. Conservation values

Central Highlands of India is one of the most important habitats in the world for the conservation of the endangered cat "Tiger". The wetlands of PTR are of great significance in the context of conservation of avian fauna too, as it not only provides suitable habitat for the residential birds; but also provide wintering grounds for many waterfowls. The islands in Totaladoh reservoir provide nesting grounds to many island nesting birds like river tern (*Sterna aurantia*), small pratincole (*Glareola pratincola*) and little tern (*Sterna albifrons*). Hence, this area has been included as an important bird area (Dungariyal 2008; Jaypal *et al.* 2005).

Besides tiger and birds, the reserve also harbors a wide range of faunal species some of which figure prominently in the IUCN Red List. These species include *Cuon alpinus, Vulpes benghalensis, Melursus ursinus, Lutra perspicillata, Panthera pardus, Bos gaurus and Python molurus.* Among vertebrates 58 species of mammals, 325 species of birds, 37 species of reptiles (Pasha *et al.* 2000; Dugariyal 2008) and 50 species of fishes have been reported so far. Among invertebrates 100 species of butterfly, 100 species of moth, 50 species of dragonfly and damselfly, 30 species of spiders and almost 250 species of other insects have been identified (Dungriyal 2008). The floral diversity comprise of about 1000 species of angiosperms, about 10 species of pteridophytes, 10 species of bryophytes and about 35 species of fungi (Dungriyal 2008).

Six species of endangered vultures are found in PTR (Majumder *et al.* 2009). They are Oriental white-backed or White-rumped vulture (*Gyps bengalensis*), Long-billed vulture (*Gyps indicus*), Red-headed or King vulture (*Sarcogyps calvus*), Egyptian vulture (*Neophron percnopterus*), Indian griffon vulture (*Gyps fulvus*) and Cinereous vulture (*Agypius monachus*).

2.4. Terrain

PTR lies in the southern lower reaches of Satpura Hill ranges. The terrain is gently undulating and criss-crossed by small streams and nullahs; most of these are seasonal. The Pench River runs through the PTR covering a length of 24 km and bisecting it into almost equal halves. The hills have gradual to steep slopes with almost flat tops. Fig. 2.2 gives detailed contour outlay of PTR.

Some of the prominent hills of the area are Chindimatta, Khumbadeo, Khairban matta, Arjal matta and Kalapahar. The term “matta” refers to the hills in local Gondi dialect. Of the hills present in the area, Kalapahar is the highest with an altitude of 650 m (Sankar *et al.* 2000).

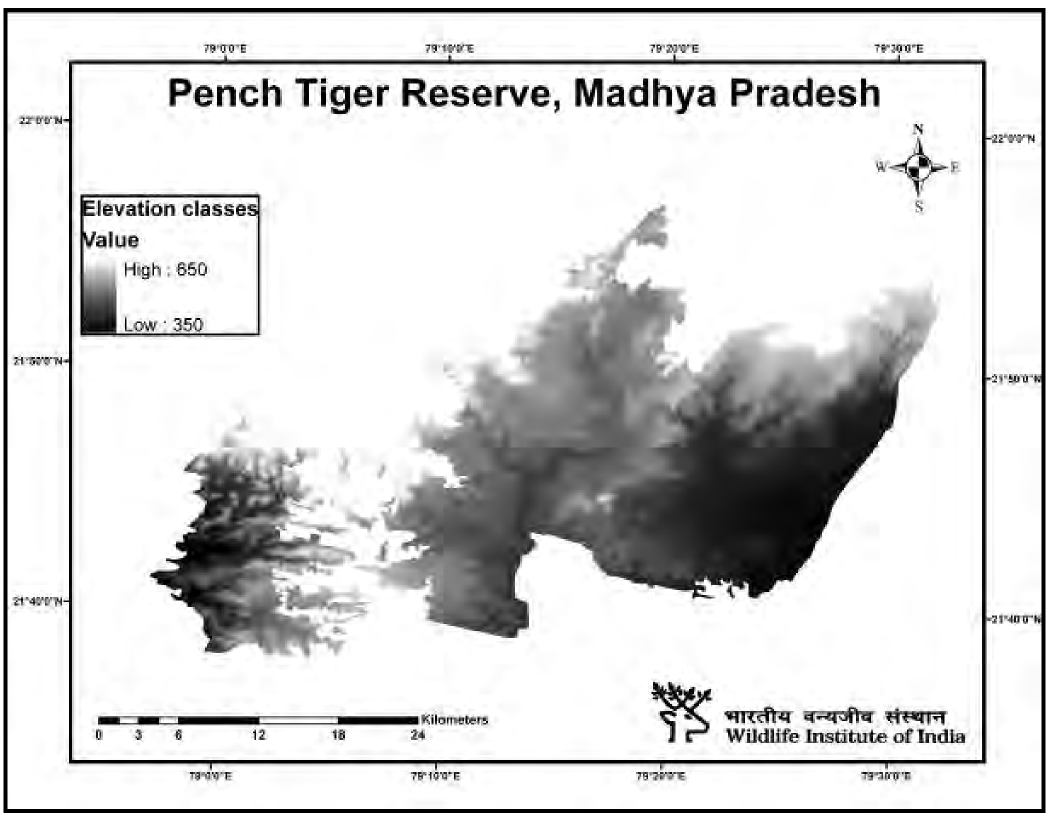


Fig. 2.2. Digital Elevation Model map of Pench Tiger Reserve (Source: Sankar *et al.* 2000).

2.5 Slope

The slope (Map 2.3) categories in PTR have been identified into three classes *viz*. (0-11 degrees, 12-22 degrees, and 23-34 degrees). Most of the protected area (PA) falls into flat to gentle slope (0-22 degrees) class. The western most part of the reserved forests has a highly rugged terrain with steep slopes (23-34 degrees).

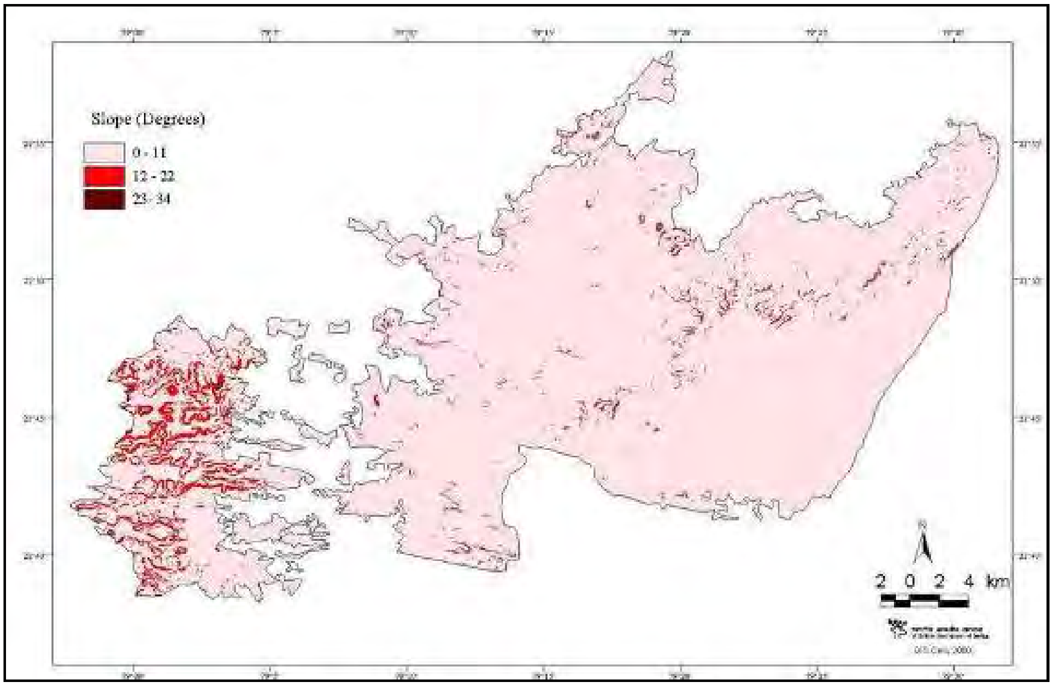


Fig. 2.3. Map showing slopes of Pench Tiger Reserve (Source: Sankar *et al.* 2000)

2.6. Soil types

Four major soil types are found in PTR (Sankar *et al.* 2000). They are sandy loam, red soil, kankar, saline soil and the alluvial soil.

2.6.1. Sandy loam soil: Most of the area inside the reserve is covered with sandy loam soil. The soil is the result of weathering of granitic gneisses. This soil type occurs commonly on gentle slopes and valleys.

2.6.2. Red soil: The high elevation areas have the red soil predominantly. This soil varies from the shallow, poor, gravely and light coloured varieties on elevated areas, whereas deeper fertile and darker varieties occupying the lower plains and valleys.

2.6.3. Kankar and saline soil: This soil type is found in the foothills in areas with less tree cover and frequent forest gaps. They contain large proportion of silica and orthoclase quartz and have low water holding capacity. They are generally mineral deficient and of low productivity. They are easily eroded under insufficient vegetation cover.

2.6.4. Alluvial soil: This soil type is mainly confined to the banks of streams and Pench river. Alluvial soil consists mostly of the siliceous debris, washed down from the hills, mixed with humus. This soil varies to a great extent in the chemical and physical properties owing to the variation in the rocks, which form the debris from place to place. The colour is yellowish brown. These soil support good teak (*Tectona grandis*) trees along the Pench river.

2.7. Water

The PTR has number of streams and nullahs, but most of them are seasonal. The Pench river that flows almost through the center of the Park is the lifeline for the area. The river dries out by the month of April and several puddles of water remain, locally known as ‘doh’ or ‘kassa’. There are also few perennial water sources occurring in the Sanctuary and as well as in the National Park. In 1990, 54.5 km² area of the PNP was submerged as a result of the construction of the hydroelectric dam. This has led to the formation of a large reservoir that not only attracts animals during the water scarcity but also many waterfowls and migratory birds visit the reservoir during winter. In addition to this there are two small tanks, the Bodhanala tank in the eastern block of the PTR and the Dudhgaon tank found in the west block of the PTR.

During summer the water resource becomes limited and scattered. To combat this problem at several places the Park authorities have constructed artificial water holes. Water is supplied to these water holes with the help of installed hand pumps in the near vicinity. Of late many anicuts and check dams have also been built to trap the available water.

2.8. Climate

PTR lies within the Tropical Zone, having three well distinct (summer, monsoon and winter) and one less distinct (post monsoon) seasons.

2.8.1. Summer

The summer sets in the month of March and lasts till around mid June, when the area receives first monsoon showers. The last fortnight of May is the hottest, and the mercury may shoot up to 45^0C. As compared to the low-lying plains outside the National Park and Sanctuary area, the hilly tract of the park and Sanctuary experiences a mild summer. The summer season is usually dry but instances of rains, hailstorms and thunder do occur in the month of March and April. The relative humidity in the early afternoon is as low as 15-20%. The forests, which have been shedding their leaves, wear a bleak look during this period. The forest floor remains covered with dry grasses and fallen leaves. The water level in the area drops drastically, and by the mid of April most of natural water sources vanish. Except for a few perennial springs and artificially created water tanks, water can be seen only in few area of the river bed of Pench river, in the shape of small water reservoirs locally called as 'Kassa' or 'Doh'.

2.8.2. Monsoon

The advent of rainy season starts with pre-monsoon showers usually received in the second or third week of June, and regular onset takes place by the first week of July.

The wettest months are July and August, when around 80% of the total annual rainfall i.e. 1200 mm is received.

2.8.3. Winter

Winter starts from November and continues till the end of February. January is the coolest month. The mean minimum temperature is 11.8^{o}c. Frost is not common in the area, but relative humidity becomes very high during the night and the incidence of dew is heavy.

2.9. Major vegetation types

PTR belongs to the Indo-Malayan phyto-geographical region (Fig. 2.4). Floristically, the Tiger Reserve can be classified, according to Champion and Seth (1968), into:

I. TROPICAL MOIST DECIDUOUS FORESTS:

i. TYPE 3B/C_{1c}: Slightly moist teak forests

II. TROPICAL DRY DECIDUOUS FORESTS:

i. TYPE 5A/C_{1b}: Dry teak forests

ii. TYPE 5A/C_3: Southern dry mixed deciduous forests

Teak (*Tectona grandis*) and associated species such as *Madhuca indica*, *Diospyros melanoxylon*, *Terminalia elliptica*, *Buchanania cochinchinensis*, *Lagerstroemia parviflora*, *Desmodium oojeinense*, *Miliusa velutina* and *Lannea coromandelica*, occur on 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 forests occur in the hill slopes and along streams. Some of the open patches of the PTR are covered with tall grasses interspersed with *Butea monosperma* and *Zizyphus mauritiana*. Evergreen tree species like *Terminalia arjuna*, *Syzygium cumini* and *Ixora parviflora* are found in riparian vegetation along nullahs and river banks. *Cleistanthus collinus* dominant patches are also found in some parts of the Tiger Reserve.

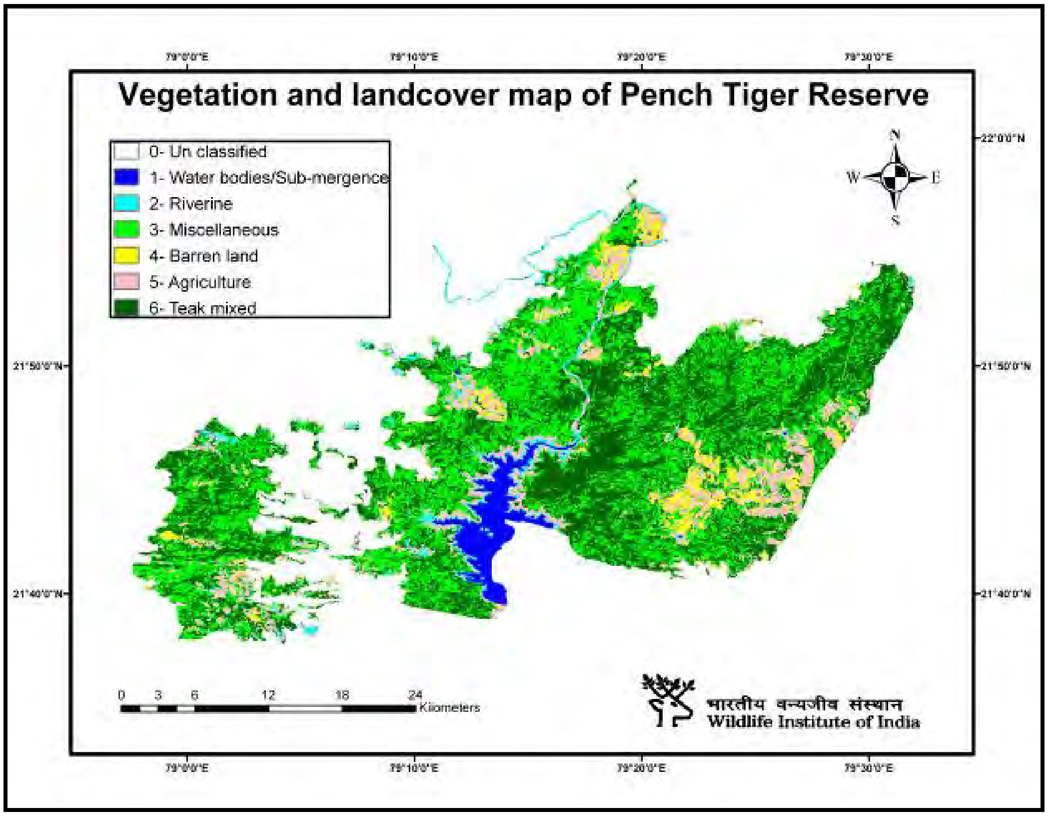


Fig.2.4. Land use and land cover map of Pench Tiger Reserve, Madhya Pradesh

Teak, as such, is a ubiquitous species in the region, with a presence ranging from a sporadic distribution in most parts of the study area to localized teak-dominated patches. The tracts that previously formed pastures of villages (subsequently relocated outside the National Park limits) now constitute open grassy meadows much favoured by the gregarious herbivores. With the approach of summer, the extent of open areas of the PTR gradually increases with the recession of reservoir's waters.

2.10. 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).

2.11. People and livestock

There are over 51,648 inhabitants in 107 villages around the notified buffer zone of PTR. The locals are predominantly tribal (62%) belonging to Gond and Baiga community. The rest include Scheduled Castes (15%), OBCs (13%) and few (9 per cent) belonging to the General category. For majority of the people, agriculture and allied vocations (animal husbandry, farm labour and forestry labour) provide main source of livelihood. Out of them, about 43% people are below poverty line. There are 60,000 livestock present in the villages (Dungariyal 2008).

Plate 2.1. Pench Tiger Reserve landscape- An overview

Plate 2.2. Backwater of Pench River

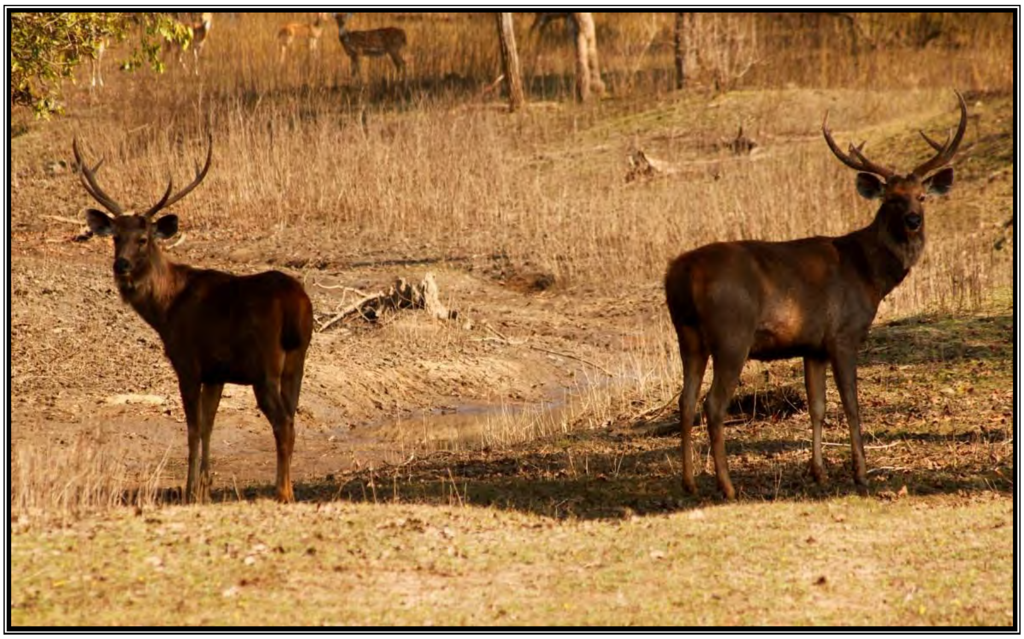
Plate 2.3. The relocated village site at Chendia

Plate 2.4. Totladoh reservoir

Plate 2.5. Stagnant water “Kassa” or “Doh” along the Pench River

Plate 2.6. Artificial water-holes in the study area

Chapter 3



Chapter 3

ESTIMATION OF PREY AVAILABILITY OF TIGER, LEOPARD AND DHOLE

3.1. 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 carnivore 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 large carnivore 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 large carnivore. For long term survival of large carnivores 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.

3.2. Review of literature

Population estimation for different prey species has been carried out using both direct and indirect methods. Direct count method involves counting individuals animals in any given area. This may be in the form of aerial survey and waterhole count. Though this method largely followed in African Savannah (Koster and Hart 1988) to estimate prey species of various carnivores but direct or total counts in large areas are subject to vegetation cover limitations and high cost.

Population of herbivore can also be estimated by indirect sampling, in which animal signs, such as dung or tracks, are used (Eberhardt 1978). Pellets or dung provide information such as a population's distribution, size and diet that can be difficult to obtain for elusive species (Putman 1984). However, these methods do not reliably take into account factors such as probabilities of detecting animals and their non random distribution in space. Often, the uncertainty regarding the estimate is not even considered.

As a result, recent studies have made use of advanced population estimating techniques, and have used sample survey methods such as line transects to estimate mean densities and their associated variance in a quantitative, model based framework. Line transects are therefore found to be more reliable methods in forest types. The theory of line transect sampling has been developed along rigorous statistical principles since 1968. Gates *et al.* (1968) derived an estimator based on radial distance. Anderson and Pospahala (1970), studied waterfowl nesting by line transects. Seber (1973) presented a general model structure for line transects sampling and gave an approached based on effective strip width. Sen *et al.* (1974) discussed the estimation of wildlife densities using both right angle and radial distances.

Burnham and Anderson (1976) gave a general mathematical theory of line transect which supplied a framework for either parametric or non parametric density estimation based on either right angle or sighting distances. Pollock (1978) considered a family of density estimators for line transects sampling.

Anderson *et al.* (1978) provided guidelines for field sampling including practical considerations.

A log linear approach for estimation of population size using the line transects method was given by Anderson *et al.* (1978). He emphasized that it is crucial to conduct observations allowing straight lines and obtain accurate measurements of distance and sighting animals. Care must be taken so that objects on the centre of line transects are seen with probability one. Eberhardt (1978) addressed the general question of determining sample size for population studies. Line transect based on right angled distances were discussed by Eberhardt (1979). Some parametric models for line transect sampling have been introduced by Ramsey (1979) and Quinn and Gallucci (1980).

A parametric generalization of the Hayne estimator for line transects sampling and robust estimation from the line transects data was given by Burnham (1979). A generalization of Hayne –type estimator as an application of line transects sampling was given by De Vries (1979). Alldredge and Gates (1985) discussed line transect estimators such as exponential or half normal for left truncated distributions. The Fourier series model for analyzing perpendicular distance data from the line transect sampling was proposed by Crain *et al.* (1979).

Burnham *et al.* (1980) provided a monograph on line transect sampling theory and application. Their extensive work provided a review of previous methods and presented guidelines for field use and identified a small class of estimators that seemed generally useful. Usefulness was based on four criteria: Model robustness, Pooling robustness, Shape criterion and Estimator efficiency.

Laake *et al.* (1979) and Gates (1980) produced comprehensive computer software packages, **TRANSECT** and **LINETRAN** respectively, for the analysis of line transect data. Buckland (1982) discussed Fourier series model as a powerful procedure for analyzing line transect data. Three solutions for finding confidence interval, one using Monte Carlo techniques, another making use of replicate lines and the third based on Jackknife method were discussed and compared (Mercey 1998). Radial distance models for the line transect method was discussed by Hayes and Buckland (1983). They compared, modified and generalized Hayne's model. Anderson *et al.* (1979) suggested that for reasons of efficiency and validity, transect count studies should record perpendicular distance data. Buckland (1985) discussed perpendicular models for line transect sampling and found the hazard rate model to be the most promising. Zahul (1989) gave a model for line transect sampling for the purpose of estimating animal population density which makes no assumption about the value of the detection probability along the transect or about the form of the detection probability function other than continuity. Routledge and Fyfe (1992) presented confidence limits for line transect estimates based on shape restrictions, while fitting density functions with polynomials was tried by Buckland (1992). Quinn (1979), Rao and Portier (1981) and Cook and Martin (1974) proposed estimation technique to clustered populations. The approach of Cook and Martin (1974) was incorporating constant p as the probability of detecting an individual animal such that $0 < p < 1$ and that the detection of individual animals in the same group are independent (Bernoulli tests, Mercey 1998). Quinn (1979), however, examined the effect of pooling data over the various cluster sizes. Tacha *et al.* (1982) discussed radial distance models for the line transects methods.

Drummer and McDonald (1987) introduced cluster size variable as a covariate in the detection functions. Drummer (1991) gave a computer software package "**SIZETRAN**" to cater the needs of computations. Seber (1992) had given an extensive review of statistical methodology involved in estimating animal abundance. He broadly grouped the methods as applicable to closed populations, that is, unchanging except for known removals during the period of investigation and as those for open population where migrations, births, and deaths occur. He discussed the use of plots, strips, lines and points for estimating population density or for providing an index of density based on indirect signs (Mitra 2004). Eberhardt and Simmons (1987) discussed calibrating population indices by double sampling. This technique is based on an approach known as ratio estimation which depends on knowing the value of an auxiliary variable (here index of abundance) over all sampling units in a study site. Simulations were conducted to check the existing equation for estimating means and variances. Rivest and Crepeau (1990) gave a two phase sampling plan for the estimation of moose population. The two phases correspond to two different ways of search, an airplane search and a helicopter search. Regression of helicopter search on the variables of airplane search was used to estimate the population size. Quang (1990) gave methods for establishing confidence interval for density in line transects sampling. When the probability density function of perpendicular distances is peaked at zero or it is long tailed, the bias reduction offered an improvement. Turnock and Quinn (1991) discussed effects of responsive movement on abundance estimation using line transect sampling. They presented and compared two approaches to correct estimators with auxiliary information on movement; a correction factor approach and a decomposition approach. The later was preferred over the former. The methods were illustrated with survey data of Dall's porpoise in the Gulf of Alaska.

Brown (1984) discussed the line transect estimators such as exponentials or half normal for left truncated distributions. Parametric estimators derived from an aerial survey using dolphin data were used. Quang (1991) reported a program **NPARTRAN** for line transect data analysis, giving confidence limits for line transect estimates based on shape restrictions. A computer program **DISTANCE** (Laake *et al.* 1993;

Buckland *et al.*1993) was developed to allow comprehensive analyses of the type of distance data. The program **DISTANCE** 5.0 allows more concentration on the results and interpretation of biology of population, its habitat and survey part rather than on computational details.

3.3. Methods

3.3.1 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. 3.1) were walked during winter (total effort= 1016 km) and summer (total effort =1168 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 I estimated densities of potential prey species such as chital, sambar, wild pig, nilgai, gaur and common langur from winter and summer line transect data for the year 2007, 2008, 2009, 2010 separately (post stratified) and pooled or overall (seasonwise). Although barking deer and chousingha 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).

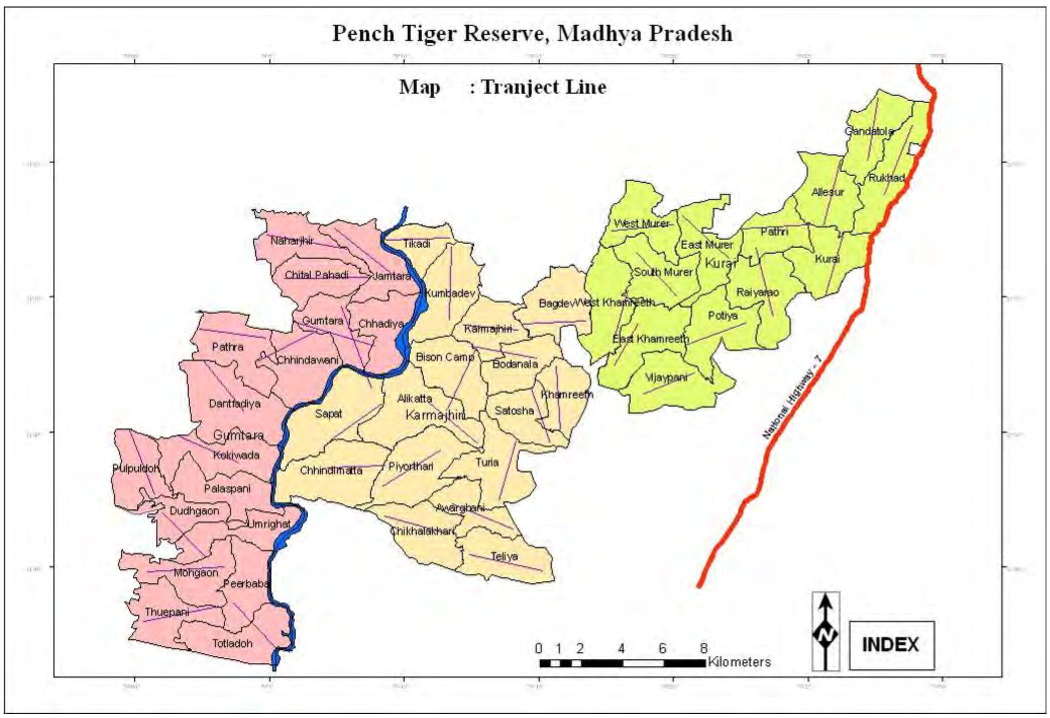


Fig 3.1. Distribution of line transect in the Intensive study area of Pench Tiger Reserve, Madhya Pradesh

3.3.2 Vehicle transects

Vehicle transects were used to estimate group size and composition of prey species of large carnivores 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 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.

3.3.3. 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.

3.3.4. 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).

3.3.5. 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.

3.3.5.1. 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.

3.4. Results

3.4.1. Line transect

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

3.4.1.1. 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, 930 in 2010 and 1273 in overall before truncation and after truncating upto 150 m it was 60 in 2007, 40 in 2008, 241 in 2009, 928 in 2010 and 1269 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 was

64.1 (SE± 3.3) 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 densitiy in winter was 50 SE±7.1)/ km², whereas 48 (SE ±15)/ km² in summer 2007, 34 (SE ±12)/ km² in summer 2008, 115 (SE ±20)/ km² in summer 2009, 70 (SE ±11.3)/ km² in summer 2010 and 71.1 (SE ±11.1)/ km² in overall summer (Table 3.1, Figure 3.2a and 3.2b). Group densities chital for summer and winter of 2007, 2008, 2009, 2010 and overall group density were presented on the Table 3.1.

Table 3.1. Densities of chital in Pench Tiger Reserve, Madhya Pradesh, during winter and summer (2007 to 2010)

Years/ Seasons	**Chital Winter**					**Chital Summer**				
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	1168
Total Observations	67	44	68	741	920	61	40	242	930	1273
Truncated at	150					150				
Observation after Truncation	67	44	66	734	911	60	40	241	928	1269
Density ± SE/ km²	30±7.7	32±10.1	29.1±3.7	60±9	50±7.1	48±15	34±12	115±20	70±11.3	71.1±11.1
Group Density ± SE/ km²	7±1.8	6.8±1.9	3±0.8	8.9±1.2	7.8±1.1	7.8±2.3	5±1.5	15.6±20.4	7.8±1.2	8.5±1.3
Effective Strip Width± SE (m)	55.8±1.4					64.1±3.3				
AIC value	2023.7					2968.5				
Model+ Adjustment term	Half normal cosine					Half-normal cosine				

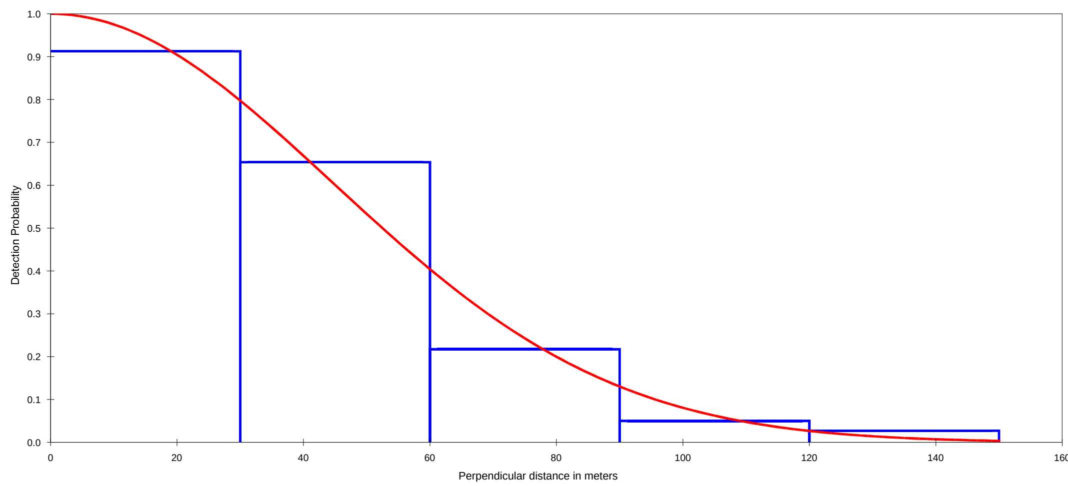


Fig. 3.2a. Probability of chital detections from line transect sampling (winter)

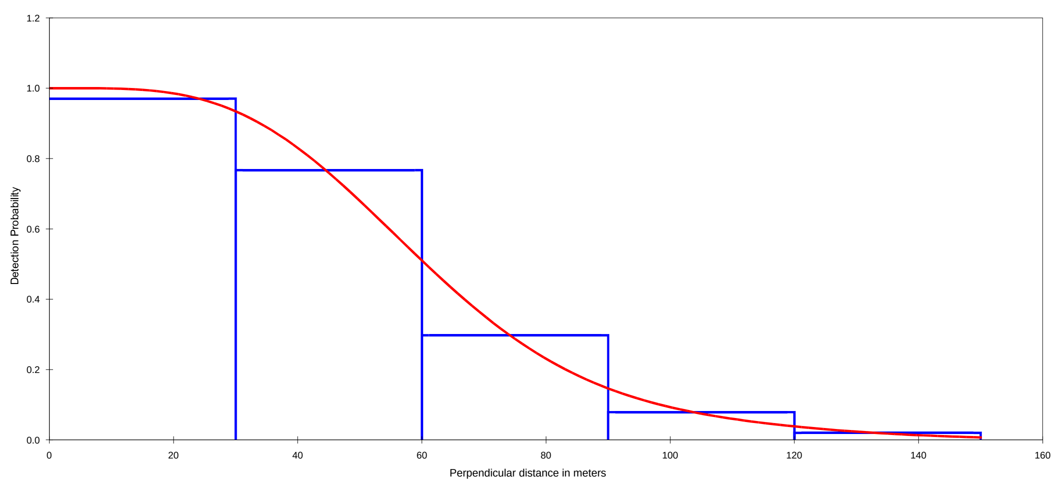


Fig. 3.2b. Probability of chital detections from line transect sampling (summer)

3.4.1.2. **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 and overall 418 before truncation and after truncating upto 150 m it was 17 in 2007, 21 in 2008, 49 in 2009, 321 in 2010 and 408 in overall. Half-normal cosine for winter and Half-normal hermite polynomial 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 was 54.9 (SE± 2.1) m. The density of sambar was estimated to be 3.1 (SE±1.1)/ km^2 in winter 2007, 2.3 (SE±0.9)/ km^2 in winter 2008, 4 (SE± 0.9)/ km^2 in winter 2009, 7 (SE±0.8)/ km^2 in winter 2010 and overall densitiy in winter was 6 (SE±0.5)/ km^2, whereas 9 (SE ±3.4)/ km^2 in summer 2007, 10 (SE ±2.8)/ km^2 in summer 2008, 8 (SE ±2)/ km^2 in summer 2009, 9 (SE ±1.1)/ km^2 in summer 2010 and 9 (SE ±1.1)/ km^2 was overall desnity of sambar in summer (Table 3.2, Figure 3.3a and 3.3b). Seasonal group densities for the year 2007, 2008, 2009, 2010 and overall group density were presented on Table 3.2.

Table 3.2. Densities of sambar in Pench Tiger Reserve, Madhya Pradesh, during winter and summer (2007 to 2010)

Years/ Seasons	**Sambar Winter**					**Sambar Summer**				
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	Pooled
Total effort	86	58	136	736	1016	60	64	120	924	1168
Total Observations	17	10	28	225	280	17	21	49	331	418
Truncated at	150					150				
Observation after Truncation	17	10	28	225	280	17	21	49	321	408
Density ± SE/ km²	3.1±1.1	2.3±0.9	4±0.9	7±0.8	6±0.5	9±3.4	10±2.8	8±2	9±1.1	9±1.1
Group Density ± SE/ km²	1.7±0.5	1.6±0.5	1.7±0.4	2.6±0.4	2.5±0.3	2.6±0.9	3.1±0.7	3.7±0.9	3.2±0.4	3.2±0.4
Effective Strip Width± SE (m)	54±2.4					54.9±2.1				
AIC value	618.7					937.3				
Model+ Adjustment term	Half normal cosine					Half normal Hermite polynomial				

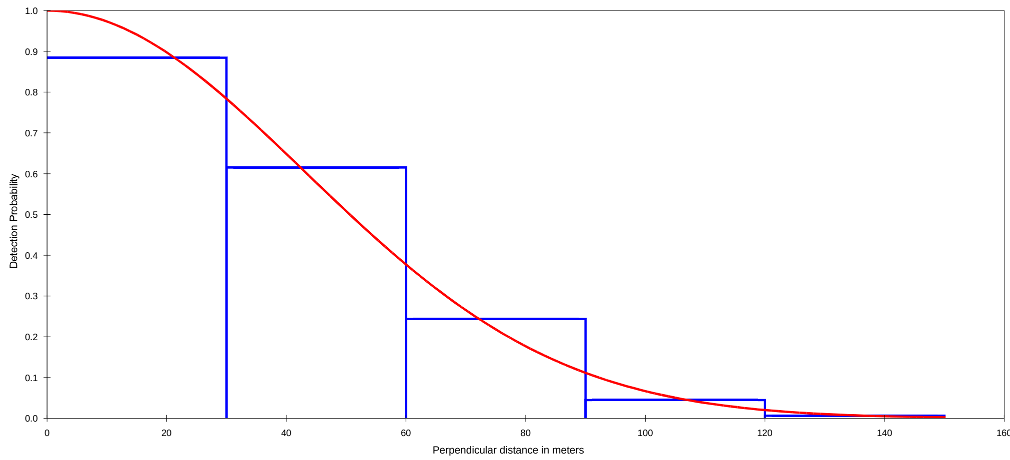


Fig. 3.3a. Probability of sambar detections from line transect sampling (winter)

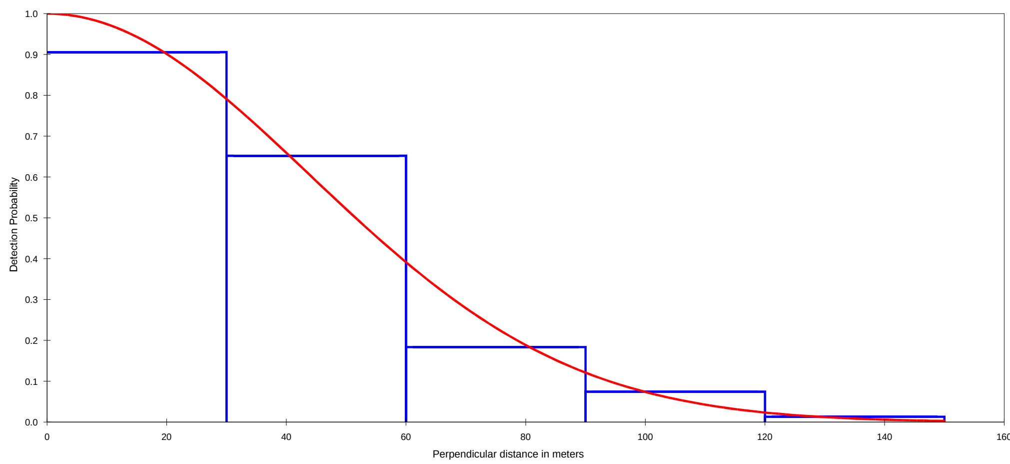


Fig. 3.3b. Probability of sambar detections from line transect sampling (summer)

3.4.1.3. **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, 117 in 2010 and 141 in overall before truncation and after truncating upto 150 m observation remained same for the year 2007, 2008 and 2010, 14 in 2009 and 140 for overall observations. Half-normal hermite polynomial for both winter and summer were selected as the best fit estimator for computing effective strip width. The effective strip width for winter was 60.3 (SE ±5) m, whereas for summer was 57.4 (SE± 3.6) 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 densitiy in winter was 2 (SE±0.5)/ km², whereas 2.4 (SE ±1.2)/ km² in summer 2007, 0.5 (SE ±0.2)/ km² in summer 2008, 2.5 (SE ±0.9)/ km² in summer 2009, 2.1 (SE ±0.3)/ km² in summer 2010 and 2.1 (SE ±0.5)/ km² was overall desnity of nilgai in summer (Table 3.3, Figure 3.4a and 3.4b). Seasonal group densities for the year 2007, 2008, 2009, 2010 and overall group density were presented in the Table 3.3

Table 3.3. Densities of nilgai in Pench Tiger Reserve, Madhya Pradesh, during winter and summer (2007 to 2010).

Year/Seasons	**Nilgai Winter**					**Nilgai Summer**				
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	1168
Total Observations	2	4	6	83	95	7	2	15	117	141
Truncated at	150					150				
Observation after Truncation	2	4	6	81	93	7	2	14	117	140
Density ± SE/ km²	0.3±0.2	1.1±0.5	3±1.7	1.8±0.4	2±0.5	2.4±1.2	0.5±0.2	2.5±0.9	2.1±0.3	2.1±0.5
Group Density ± SE/ km²	0.2±0.1	0.6±0.3	0.6±0.2	0.9±0.2	0.8±0.1	1±0.3	0.2±0.2	0.9±0.2	1.1±0.1	1.3±0.2
Effective Strip Width± SE (m)	60.3±5.6					57.4±3.6				
AIC value	226.1					329.3				
Model+ Adjustment term	Half normal Hermite polynomial					Half normal Hermite polynomial				

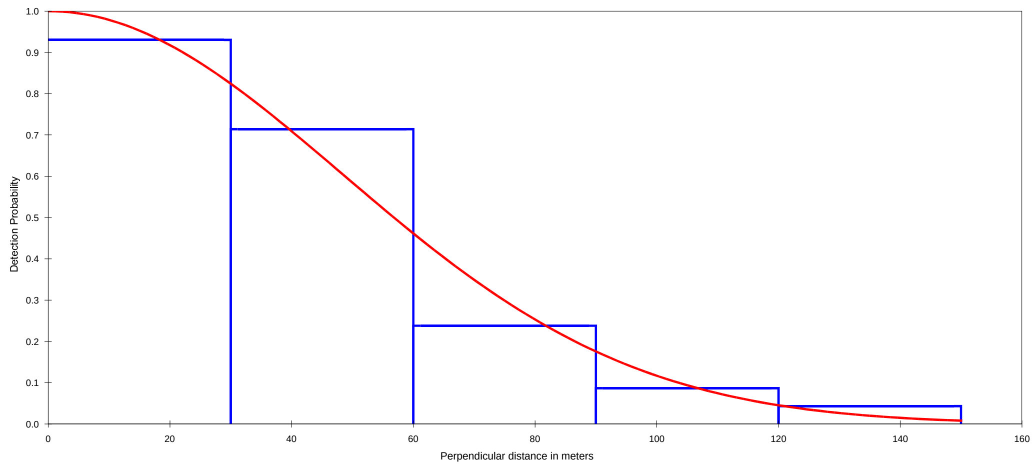


Fig. 3.4a. Probability of nilgai detections from line transect sampling (winter)

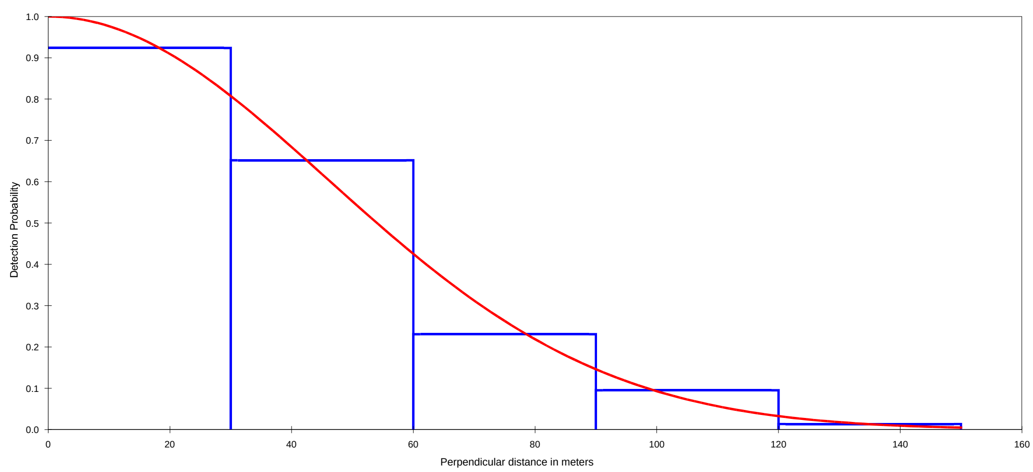


Fig.3.4b. Probability of nilgai detections from line transect sampling (summer)

3.4.1.4. **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 and 305 in overall before truncation and after truncating upto 150 m observation remained same. Hazard rate cosine for winter and half normal 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 was 49 (SE± 2.1) m. The density of wild pig was estimated to be 3.4 (SE±3.2)/ km^2 in winter 2007, 3 (SE±2.7)/ km^2 in winter 2008, 2.4 (SE± 1.1)/ km^2 in winter 2009, 6.3 (SE± 1.3)/ km^2 in winter 2010 and overall densitiy in winter was 5.2 (SE±1.2)/ km^2 whereas 17 (SE ±9.4)/ km^2 in summer 2007, 5 (SE ±2.8)/ km^2 in summer 2008, 9 (SE ±3.3)/ km^2 in summer 2009, 12.4 (SE ± 1.4)/ km^2 in summer 2010 and 12 (SE ±1.5)/ km^2 was overall desnity of wild pig in summer (Table 3.4, Figure 3.5a and 3.5b). Seasonal group densities (summer and winter) for the year 2007, 2008, 2009, 2010 and overall group density were presented in the Table 3.4.

Table 3.4. Densities of wild pig in Pench Tiger Reserve, Madhya Pradesh, during winter and summer (2007 to 2010).

Year/Seasons	Wild pig Winter					Wild pig Summer				
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	1168
Total Observations	3	2	8	93	106	11	8	26	260	305
Truncated at	150					150				
Observation after Truncation	3	2	7	93	105	11	8	26	260	305
Density ± SE/ km²	3.4±3.2	3±2.7	2.4±1.1	6.3±1.3	5.2±1.2	17±9.4	5±2.8	9±3.3	12.4±1.4	12±1.5
Group Density ± SE/ km²	0.4±0.2	0.3±0.1	0.4±0.1	1.2±0.2	0.9±0.2	1.8±0.8	1.3±0.5	2.4±0.6	2.9±0.3	2.7±0.2
Effective Strip Width± SE (m)	49±1.8					49±2.1				
AIC value	222.7					615.6				
Model+ Adjustment term	Hazard rate cosine					Half normal cosine				

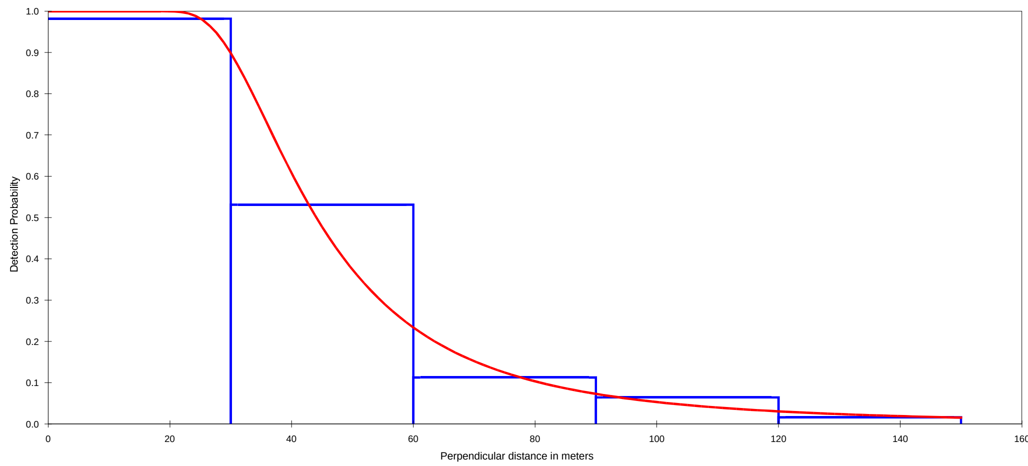


Fig. 3.5a. Probability of wildpig detections from line transect sampling (winter)

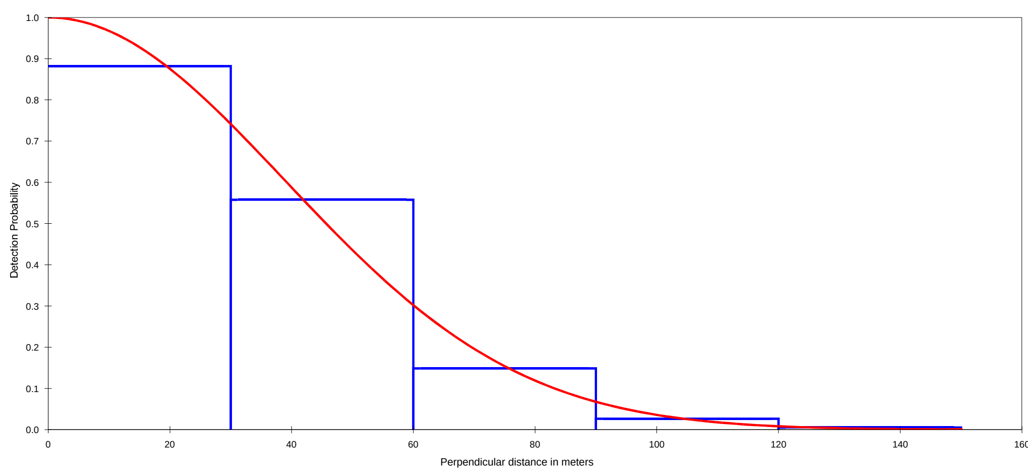


Fig. 3.5 b. Probability of wild pig detections from line transect sampling (summer)

3.4.1.5. **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 and 41 for overall. Half normal 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 53.1 (SE ±7.3) m, whereas for summer was 61 (SE± 8.1) m. The density of gaur was estimated to be 4 (SE±2.1)/ km^2 in winter 2007, 1.2 (SE± 0.4)/ km^2 in winter 2010 and overall densitiy in winter was 5.4 (SE±1)/ km^2 whereas 0.3 (SE ± 0.1)/ km^2 in summer 2007, 1.6 (SE ±0.4)/ km^2 in summer 2008, 1.6 (SE ± 0.5)/ km^2 in summer 2010 and 1.4 (SE ±0.5)/ km^2 was overall desnity of gaur in summer (Table 3.5, Fig. 3.6a and 3.6b). The density of gaur on winter 2008, 2009 and summer 2007, 2009 was not assessed because of very low sample size. Seasonal group densities for the year 2007, 2008, 2009, 2010 and overall group density were presented in the Table 3.5.

Table 3.5. Densities of gaur in Pench Tiger Reserve, Madhya Pradesh, during winter and summer (2007 to 2010).

Year/ Seasons	**Gaur Winter**					**Gaur Summer**				
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	1168
Total Observations	5	1	2	26	34	0	3	0	38	41
Truncated at	100					No Truncation				
Observation after Truncation	5	1	2	26	34	0	3	0	38	41
Density ± SE/ km^2	4±2.1	NA	NA	1.2±0.4	1.4±1	NA	0.3±0.1	NA	1.6±0.4	1.4±0.5
Group Density ± SE/ km^2	0.5±0.3	NA	NA	1.2±0.2	0.3±0.1	NA	0.3±0.2	NA	0.3±0.01	0.3±0.1
Effective Strip Width± SE (m)	53.1±7.1					61±8.1				
AIC value	74.9					383.7				
Model+ Adjustment term	Half normal cosine					Uniform cosine				

NA- Not Assesed

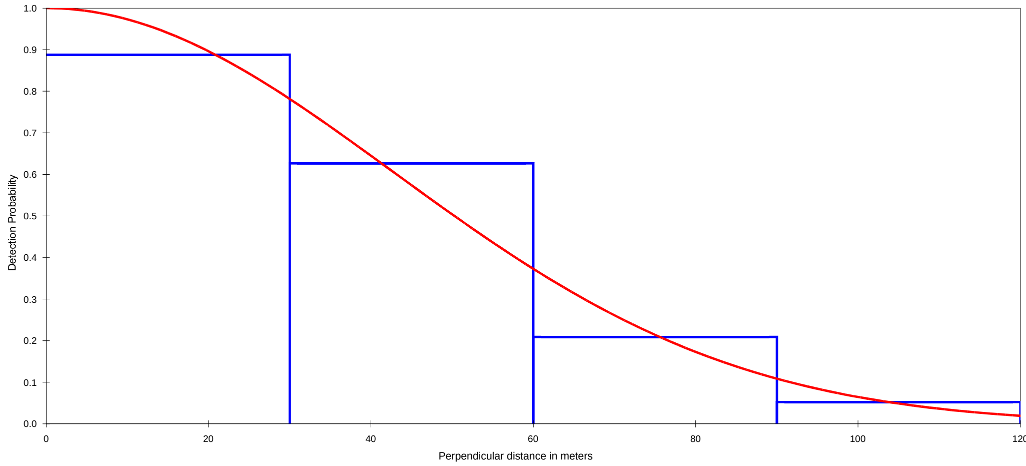


Fig. 3.6a. Probability of gaur detections from line transect sampling (winter)

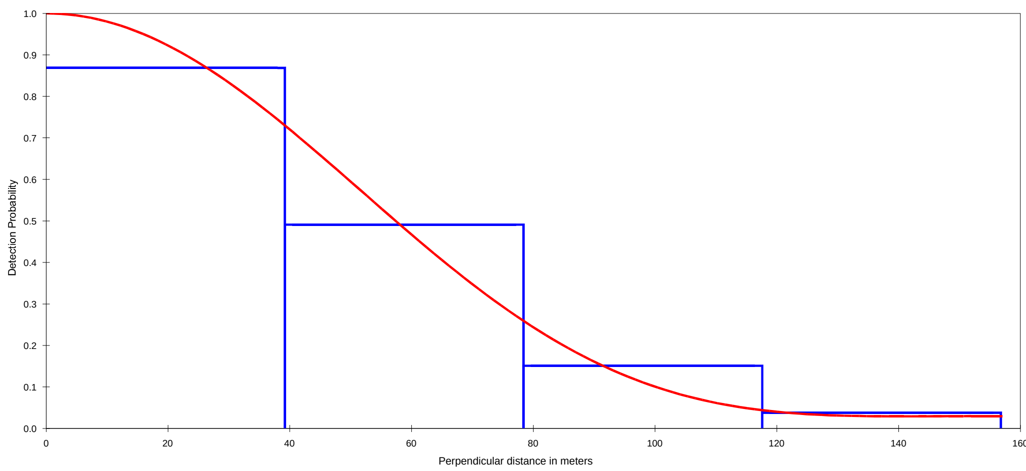


Fig. 3.6 b. Probability of gaur detections from line transect sampling (summer)

3.4.1.6. **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 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 and 1108 and truncating upto 150 m the observation remained same for all years. Half normal 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 40.1 (SE ±1) m, whereas for summer was 45 (SE± 1.1) m. The density of 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 densitiy in winter was 73 (SE±7.6)/ km² whereas 143 (SE ± 30.8)/ km² in summer 2007, 66 (SE ± 13.8)/ km² in summer 2008, 111 (SE ± 12)/ km² in summer 2009, 85 (SE ± 8.6)/ km² in summer 2009 and 90 (SE ± 8.2)/ km² was overall desnity of langur in summer (Table 3.6, Fig. 3.7a and 3.7b). Seasonal group densities of common langur for the year 2007, 2008, 2009, 2010 and overall group density were presented in the Table 3.6.

Table 3.6. Densities of common langur in Pench Tiger Reserve, Madhya Pradesh during winter and summer (2007 to 2010).

Year/ Seasons	**Langur winter**					**Langur summer**				
	2007	2008	2009	2010	Pooled	2007	2008	2009	2010	Pooled
Total effort	86	58	136	736	1016	60	62	120	924	1168
Total Observations	43	31	119	654	847	77	56	187	788	1108
Truncated at	120					150				
Observation after Truncation	42	31	119	651	843	77	56	187	788	1108
Density ± SE/ km²	62±14	41±9.5	54.2±9.8	81±7.1	73±7.6	143±30.8	66±13.8	111±12	85±8.6	90±8.2
Group Density ± SE/ km²	6.1±1.1	6.7±1.2	10.3±1.7	11±0.8	10±0.5	14±2.5	9.9±1.3	17±1.4	9.4±0.8	10.5±0.8
Effective Strip Width± SE (m)	40±1					45±1.1				
AIC value	2036					2084				
Model+ Adjustment term	Half normal cosine					Uniform cosine				

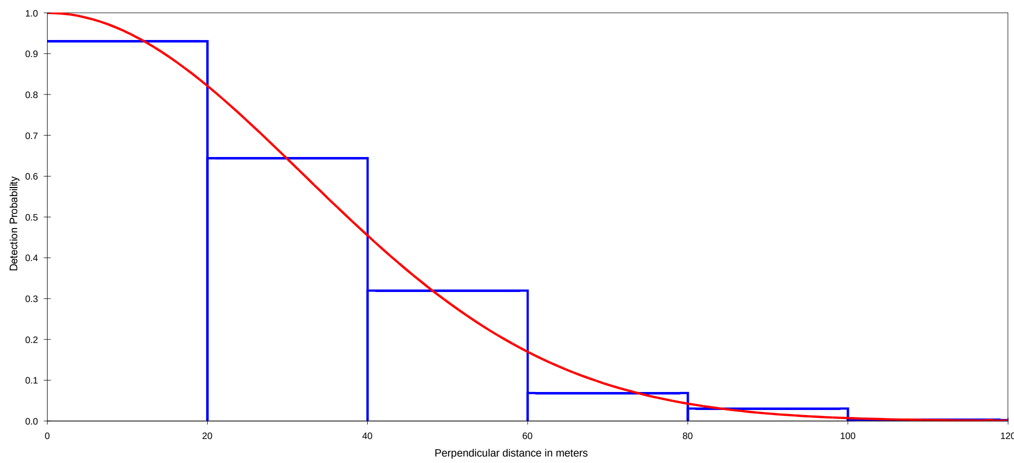


Fig. 3.7a. Probability of common langur detections from line transect sampling (winter)

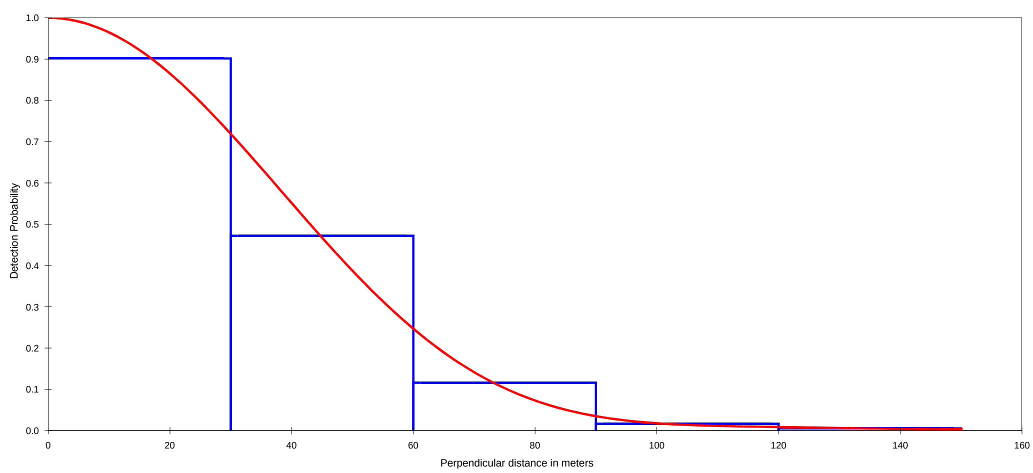


Fig. 3.7b. Probability of common langur detections from line transect sampling (summer)

3.4.2. 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 6705 ±1080 kg/km^2 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 winter and summer (Table. 3.7).

Table 3.7. The estimated biomass of the prey species in Pench Tiger Reserve, Madhya Pradesh (2007 to 2010).

Species	Average body weight (Kg)	Biomass (W)	Biomass (S)
Chital	47	2350±334	3342±522
Sambar	134	804±67	1206±147.4
Nilgai	180	360±90	378±72
Gaur	450	630±450	675±225
Wild pig	32	167±44.8	384.4±48
		4894.4±1046.3	6705±1080

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

3.4.3. 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 3.8. In case of wild pig only adult male, female and young ones were classified.

In total 1723 chital were observed 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 in 155 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 (31 on vehicle transect and 27 on line transect) and 94 in summer, gaur in 156 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 on 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 3.8. Proportions of different age and sex classes among different ungulate species in Pench Tiger Reserve, Madhya Pradesh (2007 to 2010)

Species	Winter						Summer					
	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 3.9). 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 for winter and 100:60 for summer whereas adult female: young was 100:60 for both winter and summer. In case of wild pig, adult sex ratio was 100:80 for both winter and summer whereas adult female: young ratio was 100:80 for winter and 100:50 for summer.

Table 3.9. Seasonal variation in age-sex ratios among different ungulate species in Pench Tiger Reserve, Madhya Pradesh (2007 to 2010).

Species	Winter			Summer		
	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 3.10. In both winter and summer chital and common langur with group size class of 4 to 10 contributed maximum (>40%), whereas in case of nilgai, sambar, wild pig and gaur, solitary individuals and family associations (two to three individuals) comprised > 50%.

Incase of chital, the estimated mean group size ± Standard Error or SE in winter was 4± 0.3 and in summer was 7.5±0.8. Incase of sambar, the mean group size in winter was 2.2±1.3 and in summer was 3.1±0.3. Incase of nilgai, the estimated mean group size in winter was. 2.1±1.4 and in summer was 1.9±0.3. Incase of wild pig, the estimated mean group size in winter was 5.7±2.2 and in summer was 4.3±0.8. Incase of gaur, the estimated mean group size in summer was 2.3±0.8, whereas the winter data of gaur was not assessed because of low sample size. Incase of common langur, the estimated mean group size in winter was 6.7±0.5 and in summer was 7.4±0.6.

In case of chital, the seasonal group size varied from 1 to 32 during winter and from 1 to 203 during summer. In case of sambar, the seasonal group size varied from 1 to 5 in winter and from 1 to 12 in summer. In case of nilgai, the seasonal group size varied from 1 to 5 in winter and from 1 to 6 in summer. In case of gaur, the seasonal group size varied from1 to15 in winter and from 1 to 4 in summer. In case of wild pig, the seasonal group size varied from 1 to 28 in winter and from 1 to 14 in summer. In case of common langur the seasonal group size varied from 1 to 23 in winter and from 1 to 39 in summer.

Table 3.10. Group size distribution of the ungulates and common langur in Pench Tiger Reserve, Madhya Pradesh (2007 to 2010).

Species	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+**
Cheetal	898	15.3	28.3	40.5	13.5	2.4	996	1	19.3	43.0	23.2	4.5
Sambar	273	33.0	48.7	17.9	0.4	--	355	23.4	54.4	20.8	1.1	0.3
Nilgai	97	49.5	38.1	11.3	1.0	--	130	36.9	43.1	2	--	--
Wild pig	105	35.2	18.1	33.3	13.3	--	276	34.1	20.7	33.3	12.0	--
Gaur	34	35.3	26.5	26.5	11.8	--	45	8.9	26.7	53.3	11.1	--
Common Langur	765	12.9	17.3	47.8	21.8	0.1	929	8.5	16.0	44.7	29.2	1.6

--not observed during the sampling period; Obs- total numbers of animal classified

3.5. Discussion

3.5.1. 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 density estimation. 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 large carnivores during study period

On comparing densities (± standard error or SE) of prey species during the study period in winter (Fig. 3.8a), it was evident that incase of chital, densities didnot 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. 3.8a). In case of sambar, nilgai, and wild pig, densities (± SE)/ km²) did not differ significantly (p >

0.05) over the period (Fig. 3.8a). 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 3.8b).

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 transect for the years 2007, 2008 and 2009 respectively. 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.

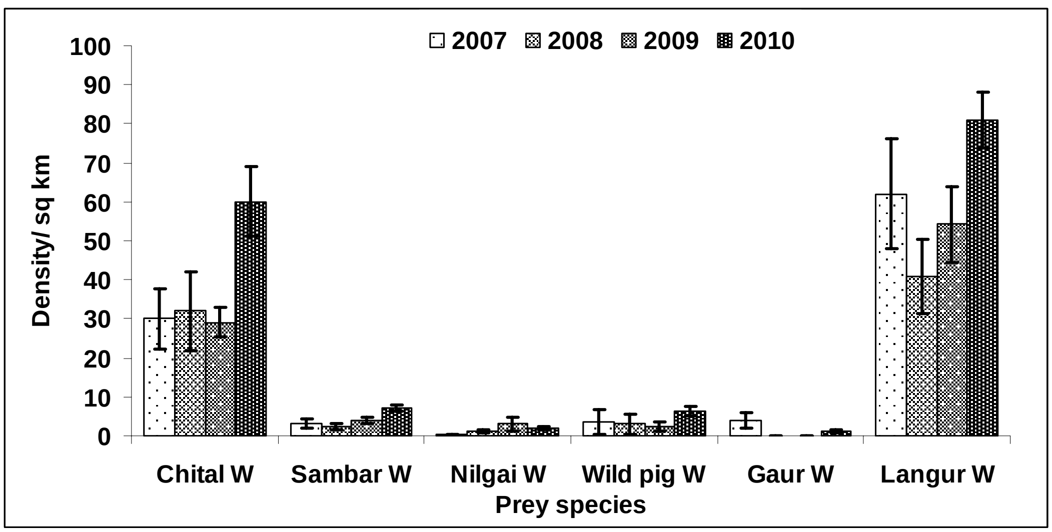


Fig. 3.8a Comparative densities (± SE)/ km² of major prey species of large carnivores in Pench Tiger Reserve during winter (2007 to 2010)

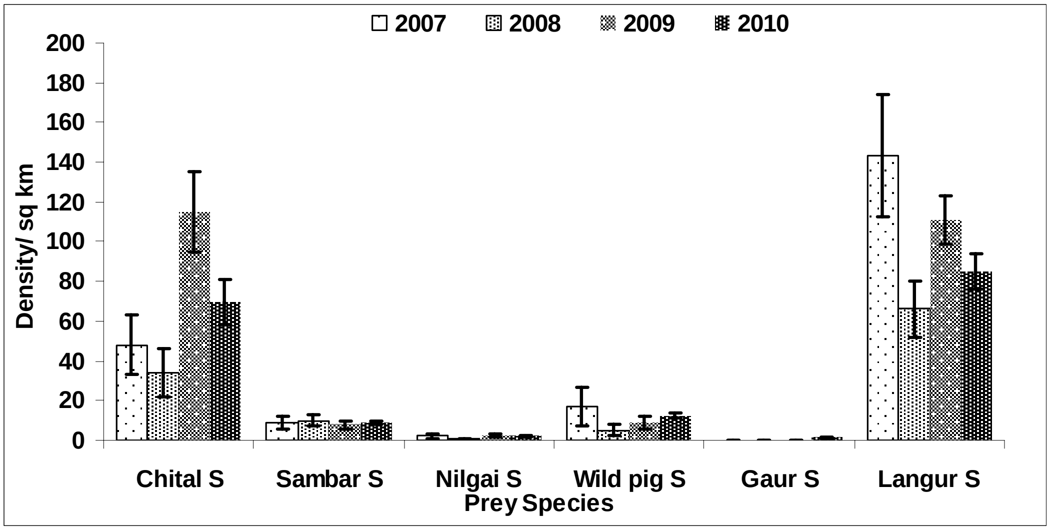


Fig.3.8b. Comparative densities (± SE)/ km² of major prey species of large carnivores in Pench Tiger Reserve during summer (2007 to 2010).

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 prey biomasses of 6,061.3 kg/km^2 which is the sixth largest estimate of prey biomass density in the country followed by Sariska Tiger Reserve (Sankar *et al.* 2010), Mudumalai Tiger Reserve (Ramesh 2010), Nagarhole Tiger Reserve (Karanth and Nichols 1998), Rajaji National Park (Harihar 2005) and Ranthambore Tiger Reserve (Bagchi *et al.* 2003). 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 density in PTR is one of the highest in Indian Sub-continent.

Table 3.11. Densities and biomass of prey species of tiger, leopard and dhole from different study areas in the Indian sub-continent.

Location	Chital	Sambar	Wild Pig	Nilgai	Gaur	Common langur	Biomass (kg/km^2)
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
Present study*	**60.5**	**7.5**	**8.6**	**2.1**	**1.5**	**81.5**	**5780**

[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.

3.5.2. 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; Acharya and Sankar 2004; 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), Flordia, 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 Flordia (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. The smaller group size of 1-5 individuals was recorded >70 percent throughout the year also 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. Increased group size in wild pig in PTR was recorded only in the winter season and this may be attributed to food availability and peak littering period. 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 numbers.

Plate 3.1. Major prey species for large carnivores in the study area

Chapter 4

Chapter 4

PREY SELECTION AND FOOD HABITS OF SYMPATRIC CARNIVORES

4.1. 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 studies on food habits of leopard suggest that it has a more diverse diet ranging from lower size classes of animals to medium sized wild species weighing less than 5 kg (Eisenberg and Lockhart 1972; Santiapillai *et al.* 1982; Rabinowitz 1989;

Seidensticker *et al.* 1990). The ability to scale trees allows the leopard to overcome its carnivorous competitors, often taking its prey far out of reach of them (Bailey 1993). Leopard tends to select prey smaller than themselves (Johnsingh 1983; Karanth and Sunquist 1995; Schaller 1972; Sunquist 1981). It can be considered as an ecological generalist, rather than a specialist (Bailey 1993) as it predates on species ranging from rodents to buffaloes (Bothma and Riche 1984; Sathyakumar 1988; Santiapillai and Ramono 1992; Karanth and Sunquist 1995; Sankar and Johnsingh 2002; Edgaonkar and Chellam 1998; Henschel *et al.* 2005).

Dhole is group-living canids, in many ways resembling with wolves and the African wild dogs in their life history traits (Johnsingh 1982). Like wolves, dhole run down their prey, biting as they chase, and feeding while the prey is still alive and in most places their prey base consist of cervids, bovids, suids and primates (Ramesh 2010).

Earlier studies on large carnivore dietary pattern in PTR were species specific (eg. Biswas and Sankar (2002) on tiger and Achariya *et al.* (2007) on dhole) and hence a detail long term study was always need of hour on their dietary overlap. Owing to that, this present study on food habits of tiger, leopard and dhole was carried out with comparable scientific methods.

4.2. Literature review

Knowledge of the food habits of a carnivore is also central to understanding many aspects of its behavior and ecology (Mills 1992). Feeding ecology of carnivores has been studied using different methods like observation in the field, stomach content analysis (Smuts 1979), identifying kills and analysis of scat (Reynolds and Aebischer 1991).

Stomach analysis is a very quick and easy method for diet analysis. Smuts (1979) assessed the diet of lions and spotted hyenas by analyzing remains in the stomach contents of animal killed during predator-control experiment in Kruger National Park. This method is not always possible to determine if food was killed or was scavenged. The spoor of lion (Eloff 1973, 1984), cheetah (Labuschagne 1979), leopard (Bothma and le Riche 1984, 1990), and spotted hyena (Mills 1990) have revealed much useful data on the feeding habits of these species in the southern Kalahari (Mills 1984).

Observations of kills encountered opportunistically are easy to make, and have been utilized in a number of studies on the food habits of large African carnivores (Schaller 1972; Mills 1984) and Indian sub-continent (Chundwat *et al.* 1999). Such observations are clearly biased towards large animals, however, and must be treated with caution when used to describe the diet of a species (Mills 1990).

For long term studies on large and elusive carnivores, feeding pattern of radio-collared individual is often applicable. This method is widely used on large carnivores like lion (Mills 1992; Hayward 2007), tiger (Seidensticker 1976a; Sunquist 1981; Karanth and Sunquist 2000; Chundawat *et al.* 1999; Sankar *et al*. 2010), Jaguar (Scognamillo *et al.* 2003), Leopard (Seidensticker 1976a; Bertram 1982), dhole (Acharya *et al.* 2007), African wild dog (Mills 1992), cheetah (Caro 1994), mountain lion (Scognamillo *et al.* 2003; Pierce *et al.*1998), wolf (Jhala 1993; Mech 1977; Jhala and Giles 1991), Couger (Koehler and Hornocker 1991) and Coyote (Litvaitis and Shaw 1980). This method is biased towards larger prey and huge monetary involvement is also required (Mills 1992).

Following carnivores in a vehicle and then observing them in the hunt is an important method of studying the food habits of large African carnivores (Kruuk 1972; Schaller 1972; Elliot *et al.* 1977; Mills 1990, 1992; Van Orsdol 1982, 1984, 1986; Stander, 1991; Fanshawe and Fitz Gibbon 1993). This method is very much labour intensive and possible only in certain habitat conditions. In addition, animals may be disturbed during close observations.

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; Edgaonkar 2008; Ramesh *et al.* 2009), leopard (Johnsingh 1983; Mukherjee *et al.* 1994b; Satyakumar 1988; Dharaiya and Soni 2010), dhole (Fox and Johnsingh 1975; Cohen *et al.* 1978; Johnsingh 1983; Andheria *et al.* 2007; Acharya *et al.* 2007; Wang and MacDonald 2009a; Arivazhagan *et al.* 2007; Edgaonkar 2008).

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 complementary techniques. Owing to that, both analysis of scat and kills of prey species were undertaken to study the dietary pattern of these three sympatric carnivores in PTR.

4.3. Methods

4.3.1. Collection of scats

Scats of tiger, leopard and dhole were collected opportunistically as well as systematically along animal and man made trails and dirt roads in the study area. Scats of the three carnivore species 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. Leopard scats were differentiated from that of other carnivore species on the basis of diameter (Rabinowitz 1989), pointed ends and numerous lobes (Edgaonkar and Chellam 1998). Dhole scats were easily distinguishable from those of the leopard scats. Dhole scats are much smaller, with a characteristic odour, usually found in a bunch at cross-roads or intersections, and mostly deposited on bare or exposed soil (Acharya *et al.* 2007). 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). A total of 467 tiger scats were collected during winter and 155 tiger scats during summer, 91 leopard scats in winter and 120 in summer and 199 dholes scats collected in winter and 139 scats in summer.

4.3.2. Analysis of scats

All collected scat samples were oven dried at 60 ºC 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.

4.3.2.1. 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, wildpig, 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.

4.3.2.2. 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.

4.3.2.3. 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).

4.3.2.4. 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).

4.3.2.5. 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. 4.1).

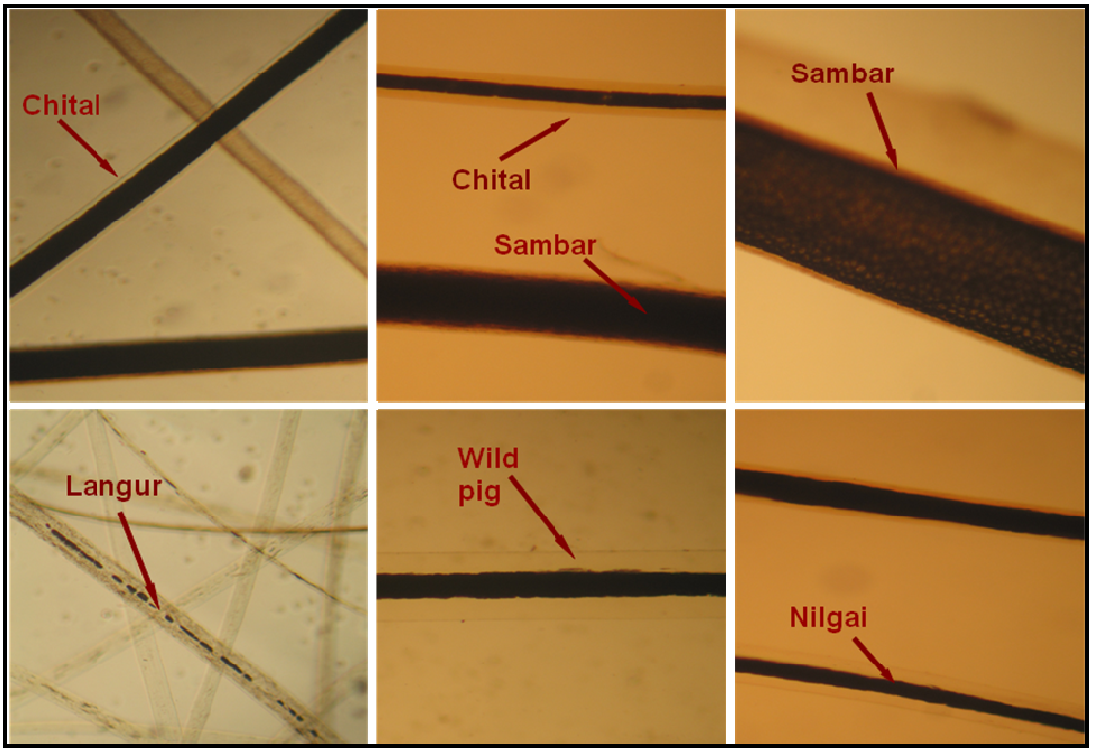


Fig. 4.1. Microphotography of medullar structure of hairs of different prey species of tiger, leopard and dhole

4.3.3. 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). 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. 4.2) and out of 467 tiger scats, 300 to 310 scats were found adequate in winter (Fig. 4.3).

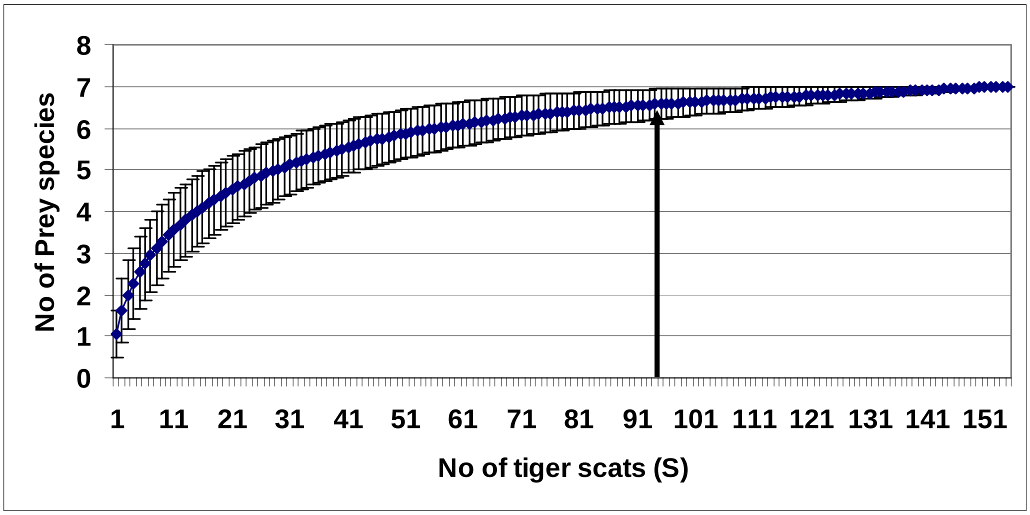


Fig. 4.2. Scat sample stabilization curve for summer diet of tiger in Pench Tiger Reserve (March-July, between 2007 and 2010).

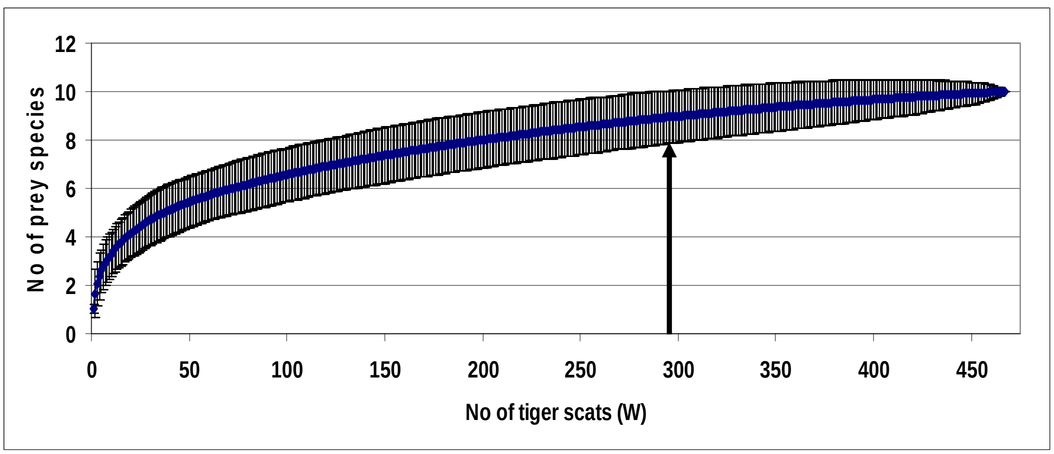


Fig 4.3. Scat sample stabilization curve for winter diet of tiger in Pench Tiger Reserve (November- February, between 2006 and 2010).

In the case of leopard, out of 120 scats, analysis of 60 to 65 leopard scats were found adequate to stabilize the dietary spectrum of leopard in summer (Fig.4.4) and out of 91 scats, 45 to 50 scats were found adequate in winter (Fig.4.5).

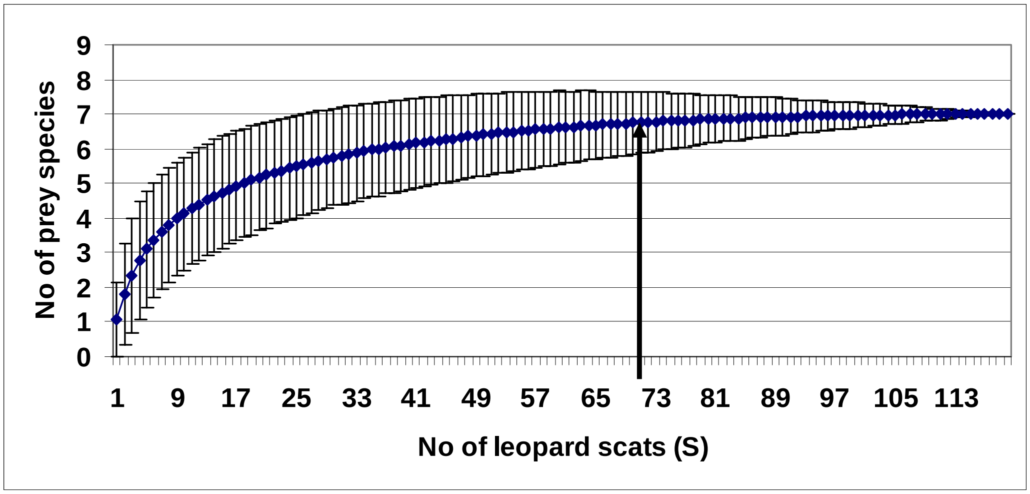


Fig.4.4. Scat sample stabilization curve for summer diet of leopard in Pench Tiger Reserve (March-July, between 2007 and 2010).

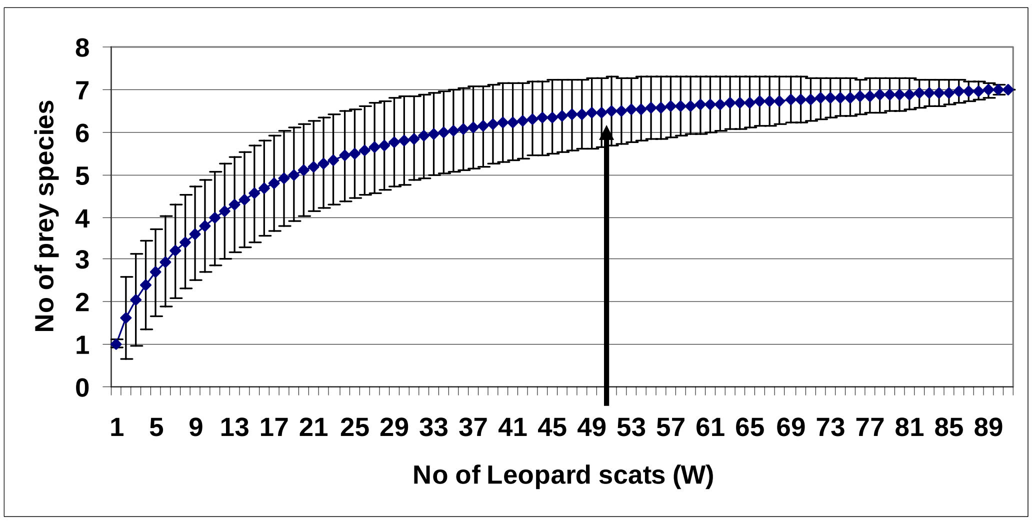


Fig. 4.5. Scat sample stabilization curve for winter diet of leopard in Pench Tiger Reserve (November- February, between 2006 and 2010).

Out of 139 dhole scats, analysis of 100 to 110 dhole scats were found adequate to stabilize the dietary spectrum of the dhole in summer (Fig. 4.6) and out of 199 scats, 95 to 105 scats were found adequate in winter (Fig. 4.7).

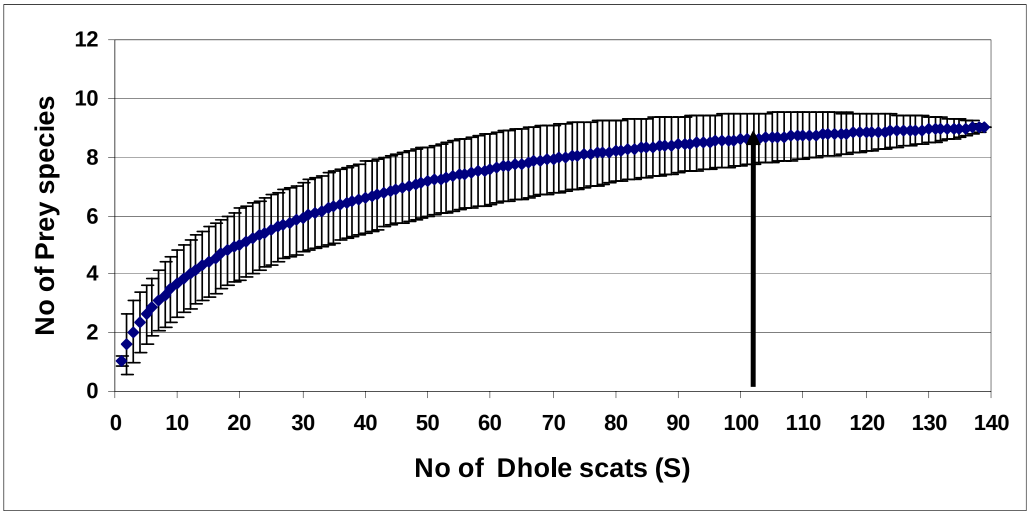


Fig. 4.7. Scat sample stabilization curve for the summer diet (S) of dhole in Pench Tiger Reserve (March-July, between 2007 and 2010).

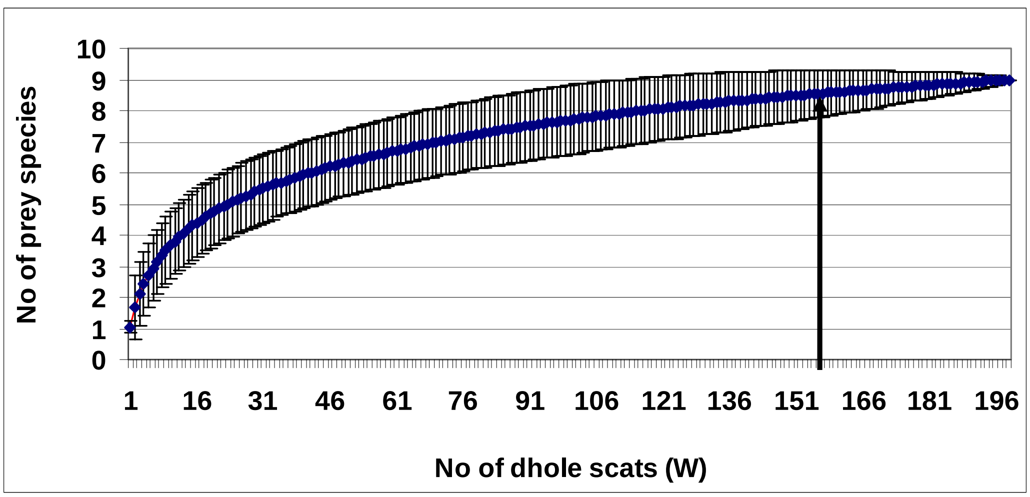


Fig. 4.6. Scat sample stabilization curve for the winter (W) diet of dhole in Pench Tiger Reserve (November- February, between 2006 and 2010).

4.3.4. 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).

4.3.4.1. 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 and leopard and Jethva and Jhala (2003) from feeding studies of wolf was used for dhole 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, leopard and dhole were 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.

Λi = 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 and leopard)

Y= 0.135 +0.0148X (dhole)

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.

4.3.4.2. Dietary overlap of sympatric carnivores

A variety of diet overlap indices were used in field measurements of ecological niche separation (Pianka 1973). Pianka's index was used for measuring diet overlap between predators. $Oab=\Sigma nPiaPib/(\sum P^2iaP^2ib)^{1/2}$ where Pia is the relative frequency of the item i found in the diet of species a (Pib is the relative frequency of i found in the faeces of species b). This index ranges in value from 0 (indicating no overlap between two predator species) to 1.0 (complete overlap).

4.3.5. Kills

Kills made by these three sympatric carnivores were 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 bengalensis*). 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 predator. 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 sympatric carnivores were compared between these seasons and focused on frequency of occurrence of prey remains. A total of 120 tiger kills were recorded during winter and 156 during summer, for leopard, 35 kills were recorded during winter and 55 during summer and for dholes 25 kills were recorded during winter and 58 during summer. Detection of kills during winter is less as compared to summer in the case of all three carnivores because of thick vegetation cover and low scavenger activities.

The age-sex 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 the sympatric carnivores 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.

4.3.5.1. 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 large carnivores. 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.

4.4. Results

4.4.1. Analysis of scats

The scat analysis revealed the presence of ten prey species in the diet of tiger in winter and seven prey species in summer; eight prey species both in the diet of leopard in winter and summer, whereas nine prey species in the diet of dhole in winter and seven prey species in summer (Table 4.1, 4.2 and 4.3). Of the prey species found in tiger scats, (Table 4.1) 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 (0.6% in winter), hare (0.2% in winter), unknown birds (0.4%) and porcupine (0.6 % in summer). In leopard scats (Table 4.2), chital contributed maximum (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 (only 2.3% in summer). In the diet of dhole, (Table 4.3) 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), 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% only in summer), porcupine and reptiles (0.5% both in winter). No attempt was made to identify the species of rodents, birds and reptiles observed 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 one 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 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 4.3). 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 4.4). 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 4.1. 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.

Table 4.2. Leopard diet (n = 107 in winter and n = 82 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 (W)**	**CF**	**RIC (W)**	**RIC (S)**	**Ivlevs (W)**	**Ivlevs (S)**
Chital	0.38	0.36	47	61	55.45	38	42.70	3.63	0.56	0.46	0.209	0.121
Sambar	0.04	0.05	134	10	9.09	6	6.74	6.67	0.17	0.13	0.587	0.491
Nilgai	0.01	0.01	180	3	2.73	1	1.12	8.28	0.06	0.03	0.622	0.444
Wild pig	0.05	0.07	32	9	8.18	8	8.99	2.26	0.07	0.08	0.300	0.153
Common langur	0.50	0.50	8	18	16.36	26	29.21	17.73	0.10	0.20	-0.675	-0.398
Hare			2.1	4	3.64	4	4.49	2.05	0.02	0.03		
Cattle			180	0	0.00	2	2.25	8.28	0.00	0.06		
Rhodent			0.5	4	3.64	2	2.25	2.00	0.02	0.01		
Bird				1	0.91	2	2.25					

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 leopard.

Table 4.3. Dhole diet (n=199 in winter and n=139 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 (W)	CF	RIC (W)	RIC (S)	Ivlevs (W)	Ivlevs (S)
Chital	0.38	0.36	47	120	57.42	88	61.54	0.83	0.54	0.57	0.152	0.138
Sambar	0.04	0.05	134	43	20.57	25	17.48	2.12	0.32	0.26	0.824	0.766
Nilgai	0.01	0.01	180	0	0.00	3	2.10	2.80	0.00	0.04	-1	0.674
Wild pig	0.05	0.07	32	5	2.39	5	3.50	0.61	0.02	0.03	-0.428	-0.507
Common langur	0.50	0.50	8	18	8.61	12	8.39	0.25	0.06	0.06	-0.919	-0.917
Hare			2.1	15	7.18	4	2.80	0.17	0.05	0.02		
Cattle			180	0	0.00	1	0.70	2.80	0.00	0.01		
Rodent			0.5	3	1.44	3	2.10	0.14	0.01	0.01		
Porcupine			10	1	0.48	0	0	0.28	0.00	0		
Bird				3	1.44	2	1.40					
Reptiles				1	0.48	0	0					

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 dhole

4.4.2. 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 4.4). 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. 4.8a and Fig. 4.8b). In winter, nilgai, sambar, chital and wild pig were siginificantly consumed ($p<0.05$) more than their availabilities by leopard and common langur were less consumed in both winter and summer (Table 4.4). The index of selectivity at individual level prey species by leopard in winter: nilgai> sambar> wild pig> chital> common langur and in summer: sambar>nilgai>chital>wild pig>common langur (Fig.4.8a. and Fig. 4.8b.). In winter, sambar and chital were significantly consumed more than their availabilities by dhole, wildpig and common langur were less consumed whereas in summer sambar, nilgai and chital were consumed more than their availabilities and wild pig and common langur were less consumed (Table 4.4). The index of selection at individual level prey species by dhole was ranked in the following order in winter: sambar> chital> wild pig> nilgai> common langur and in summer:sambar> nilagi> chital> wildpig> common langur (Fig.4.8a and Fig. 4.8b).

Table. 4.4. Preference of prey species by tiger, leopard and dhole in Pench Tiger Reserve based on availability of individuals and utilization from analsys of scats (November 2006 to July 2010)

Carnivores		**Winter**			**Summer**		
	Prey species	**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
leopard	Chital	0.0020	0.0032± 0.0001	0.0085± 0.001	0.250	0.2661±0.0021	0.3119±0.0061
	Sambar	0.5500	0.5512±0.003	0.5673±0.0032	0.307	0.3104±0.0016	0.3309±0.0029
	Nilgai	0.6660	0.6650± 0.0034	0.6739±0.0035	0.306	0.3057±0.0015	0.3156±0.0017
	Wild pig	0.0670	0.0702±0.0005	0.0808±0.0016	0.231	0.2334±0.0012	0.2455±0.0018
	Langur	0.0000	0.0001±0.0000	0.0004±0.0001	0.454	0.4631±0.0026	0.5102±0.0053
Dhole	Chital	0.0001	0.0001±0.0001	0.0001±0.0001	0.000	0.001±0.0001	0.0001±0.0001
	Sambar	0.0001	0.0001±0.0001	0.001±0.0001	0.006	0.0065±0.0001	0.0108±0.0005
	Nilgai	NA	NA	NA	0.488	0.488±0.0025	0.4965±0.0027
	Wild pig	0.1260	0.1401±0.0014	0.1675±0.0032	0.1690	0.1738±0.001	0.1922±0.0023
	Langur	0.0001	0.0001±0.0001	0.0001±0.0001	0.0001	0.001±0.0001	0.001±0.0001

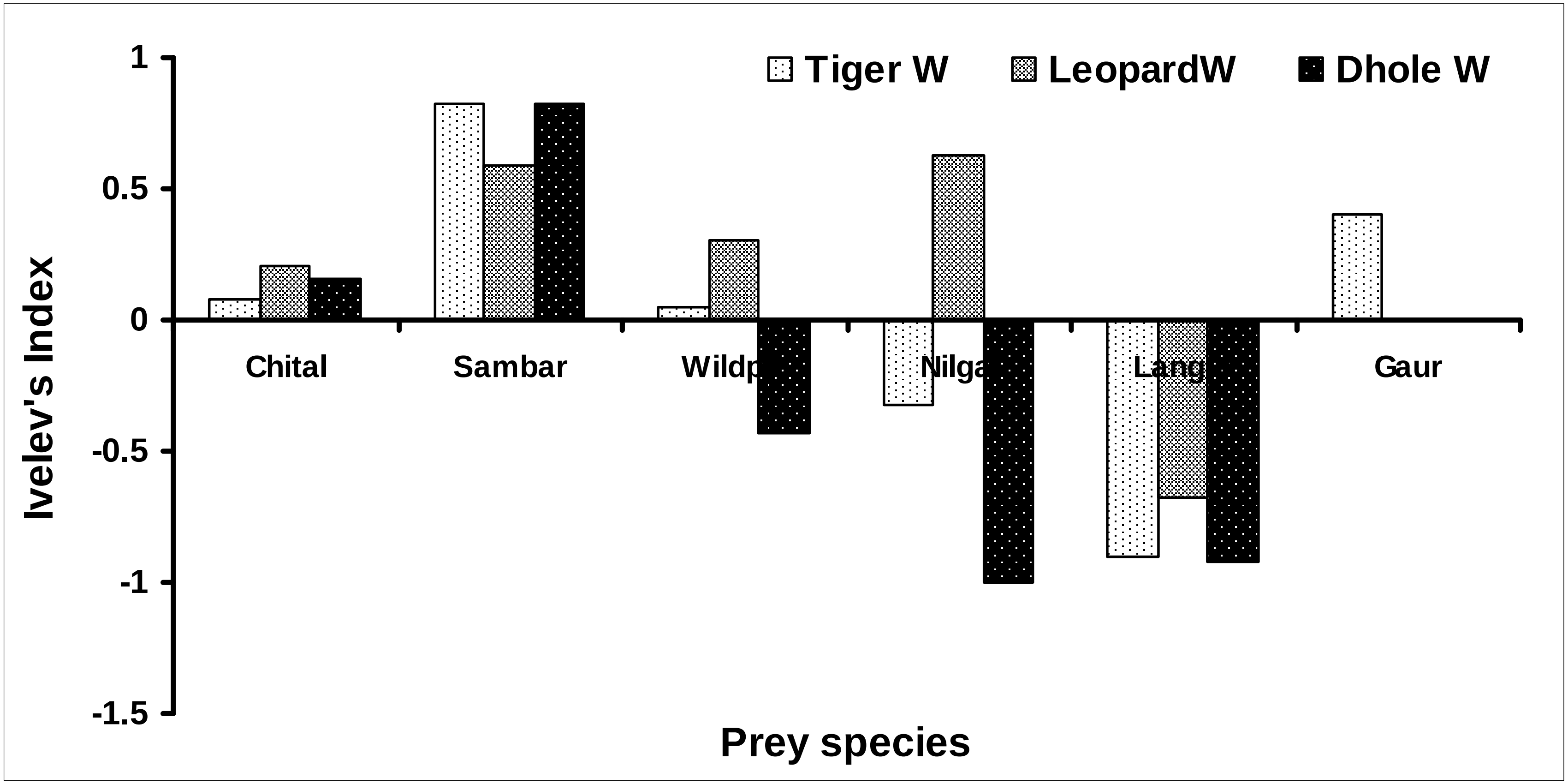


Fig. 4.8a. Prey selection of tiger, leopard and dhole as shown by scat analysis in Pench Tiger Reserve, Madhya Pradesh in winter (November- February, between 2006 and 2010).

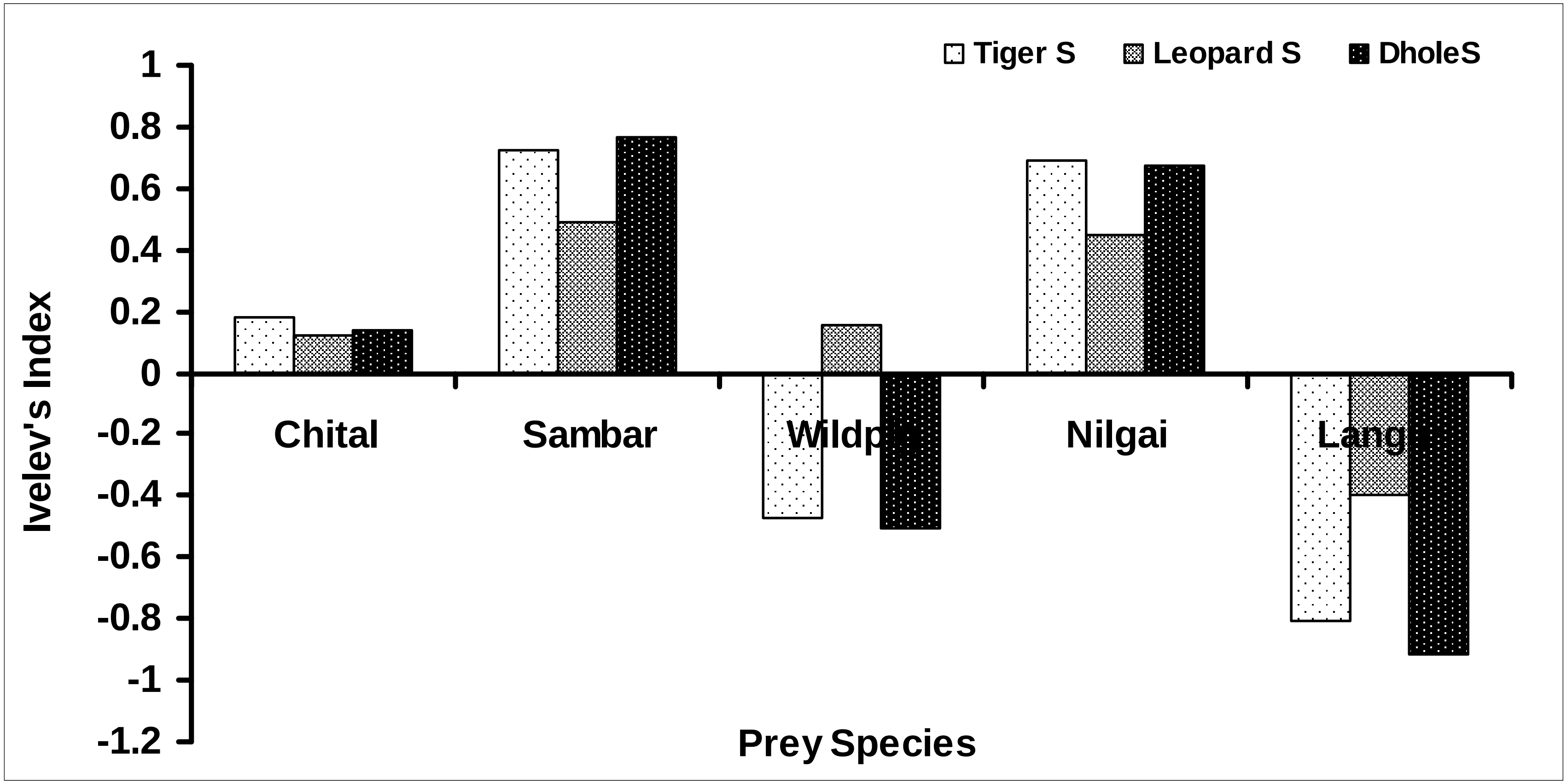


Fig. 4.8b. Prey selection of tiger, leopard and dhole as shown by scat analysis in Pench Tiger Reserve, Madhya Pradesh in summer (March-July, between 2007 and 2010).

4.4.3. Dietary overlap between three sympatric carnivores

The estimated dietary overlap between tiger and leopard using Pianka's index was 91% in winter and 88% in summer, between tiger and dhole was 97% in winter and 99% in summer and between leopard and dhole was 96% in winter and 88% in summer. The overall dietary overlap between tiger and leopard was 89%, tiger and dhole was 98% and leopard and dhole was 92% (Table 4.5).

Table. 4.5. Dietary overlap of tiger, leopard and dhole in Pench Tiger Reserve, Madhya Pradesh (November 2006 to July 2010)

Species	**Winter**	**Summer**	**Overall**
Tiger and Leopard	0.91	0.88	0.89
Tiger and Dhole	0.97	0.99	0.98
Leopard and Dhole	0.96	0.88	0.92

4.4.5. Kills

Of the 292 tiger kills recorded, 127 were observed during winter and 165 kills during summer, in case of leopard 36 kills were recorded during winter and 55 kills were recorded during summer; whereas 32 kills in winter and 55 kills in summer were recorded in case of dhole (Table 4.6). Chital adult male contributed maximum in case of all three carnivores in both winter and summer (for tiger 19.7% in winter and 33.3% in summer, for leopard 33.33% in winter and 40% in summer and for dhole 21.9% in winter and 29.1% in summer) followed by sambar adult female (for tiger 14.2% in winter and 9.1% in summer, for leopard 1.8% in summer and for dhole 18.8% in winter and 5.5% in summer). Gaur contributed only in the diet of tiger. Common langur was predated maximum by leopard (11.1% in winter and 12.7%) in summer followed by tiger (0.8% in winter and 1.2% in summer). 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 4.6).

Table 4.6. Food habits of tiger, leopard and dhole as shown by kill data in Pench Tiger Reserve, Madhya Pradesh (November 2006 to July 2010).

		Tiger (% frequency of occurrence)		**Leopard (% frequency of occurrence)**		**Dhole (% frequency of occurrence)**	
Species	**Age**	**Winter (n=127)**	**Summer (n=165)**	**Winter (n=36)**	**Summer (n=55)**	**Winter (n= 32)**	**Summer (n=55)**
Chital	AM	19.7	33.3	33.3	40	21.9	29.1
	AF	7.1	7.3	13.9	23.6	18.8	7.3
	SAM	1.6	2.4	16.7	0	0	1.8
	SAF	1.6	2.4	0	1.8	12.5	7.3
	Young	3.1	4.2	8.3	10.9	6.3	14.5
Sambar	AM	15.0	4.8	0	0	3.1	0
	AF	14.2	9.1	0	1.8	18.8	5.5
	SAM	0.8	1.2	0	1.8	0	1.8
	SAF	0.8	0.6	0	0	0	1.8
	Young	3.1	1.8	2.8	1.8	3.1	16.4
Nilgai	AM	9.4	6.1	0	0	3.1	3.6
	AF	2.4	1.8	0	0	3.1	0
	SAM	1.6	0	0	0	0	0
	SAF	0.8	0	0	0	0	0
	Young	1.6	1.2	5.6	0	3.1	1.8
Wild pig	AM	8.7	7.9	2.8	0	3.1	7.3
	AF	1.6	1.2	0	1.8	3.1	1.8
	Young	0.8	0	5.6	3.6	0	0
Gaur	AM	0.8	6.1	0	0	0	0
	AF	0.8	2.4	0	0	0	0
	SAM	0	3.0	0	0	0	0
	SAF	0	0.6	0	0	0	0
	Young	1.6	0.6	0	0	0	0
Others	Langur	0.8	1.2	11.1	12.7	0	0
	Peafowl	1.6	0	0	0	0	0
	Cattlle	0.8	0	0	0	0	0
	Porcupine	0	0.6	0	0	0	0

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

4.4.5.1. 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.

The index of selection of prey species in different age classes by leopard in winter was ranked in the following order: sambar young> chital adult male>wild pig adult male> nilgai adult male>chital young> wild pig young> chital adult female and for summer the order was: chital adult male>sambar young>wild pig adult female>wild pig young> chital young>sambar adult female> chital adult female.

The index of selection of prey species in different age classes by dhole was ranked in winter in the following order: as nilgai adult male>chital adult male>wild pig adult female>sambar adult female>sambar adult male>chital young> chital adult female and in summer the order was: sambar adult male>chital adult male>wild pig adult male> nilgai adult male>sambar young>chital young>nilgai young> wild pig female> sambar adult female> sambar adult female> chital adult female. (Fig. 4.9a and 4.9b).

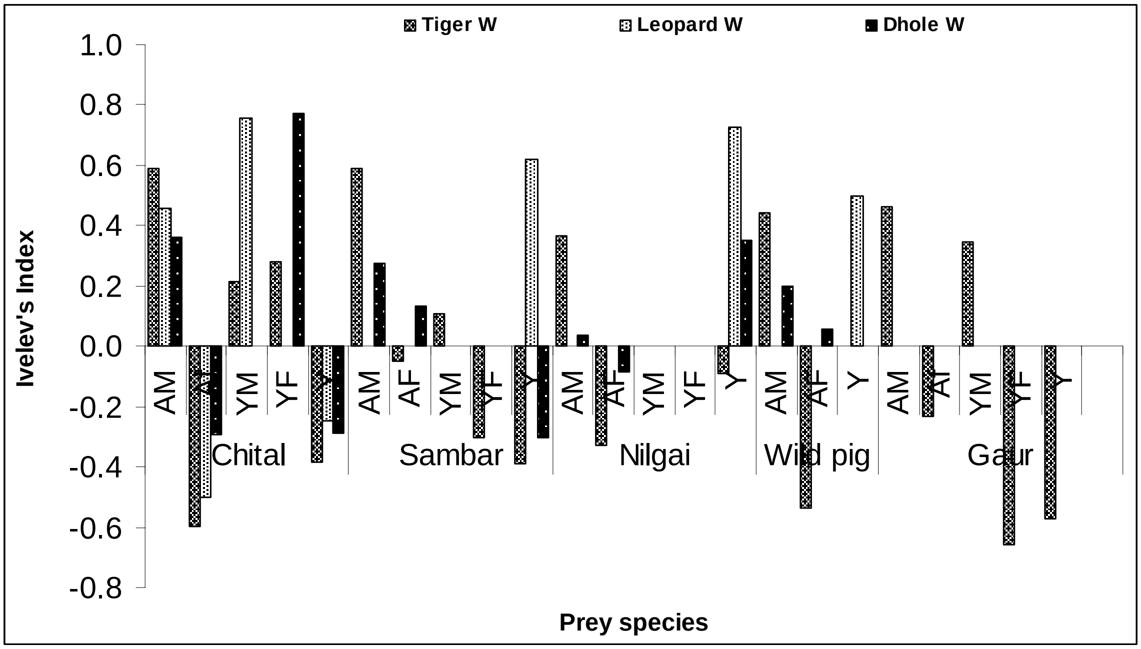


Fig. 4.9a. Prey selection of tiger, leopard and dhole as shown by kill data in Pench Tiger Reserve, Madhya Pradesh in winter (November- February, between 2006 and 2010).

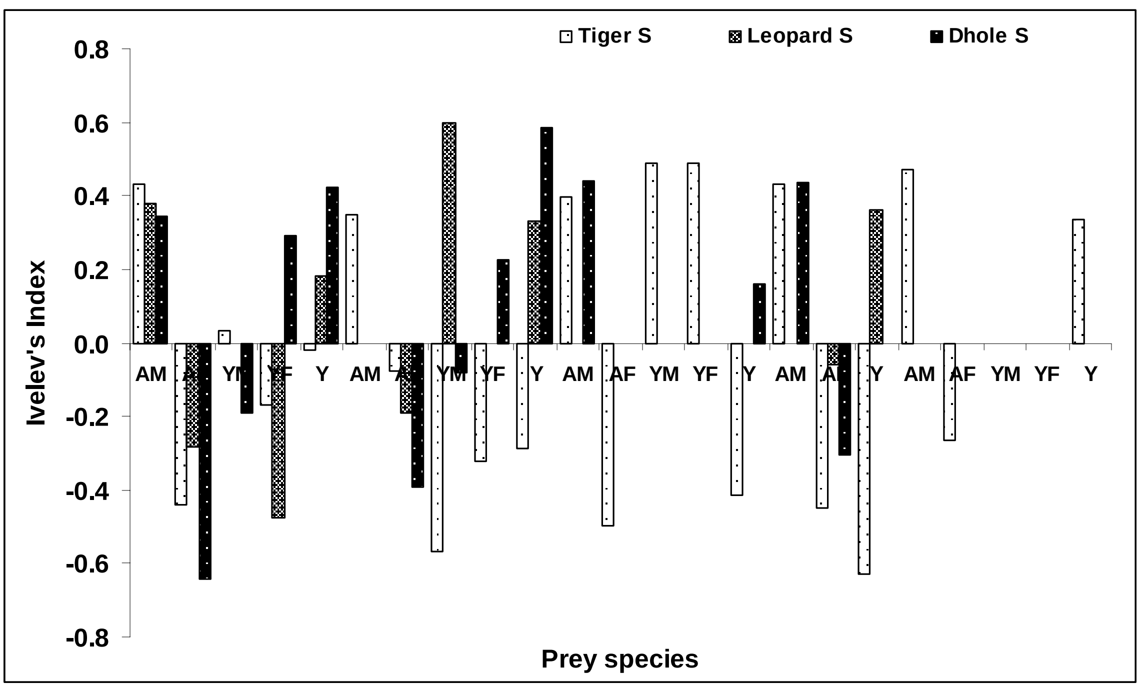


Fig. 4.9b. Prey selection of tiger, leopard and dhole as shown by kill data in Pench Tiger Reserve, Madhya Pradesh in summer (March-July, between 2007 and 2010).

4.4.5.2. 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 4.7). Of the 59 leopard kills, 30.3% was contributed by prey species with good health condition, 24.2% with medium health condition and 53.1% with poor health condition (Table 4.7). Of the 50 dhole kills, 29.2% was contributed by prey species with good health conditions, 10.1% with prey species with medium health condition and 60.8% with poor health conditions (Table 4.7).

Table 4.7. 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
Leopard (n=59)	Chital (n=46)	32.6	21.7	45.7
	Sambar (n=4)	25.0	25.0	50
	Nilgai (n=2)	0	50	50
	Wild pig (n=3)	33.3	NF	66.7
	Overall prey species	30.3	24.2	53.1
Dhole (n=50)	Chital (n=29)	51.7	6.9	41.4
	Sambar (n=15)	40	33.3	26.7
	Nilgai (n=2)	0	0	100
	Wild pig (n=4)	25.0	0	75.0
	Overall prey species	29.2	10.1	60.8

4.5. Discussion

An increase in predator size is associated with increased intake of mean prey size and prey diversity (Gittleman 1985). The analysis of scats and kills confirmed that tiger killed mainly large and medium body sized prey, but both leopard and dhole largely killed medium body sized prey. In addition to that, tiger utilized negligible amount of small body sized prey while both leopard and dhole consumed small body sized prey high amount. All three large predators showed significant level of preference towards utilization of prey species ($p < 0.05$). These predators largely depend on principle prey species such as sambar, chital, gaur, wild pig and langur > 90% in their diet and co-exist in the prey rich tropical forest of PTR. The data was found sufficient in the present study to document the food habits of predators.

Advancing the importance of competition in structuring guilds is a measurable overlap in resource use. Resource overlap is commonly used to assess the potential for competition (Schoener 1982). Overlap in carnivore diets may increase when resources are too abundant for little competition. In Pench, dietary overlap between predators was very high because of shared inclusion of major ungulates by predators in their diet. Tiger's diet overlapped >80% with that of the leopard and dhole because of shared inclusion of major prey species. The idea that competition leads to character divergence dominates on co-existence between mammalian carnivores. Previous studies on diet of sympatric carnivores 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. Leopard is more successful than tiger because of their ability to live in different environmental conditions with a flexible diet (Johnsingh 1983). The wide geographic distribution of leopard attributed to their ability to coexist with other large carnivores (Bailey 1993). The ability of the tiger to hunt prey ranging from rodent to gaur indicates that tiger takes a much wider spectrum of food resources.

4.5.1. Analysis of scats

In terms of biomass consumed, chital was found to be the important prey of leopard (56.6% in winter and 46.1% in summer), dhole (54.4% in winter and 57.01% in summer) and tiger (42.1% in winter and 52.9% in summer). Though tiger and dhole in the study area fed on 11 prey species and leopard on nine prey species, chital and sambar constituted 88.6%, 72.4% and 86.3% in winter and 81.8%, 59.6% and 83.4% respectively in summer diet of tiger, leopard and dhole respectively. The sambar and chital were found to be the important prey species for these sympatric carnivores in Bandipur and Nagarhole (Karanth and Sunquist 1995; Johnsingh 1992; Andheria *et al.* 2007). Large sized antlers in canids that may hamper their navigation through thick bushes. 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. Tamang (1982) observed male biased predation on chital in Chitwan. Schaller (1967) and Sunquist (1981) made similar observation that tiger killed male sambar frequently than female in the population. Dholes' predation rate on deer fawns appeared to be high (overall >20%) in PTR. Johnsingh (1983), Venkatraman *et al.* (1995) and Acharya *et al.* (2007) recorded high fawn predation by dhole, since, naturally young prey animals have less chance to escape from the predators than adults (Curio 1976**).** Previous studies on diet of sympatric carnivores showed that diets of large carnivores are very similar when prey species are abundant (Schaller 1967; Johnsingh 1983; Karanth and Sunquist 1995; Sunquist and Sunquist 1989; Andheria *et al.* 2007).

Leopard is more successful than tiger because of their ability to live in different environmental conditions with a flexible diet (Johnsingh 1983). The wide geographic distribution of leopard is attributed to their ability to coexist with other large carnivores (Bailey 1993). 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 large carnivores can prey on broader size ranges of prey due to their prey handling capabilities (Gittleman 1985)

4.5.2. 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 compared of prey species with good health conditions whereas diet of both (>60%) leopard and dhole compared of prey species with poor health condition. 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, leopard and dhole in Mudumalai Tiger Reserve was of good health condition.

4.5.3. Predator-prey body weight

Ecological separation of coexisting carnivores is often related to differences in diet (Karanth and Sunquist 2000; Ray and Sunquist 2001; Sunquist *et al.* 1989). Several authors have pointed out the relationship between carnivore body size and the usual weight of their prey (Rosenzweig 1966; Schoener 1969; Kruuk 1972, 1975; Schaller 1972; Kleiman and Eisenberg 1973; Carbone and Gittleman 2002). Larger carnivores tend to eat prey of larger size (Rosenzweig 1966). Many causal factors might explain why larger species prey on a wider range of foods. Larger carnivores have greater home-range areas (Gittleman and Harvey 1982) and day range lengths ($r_{28} = 0.57$, ($P<0.005$). Larger carnivores therefore must maintain flexible dietetic preferences so as to increase the absolute number of potential foods available to them. Additional size advantages accrue to the larger predators (e.g. tiger) in being able to displace smaller guild members from favoured habitats and prey types through interference competition (Mills and Biggs 1993; Mills and Gorman 1997). Therefore, for large predators in Tropical dry deciduous forests the ecological significance of the relationship between predator and prey sizes should be interpreted as larger predators having wider predatory options rather than as different-sized predators specializing on different-sized prey. Unlike the large predator guilds of tropical forests, among which prey size specialization appears to be important for co-existence (Karanth and Sunquist 1995, 2000; Hart *et al.* 1996; Ray and Sunquist 2001), my findings demonstrated wide dietary overlap among sympatric large predators and emphasized the significance of inter-specific competition in structuring the large predator guild in this reserve. Present study revealed that though medium body sized prey species contributed maximum in all three carnivore's diet, tiger being larger in body size (180 kg, Carbone and Gittleman 2002) consumed more both large (gaur, nilgai and cattle) and medium (chital and sambar) sized prey as compared to leopard (body weight 46 kg, Carbone and Gittleman 2002) and dhole (body weight 25 kg, Carbone and Gittleman 2002) (Fig. 4.10)

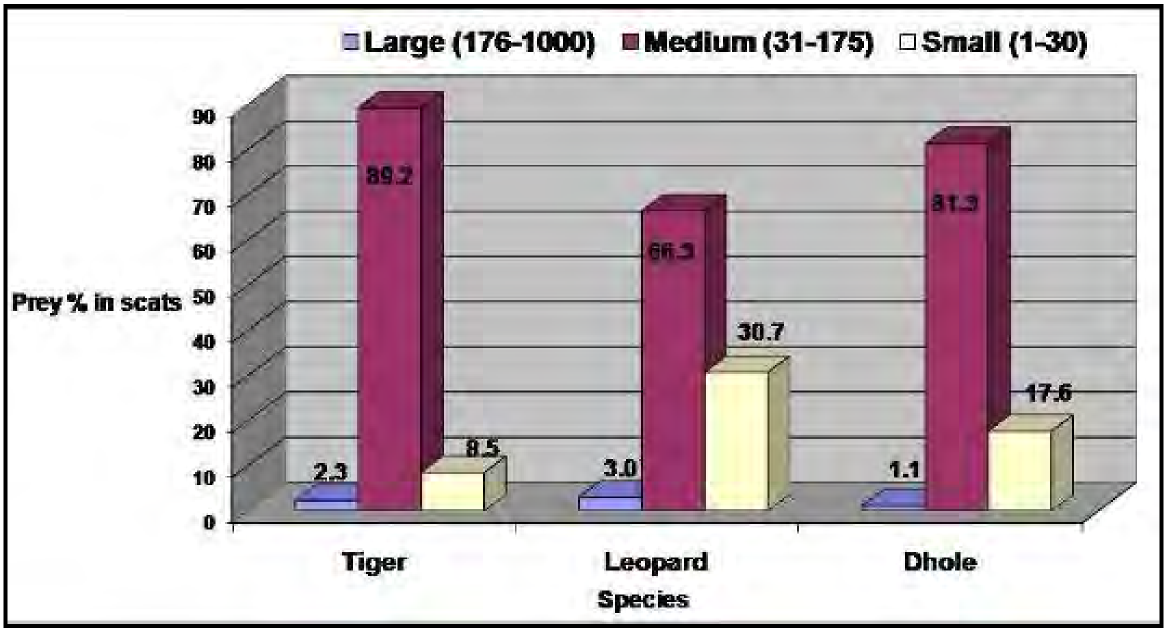


Fig. 4.10. Overall prey utilized by tiger (n=622), leopard (n=189) and dhole (n=338) in various body weight categories in Pench Tiger Reserve, Madhya Pradesh, (November 2006 to July 2010)

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 present study was compared with other major studies on food habits of these three carnivores in southern Asia (Table 4.8). The adaptabilities of these three carnivores in using different techniques for hunting and obtaining food showed that overall, they are 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 for tiger, sambar for leopard and dhole). It was also observed that, carnivores with comparatively smaller body weight (like leopard and dhole) showed plasticity to switch over to different body weight prey species (from large to medium and to small) to avoid inter-specific competition with larger body weight carnivores (like tiger and lion). My results also supported the prediction of both Giffths (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 were also related to the foraging theory which suggested that predators may select species containing the most profitable prey by the ratio of energy gain to handling time (Scheel 1993). Overall it can be concluded that, preference of diverse wild ungulate prey species biomass rather than domestic livestock, allowed all three predators to coexist in the study area.

Plate 4.1. Tiger on a nilgai male kill

Plate 4.2. Tiger on a sambar male kill

Table 4.8 Percentage frequencies of occuurence of prey remains in tiger, leopard and dhole scats in different protected areas of South Asia

Carnivores	Yak	Gaur	Cow	Buffelo	Nilgai	Sloth bear	Barasingha	Sambar	Chital	Black buck	Hog deer	Wild pig	Chinkara	chowsingha	Barking deer	Mouse Dear	Hare	Domestic dog	Sheep	Goral	Goat	Langur	Nilgiri Langur	Hog badger	Porcupine	Pangolin	Peafowl	Civets	Un known rodents	Uknown Birds	Author	Year	Study site
	NA	8.3	5.9	NA	0	NA	8.6	10.4	52	NA	NA	0.8	NA	NA	NA	0	NA	NA	NA	NA	NA	6.2	NA	NA	2.6	NA	NA	NA	NA	NA	Schaller	1967	Kanha
	NA	NA	NA	NA	NA	NA	NA	15.4	7.7	NA	NA	4	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Seidensticker	1976	Nepal
	NA	NA	NA	NA	0	NA	NA	29.3	33	NA	15.4	10.6	NA	NA	4.1	0	0.8	NA	NA	NA	NA	5.7	NA	NA	0.8	NA	NA	NA	NA	NA	McDougal	1977	Nepal
	NA	NA	1.8	NA	0	NA	NA	20	62	NA	NA	3.6	NA	NA	NA	0	NA	NA	NA	NA	NA	3.6	NA	NA	NA	NA	NA	1.8	NA	NA	Sunquist	1981	Nepal
	NA	NA	NA	NA	0	NA	NA	30.5	39	NA	NA	5.5	NA	NA	NA	0	14	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	Johnsingh	1983	Bandipur
	NA	NA	NA	NA	NA	NA	NA	7	NA	NA	NA	9	NA	NA	NA	0	NA	NA	NA	NA	NA	5	NA	NA	12	NA	NA	NA	NA	NA	Rabinwowitz	1989	Huai KhaKhaeng
	NA	17	NA	NA	0	NA	NA	24.9	31	NA	NA	9.4	NA	NA	6.1	3.1	0.2	NA	NA	NA	NA	3.9	NA	NA	0.2	NA	NA	NA	NA	NA	Karanth and Sunquist	1995	Nagrahole
	NA	NA	NA	NA	1.8	NA	1.3	0	75	NA	6.7	8.4	NA	NA	NA	0	NA	NA	NA	NA	NA	2.2	NA	NA	1.3	NA	NA	NA	NA	NA	Stoen and Wegge	1996	Barida NP
	NA	NA	11.1	NA	24.4	NA	NA	24.4	18	NA	NA	8.9	NA	6.6	NA	0	NA	NA	NA	NA	NA	8.9	NA	NA	4.4	NA	NA	NA	NA	NA	Chundwat *et al.*	2002	Panna
	NA	NA	2.7	NA	0.6	NA	NA	16.8	55	NA	NA	11.4	0.4	1.04	1.3	0	0.6	NA	NA	NA	NA	6.2	NA	NA	1.5	NA	NA	NA	NA	NA	Latika nath	2000	Bandhabgarh
	NA	NA	4.34	NA	0	1.3	NA	13.8	53	NA	NA	8.88	NA	2.7	5.3	0	NA	NA	NA	NA	NA	3.65	NA	NA	NA	NA	NA	NA	NA	NA	Biswas and Sankar	2002	Pench NP
Tiger	NA	NA	2.1	NA	2.1	NA	NA	51.4	54	NA	NA	0	NA	3.4	NA	0	NA	NA	NA	NA	NA	16.4	NA	NA	NA	NA	0.7	NA	NA	1.4	Sankar and Johnsingh	2002	Sariska
	NA	NA	2.89	2.6	3.3	NA	NA	36.9	46	NA	NA	4.6	0.6	NA	NA	0	NA	NA	NA	NA	NA	4.86	NA	NA	NA	NA	NA	NA	NA	NA	Bagchi *et al.*	2003	Ranthambore
	NA	NA	4.3	NA	NA	2.1	NA	27.6	17	NA	NA	38.2	NA	4.2	NA	0	2.1	NA	NA	NA	NA	2.1	NA	NA	2.1	NA	NA	NA	NA	NA	Reddy *et al.*	2004	Nagarjunsagar I
	NA	NA	7.3	NA	3.6	1.2	NA	9.7	26	NA	NA	28	1.2	15.8	NA	0	2.4	NA	NA	NA	NA	1.2	NA	NA	2.4	NA	NA	NA	NA	NA	Reddy *et al.*	2004	Nagarjunsagar II
	NA	NA	6.8	NA	0	NA	NA	75	11	NA	NA	6.8	NA	NA	NA	0	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	Harihar	2005	Rajaji NP
	NA	24	0.5	NA	0	0.7	NA	22.3	33	NA	NA	9.01	NA	1.1	2.48	1.4	1.8	NA	NA	NA	NA	2.2	NA	NA	NA	NA	NA	NA	NA	NA	Andheria *et al.*	2007	Bandipur
	14	NA	27.6	NA	NA	NA	NA	13.8	NA	NA	NA	6.9	NA	NA	17.2	0	NA	NA	6.9	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	Wang and MacDonald	2009a	Bhutan
	NA	NA	5.3	NA	NA	NA	NA	78.5	4.3	NA	NA	2.2	NA	NA	NA	0	NA	NA	NA	NA	NA	7.5	NA	NA	NA	NA	NA	NA	NA	NA	Edgaonkar	2008	Satpura
	NA	NA	11.5	NA	13.8	NA	NA	45.9	17	NA	NA	1.1	NA	NA	NA	0	NA	NA	NA	NA	NA	4.6	NA	NA	NA	NA	NA	NA	NA	NA	Avinandan	2003	Sariska
	NA	2.7	2.1	NA	0	0.5	NA	59.8	23	NA	NA	4.2	NA	NA	NA	0	0.5	NA	NA	NA	NA	5.3	NA	NA	0.5	NA	NA	NA	NA	NA	Ramesh et al	2009	Mudumalai
	NA	NA	19.4	NA	10.7	NA	NA	41.7	26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.9	NA	NA	NA	NA	NA	NA	NA	NA	Sankar *et al.*	2010	Sariska
	NA	0.5	0.8	NA	1.1	NA	NA	28.4	55.2	NA	NA	5.4	NA	NA	NA	0	0.2	NA	NA	NA	NA	6.6	NA	NA	0.2	NA	NA	NA	1.2	0.3	Present study	2010	Pench
	NA	NA	NA	NA	0	NA	NA	14	51	NA	NA	0	NA	NA	NA	0	11	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	Johnsingh	1983	Bandipur
	NA	NA	NA	NA	NA	NA	NA	5.4	NA	NA	NA	5	NA	NA	43	0	NA	9	NA	NA	NA	3	NA	4	8	NA	NA	NA	NA	NA	Rabinwowitz	1989	Huai KhaKhaeng
	NA	NA	NA	NA	0	NA	NA	0.5	0	NA	NA	2.4	NA	NA	NA	0	NA	NA	NA	NA	NA	1.7	NA	1.2	NA	NA	NA	NA	47.6	NA	Johnson *et al.*	1993	Woolong R
	NA	NA	1.2	NA	0	NA	NA	1.6	0	NA	NA	1.6	NA	NA	NA	0	NA	NA	NA	NA	NA	0	NA	3.2	4.8	NA	NA	NA	41.9	NA	Johnson *et al.*	1993	Woolong R
	NA	7.3	NA	NA	0	NA	NA	13.5	44	NA	NA	4.5	NA	0.4	7.5	7.1	1.1	NA	NA	NA	NA	7.1	NA	NA	1.1	NA	NA	NA	NA	NA	Karanth and Sunquist	1995	Nagrahole
	NA	NA	6.9	NA	NA	NA	NA	50	9.3	NA	NA	2.3	NA	NA	NA	6.9	16	NA	NA	NA	NA	6.9	6.9	NA	NA	3.4	NA	NA	NA	NA	Satyakumar	1988	Mundatharai
	NA	NA	12.5	NA	NA	NA	NA	5.9	28	NA	NA	NA	NA	NA	NA	0	4.6	4.6	NA	NA	NA	14.3	NA	NA	7.4	NA	6.4	4.6	NA	NA	Dharaiya et al	1998	Gir
	NA	0.6	6.1	NA	0	NA	NA	11.7	67	NA	NA	1.11	NA	NA	2.3	0	3.4	NA	NA	NA	NA	2.79	NA	NA	0.6	NA	NA	NA	1.7	NA	Ramakrishnan *et al.*	1999	Mudumalai
	NA	NA	8.3	NA	0	NA	NA	9	24	NA	NA	3.7	NA	NA	8.3	0	14	NA	NA	NA	NA	0.92	8.3	NA	5.5	NA	NA	NA	7.4	NA	Ramakrishnan *et al.*	1999	Mundatharai
	NA	NA	NA	NA	7.2	NA	NA	20	21	NA	NA	NA	NA	NA	NA	0	2.4	NA	NA	NA	NA	6.4	NA	NA	NA	NA	3.2	NA	NA	1.6	Sankar and Johnsingh	2002	Sariska
	NA	NA	14.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	NA	63.7	NA	NA	NA	11.4	NA	NA	NA	NA	NA	NA	26.1	NA	Edgaonkar and Chellam	1998	Sanjay Gandhi NP
	NA	NA	NA	NA	0	NA	NA	20.2	65	NA	NA	0	NA	NA	NA	0	NA	NA	NA	NA	NA	15.3	NA	NA	NA	NA	NA	NA	NA	NA	Mukherjee *et al.*	1994b	Gir
Leopard	NA	9.2	2.3	NA	0	NA	NA	6.1	46	NA	NA	8.4	NA	3.05	1.5	1.5	3.8	NA	NA	NA	NA	9.2	NA	NA	NA	NA	NA	NA	NA	NA	Andheria *et al.*	2007	Bandipur
	NA	NA	33.3	NA	0	NA	NA	7.8	35	NA	NA	3.9	NA	NA	NA	0	1.9	NA	NA	NA	NA	3.9	NA	NA	3.9	NA	NA	NA	NA	NA	Arivazhagan *et al.*	2007	Sigur (HD)
	NA	NA	14.7	NA	0	NA	NA	5.9	56	2.9	NA	0	NA	NA	NA	0	2.9	NA	NA	NA	NA	2.9	NA	NA	NA	NA	2.9	NA	NA	NA	Arivazhagan *et al.*	2007	Sigur (LD)
	7.2	NA	25.7	NA	NA	NA	NA	16.8	NA	NA	NA	5.3	NA	NA	8.8	0	NA	NA	9.7	8	NA	4.4	NA	NA	NA	NA	NA	NA	NA	NA	Wang and MacDonald	2009a	Bhutan
	NA	NA	1.6	NA	NA	NA	NA	52.8	20	NA	NA	2.1	NA	NA	NA	0	5.7	NA	NA	NA	NA	10.5	NA	NA	3.1	NA	NA	NA	NA	NA	Edgaonkar	2008	Satpura
	NA	NA	11.8	NA	NA	NA	NA	NA	NA	NA	NA	1.5	NA	NA	NA	0	2.5	2.5	27.2	NA	16.8	3.9	NA	NA	1.5	NA	NA	NA	35.1	NA	Chauhan	2008	Mandi, Himachal
	NA	NA	9.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	4.8	9.6	13.5	NA	18.2	4.8	NA	NA	3.8	NA	NA	NA	19.2	NA	Chauhan	2008	Hamirpur
	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Thakur	2008	Pouri Garwal
	NA	NA	10.6	NA	7.6	NA	NA	22.7	27	NA	NA	0	NA	NA	NA	0	6.1	NA	3	NA	NA	6.1	NA	NA	1.5	NA	NA	NA	16.7	NA	Sankar *et al.*	2009	Sariska
	NA	NA	4.4	NA	0	NA	NA	28.3	23	NA	NA	1.7	NA	NA	NA	0	7.9	NA	NA	NA	NA	13.2	NA	NA	NA	NA	NA	11.5	NA	NA	Maheswari	2006	Gir
	NA	2.6	3.5	NA	0	NA	NA	37.7	29	NA	NA	3.5	NA	NA	NA	0.8	1.8	NA	NA	NA	NA	17.5	NA	NA	NA	NA	NA	NA	NA	NA	Ramesh *et al.*	2009	Mudumalai
	NA	NA	23.2	NA	9.47	NA	NA	6.31	NA	NA	NA	8.42	NA	NA	NA	0	NA	15.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Dharaiya and Soni	2010	Girnar
	NA	NA	1.0	NA	2.0	NA	NA	8.0	49.7	NA	NA	8.5	NA	NA	NA	0	4.0	NA	NA	NA	NA	22.1	NA	NA	NA	NA	NA	NA	3.0	1.5	Present study	2010	Pench
	NA	NA	2	NA	NA	NA	NA	26	74	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Fox and Johnsingh	1975	Nilgiri
	NA	0.7	2	NA	NA	NA	NA	14.7	19	NA	NA	11.3	NA	NA	2	1.3	NA	NA	NA	NA	NA	24	NA	NA	NA	NA	NA	NA	14	NA	Cohen *et al.*	1978	Nilgiri
	NA	NA	NA	NA	0	NA	NA	14	52	NA	NA	0	NA	NA	NA	0	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	Johnsingh	1983	Bandipur
	NA	2	NA	NA	0	NA	NA	10.2	50	NA	NA	7.9	NA	0.7	22	4.3	1.3	NA	NA	NA	NA	0.3	NA	NA	0.3	NA	NA	NA	NA	NA	Karanth and Sunquist	1995	Nagrahole
	NA	NA	4.3	NA	NA	NA	NA	21.7	70	NA	NA	NA	NA	NA	NA	0	3.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Venkatraman *et al.*	1995	Mudumalai 1
	NA	NA	15.2	NA	NA	NA	NA	23.3	41	NA	NA	NA	NA	NA	NA	0	20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Venkatraman *et al.*	1995	Mudumalai 2
	NA	0.5	NA	NA	NA	NA	NA	7.3	55	NA	NA	5.5	NA	4.1	1.8	0.5	12	NA	NA	NA	NA	0.45	NA	NA	NA	NA	NA	NA	NA	NA	Andheria *et al.*	2007	Bandipur
Dhole	NA	NA	1.8	NA	NA	NA	NA	49	39	NA	NA	2.5	NA	NA	NA	0	2.6	NA	NA	NA	NA	4	NA	NA	NA	NA	NA	NA	0.8	NA	Acharya *et al.*	2007	Pench
	NA	NA	NA	NA	NA	NA	NA	4.8	71	NA	NA	0	NA	NA	NA	0	14	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	Arivazhagan *et al.*	2007	Sigur (HD)
	NA	NA	5.3	NA	NA	NA	NA	0	53	NA	NA	5.3	NA	NA	NA	0	26	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	NA	Arivazhagan *et al.*	2007	Sigur (LD)
	7.2	NA	9.4	NA	NA	NA	NA	60.9	NA	NA	NA	0.7	NA	NA	NA	0	NA	NA	2.2	14.5	NA	0.7	NA	NA	NA	NA	NA	NA	NA	NA	Wang and MacDonald	2009a	Bhutan
	NA	NA	NA	NA	NA	NA	NA	48.1	42	NA	NA	NA	NA	NA	NA	0	3.7	NA	NA	NA	NA	6.2	NA	NA	NA	NA	NA	NA	NA	NA	Edgaonkar	2008	Satpura
	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	5	NA	NA	NA	77.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Kawanishi and Sunquist	2008	Malyasia
	NA	NA	NA	NA	NA	NA	NA	46.9	30	NA	NA	6.1	NA	NA	1.5	0	41	NA	NA	NA	NA	4.5	NA	NA	NA	NA	NA	NA	NA	NA	Borah *et al.*	2009	Satpura
	NA	NA	0.3	NA	0.9	NA	NA	19.3	59.1	NA	NA	2.8	NA	NA	NA	0	5.4	NA	NA	NA	NA	8.5	NA	NA	0.3	NA	NA	NA	1.7	1.4	Present study	2010	Pench

NA -Not Assessed

Plate 4.3. Tiger on a chital doe kill

Plate 4.4. Leopard carrying a chital fawn

Plate 4.5. Leopard carrying a piglet

Plate 4.6. Dhole on a chital doe kill

Plate 4.7. Dhole on a sambar kill

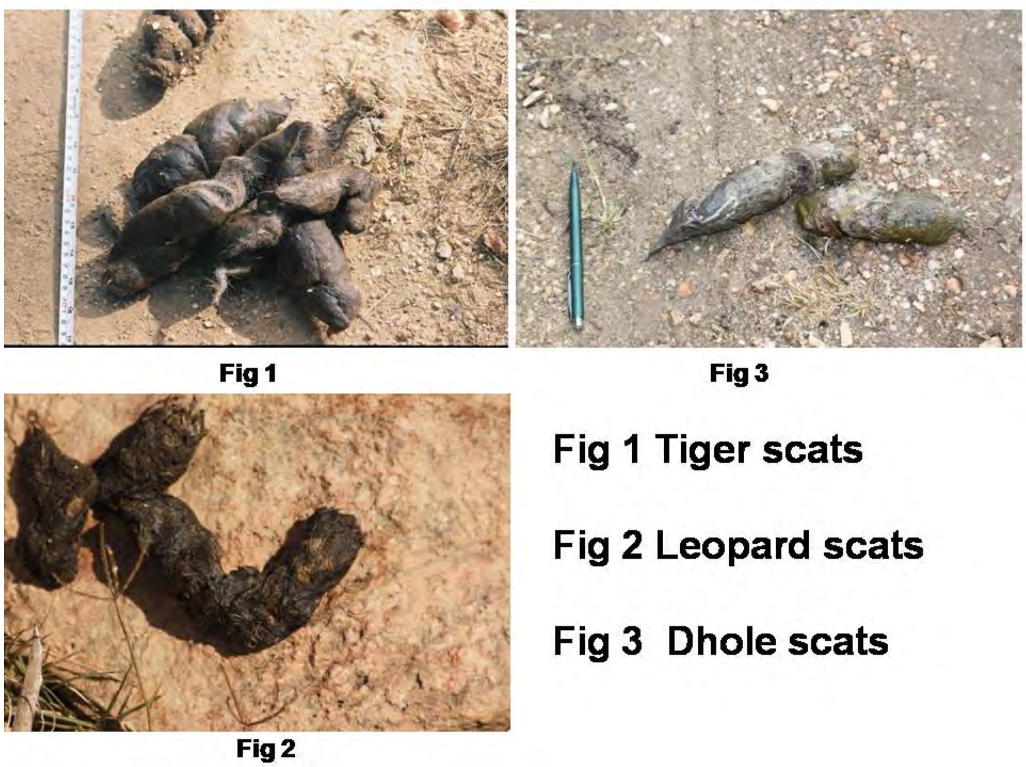


Plate 4.8. Scats of tiger, leopard and dhole

Chapter 5

Chapter 5

POPULATION ESTIMATION OF TIGER, LEOPARD AND DHOLE

5.1. Introduction

Umbrella species are those species with large area requirements, which if given an area of sufficient protected habitat, will bring many other species under protection (Noss 1990; Caro 2003). Conservation of top carnivores is a global priority, because they serve as umbrella species across a wide range of habitats and are functionally important components within their ecosystems. The decline and extirpation of top carnivores from fragmented ecosystems may generate tropic cascades that alter the structure of ecological communities, so the persistence of these keystone species can indicate levels of ecosystem health (Crooks 2002).

With the decline of most large carnivore population worldwide (Nowel and Jackson 1996) there is an urgent need for practical and accurate methods of estimating population numbers and monitoring trends (Caughley and Sinclair 1994). For years ecologists have lamented the lack of long data sets with which to test basic theoretical ideas to monitor large carnivores (Karanth *et al.* 2006). Therefore, reliable population estimates and long term monitoring systems are important in all wildlife management and conservation projects. Population estimation of large carnivores such as tiger, leopard and dhole is a main stream tool in ecological studies where these species are sympatric in similar habitats.

Having high dietary overlap between these species in their diet in a prey rich habitat and co-existence with each other, are by selecting different sized prey. The loss of habitat, poaching for trade, declining prey populations and conflicts with humans primarily provoked by predation on livestock has overall endangered tiger and threatened dhole and leopard populations (Sunquist 1981; Nowell and Jackson 1996; Wang and Macdonald 2009b).

The reported occupancy of tiger, leopard and dhole was the highest in Central Indian landscape (48610 km², 117913 km² and 85962 km² respectively) and PTR forms an important source population for them (Jhala *et al.* 2008).

5.2. Literature review

A number of methods have been developed to determine the abundance of larger carnivores, which is usually a challenging process (Karanth 1995). Smith *et al.* (1987) synthesized prior information on tiger densities derived from radio telemetry in Chitwan National Park, Nepal, with assessment of habitat quality and prey abundance, using a Geographical Information System (GIS) approach. 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.* 1987; Soisalo and Cavalcanti 2006; Acharya *et al.* 2007; Sharma *et al.* 2010). However the presence of untagged animals in the population, and the excessive effort involved in capture and radio tracking operations and high cost of radio-telemetry items limit the usefulness of this approach for estimating carnivore population size.

The population estimation in India, especially for wild tiger, derived from “pug-mark census” method (Panwar 1979; Sharma 2001). Similar approach was followed by Stander

(1998) to estimate leopard abundance in Kaudom Game Reserve, Namibia. Though pug-mark method was widely used to estimate carnivore populations because of its simplicity, found to be failure prone and invalidated (Karanth 1987, 1988). This estimate is neither total counts nor sample statistics, it bears no logical or consistent relationship to the actual size of carnivore populations. Therefore it cannot be considered as indices of relative abundance.

One of the most recent developments in estimation of population is genotyping faces. After collection of very fresh scat from the field, DNA will be extracted for species identification. Sex will be determined through mitochondrial DNA and Y- chromosome typing. Microsatellite loci will be typed from the faces and then rarefaction analysis will be done to estimate the population size from faecal genotype. Though this method may be more reliable for population estimation because of its noninvasiveness (Mithipalla 1996; Luo *et al.* 2004; Bhagavatula and Singh 2006), the major drawback, as it is very expensive and done by skilled technician in sophisticated laboratories (Kohn *et al.* 1999).

With the first animal triggered photograph being taken in 1877 (Cutler and Swann 1999), remote photography has been used to study avian nest predation, feeding ecology, nesting behaviour, determining activity patterns, presence – absence monitoring and estimating population parameters. 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). Therefore capture-recapture methods using remotely triggered cameras found to be more applicable for elusive species like tiger and leopard. From the times of Champion (1927), photographing cryptic animals such as the tiger in the Indian sub-continent using remote photographic techniques has sought popularity. Karanth (1995) developed and implemented a method of photographic capture-recapture analysis to aid estimate and monitor tiger populations in India.

With developments in capture – recapture theory (Otis *et al.* 1978; Pollock *et al.* 1990) and the use of cameras to capture individually marked or identifiable animals and photographically recapture them, resulted in the use of cameras for estimating population parameters. Since individual tiger are readily identifiable using the stripes on the body (Schaller 1967; McDougal 1977; Karanth 1995; Franklin *et al.* 1999), the sight-resight (White 1996) or capture-recapture approach can be used to estimate population parameters. The capture – recapture theory requires that all individually identifiable animals will have to be identified with surety. By estimating the capture probability *p – hat* an estimate of the population size (*N*) is arrived at (Nichols 1992). Owing to the large number of estimators available for estimating the population size (*N*) various computer programs have been formulated to aid analysis (White 1996). Years of using this method of analysis has proved that photographic capture recapture sampling is a reliable technique for estimating abundances and demography of tiger and other cryptic animals (Karanth and Nichols, 1998, 2000, 2002; Karanth *et al.* 2006; Karanth and Chundawat 2002; Carbone *et al.* 2001; Edgaonkar 2008; Jhala *et al.* 2008; Ramesh 2010; Kalle *et al.* 2011).

However most published studies report population sizes accompanied by low levels of precision (Karanth and Nichols 1998, 2000; Silver *et al.* 2004) and low sample sizes (Kawanishi and Sunquist 2004). York *et al.* (2001) evaluated remote camera and triggering system to monitor carnivores at California and Vermont. They found although some target carnivore species were photographed regularly, visitation rates of other carnivores were low, due to either low population densities or camera shyness. Cameras generally worked well under all conditions, but the pressure-plate triggering devices sometimes became inoperable during heavy rains. Other camera activation systems may reveal additional uses for this remote camera system. The issues regarding sampling design related to photographic capture-recapture analysis are being discussed by Wegge *et al.* (2004). This brings to notice that though this method of population estimation has proven successful, issues regarding sampling require rigorous field validation so as to improve the quality of the results thus obtained.

Silveira *et al.* (2003) compared Camera trap, line transect census and track surveys in Emas National Park, central Brazil and concluded that, despite the high initial costs for camera-trapping, this method is the most appropriate for mammal inventory in all environmental conditions, allowing a rapid assessment of wildlife conservation status. It also has the advantage of sampling a considerable extent of area simultaneously and also offers the possibility of being used in further population studies.

Another widely used method to estimate the proportion of sites occupied by a species of interest is occupancy based population abundance estimation (Mackenzie *et al.* 2002, 2003; Royle and Nichols 2003; Royle 2004 a, b; Mackenzie and Royle 2005; Royle *et al.* 2005; Jhala *et al.* 2008; Jhala *et al.* 2011). Basic assumption of this method is non detection of a species at a site does not imply that the species is absent unless the probability of detection is 1 (Mackenzie *et al.* 2002). For large-scale monitoring programs and investigations of meta-population dynamics this survey based method is applicable and also for those species which cannot be distinguished by uniquely identifiable marking patterns (Royle and Nichols 2003).

5.3. Methods

The remotely triggered ‘‘camera traps’’ was used in the intensive study area (410 km²) of PTR to estimate populations of tiger and leopard whereas survey-based Royal Nichols heterogeneity model was used to estimate population of dhole.

5.3.1. Equipment used for camera trapping

Three types of camera trap units were used for the present study

1) Infrared sensor or TrailMaster™ - TrailMaster™ is a two piece active infrared trail monitoring system which uses an invisible infrared beam across the trail between the transmitter and receiver with a range of 150 feet. The cameras accompanying the TM unit are cannon A1 mini DX. Each trap consisted of an electronic tripping device activated by animal movement that simultaneously activated two cameras through a multi-camera trigger to photograph both flanks of the animal. The camera units were placed 5 m away from the trail to maximize the chances of getting full body photographs of tiger and leopard. The camera delay was set at minimum (0.1= 6 sec) to minimize the chances of missing mating pairs or cubs with mothers. The pulse rate was set at 4 keeping the gait and size of the animal. To prevent possible theft and vandalism I used protective shells (Karanth and Nichols 2002) made of wooden poles.

2) Thermal sensor or DEER CAM™ - Scouting cameras work on passive infrared motion/ heat sensors which can sense up to 60 feet from the camera unit. It is equipped with 35 mm lens camera which can imprint date and time of the photograph. Two of such camera units were deployed at 5m on the either side of

the road to capture both the flanks of the animal. The camera delay was kept at minimum (15 seconds) and sensor activity was set as high.

3) Thermal and motion detector or STEALTH CAM™ is a passive camera traps. It works on passive infrared motion/heat sensor, which can sense up to 25 feet from camera unit. It is equipped with an analog camera with 55 mm fixed lens and can imprint date and time of the photograph.

5.3.2. Field study design

A pair of cameras were deployed in a systematic 2 km X2 km grid during 2006 (Fig. 5.1), 2008 (Fig. 5.2), 2009 (Fig. 5.3), 2010 (Fig. 5.4) and 2011 (Fig. 5.5) and the minimum distance between two camera locations varied between 1.5 and 2 km. The 84 km^2 was covered in 2006 (Minimum Convex Polygon), 218 km^2 in 2008, 239 km^2 in 2009, 357 km^2 in 2010 and 410 km^2 in 2011 for camera trapping. 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 and leopard photographs were examined independently. Each photograph of an individual represented a capture occasion. Identification was done based on examination of the position and shape of stripes on the flanks for tiger (Schaller 1967; McDougal 1977; Karanth 1995; Kawanishi and Sunquist 2004; Sharma *et al.* 2010; Jhala *et al.* 2011), rossete pattern for leopard (Edgaonkar 2008; Ramesh 2010), limbs and forequarters and even tail for both (Schaller 1967; McDougal 1977; Karanth 1995).

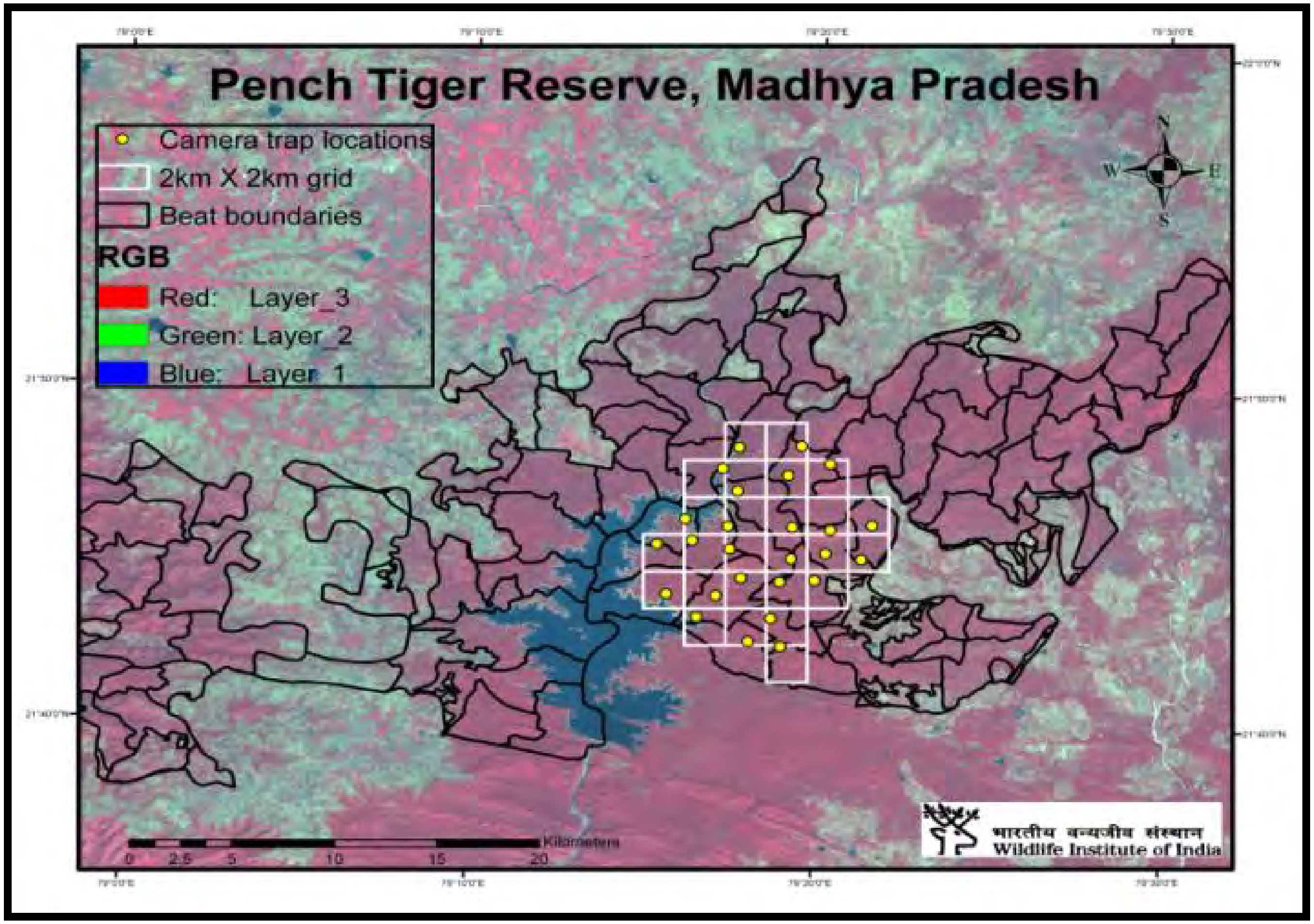


Fig. 5.1. Map showing grid wise camera trap locations in Pench Tiger Reserve, Madhya Pradesh (2006)

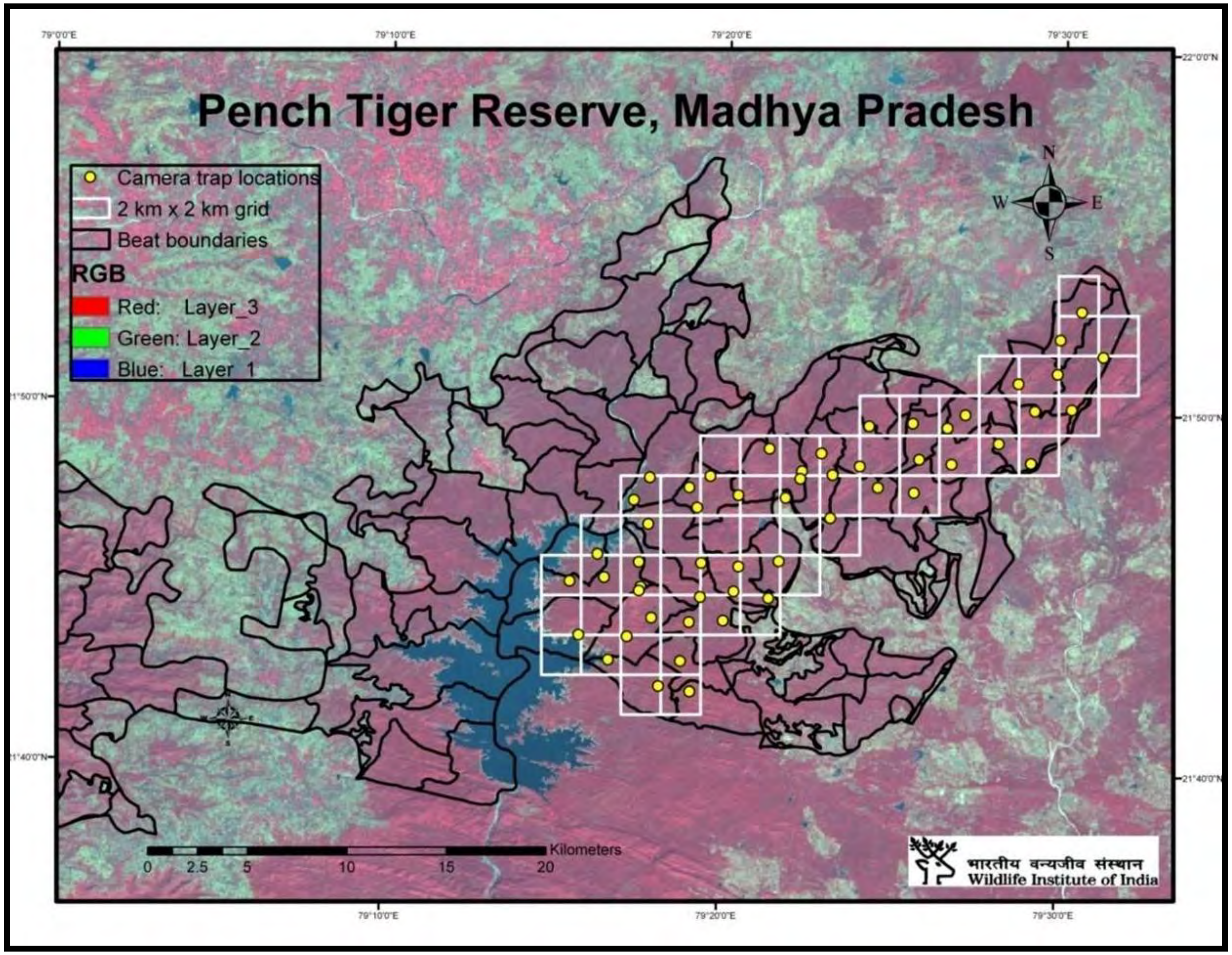


Fig. 5.2. Map showing grid wise camera trap locations in Pench Tiger Reserve, Madhya Pradesh (2008)

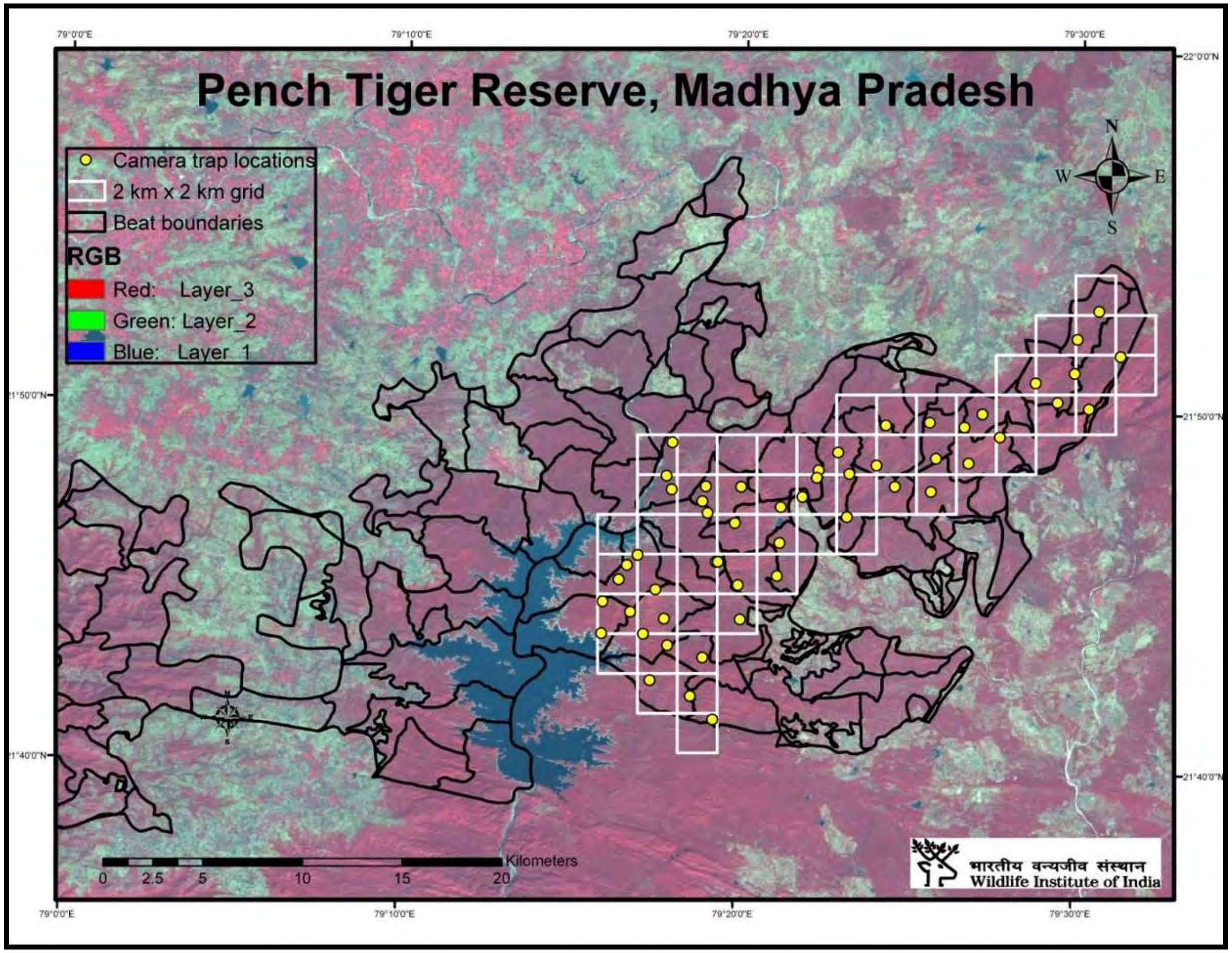


Fig. 5.3. Camera trap locations in Pench Tiger Reseve, Madhya Pradesh (2009)

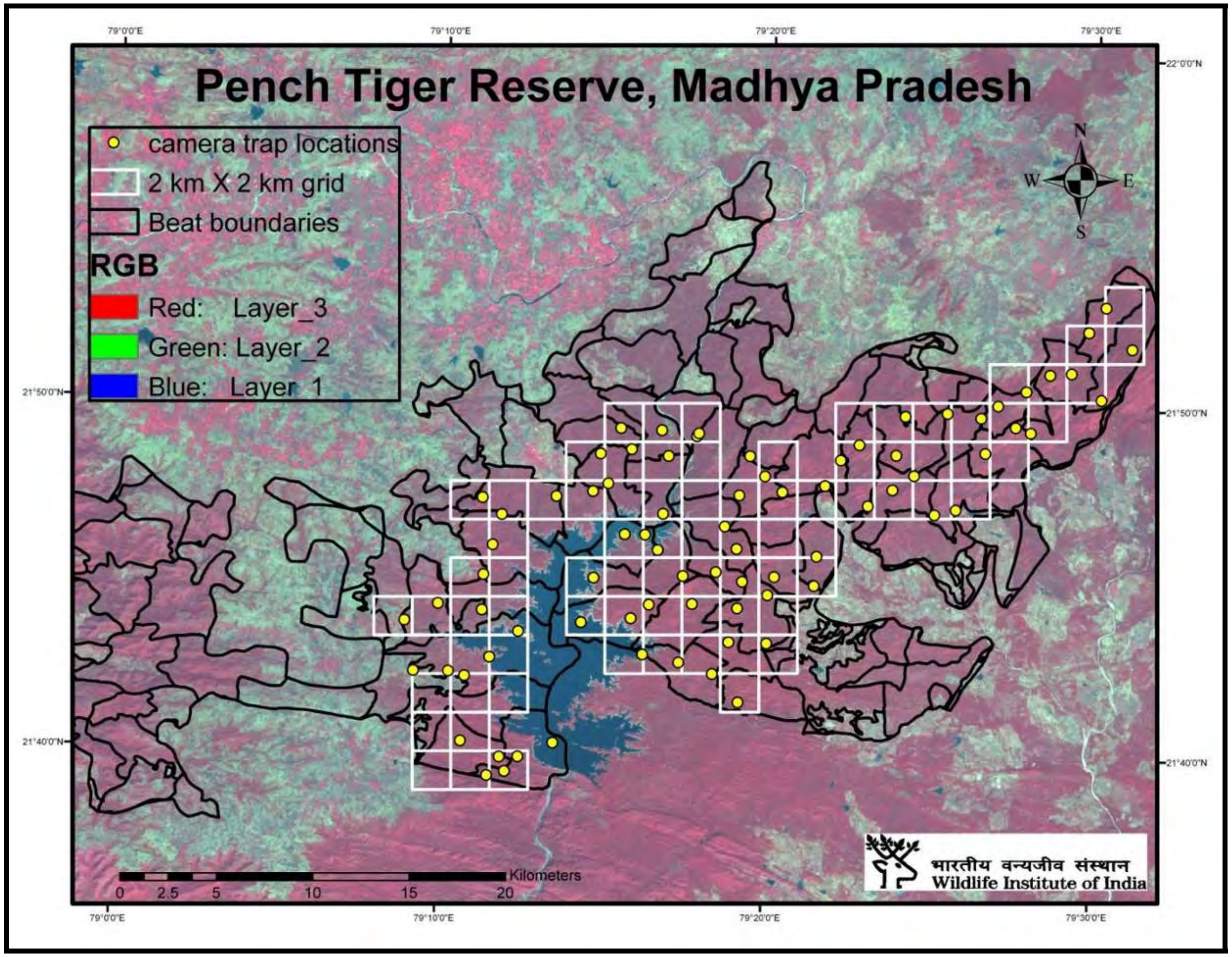


Fig. 5.4. Camera trap locations in Pench Tiger Reserve, Madhya Pradesh (2010)

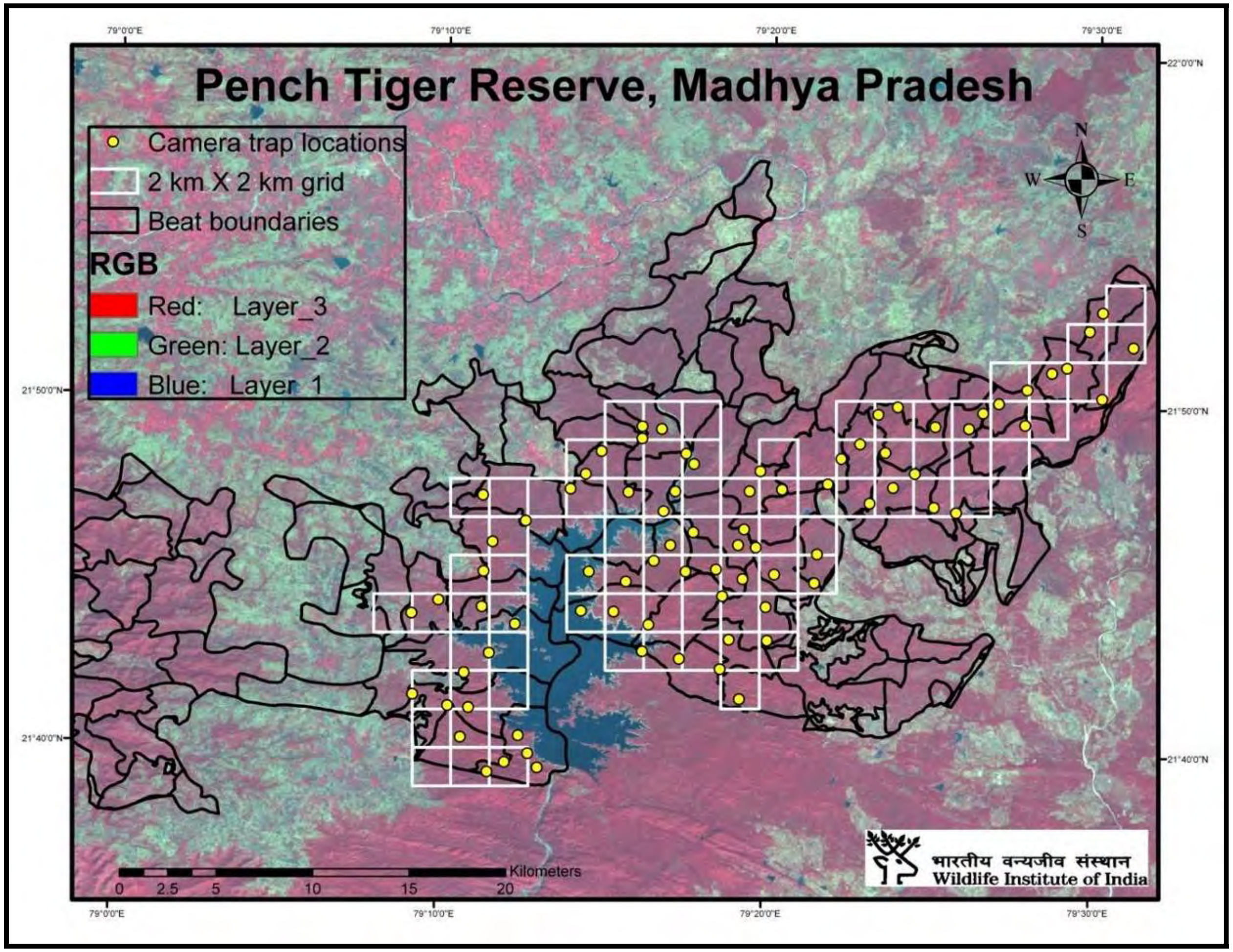


Fig. 5.5. Camera trap locations in Pench Tiger Reserve, Madhya Pradesh (2011)

5.3.3. Data analysis

5.3.3.1. Population estimation

Population of tiger and leopard was estimated in Mark-Recapture framework (Karanth 1995; Edgaonkar 2008; Jhala *et al.* 2011). Capture-recapture models can estimate parameters for both demographically closed and demographically open populations, but both types of model assumes geographical closure (Karanth 1995). Therefore following assumptions were considered during designing the study and data analysis.

1) Population is geographically closed.
2) Animals do not lose their marks.
3) All the marks are recorded correctly at each trapping occasion.
4) The assumption of equal catchability of animals.

Individual capture histories for the identified tiger and leopard were constructed using a standard 'X-matrix format' (Otis *et al.* 1978; Nichols 1992; Karanth 1995; Edgaonkar 2008), in which ' 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. The capture history for animal *i* consists of a row vector of a *t* entries, where *t* denoted the number of sampling occasions for the study site. Each entry denoted as X_{ij} for individual *i* on occasion *j* assumed a value of either '1' or '0' depending on whether the animal was captured or not captured during that particular sampling occasion.

5.3.3.2. Population close test

Because both tiger and leopard are long lived animals (Sunquist 1981; Smith 1993; Edgaonkar 2008) and sampling was carried out from 65 to 155 days during the present study, it was assumed that the sample population was demographically closed (Otis *et al.*

1978; Karanth 1995; Karanth and Nichols 1998; Stanley and Burnham 1999; Sharma *et al.* 2010; Edgaonkar 2008; Ramesh 2010).

5.3.3.3. Models used

Following models were considered for analysis of data (Otis *et al.* 1978; Nichols 1992):

Mo- Model Mo is the simplest model where all individuals have equal probability of capture i.e. capture probability is the same for all tiger/leopard and is not influenced by behavioral response, time, or individual heterogeneity.

Mh- Model Mh has the assumption that each animal has its own probability of capture independent of all other members of population i.e. capture probabilities are heterogeneous for each individual tiger/leopard, but not affected by trap response or time.

Mb- Mb allows the animal to exhibit a behavioural response to capture and become either ‘trap shy’ or ‘trap happy’ i.e. capture probabilities differ between previously caught and uncaught tiger due to trap-response behaviour, but are not influenced by heterogeneity or time.

Mt- Mt is the modification of the classical model to allow capture probabilities to vary with time i.e. capture probability is the same for all individual tiger, but varies during the survey only due to time-specific factors.

The model selection process also considered more complex models such as Mbh, Mth, Mtb and Mtbh, which incorporate the effects of heterogeneity, trap response and time, in various combinations.

Mbh- Mbh is in effect a generalization of the Mh model for allowance of capture probability to depend on the previous capture history. It has some of the disadvantages associated with models Mh and Mb.

Mth- It takes combined effect of time as well as heterogeneity. Chao and Huggins (2005) suggested that since in some capture-recapture studies of large animals actual recapture is not necessary and re-sighting records suffice to provide the required recapture information and hence there is no need to model any behaviour response to capture.

Mtb- Mtb is an extension of model Mt to incorporate behaviour response to capture. It accounts for the assumption of change in the capture probability after the first capture and temporal changes also influence the capture probability.

Mtbh- Model Mtbh considers all three sources of variation. Previously, it had been considered only conceptually useful and too complicated to be applied to practical situations if no restrictions are made, despite the assumption for closure being the most realistic in this model. This model offers a unified approach for all eight models and can offer robust estimates if reasonable assumptions can be made (White *et al.* 1982; Chao and Huggins 2005).

5.3.3.4. Software used for population estimation

Program **CAPTURE** inbuilt in program MARK ver. 6 was used (Cooch and White 1995) for the population estimation.

5.3.3.5. Software used for population closure test

To validate the closure assumption, the capture history data was analyzed using program Closure Test or CT (Stanley and Burnham 1999).

5.3.3.6. Density estimation

Population density is the single parameter of greatest intrinsic interest to biologists studying population dynamics (Krebs 1985; Buckland *et al.* 1993). Unbiased estimation of population density is a major and unsolved problem in animal trapping studies. In mark recapture studies, especially for large mammals, the trapping is done in a small area and a buffer strip is added to it to account for the space use by animal trapped at the periphery. The total area calculated thus, is known as the effective area sampled and is denoted by A (W) where W is the calculated strip width or buffer area. The strip width is calculated, most often through the half MMDM (Mean Maximum Distance Moved) between recaptures. When traps are randomly placed at high use locations to maximize capture, not in a specific designed frame, the effective trapping area is very likely to be an artifact of the placing of traps. Finally density will be calibrated based on this distance and when densities are averaged among sampling units, mean density is usually weighted by the proportion of total area in which individuals are living which may be just partly or fractionally sampled, leading to an overestimate and often high CVs (Soisalo and Cavalcanti 2006; Sharma *et al.* 2010).

Spatially explicit maximum likelyhood density model was used (Efford 2004) to estimate densities of tiger and leopard in PTR for the year 2006, 2008, 2009, 2010 and 2011. For this purposes, habitat masking was done overlaying upper confidence limit of the Mean Maximum Distance Moved (4000±2000 meter) by tiger and leopard on the available forest cover map (www.fsi.nic.in) of the study area (Fig. 5.6). This will give us better precision while estimating density of tiger and leopard.

Program DENSITY ver. 4.4 was used for density estimation of tiger and leopard under both Mean Mode Distance Moved (MMDM) and spatially explicit maximum likelihood model. For computing densities of both of these species, 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.

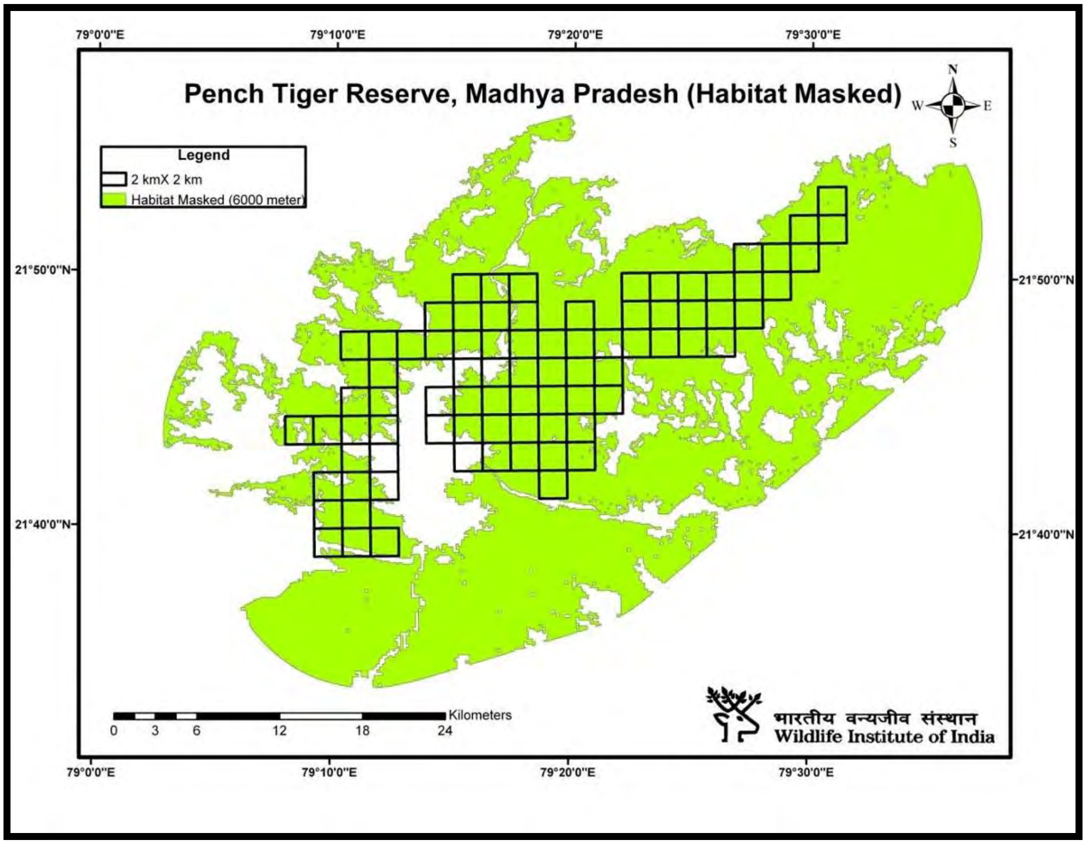


Fig.5.6. Habitat masked areas for grid wise camera trapping locations in Pench Tiger Reserve, Madhya Pradesh

5.3.3.7. Estimation of survival rate of tiger and leopard

Various statistical models have been used by wildlife biologists to estimate survival pattern of species as Cormack-Jolly-Seber (CJS), Kaplan maiyer known fate models (Kaplan and Maiyers 1958) and Pollock's robust design (Pollock 1982).

Pollock's robust design (Pollock 1982) model was used in this study to estimate survival rate of tiger and leopard for the following advantages (Cooch and White 1995).

1. Estimates of Pi, and thus Ni and recruitment are less biased by heterogeneity in capture probability (specifically, if you use heterogeneity models within season).

2. Temporary emigration can be estimated assuming completely random, Markovian or temporarily trap dependent availability for capture.

3. If temporary emigration does not occur, abundance, survival, and recruitment can be estimated for all time periods (e.g., in a 4-period study, half the parameters are inestimable using the JS method).

4. Precision tends to be better using the formal robust design models of Kendall *et al.* (1995), which include the model described above with $G'' = G' = 0$.

5. Because there is information on capture for the youngest catchable age class, estimation of recruitment into the second age class can be separated into *in situ* recruitment and immigration when there are only two identifiable age classes. Using the classic design (i.e. one capture session per period of interest), three identifiable age classes is required.

6. The robust design's two levels of sampling allow for finer control over the relative precision of each parameter.

Following parameters were observed while analyzing data under Pollock's robust design (Cooch and White 1995).

1) **Primary sampling period:** The series of periods where encounter occasions are not closed, means animal may move in or out, termed as primary period (e.g. Years like 1^{st}, 2^{nd},3^{rd} …10^{th}).

2) **Secondary sampling period:** In many cases, camera trap data were being collected in this way primary sampling might be conducted in groups of 50-100 days. The closed encounter occasions are termed *secondary* trapping sessions, and each

trapping session can be viewed as a closed capture survey (e.g. camera trap session, day 1, 2, 3, 4…n).

Primary sampling period is related with secondary sampling period in the following way:

$$\text{Primary period 1} \xrightarrow{\text{Open}} \text{Primary period 2} \xrightarrow{\text{Open}} \text{Primary period n}$$

$$\text{Primary period 1} \xrightarrow{\text{Closed}} \text{1st Secondary period}, \qquad \text{Primary period 2} \xrightarrow{\text{Closed}} \text{2nd} \ldots \text{n Secondary periods}$$

1st Secondary period (1, 2, 3 …n), 2nd …n Secondary periods (1, 2, 3…n)

In the present study there were five primary sampling periods and in each primary sampling periods there are 10 secondary occasions, primary period one followed by nine in both primary period two and three, 16 in primary period four and 11 in primary period five. While analyzing data under Robust Design by MARK ver. 6, I pooled 10 camera trap days into one occassion.

3) **Immigration rate** (Gamma′ or G′): the probability of being off the study area, unavailable for capture during primary trapping session (i) given that the animal was not present in the study area during primary trapping session (i − 1), and survives to trapping session (i).

4) **Emigration rate** (Gamma" or G″): the probability of being off the study area, unavailable for capture during the primary trapping session (i) given that the animal was present during the primary trapping session (i − 1), and survives to trapping session (i).

5) **Survival rate (Overall or S' and Interval SΔ):** survival rate denotes chances of being “live” of a particular animal. Survival or being alive of an animal for overall primary period is termed as overall survival rate (S') and chances of surviving this animal from one primary period to another primary period is termed as Interval

survival rate ($S\Delta$). In present study both trapping area (> 200 km²) and season (late winter to mid summer) were kept constant during data collection in secondery sampling period.

5.3.3.8. Software used for the estimation of survival rate

Data was analyzed in Pollock's robust design (Pollock's 1982) using MARK ver. 6 software.

5.3.3.9. Sex ratio of tiger and leopard

The present population estimation study was of a short duration (45 days), considering the life span of tiger (Sunquist 1981; Smith 1993), both tiger and leopard >1.5 month old was considered at the time of estimation of sex ratio.

5.3.3.10. Abundance estimation of dhole

Estimates of abundance are extremely valuable for species conservation, yet determining abundance for elusive and wide-ranging, carnivores it is difficult, especially for those species that cannot be identified by individual marking like tiger (Karanth 1995; Sharma *et al.* 2010; Jhala *et al.* 2011), leopard (Mondol 2006; Edgaonkar 2008; Harihar *et al.* 2009; Ramesh 2010), jaguar (Soisalo and Cavalcanti 2006) and cheetah (Marnewick *et al.* 2008). Initially, I tried obvious and subtle markings (scar, cut marks and wounds) (Kelly *et al.* 2008) of dhole to identify dhole individuals from camera trap photographs but this methodology did not work at my study site as dhole photo-captures were very poor during the study period. This low capture may result in underestimation of population and hence Royal and Nichols (2003) heterogeneity model was used for estimation of dhole abundance. This model allows estimation of abundance from repeated observations of the presence or absence of animals without having to uniquely mark individuals in the populations. The key assumptions of the Royle-Nichols model are that (1) the number of animals at a particular site follows 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' r and the site abundance, Ni.

Since the intensive study area (410 km²) was small to estimate parameters of Royal-Nichols heterogeneity model, I used larger data set (4500 km²) of the year 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. This larger study area was further sub-divided into 10 km X 10 km grids (n=45) (Fig. 5.7) and my assumption was that, cell size for which abundance estimation should be more than the home range size of a dhole pack (Royal and Nichols, 2003). The average home range of dhole pack was 63 km² 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 beats were walked early in the morning to record the signs and tracks of dhole. Each search covered about 4 to 6 km distance in areas having the best potential for dhole presence. In total 248 beats fewer than 45 large grids were covered for data collection. The data collected for the year 2006 was entered into the presence-absence format and analyzed under Royal and Nichols heterogeneity model (Royal and Nichols 2003) using the software PRESENCE ver. 3.

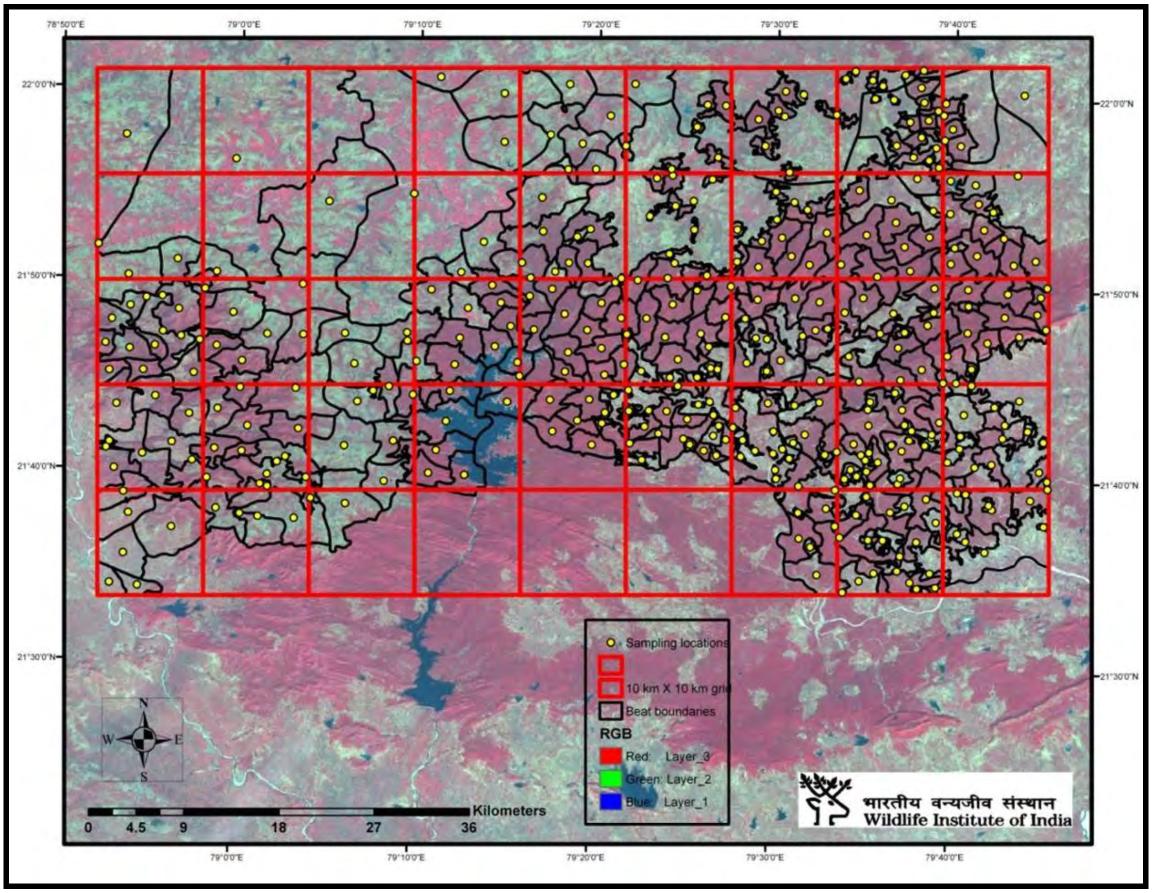


Fig.5.7. Grid wise (n=45) sampling design for estimating abundance of dhole in Pench landscape (4500 km²) for the year 2006.

5.4. Results

5.4.1. Population estimation of tiger and leopard

5*.4.1.1. Effort for population estimation*

The total trapping effort for 94 days from 36 trapping station amounted to 2,376 trap nights and documented a total of 90 photographs of 14 individual tiger (3 male and 11 female) and 24 photographs of 10 individual leopard (5 male and 5 female) for the year **2006**.

In the year **2008**, effort of 127 trap days from 52 trapping station under 6,604 trap nights yielded 71 photographs of 18 individuals tiger (6 male and 12 female) and 33 photographs of 13 individuals leopard (3 male and 10 female).

In **2009**, effort of 150 trap days from 50 trap stations under 7,500 trap nights yielded 45 photographs of 17 individuals tiger (8 male and 9 female) and 26 photographs of 17 leopard individuals (7 male and 10 female).

In **2010**, effort of 150 trap days from 80 trap stations under 12,000 trap nights yielded 65 photographs of 23 individuals tiger (8 male and 15 female) and 19 photographs of 18 individual leopard (11 male and 8 female).

In **2011**, effort of 110 trap days from 81 traps stations under 9,020 trap nights yielded 99 photographs of 22 individual tiger (7 male and 15 female) and 40 photographs of 27 individuals leopard (8 male and 11 female).

As on an average, 45 days found to be adequate for capturing all tiger and leopard in the study area for all five years, I truncated each trapping session (or year) upto 45 days and data on population estimation of both tiger and leopard was analysed for male, female and overall categories during the study period.

Table 5.1. Characteristics of camera trap efforts used during the sampling period in Pench Tiger Reserve (May 2006 to April 2011)

Block ID	Period	Minimum Convex polygon (Km²)	Total no. of camera traps used	Total no of trapping days	Total trapping nights	Total photographs		Not identifiable photographs		Identifiable photographs	
						Tiger	Leopard	Tiger	Leopard	Tiger	Leopard
A	27-5-06 - 31-7-06	84	36	65	2376	94	30	4	6	90	24
A±B	23-1-08 28-5-08	218	52	127	6604	77	35	6	2	71	33
A±B	17-1-09- 15-6-09	239	50	150	7500	50	30	5	4	45	26
A±B±C	1-2-10 30-6-10	357	80	150	12000	69	24	4	5	65	19
A±B±C	29-12-10- 17-4-11	410	81	110	9020	105	45	107	5	102	40
A= Karmajhiri Range B= Sanctuary Range C= Gumtara Range				**602**	**37500**	**395**	**164**	**126**	**22**	**373**	**142**

5.4.1.2. Tests for population closure

The statistical test for population closure using program CT (Stanley and Burnham 1999) accepted the closure assumption for all sampling occasions i.e. 2006, 2008, 2009, 2010, 2011 (Table. 5.2).

Incase of sampled population of leopard, statistical test for population closure was accepted the closure assumption for all sampling occasions i.e 2006, 2008, 2009, 2010 and 2011 (Table 5.2).

Table 5.2 Test for population closure for both tiger and leopard during the sampling occasions in Pench Tiger Reserve, Madhya Pradesh (May 2006 to April 2011).

Year	**Tiger**		**Leopard**	
	Test for addition to the population (*p* value)	Test for losses from the population (*p* value)	Test for addition to the population (*p* value)	Test for losses from the population (*p* value)
2006	>0.05	0.42	>0.05	0.37
2008	>0.05	>0.05	>0.05	0.25
2009	>0.05	>0.05	>0.05	0.69
2010	>0.05	0.06	>0.05	>0.05
2011	0.46	0.06	>0.05	0.3

(Low *p* value suggests that there is addition or loss in the population)

5.4.1.3. Model selection for tiger population estimation

M (O) null model was found to be the best fitted in case of both estimating overall tiger populations and female populations whereas M (h) Jacknife model was found to best fitted for male tiger in **2006** (Table 5.3).

In **2008** for estimation of both over all populations and female tiger populations, M (bh) model was found to be best fitted, whereas M (O) null model was selected as best model for estimation of male tiger population.

In **2009**, M (O) null model was found to be the best fitted for all three categories i.e. overall, male and female tiger populations (Table 5.3).

In **2010**, M (O) null model was found to be the best fitted for both male and over all tiger population estimation, whereas M (bh) model was found to be best fitted for female tiger population estimation (Table 5.3).

In the year **2011**, M (h) jackknife was found to the be best fitted model for both male and over all tiger population estimation, whereas M (O) null was considered as best estimator for estimation of female tiger population (Table 5.3).

5.4.1.4. Model selection for leopard population estimation

In case of estimating leopard population, M (h) jackknife estimator was found to be the best fitted model for all three categories i.e. male, female and overall for 2006.

In **2008**, M (O) null model was found to be the best fitted model for both overall and female leopard population, whereas M (bh) model was selected for males (Table 5.4).

In **2009,** M (O) null model was found to be the best fitted model for estimation of all three categories (Table 5.4).

In **2010**, M (O) null model was found to be the best fitted model for estimating both overall leopard population and females, whereas M (bh) was selected as the best fitted model for males (Table 5.4).

In **2011**, M (h) jackknife model was found to be the best fitted model for estimating overall and female leopard population, whereas M (O) null model was selected for male (Table 5.4).

Table 5.3. Population estimates of tiger under different categories (male, female and overall) calculated using different models under program CAPTURE inbuilt in MARK ver 6 for 2006, 2008, 2009, 2010 and 2011 in Pench Tiger Reserve, Madhya Pradesh

Year	**Categories**	**M(O)**	**M(h)**	**M(b)**	**M(bh)**	**M(th)**	**M(tb)**	**M(tbh)**
2006	Male	0.88	1	0.46	0.32	0.32	0.28	0.60
	Female	1	0.79	0.30	0.58	0.41	0.28	0.60
	Overall	1	0.88	0.19	0.24	0.52	0.07	0.61
2008	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	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	0.70
	Over all	1	0.95	0.32	0.54	0.43	0.35	0.63
2010	Male	1	0.94	0.51	0.75	0.40	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	Male	1	0.95	0.40	0.63	0.32	0.45	0.68
	Female	0.92	1	0.59	0.53	0.40	0.46	0.76
	Over all	0.95	1	0.74	0.51	0.54	0.61	0.89

Table 5.4. Population estimates of leopard under different categories (male, female and overall) calculated using different models under program CAPTURE inbuilt in MARK ver 6 for 2006, 2008, 2009, 2010 and 2011 in Pench Tiger Reserve, Madhya Pradesh

Year	**Categories**	**M(O)**	**M(h)**	**M(b)**	**M(bh)**	**M(th)**	**M(tb)**	**M(tbh)**
2006	Male	0.96	1	0.54	0.67	0.31	0.62	0.63
	Female	0.69	1	0.9	0.64	0.2	0.86	0.39
	Overall	0.91	1	0.77	0.87	0.32	0.66	0.71
2008	Male	1	0.94	0.40	0.60	0.35	0.45	0.61
	Female	1	0.84	0.44	0.72	0.42	0.36	0.77
	Overall	0.78	0.77	0.85	1	0.45	0.65	0.85
2009	Male	1	0.82	0.38	0.56	0.44	0.35	0.61
	Female	1	0.93	0.44	0.65	0.50	0.51	0.74
	Overall	1	0.81	0.38	0.62	0.50	0.34	0.63
2010	Male	0.95	0.85	0.70	1	0.56	0.57	0.98
	Female	1	0.85	0.40	0.69	0.44	0.35	0.75
	Overall	1	0.88	0.64	0.94	0.54	0.47	0.93
2011	Male	1	0.81	0.39	0.67	0.43	0.32	0.68
	Female	0.96	1	0.73	0.81	0.28	0.73	0.69
	Overall	0.97	1	0.45	0.51	0.31	0.43	0.63

5.4.1.5. Population estimation of tiger

In **2006,** the estimated overall tiger population was 12 ±0.3 (p-hat or capture probability was 0.07) under M (O) null model and 14±2.1 (*p*-hat = 0.06) under M (h) Jackknife model. The estimated male tiger population under M (O) null model was 3±0.01 (*p*-hat = 0.2) and under M (bh) model was 3±0.01 (*p*-hat = 0.2). The female tiger population was 9±0.5 (*p*-hat = 0.05) under M (O) null model and 11.9±2.1 (*p*-hat = 0.05) under M (h) Jacknife model. The estimated over all tiger density under ½ MMDM (Mean Maximum Distance Moved) method was 8.7±1.8/100 km^2 under M (O) null model and 7.5±1.1 /100 km^2 under M (h) Jackknife model. The estimated density of male tiger using the same method was 1±0.6 for both M (O) null and M (bh) models, whereas the estimated density of female tiger under M (O) null model was 6.4±0.9/100 km^2 and under M (h) Jackknife modell was 7.7 ± 1.7 /100 km^2. The Effective Trapping Area or ETA (½ MMDM) for overall tiger population it was 160 km^2, for male it was 298.7 km^2 and for female it was 141.2 km^2. The overall tiger density under Maximum likelihood method (ML- Den) was 4 ±1.2/100 km^2 for both M (O) null and M (h) jackknife models. Estimated density of male tiger using same method (ML-Den) was 0.9 ±0.5 /100 km^2 for both M (O) and M (bh), whereas for female tiger it was 3.9±1.5/100 km^2 for both M (O) null and M (h) Jacknife models.

In **2008**, the estimated overall tiger population was 17±0.8 (*p*-hat = 0.07) under M (O) null model and 22.1 ±4.4 (*p*-hat = 0.04) under M (h) Jackknife model. The estimated male tiger population was 5±0.1 (*p*-hat = 0.1) under M (O) null model and 7±2.1 (*p*-hat = 0.08) under M (h) Jackknife model. The estimated female tiger population was 13±1.5 (*p*- hat = 0.05) under M (O) null model and 14.8±3.5 (*p*-hat = 0.04) under M (h) Jackknife model.

The estimated density using ½ MMDM method for over all tiger population was 2.1±0.5 /100 km² under M (O) null model and 2.8±0.08/100 km² under M (h) Jackknife models. The estimated male tiger density was 0.7±0.1/100 km² under M (O) null model and 1±0.3 /100 km² under M (h) Jackknife model. The estimated density of female tiger was 3±0.5/100 km² under M (O) null model and 3.4±0.9 /100 km² under M (h) Jackknife model. The ETA for overall tiger population was 784.1 km², male tiger was 698.8 km² and female tiger was 427 km². The estimated density obtained from ML- Dens method for overall tiger population was 2.7±0.9/100 km² for both of these models whereas the estimated ML-Dens for male tiger was 0.7±0.3/100 km² under both M (O) model and M (h) jackknife models. Estimated density of female tiger under ML-Dens method was 2.7±0.9/100 km² under both M (O) and M (h) models.

In **2009,** the estimated overall tiger population under M (O) null model was 17±2.5 (*p*-hat = 0.03) and M (h) model was 23.8±7.2 (*p*-hat = 0.02). The estimated male tiger population was 5±0.58 (*p*-hat = 0.05) under M (O) null model and 7±6.2 (*p*-hat = 0.02) under M (bh) model. The estimated female tiger population was 11±2.4 (*p*-hat = 0.03) under M (O) null model and 12±3.5 (*p*-hat = 0.16) under M (h) Jackknife models.

The estimated over all density of tiger under ½ MMDM methods was 4.8±0.9/100 km² under M (O) null model and 6.5±2.1/100 km² under M (h) Jackknife models. The estimated density of male tiger using the same method under M (O) null model was 1.1±0.5/100 km² and under M (bh) model was 1.6±1.5/100 km². The estimated female tiger density under M (O) model was 3.3±0.8/100 km² and under M (h) Jackknife model was 3.6±1.1/100 km². The ETA (½ MMDM) for overall tiger population was 364.2 km², for male it was 429.3 km² and for female it was 332.9 km².

The estimated density of tiger under ML- Dens method was 4.9±1.2/100 km² under both M (O) null and M (h) Jackknife models. The estimated density of male tiger using the same method was 1.3±0.7/100 km² under both M (O) and M (bh) models. The estimated density of female tiger using the same method was 4.4±1.9/100 km² under both M (O) null and M (h) Jackknife models.

In **2010,** the estimated overall tiger population under M (O) null model was 28±7.9 (*p*-hat = 0.02) and under M (bh) model was 18±3.3 (*p*-hat =0.04). Male tiger population was 7±1.7 (*p*-hat = 0.03) under M (O) null model and 8±5.3 (*p*-hat = 0.03) under M (bh) model. The estimated female tiger population was 19.8±6.6 (*p*-hat = 0.07) under M (O) null model and 10.1±1.1 (*p*-hat = 0.05) under M (bh) model.

The estimated tiger density for overall tiger population in **2010** using ½ MMDM method was 3.1±0.1/100 km² under M (O) null model and 2.1±0.5/100 km² under M (bh) model. In case of male tiger the estimated density using the same method was 0.7±0.1/100 km² under both M (O) null and M (bh) models. The estimated female density was 2.4±1.2/100 km² under M (h) Jackknife model and 1.2 ±0.3 /100 km² under M (bh) model. The ETA (½ MMDM) was 897.7 for overall, 1038 km² for male and 830.4 km² for female tiger population. The estimated density using Ml- Dens method for overall tiger population was 3.6±1.5/100 km² under both M (O) null and M (bh) models. The estimated density of male tiger using the same method was 1±0.2/100 km² under M (O) null model, 1±0.1 /100 km² under M (h) Jackknife model and 1±0.3/100 km² under M (bh) model. The estimated density of female tiger using the same method was 3.7±1.2 /100 km² under all three models.

In **2011,** the estimated overall tiger population was 22±0.4 (*p*-hat = 0.1) under M (O) null model and 22±0.7 (*p*-hat = 0.1) under M (bh) model. The estimated male tiger population was 7±0.3 (*p*-hat = 0.1) under M (O) null model and 9±2.1 (*p*-hat = 0.04) under M (h) Jackknife model. The estimated female tiger population was 15±0.7 (*p*-hat = 0.07) under M (O) null model and 17.1±3.3 (*p*-hat = 0.02) under M (h) Jackknofe model.

The estimated density using ½ MMDM method for overall tiger population was 2.8±0.2 /100 km^2 under both M (O) null and (bh) models. The estimated density of male tiger using same method was 0.8±0.1/100 km^2 under M (O) null model and 1.1±0.02/100 km^2 under M (h) Jackknife model. The estimated density of female tiger using the same method was 1.8±0.2 /100 km^2 under M (O) null model and 2.3±0.2 /100 km^2 under M (h) Jackknife model. The ETA was 784.8 km^2 for over all tiger population, 939.6 km^2 for male tiger population and 851.6 km^2 for female tiger population.

The estimated density using the Ml-Density method for overall tiger population was 2.5±0.5/100 km^2 under both M (O) and M (bh) models. The estimated density of male tiger population using

the same method was 0.7±0.3 under both M (O) null and M (h) Jackknife models. The estimated (ML) desnity of female tiger was 1.9±0.5 /100 km^2 under both M (O) null and M (h) Jackknife models. All estimated results in details (2006 to 2011) of tiger population were shown in Table 5.5.

Table 5.5. Population and density (100 km⁻²) estimation of tiger in Pench Tiger Reserve, Madhya Pradesh (May 2006 to April 2011)

Year	**Models**	**2006**			**2008**			**2009**			**2010**			**2011**		
Tiger		**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**
Number		3	9	12	5	12	17	5	9	14	6	10	16	7	15	22
Number of capture		37	35	72	30	29	59	12	16	28	11	12	23	33	51	84
Capture probabilities or p-hat	M(O)	0.2	0.05	0.07	0.1	0.05	0.07	0.05	0.03	0.03	0.03	NA	0.02	0.1	0.07	0.08
	M(h)	NA	0.05	0.06	0.08	0.04	0.04	NA	0.03	0.02	NA	0.08	NA	0.07	0.06	NA
	M(bh)	0.2	NA	NA	NA	NA	NA	0.02	NA	NA	0.02	0.06	0.04	NA	NA	0.1
Population ±SE	M(O)	3±0.1	9±0.5	12±0.3	5±0.13	13±1.5	17±0.8	5±0.8	11±2.4	17±2.5	7±1.7	NA	28± 7.9	7±0.3	15±0.7	22± 0.4
	M(h)	NA	11±2.1	14±2.1	7±2.1	14.8±3.5	22.1±4.4	NA	12±3.5	23.8±7.2	NA	19.8±6.6	NA	9±2.1	17.1± 3.3	NA
	M(bh)	3±0.1	NA	NA	NA	NA	NA	7±6.2	NA	NA	8±5.3	10±1	18± 3.3	NA	NA	22±0.7
ETA 1/2 MMDM (km²)		298.7	141.2	160	698.8	427	784.1	429.3	332.9	364.2	1038	830.4	897.7	939.3	851.5	784.8
Density (1/2 MMDM)	M(O)	1±0.6	6.4±0.9	8.7±1.8	0.7±0.1	3±0.5	2.1±0.5	1.1±0.4	3.3±0.8	4.8±0.9	0.8±0.1	NA	3.1± 0.1	0.8±0.1	2±0.2	2.8± 0.2
	M(h)	NA	7.7±1.7	7.5±1.1	1±0.3	3.4±0.9	2.8±0.08	NA	3.6±1.1	6.5±2.1	NA	2.4±1.2	NA	1.1±0.02	2.3±0.5	NA
	M(bh)	1±0.5	NA	NA	NA	NA	NA	1.6±1.5	NA	NA	0.8±0.1	1.2±0.3	2.1± 0.5	NA	NA	2.8± 0.2
Density (Maximum likely hood or ML-Dens)	M(O)	0.9±0.5	3.9±1.5	4±1.2	0.7±0.3	2.7±0.9	2.6±0.6	1.3±0.7	4.4±1.9	4.9±1.6	1±0.6	NA	3.6± 1.5	0.7±0.3	1.9±0.5	2.5± 0.5
	M(h)	NA	3.9±1.5	4±1.2	0.7±0.3	2.7±0.9	2.6±0.6	NA	4.4±1.9	4.9±1.6	NA	3.4±2.8	NA	0.7±0.3	1.9±0.5	NA
	M(bh)	0.9±0.5	NA	NA	NA	NA	NA	1.3±0.7	NA	NA	1±0.6	3.4±2.8	3.6± 1.5	NA	NA	2.5± 0.5
M L Sigma		3039± 594.6	2155.3± 343.4	2708.4 ±328.4	4101.9 ±536.8	2858.5± 458.9	3769.3± 379.2	2446.5 ± 612.4	1543±360	2027.1± 344.1	3603± 1318.1	4658.8± 2043.6	4049.5± 1063.7	3690.7 ±513.7	3114± 343.7	3332.5 ±295.5

NA= Not Assesed

5.4.1.6. Population estimation of leopard

In **2006,** the estimated overall leopard population was 11±1.4 (*p*-hat or capture probability was 0.04) under M (O) null model and 10.1±2.8 (*p*-hat = 0.04) under M (h) Jackknife model. The estimated population of male leopard under M (O) null model was 5±0.8 (*p*-hat =0.04) and M (h) Jackknife model was 6±0.2 (*p*-hat = 0.03). The estimated population of female leopard using the same method was 5±0.8 (*p*-hat 0.05) under M (O) null model and 6.9±2.1 (*p*- hat = 0.03) under M (h) Jackknife model. The estimated over all leopard density using ½ MMDM method was 8.2±1.9/100 km² under M (O) null model and 7.5±2.6/100 km² under M (h) Jackknife model. The estimated density of male leopard using the same method was 3.5±1.2/100 km² under M (O) null model and 4.1±1.9 /100 km² under M (h) Jackknife model. The estimated density of female leopard using the same method under M (O) null model was 4.1±1/100 km² and M (h) Jackknife model was 5.6±2/100 km². The ETA (½ MMDM) for overall leopard population was 134.3 km², for male it was 143.1 km² and for female it was 123.1 km². The estimated overall leopard density using ML-Dens was 7.3±2.6/100 km² for both M (O) null model and M (h) Jackknife model. The estimated density of male leopard using the same method was 3.1±1.9/100 km² for both M (O) null and M (h) Jackknife models. The estimated density of female leopard using the same method was 3.8±1.9/100 km² under both these models.

In **2008**, the estimated overall leopard population was 12±1.3 (*p*-hat 0.04) under M (O) null model and 14±3.2 (*p*-hat = 0.04) under M (h) Jackknife model. The estimated male leopard population was 3±0.3 (*p*-hat = 0.07) under M (O) null model and 3±0.1 (*p*-hat = 0.03) under M (bh) model. The estimated female leopard population was

9±1.5 (*p*- hat =0.04) under M (O) null model and 8.2±2.6 (*p*-hat =0.04) under M (h) Jackknife model.

The estimated density using ½ MMDM method for over all leopard population was 2.5±0.6/100 km² under M (O) null model and 2 ±0.4/100 km² under M (h) Jackknife model. The estimated male leopard density was 0.6±0.2 /100 km² under both M (O) null and M (bh) models. Density of female leopard was 1.3±0.3/100 km² under M (O) Null model and 1.2 ±0.4/100 km² under M (h) Jackknife model. The ETA for over all leopard population was 600.2 km², male leopard was 451.2 km² and female leopard was 697.3 km². The estimated density of overall leopard population using the Ml-Dens method was 1.5±0.5/100 km² for both M (O) and M (h) models. The estimated density of male leopard population using the same method was 0.5±0.3/100 km² under both M (O) and M (h) Jacknife models. The estimated density of female leopard population using the same method was 1.1±0.4 /100 km² under both M (O) and M (bh) models.

In **2009,** the estimated overall leopard population under M (O) null model was 25±6.9 (*p*-hat = 0.01) and M (bh) model was 16±2.1 (*p*-hat = 0.03). The estimated male leopard population was 15.6±6.2 (*p*-hat = 0.01) under M (h) Jackknife model and 10±7.3 (*p-hat* = 0.01) under M (bh) model. The estimated female leopard population was 10±2.4 (*p*-hat = 0.04) under M (O) null model and 8±1.3 (*p*-hat = 0.06) under M (bh) model.

The estimated over all density under ½ MMDM methods was 6.4 ±2/100 km² under both M (O) null and M (bh) models. The estimated density of male leopard using the same method was 2.6±1.2/100 km² under M (h) model and 1.7±0.8/100 km² under M (bh) model. The estimated female density using the same method was 4.1±2 /100 km² under M (O) model 3.2±2/100 km² under M (bh). The ETA (½ MMDM) for overall leopard population was 248.9 km² for overall, male and female tiger.

The estimated overall density under Ml- Dens method was 8.5 ±5.5/100 km² for both M (O) null and M (bh) models.

The estimated density of male leopard using the same method was 0.8±0.6 /100 km² under both M (h) Jackknife and M (bh) models. The estimated density of female leopard using the same method was 6.2±2.5/100 km² under both M (O) null and M (bh) models.

In **2010,** the estimated density of overall leopard population under M (O) null model was 85±54.2 (*p-hat* = 0.008), under M (h) Jackknife model was 58±16.5 (*p*-hat = 0.01) and under M (bh) model was 22±5.4 (*p*-hat = 0.05). The estimated male leopard density was 51±45.3 (*p-hat* = 0.003) under M (O) null model, 30.5±11 (*p*-hat = 0.003) under M (h) Jackknife model and 10±1.3 (*p-hat* = 0.01) under M (bh) model. The estimated female leopard density was 32±27 (*p*-hat = 0.01) under M (O) null model, 20±7.5 (*p*-hat = 0.01) under M (h) Jackknife model and 13±81. (*p*-hat = 0.04) under M (bh) model.

The estimated overall leopard density using ½ MMDM methods was 4.9±1.2 /100 km² under M (bh) model. The density under M (O) null and M (h) Jackknife model was not assessed because of high standard error. The estimated density of male leopard using the same method was 7.7±4.2/100 km² under M (O) null model, 4.6±1.2/100 km² under M (h) Jackknife model and 2.3±0.8 under M (bh) model. The estimated density of female leopard using the same method was 1.7±1/100 km² under M (O) null model, 1.98±0.5 /100 km² under M (h) Jackknife model and 1.2 ±0.5/100 km² under M (bh) model. The ETA (½ MMDM) was 452.1 km² for over all leopard population, 887.5 km² for male and 657.1 km² for female. The estimated density of overall and female leopard was not assessed under ML-Dens method because of high standard error. The estimated density of male leopard under Ml-Dens was 1.9±1.2/100 km^2 under both M (O) null and M (h) Jackknife models.

In **2011,** the estimated overall leopard population was 64.5±18.1 (*p*-hat = 0.01) under M (O) null model and 39±24.1 (*p*-hat = 0.01) under M (bh) model. The estimated male leopard population was 25±21 (*p*-hat = 0.009) under M (O) null model and 15.6±6.2 (*p*-hat = 0.03) under M (h) Jackknife model. The estimated female leopard population was 36±14.7 (*p*-hat = 0.01) under M (O) null model and 18±4.6 (*p*-hat = 0.001) under M (bh) model.

The estimated density of overall leopard population using ½ MMDM method was 10.6±3.2/100 km^2 under M (h) Jackknife model and 6.4±4.1/100 km^2 under M (bh) model. The estimated male leopard density using the same method was 5.5±2/100 km^2 under M (O) null model and 3.2±1.2/100 km^2 under M (h) Jackknife model. The estimated density of female leopard was 5.4±2.3/100 km^2 under M (O) null model and 2.7±0.8/100 km^2 under M (bh) model. The ETA was 607 km^2 for over all leopard population, 447.2 km^2 for male and 663.3 km^2 for female leopard. The estimated Ml-Density of overall leopard population was 7.5±2.1/100 km^2 under M (O) null model and 9±4/100 km^2 under both M (h) Jackknife and M (bh) models. The estimated density of male leopard using the same method was 1.8±1.4/100 km^2 under both M (O) null and M (h) Jackknife models. The estimated density of female leopard was 5±2.5/100 km^2 under both M (O) null and M (bh) models. All estimated results (2006 to 2011) of leopard population were shown on Table 5.6.

Table 5.6. Population and density (100 km⁻²) estimation of leopard in Pench Tiger Reserve, Madhya Pradesh (May 2006 to April 2011)

Year		2006			2008			2009			2010			2011		
Tiger	**Model**	**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**	**Male**	**Female**	**Over all**
Number		5	5	10	3	8	11	7	8	15	10	8	18	7	15	22
Number of capture		12	12	24	10	18	28	8	14	22	11	8	19	8	19	27
Capture probabilities or p-hat	M(O)	0.04	0.05	0.04	0.07	0.04	0.04	NA	0.04	0.01	NA	NA	NA	0.007	0.01	NA
	M(h)	0.035	0.03	0.04	NA	0.04	0.04	0.008	NA	NA	0.003	0.006	0.01	0.01	na	0.01
	M(bh)	NA	NA	NA	0.11	NA	NA	0.01	0.06	0.03	0.01	0.006	0.05	NA	0.03	0.01
Population ±SE	M(O)	5±0.8	5±0.8	11±1.4	3±0.3	9±1.5	12±1.3	NA	10±2.4	25±6.9	NA	NA	NA	25±21	36±14.7	NA
	M(h)	6±2	6.9±2.1	10.1±2.8	3±0.1	8.2±2.6	14±3.2	15.6±6.2	NA	NA	30.5±11	20±7.5	58±16.5	15.6± 6.2	NA	64.5±18.1
	M(bh)	NA	NA	NA	NA	NA	NA	10±7.3	8±1.3	16±2.1	10±1.3	13±11.8	22±5.4	NA	18±4.6	39±24.1
ETA 1/2 MMDM (km²)		143.1	123.04	134.3	451.2	697.3	600.2	248.9	248.9	248.9	887.5	657.1	452.1	447.2	663.3	607
Density (1/2 MMDM)	M(O)	3.5±1.2	4.1±1	8.2±1.9	6±0.2	1.3±0.3	2±0.4	NA	4±2	6.4±2	NA	NA	NA	5.5±3.2	5.4±2.3	NA
	M(h)	4.1±1.9	5.6±2	7.5±2.6	NA	1.2±0.4	2.3±0.6	2.6±1.2	NA	NA	4.6±1.2	1.98±0.5	NA	3.5±2	NA	10.6±3.2
	M(bh)	NA	NA	NA	6±0.2	NA	NA	1.7±0.8	3.2±2	6.4±4	2.3±0.8	1.2±0.5	4.9±1.2	NA	2.7 ±0.8	6.4±4.1
Density (Maximum likely hood or ML-Dens)	M(O)	3.1±1.9	3.8±1.9	7.3±2.6	0.5±0.3	1.1±0.4	1.5±0.5	NA	6.2±2.5	8.5±5.5	0.8±0.6	NA	NA	1.8± 1.4	5±2.5	NA
	M(h)	3.1±1.9	3.8±1.9	7.3±2.6	NA	NA	1.5±0.5	0.8±0.6	NA	NA	0.6±0.2	NA	NA	1.8±1.4	NA	9±4
	M(bh)	NA	NA	NA	0.5±0.3	1.1±0.4	NA	0.8±0.6	6.2±2.5	8.5±5.5	NA	NA	NA	NA	5±2.5	9±4
M L Sigma		2349± 826.2	1073.2± 574.6	1721.9± 377.5	4445.3± 1514.8	9915.8 ±4804.4	7019.2± 1719.8	1462.3 ±385.3	108.9 ±20.6	195± 61.6	4000± 189	4000±189	4000±189	142.4 ±43	2397.2±247	2178.6± 566.5

NA= Not Assesed

5.3.1.7. Adult sex ratio in tiger and leopard

Based on camera trap photographs, the estimated adult sex ratio (female: male) for tiger during 2006 (number of individual or n= 12) was 100:33 followed by 100:42 in 2008 (n= 17), 100:56 in 2009 (n=14), 100:60 in 2010 (n=16) and 100:47 in 2011 (n=22) (Table 5.7).

In case of leopard, the adult sex ratio during 2006 (number of individual or n= 10) was 100:100 followed by 100:38 in 2008 (n= 11), 100:88 in 2009 (n=15), 100:125 in 2010 (n=18) and 100:47 in 2011 (n=22) (Table 5.7).

Table 5.7. Adult sex ratio of tiger and leopard in Pench Tiger Reserve, Madhya Pradesh, (May 2006 to April 2011)

	Tiger		**Leopard**	
Year	**Adult female**	**Adult male**	**Adult female**	**Adult male**
2006	100	33	100	100
2008	100	42	100	38
2009	100	56	100	88
2010	100	60	100	125
2011	100	47	100	47

5.4.1.8. Survival rate of tiger and leopard

During present study for survival rate estimation, a total of 33 tigers (12 male and 21 female) and 28 (8 male and 20 female) leopards were monitored over 5 years period. As larger area was covered (>200 km²), various model combination of time variant (t) and constant (.) with temporary immigration (G′), temporary emigration (G″) and survival rate (S′) of both tiger and leopard were tested under M (O), M (h), M (b), M (bh), M (t) and (Mth) models. Survival rate was estimated from best fitted model based on the lowest

AIC value. Though for estimating survival rate of both tiger and leopard, following combinations (Table 5.8) of models were tested, only best five models were shown on the Table 5.9 and 5.10.

Table 5.8. Combination of models for estimating survival rate of tiger and leopard

Parameters	**Combination**
Survival rate or S	Constant (.) / time variant (t)
Immigration or G′	Constant (.)/time variant (t)/ fixed (0) i.e. no temporary immigration (Mh, M (O), Mb, Mbh, Mt, Mth) and Markovian
Emigration or G″	Constant (.)/time variant (t)/ fixed (0) i.e. no temporary emigration (Mh, M (O), Mb, Mbh, Mth) and Markovian
Probability of mixture or pi	Constant (.) or time variant (t)
Capture probability or p = Recapture probability or c i.e. cg (.) or (t) = pg (.) or (t) (Mh, M (O), Mb, Mbh, Mt, Mth)	
Abundance or population	Time variant $N_{1,} N_{2\ldots} N_n$ (t)

Table 5.9. Model selection statistics for robust design analysis of tiger (overall, male and female) capture data from Pench Tiger Reserve, Madhya Pradesh (May 2006 to April 2011).

Criteria	Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
Overall	**{S (.) G'(0)G"(0) pi (.) cg (.)=pg (.)}**	**587.8463**	**0**	**0.85434**	**1**	**9**	**561.3561**
	{S (.) G'(0)G"(0) pi (.) cg(t)=pg (t)}	593.0417	5.1954	0.0636	0.0744	17	547.4857
	{S (t) G'(.)=G"(.) pi(.) cg (t)= pg (t)}	593.4781	5.6318	0.05113	0.0598	12	560.0782
	{S (.) G'(.)=G"(.) pi(.) cg(t)=pg (t)}	595.5749	7.7286	0.01792	0.021	18	547.4857
	{S (t) G'(0)G"(0) pi (.) cg(.)=pg(.)}	596.2173	8.371	0.013	0.0152	17	550.6613
Male	**{S (.) G'(0)G"(0) pi(.) cg(.)=pg(.)}**	**247.5145**	**0**	**0.71097**	**1**	**8**	**201.7806**
	{S (.) G'(.)=G"(.) pi(.) cg (.)=pg (.)}	250.1798	2.6653	0.18754	0.2638	9	201.6858
	{S (.) G'(.)G"(.) pi(.) cg (.)=pg (.)}	253.0378	5.5233	0.04492	0.0632	10	201.6732
	{S (.) G'(0)G"(0) pi(.) cg (.)=pg (.)}	253.0378	5.5233	0.04492	0.0632	10	201.6732
	{S (.) G'(0)G"(0) pi (.) cg (t)=pg (t)}	255.7389	8.2244	0.01164	0.0164	15	188.1076
Female	**{S (.) G'(0)G"(0) pi (.) cg (.)= pg (.)}**	**418.5956**	**0**	**0.49508**	**1**	**8**	**390.9503**
	{S (.) G'(.)=G"(.) pi (.) cg (.)= pg (.)}	418.6463	0.0507	0.48269	0.975	9	388.5834
	{S (t) G'(t)G"(t)pi (.) cg (.)= pg (.)}	425.2262	6.6306	0.01798	0.0363	15	379.449
	{S (t) G'(0)G"(0) pi (.) cg (.)= pg (.)}	428.9396	10.344	0.00281	0.0057	16	380.3225
	{S (t) G'(.)=G"(.) pi (.) cg (.)= pg (.)}	430.2861	11.6905	0.00143	0.0029	17	378.7598

S= Survival rate, Gamma'= Immigration rate, 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 5.10. Model selection statistics for robust design analysis of leopard (overall, male and female) capture data from Pench Tiger Reserve, Madhya Pradesh (May 2006 to April 2011)

Criteria	Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
Overall	**{S(.)G'(0) G"(0) pi (.) cg (.)= pg (.)}**	**262.5959**	**0**	**0.93671**	**1**	**9**	**164.1657**
	{S (.)G'(.)=G"(.) pi (.) cg (.)= pg (.)}	269.3089	6.713	0.03265	0.0349	9	170.8788
	{S(.)G'(.)G"(.) pi(.)pg (.) =cg (.)}	269.4762	6.8803	0.03003	0.0321	10	168.0933
	{S(.)G'(t)= G"(t) pi (.) cg (.)= pg (.)}	278.5613	15.9654	0.00032	0.0003	14	163.961
	{S(.)G'(t)G"(t) pi (.) cg (.)=pg (.)}	279.1159	16.52	0.00024	0.0003	14	164.5155
Male	**{S(.)G'(0)G"(0) pi (.) cg (.)=pg (.)}**	**160.5141**	**0**	**0.99795**	**1**	**9**	**117.6841**
	{S(.) G'(0) G"(0) pi (.) cg (t)=pg (t)}	172.9982	12.4841	0.00194	0.0019	12	106.8144
	{S(.) G'(t)=G"(t) pi (.) cg (.)=pg (.)}	179.8251	19.311	0.00006	0.0001	12	113.6412
	{S(.) G'(t)G"(t) pi (.) cg (.)= pg (.)}	180.4992	19.9851	0.00005	0.0001	12	114.3153
	{S(t) G'(t) G"(t) pi (.) cg (.)=pg (.)}	223.0173	62.5032	0	0	15	113.462
Female	**{S(.)G'(0)G"(0) pi (.) cg (.)=pg (.)}**	**182.3406**	**0**	**0.8606**	**1**	**9**	**84.8046**
	{S(.)G'(0)=G"(0) pi (.) cg (.)=pg (.)}	186.2036	3.863	0.12473	0.1449	10	84.6024
	{S(.)G'(.)G"(.) pi (.) cg (.) =pg (.)}	190.4852	8.1446	0.01466	0.017	11	84.4492
	{S(.)G'(t)=G"(t) pi (.) cg (.) =pg (.)}	205.4295	23.0889	0.00001	0	14	83.2883
	{S(t)G'(t)G"(t) pi (.) cg (.)=pg (.)}	209.2204	26.8798	0	0	15	80.5177

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

According to best fitted model the estimated overall survival rate of tiger was 0.64±0.06, whereas for male tiger it was 0.54±0.12 and for female tiger it was 0.67±0.08 (Table 5.16). In case of leopard the estimated overall survival rate was 0.63±0.11, whereas for male leopard it was 0.76±0.13 and female leopard it was 0.42±0.16 (Table 5.17).

Table 5.11 Estimated survival rate, capture probabilities and abundance of tiger in Pench Tiger Reserve, Madhya Pradesh, (May 2006 to April 2011)

Tiger	**Male**	**Female**	**Over all**
S'+SE	0.54±0.12	0.67±0.08	0.64±0.06
Pi	0.26±0.1	0.14±0.08	0.17±0.05
p for group 1	0.61±0.06	0.54±0.11	0.57±0.06
p for group 2	0.11±0.03	0.14±0.02	0.12±0.02
Abundance or N for the 1st year	3.2±1.1	12.9±1.9	17.6±2.6
For 2nd year	4.7±1.4	9.6±1.8	15.6±2.6
For 3rd year	6.1±1.6	8.3±1.6	15.6±2.6
For 4th year	5±0.003	5±0.007	12.8±1.4
For 5th year	3.1±1.02	10.1±1.5	14.4±2.1

(S′= Survival rate± Standard Error, Pi= probability of mixture, p= capture= recapture probabilities)

Table 5.12 Estimated surbvival rate, capture probabilities and abundance of leopard in Pench Tiger Reserve, Madhya Pradesh (May 2006 to April 2011)

Tiger	**Male**	**Female**	**Over all**
S'+SE	0.76±0.13	0.42±0.16	0.63±0.11
Pi	0.14±0.02	0.06±0.05	0.08±0.05
P for group 1	0.28±0.18	0.37±0.17	0.31±0.11
P for group 2	0.07±0.04	0.05±0.03	0.04±0.02
Abundance or N for the 1st year	10.8±5.3	14.6±8.2	31.6±12.8
For 2nd year	7.1±3.5	11.9±6.4	23.2±9.3
For 3rd year	3.6±2.5	10.3±6.1	16.8±7.6
For 4th year	3.9±1.9	6.7±3.4	13.1±5.1
For 5th year	2.9±1.8	12.3±6.1	17.7±7.1

(S′= Survival rate ± Standard Error, Pi= probability of mixture, p= capture= recapture probabilities)

5.4.1.9. Abundance estimation of dhole

The estimated average abundance of dhole in the study area was 0.24± 0.08 (Standard Error or SE) /100 km². The estimated occupancy was 0.21± 0.08 (SE). Detection probability or r was 0.74± (SE) 0.09. The average or mean dhole pack size was 13.9± (SE) 1.4. The estimated individual density of dhole in the study area (multiplying average pack size of dhole with average abundance) was 3.3±1.2/100 km² for the year 2006.

5.5. Discussion

As reported in various studies (Karanth and Nichols 1998, 2000, 2002; Silver *et al.* 2004; Edgaonkar, 2008; Ramesh 2010) the population estimation of individually identifiable cryptic animals such as tiger, ocelot, jaguar and leopard using photographic capture recapture analysis is most reliable. Though photographic capture frequency may serve as an index to the population (Carbone *et al.* 2001) this may not hold true for all species (Jennelle *et al.* 2002). Since its initiation (Karanth, 1995), this method has been advocated to be used throughout the country in various protected areas so as to arrive at estimates of tiger densities (Karanth and Nichols 1998; Karanth *et al.* 2004b; Jhala *et al.* 2011). However issues regarding sampling design have received less attention (Wegge *et al.* 2004). The data collected from this study was found adequate to answer various questions pertaining to sampling design. Though PTR has well connecting forest patch, but my sampling tiger and leopard population found to be demographically and geographically closed. Though study area was gradually increased over the period and covered entire Pench protected area (> 410 km²) i.e. Pench Natinal Park and Sanctuary but for estimating survival rate of tiger and leopard I maintained the trapping area (>200 km²) and season constant over the period which help to maintain the population closure assumption (geographically) in each secondary sampling period under Pollock's robust design (Pollock 1982).

Understanding the variation in population density among different species within habitat and within species across habitat is of central importance in wildlife ecology and critical to conservation efforts of threatened and endangered species (Andrewartha and Birch 1954). Methods like ½ MMDM, Full MMDM are being site specific and stripe width based, Maximum Likelihood (ML) method appeared to be more robust as density estimate by this method did not vary over the years and this estimate can be extended to the adjoining areas. ML method does not restrict to the sampled area as it is not dependent on strip width unlike 1/2MMDM and Full MMDM. The best approach of ML in the absence of telemetry-based home-range data is to use the spatial capture histories of camera traps in a likelihood-based density estimation framework (Efford *et al.* 2009; Kalle *et al.* 2011).

Since camera density played a major role in the capture rate of individual tiger and leopard, it was necessary to use less inter-trap distance between camera trap locations. Density estimate for tiger and leopard excluded cubs <1yr old during the present study. Karanth and Stith (1999) predicted using demographic models that cub may form 25% of the normal wild tiger population.

The presence-absence based population estimation technique gave a reliable estimate for the animals like dhole which cannot be identified by their unique mark pattern.

Tiger: The estimated tiger density per 100/ km^2 in the Indian sub – continent ranged from 0.36 to 19.3 (Table 5.19). Tiger density 3.1±0.2/100 km^2 in PTR (2011) was found lower than Barida, Nepal (Wegge *et al.* 2009), Corbett (Jhala *et al.* 2011), Bandhavgarh (Jhala *et al.* 2011), Kanha (Jhala *et al.* 2011), Ranthambore (Jhala *et al.* 2011), Kaziranga (Karanth *et al.* 2004b), PTR, Maharastra (Karanth *et al.* 2004b), Melghat (Jhala *et al.* 2011), Nagarahole (Jhala *et al.* 2011), Bandipur (Jhala *et al.* 2011), Rajaji (Harihar *et al.* 2011), Mudumalai (Ramesh 2010), Bhadra (Karanth *et al.* 2004b) and Tadoba (Jhala *et al.* 2011) and higher than Pakke (Chauhan *et al.* 2006), Jigme Singye Wangchuck, Bhutan (Wang and Macdonald 2009), Satpura (Jhala *et al.* 2011), Valmiki (Jhala *et al.* 2011), Parambikulam (Jhala *et al*. 2010), Taman Negara National Park (Kawanishi and Sunquist 2004) and Bukit Barisan Selatan National Park (O’Brien et al. 2003).

Table. 5.13 The estimated densities of tiger in different Protected Areas in South East Asia.

Place	**Effective trapping area (Km²)**	**Population ±SE**	**Tiger Density ±SE**	**Author(s) (Year)**
Bandhavgarh	210	26±4.2	13.6±1.7	Jhala *et al.* (2011)
Corbet	545	127±9.4	19±0.64	Jhala *et al.* (2011)
Dudhwa	221	14±1.5	6.15±0.87	Jhala *et al.* (2011)
Kanha	108	13±1.8	12±2	Jhala *et al.* (2011)
Melghat	267	11±1	4.12±0.15	Jhala *et al.* (2011)
NSTR	272	3±0.003	1.49±0.005	Jhala *et al.* (2011)
PTRTR	152	17±2.6	9.5±0.84	Jhala *et al.* (2011)
Ranthambore	275	28±2.8	9.81±0.75	Jhala *et al.* (2011)
Satpura	136	5±1.5	1.64±0.55	Jhala *et al.* (2011)
Simlipal	323	7±1.1	0.64±0.23	Jhala *et al.* (2011)
Tadoba	250	10±0.3	4±0.21	Jhala *et al.* (2011)
Valmiki	215	3 ±1.1	1±0	Jhala *et al.* (2011)
Nagarahole	231.8	30 ±2.1	12.9±1.0	Karanth *et al.* (2006)
Bandipur	284	34 ±9.9	11.9 ±3.7	Karnath *et al.* (2004b)
Rajaji		28.1±2.05	5.8±0.9	Harihar *et al.* (2011)
Kaziranga	167	28 ±4.5	16.7 ±2.9	Karanth *et al.* (2004b)
Pench-Maharastra	274	20±4.4	7.3±2.5	Karanth *et al.* (2004b)
Bhadra	263	9± 1.93	3.42± 0.84	Karanth *et al.* (2004b)
Jigme Singye Wangchuck National Park,Bhutan	1546.06	8±2.1	0.52±0.05	Wang and Macdonald (2009)
Taman Negara NationalPark, Malyasia	376	6±2.23	1.66±0.21	Kawanishi and. Sunquist, (2004)
Bukit Barisan Selatan National Park, Indonesia	836	13 ± 3.66	1.56±0.29	O' Brien *et al.* (2003)
Parambikulam	303.8	8.0±1.5	2.48±0.7	Jhala *et al.* (2010)
Mudumalai	162.5	28.9±4.5	17.1±3.3	Ramesh (2010)
Pakke	158	4.0±2.56	1.1±0.8	Chauhan *et al.* (2006)
Pench-Madhya Pradesh	784.8	27.1±4	2.8±0.2	Present study (2011)

Leopard: The density of leopard/100 km² ranged from 1.0 to 25.5 individuals in the Indian sub- continent (Table 5.20). Estimates for leopard density (12.2/100 km²) in the present study (2011) was lower than Mudumalai (Ramesh 2010), Parambikulam (Jhala *et al.* 2010), Chilla-Rajaji National Park (Harihar *et al.* 2009), higher than Satpura (Edgaonkar 2008), Sariska (Sankar *et al.* 2009), Mkhuze (Balme *et al.* 2010), Phinde (Balme *et al.* 2009), KuaZulu Natal (Balme *et al.* 2010) and Jigme Singye Wangchuck, Bhutan (Wang and Macdonald 2009b).

Table.5.14. The estimated leopard densities using ½ MMDM method from different Protected Areas in Asia and Africa

Study area	Effective Sampling area	Population ±SE	Density±SE	Author(s) (Year)
Jigme Singye Wangchuck National Park,Bhutan	1546.1	16±2.91	1.04±0.01	Wang and Macdonald (2009)
Satpura National Park and Bori WLS	135.8	12.4±4.2	8.1±3.1	Edgaonkar, (2008)
Chilla-Rajaji NP	86.72	13±6.02	14.9±6.9	Harihar (2009)
Mudumalai	192.8	26±2.5	25.5±4.2	Ramesh (2011)
Parambikulam	146.04	18±3	13.2±1.07	Jhala *et al.* (2010)
Sariska	213.8	17.0 ± 2.6	6.5±0.1	Sankar *et al.* (2009)
Pench- Madhya Pradesh	607	64.5±18.1	10.6±3.2	Present study
Mkhuze , South Africa	158	17±4.3	10.7±1.8	Balme *et al.* (2009)
Phinda, South Africa	158	16±2.9	7.17±1.12	Balme *et al.* (2009)
KwaZulu Natal, South Africa	121	3±0.23	2.49±0.87	Balme *et al.* (2009)

NP- National Park

Dhole: The estimated dhole density i.e. 3.3±1.2 /100 km² in the present study was found lower than Bandipur (Johnsingh, 1983), Mudumalai (Ramesh 2010), (Acharya *et al.* 2007), Mudumalai (Venkatraman *et al.* 1995) and Nagarahole (Karanth 1993) (Table 5.21). Observed pack range in the present study was also found higher than other studies (Cohen *et al.* 1978; Johnsingh 1983; Venkatraman *et al.* 1995, Karanth 1993; Acharya 2007; Ramesh *et al.* 2010)

Table 5.15. Estimated dhole densities (individuals/100 km²) from different Protected Areas in Indian sub-continent.

Locations (Authors and year)	**Density/ 100 km²**	**Pack Size Range**	**Method**
Mudumalai (Ramesh 2010)	43.0±21.0	1 - 28	Vehicle Transect
Mudumalai (Venkatraman *et al.* 1995)	31.2±-	4 - 25	Direct observation
Bandipur (Johnsingh 1983)	35-90±-	7 - 18	Direct observation
Nagarhole (Karanth 1993)	14.0±-	3 - 10	Direct observation
Pench TR (Acharya *et al.* 2007)	29.0±2.0	1 - 14	Radio Telemetry
Nilgiri Plateau (Cohen *et al.*1978)		1 - 5	Direct observation
Present study	3.3±1.2	1-29	Royal and Nichols (2003) heterogeneity model

Sampling under Pollock's robust design is the best way of obtaining unbiased estimates of survival of large carnivores if there is temporary emigration (Pollock 1982; Kendall *et al.* 1997; Bailey *et al.* 2004). Overall observed survival rate of tiger from the present study is comparable with survival rate of tiger in Nagarahole (0.77±0.051) (Karanth *et al.* 2006). In the present study both tiger and leopard abundance had relatively wide variances. This is because, the model explicitly incorporated uncertainties arising from factors related to large carnivore ecology as well as sampling issues. The present study showed high survival rate of tiger female than male, but in case of leopard the annual survival rate is more incase of male than female. Survival rate of female leopard might be low due to the high abundance of breeding female tiger with cubs in the sampling area. The adult sex ratio (Female: Male) in PTR found to be female biased over the year in case of tiger and whereas this ratio varied over the year in case of leopard.

Both camera-trap and occupancy based abundance studies have showed moderately high densities of large carnivores in the study area. These are excellent models of species abundance estimates for exploring parts of mechanisms of coexistence between large sympatric carnivores. The moderately high densities of large predators, high rate of immigration and low rate of emigration especially in case of male, suggested that the study area is acting as a source population for the surrounding areas. Qureshi *et al.* (2006) also reported that PTR has forest connectivity with Kanha Tiger Reserve and Satpura Tiger Reserve and forms one of the important meta-population of tiger and its co-predators in central Indian landscape. As, carnivore densities are positively correlated with prey biomass (Carbone and Gittleman 2002; Karanth *et al.* 2004b) a high level of prey availability may causes an increase in the presence of transient or immigrant animals and may also increase reproduction and survival of neonates and juveniles within the population. It can be expected that larger forest continuity proximal to high population of large predators have greater chance for their long-term survival in PTR landscape.

Plate 5.1 and 5.2. Two tigers showing unique stripe patterns based on right flanks

Plate 5.3 and 5.4. Two tigers showing unique stripe patterns based on left flanks

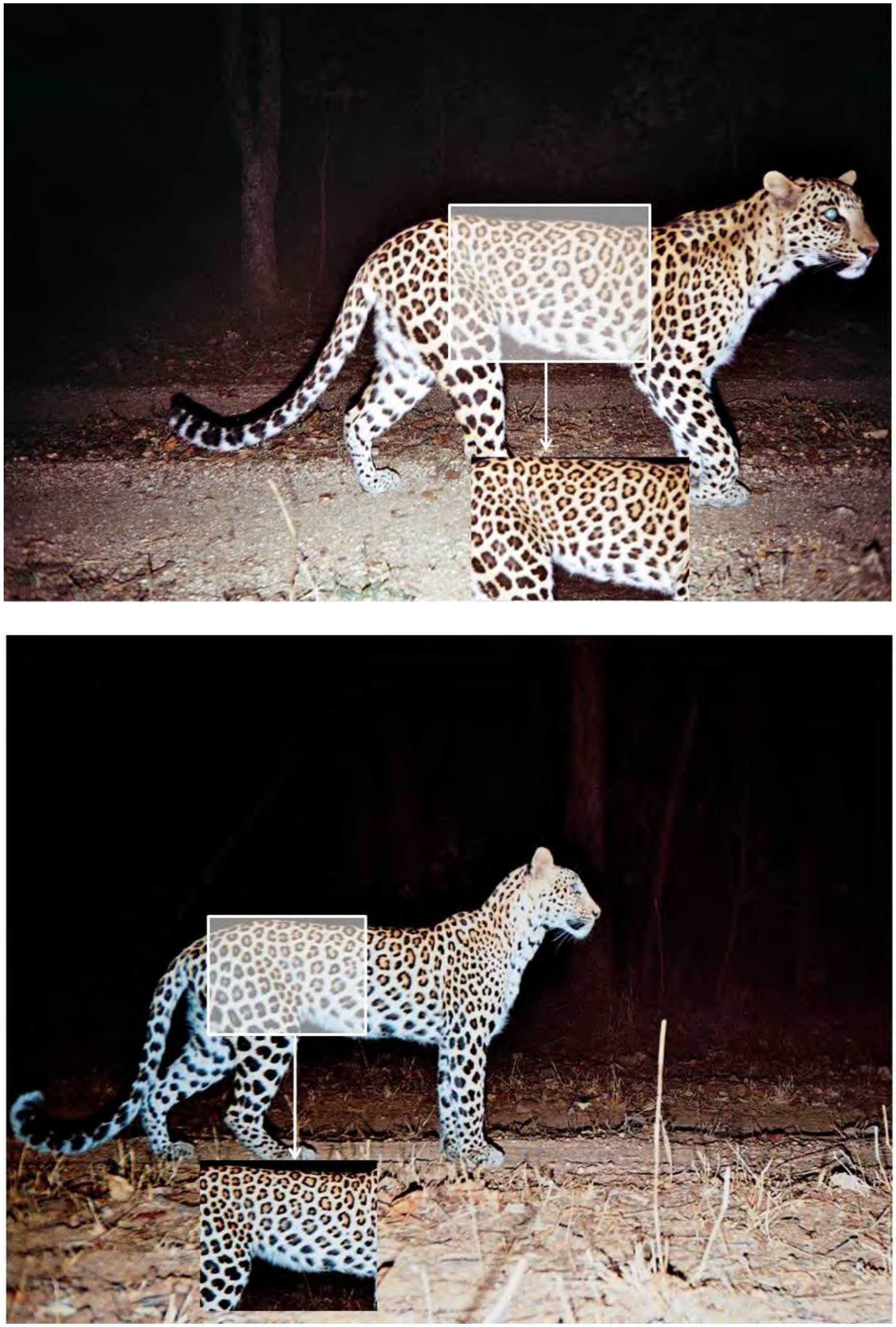


Plate 5.5 and 5.6. Two leoprads showing unique rosette patterns based on right flanks

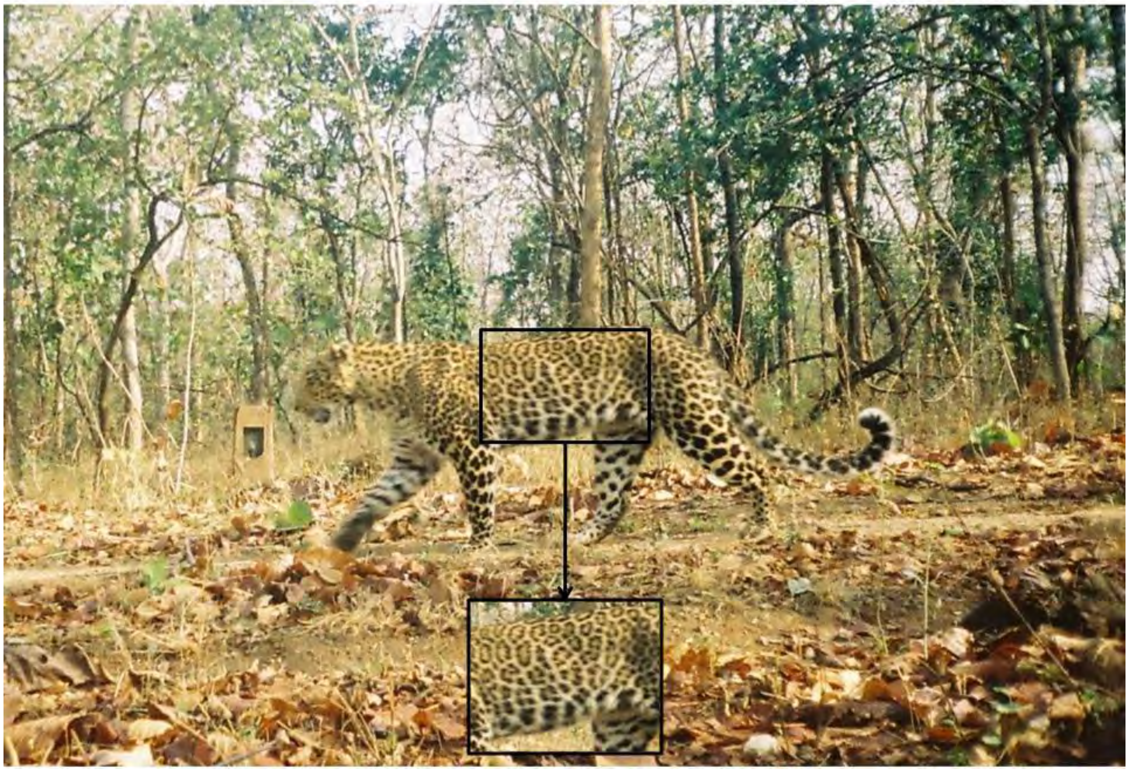
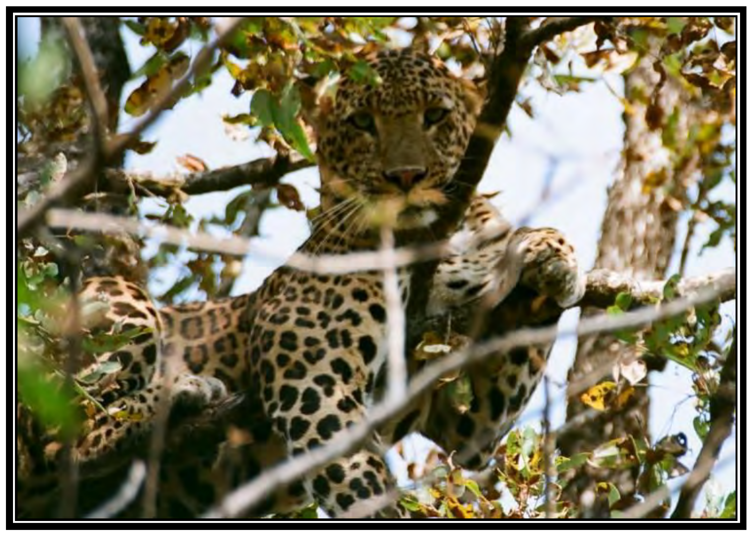


Plate 5.7 and 5.8. Two leoprads showing unique rosette patterns based on left flanks

Chapter 6



Chapter 6

SPATIO-TEMPORAL UTILIZATION OF AVAILABLE HABITATS BY TIGER, LEOPARD AND DHOLE

6.1. Introduction

Habitat loss and fragmentation are two of main challenges in conservation and management of large carnivore worldwide (Peyton 1999; Tirira *et al.* 2001). Habitat fragmentation can result in small, isolated populations which become increasingly vulnerable to extinction (Diamond 1986; Wilcove 1987). Fragmentation has reduced influences on these species who are generalized (Virgo´s 2002; Virgo´s *et al.* 2002), whereas specialists are more affected by fragmentation and thus have difficulty maintaining minimum viable populations (Beier 1993; Maehr and Cox 1995; Lidicker and Koenig 1996). Animals generally select habitats that satisfy their demands for energy, water, and resting sites to optimize survival and reproduction (Boyce and McDonald 1999; Chamberlain *et al.* 2002). Though, several hypotheses have been proposed to explain the coexistence pattern of these sympatric carnivores in forested habitat (Karanth and Sunquist 1995), a comparison of habitat use by sympatric species allows an assessment of their interactions.

In India, tiger, leopard and dhole were found to be utilized a wide range of habitats (Johnsingh 1983; Edgaonkar 2008; Jhala 2008, 2010; Ramesh 2010). Conservation of habitat of these sympatric carnivores in the human dominated landscape of India has always been a challenging task for many wildlife managers (Wikramanayaeke *et al.* 1998) as their habitats have been fragmented because of biotic and abiotic pressure (Qureshi *et al.* 2006; Jhala *et al.* 2008). In order to develop an effective conservation strategy for protecting habitat of those carnivores, it is often essential to know their detailed habitat requirements. In this chapter I examined the seasonal utilization of different habitats by these three sympatric carnivores and their spatio-temporal segregation as a part of resource utilization pattern in the study area from June 2006 to April 2011, in winter and summer.

6.2. Method

The available habitat resources of the study area was divided in to three major categories: 1) Land use and land cover, 2) Canopy cover and 3) Elevation types

6.2.1. Evaluation of habitat categories using Remote Sensing and GIS

Land use and land cover of the study area was classified from Indian Remote Sensing Satellite imagery (IRS-ID/LISS III) on a 1:50,000 scale with four bands (blue, green, infrared and near infrared) into six broader land use and land cover types using a combination of unsupervised, supervised (Schowengerdt 1983) and ground validation methods. The following six major land use and land cover types were identified in the intensive study area: submergence, riverine, miscellaneous, agriculture, barren land and *teak*-mixed.

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.

6.2.2. Habitat selection by tiger, leopard and dhole

The chi-square test was used to determine whether there is a significant difference between the "expected" and actual utilization of habitat (Zar 1984). When a statistically significant difference was observed between the utilization and availability of the habitat types, it was further investigated using Bonferroni confidence interval (Neu *et al.* 1974) to determine which habitat types were being preferred over the others. The Bonferroni probability statements hold without reference to the initial significance of the chi-square test or whether or not it has been conducted. The chi-square and Bonferroni procedures involve count (enumeration) data; the biologist needs to find the observed number of instances of use and the "expected" number of occurrences based upon the known availability of habitat types in the field (Byers and Steinhorst 1984). 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). The index “- - “, “++” and “**” provided the basis for ranking the relative habitat preference by all three carnivores for different habitat categories.

6.2.3. Utilisation of different habitat classes

Direct and indirect (i.e. carnivore sign survey; >750 km during winter and >800 km during summer and camera trap data) locations of tiger, leopard and dhole in winter and summer were analyzed to evaluate temporal use of vegetation classes by these three carnivores. In total 1,303 locations were collected during winter and 2,238 locations during summer for tiger followed by 362 locations in winter and 608 locations in summer for leopard and 264 locations in winter and 324 locations in summer for dhole. Their locations were plotted on the classified landuse and landcover map. Landuse and landcover type used by these three carnivores was estimated as the percent numbers of locations in each vegetation class as suggested by Aebischer *et al.* (1993) and White and Garrot (1990). Fifteen hundred random points were generated using Arc GIS 9.2 with in the Intensive study area of 100% MCP to determine the available landuse and landcover characteristics. Distribution of tiger, leopard and dhole signs were plotted on the land use and land cover map (Fig. 6.1, 6.2. and 6.3) to understand their utilization pattern. The observations were summarized for different landuse and landcover class categories.

Following the same methodology, utilzation of different canopy classes (Fig. 6.4, 6.5 and 6.6) and elevation classes (Fig. 6.7, 6.8 and 6.9) by all three carnivores were studied in the study area.

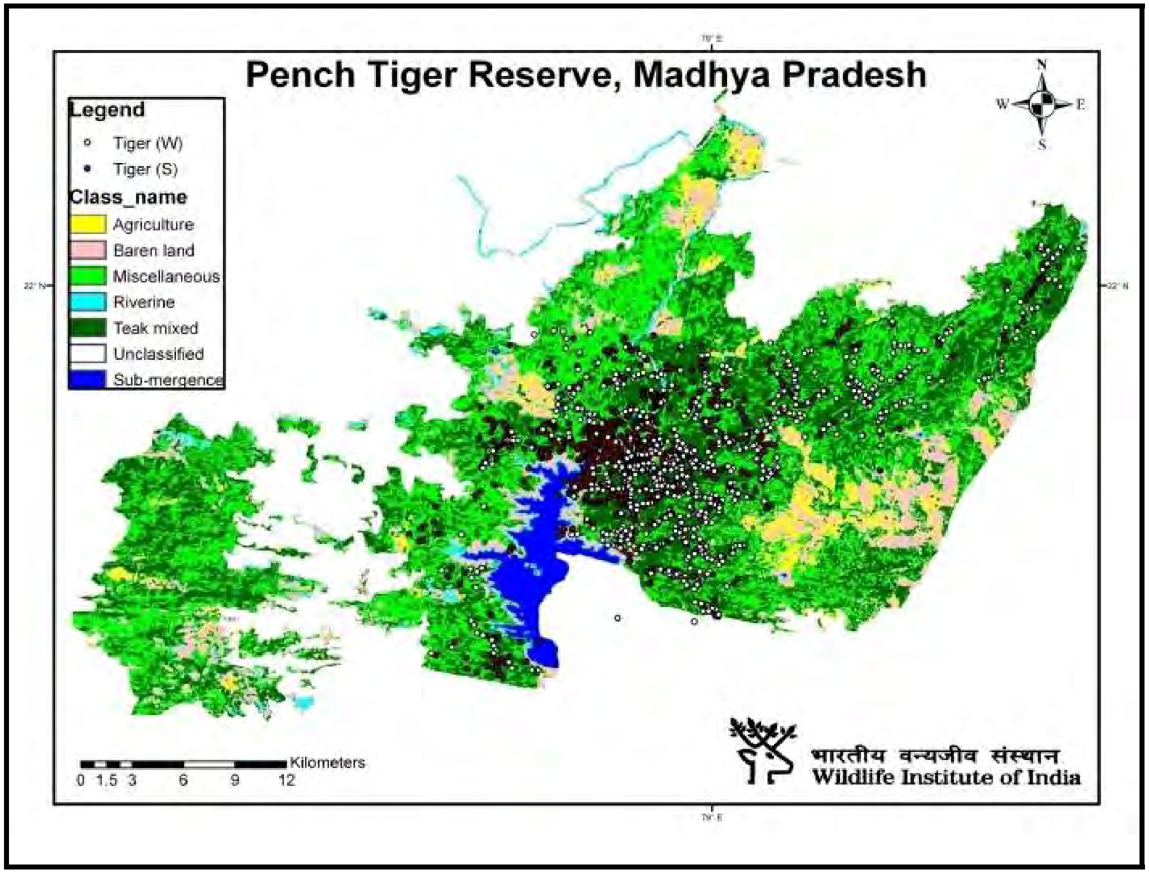


Fig 6.1. Distribution of tiger signs in different land use and land cover classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

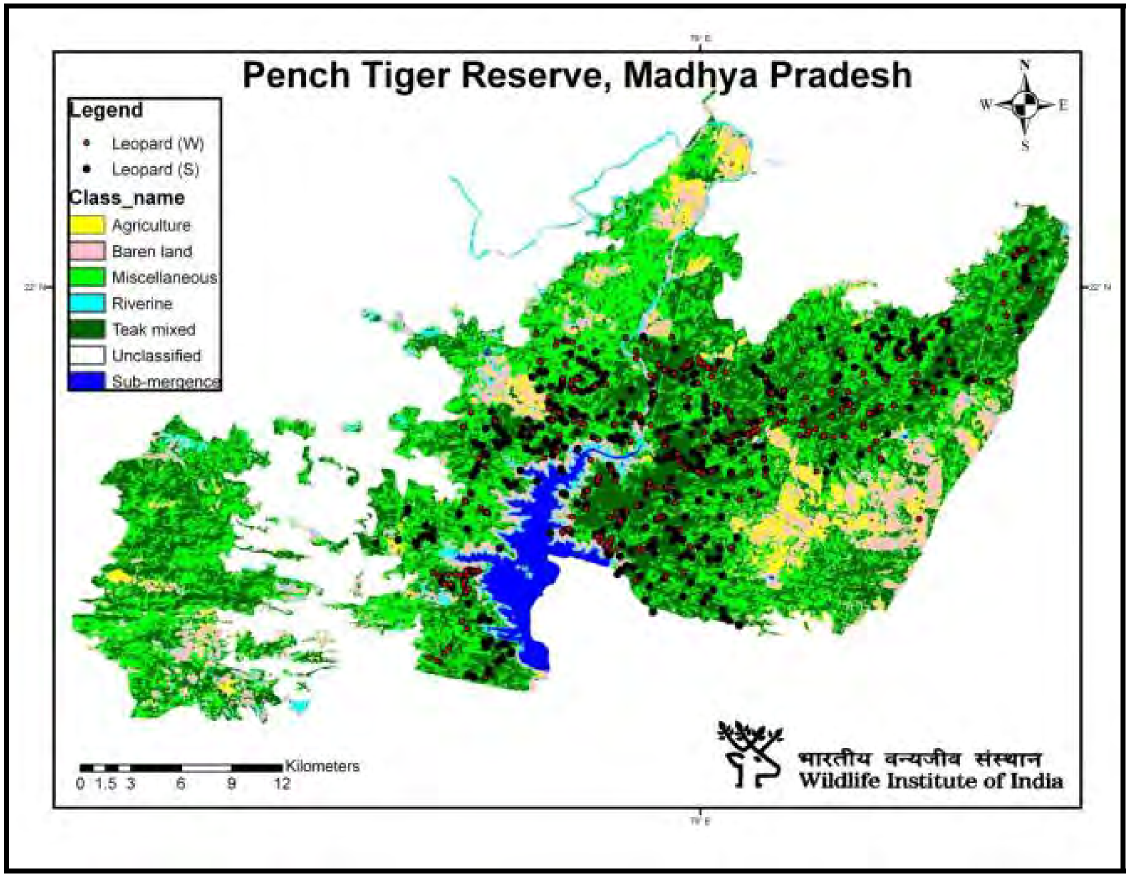


Fig. 6.2. Distribution of leopard signs in different land use and land cover classes of Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

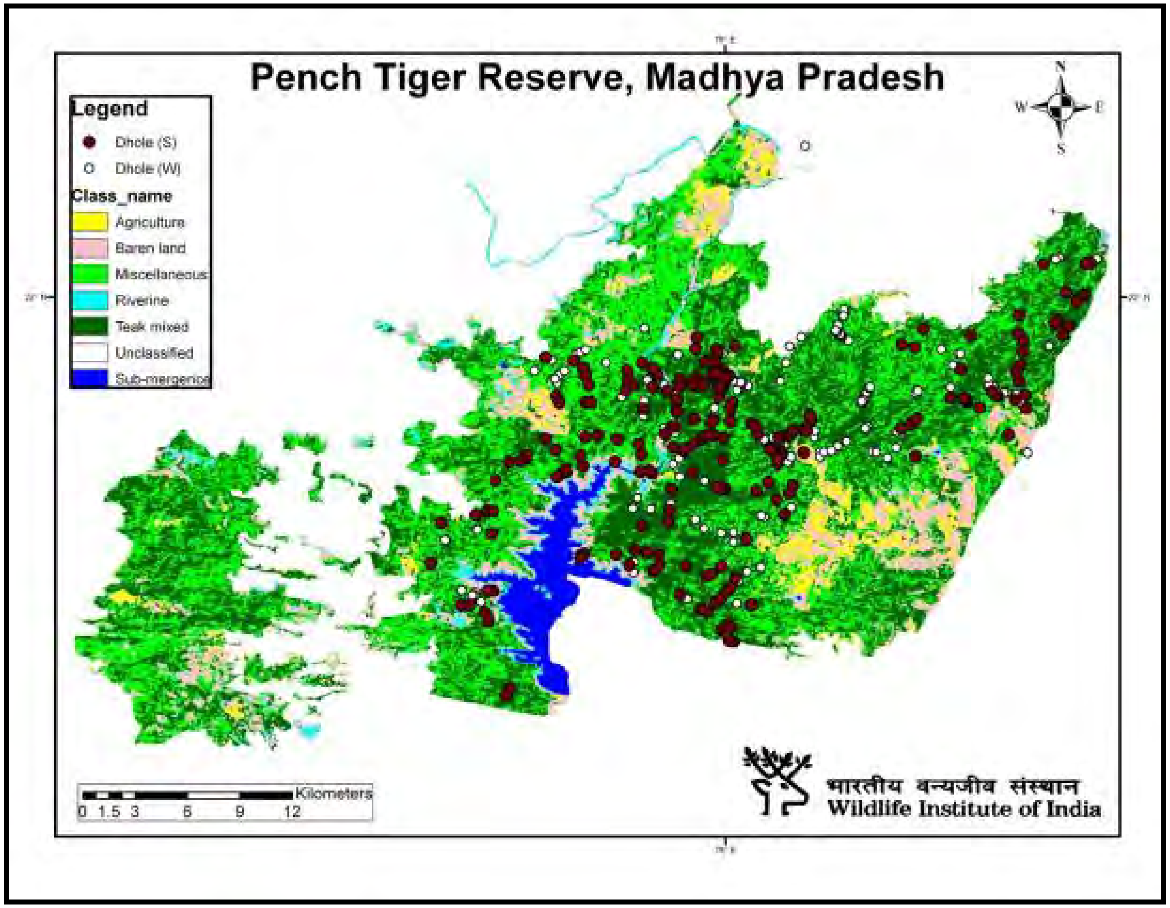


Fig. 6.3. Distribution of dhole signs in different land use and land cover classes of Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

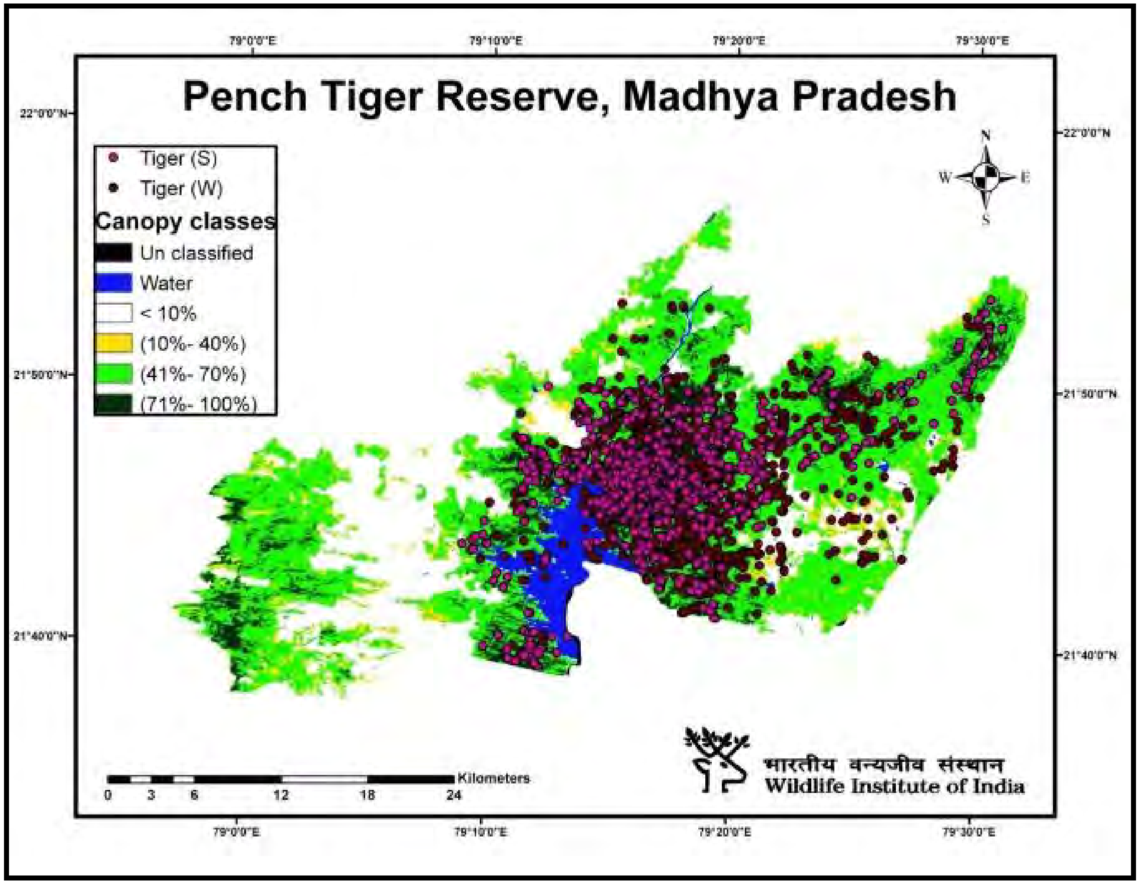


Fig.6.4. Distribution of tiger signs in different canopy classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

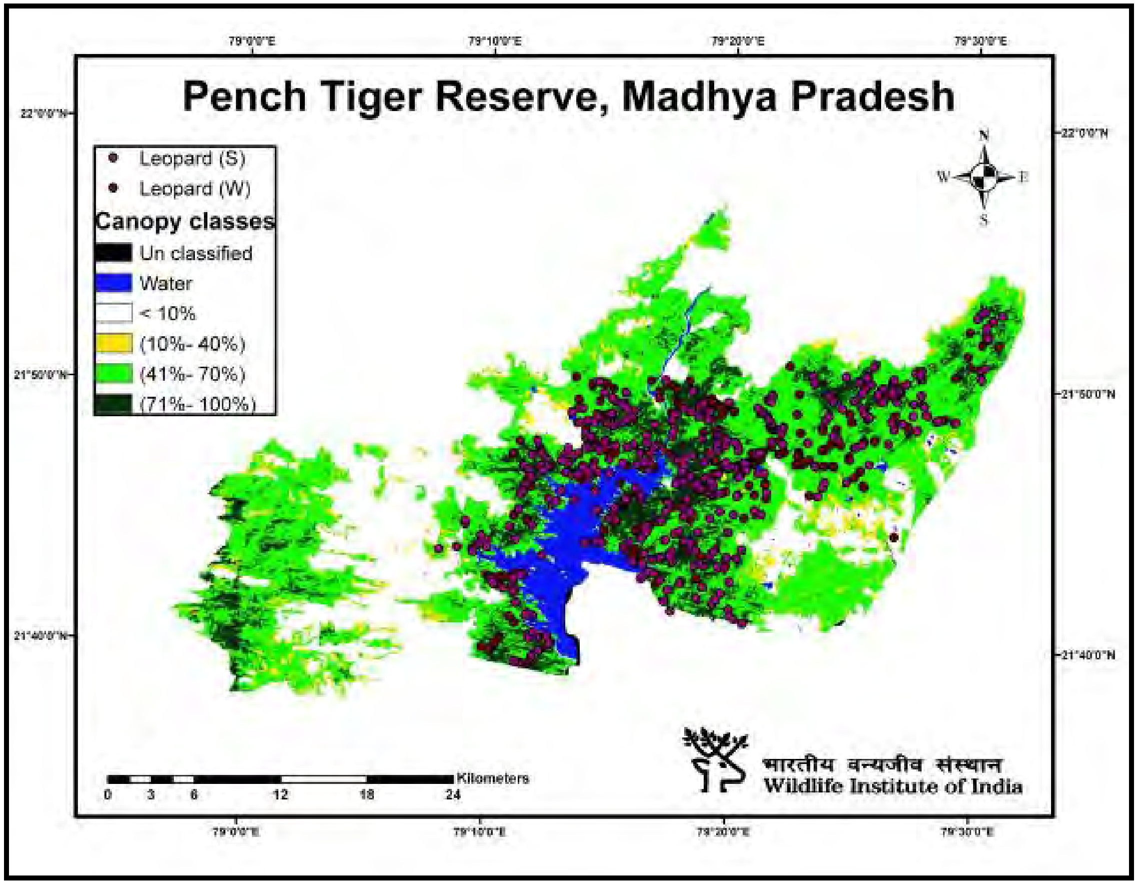


Fig. 6.5. Distribution of leopard signs in different canopy classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

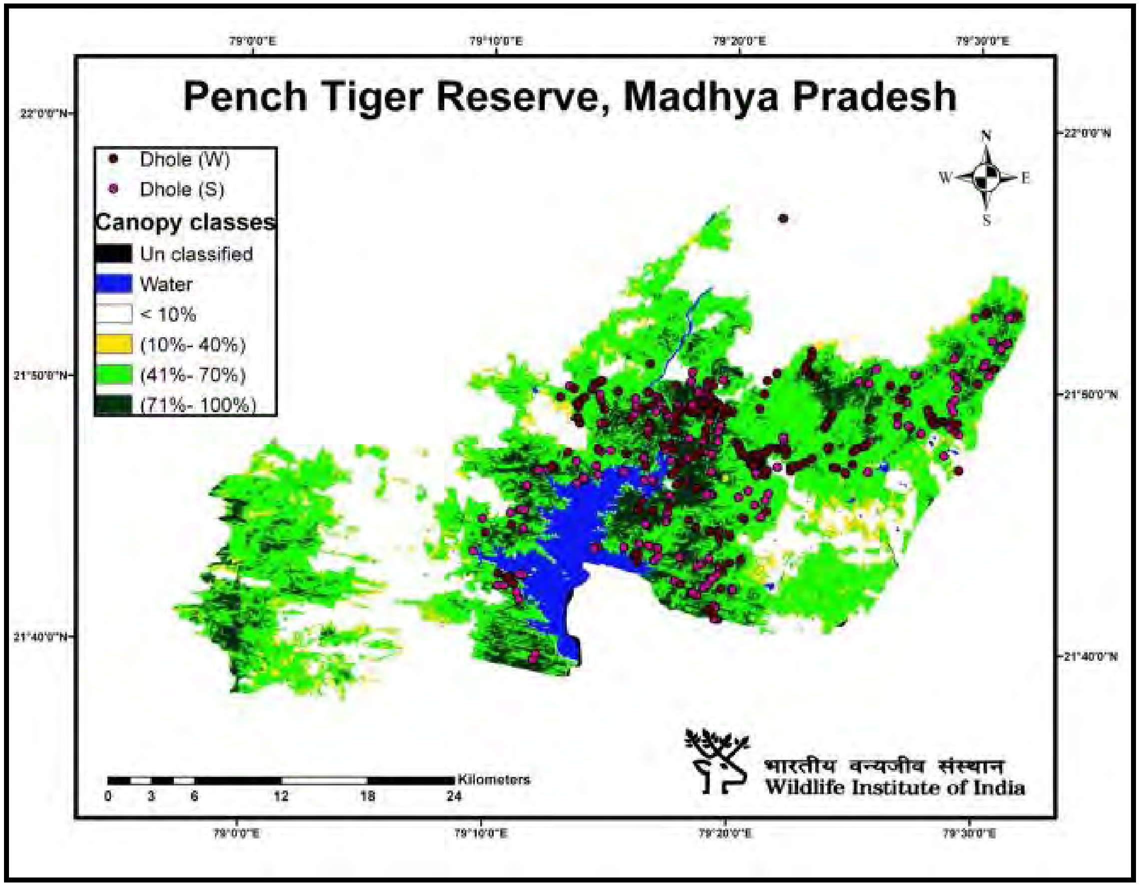


Fig. 6.6. Map showing distribution of dhole signs in different canopy classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

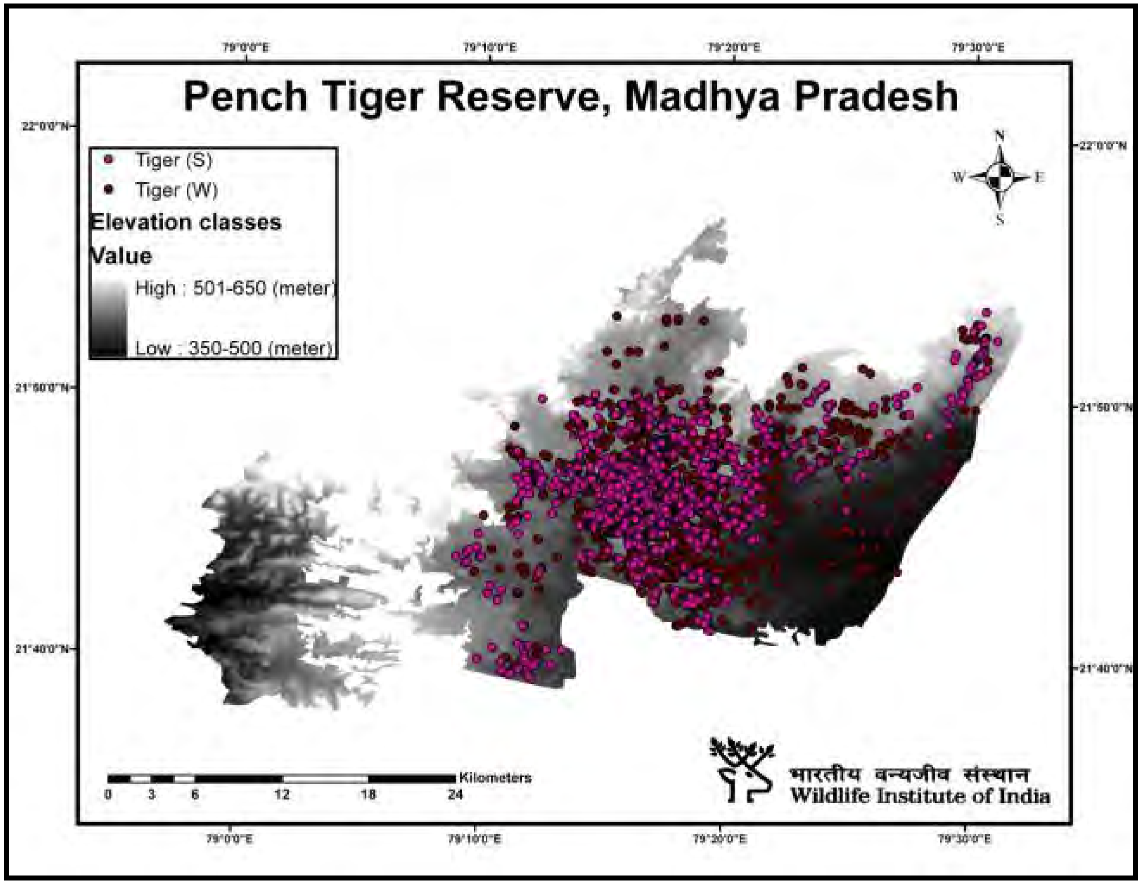


Fig. 6.7. Distribution of tiger signs in different elevation classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

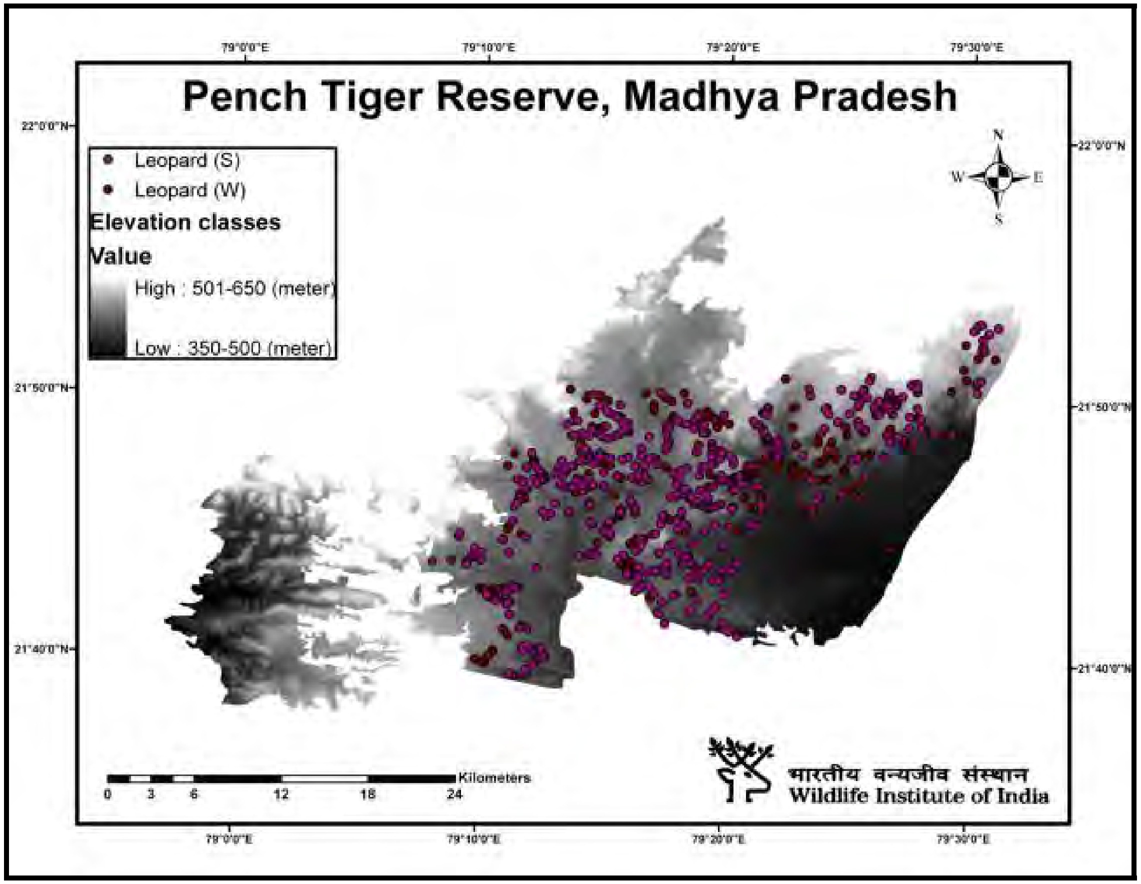


Fig. 6.8. Distribution of leopard signs in different elevation classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

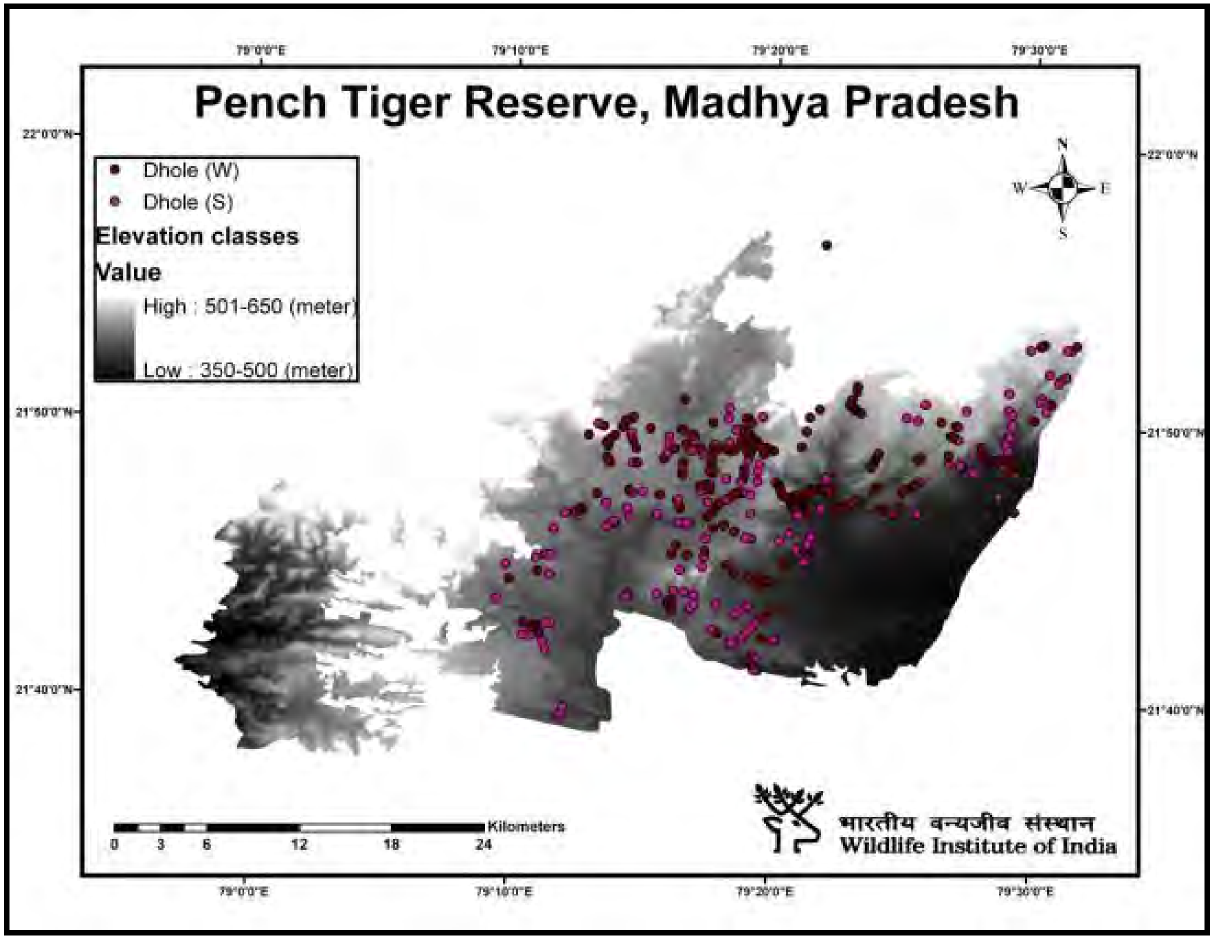


Fig. 6.9. Distribution of dhole signs in different elevation classes in Pench Tiger Reserve, Madhya Pradesh in winter (W) and summer (S), (2006 to 2011).

6.2.4. Spatial segregation of habitat resources by tiger, leopard and dhole

To understand whether any significant difference occurred between these three sympatric carnivores while utilizing particular habitat types, G-test (Zar 1984) was done.

6.2.5. Temporal activity patterns of tiger, leopard and dhole

Information on temporal activity pattern was obtained from camera trap data. The study areas was divided into 2 x 2 km^2 grids and in each grid pair of self-triggered analog cameras were deployed. In total 52 pairs of cameras were run continuously for 24 hrs period between January and June 2008- 2009 for two successive years. The cameras were equipped with 35 mm lens which recorded the date and time of each photographs. The camera delay was kept at minimum (15 seconds) and sensor activity was set as high. I maximized the 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 photo-capture of identified individuals of tiger, leopard and dhole, their total were pooled into different time categories: 06:01– 10:00 hrs; 10:01–14:00 hrs; 14:01–18:00 hrs; 18:01–22:00 hrs; 22:01-02:00 hrs and 02:01-06:00 hrs. I performed Watson U^2 test (Eisenberg and Seidensticker 1976; Mardia and Jupp 2000) in Oriana Version 3 (Kovach Computing Services) to evaluate the difference of time activities between the predator species. No significant ($p<0.005$) difference was observed between their seasonal activity patterns and hence the data was pooled and the temporal activity patterns were analyzed species wise for two years.

6.3. Results

6.3.1. Tiger

Land use and land cover: It was observed that the expected number of tiger signs (total of all types of signs) in each land use and land cover type, differed significantly from the occurrence of different landuse and landcover categories within the study area in winter (χ^2 = 18.3, df = 5, p = 0.002) as well as in summer (χ^2 = 24.6, df =5, p=0.0001).

It was observed that, during winter, tiger used *teak*-mixed forest more than its availability, riverine and miscellaneous forests were used in proportion to their availabilities, whereas submergence, agriculture and barren land were used less than their availabilities. In summer, tiger used riverine and submergence forest habitat more than their availabilities, barren land and teak-mixed forest types were used in proportion to their availabilities, whereas both agriculture and miscellaneous forest types were used less than their availabilities.

Canopy : It was observed that the expected number of tiger signs in each canopy classes differed significantly from the occurrence of different canopy classes within the study area in winter (χ^2 = 38.5, df = 3, p = 0.00001) as well as in summer (χ^2 = 39.9, df =3, p=0.00001).

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.

Elevation : It was observed that the expected number of tiger signs in each elevation type did not differ significantly from the occurrence of different available elevation types within the study area in winter (p = 0.16) but differed significantly in summer (p= 0.03).

It was observed that both in winter and summer, tiger used high elevation class (500 m – 650 m) more than its availability whereas low elevation type was utilized less than its availability.

6.3.2. Leopard

Land use and land cover : It was observed that the expected number of leopard signs in each landuse and landcover type differed significantly from the occurrence of different land use and land cover categories within the study area in winter ($\chi^2 = 21.2$, df = 5, $p = 0.0007$) as well as in summer ($\chi^2 = 14.8$, df =5, p=0.01).

It was observed that, during winter, leopard used both *teak*-mixed and miscellaneous forest more than their availabilities, used barren land and riverine forest less than their availabilities, whereas no signs of leopard were obtained from submergence area and agricultural land. In case of summer they used *teak*-mixed forest more than its availability; miscellaneous forest was used as proportion to its availability and whereas riverine, agriculture land, barren land and submergence area were utilized less than their availabilities.

Canopy : It was observed that the expected number of leopard signs in each canopy classes differed significantly from the occurrence of different canopy classes within the study area in winter ($\chi^2 = 18.6$, df = 3, $p = 0.0003$) as well as in summer ($\chi^2 = 38.1$, df =3, p=0.00001).

It was observed that, during winter, leopard used both 40% to 70% (moderately dense) and 70% to 100% (very dense) canopy classes more than their availabilities. In summer leopard used 70% to 100% (very dense) canopy class more than its availability; 40% to 70% (moderately dense) canopy class was used in proportion to its availability and both < 10% and 10% to 40% canopy classes were utilized less than their availabilities.

Elevation : It was observed that the expected number of leopard signs in each elevation type did not differ significantly from the occurrence of different elevation type within the study area in both winter (p = 0.55) and summer (p=1.06).

It was observed that in both winter and summer, leopard used high elevation class (500 m- 650 m) less than its availability whereas low elevation class (350 m- 500 m) was used more than its availability.

6.3.3. Dhole

Land use and land cover : It was observed that the expected number of dhole signs in each landuse and landcover type, differed significantly from the occurrence of different land use and land cover categories within the study area in winter (χ^2 = 18.2, df = 5, p = 0.002) as well as in summer (χ^2 = 16.3, df = 5, p = 0.005).

It was observed that, during winter, dhole used both barren land and *teak*-mixed forest more than their availabilities, riverine and miscellaneous forest in proportion to their availabilities, whereas no dhole signs were obtained from submergence area and agricultural land. In summer, dhole used *teak*-mixed forest more than its availability, riverine and miscellaneous forest in proportion to their availabilities, barren land, agricultural land and submergence areas were utilized less than their availabilities.

Canopy : It was observed that the expected number of dhole signs in each canopy classes differed significantly from the occurrence of different canopy classes within the study area in winter (χ^2 = 21.9, df = 3, p = 0.00001) as well as in summer (χ^2 = 38.6, df = 3, p = 0.00002).

It was observed that, during winter, dhole used both canopy cover 40% to 70% and 70% to 100% more than their availabilities, whereas canopy cover < 10% was used less than its availability and no signs of dhole was observed in canopy classes 10% to 40%. In case of summer, dhole used canopy class 70% to 100% (very dense forest) more than its availability, 40% and 70% (moderately dense) in proportion to its availability, whereas both canopy classes of < 10% (non-forest) and 10% to 40% (open forest) were utilized less than their availabilities.

Elevation: It was observed that the expected number of dhole signs in each elevation type did not differ significantly from the occurrence of different elevation type within the study area during winter (p = 0.19) and summer (p = 0.79). It was observed that during winter and summer, dhole used both high and low elevation types in proportion to their availabilities.

Table 6.1. Utilization of different land use and land cover types by tiger, leopard and dhole 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	*
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	++

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

Table 6.2. Tree canopy cover used by tiger, leopard and dhole 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	++
Leopard	Non Forest	<10 %	136	0.115	3	0.008	-0.004	0.021	--	4	0.007	-0.004	0.018	--
	Open	10%-40%	67	0.057	1	0.003	-0.004	0.010	--	0	0.000	0.000	0.000	--
	MDF	40%-70%	750	0.635	257	0.728	0.669	0.787	++	340	0.592	0.541	0.644	**
	VDF	70%-100%	229	0.194	92	0.261	0.202	0.319	++	230	0.401	0.350	0.452	++
Dhole	non Forest	<10 %	136	0.115	2	0.008	-0.001	0.017	--	5	0.016	-0.002	0.034	--
	Open	10%-40%	67	0.057	0	0.000	0.000	0.000	--	0	0.000	0.000	0.000	--
	MDF	40%-70%	750	0.635	181	0.693	0.622	0.765	++	177	0.575	0.504	0.645	**
	VDF	70%-100%	229	0.194	78	0.299	0.228	0.370	++	126	0.409	0.339	0.479	++

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

Table 6.3. Utilization of different elevation types by tiger, leopard and dhole 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	++
	Low	350-500	703	0.455	182	0.501	0.472	0.530	++	296	0.486	0.457	0.515	++
Leopard	**High**	501-600	843	0.545	181	0.499	0.470	0.528	--	313	0.514	0.485	0.543	--
	Low	350-500	703	0.455	117	0.437	0.377	0.496	**	144	0.442	0.382	0.502	**
Dhole	**High**	501-600	843	0.545	151	0.563	0.504	0.623	**	182	0.558	0.498	0.618	**

--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

6.4.1. Spatial segregation by **tiger, leopard and dhole**

Land use and land cover types: Significant differences were observed between tiger, leopard and dhole while comparing their utilization pattern of same landuse and landcover type during winter (p = 0.0001) and summer (p = 0.01) (Table 6.4).

Table 6.4. Spatial segregation among three carnivores in summer and winter while utilizing differnt landuse and landcover types at Pench Tiger Reserve, (May 2006 to April 2011)

G-Test statistics	**Winter**	**Summer**
G- adjusted	29.04	21.7
G-Critical	12.6	18.3
p-value	0.0001	0.01
Degree of freedom	6	10
Error report	No errors encountered	No errors encountered

Canopy classes: There was a significant difference observed while utilizing different canopy classes by all three carnivores during winter (p = 0.001) but no significant difference (p = 0.754) was observed during summer (Table 6.5).

Table 6.5. Spatial segregation among three carnivores in winter and summer while utilizing different canopy classes at Pench Tiger Reserve, (May 2006 to April 2011)

G-Test statistics	**Winter**	**Summer**
G- adjusted	17.735	1.8959
G-Critical	9.487	9.487
p-value	0.001	0.754
Degree of freedom	4	4
Error report	No errors encountered	No errors encountered

Elevation types: No significant differences was observed in both winter ($p = 0.2$) and summer ($p = 0.08$) while utilizing high and low elevation types by all three carnivores (Table 6.6).

Table 6.6. Spatial segregation among three carnivores in summer and winter while utilizing different elevation types at Pench Tiger Reserve, (May 2006 to April 2011)

G-Test statistics	**Winter**	**Summer**
G- adjusted	3.201	4.839
G-Critical	5.991	5.991
p-value	0.201715	0.088936
Degree of freedom	2	2
Error report	No errors encountered	No errors encountered

6.4.2. Temporal activity patterns

Eight thousand five hundred and sixty camera-trap days revealed 209 tiger captures, 102 leopard captures and 39 dhole captures. Tiger and leopard had two temporal activity peaks; in the evening (18:01- 22:00 hrs) and early morning (02:01 – 06:00 hrs and dhole had two activity peaks, in the morning (06.01-10.00hrs) and afternoon (14.01-18.00 hrs) (Fig 5.18). It was observed that tiger and dhole ($U^2 = 0.955$, $P<0.001$) and leopard and dhole ($U^2 = 0.553$, $p<0.001$) showed significant difference in temporal activity while tiger and leopard ($U^2 = 0.184$, $p>0.05$) had no significant difference in the same.

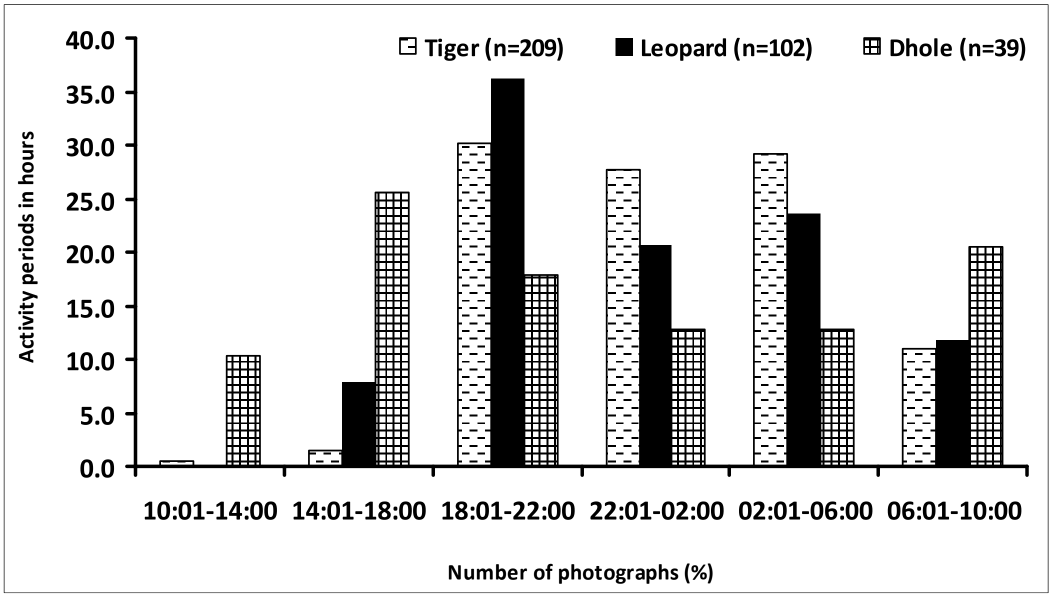


Fig. 6.10. Tiger, leopard and dhole temporal activity patterns in Pench Tiger Reserve, as determined by camera trap data (January-June 2008 and 2009).

6.5. Discussion

Broad-scale relationships between habitat and animals have long been recognized. The classic *life zone* concept of Merriam (1898) used temperature boundaries to describe the limits of major vegetation associations (life zones) and their associated animal species.

It was revealed that habitat used by three carnivores was selective, and the pattern of selection differed between seasons. These seasonal differences suggested that habitat selection changed over time, and that our assumption of constant selection within a season was examined more closely. The present study supported the findings of earlier studies in Indian sub-continent that large carnivore prefer thick forested habitat for their different biological activities (Seidensticker 1976a; Biswas and Sankar 2002; Edgaonkar 2008; Jhala *et al.* 2008). During the present study signs of all three species were mostly observed in teak-mixed and miscellaneous forests (together >90%) during summer and winter. Seidensticker's (1976a) finding in a deciduous forest habitat of Nepal revealed that tiger and leopard used extensively overlapping areas in the riverine forest/tall grass type. In PTR, especially during summer, tiger largely used riverine and submergence areas as compared to leopard and dhole.

During summer, both submergence (>60 km²) and riverine habitats were favoured by chital, which is one of the major prey species of tiger, due to the availability of *Cynodon dactylon* grass (Biswas and Sankar 2002). Another probable reason was the availability of *Lantana* in both sides of the submergence areas of Pench River as cover. Since Pench is predominantly a dry deciduous forest, most of the trees become leafless during summer, thus *Lantana* plays as a green gave for carnivores, different hervivores and ground dwelling birds in the study area. Tiger largely utilized this type of habitat during the time of raising cubs. All three species avoided agricultural habitat present in the fringes of forest boundary. Few signs of tiger that were observed in this type of habitat might be because of their large ranging pattern. Tiger used agricultural and poorer habitat especially during the time of their dispersal as observed by Smith (1993) in Nepal. The rocky and barren land used by dhole more than their availabilities during winter may be due to denning and rearing pups as reported by Acharya *et al.* (2007). Though submergence area is one of the important habitats of chital during summer and chital is also one of the major preys for leopard and dhole, both of them used this habitat less than its availability may be to avoid compitition with tiger which is comparatively larger body sized. Although, the study area falls mostly under tropical dry deciduous forest (Champion and Seth 1968), not all plant species (tree and shrub) become deciduous at the same time and some parts of the study area remain with green foliage through out the year.

Results of the present study showed that, while utilizing different elevation types, though these three carnivores did not differ significantly, in winter and summer, tiger used high elevation more than its availability and low elevation less than its availability, whereas leopard utilized high elevation less than its availability but low elevation was used more than its availability. Since majority of the study area comes under gently undulating terrain and the elevation is also not considerably very high, the observed spatial segregation by leopard while utilizing different elevation types might be to avoid inter-specific conflict with tiger.

Tiger and dhole, leopard and dhole showed a significant difference (p <0.05) in temporal activity while tiger and leopard had no significant difference (p > 0.05) in the same. The variation in temporal activity patterns among these large carnivores may largely lie in utilization of habitat resources and to avoid competition in different times (hours) of a day (leopard being nocturnal, tiger crepuscular and dhole diurnal) (Johnsingh 1992). Though behavioral and morphological differences permitted tiger, leopard and dhole to partition the use of habitats and prey, but temporal variation in their activity patterns influenced the selection and degree of overlap of resource use. Since the remotely trigerred camera traps were used in the entire study area and run for 24 hours basis without disturbing the animals, offered a large scale picture to understand their temporal separation. Seidensticker (1976a) observed that both tiger and leopard were active throughout the diel cycle and moved less during the midday period than in the morning or evening in the Chitwan National Park, Nepal. Radio-telemetry studies in Chitwan and Nagarhole (Sunquist 1981; Karanth and Sunquist 2000) showed that tigers moved around a lot more during night (80% of locations) compared to mid day (10% locations). Acharya *et al.* (2007) reported diurnal activity of dhole using radio-telemetry in PTR. Sunquist (1981) found that tigers are mostly active during night. Another study based on the time of photographic captures by Kawanishi (2002), revealed that both tigers and leopards were more diurnal than nocturnal and there was considerable overlap in their temporal activity. As captures of dholes were excluded because of low sample size, temporal variations between all three carnivores were not compared in her study.

The results highlighted both the potential and the difficulties involved in multispecies conservation planning as all three carnivores showed plasticity to remain in different forested habitat of PTR, segregating spatially with each other. This observed spatial segregation between these carnivores to reduce inter-specific competition may be influenced in their co-existence in the study area. The study clearly suggested that effective wildlife conservation is necessary for the management of adjacent forest patches of PTR, as the observed spatial variation in all three carnivores' among the different forested habitats may indicate continuous movements of those species even outside this reserve. PTR is connected with Kanha Tiger Reserve in north east and PTR of Maharastra in south (Sankar *et al.* 2000) and hence the continuous monitoring of these habitats using comparable scientific method is equally crucial for the long term survival of large carnivores in the central Indian Landscape.

6.6. Management recommendations:

The findings of the present study will be useful in strengthening the conservation of large 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 large carnivores and their prey in the study area which should be effectively utilized for conservation of entire Pench landscape.
- The present study provided information on the demographic structure of potential prey species of large carnivores 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.

- Among all prey species, chital plays an important role to structure the diet of all three carnivores. They were mostly found in the sub-mergence habitat of the study area for grazing. The weed species such as *Datura metel, Parthenium sp.* and *Cassia tora* found along the sub-mergence area should be eradicated on a regular basis to allaow the establishment of the *Cynodon dactylon* grass the most palatable grazing fodder for all ungulates. Based on the findings from the present study the Pench Tiger Reserve harbours significant populations of wild ungulates and also protects a diverse wild ungulate species and their habitat and hence PTR should be considered as one of the key areas for the conservation of ungulates in South- East Asia.
- 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 and leopard for hiding kills and rearing cubs.
- Pench's carnivore population forms a major source population to the surrounding forested areas. Ecological monitoring in the adjacent forest areas of Pench National Park and Sanctuary is equally important for long term survival of these carnivores in the entire landscape.
- Apart from carnivores and herbivores, Pench, also harbours a large number of *Gyps* vultures species, one of the major scavengers in this ecosystem. Their population, chick survival and breeding habitat also need to be monitored on a long-term basis.

Plate 6.1. The submergence area of Pench reservoir

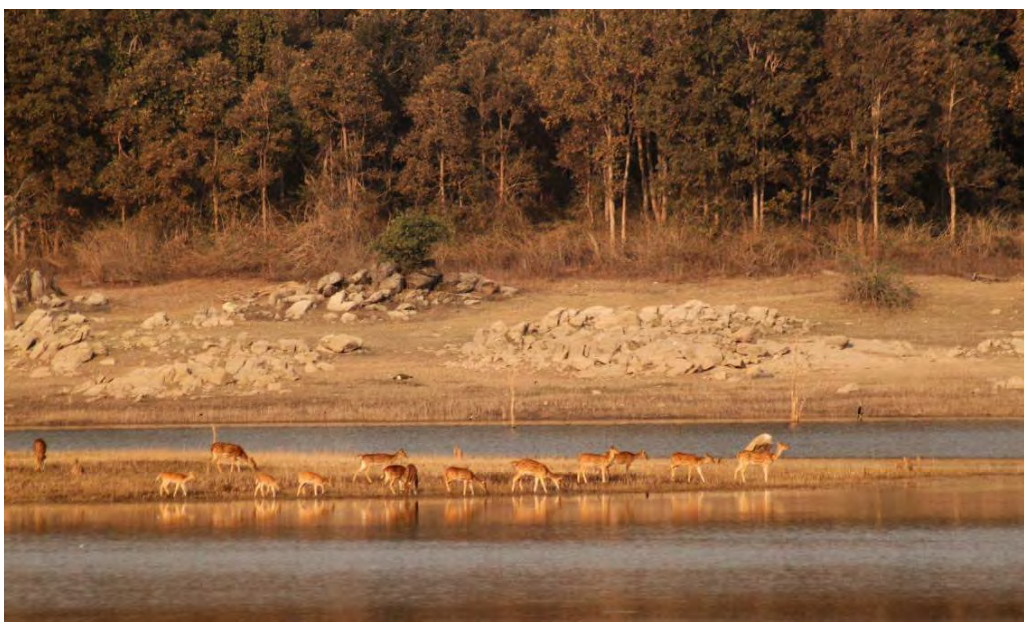


Plate 6.2. Dry- Riverine forest

Plate 6.3. Moist-Riverine forest

Plate 6.4. Teak-mixed forest

Plate 6.5. Miscellaneous forest

Plate 6.6. A breeding den of tiger

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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"
Bison Camp	2.8	N21° 45' 56.5"	E079° 19' 18.6"	N21° 46' 04.8"	E079° 19' 22.5"

Transect	Transect Length (Km)	Starting Lat	Starting Long	Ending Lat	Ending Long
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 (n=81) in Pench Tiger Reserve Madhya Pradesh, 2011

Camera id	Place	Lat	Long
K2	Powerjhiria talab	21.7503	79.3211
K4	Pipal nallah	21.7547	79.3075
K3	Kalapahar handpump	21.7534	79.2919
K9	Sapat purana camp	21.7526	79.2425
K10	Dourikund road	21.7583	79.2756
K11	Hati pakdandi	21.7481	79.2616
K7	25 no Stop Dam	21.7420	79.3109
K8	Piorthadi hatipakdandi	21.7277	79.2734
K25	37 no pad Raiakassa	21.8050	79.2952
K24	Sitaghat diek tirha	21.7917	79.2859
K19	Sagunban	21.7665	79.3185
K20	Patdeo road	21.7741	79.3214
K22	Bansnala	21.8021	79.3293
K21	Jhandimatta road	21.7924	79.3239
K23	7 no Tuta handpump	21.7723	79.2955
K1	2 no Lantana	21.7659	79.2839
K33	36 no lantana	21.7211	79.3341
K28	Dub road Chiklakhari	21.7149	79.2705
K27	Chiklakhari handpump	21.7116	79.2894
K30	Chiklakhari road	21.7070	79.3103
K29	Beltirha,moyakatta	21.6928	79.3204
K26	Datachoupan talab	21.7212	79.3146
K14	Baramor	21.7935	79.3405
K13	Pania-billo Nalah	21.7965	79.3638
K12	Bandarchua	21.8087	79.3704
K15	Near khamreet campt	21.7628	79.3589
K18	Kharranalah	21.7490	79.3578
K17	Baghinnala tirha	21.7528	79.3372
K6	Chindimmata Camp Back road	21.7337	79.2389
K5	Sapat pakdandi	21.7336	79.2556
K32	Chiklakhari seonnala	21.7371	79.3332
K-16	Arjalmatta	21.7656	79.3276
G1	Pipal chattan	21.8168	79.2686
G3	Chitalpahari nalah	21.8226	79.2686
G7	Chendia maidan tirha	21.8215	79.2785
G8	Sitakassa raiakassa	21.8099	79.2912
G2	Shardamai chawak	21.7821	79.2801
G6	Chandiakassa	21.7993	79.2401
G5	Dhwabarra	21.8104	79.2479
G4	Golpahari tirha	21.7910	79.2620
G9	Chindwani jhirpa	21.7921	79.2324
G13	Uchakarari barwala	21.7764	79.2098
G14	Sandal kassa	21.7883	79.1878

Camera id	Place	Lat	Long
G10	Manjhori nallah	21.7661	79.1931
G11	Jt marg	21.7519	79.1888
G16	Kormatta	21.7269	79.2053
G12	Palaspani tirha	21.7349	79.1882
G17	Bagharia nalla	21.7377	79.1660
G18	Faldan	21.7312	79.1523
G19	Ambamai nalla Namak chattan	21.7032	79.1797
G15	Kailasor tirha	21.7128	79.1923
G28	Tendumor	21.6583	79.2179
G25	Kaliakamat nallah	21.6559	79.1923
G27	Amadoh road	21.6606	79.2011
G26	Bamnijhiria	21.6650	79.2129
G22	Sajwalidobri	21.6865	79.1822
G21	Nalitekri	21.6924	79.1536
G23	Dubroad pirbaba	21.6735	79.2079
G24	Mahaljhori	21.6723	79.1783
G20	Kherwan choupan	21.6873	79.1716
S1	Potimarg	21.7876	79.3853
S2	Gangerkund	21.7953	79.3972
S3	Gaighat nala- purana stop dam	21.8022	79.4082
S4	Toer talab	21.8159	79.3799
S5	Lamondoh rd	21.8248	79.4182
S6	Datachoupan	21.7861	79.4182
S7	Puranbarra tirha	21.7837	79.4296
S8	Toer talab road	21.8241	79.4354
S9	Kharona banjari khaoli	21.8261	79.4641
S10	Chindbarri chowraha	21.8119	79.3929
S11	Ruthia nala	21.8339	79.3988
S12	Dutera camp	21.8302	79.3890
S13	Dhakni tongi talab	21.8316	79.4425
S14	Garariban gandhatola	21.8513	79.4773
S15	Baheral paththar	21.8539	79.4850
S16	Bherban	21.8716	79.4963
S17	Gandhatola	21.8806	79.5029
S18	Patrai tirha	21.8363	79.4505
S19	Lavanguri	21.8431	79.4649
S20	Dudhia watch tower	21.8393	79.5032
S21	Renubai gate	21.8641	79.5188