Ecology of leopard (*Panthera pardus*) in Sariska Tiger Reserve, Rajasthan

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Dedicated to my

Dear Granny

Mrs. (Late) RaiRani Mondal

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Executive Summary

The leopard *Panthera pardus fusca* is listed as a species of near threatened by the IUCN red list. In India, this species is listed in Schedule I of the Indian Wildlife (Protection) Act, 1972, under the highest level of protection. Habitat destruction, loss of wild prey, poaching for skins, bones and claws, and poisoning carcasses of livestock killed by leopards are a significant threat to the species. As a result the geographic ranges of leopard have contracted and their populations have declined. There is an urgent need to conserve many carnivore species including leopard and the first step towards this is to obtain knowledge about their basic biology. Little is known about the conservation status of leopard in human dominated Aravalli landscape. There has long been an assumption that leopards can cope in human-dominated landscapes and persevere despite pressures such as habitat fragmentation due to their great adaptability. However, conservation scientists agree that leopards may be more vulnerable to extinction than previously thought.

The present study estimated the prey availability and prey consumption, population and survival rate and the home ranges and resource selection of leopard in Sariska Tiger Reserve. The Sariska Tiger Reserve (STR) (N27^{o}05’ to N27^{o}45’ and E76^{o}15’ to E76^{o}35’) is situated in the Aravalli Hill Range and lies in the semi-arid part of Rajasthan. It became a Wildlife Sanctuary in 1955 and Tiger Reserve in 1982. The total area of the Tiger Reserve is 881km^2, of which 273.8 km^2 is a notified National Park. The altitude of Sariska varies from 540 to 777 m. Sariska terrain is undulating to hilly in nature and has numerous narrow valleys.

The climate of this tract is subtropical, characterized by a distinct summer, monsoon, post monsoon and winter. The vegetation of Sariska falls under Northern Tropical Dry Deciduous Forests and Northern Tropical Thorn Forest. The major vegetation types are *Anogeissus* dominated forest, *Boswellia* dominated forest, *Acacia* mixed forest, *Zizyphus* mixed forest, *Butea* mixed forest, scrubland and forest and nallah.

Apart from leopard and tiger, other carnivores present are striped hyena *(Hyaena hyaena)*, jackal *(Canis aureus)*, jungle cat (*Felis chaus*), common mongoose *(Herpestes edwardsi*), small Indian mongoose (*H. auropunctatus*), ruddy mongoose (*H. smithi*) palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*) and ratel (*Mellivora camensis*). In 2009, desert cat (*Felis silvestris*) was reported from Sariska. Prey species of leopards and tigers in the area include chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), common langur (*Seminopithecus entellus*), wild pig (*Sus scrofa*), rhesus macaque (*Macaca mulatta*), porcupine (*Hystrix indica*), rufous tailed hare (*Lepus nigricollis ruficaudatus*) and Indian peafowl (*Pavo cristatus).* The predominant domestic livestock found inside the reserve are buffaloes (*Bubalis bubalis*), brahminy cattle (*Bos indicus*) and goats (*Capra hircus*). There are 10 villages located inside the National Park area which are still due for relocation since 1984. The human population is over 1700 in the villages of National Park along with a population 10,000 livestock including buffalo, cow, goat and sheep here are 21 villages located outside the National Park but within the Tiger Reserve. The human population in these villages is around 6000 and the livestock population is more than 20,000.

The present study was conducted in 274 sq. km. area which is the National Park area of Sariska Tiger Reserve for four consecutive years from 2007 to 2010 covering winter (November to February) and summer (March to June), with the following objectives:

1. To estimate the prey availability of leopard
2. To study the food habits and prey selection of leopard
3. To estimate the population of leopard and
4. To study the home range and habitat use of leopard.

Prey species density in the study area was estimated by line transect method under distance sampling technique (Burnham *et al.* 1980). The entire Sariska Tiger Reserve was sampled for prey species covering 72 beats spreaded over four ranges (Sariska, Akbarpur, Tehla and Talbriksh). Each beat contained one line transect varying in length from 1.6 km to 3 km. The line transects in Sariska range were walked thrice and rest were walked once during the year 2007. Later 32 permanent line transects varying in length from 1.6 km to 2 km were laid in the intensive study area covering 160 km^2 area of National Park of Sariska Tiger Reserve. These transects were walked three times in early morning hours for three successive years from 2008 to 2010. The total transects length in the intensive study (National Park) area was 60.4 km. Record was kept for all ungulates, primates, livestock, hare and peafowl that were seen during the walk. On each sightings of the target species, group size, age and sex composition, radial distance and sighting angle were recorded.

In total nine potential prey species were recorded on line transects. These were four ungulate species (chital, sambar, nilgai and wild pig), one primate (common langur), one small mammal (hare), two livestock (cow and goat) and one bird (peafowl). The Sariska Tiger Reserve was found to hold a high wild ungulate density i.e. 127.9 individuals/ km^2. Goat was found to be the most abundant (129.3/ km^2) prey species in the entire Sariska Tiger Reserve followed by peafowl (60.2/ km^2), nilgai (52.8/ km^2), common langur (52.4/ km^2), cattle (41.3/ km^2), wild pig (25.5/ km^2), chital (20.5/ km^2), sambar (19.1/ km^2) and hare (4.3/ km^2). In the intensive study area (Sariska National Park), the density of chital varied from 33.6/ km^2 in 2007 to 44.3/ km^2 in 2008, 40.4/ km^2 in 2009 and 12.6/ km^2 in 2010. The density of sambar varied from 26.1/ km^2 in 2007 to 25.2/ km^2 in 2008, 16.4/ km^2 in 2009 and 8.3/ km^2 in 2010. The densities of nilgai, wild pig and common langur declined in the intensive study area in the study period. The density of nilgai declined from 42.3/ km^2 in 2007 to 18.9/ km^2 in 2008, 22.7/ km^2 in 2009 and 13.5/ km^2 in 2010. The density of wild pig declined from 31.3/ km^2 in 2007 to 14.9/ km^2 in 2008, 6.7/ km^2 in 2009 and 4.1/ km^2 in 2010. Similarly, the density of common langur declined from 50.2/ km^2 in 2007 to 22.1/ km^2 in 2008, 11.4/ km^2 in 2009 and 4.3/ km^2 in 2010. The density of peafowl was recorded as 55.7/ km^2 in 2007, 121.4/ km^2 in 2008, 100.7/ km^2 in 2009 and 113.4/ km^2in 2010 in the study area. The density of hare was recorded as 0.7/ km^2, 3.5/ km^2, 1.8/ km^2 and 1.8/ km^2 in 2007, 2008, 2009 and 2010 respectively.

The prey densities estimated from the present study compared with those from other parts of the country revealed that Sariska Tiger Reserve harbors high densities of chital, sambar, nilgai and wild pig. In India both tropical dry deciduous and tropical moist deciduous forests are equally potential as a wild prey base habitat. Comparing with other dry and moist deciduous forests of the country it was observed that Sariska Tiger Reserve holds a comparable biomass density of potential wild prey species like Bandipur Tiger Reserve and Nagarhole Tiger Reserve.

In the present study, food habits and prey selection of leopard were examined during the study period following scat analysis method and kill records. Leopard scats were collected whenever encountered during the study period. Leopard scats were differentiated from that of other carnivore species on the basis of size, shape and diameter. A number of 66 scats were collected in 2007, 171 scats in 2008, 90 scats in 2009 and 82 scats in 2010. Leopard kills were recorded whenever encountered in the study area. On each leopard kill, the species were identified and its sex and age class were recorded.

In the year 2007, amongst all the prey species identified from the leopard scats, chital constituted the maximum (23.7%) followed by sambar (21.1%), rodent (14.5%), peafowl (10.5%) cattle (9.2%), nilgai (6.6%), common langur (5.3%), hare (5.3%), goat (2.6%) and porcupine (1.3%). In 2008, sambar constituted maximum (40.4%) in leopard diet followed by chital (22.4%), nilgai (11.5%), common langur (10.4%), hare (4.4%), cattle (3.8%), porcupine (2.7%), wild pig (2.2%), peafowl (1.6%) and domestic dog (0.5%). In 2009, amongst the prey species identified from the leopard scats, sambar constituted the most (45.5%) followed by chital (15.2%), nilgai (8.9%), cattle (7.1%), common langur (6.3%), peafowl (6.3%), porcupine (5.4%), hare (2.7%) and wild pig (2.7%). In 2010, sambar constituted maximum (33.7%) in leopard diet followed by chital (20.8%), cattle (11.9%), common langur (10.9%), peafowl (8.9%), nilgai (5.0.5%), rodent (4.0%), wild pig (2.0%), porcupine (2.0%) and hare (1.0%).

Overall, for the entire study period, sambar contributed maximum (35.2%) in leopard's diet followed by chital (20.5%), common langur (8.2%), nilgai (8.0%), cattle (8.0%), peafowl (6.8%), rodent (4.6%), hare (3.4%), porcupine (2.9%), wild pig (1.7%), goat (0.7%) and domestic dog (0.1%).

It was found that sambar and chital were the most preferred prey species by leopard in the study area throughout the study period. In 2007, sambar and chital were preyed more than their availability, while nilgai were preyed less than their availability. Common langur, cattle and peafowl were preyed in proportion to its availability. In 2008, sambar and chital were preyed more than their availability, while nilgai, cattle and peafowl were preyed less than their availability. Common langur was preyed in proportion to its availability. In 2009, sambar was preyed more than their availability, while cattle and peafowl were preyed less than their availability. Nilgai, chital and common langur were preyed in proportion to its availability. In the year 2010, sambar, chital and common langur were preyed more than their availability, while nilgai and peafowl were preyed less than their availability. Cattle was preyed in proportion to its availability.

In contrast to most dietary studies of leopard in India and elsewhere, results from this study showed the dominance of wild ungulates in the diet of leopard. Consumption of livestock and smaller rodents which were earlier being reported from many studies were found negligible in the diet of leopard in the study area. Leopard utilized broad diet during the study period, chital and sambar were the most preferred prey consumed while livestock (cattle and goats) and rodents were supplementary food item.

One of the most challenging issues in carnivore conservation has been the estimation of population abundance and population trend. To estimate the population of leopard, camera trapping data was collected from January 2007 to June 2010 in the study area. The entire study area was divided into two 80 km^2 blocks and each block was subdivided into 20 grids of 2x2 km^2. One pair of cameras was placed in each 2x2 km^2 grid. A total of 40 locations were selected for the placement of camera traps in the study area. Every two nights were considered as a single occasion, resulting in 44 occasions and effort of 3520 trap nights in 2007, 59 occasions and effort of 4320 trap nights in 2008, 65 occasions and effort of 5200 trap nights in 2009 and 43 occasions and effort of 3440 trap nights in 2010. The density (D) of leopard in the study area was estimated using different methods such as spatially explicit model using program DENSITY 4.1 and SPACECAP, full MMDM, half MMDM, spatially explicit Inverse

Prediction density (IP dens) and spatial maximum likely-hood density (ML dens). To estimate the survival rates of leopard in the study area, binary X matrix was used following 'Robust Design' model in program MARK.

Population estimates were calculated using model Mh by considering same camera trapping design and systematically in the same study area between 2007 and 2010. The estimate suggests that minimum 50 days of sampling is required to get reliable estimates of the population of leopard in 220 to 250 km^2 effective trapping area of Sariska National Park. The estimated population (*N*) of leopard in the study area with Mh Jacknife estimator was 22.2 ± 3.6 in 2007, 17.9 ± 3.0 in 2008, 16.3 ± 3.3 in 2009 and 9.0 ± 1.5 in 2010. The estimated densities with Mh jackknife estimator and half mean maximum distance moved model (MMDM/2) were 10.7 ± 1.8 individuals/ 100 km^2 in 2007, 7.6 ± 0.6 individuals/ 100 km^2 in 2008, 6.2 ± 0.8 individuals/ 100 km^2 in 2009 and 3.1 ± 0.4 individuals/ 100 km^2 in 2010 (table 5.4). Half normal detection function fitted the best and the densities arrived using multiple likelihood model (MLDens) were 9.3 ± 2.2 individuals/ 100 km^2 in 2007, 7.7 ± 1.9 individuals/ 100 km^2 in 2008, 5.3 ± 1.4 individuals/ 100 km^2 in 2009 and 3.3 ± 1.2 individuals/ 100 km^2 in 2010. The survival rate of leopard in the study area varied from 0.67 ± 0.11 between 2007 and 2008 to 0.58 ± 0.12 between 2008 and 2009 and 0.45 ± 0.07 between 2009 and 2010. The overall survival rate of leopard in the entire sampling period was estimated to be 0.57 ± 0.07. The estimated overall survival rate of leopard in the study area was low (57%) compared to other studies in Africa. This may be attributed to permanent or temporary emigration of leopard from the study area due to tiger re-introduction, as avoidance of competitor species apparently increases fitness of one species, which is a basic phenomenon of animal behavior.

Radio-telemetry technique was followed to estimate the home range and habitat use of leopard as this technique is found to be the most updated and useful practice to gather information on home range, daily and seasonal movement pattern of big cats. To understand the ranging pattern of leopard, two male leopards were captured from conflicted areas outside Sariska TR and released in the study area. The first male leopard (SP1) was fitted with Telonics made VHF radio-collar and released in the study area (Kalighati) on 27th March 2009. The second male leopard (SP2) was rescued from a 96 ft deep dry well at Madhogarh fort which is 100 km away from Sariska TR, radio-collared and released in the study area on 28th October 2009. Radio-locations of each collared animal were determined by ground tracking through VHF signal following 'homing in' and 'triangulation' techniques. In total, 148 locations were collected from the first male leopard (SP1) and 268 locations from second male leopard (SP2). Program CALHOME and ArcGIS 9.2 with Hawth's tool and HRT tool was used to estimate home ranges in different methods.

Since, radio-collaring data from two individual is a very small sample size to understand the habitat use of leopard, *ad libitum* data of seven individually identified leopard (three males and four females) were also added to the analysis. Second order resource selection function was evaluated to understand the habitat selection of leopard in the study area. The extent of the geographic range (412.4 km^2) was defined by calculating a minimum convex polygon around the collective home-ranges of all the study animals. Individual Utilization Distribution (UD) grids were overlaid on a GIS layer derived from the landcover map for the study area within ArcGIS 9.2. An individual's use of the habitat is defined by the proportion of UD volume in each habitat type within the overall geographic range combining the home ranges of all animals. The program Resource Selection for Windows (RSW) was used to conduct the compositional analysis.

Camera trapping method was adopted to generate habitat suitability model for leopard. Presence/absence information along with direct sighting data of leopard was collected in the intensive study area from January 2007 to June 2010. If leopard was detected at least once at a site over the entire sampling duration then it was recorded as present '1' or '0' otherwise. The data was analyzed using program MaxEnt.

Home range of leopard was estimated following minimum convex polygon method and kernel method. With 100 % MCP, the home range of SP1 male leopard was 84.3 km^2 and that of SP2 male leopard was 170.1 km^2. With 90% Kernel, the estimated home range of SP1 was 72.4 km^2 and that of SP2 was 54.6 km^2. The summer home range of SP1 was 67.8 km^2 and that of SP2 was 56.9 km^2. The monsoon home ranges were 57.8 km^2 and 13.6 km^2 for SP1 and SP2 respectively. The winter home ranges were 29.6 km^2 and 170.1 km^2 for SP1 and SP2 respectively.

The habitat use by leopard in Sariska TR was in the following order: *Zizyphus* mixed forest> *Acacia* mixed forest> *Butea* dominated forest> *Anogeissus* dominated forest> *Boswellia* dominated forest> Scrubland> Barren land> agricultural land. There were no detectable differences between selection of *Acacia* mixed forest, *Butea* dominated forest, *Anogeissus* dominated forest and *Boswellia* dominated forest, but each habitat showed greater use then remaining habitat types. The distances to water from leopard presence locations contributed maximum (19.8%) to the habitat suitability model for leopard. Amongst the prey species, distribution of peafowl (11.9%) and chital (11.5%) contributed maximum to the habitat suitability model for leopard followed by livestock (7%), sambar (5.9%), wild pig (5.2%) and common langur (0.8). Amongst the vegetation types, *Zizyphus* mixed forest contributed most (8.4%) for leopard's distribution followed by *Boswellia* dominated forest (4.7%), agricultural land (4.4%), *Anogeissus* dominated forest (2.8%), scrubland (1.5%), *Acacia* dominated forest (1.5%), barren land (1.3%) and *Butea* dominated forest (0.4%).

Comparing with other studies it was found that the home ranges of leopard in tropical forest are lesser than the dry deciduous forest or savanna forest. Most of the African studies on leopard home range reported larger home ranges in woodland savanna or dry thorn forest. The home range estimate in the present study was similar to the estimates in African studies as the habitat of Sariska TR falls under dry deciduous forest (with some savanna patches) and dry thorn forest. Though the area of *Anogeissus* forest within each animal's home range was higher than any other habitat categories, *Zizyphus* forest was found to be the preferred habitat by leopard. Compositional analysis is a comparison of used habitat types against available habitat. The area of *Zizyphus* forest is less (6%) in the total available habitat, but considering kernel utilization distribution, the *Zizyphus* forest was used more than its availability, thereby ranked as most preferred habitat by leopard in the study area. Although the leopard has the widest habitat tolerance of any large felid and is more resilient than other, sympatric large cat species in the face of anthropogenic threats, the widely held perception that leopards are 'super-generalists' with little need for dedicated conservation action is increasingly viewed with suspicion. The results in the present study indicated that leopards show some degree of specialization, at least in their choice of prey and habitat.

The result of this study presented the abundance of prey species of leopard and their consumption by leopard in Sariska TR. The study also estimated the population and survival rate of leopard in Sariska TR. Home range and habitat use of leopard was estimated in the present study and a habitat suitability model for leopard was generated in and around Sariska TR. These finding have potential to develop a conservation action plan for leopard in Sariska TR and surrounding similar habitat in Aravalli landscape.

Chapter 1

INTRODUCTION

1. 1. BACKGROUND

No group of organisms offers more challenges to conservation biology and conservation politics than large carnivores. Now-a-days the decline of large predator population is a global problem. From Asia and Africa to America, the largest of the felids, canids and ursids suffer from multiple pressures of habitat degradation, hunting, disease and commercial market of body parts. Tiger (*Panthera tigris*), Asiatic black bear (*Salenarctos thibetanus*), jaguar (*Panthera onca*), African wild dog (*Lycaon pictus*) and leopard (*Panthera pardus*) all face the prospect of extinction or local extermination. In a general review of 30 large carnivore species in five families, Fuller (1995) found that 22 of the species were cited as endangered by IUCN. Yet, despite this status, more than half of these species are 'poorly studied' including leopard. Increasing the understanding of leopard ecology and reversing their decline are among the most urgent conservation challenges for management of leopard population in the Indian sub-continent.

Regardless of the conceptual merit of ecosystem management, ecosystems are complex, and they generally cannot be managed directly. Ecosystems can be identified as vegetation types or habitats, can be mapped and can be evaluated in terms of current area and extent of change from historical conditions (Crumpacker *et al*. 1988, Scott *et al*. 1993, Noss *et al.* 1995). But managing an ecosystem requires attention to specific, measurable indicators of the composition, structure and function of that system (Franklin *et al*. 1981, Noss 1990, 1995). Those indicators can be monitored and to some extent managed. The concept of "management indicator species," whereby a single species is assumed to represent the status of all others associated with the same habitat (Landres *et al*. 1988, Noss 1990). In most of the Indian National Parks, tiger and leopard play the leading role as the representative of the associated ecosystem. So it is well understood that leopard as the top carnivore in many Indian forests needs special attention (specifically population monitoring) for the better management of respective forest and food chain. To understand the population trend in the Sariska National Park, the density and survival rates of leopard are estimated in the present study between 2007 and 2010.

Ecological studies of large carnivores in northern North America suggest they are capable of controlling their own numbers through social behavior (Hornocker 1969, 1970, Seidensticker *et al*. 1973, Beecham 1983, Hornocker and Bailey 1986), but their numbers can respond to changes in prey abundance (Fuller 1989, Quigley *et al*. 1989). In some cases, such as wolves (*Canis lupus*) at high latitudes (Bergerud and Ballard 1988), predators have been shown to regulate prey populations. Where natural predators have been eliminated or severely reduced, dramatic increases in herbivore populations are more likely than they would be in the presence of large carnivores (Ballard *et al*. 1987, Warren 1991). Alternatively, prey population is also found to contribute to survival rates of a predator population (Carbone and Gittleman 2002), as prey-predator relations (in terms of availability and consumption) always play a key role to maintain the balance of an eco-system. In the present study, to understand the relation between leopard and its prey, prey availability and prey consumption are estimated in Sariska National Park for consecutive four years.

In many of the research areas of conservation biology, population viability analysis, reserve design and landscape use by the carnivore are the matter of concern, which is directly related with the trophic status of the species. It is commonly assumed that a conservation plan focused on large carnivores will protect most other species as well (Foreman 1992). Evidently, tiger and leopard as the top carnivores act as the "umbrella species" and provide a "coattail effect" (Soule 1985) for all the species associated in the eco-system. Hence it is always necessary to understand the habitat requirements and the pattern of habitat use by the carnivore for conservation of a landscape. In the present study, the ranging pattern and resource selection of leopards are estimated and a habitat suitability model is predicted for Sariska Tiger Reserve and its adjoining areas.

As the larger predator in Asia, the leopard has been revered as a cultural icon throughout of its former and present range. Yet for more than a millennium this predator has been relentlessly hunted for sport, killed for its body parts believed to have medicinal properties, and both feared and persecuted because of its ill-deserved reputation as a dangerous killer of human and livestock. Only recently people have come to the alarming realization that this large felid is facing tremendous population decline (http://www.wpsi-india.org/statistics/leopard.php), which may lead to imbalance in the eco-system.

1. 2. LEOPARD ECOLGY

The leopard has the greatest geographic distribution of any felid. Its range has been reduced in recent times, although historically leopard was distributed throughout northern Africa and over much of sub-Saharan Africa. Beyond Africa, the leopard range extended through Central Asia, India, Sri Lanka, Southeast Asia, China, Tibet and the Russian Far east (Figure 1.1) (Smithers 1983, Stuart 1981, Harrison and Bates 1991, Kingdon 1977, Corbett and Hill 1992). The oldest leopard fossils have been found in the Siwalik Hills of the Indian subcontinent. They date to about 2 million years ago, which was during the early Pleistocene. This evidence indicates that leopards may have originated in Asia, probably during the late Pliocene. However, leopards did not stay in Asia. They migrated and colonized Africa and other regions to a great extent. By the middle of the Pleistocene, leopards were distributed extensively in East Asia, including Southeast Asia. Some migrated into Northeast Asia, including Japan. Leopards came into Europe during the middle of the Pleistocene. Fossils of them have been found as far west as the British Isles. A large number of leopard fossils have been found in a cave site in Italy called Equi. Leopards died out in Europe and in many parts of Asia. Today they are found in Africa and parts of southern Asia. Their numbers have declined sharply, partly due to hunting and habitat degradation (Robbins 2005).

As might be predicted from its widespread distribution, the leopard can be found in many different habitat types (Jerdon 1867). Although they are absent from true deserts and over the tree line in mountains, leopards do live in almost every type of habitat. It is revealing to consider which factors may limit this cat's distribution. Limitations in food, cover and water are usually the major factors affecting an animal's distribution (Stuart 1981), but for a leopard the definition of these basic requisites is extremely broad. Leopards were found to consume a number of species from beetles to large ungulates like eland and sambar. Leopards even can survive in few scattered shrubs and trees to dense moist tropical evergreen forest (Bothma and Le Riche 1986). Desert leopard have been known to drink only once in ten days and in China and Russia they survive long periods of sub-freezing temperatures although they do not appear to be well adapted to deep snow (Bothma and Le Riche 1986, Miquelle *et al.* 1996)

Figure 1.1. Present distribution range of leopard in the World

Leopard is found in a range of forests from woodlands to Acacia savannas, scrub forest, exotic pine plantations, rocky hills and mountain terrains from sea level to elevations of 5000 m (Harrison and Bates 1991). Leopards can live areas receiving almost no rainfall (50 mm per year) as well as in parts of West Africa and Tropical Asia where the mean annual rainfall is well over 2000 mm (Anon. 2005).

The two major factors that appear to limit the distribution of this rough and versatile generalist cat are the presence of competitors and the presence of humans. In many parts of its range the leopard co-exists with other large predators. In Africa it lives alongside lions and hyenas and in Asia it shares many habitats with tigers and wild dogs (Ramesh *et al.* 2008). Leopards do have their livelihood strategy to co-exist with these predators, similarly, they can live in proximity to humans as long as they are not persecuted and have a safe retreat (Bothma and Le Riche 1986).

Despite the leopard's widespread distribution, there is little detailed information available on this elusive cat. The work of Hamilton (1976) in Tsavo National Park, Kenya represented the first major study of leopards to incorporate radio-telemetry techniques. At the same time, Bailey (1993) initiated his study in Krugar National Park. The longest telemetry study of leopards is that of Ilany (1981) in Israel, he tracked many individuals over a 12 years period. Small scale radio-tracking studies on leopard have been conducted in conjunction with lion research in the Serengeti by Schaller (1972) and Bertrum (1982). Mizutani and Jewell (1998) studied 11 radio-tagged leopards on a ranch in Kenya. In northern Namibia, Stander *et al.* (1997) studied 18 radio-tagged leopards. Radio-tracking studies of leopard have also been part of the research on tigers in southern Nepal and Southern India (Seidensticker 1976, Sunquist 1981, Karanth and Sunquist 1995).

There is a general belief that leopards are mostly nocturnal. But, leopards are reportedly less nocturnal and more terrestrial in areas lacking tigers and lions (Grassman 1999, Eisenberg and Lockhart 1972, Karanth and Sunquist 2000). Seidensticker (1976) found that leopards living within Chitwan National Park in Southern Nepal, where tigers are also numerous, were active and moving at any time of the day and night. In contrast, those leopards living along the Park-village interface were essentially nocturnal, they were seldom found moving about during the daytime, presumably to avoid villagers (Sunquist 1981).

In the Kalahari Desert, leopards typically spend the daytime hours resting under vegetation or in burrows made by porcupines or aardvarks. Male leopards are too large to use most burrows and usually rest under bushes and trees. Kalahari leopards move mainly at night, but they frequently rest during the early part of the night and again just before dawn (Bothma and Le Riche 1986). In contrast, leopards living in the Judean desert of southern Israel rarely hunt at night, except when occasionally hunting porcupines or house cats in human settlements. The main food items of leopards in this area are hyraxes and ibex, both of which are diurnal and so leopard in also diurnal (Ilany 1981).

In Huai Kha Khaeng Sanctuary, Thailand, a male and female leopard radio-tracked by Rabinowitz (1989) were found to be moving during the day time as at night and both were active 49-67% of the time. A similar activity pattern was recorded for leopards in Kaeng Krachen National Park, Thailand (Grassman 1999). This pattern and degree of activity is different from most of observations of leopards, although a female leopard with small cubs in Chitwan National park was active about 75% of the time (Seidensticker 1976).

The movement pattern in terms of distance traveled by leopards in their daily activities is highly variable. The walking speed of leopard is 3- 6 km per hour and they can cover up to 12-14 km in one night (Bailey 1993, Turnbull-Kemp 1967). Distances of 3 5 km per day were measured in areas with abundant prey, but in less productive habitats leopards may walk 10 to 20 km during hunting in night time (Hamilton 1976). In the interior of the Kalahari Gemsbok National Park, both males and females moved 16 to 33 km per day. It was also found that leopards in Kalahari moved increasingly longer distances per day as the number of days since they last fed increased (Hamilton 1976, Bothma and Le Riche 1990).

Leopards often catch prey opportunistically, killing vulnerable animals as they are encountered. In the Kalahari Desert, tracks revealed that leopards usually killed small prey without deliberate stalk or chase (Bothma and Le Riche 1986). In

Serengeti, Bertram (1982) reported seeing leopards investigating small clumps of vegetation and pursuing any small animals flushed out. A leopards takes whatever it can catch and its diet in many areas consist largely of small to medium sized mammals (5 to 120 kg). Leopard has the ability to survive on extremely small prey, which allows them to exist in places where large prey has been exterminated. Leopards take much wider range of prey of different sized and types than most of other large cats. A number of 92 prey species were recorded in the diet of sub-Saharan leopards (Bailey 1993). In the Serengeti, a sample of 137 leopard kills included 31 different prey species (Schaller 1972). A list of mammals killed by leopards includes numerous kinds of rodents, hares, several species of deer duiker, antelope, pigs, zebras, jackals and foxes, porcupines, pangolins and monkeys. Leopard also fed on birds which include doves, partridge, guinea-fowl, peafowl, vultures, ostriches etc. Reptiles, amphibians, invertebrates and grass are also eaten by leopard. In areas where leopards live in proximity to humans, their diet often includes dogs, cats and domestic livestock including goats, sheep, calves of cow and buffalo, pigs. Instances of ‘surplus killing’ of domestic livestock sometimes occur and while large numbers of animals may be killed in this situation, few are actually eaten (Turnbull-Kemp 1967).

Where the leopard lives with lions and tigers, they feed on many of the same species, though competition may exists between them. Few studies have looked at leopard food habits in areas where they are sympatric with lions or tigers (Sankar and Johnsingh 2002, Ramesh *et al.* 2008). In presence of sympatric competitor, leopard generally feed on a wider variety of prey, many of which are small animals or the young of the larger prey species. In the Serengeti, leopards feed on Thomson’s gazelles, Grant’s gazelles, reedbuck and a variety of small prey species, while lions in the same area eat mainly wildbeasts, zebras, Thomson’s gazelles and wild buffalo

(Schallar 1972). In the Kalahari Desert, leopards take juveniles of various species including bat-eared foxes, porcupines, aardvarks, steenbok, duiker and gemsbok, whereas the main food of the lion is adult gemsbok and springbok (Bothma and Le Riche 1984). In contrast, impalas are the dominant prey of both leopards and lions in Kruger National Park, South Africa.

In Chitwan National Park, leopards feed primarily on ungulates weighing less than 50 kg, including wild pigs, hog deer and fawn or yearling of chital and sambar. Tigers in the same area tend to take prey weighing more than 50 kg which include more adult sambar, chital and wild pigs in their diet (Sunquist 1981). In Nagarhole Tiger Reserve, leopards prey extensively on chital, whereas tigers take the larger gaur and sambar (Karanth and Sunquist 1995). In Huai Kha Khaeng Wildlife Sanctuary, the major prey of both tiger and leopard is barking deer but leopards feed upon a greater diversity of small species and they take more primates than tigers do (Rabinowitz 1989).

The principal means of social integration among leopards appears to be via olfactory information carried in urine, anal sac secretions and feces. Scent may not carry information as far as a call but it is more persistent (Anon 2005), and it is not diminished by darkness as visual signs would be. Scent also has the advantage of being able to convey information long after the animal has left the spot. Auditory, tactile and visual signals are also used to attract mates or advertise that an area is occupied, but scent markings appears to be an efficient method of communication among these wide-ranging, solitary predators. Scent markings are typically deposited along commonly used travel routes, especially at road junctions or trail intersections or at conspicuous places along home range boundaries. Some marks are renew at intervals of a few days to a month or more, suggesting that these marks remain effective for relatively long periods (Smith 1977). Feces and scrapes are also left at these sites, thus providing both an olfactory and visual mark (Bothma and Le Riche 1984). Researchers in the Kalahari found that leopards urinate in two different ways. One is copious urination that lacks any apparent informational significance, while the involves squirts of small volume deposited at regular intervals. These squirts are directed at shrubs, low branches, tree trunk or grass and are sometimes followed by raking with the hind feet (Bothma and Le Riche 1984).

The coughing, sawing or rasping vocalization of the leopard may also function to bring animals together for mating or to space out individuals, depending upon their sex and their reproductive and social status. Under favorable condition, the sawing vocalization can carry for 2 to 3 km. The leopard in making this vocalization keeps its mouth partly open and expels and inhales air back and fore across the soft palate (Brander 1923).

Leopard females can come into estrus at any time of the year and remain in heat for one or two weeks. If conception does not occur, the female may cycle again. The average length of time between estrous periods is 45 days with a variation from 20-50 days (Sadleir 1966). The onset of a heat is associated with an increase in head rubbing, rolling and vocalizing. If a male and female are not familiar with each other, aggressive encounter may occur before mating (Desai 1975). During the peak of estrous mating occurs frequently, one pair copulated 60 times during nine hour period (Desai 1975). Leopard cubs are born after a gestation period of 96 days, although zoo records suggest that gestation can take from 90 to 105 days (Hemmer 1979, Seager and Demorest 1978). Litter size of leopard commonly varies from one to three and there are records of females giving birth as many as six cubs but most litter consists of two cubs (Zuckerman 1953, Dobroruka 1968, Reuther and Doherty 1968). Female leopards use caves, thickets, hollow trees, abandoned burrows and rock piles as birth dens (Hemmer 1979).

1. 3. OBJECTIVES

The present study on ecology of leopard in Sariska Tiger Reserve, Rajasthan, was carried out with the following objectives:

1. To estimate the prey availability of leopard
2. To study the food habits and prey selection of leopard
3. To estimate the population of leopard and
4. To study the home range and habitat use of leopard.

1. 4. STUDY PERIOD

The study was conducted from November 2006 to June 2010 covering two different seasons winter (November to February) and summer (March to June).

1. 5. STUDY SPECIES

Since *Carl Linnaeus* published his description of leopards in the ***10th edition of** Systema Naturae* in 1758, as many as 27 leopard subspecies were subsequently described by naturalists from 1794 to 1996. The most common of all the leopard sub-species are:

- African leopard (*P. p. pardus*), (Linnaeus, 1758) — inhabits sub-Saharan Africa;
- Indian leopard (*P. p. fusca*), (Meyer, 1794) — inhabits the Indian Subcontinent;
- Javan leopard (*P. p. melas*), (Cuvier, 1809) — inhabits Java, Indonesia.

- Arabian leopard (*P. p. nimr*), (Hemprich and Ehrenberg, 1833) — inhabits the Arabian Peninsula;
- Amur leopard (*P. p. orientalis*), (Schlegel, 1857) — inhabits the Russian Far East, Korean Peninsula and Northeast China;
- North Chinese leopard (*P. p. japonensis*), (Gray, 1862) — inhabits northern China;
- Caucasian leopard (*P. p. ciscaucasica*), (Satunin, 1914), later described as
- Persian leopard (*P. p. saxicolor*), (Pocock, 1927) – inhabits central Asia: the Caucasus, Turkmenistan and northern Iran;
- Indo-Chinese leopard *(P. p. delacouri*), (Pocock, 1930) — inhabits mainland Southeast Asia;
- Sri Lankan leopard (*P. p. kotiya*), (Deraniyagala, 1956) — inhabits Sri Lanka.

A morphological analysis of characters of leopard skulls implies the validity of two more subspecies

- Anatolian leopard (*P. p. tulliana*), (Valenciennes, 1856) — inhabits Western Turkey;
- Baluchistan leopard (*P. p. sindica*), (Pocock, 1930) — inhabits Pakistan, and possibly also parts of Afghanistan and Iran.

In the present study, the Indian subspecies of leopard is *Panthera pardus fu*sca was studied. This species was first described by Friedrich Albrecht Anton Meyer in 1974, in his first description of *Felis fusca*, in which he gave account of a panther-like cat from Bengal. On the Indian subcontinent, topographical barriers to the dispersal of *Panthera pardus fusca* are the Indus River in the west and the Himalaya in the North.

In the east, the lower course of the Brahmaputra and the Ganges Delta form natural barriers to the distribution of the Indo-Chinese leopard. Indian leopards are distributed all over India, Nepal, Bhutan, Bangladesh and parts of Pakistan. They inhabit in a range of forests from tropical rain forests to deciduous forests, temperate forests and coniferous forests up to an altitude of 2500 m (8200 ft) above sea level. But Indian leopard do not inhabit in the Thar desert, above tree line in Himalaya and the mangrove forests of the Sundarbans.

Panthera pardus fusca is listed as a species of near threatened by the IUCN red list. In India, this species is listed in Schedule I of the Indian Wildlife (Protection) Act, 1972, under the highest level of protection. Habitat destruction, loss of wild prey, poaching for skins, bones and claws, and poisoning carcasses of livestock killed by leopards are a significant threat to the species. As a result the geographic ranges of leopard have contracted and their populations have declined. There is an urgent need to conserve many carnivore species including leopard and the first step towards this is to obtain knowledge about their basic biology: how many exist, what they eat and where they live.

1. 6. ORGANIZATION OF THESIS

The thesis is structured into six chapters.

First chapter gives introduction to the study which includes the background of carnivore conservation and details in ecological aspects of leopard. This chapter also describes the study species and the objectives of the study.

Chapter 2 deals in descriptive account of the study area, which includes the topography and vegetation, available fauna and the human settlement in the study area.

Chapter 3 deals with the prey species abundance in the study area. This chapter further explains the method for estimation of prey species abundance, density estimates and trend in population in for four consecutive years.

Chapter 4 describes prey selection and food habits of leopard, which includes the percentage occurrence of each prey species in leopard's diet, proportion of their biomass consumption and prey selection of leopard.

Chapter 5 covers population estimation of leopard using different methods in the study area. This chapter also describes the methodology for population estimation of leopard following different models, density estimates and the survival rates of leopard in the study area.

Chapter 6 describes the home range estimation and habitat use of leopard in the study area, which includes home range estimates of leopard using different methods and resource selection of leopard comparing with different vegetation types available. This chapter also explains a habitat suitability model for leopard for Sariska Tiger Reserve and surrounding areas.

Chapter 7 discussed the issues raised from this study on conservation of leopard in Sariska Tiger Reserve.

Chapter 2

STUDY AREA

2.1. INTRODUCTION

The Sariska Tiger Reserve (Sariska TR) is located in the Aravalli hill range and lies in the semi arid tract of Alwar district of the state of Rajasthan. It once served as hunting ground for the royal family of Alwar and functionaries of British Government till 1955. After independence, Sariska was declared as a Wild Life Reserve on 7th November, 1955, under the Rajasthan Wild animals and Birds Protection Act, 1951. Sariska was included in the list of Tiger Reserves by Government of India in 1978 as the 11th Tiger Reserve. The total area of the Sariska Tiger Reserve is 881 km^2. In 1982, an area of 274 km^2 was declared as Sariska National Park vide Preliminary Notification *NO. F11 (22) Raj-8/78 Jaipur Dated 27 August 1982 under Wild Life Protection Act 1972 (Central Act No. 53) section 35 (1)*.

Within Sariska TR, there are several places of historical interest. The Pandupole temple which is a major attraction for tourists and pilgrims lies in the National Park area of the Reserve. The temple and the surroundings are associated to the *Hanuman* the Monkey God and the Pandavas when they were in exile in the Mahabharata epic. The Neelkanth temple and ruins of several other temples found inside Sariska TR are now protected by the Archaeological Survey of India. Evidence of *Mughal* invasions are retained in the forts located in and around the Sariska TR. The Kankawari fort, originally built by *Maharaja* Jai Singh II of Jaipur, located in the National Park area of the Reserve, where in the *Mughal* Emperor Aurangzeb had briefly imprisoned his elder brother Darashikoh during the struggle for succession of the throne.

2.2. LOCATION AND AREA

The Sariska Tiger Reserve lies between Longitude: N27°05' to N27°45' and Latitude: E76°15' to E76°35' and is located in the hill range of Aravallis spreading over the tract starting from Mount Abu and culminating on Delhi ridge (Figure 2.1). The Tiger Reserve falls in Gujarat-Rajputana Biogeographic zone (Rodgers and Panwar 1988). The Reserve lies on Delhi-Jaipur State Highway via Alwar, at a distance of 200 km from Delhi, 36 km from Alwar and 110 km from Jaipur. The total area of Sariska Tiger Reserve is 881.11 km^2 which has been notified as critical tiger habitat in the official gazette of the state vide Notification No. *F3 (34) Forest/ 2007 Dated December 28, 2007.* Of these, Reserved Forest occupies 604.97 km^2 areas and the protected area is 276.13 km^2.

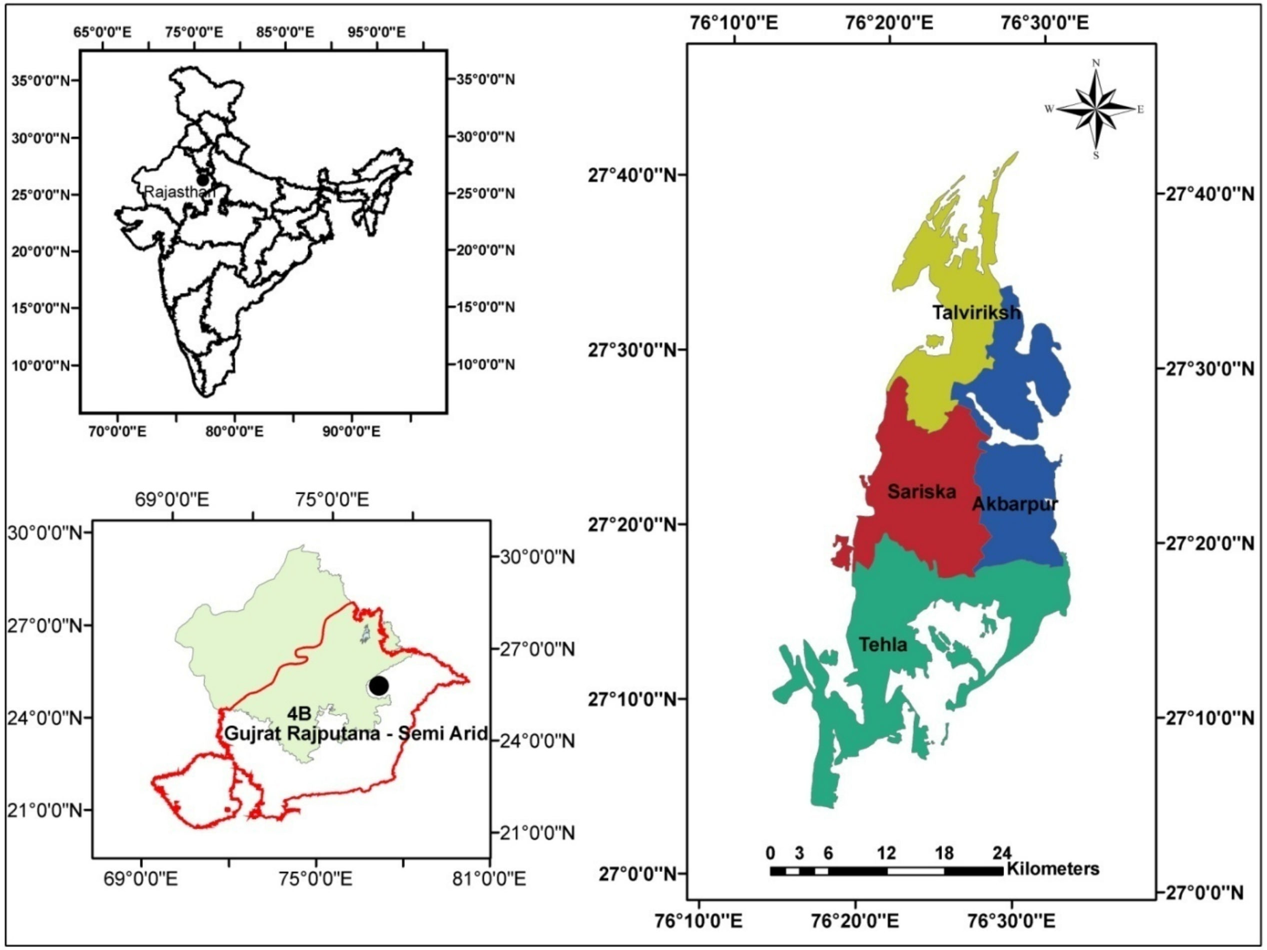
2.3. TOPOGRAPHY, DRAINAGE AND GEOLOGY

Sariska TR is characterized by rugged terrain, valleys and plateau with the altitudinal variation from 540 m to 777 m. The two main plateaus are Kankawari (524 m) and Kiraska (592 m). The most remarkable characteristics of the hills are their homogenetic regularity of height, level summits and uniform appearance, stretching out from northeast to south-west (Soni 2000).

The Ruparel River runs through the middle of the Tiger Reserve in North South direction. The drainage from most areas of the northern portion of the Tiger Reserve including Bandipul stream flows into the Ruparel River, while the drainage of the southern part of the Tiger Reserve flows into the Mansarovar Lake**.**

Major part of the area is occupied by rocks of Delhi system and Aravalli system comprising of quartzites, conglomerates, grits, Limestone, phyllites, granites and schists (Pascoe 1950). Most of the high ridges are comprised of quartzites, conglomerates and grits. Evidences of lava conglomerates are also occasionally seen. These ancient crystalline and metamorphic rocks with gneiss and schists etc. are generally covered by red sandy soils. Red soils are poor in nitrogen, phosphorus and humus contents and alkaline in nature. There are comparatively rich, fertile and dark colored soils in plains and river valleys. The depth of soil layer is more than 1 m in valleys, whereas it is only a few centimeters deep on the hill slopes. The soil is sandy loam and alkaline with pH varying from 7.25 to 8.00 (Yadav and Gupta 2006).

Figure 2. 1. Location and administrative boundary of Sariska Tiger Reserve



2.4. CLIMATE

Sariska Tiger Reserve is characterized by sub-tropical dry climate with distinct winter (November-February), summer (March-June), monsoon (July-August) and post-monsoon (September-October) seasons. The highest temperature (above 47^0C) is recorded in May-June and the lowest (up to 2^oC) in December-January. The bulk of the precipitation is from South West monsoon and occurs during the months of July to September. Average annual rainfall recorded is 650 mm (Sankar 1994). The rainfall during the period from June-September constitutes about 92% of the annual rainfall. The relative humidity is generally low in most parts of the year; it becomes as low as 10 to 15 percent during summer months. However during the rainy days the relative humidity goes over 60%.

2.5. VEGETATION

The vegetation of Sariska TR correspond to (1) Northern tropical dry deciduous forests (subgroups 5B; 5/E1 and 5/E2) and Northern Tropical Thorn forest (subgroup 6B) (Champion and Seth 1986). *Anogeissus pendula* is the dominant tree species covering over 30% area of the forest. *Boswellia serreta* and *Lannea coromandelica* grow at rocky patches. *Acacia catechu, Butea monosperma* and *Zizyphus mauritiana* are common in the valleys. *Dendrocalamus strictus* is extremely limited in distribution and is found along well drained reaches of the streams and moist and cooler parts of the hills. *Albizia lebbeck, Diospyros melanoxylon, Holoptelia integrifolia* and *Ficus sp* are found in moist localities (Sankar 1994). A number of exotic invasive species have become common in the heavily grazed areas of the Reserve, such as the annual herb

Cassia tora and the short-statured tree *Prosopis juliflora. Adhatoda vasica*, though a native under storey species, has become very common in disturbed and over-grazed areas, and appears to suppress grass and other native herbaceous species.

Parmar (1985) and Rodgers (1985) have classified vegetation of Sariska TR as follows:

1. *Anogeissus pendula* forest
2. *Boswellia serrata* forest
3. *Acacia catechu* forest and
4. *Miscellaneous forest,* which is further sub-divided into three categories viz.
   a) *Butea monosperma* forest
   b) Forest along nallas and
   c) Scrub land

Nine different vegetation and land cover categories have been delineated in Sariska TR (Sankar *et al.* 2009) (Figure 2.2). They are *Anogeissus* dominated forest, *Boswellia* dominated forest, *Butea* dominated forest, *Acacia* mixed forest, *Zizyphus* mixed forest, Scrubland, Agricultural land, Water body and Barren land. The percentage proportion of above mentioned vegetation and land cover categories are given in Table 2.1.

Figure 2. 2. Vegetation and land cover map of Sariska Tiger Reserve.

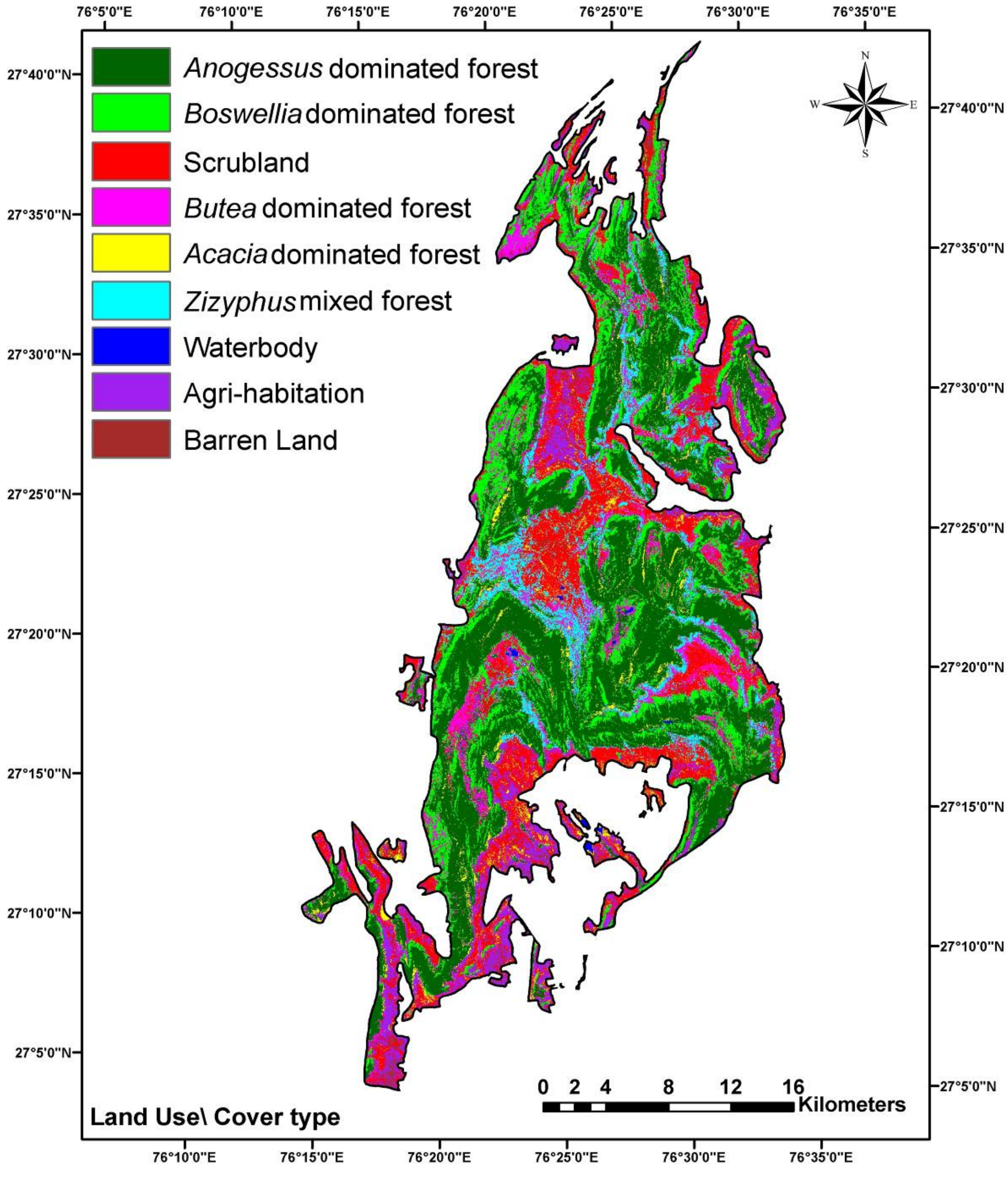


Table 2.1. Vegetation and land cover classes in Sariska Tiger Reserve

Vegetation/Landcover type	**Area (sq. km.)**	**Percentage**
Anogeissus dominated forest	283.3	35.4
Scrubland	152.5	19.1
Boswellia dominated forest	123.5	15.5
Agriculture/Habitation	74.7	9.3
Butea dominated forest	63.6	7.9
Zizyphus mixed forest	47.5	5.9
Acacia mixed forest	32.2	4.1
Barren land	20.6	2.6
Water body	1.6	0.2
Total	**799.5**	**100**

***Anogeissus* dominated forest:** The *Anogeissus pendula* that occupies 35.4% of the overall vegetation types is the dominant vegetation type in the entire STR distributed largely in gentle slopes. This species is found in association with *Acacia catechu* and *Lanea coromandelica,*. The under storey is formed by *Adathoda vasica, Grewia flavescens, Capparis sepiaria* and *Nycatanthus sp*. Ground cover mainly comprises of *Aristida sp*., *Setaria sp.* and *Chloris sp*.

***Boswellia* dominated forest:** *Boswellia serrata* that occupies 15.4% of the overall vegetation types is found largely in steep slopes and plateaus. This species is found in association with *Anogeissus pendula*, *Doispyros melanoxylon*, *Acacia catechu, Wrigtia tinctoria, Bauhinia racemosa, and Ehretia laevis*. The under storey comprises of *Eurphobia nerifolia, Grewia flavescens, G. tenax* and

Capparis sepiaria. Grass cover is sparse and is formed by *Aphluda sp* and *Chloris sp.*

***Butea* dominated forest:** *Butea* dominated forest occupies 7.9% of the Tiger Reserve. This species is found in association with *Zizyphus mauritiana, Cordia mixa, Phoenix Slyvesteris* (along the streams), *Holoptelea integrifolia* and *Cassia fistula*. The *Capparis sepiaria, Grewia flavescence and Rhus mysorenses* are the common under storey. Ground layer comprises of *Heteropogon sp* and *Chloris dolichostachya.*

Scrubland: This vegetation type occupies 19.1% of the forest cover in which the tree species such as *Prosopis juliflora, Acacia leucophloea, Acacia nilotica, Acacia senegal, Maytenus senegalensis and Balanites aegeptiaca* are sparsely distributed. The under story is formed by *Capparis decidua, C. sepiaria, Rus mysorensis, Grewia favescens, G. tenax, Zizyphus nummularia, Adathoda vasica and Dicrostachys cinera.* Grass cover is sparse and is mainly formed by *Cynaodon sp, Chloris sp, Sporobolus sp,* and *Synchrus sp.*

***Acacia* mixed forest:** The *Acacia* mixed forest occupies 4.1% of the total vegetation types in Sariska TR. The *Acacia leucophloea* is the dominant vegetation type is found in association with *Prosopis juliflora, Acacia senegal, Dicrostachys cineria* and *Maytenus emarginata.* The understory is formed by *Capparis sepiaria, D. cinera and M. emarginata,* Grasses found are *Apluda mutica, Cynodon dactylon* and *Desmostachya bipinnata.*

***Zizyphus* mixed forest:** This vegetation community that occupies 5.9% of the total vegetation type in Sariska TR is dominated by *Zizyphus mauritiana* in combination with *Acacia catechu, A. leucophloea* and *B. monosperma.* The understory is formed by *Adathoda vasica, Cassia tora, Capparis sepiaria and Zizyphus nummularia. Cynodon sp, Eragrostis sp, and Chloris sp* are typical grasses found along with this type of vegetation type.

2.6. FAUNA

The large carnivores found in Sariska TR include Tiger (*Panthera pardus*), leopard (*Panthera pardus*) and hyena (*Hyena hyaena*). Smaller carnivores include jungle cat (*Felis chaus*), ratel *(Mellivora capensis*), palm civet (*Paradoxurus hermaphroditus*), small India civet (*Viverricula indica*), common mongoose (*Herpestes edwardsii*), small Indian mongoose (*H. auropunctatus*) and ruddy mongoose (*H. smithi*). In 2009, desert cat (*Felis silvestris*) was reported from Sariska (Gupta *et. al.* 2009).

Till 2004, tigers survived in most parts of the Tiger Reserve but, unfortunately, poaching exterminated this animal from Sariska TR. The Wildlife Institute of India, Rajasthan State forest Department and National Tiger Conservation Authority, New Delhi in their joint effort reintroduced six tigers (three males and three females) from Ranathambore Tiger Reserve to Sariska TR during 2008-2011. The wild ungulates of the park are spotted deer (*Axis axis*), sambar deer (*Rusa unicolor*), nilgai (*Boselephous tragocamelus*) and wild pig (*Sus scrofa*). Common langur (*Seminopithecus entellus*) and rhesus macaque (*Macaca mulatta*) are the two primate species found. The other smaller mammals found are rufous tailed hare (*Lepus nigricollis*), pangolin (*Manis crassicaudata*) and porcupine (*Hystrix indica*). Due to presence of villages inside and on the periphery a large variety of domesticated animals also occur within the park. These include buffalo (*Bubalus bubalis*), cow (*Bos indicus*), goat (*Capra hircus*), sheep (*Ovis aries*), camel (*Camelus dromedarius*), dog (*Canis Familiaris*) and domestic cat (*Felis domesticus*).

Eleven species of small rodents were captured during the present study. Indian gerbil (*Tatera indica*), Indian bush rat (*Golunda ellioti*), spiny tailed mouse (*Mus platythrix*), house mice (*Mus musculus*), little Indian field mice (*Mus booduga*) long tailed tree mouse (*Vandeleuria oleracea*), sand colored Rat (*Millardia gleadowi*), soft fur field rat (*Millardia meltada*), brown rat (*Rattus norwegicus*), house rat (*Rattus rattus*) and pygmy gerbil (*Gerbillus nanus*) are the potential prey for small carnivores found in Sariska.

Sariska also holds a variety of bird species including some winter migrants. Sankar *et al.* (1993) recorded 211 species of birds, of which 120 resident, 73 were were migrant visitors and 18 considered as vagrants. It has very high density of peafowl as well as grey francolin (Kidwai 2008).

Though there is no perennial river or water stream), there are a number of ephemeral streams and pools found in Sariska TR. Except for a few natural springs, water in these locations dries up in summer (Sankar 1994). The common fish species found in water bodies in this park are *Noemachilus botia, Labio boggut, Puntius sarana, Garra gotyla* and *Rasbora daniconius* (Ajith kumar and Sankar 1993).

2.7. HUMAN SETTLEMENT

Presently, there are 10 villages located inside the National Park area of the Tiger Reserve, which are due for relocation since 1984. One village named Bhagani has already been successfully relocated in November 2007. People living in these villages mostly belong to the Gurjar community, traditionally dependent on livestock for milk-production economy along with the Meenas inhabiting some villages. The human population is over 1700 in the villages of National Park along with a population 10000 livestock including buffalo, cow, goat and sheep (Sankar *et al.* 2009). There are 22 more villages inside the Tiger Reserve (outside National Park). The human population in these villages is around 6000 and the livestock population is more than 20000 (Sankar *et al.* 2009). These villagers depend totally on forests for their livelihood. The people inhabiting these villages are traditionally pastoralist and their main source of income is selling milk and its products like “Mawa and Ghee”. The economy of villagers of Kankawari, Umri, Kiraska, Lilunda and Kundalka is dependent on animal husbandry, while villagers of Dabli, Sukola and Haripura also work as daily wage labourers in adjoining areas. The villages like Dabli, Deori and Rekhamala (located on the boundary of the Tiger Reserve), have some agricultural land in core area (Sankar *et al.* 2009). The land holdings in these villages are small and the quality of cattle is also poor which results in poor economy of the people in general.

2.8. ADMINISTRATIVE UNITS

Sariska Tiger Reserve comes under Sariska Circle and Sariska Division (Figure 2.1). Sariska TR has four ranges: Sariska, Akbarpur, Tehla and Talvriksh. Sariska range constituted of 20 beats, Akbarpur 17 beats, Tehla 25 beats and Talvriksh 13 beats.

2.9. INTENSIVE STUDY AREA

The present study was conducted in 274 sq. km. area which is the National Park area of Sariska Tiger Reserve (Figure 2.3) for four consecutive years from 2007 to 2010 covering winter (November to February) and summer (March to June).

Figure 2. 3. Intensive study area in Sariska Tiger Reserve.

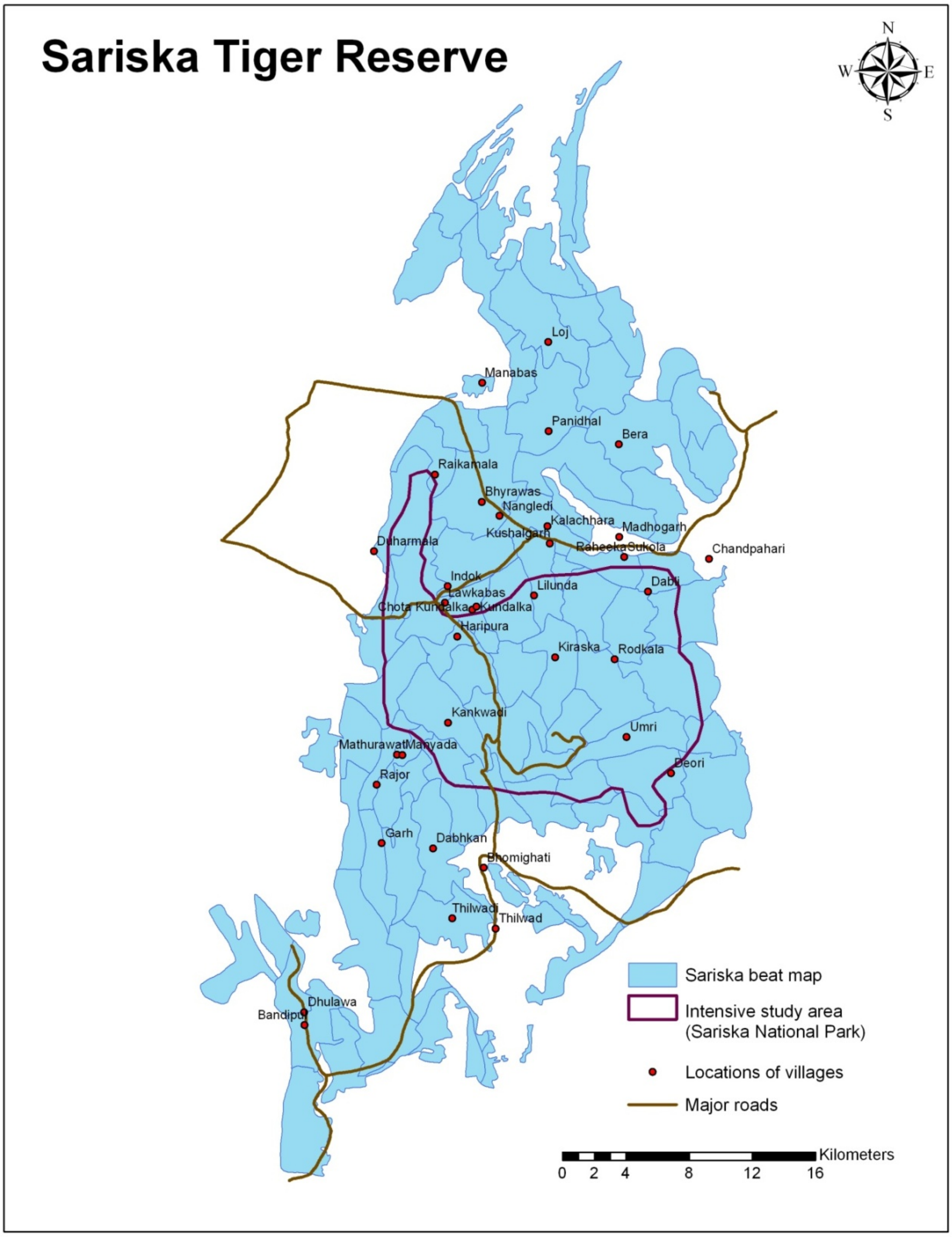


Plate 1a. ***Anogeissus*** **dominated forest in Sariska Tiger Reserve**

Plate 1b. ***Boswellia*** **dominated forest in Sariska Tiger Reserve**

Plate 2a. Scrubland in Sariska Tiger Reserve

Plate 2b. *Zizyphus* mixed forest in Sariska Tiger Reserve

Chapter 3

ESTIMATION OF PREY ABUNDANCE OF LEOPARD

3.1. INTRODUCTION

Studies of prey population estimation of large carnivores have obvious, immediate, and more important application. These add to the relatively scarce reliable quantitative information regarding the distribution, abundance and habitat requirements of these species. Fragmented populations are often difficult to conserve due to their unique habitat and forage requirements. However, the greatest relevance of prey population studies is as resource base estimation for species focusing to conservation. Large mammalian carnivore populations are mainly resource limited (Slobodkin *et al.* 1967), with the fitness of a predator population depending on the availability of its prey (Sunquist and Sunquist 1989). The evolution and radiation of the *Panthera* stock in fact shows close correlation to that of the Cervid and Bovid species (Sunquist *et al.* 1999). Karanth *et al.* (2004) developed simple mechanistic models for predicting large carnivore densities as a function of prey density and found results reasonably consistent with model predictions which eventually re-emphasize the importance of prey species as a limiting factor for large carnivore conservation at the macro-ecological scale. Thus, estimating the prey population size or density in an area is fundamental to understanding the status of the predators and to plan for its management and conservation (Varman and Sukumar 1995).

In the present study, densities of the prey species was estimated using the line transect method (Anderson *et al.* 1979, Burnham *et al.* 1980, Buckland *et al.* 1993).

Line transects have been found to be very effective and reliable in estimating densities of ungulates in the Indian subcontinent (Karanth *et al.* 2004).

3.2. LITERATURE REVIEW

Recent developments in predator ecology show that predator abundances are well explained by gradients in prey biomass and abundances (Carbone and Gittleman 2002, Karanth *et al.* 2004). Line transect sampling is one of the abundance estimating approaches collectively known as distance sampling methods (Thomas and Karanth 2002). This method actually helps in estimating the abundance of some biological population in an area of known size and boundaries. It has been used since early 1930s to obtain estimates of wildlife abundance. In 1949(b), Hayne gave the first estimator which was based only on sighting distances. After this no significant theoretical advances took place until 1968 when Gates *et al.*(1968) suggested that probability density function f(x) be taken as a negative exponential form , f(x) = a exp (- ax) where a is an unknown parameter to be estimated. Then Gates again in 1969 suggested an estimator based on radial distances. Seber (1973) prescribed a general model structure for line transect sampling. After this Robinette *et al.* (1974) presented a series of field evaluations of various line transect methods while at the same time Sen *et al.* (1974) developed theory for estimating wildlife density using both right angle and radial distances.

The current model of line transect was based on general mathematical theory by Burnhum and Anderson (1976) which abounding a framework for either parametric or non parametric density estimation based on either right angle or sighting distances. Anderson *et al.* (1978) provided a course of action for field sampling including practical considerations. A log linear advancement to estimation of population size using the line transect method was given by Anderson *et al.* (1978). Eberhardt (1978 and 1979) discussed a very important aspect of line transect based on right angle distances and the general question of determining sample size for population studies.

Lately, Buckland (1985) proposed perpendicular models for line transect sampling and found that the hazard rate model to be the most promising and Routledge and Fyfe (1992) offered confidence limits for line transect estimates based on shape restrictions, while fitting density functions with polynomials was tried by Buckland (1992). At the same time, an extensive review of statistical methodology involved in estimating animal abundance was given by Seber (1992). He had discussed the use of plots, strips, lines and points for estimating population density or for providing an index of density based on indirect signs (Banerji 2005, Mondal 2006). Buckland and Turnock (1991) discussed effects of responsive movement on abundance estimation using line transect sampling.

In the Indian sub-continent Karanth and Sunquist (1992) employed line transect sampling to estimate the herbivore populations in the tropical forests of Nagarhole, southern India favoring Fourier Series Estimator. An another study on line transect method for estimating densities of large mammals in a tropical deciduous forest was done by Varman and Sukumar (1995). Concerning India, the study of animal abundance across the sub-continent reveals that ecological densities of ungulate species range from a total of 10 individuals / km^2 (Jathanna *et al.* 2001) to 90.3 individuals / km^2 (Biswas and Sankar 2002, Harihar 2005, Mondal 2006 and Sankar *et al.* 2009). This range of values brings to notice that habitat types across the subcontinent support varied densities of ungulate species (Karanth *et al.* 2004).

The simplified protocol which is followed in the present study is given by National Tiger Conservation Authority and Wildlife Institute of India for the line transect based sampling (Jhala and Qureshi 2004). A number of studies had been conducted in Sariska on predators and their prey base. Mathur (1991) studied ungulate population and their habitat interaction. Sankar (1994) studied ecology of sympatric herbivores. Sankar and Johnsingh (2002) studied food habits of tiger and leopard and Avinandan (2008) studied prey selection by tigers in Sariska.

Statistical Development of Distance Sampling Method:

Drummer and McDonald (1987) introduced the cluster size variable as a covariate in the detection functions. Drummer (1991) developed a computer software package **SIZETRAN** to furnish the needs of computations. A program **NPARTRAN** for line transect data analysis, giving confidence limits for line transect estimates based on shape restrictions was developed by Quang (1991). A computer program **DISTANCE** (Laake *et al.*1993) was developed to allow all-inclusive analyses of the type of distance data. The program is written in **FORTRAN** and runs only on any IBM PC compatible micro computer with 640 KB of RAM (Buckland *et al.*1993). The program **DISTANCE** allows more attentiveness on the results and elucidation of biology of population. The present study used a superior version of this program **DISTANCE 5** for analysis of animal abundance.

3.3. METHODOLOGY

Prey species density in the study area was estimated by line transect method under distance sampling technique (Burnham *et al.* 1980). This method has been widely applied to estimate densities of prey species in different forest in Indian subcontinent (Khan *et al.* 1996 and Karanth and Sunquist 1995, Biswas and Sankar 2002, Bagchi *et al.* 2003). The following assumptions were made for the line transect sampling in the present study:

1. The animals are randomly and independently distributed in the study area
2. The sighting of one animal is independent of the sighting of another.
3. No animal is counted more than once.
4. Animals are fixed at the initial sighting position and do not move before being counted.
5. The response behavior of the population as a whole does not substantially change in the course of running a transect.
6. The individuals are homogeneous with regard to their responsive behavior, regardless of sex, age etc.
7. The probability of an animal being seen , given that it is a right angle distance y from the line transect path (irrespective of which side of path it is on) , is a simple function g(y) , say of y , such that g(0) =1(i.e. probability 1 of seeing an animal on the path).
8. Animals directly on the line will never be missed.
9. Distances and angles are measured accurately. (After Burnham *et al.*1980, Buckland *et al.* 2001 and Seber 1982)

In Sariska TR, distribution of prey species cannot be treated as random especially in summer when the animals tend to concentrate around water sources (Sankar 1994). However by placing the line transects randomly in the intensive study area the first assumption is not violated. There is very little chance of violating the other four assumptions in Sariska where substantially open habitat conditions permit easy detection and accurate recording of data.

The entire Sariska Tiger Reserve was sampled for prey species covering 72 beats spreaded over four ranges (Sariska, Akbarpur, Tehla and Talbriksh). Each beat contained one line transect varying length from 1.6 km to 3 km (Figure 3.1). The line transects in Sariska range were walked thrice and rest were walked once during the year 2007. Later 32 permanent line transects varying in length from 1.6 km to 2 km were laid in the intensive study area covering 160 km^2 area of National Park of Sariska Tiger Reserve (Figure 3.2). These transects were walked three times in early morning hours for three successive years from 2008 to 2010. The total transects length in the intensive study (National Park) area was 60.4 km. For each transect the beginning and end point coordinates (Latitude and Longitude) was recorded by a Global Positioning System. The broad forest type and terrain type that the transect traverses was recorded. Record was kept for all ungulates, primates, livestock, hare and peafowl that were seen during the walk. On every walk the followings were noted:

Species identity: Data on each potential prey species was collected separately on each transect walk.

Group size: An individual animal or more than one animal of the same species within 20 m to each other were considered to be a single group.

Age and sex composition: Whenever a group was observed the age structure and gender of the individuals comprising that group was also collected whenever possible.

Radial distance: Laser Range Finder was used to measure the radial distance of the animal. In case of a herd, distance to the centre of the herd was recorded.

Sighting angle: Magnetic compass was used to find the bearing of the animal seen with respect to the transect line from the initial point of observation. In case of the herd, the angle between the point of the observation and the centre of herd was recorded.

Program DISTANCE 5 (Laake *et al*. 2001) was used to estimate the density of prey species. The data after entry into DISTANCE 5 was primarily examined by assigning very small intervals to the perpendicular distance classes. On the basis of the general distribution of the data, suitable cut off points were chosen to optimize the best fit of the model. The best fitted model was selected on the basis of the lowest Akaike Information Criterion (AIC) (Burnhum *et al*. 1980, Buckland *et al*. 1993).

The number of individuals in each species per unit area multiplied by the average weight for the species gives an estimate of the biomass or prey species (Schaller 1967). In the present study, the biomass estimation was done by multiplying the density (density/km^2) of each prey species in the intensive study area by their average body weight (Sankar and Johnsingh 2002, Avinandan 2008).

Figure 3.1. The locations of line Transects in Sariska Tiger Reserve.

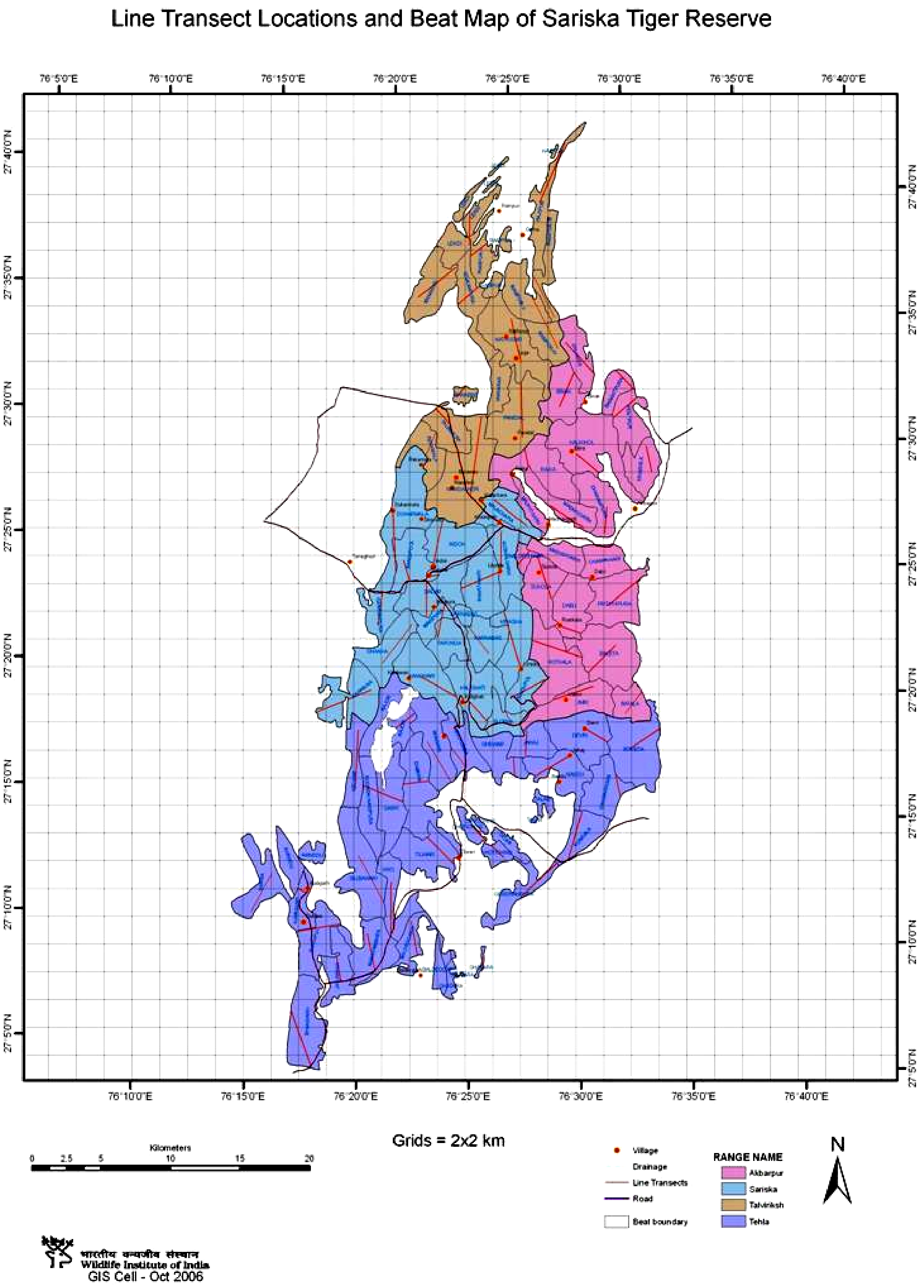
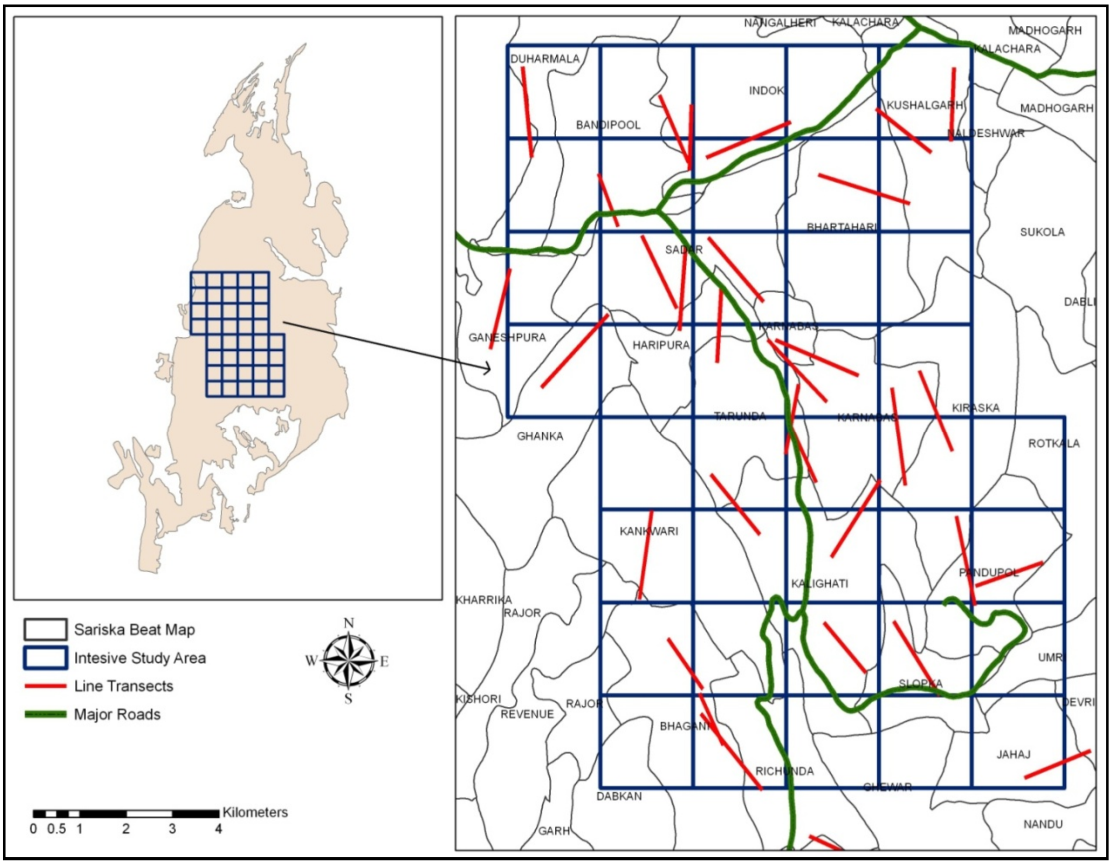


Figure 3.2. The locations of line Transects in the intensive study area (Sariska National Park)



3.4. RESULTS

In total nine potential prey species were recorded on line transects. These were four ungulate species (chital, sambar, nilgai and wild pig), one primate (common langur), one small mammal (hare), two livestock (cow and goat) and one bird (peafowl). There were a number of sightings of buffaloes while walking line transects, but excluded from the analysis. Since, there was no record of buffalo kill by leopards and buffalo remains in leopard scat in the study period, it was not considered as a prey species of leopard.

The estimation of cluster size, group encounter rate and density of different prey species in Sariska Tiger Reserve was given in the table 3.1. The selected model was half normal with cosine adjustment 2, 3, 4 (P = 0.30886, Chi-square = 1.0356 and degree of freedom = 1) based on minimum Akaike Information Criterion (AIC) for the entire Tiger Reserve (Figure 3.1). The total number of walk was calculated to be 107 with total effort of 244.1 km walk. The effective strip width for all species was calculated as 25.91 m (figure 3.3).

In the intensive study area (Sariska National Park), estimation of cluster size, group encounter rate and density of different prey species was given in the table 3.2 to 3.5 for consecutive four years between 2007 and 2010. The selected model was half normal with cosine adjustment 2 (P = 0.53612, Chi-square = 1.2468 and degree of freedom = 2) based on minimum Akaike Information Criterion (AIC) in the year of 2007, while in 2008, the selected model was half normal with cosine adjustment 2, 3 (P = 0.69783, Chi-square = 0.1507 and degree of freedom = 1), in 2009, the selected model was half normal with cosine adjustment 2, 3, 4 (P = 0.45662, Chi-square = 0.5542 and degree of freedom = 1) and in 2010, the selected model was half normal with cosine adjustment 2 (P = 0.45501, Chi-square = 1.5749 and degree of freedom = 2).

The total number of walk was calculated to be 53 with total effort of 115.6 km walk in 2007, 92 with total effort of 181.2 km in 2008, 96 with total effort of 186.3 km in 2009 and 96 with total effort of 195 km in 2010. The effective strip width for all species in the intensive study area was calculated to be 29.12 m, 27.43 m, 25.18 m and 34.09 m in the year of 2007, 2008. 2009 and 2010 respectively (figure 3.4 to 3.7).

The Sariska Tiger Reserve was found to hold a high wild ungulate density i.e. 127.9 individuals/ km^2. Goat was found to be the most abundant (129.3/ km^2) prey species in the entire Sariska Tiger Reserve followed by peafowl (60.2/ km^2), nilgai

(52.8/ km^2), common langur (52.4/ km^2), cattle (41.3/ km^2), wild pig (25.5/ km^2), chital (20.5/ km^2), sambar (19.1/ km^2) and hare (4.3/ km^2).

In the intensive study area (Sariska National Park), the density of chital varied from 33.6/ km^2 in 2007 to 44.3/ km^2 in 2008, 40.4/ km^2 in 2009 and 12.6/ km^2 in 2010 (table 3.2 to 3.5). The density of sambar varied from 26.1/ km^2 in 2007 to 25.2/ km^2 in 2008, 16.4/ km^2 in 2009 and 8.3/ km^2 in 2010 (table 3.2 to 3.5).

The densities of nilgai, wild pig and common langur declined in the intensive study area in the study period (figure 3.6). The density of nilgai declined from 42.3/ km^2 in 2007 to 18.9/ km^2 in 2008, 22.7/ km^2 in 2009 and 13.5/ km^2. The density of wild pig declined from 31.3/ km^2 in 2007 to 14.9/ km^2 in 2008, 6.7/ km^2 and 4.1/ km^2 in 2010. Similarly, the density of common langur declined from 50.2/ km^2 in 2007 to 22.1/ km^2 in 2008, 11.4/ km^2 in 2009 and 4.3/ km^2 in 2010.

The density of peafowl was recorded as 55.7/ km^2 in 2007, 121.4/ km^2 in 2008, 100.7/ km^2 in 2009 and 113.4/ km^2in 2010 in the study area. The density of hare was recorded as 0.7/ km^2, 3.5/ km^2, 1.8/ km^2 and 1.8/ km^2 in 2007, 2008, 2009 and 2010 respectively.

Since there are ten villages inside the Sariska National Park area, the abundance of livestock was comparatively high in the study area. The density of goat in the study area was recorded as 62.8/ km^2 in 2007, 54.1/ km^2 in 2008, 60.9/ km^2 in 2009 and 58.9/ km^2 in 2010. A large number of unguarded feral cattle were recorded on the line transects, and their density showed declining trend over the years. The density of cattle in the study area was recorded as 27.8/ km^2 in 2007, 36.5/ km^2 in 2008, 28.3/ km^2 in 2009 and 10.8/ km^2 in 2010.

The available prey biomass for leopard was calculated to be 23915.2 kg/ km^2 in the entire Sariska Tiger Reserve considering all the prey species and out of that wild ungulate biomass was 13779.3 kg/ km^2. In the intensive study area (Sariska National Park), the available prey biomass was calculated to be 20177.5 kg/ km^2 in 2007, 17158.3 kg/ km^2 in 2008, 14724.5 kg/ km^2 in 2009 and 7506.5 kg/ km^2 in 2010. The available wild ungulate prey biomass for leopard in the study area declined from 13582.3 kg/ km^2 in 2007 to 9119.2 kg/ km^2 in 2008, 8209.1 kg/ km^2 in 2009 and 4188.2 kg/ km^2 in 2010.

Table 3. 1. Density, cluster size and group encounter rate of different prey species in Sariska Tiger Reserve.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/km^2
		Mean	SE	ER	SE	D	SE	
Chital	32	8.09	2.16	0.13	0.02	20.47	7.10	921.15
Sambar	75	3.22	0.26	0.30	0.04	19.13	3.26	2391.25
Nilgai	173	4.11	0.24	0.70	0.07	52.76	7.71	9496.80
Wild pig	46	7.02	0.81	0.18	0.03	25.53	5.53	970.14
Peafowl	216	3.52	0.24	0.88	0.09	60.16	7.96	204.54
Cow	66	7.90	0.73	0.27	0.03	41.26	7.16	7426.80
Goat	65	25.16	1.28	0.26	0.04	129.33	23.96	2069.28
Hare	24	2.25	0.56	0.09	0.02	4.26	1.41	15.34
Common langur	49	13.55	1.49	0.20	0.03	52.49	11.46	419.92

SE = Standard error Group ER = Group encounter rate D = Density

Figure 3.3. Detection probability curve for all prey species in Sariska Tiger Reserve.

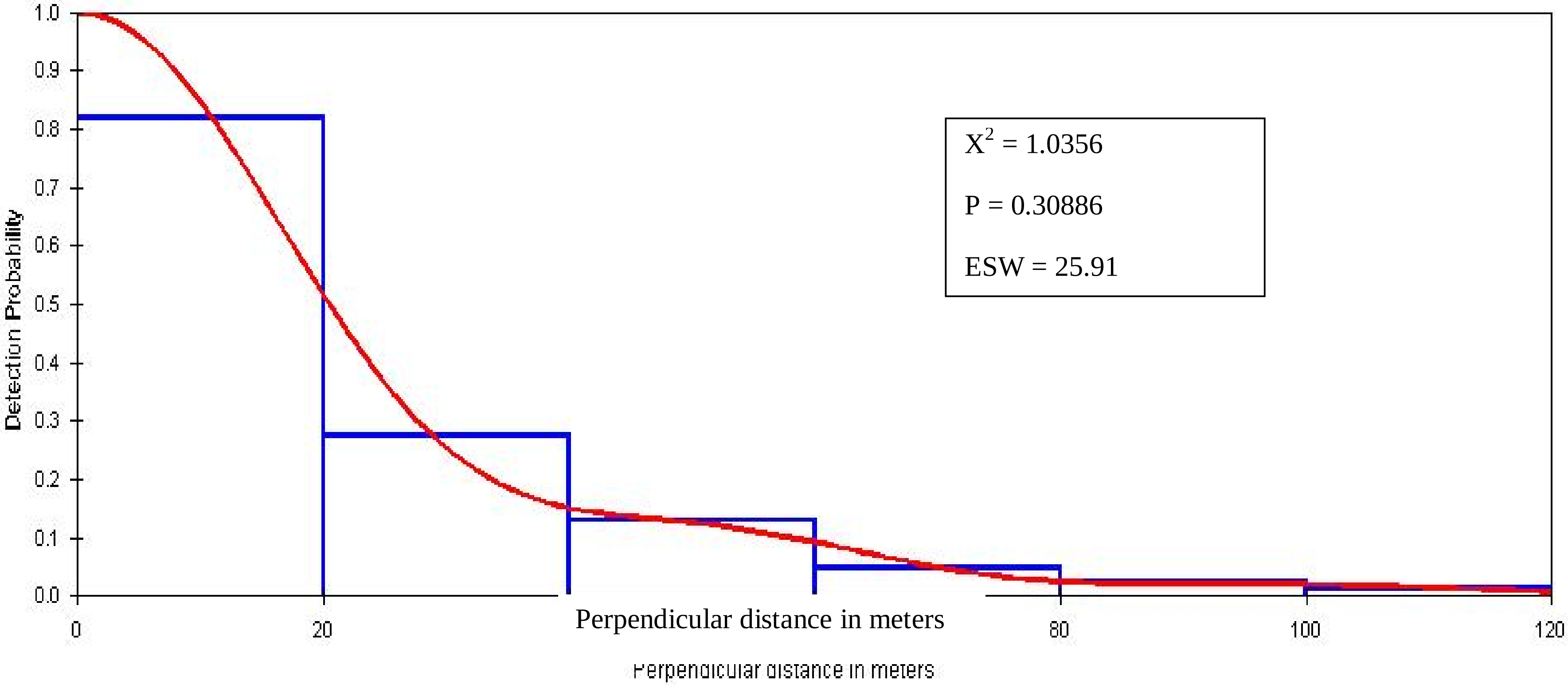


Table 3. 2. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2007.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/km^2
		Mean	SE	ER	SE	D	SE	
Chital	27	8.37	2.51	0.23	0.05	33.55	12.63	1509.75
Sambar	53	3.32	0.33	0.45	0.07	26.13	5.27	3266.25
Nilgai	91	3.13	0.33	0.78	0.14	42.31	9.05	7615.80
Wild pig	31	6.80	1.09	0.26	0.05	31.33	8.52	1190.54
Peafowl	134	2.79	0.23	1.15	0.14	55.68	8.79	189.31
Cow	24	7.79	1.49	0.20	0.05	27.76	4.48	4996.80
Goat	15	28.20	3.55	0.12	0.05	62.81	28.27	1004.96
Hare	5	1.00	0.00	0.04	0.02	0.74	0.42	2.66
Common langur	29	11.65	2.08	0.25	0.06	50.18	15.61	401.44

SE = Standard error Group ER = Group encounter rate D = Density

Figure 3.4. Detection probability curve for all prey species in the intensive study area (National Park) in 2007.

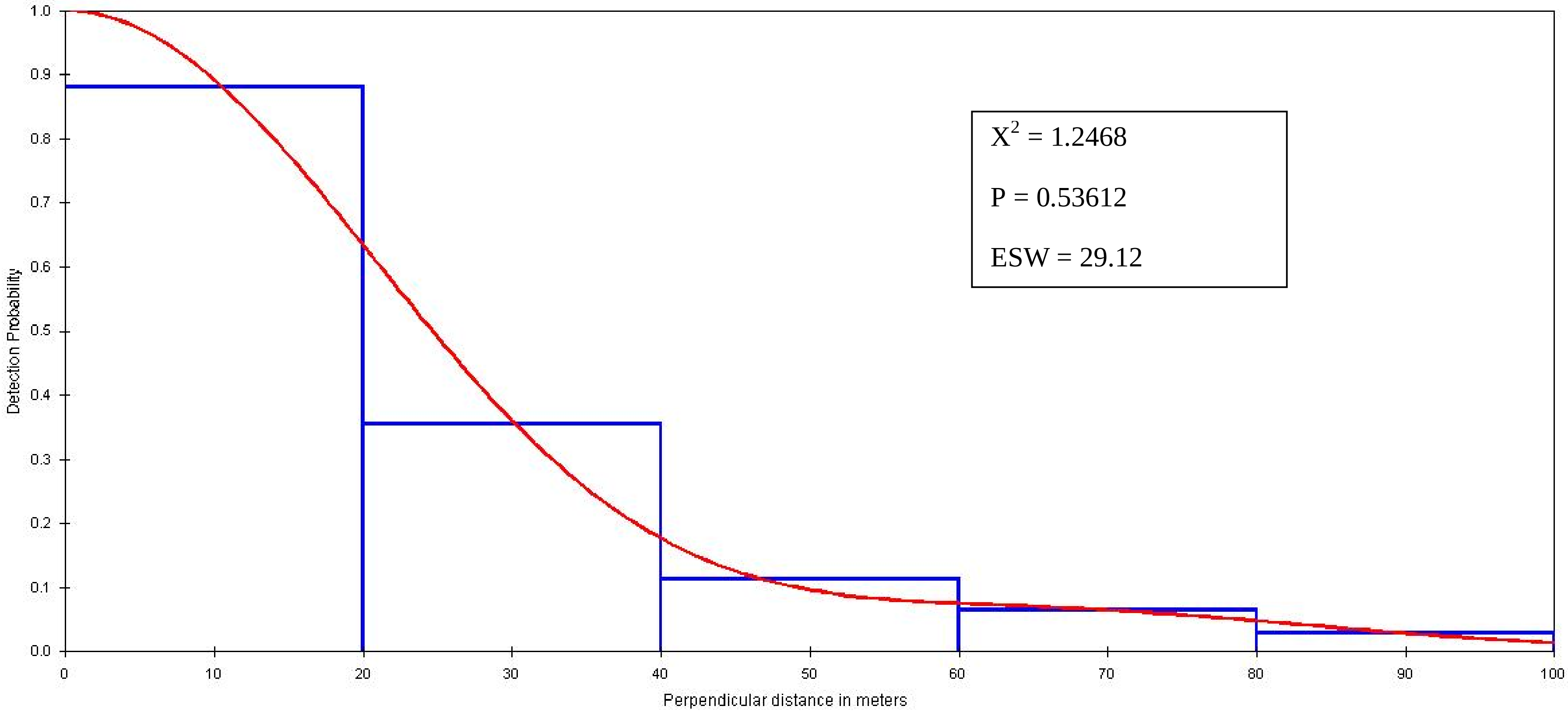


Table 3.3. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2008.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/km^2
		Mean	SE	ER	SE	D	SE	
Chital	64	6.40	0.67	0.37	0.06	44.30	9.26	1993.50
Sambar	71	3.14	0.24	0.44	0.07	25.23	4.83	3153.75
Nilgai	73	2.47	0.21	0.41	0.05	18.91	3.24	3403.80
Wild pig	27	5.44	1.00	0.15	0.03	14.95	4.31	568.10
Peafowl	223	5.35	0.42	1.24	0.10	121.43	15.02	412.86
Cow	38	9.44	1.46	0.21	0.05	36.51	11.51	6571.80
Goat	23	23.13	2.11	0.12	0.03	54.10	16.19	865.60
Hare	27	1.25	0.08	0.15	0.03	3.45	0.92	12.42
Common langur	21	10.33	1.29	0.11	0.02	22.06	6.39	176.48

SE = Standard error Group ER = Group encounter rate D = Density

Figure 3.5. Detection probability curve for all prey species in the intensive study area (National Park) in 2008.

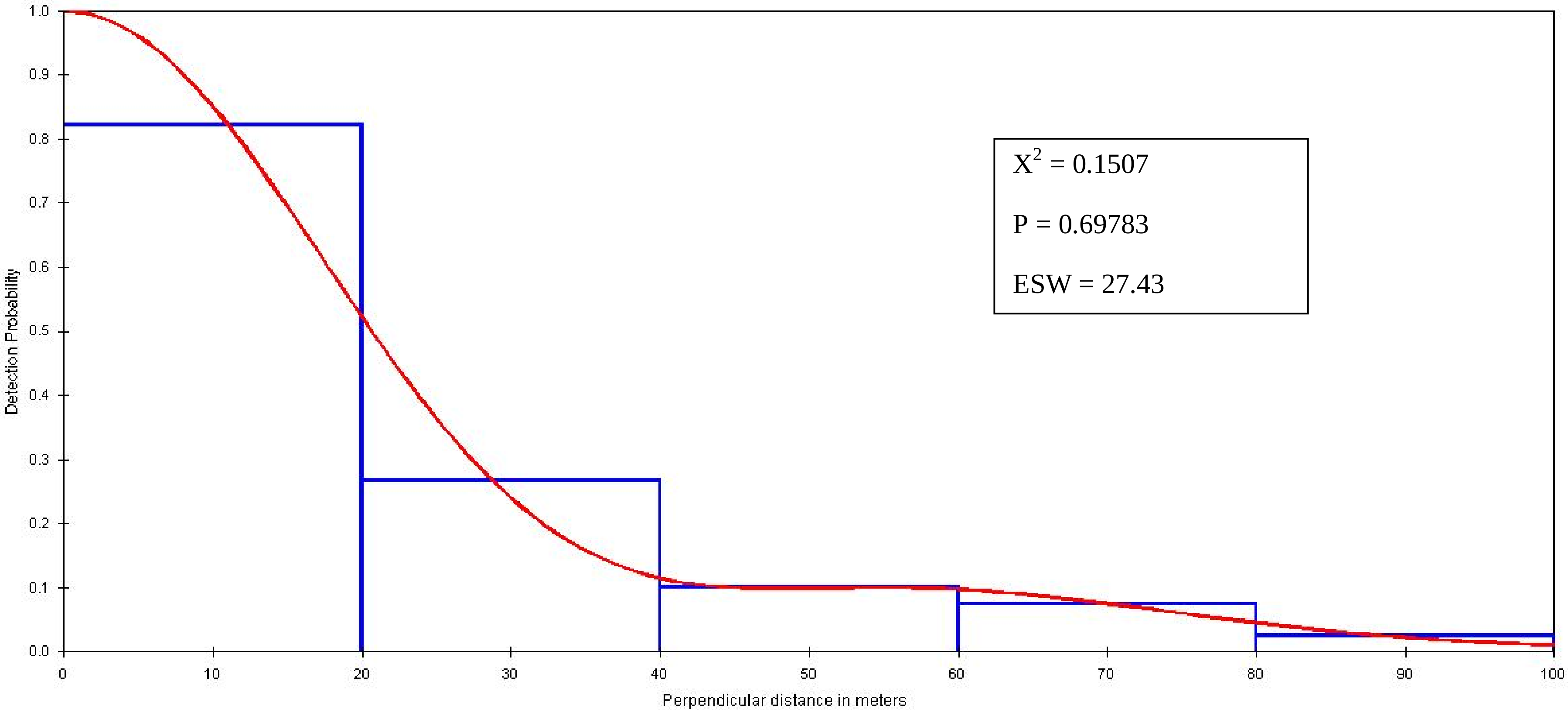


Table 3.4. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2009.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/km^2
		Mean	SE	ER	SE	D	SE	
Chital	63	5.95	0.62	0.34	0.05	40.40	7.97	1818.00
Sambar	49	3.10	0.31	0.26	0.04	16.37	3.09	2046.25
Nilgai	85	2.48	0.18	0.46	0.05	22.73	3.34	4091.40
Wild pig	11	5.63	1.16	0.05	0.02	6.67	2.64	253.46
Peafowl	192	4.86	0.33	1.04	0.10	100.73	12.91	342.48
Cow	21	12.52	5.48	0.11	0.03	28.33	15.31	5099.40
Goat	20	28.50	4.72	0.10	0.03	60.97	24.44	975.52
Hare	14	1.21	0.11	0.07	0.02	1.83	0.66	6.59
Common langur	12	8.83	1.03	0.06	0.02	11.42	3.82	91.36

SE = Standard error Group ER = Group encounter rate D = Density

Figure 3.6. Detection probability curve for all prey species in the intensive study area (National Park) in 2009.

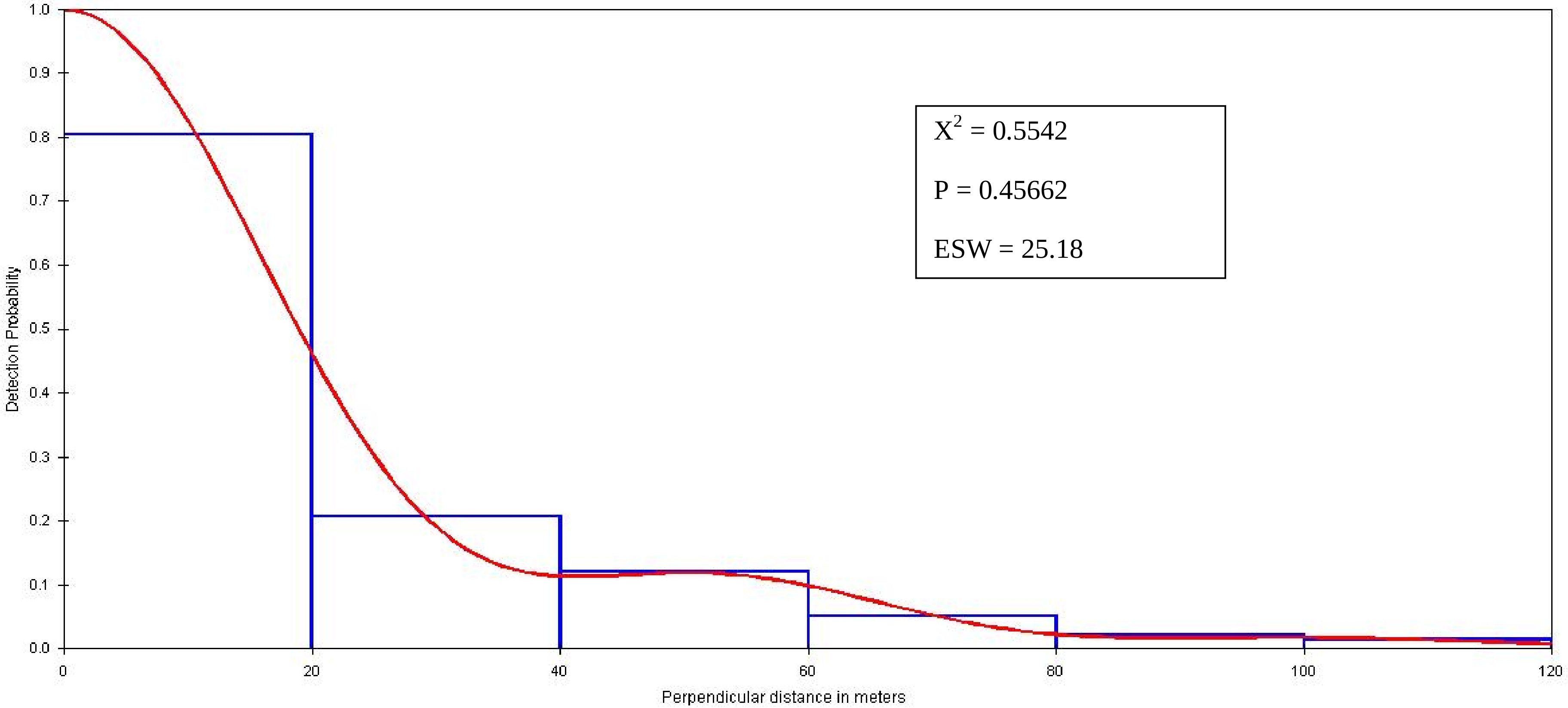
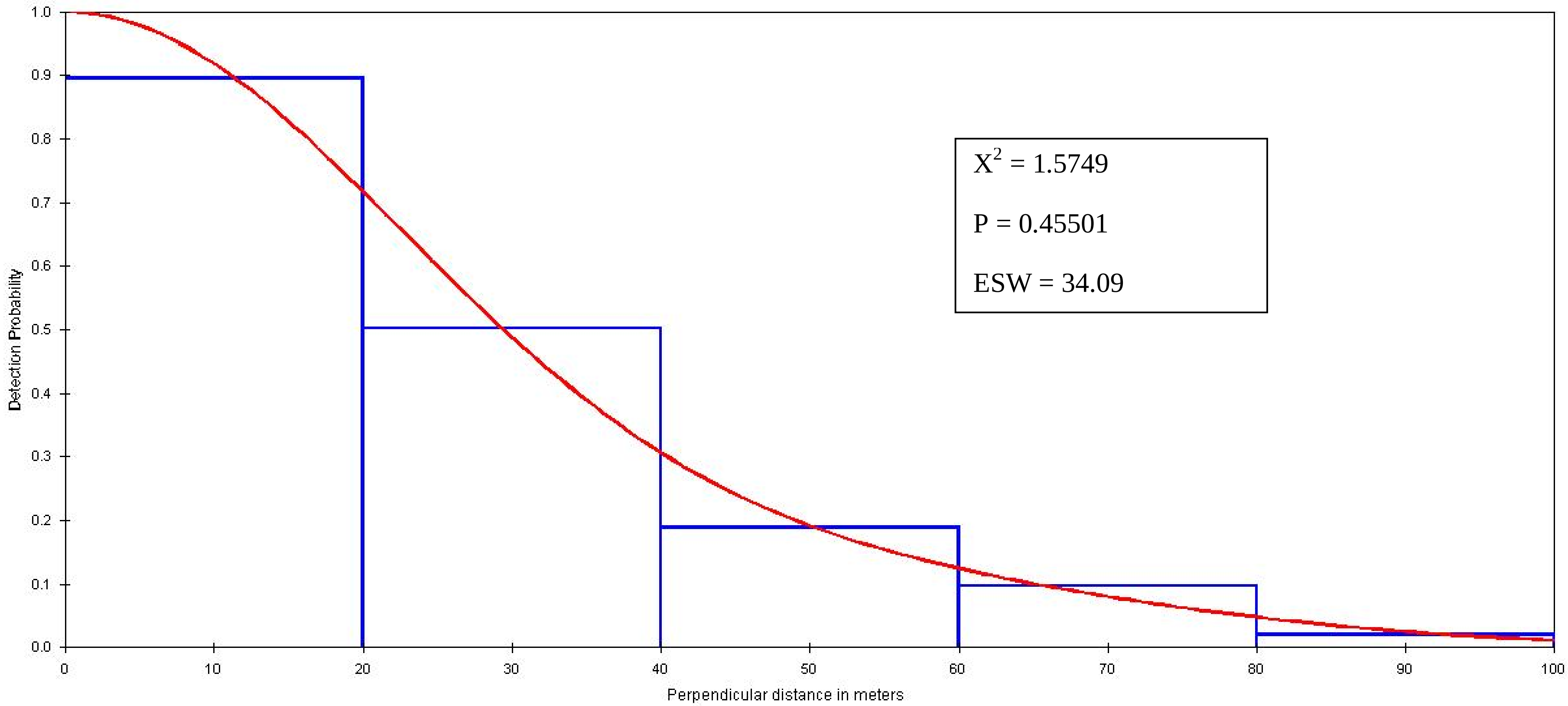


Table 3.5. Density, cluster size and group encounter rate of different prey species in the intensive study area (National Park) in 2010.

Species	No. of sightings	Cluster Size		Group Encounter Rate		Density/km^2		Biomass/km^2
		Mean	SE	ER	SE	D	SE	
Chital	50	3.34	0.25	0.25	0.03	12.55	2.14	564.75
Sambar	54	2.03	0.15	0.27	0.04	8.27	1.44	1033.75
Nilgai	72	2.50	0.17	0.36	0.04	13.53	2.06	2435.40
Wild pig	17	3.17	0.39	0.08	0.01	4.06	1.03	154.28
Peafowl	299	5.06	0.67	1.53	0.13	113.77	18.72	386.82
Cow	24	6.00	0.99	0.12	0.03	10.82	3.87	1947.60
Goat	30	26.13	2.49	0.15	0.03	58.95	14.33	943.20
Hare	21	1.14	0.07	0.10	0.02	1.80	0.40	6.48
Common langur	10	5.70	1.04	0.05	0.01	4.28	1.51	34.24

SE = Standard error Group ER = Group encounter rate D = Density

Figure 3.7. Detection probability curve for all prey species in the intensive study area (National Park) in 2010.



3.5. DISCUSSION

The prey densities estimated from the present study compared with those from other parts of the country revealed that Sariska Tiger Reserve harbors high densities of chital, sambar, nilgai and wild pig (Table 3.6). The density of sambar and nilgai were found higher than any other available studies in the Indian sub-continent (Karanth and Nichols 1998, Khan *et al.*1995, Chundawat 2001 and Banerjee 2005).

Table 3.6. Estimated densities of ungulate species in different protected areas of India.

Locations	Chital*	Sambar*	Nilgai*	Wild pig*	Sources
Sariska TR	20.47	19.13	52.76	25.53	Present study
Ranathambore	31.00	17.15	11.36	9.77	Bagchi *et al.* 2003
Panna	10.80	9.16	6.02	-	Chundawat 1999
Kanha	49.70	1.50	NP	2.50	Karanth and Nichols 1998
Gir	57.30	3.50	0.58	-	Khan *et al.* 1996
Rajaji	22.90	9.23	8.29	-	Mondal 2006
Kuno	4.63	0.31	3.93	-	Banerjee 2005
Pench	80.70	6.09	0.43	2.59	Biswas and Sankar 2002
Keoladeo	9.79	0.75	7.00	2.24	Haque 1990
Mudumalai	55.30	2.80	-	0.40	Ramesh *et al.* 2008

*** Density: number of individuals/ km^2**

The densities of wild ungulate species were found higher in the intensive study area (Sariska National Park) than the other Tiger Reserve area. As the study was conducted covering two seasons, winter and summer, the availability of the grass species like *Chloris dolychostachya*, *Heteropogon contortus* and *Cynodon dactylon* and fallen leaves of *Anogeissus pendula* and fallen *Zizyphus* fruits and leaves might have influenced congregation of chital, sambar and nilgai in the valley habitats of the study area. In winter and early summer, fallen leaves of *Anogeissus pendula* and fallen *Zizyphus mauritiana* leaves and fruits which contain high protein (Sankar 2004), brings large assemblage of ungulates in the study area. The density of common langur was also very high in the study area, because of availability of food plants for common langurs throughout the year.

Several studies have documented the available prey base density in the study area since 1991 (table 3.7). It was evident that the density of nilgai increased in last decade which was an indicator of increase in anthropogenic pressure on the available habitat that resulted in open forest conditions. It was also observed that the sambar density was increased since 2003 after the extermination of tigers from Sariska.

Table 3.7. Estimated densities of wild ungulates in the study area (Sariska National Park) in the last two decades.

Studies	Chital*	Sambar*	Nilgai*	Wild pig*
Mathur (1991)	10.0	5.2	11.1	
Sankar (1994)	30.7	15	18.3	
Avinandan (2008)	27.6	8.4	5.2	17.5
Tiger Task Force (2005)	10.3	13.3	23.3	4.1
Present Study (2007)	33.5	26.1	42.3	31.3
Present Study (2008)	44.3	25.2	18.9	14.9
Present Study (2009)	40.4	16.4	22.7	6.7
Present Study (2010)	12.6	8.3	13.5	4.1

*** - Density (Number of individuals/km^2)**

The decline in densities of prey species in the National Park area (2007-2010) may be attributed to two different reasons i.e. natural and human induced (Figure 3.8). During 2008 and 2010, six tigers were introduced in the study area, and tiger predation on prey species may be attributed as one of the reasons for decline in prey species population. During 2009 and 2010, Sariska TR experienced severe drought in summer. The temperature reached to 49^{o}C in the day time along with scarcity of water for the prey species, which led to a number of sambar mortality in the National Park (>40). In addition, sambar (N=19) and wild pig (N=6) died in the study area due to foot and mouth disease (FMD) during summer 2009. The decline in density of chital may be attributed to the sudden outburst of *Cassia tora* in the study area in 2010. *Cassia tora* is a weed and restrict the growth of palatable grass species, which might have limited the congregation of chital in the valley areas. Seventy sambar were trans-located to Kumbhalgarh Wildlife Sanctuary from Sariska National Park during May-

June of 2010 by the Park authorities which again contributed to population decline of sambar in National Park area.

The density of hare in the study area was found comparatively low than other prey species throughout the study period (Figure 3.8). As the densities of prey species were determined from the data obtained from line transect walks during morning time, the sightings of hare were very less (as they were largely nocturnal), which led in underestimation of its density.

Since there were ten villages inside the study area, the densities of livestock species may be an artifact of overlap between the grazing time by the villagers and time of line transect walking. Sankar *et al.* (2009) studied the livestock population in the study area and estimated 896 cows, 6160 goats and 234 sheep from the villages located inside the Sariska National Park. However, no sheep was recorded on the line transects during the present study.

In India both tropical dry deciduous and tropical moist deciduous forests are equally potential as a wild prey base habitat. Comparing with other dry and moist deciduous forests of the country it was observed that Sariska Tiger Reserve holds a comparable biomass of potential wild ungulate prey species like Bandipur Tiger Reserve and Nagarhole Tiger Reserve (Table 3.8) (Johnsingh 1983 and Karanth and Sunquist 2002).

Table 3.8. Estimated wild ungulate biomass in different dry deciduous forest of the country.

Locality	Forest Type	Biomass Kg/km^2
Sariska Tiger Reserve (Present Study)	Tropical moist deciduous	13779.3
Gir WLS(Berwick 1971)	Tropical dry deciduous and thorn	6342.9
Pench TR (Biswas and Sankar 2002)	Tropical dry deciduous	6013.25
Kanha TR (Schaller 1967)	Tropical moist deciduous	3902.3
Bandipur TR (Johnsingh 1983)	Tropical dry deciduous	14520
Nagarhole TR (Karanth and Sunquist 1992)	Tropical dry and moist deciduous	14744
Kuno WLS (Banerji 2005)	Tropical dry deciduous	2141.03

Figure 3.8. Estimated densities of different prey species in the study area (Sariska National Park) between 2007 and 2010.

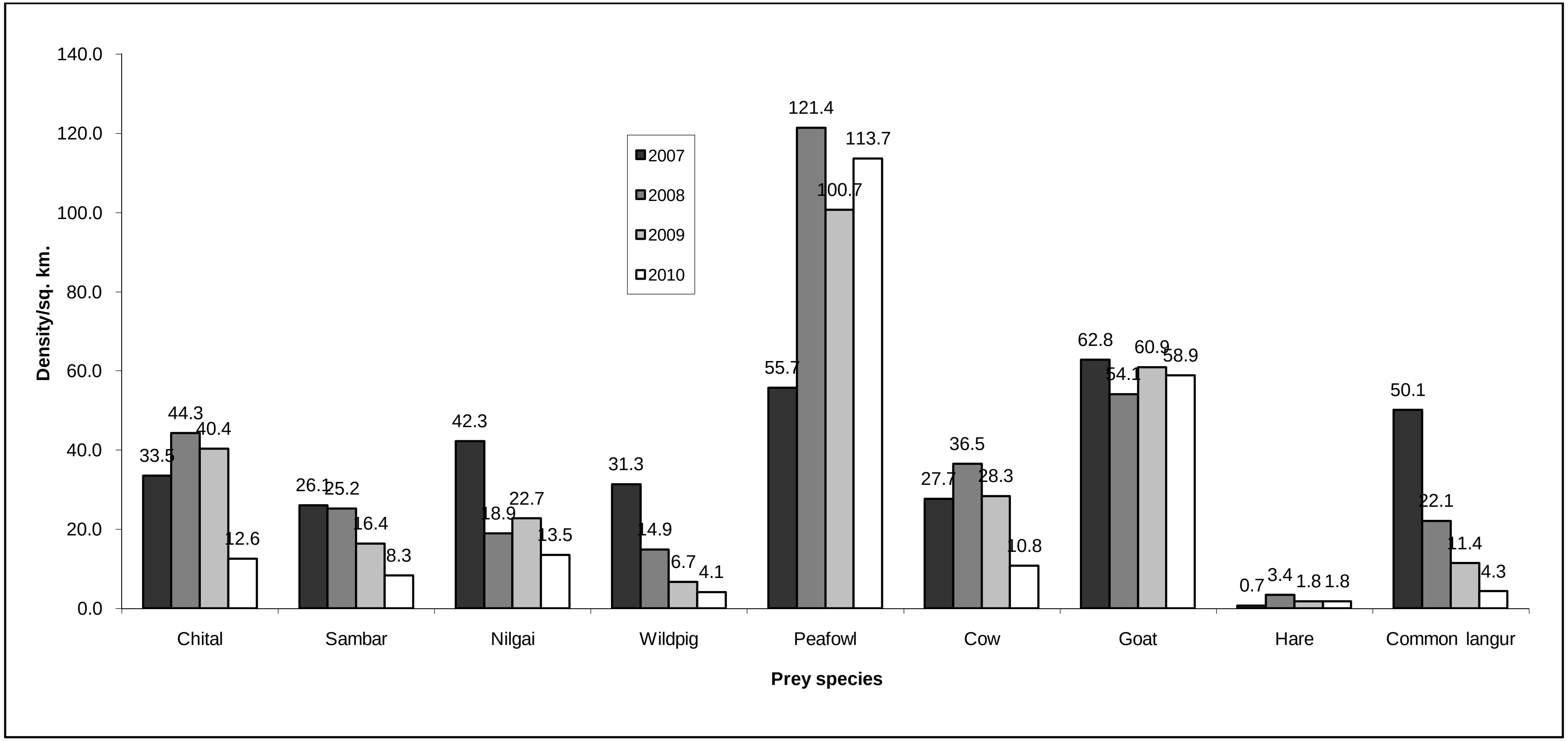


Plate 3a. Chital (*Axix axis*)

Plate 3b. Sambar (*Rusa unicolor*)

Plate 4a. Nilgai (*Boslephus tragocamelus*)

Plate 4b. Common Langur (*Seminopithecus entellus*)

Chapter 4

PREY SELECTION AND FOOD HABITS OF LEOPARD

4.1 INTRODUCTION

The survival of any predator is directly related to its habitat, presence of other competitor species and quality and quantity of its diet (Melville 2004). Prey selection of a predator determines spacing patterns, population growth rate and distribution of the species. The key factors that determine large carnivore habitats are prey abundance, less disturbance, water availability and forest continuity. The acquirement of food is a fundamental component for every predator's existence. Hence, prey selection is critical for understanding life history strategies of any carnivore (Miquelle *et al.* 1996). The leopard is one of the largest obligate terrestrial carnivore in any of the mammalian assemblages in which it occurs and preys on a large range of prey species living in those assemblages (Seidensticker 1997). Study on food habits of leopard comprise one of major determinants of various life history patterns including spacing pattern, movement, habitat selection, success of reproduction and geographical distribution (Krebs 1978, Sunquist and Sunquist 1989, Avinandan *et al.* 2008). The factors affecting prey preference of leopard are a result of a complex interplay of various ecological parameters, which varies at the extremes of distribution of the same species (Sunquist and Sunquist 1989).

In the present study, food habits and prey selection of leopard were examined during the study period following scat analysis method and kill records (Biswas and Sankar 2002, Sankar and Johnsingh 2002, Karanth and Sunquist 1995).

4.2 LITERATURE REVIEW

Among various studies undertaken on ecological, biological and behavioral aspects for carnivores, study on food habits has always been crucial for planning better conservation of species. Historically, dietary studies of a number of species relied on identifying the stomach contents of individuals that were culled (Murie and Lavigne 1986, Spalding 1964). More recently, greater emphasis has been placed on developing non-destructive methods to determine the diet (Korschegen 1980, Putman 1984, Litvaitis 2000). Subsequently, scat analysis has been developed as an alternative technique, which includes the identification and quantification of identifiable parts that have passed through the digestive systems of mammals (Harvey 1989, Corbett 1989, Reynolds and Aebischer 1991, Bowen 2000, Zabala and Zuberogoitia 2003, Tollit *et al*. 2004).

Scats analysis has been widely used to know the food and feeding habits of wild canids and felids by several investigators. Scott (1941) described the methods of computation in feacal analysis with reference to red fox. Windberg and Mitchell (1990) worked on the winter diet of coyotes in relation to prey abundance in Southern Texas. Norton *et al.* (1986) studied the prey utilization of leopard of South Western Cape provinces. Reynold and Aebischer (1991) provided critiques with recommendation based on a study on Fox (*Vulpes vulpes*) for comparison and quantification of the carnivore diet by faecal analysis. Mukerjee *et al.* (1994) further refined and standardized the method of scat analysis for Asiatic lion (*Panthera leo persica*) and leopard (*Panthera pardus*). Tiger food habits have been studied in detail by scat analysis in Sariska TR (Avinandan *et al*. 2008, Sankar *et al.* 2010), Pench Tiger Reserve (Biswas and Sankar 2002), Nagarhole Tiger Reserve (Karanth and Sunquist 1995), Bandipur Tiger Reserve (Johnsingh 1983), Mudumalai Tiger Reserve

(Ramesh *et al.* 2008), Ranathambore Tiger Reserve (Bagchi *et al.* 2003), Kanha Tiger Reserve (Schaller 1967) and Panna Tiger Reserve (Chundawat 2001).

Leopard food habits have been studied in detail in open habitats (Kruuk and Turner 1967, Pienaar 1969, Schaller 1972, Bailey 1993, Henschel *et al.* 2005). Later, leopard's diet has been the subject of study in the dense tropical forests of west and central Africa (Hoppe-Dominik 1984, Ray and Sunquist 2001). Among a number of studies in Asia, food habits of leopard has been studied in Wolong Reserve, China (Johnson *et al.* 1993), Wilpattu National Park, Sri Lanka (Eisenberg and Lockhart 1972), Royal Chitawan National Park, Nepal (Seidensticker *et al.* 1990), Kalakad-Mundanthurai Tiger Reserve, Tamil Nadu (Sathyakumar 1992), Nagarahole National Park, Karnataka (Karanth and Sunquist 1995), Sariska Tiger Reserve, Rajasthan (Sankar and Johnsingh 2002, Mondal *et al.* 2011), Sanjay Gandhi National Park, Maharashtra (Edgaonkar and Chellam 2002), Mudumalai Tiger Reserve, Tamil Nadu (Ramesh *et al.* 2008) and Pauri Garhwal District, Uttaranchal (Chauhan and Goyal 2001). 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 50 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). Leopards tend to select prey smaller than themselves (Johnsingh, 1983, Karanth and Sunquist 1995, Rabinowitz 1989, Schaller 1972, Sunquist 1981, Grassman Jr. 1999). Jhonson *et al.* (1993) studied leopard food habits in Wolong Reserve, China and found a considerable amount of rodent occurrence in leopard diet. Thirty two prey species was recorded in leopard's diet in Marahoue National Park, West Africa (Bodendorfer *et al.* 2006). Hayward *et al.* (2006) estimated prey preference of leopard based on leopard kill records from 29 study sites throughout its distribution.

Leopard can be considered as an ecological generalist, rather than a specialist (Bailey 1993). Leopard predates on species ranging from rodents to buffaloes (Bothma and Riche 1982, Sathyakumar1988, Santiapillai and Ramono 1992, Karanth and Sunquist 1999, Sankar and Johnsingh 2002, Edgaonkar and Chellam 2002, Henschel *et al.* 2005). In India, Karanth and Sunquist (1995) estimated the prey selection by tiger and leopard in Nagarhole Tiger Reserve and they found that leopard consumed large body size prey in less quantity than tiger, though the frequency of occurrence of each prey species were similar in leopard and tiger diet. In Duduwa National Park, Ahmed and Khan (2008) studied the food habits of leopard and found 20 prey items in 74 scats. Edgaonkar and Chellam (1998) studied food habits of leopard in Sanjay Gandhi National Park and reported more than 60% occurrence of domestic dog in leopard's diet. Das (2006) studied the food habits of leopard in high conflict zones of Garwal Himalaya. In the present study area, Sankar and Johnsingh (2002) studied the food habits tiger and leopard and reported high occurrence of rodent species in leopard's diet.

Using the scat analysis, most of information regarding the diet of leopards has been based on frequency of occurrence of prey found in proportion to prey consumed (Hayward *et al*. 2006, Mondal *et al.* 2011). To address the problem of prey size (body weight of prey species) being over represented in scats, a linear regression model has been developed to convert scat data to relative biomass and relative number of prey consumed by cougar, tiger and leopard (Ackerman *et. al.* 1984, Karanth and Sunquist 1995).

4. 3. METHODOLOGY

4. 3. 1. Estimation of food habits of leopard

4.3.1.1. Scat collection and analysis

Leopard scats were collected whenever encountered in the study area during the study period. Leopard scats were differentiated from that of other carnivore species on the basis of diameter (Norton *et al.* 1986, Rabinowitz 1989), pointed ends and numerous lobes (Edgaonkar and Chellam 2002). The scats were collected in paper bags and the date, locality and Global Positioning System (GPS) locations were noted. A number of 66 scats were collected in 2007, 171 scats in 2008, 90 scats in 2009 and 82 scats in 2010. 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. Undigested prey hair which remained in the scat after washing was used for the identification of prey species as described by Mukherjee *et al.* (1994). At least 20 hairs were picked up randomly from each scat for the preparation of slides. A combination of hair characteristics like color, length, width, medullary structure, ratio of medulla width to hair width, cuticular pattern of the prey hairs of each scat collected were observed under a microscope and compared with the reference slides available in the laboratory of Wildlife Institute of India, Dehradun. To determine the effective sample size to understand the food habits of leopard from scat analysis, ten leopard scats were chosen at random and their contents analyzed. This was continued until all the scats in the sample in each year had been analyzed once. The cumulative frequency of occurrence of different prey species in the leopard scats over successive random draws was then assessed for each year to infer the required sample size.

4.3.1.2. Kill data

Leopard kills were recorded whenever encountered in the study area. On each leopard kill, the species were identified and its sex and age class were recorded. The date and GPS locations were also recorded on each kill. In total, a number of 82 leopard kills were recorded during the study period.

4.3. 2. Estimation of relative biomass, number of prey consumed and prey selectivity

The biomass and number of individuals of the prey consumed by leopard was estimated using Ackerman's equation (Ackerman *et al.* 1984). The equation used was as follows: Y= 1.980 + 0.035X, where Y= kg of prey consumed per field collectible scat; X=average weight of an individual of a particular prey type. The assumption for exploration of the above equation is that leopards and cougars *(Felis concolor concolor)* have similar utilization and digestibility (Karanth and Sunquist 1995, Mondal *et al.* 2011). We also presume that the scats containing various prey items have similar decay rates and their detection is equally probable. The average body weights of prey species of leopard required for biomass estimation were taken from Karanth and Sunquist (1995), Sankar and Johnsingh (2002), Ramesh *et al*. (2008) and Mondal *et al.* (2011). The values of Y from the above equation gave the number of collectible scats produced per kill for each prey type. The proportion of number of individual consumption for each species was calculated dividing the biomass contribution of each species by their respective body weight.

Prey selection of leopard was estimated for each species by comparing the proportion of the prey species utilized from scats with the expected number of scats available in the environment for each of the prey species consumed. The expected proportion of scats in the environment (i.e. availability) was calculated using the following equation (Karanth and Sunquist 1995): fi={(di/dt * λi/ Σ {(di/ Σ di—dn) * λi}, (where fi= expected scat proportion in the environment, di= density of i th species, Σ di—dn= sum of the density of all species, λi= X/Y = the average number of collectible scats produced by leopard from an individual of i th prey species, X = Average body weight of the species, Y = Ackerman's equation). To know the prey selection by leopard in the study area, comparison of observed utilization and expected availability was done using Ivlev's index (Ivlev 1961). E = (U – A) / (U + A), where, U = relative frequency occurrence of prey items in predator scats and A = expected scat proportion in the environment. If a species was preyed relatively more frequently than it exists in the prey population then it was considered preferred, whereas if it was taken less frequently it was avoided

The exact variability of prey items in scats was not known and in order to account for that sensitivity analysis was done by changing the coefficient of variance from 10% to 40% (Link and Karanth 1994, Ramesh *et al*. 2008). The data was analyzed using program SCATMAN (Link and Karanth 1994) to evaluate prey preference. Program SIMSTAT (Peladeau 2000) was used for re sampling the scat analysis using 1000 bootstrap stimulation. The original samples were iterated 1000 times to generate the mean and bias corrected for 95% CI.

4. 4. RESULTS

In total, 66 scats were collected in 2007, 171 scats in 2008, 90 in 2009 and 82 in 2010. To know the required sample size to analyze the food habits of leopard in the study area, successively ten scats were randomly drawn from the sample of each year, which gave the cumulative frequency of occurrence of each species for each year (figure 4.2, 4.4, 4.6 and 4.8). The proportion of different prey species in scats got stabilized once a sample 60 scats were analyzed every year (figure 4.1, 4.3, 4.5 and 4.7). Hence, it is suggested that a minimum of 60-70 scats should be analyzed annually to understand the food habits of leopard in the study area. In addition, no new prey species were found after analyzing 60 scats, as shown by diet stabilization curve (figure 4.1, 4.3, 4.5 and 4.7). In total, 12 prey species were identified in leopard's scat during the study period, though only ten prey species were identified in 2007, 2008 and 2010 and nine in 2009. Only one dog remains were found in leopard's scat in 2008. Remains of goat were observed in two leopard scats in 2007. Remains of rodent in leopard scat were observed only in 2007 and 2010.

Frequency of occurrence and percentage frequency of occurrence of prey remains in leopard scats are given in table 4.1 between 2007 and 2010 in the study area. In the year 2007, amongst all the prey species identified from the leopard scats, chital constituted the maximum (23.7%) followed by sambar (21.1%), rodent (14.5%), peafowl (10.5%) cattle (9.2%), nilgai (6.6%), common langur (5.3%), hare (5.3%), goat (2.6%) and porcupine (1.3%).

In 2008, sambar constituted maximum (40.4%) in leopard diet followed by chital (22.4%), nilgai (11.5%), common langur (10.4%), hare (4.4%), cattle (3.8%), porcupine (2.7%), wild pig (2.2%), peafowl (1.6%) and domestic dog (0.5%).

In 2009, amongst the prey species identified from the leopard scats, sambar constituted the most (45.5%) followed by chital (15.2%), nilgai (8.9%), cattle (7.1%), common langur (6.3%), peafowl (6.3%), porcupine (5.4%), hare (2.7%) and wild pig (2.7%).

In 2010, sambar constituted maximum (33.7%) in leopard diet followed by chital (20.8%), cattle (11.9%), common langur (10.9%), peafowl (8.9%), nilgai (5.0.5%), rodent (4.0%), wild pig (2.0%), porcupine (2.0%) and hare (1.0%).

Overall, for the entire study period, sambar contributed maximum (35.2%) in leopard's diet followed by chital (20.5%), common langur (8.2%), nilgai (8.0%), cattle (8.0%), peafowl (6.8%), rodent (4.6%), hare (3.4%), porcupine (2.9%), wild pig (1.7%), goat (0.7%) and domestic dog (0.1%).

The number of scat produced for each animal of each prey species was calculated dividing the average body weight (B) of each prey species by the weight of prey consumed per field collectible scat (Y) (derived from Ackerman's equation) (table 4.2). The production of scat was maximum by nilgai (21.8%) because of higher body weight and high density followed by cattle (21.7%), sambar (19.7%), chital (12.7%), wild pig (11.5%), domestic dog (6.7%), goat (5.9%), common langur (5.7%), porcupine (5.67%), hare (1.7%), peafowl (1.6%) and rodent (0.1%) (Table 4.2).

Biomass contribution of each prey species in different years in the diet of leopard is given in table 4.3. Proportions of number of individual consumption of leopard for each species in different years are given in table 4.3. After comparing the utilization (from scat analysis) and availability (from distance sampling analysis) of prey species, an index of selection of each species was derived (Ivlev's index). It was found that sambar and chital were the most preferred prey species by leopard in the study area throughout the study period. In 2007, Sambar ($P<0.01$) and chital ($P<0.01$) were preyed more than their availability, while nilgai ($P<0.01$) were preyed less than their availability. Common langur, cattle and peafowl were preyed in proportion to its availability ($P>0.05$) (figure 4.9).

In 2008, sambar ($P<0.01$) and chital ($P<0.01$) were preyed more than their availability, while nilgai ($P<0.01$), cattle ($P<0.01$) and peafowl were preyed less than their availability. Common langur was preyed in proportion to its availability ($P>0.05$) (figure 4.10).

In 2009, sambar ($P<0.01$) was preyed more than their availability, while cattle ($P<0.01$) and peafowl were preyed less than their availability. Nilgai, chital and common langur were preyed in proportion to its availability ($P>0.05$) (figure 4.11).

In the year 2010, sambar ($P<0.01$), chital ($P<0.01$) and common langur ($P<0.01$) were preyed more than their availability, while nilgai ($P<0.01$) and peafowl were preyed less than their availability. Cattle was preyed in proportion to its availability ($P>0.05$) (figure 4.12).

The index of prey selection by leopard at individual species level in 2007 was in the following order: sambar > chital > common langur = cattle = peafowl > nilgai (figure 4.9).

The index of prey selection by leopard at individual species level in 2008 was in the following order: sambar > chital > common langur > nilgai > cattle > peafowl (figure 4.10).

The index of prey selection by leopard at individual species level in 2009 was in the following order: sambar > chital = common langur = nilgai > peafowl > cattle (figure 4.11).

The index of prey selection by leopard at individual species level in 2010 was in the following order: common langur > sambar > chital = cattle = nilgai > peafowl (figure 4.12).

In total 82 kills of leopard were recorded in the study area during the study. Sambar contributed maximum (44%) to the leopard’s diet as per the kill records followed by chital (16%), goat (15%), peafowl (7%), nilgai (6%), cattle (6%), wild pig (5%) and common langur (1%) (Table 4.4).

Figure 4. 1. Diet stabilization curve of leopard in the study area in 2007

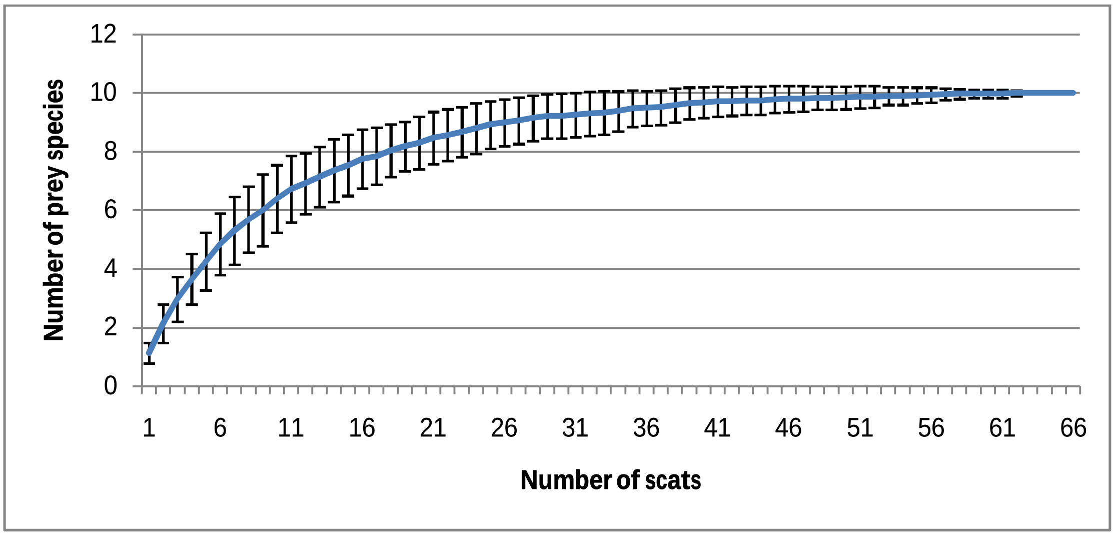


Figure 4. 2. Relationship between contributions of ten prey species in leopard's diet with number of scats studied in the study area in 2007.

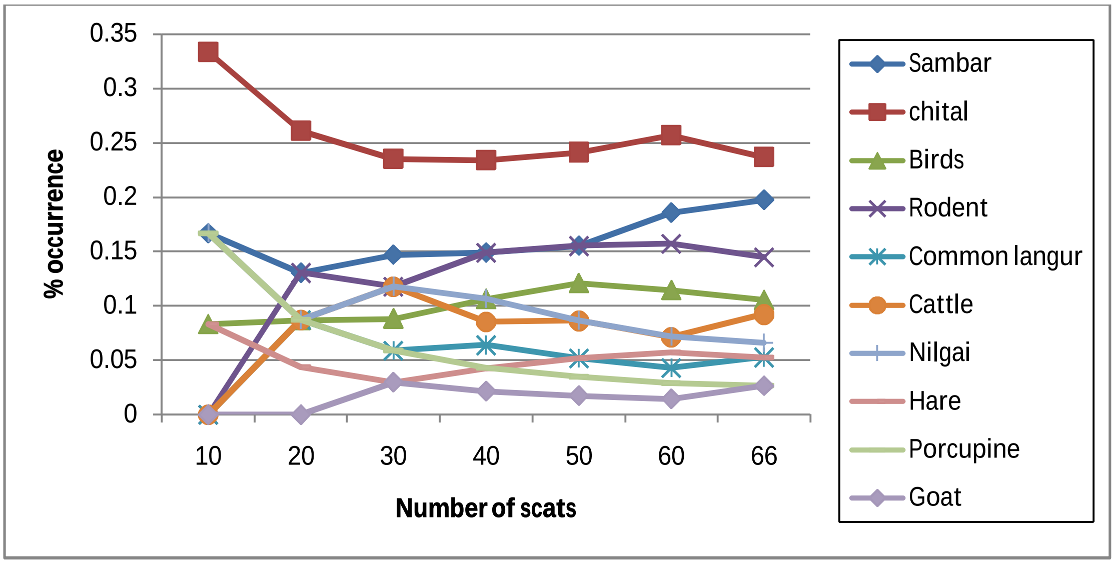


Figure 4. 3. Diet stabilization curve of leopard in the study area in 2008

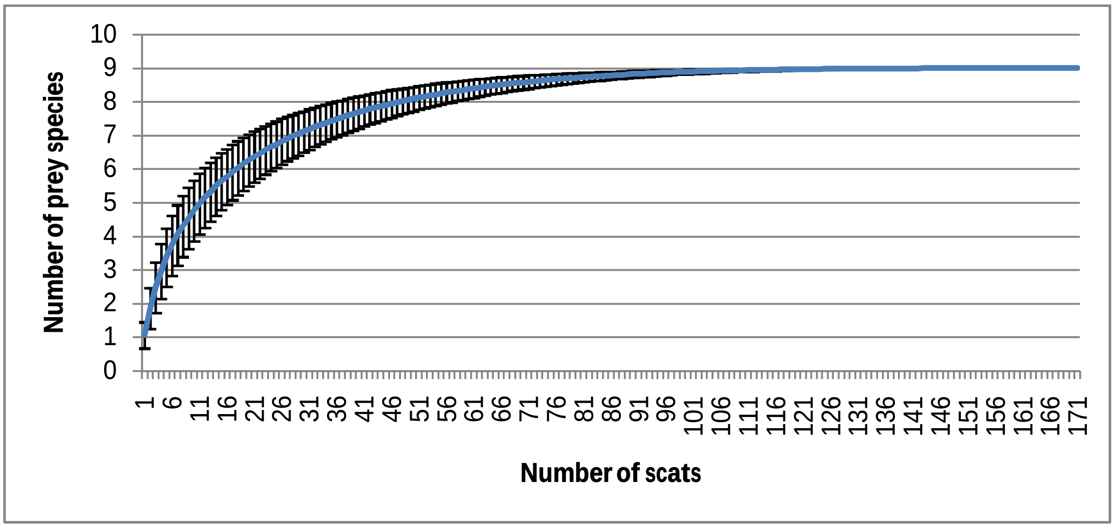


Figure 4. 4. Relationship between contributions of ten prey species in leopard's diet with number of scats studied in the study area in 2008.

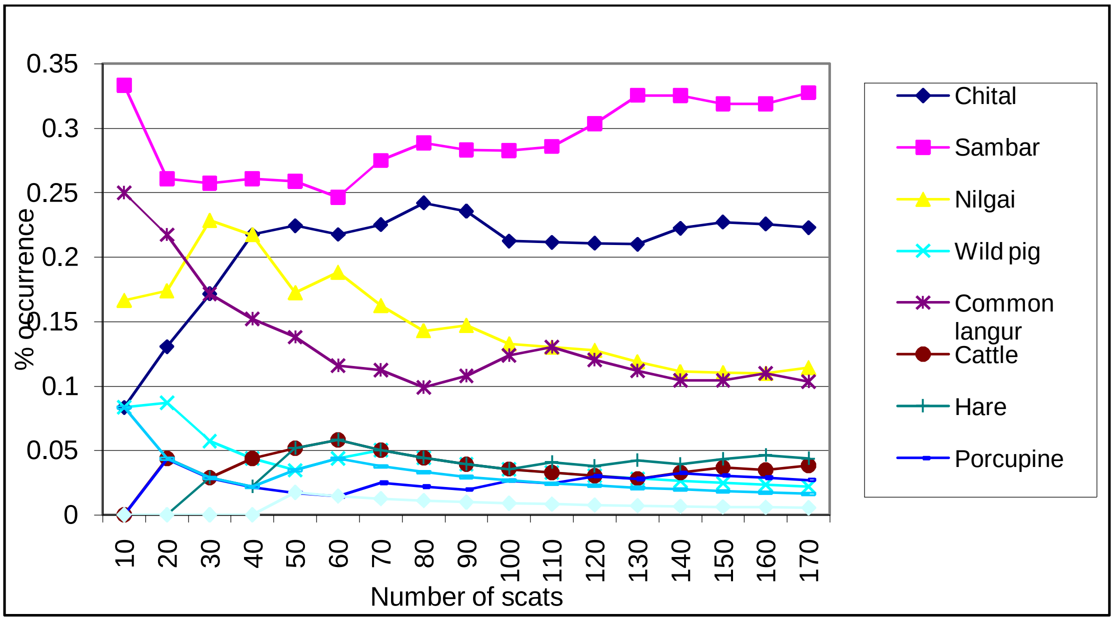


Figure 4. 5. Diet stabilization curve of leopard in the study area in 2009

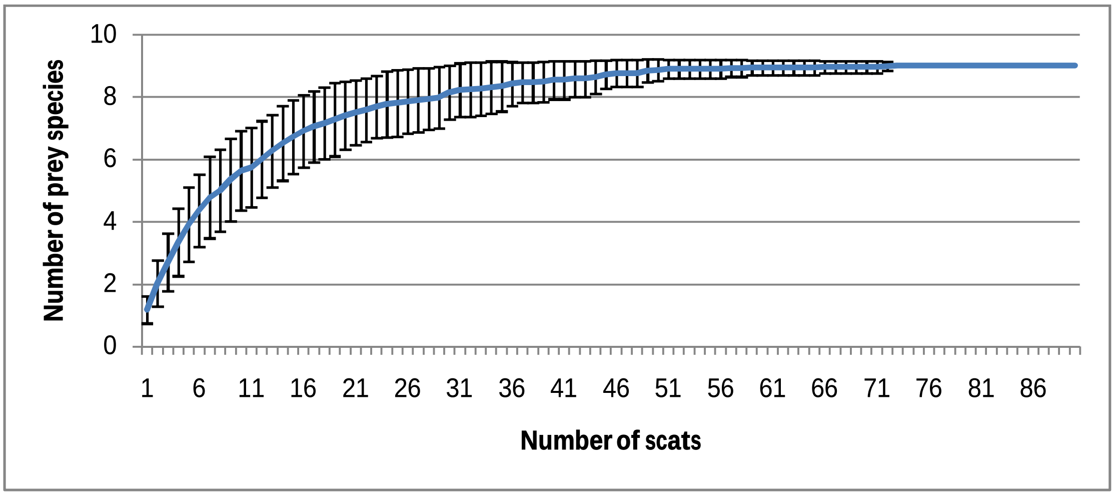


Figure 4. 6. Relationship between contributions of ten prey species in leopard's diet with number of scats studied in the study area in 2009.

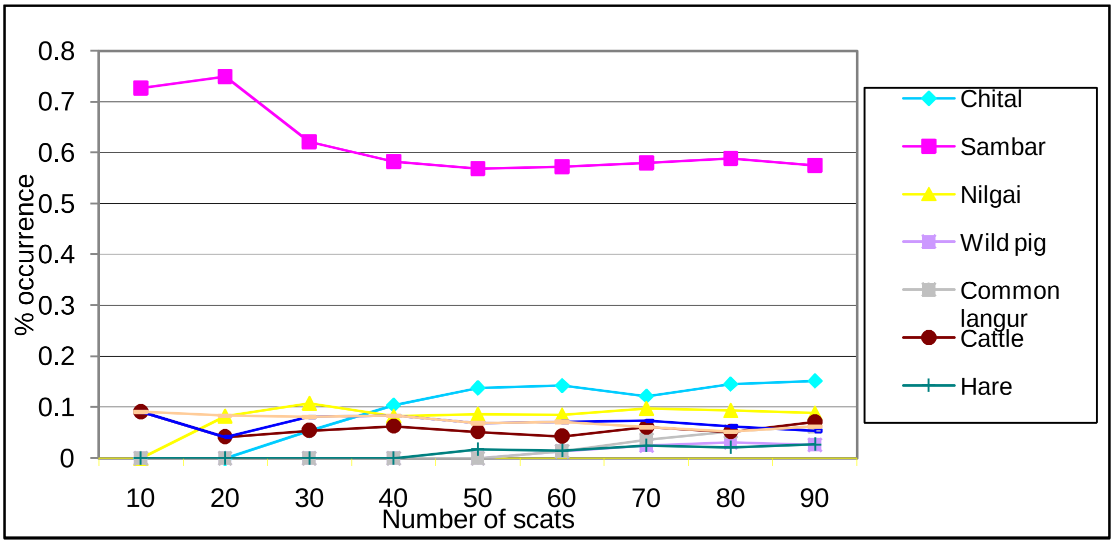


Figure 4. 7. Diet stabilization curve of leopard in the study area in 2010

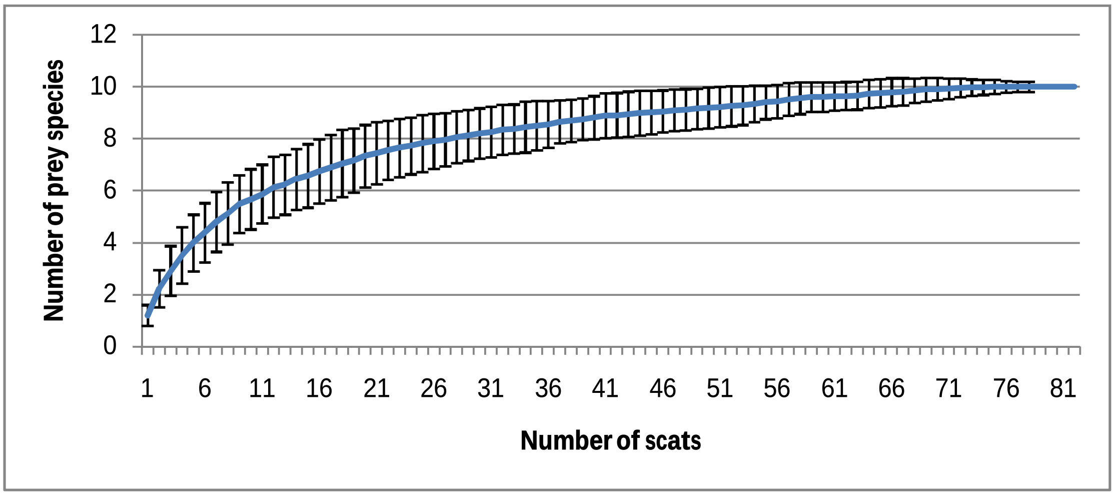


Figure 4. 8. Relationship between contributions of ten prey species in leopard's diet with number of scats studied in the study area in 2010.

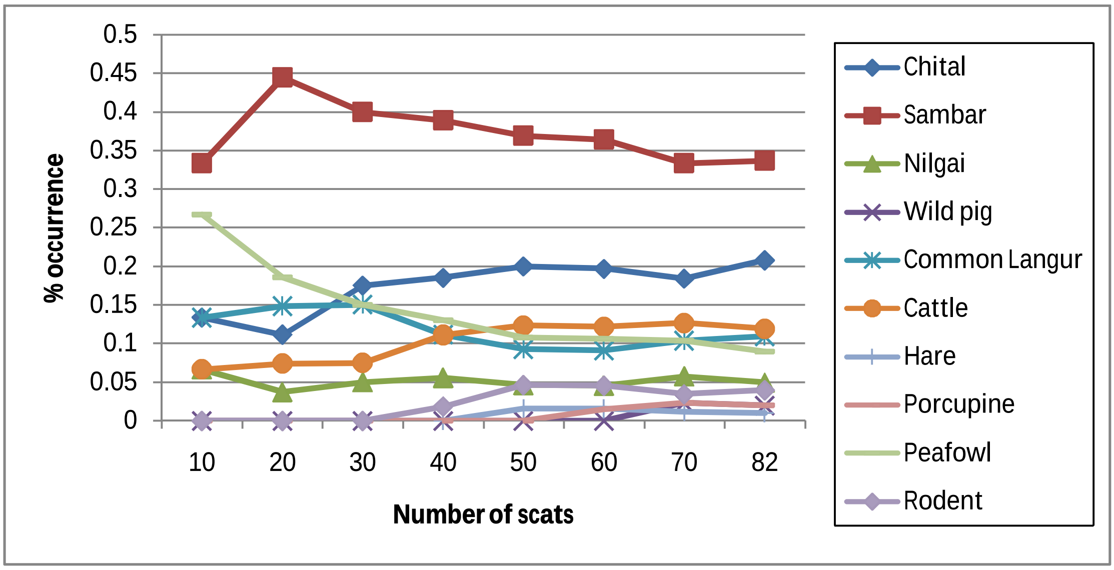


Table 4. 1. Number and frequency of occurrence of each prey species in leopard scats in Sariska National Park (2007-2010).

Species	2007		2008		2009		2010	
	No. of Scats (N=66)	**% frequency of occurrence (%F)**	**No. of Scats (N=171)**	**% frequency of occurrence (%F)**	**No. of Scats (N=90)**	**% frequency of occurrence (%F)**	**No. of Scats (N=82)**	**% frequency of occurrence (%F)**
Chital	18	23.7	41	22.4	17	15.2	21	20.8
Sambar	16	21.1	74	40.4	51	45.5	34	33.7
Nilgai	5	6.6	21	11.5	10	8.9	5	5.0
Wild pig	0	0.0	4	2.2	3	2.7	2	2.0
Common langur	4	5.3	19	10.4	7	6.3	11	10.9
Cattle	7	9.2	7	3.8	8	7.1	12	11.9
Hare	4	5.3	8	4.4	3	2.7	1	1.0
Porcupine	1	1.3	5	2.7	6	5.4	2	2.0
Peafowl	8	10.5	3	1.6	7	6.3	9	8.9
Dog	0	0.0	1	0.5	0	0.0	0	0.0
Goat	2	2.6	0	0	0	0.0	0	0.0
Rodent	11	14.5	0	0	0	0.0	4	4.0

Table 4. 2. Average body weight and proportion of prey consumed of each prey species of leopard in the study area.

Species	Average body weight (Kg)(B)	Prey consumed per field collectible scat (kg) (Y)	Number of scat produced/ Animal (B/Y)
Chital	45	3.555	12.66
Sambar	125	6.355	19.67
Nilgai	184	8.42	21.85
Wild pig	38	3.31	11.48
Common langur	14	2.47	5.67
Cattle	180	8.28	21.74
Hare	3.6	2.106	1.71
Porcupine	14	2.47	5.67
Peafowl	3.4	2.099	1.62
Dog	18	2.61	6.90
Goat	15	2.505	5.99
Rodent	0.2	1.987	0.10

Table 4. 3. Proportion of biomass consumed and number of individual consumed by leopard for different prey species in the study area (2007-2010).

Species	2007		2008		2009		2010	
	Biomass consumed (F x Y) in % (D)	Number of individual consumed (D/B) in n%	Biomass consumed (F x Y) in % (D)	Number of individual consumed (D/B) in n%	Biomass consumed (F x Y) in % (D)	Number of individual consumed (D/B) in n%	Biomass consumed (F x Y) in % (D)	Number of individual consumed (D/B) in n%
Chital	19.77	1.18	15.36	16.57	10.11	10.03	14.94	3.16
Sambar	31.42	0.63	49.55	19.25	54.20	19.36	43.23	3.29
Nilgai	13.01	0.19	18.63	4.92	14.08	3.42	8.42	0.44
Wild pig	0.00	0.00	1.40	1.78	1.66	1.95	1.32	0.33
Common langur	3.05	0.59	4.94	17.15	2.89	9.22	5.44	3.70
Cattle	17.91	0.27	6.11	1.65	11.08	2.75	19.88	1.05
Hare	2.60	1.94	1.78	23.95	1.06	13.10	0.42	1.11
Porcupine	0.76	0.15	1.30	4.51	2.48	7.90	0.99	0.67
Peafowl	5.19	4.10	0.66	9.48	2.46	32.27	3.78	10.58
Dog	0.00	0.00	0.28	0.74	0.00	0.00	0.00	0.00
Goat	1.48	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Rodent	6.75	90.63	0.00	0.00	0.00	0.00	1.59	75.67

Figure 4. 9. Prey selection by leopard in the study area based on availability of individuals and utilization as shown by scat analysis in 2007.

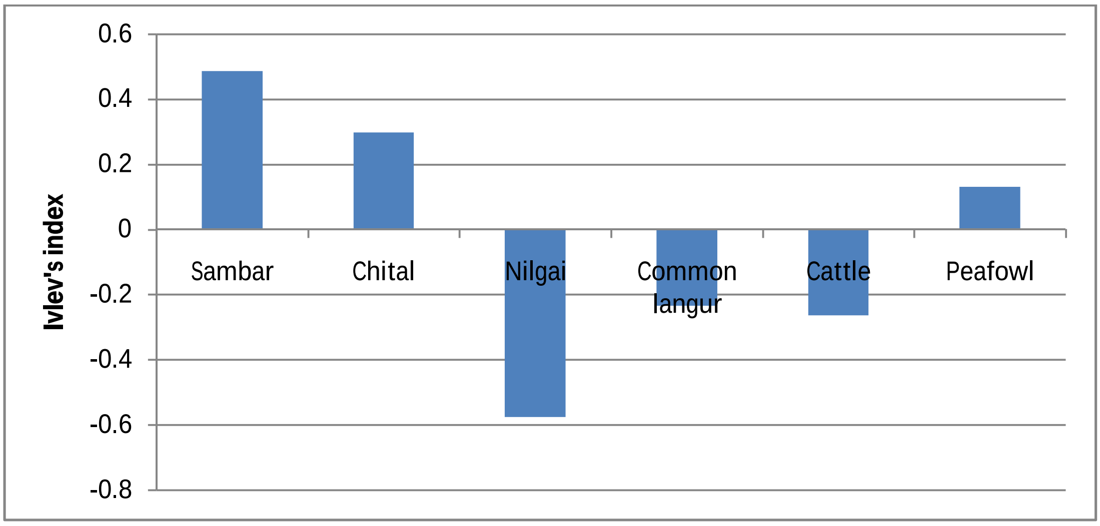


Figure 4. 10. Prey selection by leopard in the study area based on availability of individuals and utilization as shown by scat analysis in 2008.

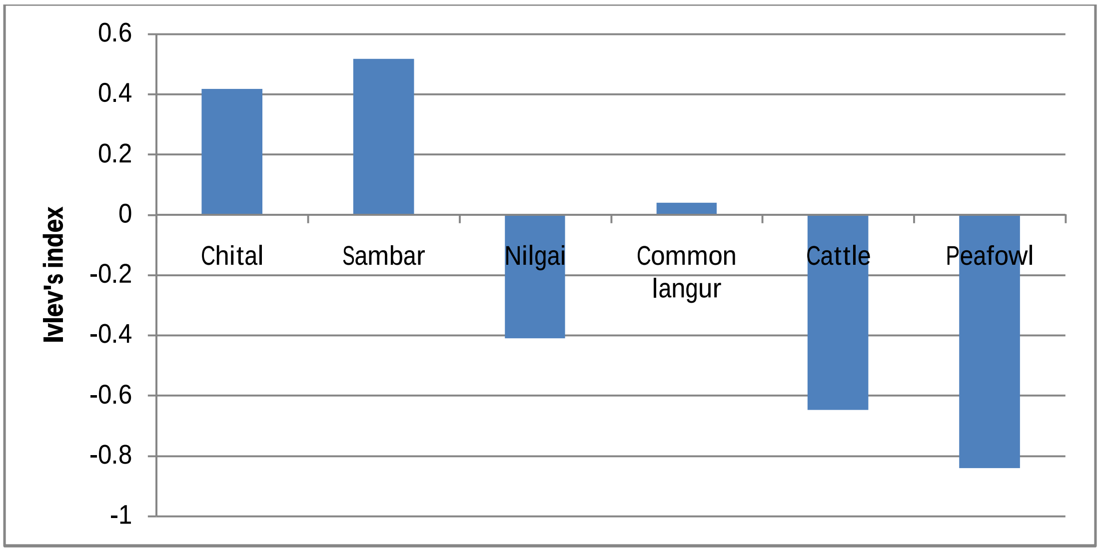


Figure 4. 11. Prey selection by leopard in the study area based on availability of individuals and utilization as shown by scat analysis in 2009.

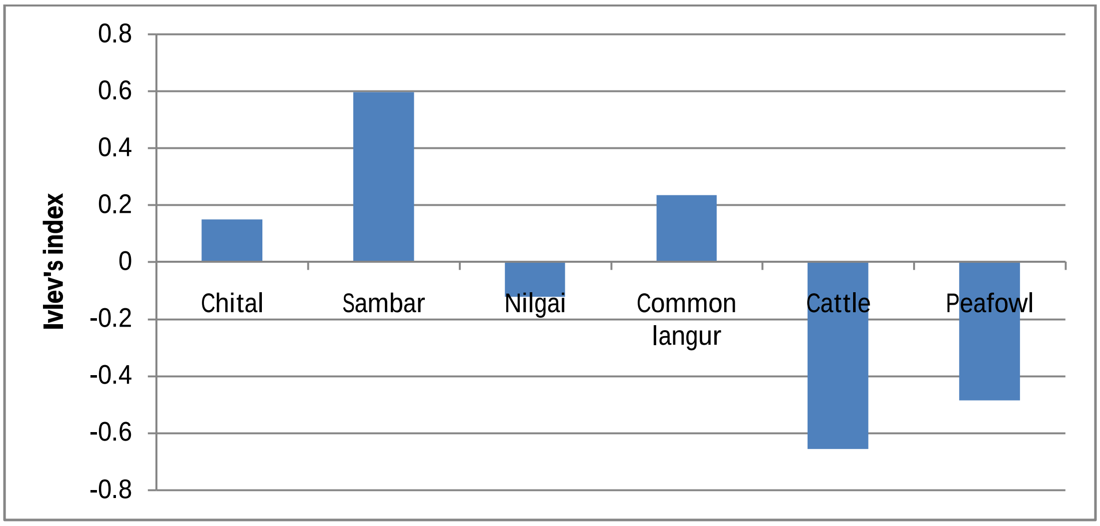
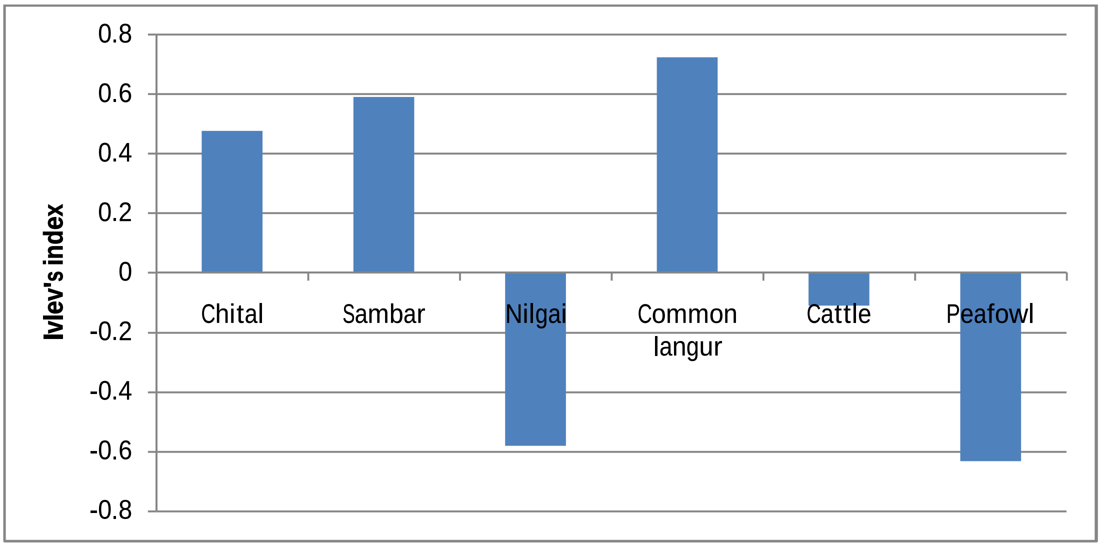


Figure 4. 12. Prey selection by leopard in the study area based on availability of individuals and utilization as shown by scat analysis in 2010.



4. 5. DISCUSSION

From the present study, it was evident that sambar and chital were consumed by leopard more than 50% during the study period in the study area. In terms of prey biomass consumed, chital and sambar contributed most in the diet of large carnivores in India (Bagchi *et al.* 2003, Biswas and Sankar 2002, Avinandan *et al.* 2008, Ramesh *et al*. 2008, Sankar *et al*. 2010, Mondal *et al.* 2011). The estimated density of wild ungulates from this study, when compared with other parts of the country (Haque 1990, Chundawat *et al.* 1999, Khan *et al.* 1996, Biswas and Sankar 2002, Bagchi *et al*. 2003, Banerjee 2005, Mondal 2006), revealed that the study area harbors high densities of chital, sambar, and nilgai **(Chapter 3)**. The high densities of different prey species in the present study may be attributed to the availability of variety of vegetation types ranging from dry thorn forests to riparian forests, availability of food, water and forest protection. The percent occurrence of three ungulates (chital, sambar and nilgai) was relatively higher in the diet of leopard throughout the study period. Peafowl was found to be an important prey species in the diet of leopard in the study area. Though the abundance of peafowl in the study area was the highest in the country (**Chapter 3**), the proportion of consumption of peafowl was less than its availability by leopard

Though sambar and chital found to be the most preferred prey species of leopard as shown by scat analysis, more than 75% sambar and chital kills were adult females, sub-adults of both sex and fawn (table 4.4).

Table 4.4. Age-sex class of prey species observed by kill records of leopard (n=82) in the study area.

Prey species	Number of kill recorded	% frequency	Sex class of kill (numbers)			
			Male	**Female**	**Sub-adult**	**Fawn/calf**
Chital	13	0.16	6	4	2	1
Sambar	36	0.44	6	22	4	4
Nilgai	5	0.06	1	2	0	2
Wild pig	4	0.05	1	1	2	0
Common langur	1	0.01	1	0	0	0
Peafowl	6	0.07	5	1	0	0
Cow	5	0.06	0	5	0	0
Goat	12	0.15	0	12	0	0

When compared with the other studies, predation rate of sambar by leopard in Sariska TR was more than Mudumalai, Bandipur, Nagarhole, Kalakad-Mundanthurai and Dudhuwa Tiger Reserves (table 4.5), but predation of chital was found lower than these areas. More sambar predation in the present study may be attributed to the wide distribution of sambar across the study area while distribution of chital was largely restricted in the valley habitats (Avinandan *et al*. 2008).

Table 4.5. Relative frequency of occurrence of the prey species in diet of leopard based on scat analysis from different study areas in India.

	Chital (%)	Sambar (%)	Common langur (%)	Wild pig (%)
Present Study (2010)	20.8	33.7	10.9	2.0
Mudumalai Tiger Reserve	67.2	11.6	2.7	1.1
Bandipur Tiger Reserve	48.8	6.1	9.1	8.4
Nagarhole Tiger Reserve	43.7	13.5	7.1	4.5
Kalakad-Mundanthurai Tiger Reserve	24.3	9.0	0.9	3.7
Dudhuwa Tiger Reserve	18.9	2.8	1.9	2.1

Mudumalai and Nagarhole: Karanth and Sunquist - (1995), Bandipur: Andheria *et al.* (2007), Kalakad Mundanthurai: Ramakrishnan *et al.* (1999), Duduwa: Ahmed and Khan (2008).

In contrast to most dietary studies of leopard in India and elsewhere, results from this study showed the dominance of wild ungulates in the diet of leopard. Consumption of livestock and smaller rodents which were earlier being reported from many studies (Edgaonkar and Chellum 1998, Sankar and Johnsingh 2002, Das *et al.* 2006) were found negligible in the diet of leopard in the study area. Leopard utilized broad diet during the study period, chital and sambar were the most preferred prey consumed while livestock (cattle and goats) and rodents were supplementary food item.

Small prey constituted a significant proportion of leopard diet in Tsavo, Kenya (Hamilton 1976). Muckenherin and Eisenberg (1973) reported that in Sri Lanka leopard preyed mainly on chital and wild pig, whereas sambar, common langur, black-naped hare, porcupine and calves of domestic buffalo were the other predated species. In India, Schaller (1967), Johnsingh (1983), Karanth and Sunquist (1995, 2000) studied leopard food habits; the major prey reported were chital, sambar, barking deer, goral and livestock. In Bandipur, Johnsingh (1983) found that 66% of leopard's kills were chital. Chellam (1993) found that in Gir, 40% of leopard scats were chital and 25% common langur. In the tropical forest of Nagarhole, Karanth and Sunquist (2000) found that chital constituted the major prey base of leopards. Comparing with previous study, in the present study area, it was found that leopard largely preyed upon rodent when there was an established population of 20-24 tigers in Sariska TR (Sankar and Johnsingh 2002). The present study revealed that, leopard largely preyed upon sambar and chital (table 4.6). Proportion of 44% rodent was reported in leopard's diet in 2002 (Sankar and Johnsingh 2002), whereas during the present study, rodent remains were recorded in negligible proportion and no rodent remains were noted between 2008 and 2009 in leopard diet. Leopard shifted their diet from lesser prey species to large ungulates after tiger extermination from Sariska TR (Sankar *et al.* 2009). Unlike the study of Arivazhagan *et al. (*2007) and Seidenstickker and Lumpkin (1996), where leopards were more likely to move through open terrain and raid villages for domestic prey, in Sariska TR leopard utilized more wild prey species than domestic prey species.

Table 4.6. Percentage occurrence of different prey species of leopard between 2002 and 2010.

Prey Species	% frequency of occurrence				
	2002*	**2007****	**2008****	**2009****	**2010****
Chital	20.2	23.7	22.4	15.2	20.8
Sambar	19.4	21.1	40.4	45.5	33.7
Nilgai	7.0	6.6	11.5	8.9	5.0
Common langur	6.2	5.3	10.4	6.3	10.9
Rodent	44.2	14.5	0.0	0.0	4.0
Peafowl	3.1	10.5	1.6	6.3	8.9

* Sankar and Johnsingh 2002

** Present study

Plate 5a. Leopard scat (fresh)

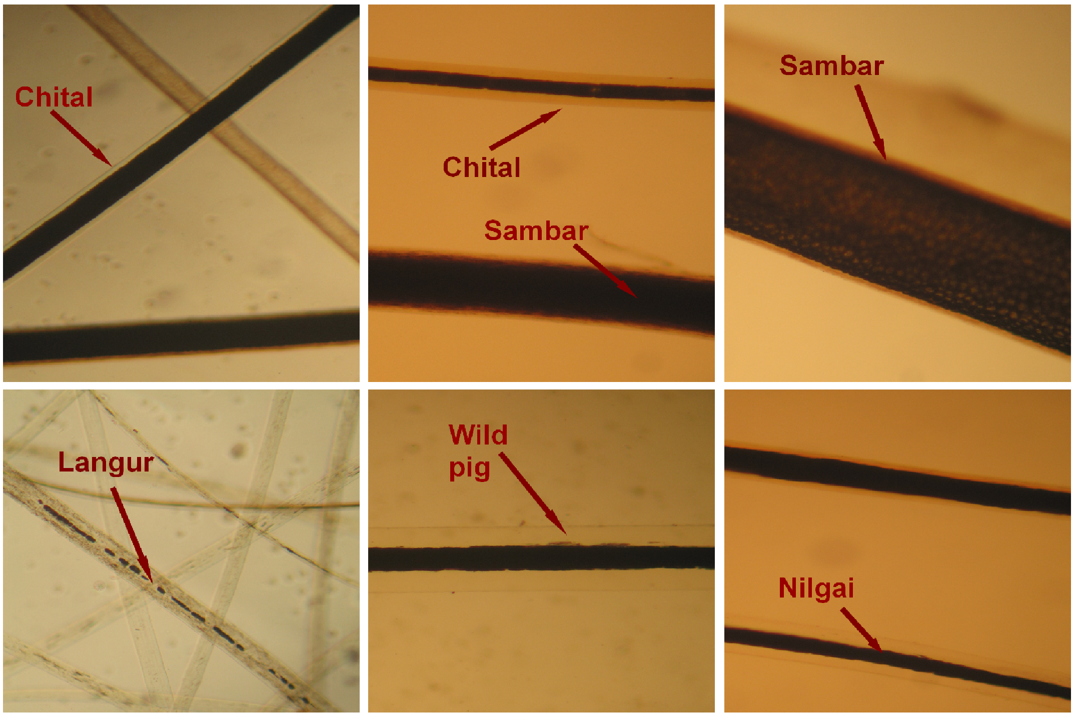


Plate 5b. Micro-histological structures of hairs of prey species

Chapter 5

POPULATION ESTIMATION OF LEOPARD

5.1. INTRODUCTION

Population estimation of carnivores is extremely difficult owing to an extensive spatio-temporal distribution, secretive life, wide ranging behavior, low detectability and low densities (Sharma 2005). With time, several technologically sophisticated methods are evolved to estimate carnivore population. In Indian context, for carnivore density estimation, capture-recapture framework through camera trap has been found useful (Karanth 1995). Camera trapping technique and the use of well developed capture-recapture models have increased the use of remote surveying and monitoring methodologies for identifiable terrestrial carnivore species (Karanth 1995, Jhala *et al.* 2008). Camera traps have also enabled more accurate estimates of species abundance, species distribution, spatial variation and population size of cryptic carnivores like leopard and tiger. With long-term use, camera traps enable monitoring of changes in populations over time.

5.2. LITERATURE REVIEW

Formerly any information regarding cryptic carnivores, were derived either from direct observations or indirect signs (Krucera and Barrett 1993). Estimating the population of tigers and other individually identifiable animals, camera trapping within a capture-recapture framework has been found reliable (Karanth and Nichols 1998, 2000, 2002, O'Brien *et al.* 2003, Trolle and Kery 2003, Karanth *et al.* 2004, Jhala *et. al.* 2008). In the past, tiger or leopard population enumeration was done using traditional methods like ‘Pugmark Census’ (Panwar 1979). In the last two decades the Capture-Recapture technique (Seber 1982) by camera trap photos has been introduced for estimating tiger or felid population (Karanth 1995). The camera trap based on capture-recapture framework to estimate population of large carnivores has proven to be amongst the most successful non-invasive method based on the natural markings on their bodies for species, such as tiger *Panthera tigris* (Karanth and Nichols 1998, Karanth *et. al.* 2004), leopard *Panthera pardus* (Harihar *et al.* 2009, Mondal 2006), jaguar *P. onca* (Silver *et al.* 2004), Geoffrey’s cat *L. geoffroyi* (Cuéller *et al.* 2006), snow leopard *Uncia uncia* (Jackson *et al.* 2006) and striped hyena *Hyaena hyaena* (Gupta *et al.* 2009, Harihar *et al.* 2010).

Since their development in the early 1980s camera traps have become an important tool for monitoring rare, cryptic species in a wide range of environments (Champion 1992, Griffiths and Van Schaik 1993, Karanth and Nichols 1998, Cutler and Swann 1999). Karanth (1995) initiated the use of camera traps within mark-recapture framework to estimate the densities of tiger. Carbone *et al.* (2001) proposed the use of photographic rates to estimate the densities of tigers and other cryptic mammals. They also emphasized the use of the technique proposed by them in arriving at abundance estimates of animals that do not have a unique identification. However Jennelle *et al.* (2002) pointed out the shortcomings of this approach and concluded that when individuals can be identified, the best value of camera trapping technique are obtained within the mark-recapture framework. Eventually, the camera trapping technique was used widely and issues regarding sampling design received more attention. Wegge *et al*. (2004) in their study in Royal Bardia National Park in Nepal showed the effects of trapping effort and trap shyness on estimates of tiger abundance.

Camera trap data are increasingly being used to address questions about spatial and temporal dynamics of animal populations. Karanth *et al*. (2004) used empirical information on the proportions of prey populations typically taken by tigers and on the kill rates of individual tigers to develop a model predicting tiger density as a function of prey density. They obtained camera trap estimates of tiger densities and distance-sampling estimates of prey densities from 11 sites throughout India. Questions about temporal dynamics can be addressed by sampling the same areas at multiple points in time. For example, Karanth *et al.* (2006) used camera traps to sample tigers at Nagarahole Park periodically from 1991 to 2000. This work resulted in estimates of annual survival probability and of population growth rate that were used to draw inferences about population viability and stability.

Camera trap surveys at relatively large geographic scales can be used to estimate occurrence of a species across the landscape using occupancy models (Nichols and Karanth 2002, MacKenzie *et al.* 2006) that do not require individual identification. For example, MacKenzie *et al*. (2005) used data on gaur (*Bos frontalis*) at different study areas in Malaysia to test hypotheses about area-specific variation in probabilities of occupancy. O'Connell *et al*. (2006) used occupancy modeling in conjunction with camera trapping (and two other sampling methods) to select from a variety of hypotheses about the influence of habitat on occupancy of several species of medium and large-sized mammals on Cape Cod, Massachusetts, USA. Camera trap studies can also be used to test hypotheses of community ecology (Tobler *et al*. 2008). Species list data can be obtained for species photographed in different locations and resulting data can be used to draw inferences about species richness using capture-recapture (Burnham and Overton 1979, Nichols and Conroy 1996) or occupancy (MacKenzie *et al. 2*006; Royle and Dorazio 2008) approaches to modeling. Both modeling approaches lead directly to approaches for drawing inference about variation over time and space as well (Nichols *et al*. 1998, Williams *et al*. 2002, Dorazio and Royle 2005, Royle and Dorazio 2008).

Since individual leopard are readily identifiable using the rosettes on the body (Schaller 1967, McDougal 1977, Karanth 1995,), the sight-resight (White 1996) or capture-recapture approach can be used to estimate population parameters. The mark–recapture theory requires that all individually identifiable animals will have to be identified with surety. Several studies reported leopard population estimate or density under this framework worldwide in different forest types. Harihar (2009) and Mondal (2006) estimated leopard density in moist deciduous habitat using mark-recapture framework in different ranges of Rajaji National Park. Research on the Sri Lanka sub-species of leopard (*Panthera pardus kotiya*) has largely focused on populations of Yala National Park (Kittle and Watson, unpublished) and Wilappatu National Park (Eisenberg and Lockhart 1972, Muckenhirn and Eisenberg 1973), representing dry climatic zones of the southeast and northwest extents of the country. In Bhutan, Wang and Mcdonald (2009) also used camera trap technique for estimation of leopard population in Jigme Singye Wangchuck National Park. Waseem (2008) developed monitoring protocol for leopard in Northern Pakistan based on capture-recapture framewrok.

5.3. METHODOLOGY

5. 3. 1. Estimation of population of leopard

To estimate the population of leopard, camera trapping data was collected from January 2007 to June 2010 in the study area. A preliminary survey was carried out during November to December 2006 in the intensive study area of 160 km^2 in the

Sariska National Park by surveying available trails (figure 5.1). Indirect signs such as pugmarks and scats of leopard were identified and marked using a hand held Global Positioning System. The entire study area was divided into two 80 km^2 blocks and each block was subdivided into 20 grids of 2x2 km^2. One pair of cameras was placed in each 2x2 km^2 grid (figure 5.1). Camera traps were placed on the basis of leopard evidence (pugmark, scats) on the trails.

A comprehensive overview of camera trapping tigers and leopards for the purpose of estimating abundance is given by Karanth (1995) and Karanth and Nichols (1998). The concept of the camera traps in the area of interest should be in a manner that to maximize the chances of photographing the resident animals. The main concern was to cover the area fairly completely, in the sense that it would be difficult for a leopard in the sampled area to travel about and not encounter at least one camera trap (Karanth and Nichols 2002).

Forty units of analog cameras were used which worked on passive infrared motion/ heat sensors. The camera traps were equipped with 35 mm lens and recorded the date and time of each photograph. The camera delay was kept at minimum (15 seconds) and sensor sensitivity was set at high. A total of 40 locations were selected for the placement of camera traps in the study area. Every two nights were considered as a single occasion, resulting in 44 occasions and effort of 3520 trap nights in 2007, 59 occasions and effort of 4320 trap nights in 2008, 65 occasions and effort of 5200 trap nights in 2009 and 43 occasions and effort of 3440 trap nights in 2010. Individual leopard obtained from camera trap photographs were identified by combination of distinguishing character such as position and shape of rosettes on flanks, limbs and forequarter (Schaller 1967, Karanth 1995). Any photograph with distorted perspective or which lacked clarity, were discarded (n=7). Every leopard captured was given a unique identification code like L1, L2, L3 etc.

Capture history of each individual was generated in an X matrix format (Otis *et. al* 1978). Occasion-wise capture matrix was prepared for the analysis of population estimation. Estimation of population size using closed capture models requires the population under investigation to be both demographically and geographically closed. Population closure test was performed using software CAPTURE (Otis *et. al* 1978; Rexstad and Burnham 1991). The density (D) of leopard in the study area was estimated using different methods such as spatially explicit model (Efford 2004) using program DENSITY 4.1 (Efford 2004) and SPACECAP (Singh *et al.* 2010), full MMDM, half MMDM, spatially explicit Inverse Prediction density (IP dens) and spatial maximum likely-hood density (ML dens) (Efford 2004).

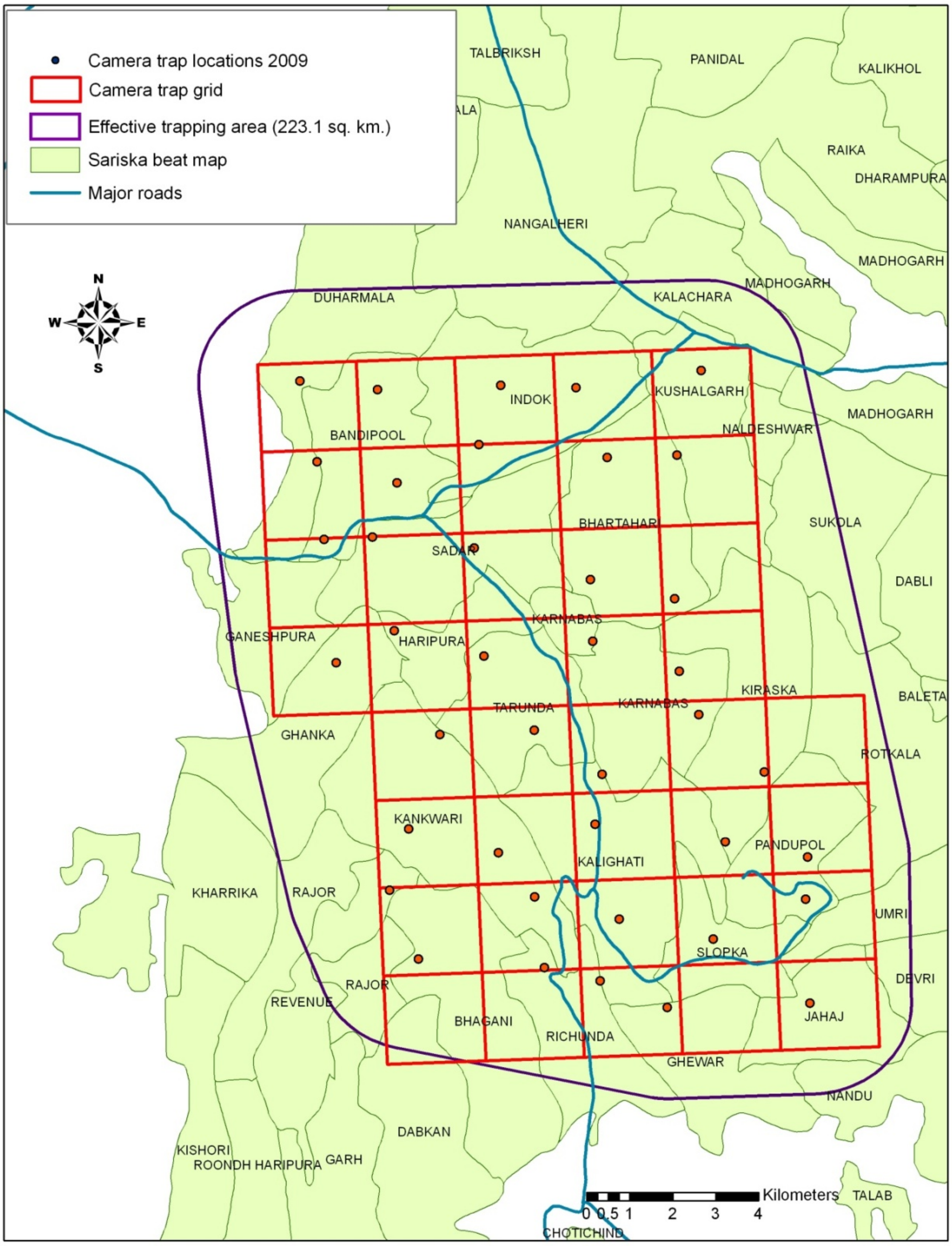
5. 3. 2. Estimation of survival rates of leopard

To estimate the survival rates of leopard in the study area, the same X matrix (Otis *et. al* 1978) was used following 'Robust Design' (Pollock 1982, Kendall *et al*. 1995, 1997, Williams *et al*. 2002) model in program MARK (White and Burnham 1999). The study consisted of four "primary periods" sampling covering four years. The leopard population was expected to be open to gains and losses between these primary periods. There were multiple "secondary sampling periods" within each primary period. Each occasion in the primary sampling period was considered as one secondary sampling period and the population was assumed to be closed to gains and losses among these secondary periods.

The analytic methods dealt with possible effects of individual heterogeneity, trap-response behavior, and time-related variations on capture probabilities (Otis *et al*. 1978, Williams *et al.* 2002, Karanth *et al.* 2006). Given prior knowledge about leopard movements, temporary emigration (the probability of an individual leopard not being available for trapping during one or more primary sampling period); transience (the probability that a newly captured individual leopard was just passing through the study area, with a near-zero chance of returning to be recaptured during the study); and losses (the probability of death or permanent emigration) were considered (Karanth *et al*. 2006).

Population closure test on capture data from each primary period was done separately, using program CAPTURE (Otis *et al*. 1978, Rexstad and Burnham 1991). I also investigated the modeling of capture probabilities by assessing the discriminant function model selection statistics for the four likely models (Otis *et al.* 1978) for leopard data: M^0 (constant capture probability), M^h (capture probability heterogeneous among individuals), M^{bh} (behavioral response in capture probability with heterogeneity among individuals), and M^{tbh} (capture probability affected by secondary sampling period, trap response, and heterogeneity). Accordingly, the overall X matrix was analyzed to estimate the survival rates for the entire study period and also for each primary sampling period in the study area.

Figure 5.1. The location of camera traps and effective trapping area in the study area.



5.4. RESULTS

5. 4. 1. Photographic capture of leopard

The camera trapping resulted in a total of 71 photographs of 19 individual leopards in 2007, 64 photographs of 17 individuals in 2008, 61 photographs of 14 individuals was recorded in 2009 and 34 photographs of 8 individuals in 2010. The 40 trapping locations covered minimum convex polygon area of 118 $km^2$and an effective trapping area (ETA) of 206.1 km^2, 223.8 km^2, 223.1 km^2 and 250.5 km^2 with a buffer of half mean maximum distance moved model (1/2 MMDM) in 2007, 2008, 2009 and 2010 respectively (table 5.1).

Table 5.1. Primary and secondary sampling periods, sampled areas, camera-trapping effort and number of individual leopards photo-captured at Sariska from 2007 to 2010.

Primary Period	No. of secondary period	No. of days	Effective trapping area	Effort trap nights	No. of leopards caught	Cumulative number of leopards caught
1 (2007)	44	88	206.6	3520	19	19
2 (2008)	59	108	223.8	4320	17	25
3 (2009)	65	130	223.1	5200	14	32
4 (2010)	43	86	250.5	3440	8	34

5. 4. 2. Model selections

The statistical test for population estimation of leopard using program CAPTURE (Otis *et. al* 1978; Rexstad and Burnham 1991) was consistent with the assumption that the population was closed for the duration of study (2007-2010) (Otis *et. al.,* 1978). The model selection algorithm of CAPTURE identified Mh as most appropriate model which was highest in the model selection criteria for the entire study period (table 5.2). High model score indicates a better relative fit of the model to the specific capture history data generated by the survey. For each analysis, the program CAPTURE estimated capture probabilities per sample (p-hat) and the leopard population size, (i.e. the number of leopard in the sampled area, inclusive of animals that were not photo-captured at all). Although Mo scored high in 2008 and 2010, this model is not robust to any deviations from the model assumption of homogeneous capture probabilities among individuals. Mh jackknife and half normal detection function for spatially explicit density was used for all the four years (2007-2010) to estimate the leopard population in the study area. The overall model selection test based on discriminant functions comparatively scored over various models between 2007 and 2010 is given in Table 5.2.

Table 5.2. Tests for population closure and model selection statistics based on leopard photographic capture history data in Sariska from 2007 to 2010.

Primary Period	**Closure test Z**	**Closure test P**	**Model score**			
			M^0	**M^h**	**M^{bh}**	**M^{tbh}**
1 (2007)	-2.889	0.0669	0.98	1.00	0.63	0.68
2 (2008)	-6.042	0.0536	1.00	1.00	0.48	0.59
3 (2009)	-3.525	0.0684	0.94	1.00	0.64	0.64
4 (2010)	-1.906	0.0749	1.00	1.00	0.53	0.61

5. 4. 3. Required sampling efforts

Population estimates were calculated using model Mh by considering same camera trapping design and systematically in the same study area between 2007 and 2010. The estimate suggests that minimum 50 days of sampling is required to get reliable estimates of the population of leopard in 220 to 250 km^2 effective trapping area of Sariska National Park **(**Figure 5.2 to 5.5**)**. This method was used to understand whether the primary period of camera trapping in each year was adequate to capture all the resident individuals in the study area. Subsequently, the result also helped to optimize the trapping effort and minimum cost for camera trap studies for leopard in the study area in each year.

Figure 5. 2. Number of individual leopard and number of total photographs with increasing number of sampling occasions to evaluate sampling adequacy in 2007.

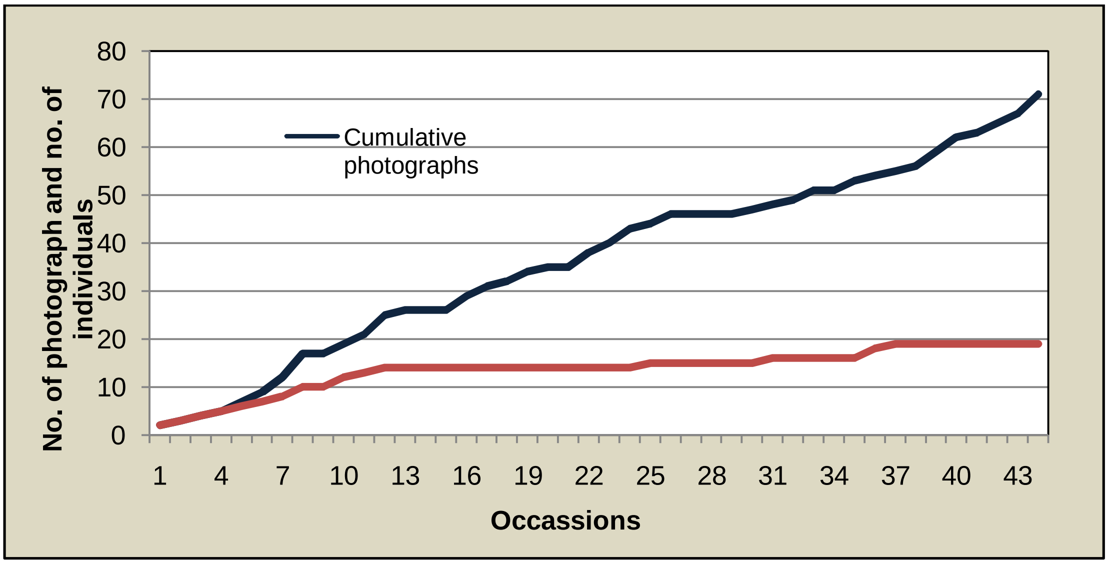


Figure 5. 3. Number of individual leopard and number of total photographs with increasing number of sampling occasions to evaluate sampling adequacy in 2008.

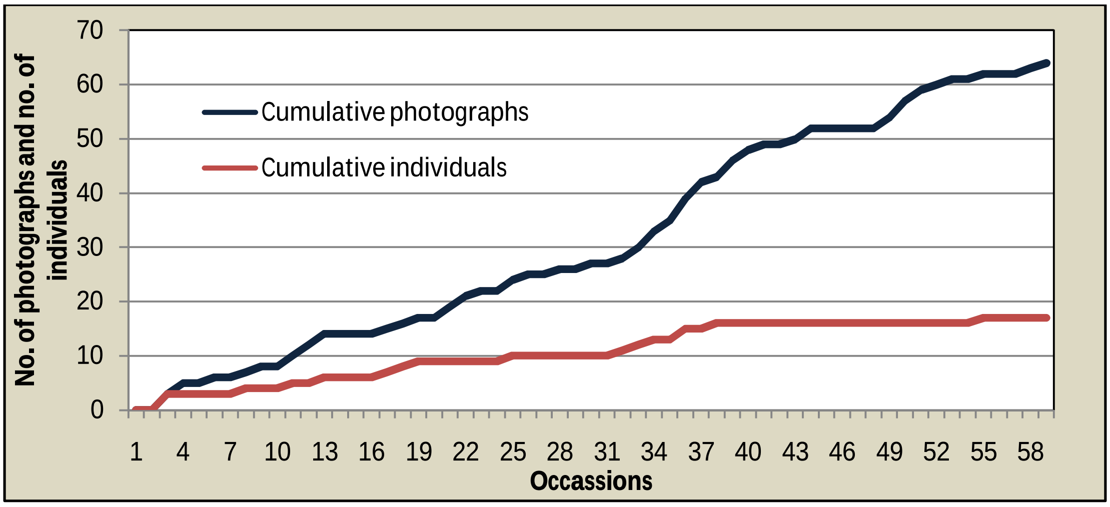


Figure 5. 4. Number of individual leopard and number of total photographs with increasing number of sampling occasions to evaluate sampling adequacy in 2009.

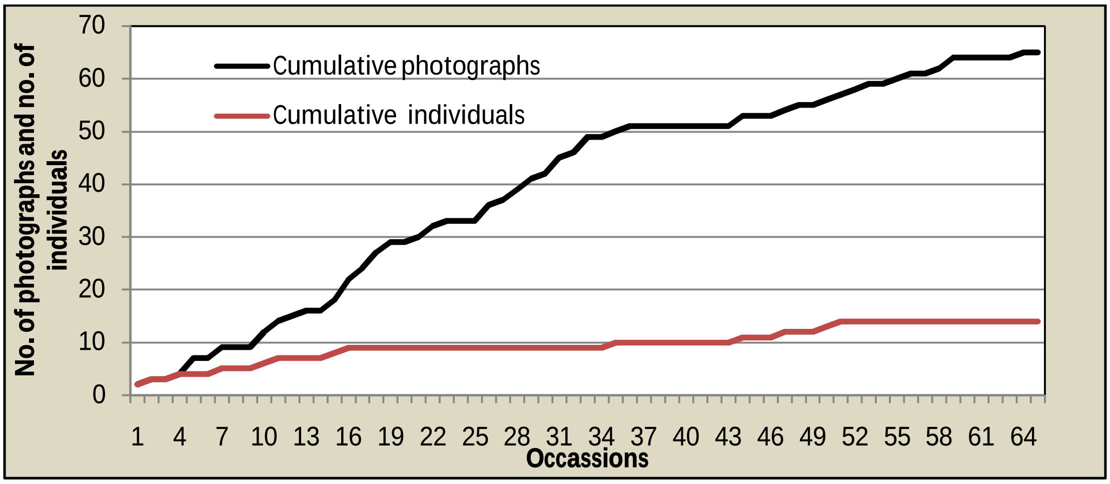
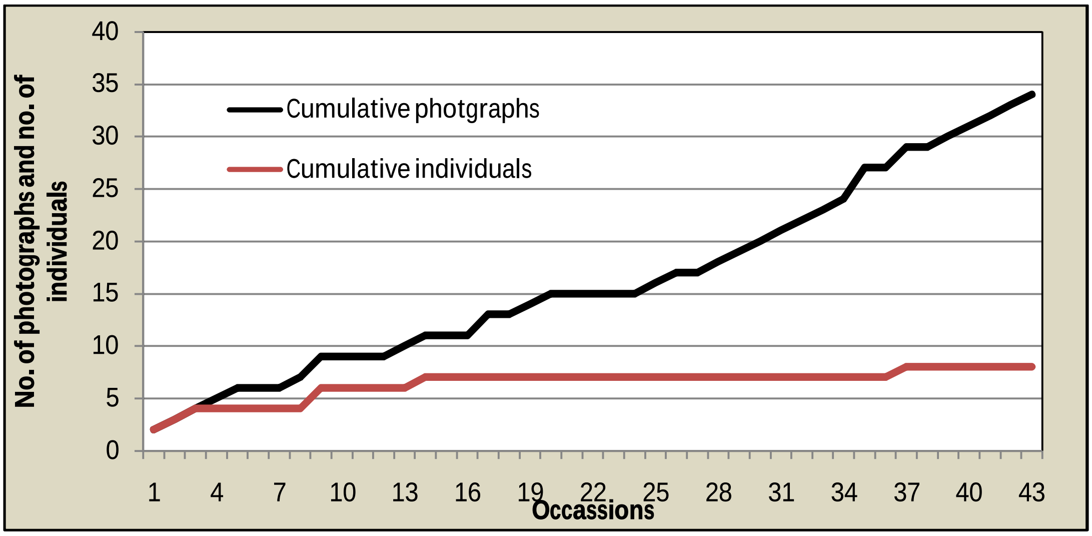


Figure 5. 5. Number of individual leopard and number of total photographs with increasing number of sampling occasions to evaluate sampling adequacy in 2010



5. 4. 4. Estimation of capture probabilities, population and density.

The closed capture–recapture model Mh, with jackknife estimator, which incorporates individual heterogeneity in capture probabilities, estimated capture probability p-hat = 0.06 in 2007, 0.07 in 2008, 0.06 in 2009 and 0.07 in 2010. Since the population estimation was done separately between years, it was found to be geographically and demographically closed for each year. The population and density of leopard in the study area was estimated using the program DENSITY 4.1 (Efford 2007). The estimated population (*N*) of leopard in the study area with Mh Jackknife estimator was 22.2 ± 3.6 in 2007, 17.9 ± 3.0 in 2008, 16.3 ± 3.3 in 2009 and 9.0 ± 1.5 in 2010 (table 5.3). The population of leopard was also estimated with Mo, Mh chao Mb model, which is given in table 5.3.

Table 5. 3. Population estimation of leopard in the study area between 2007 and 2010.

Primary Period	**Estimated population in the study area**			
	Mo	**Mh (Jacknife**	**Mh (Chao)**	**Mb (Zippin)**
1 (2007)	19.0 (0.9)	22.2 (3.6)	23.5 (4.8)	20.0 (1.9)
2 (2008)	17.0 (0.6)	17.9 (3.0)	18.6 (2.2)	19.1 (3.1)
3 (2009)	14.0 (0.6)	16.3 (3.3)	18.2 (4.9)	16.0 (3.4)
4 (2010)	8.0 (0.3)	9.0 (1.5)	8.0 (0.7)	8.0 (0.5)

Note: The number in the parentheses is the standard error of that estimator

The estimated densities with Mh jackknife estimator and half mean maximum distance moved model (MMDM/2) were 10.7 ± 1.8 individuals/ 100 km^2 in 2007, 7.6 ± 0.6 individuals/ 100 km^2 in 2008, 6.2 ± 0.8 individuals/ 100 km^2 in 2009 and 3.1 ± 0.4 individuals/ 100 km^2 in 2010 (table 5.4). Half normal detection function fitted the best and the densities arrived using multiple likelihood model (MLDens) were 9.3 ± 2.2 individuals/ 100 km^2 in 2007, 7.7 ± 1.9 individuals/ 100 km^2 in 2008, 5.3 ± 1.4 individuals/ 100 km^2 in 2009 and 3.3 ± 1.2 individuals/ 100 km^2 in 2010 (table 5.4). The estimated densities using mean maximum distance moved model (MMDM) and spatial explicit inverse prediction model (IPDens) are given in table 5.4.

Table 5. 4. Density estimation of leopard in the study area between 2007 and 2010.

Primary Period	Density / 100 km^2			
	MMDM	**MMDM/2**	**IPDens**	**MLDens**
1 (2007)	7.0 (1.3)	10.7 (1.8)	9.2 (2.5)	9.3 (2.2)
2 (2008)	4.8 (0.4)	7.6 (0.6)	7.6 (2.0)	7.7 (1.9)
3 (2009)	3.9 (0.7)	6.2 (0.8)	6.2 (1.6)	5.3 (1.4)
4 (2010)	1.8 (0.4)	3.1 (0.4)	3.4 (1.3)	3.3 (1.2)

Note: The number in the parentheses is the standard error of that estimator

5. 4. 5. Estimation of survival rates of leopard

The survival rates of leopard in the study area, was estimated using X matrix (Otis *et. al* 1978) following ‘Robust Design’ (Pollock 1982, Kendall *et al.* 1995, 1997, Williams *et al.* 2002) model using the program MARK (White and Burnham 1999). Model selection statistics for the full robust-design likelihoods (table 5.5) provided inferences about relevant sources of variation in the parameters. The model with the lowest AICc was judged to be substantially better than the others in the set of 7 models (AICc weight = 0.46; the AICc weight of the nearest competitor is 0.04). Thus, inferences were based on this model and it was decided not to use model averaging for parameter estimates.

Model {S(t), γ”(.), γ’(.), π(.), p(t), N(t)} (Where survival rate, probability of capture and number of individual captured each year were not constant) was selected the lowest AICc model. Estimates for leopard population survival rates are reported in table 5.6. The survival rate of leopard in the study area varied from 0.67 ± 0.11 between 2007 and 2008 to 0.58 ± 0.12 between 2008 and 2009 and 0.45 ± 0.07 between 2009 and 2010. The overall survival rate of leopard in the entire sampling period was estimated to be 0.57 ± 0.07. The probability of temporary emigration (γ”) of one individual from the sample between sampling occasions was estimated to be 0.002, and the probability of remaining in the sample (1-γ”) between sampling occasions was 0.998. The probability of remaining outside the sample (γ’) (not emigration) was estimated to be 0.999, and the probability of an individual which was out of the sample (1−γ’) in one sampling period but enters the sample in the next sampling period (i.e., return rate of temporary emigrants) was 0.001.

Table 5. 5. Model selection statistics for robust design analysis of leopard capture data in Sariska from 2007 to 2010.

Model	**AICc**	**Delta AICc**	**AICc weight**	**Model Likelihood**	**No. of parameters**	**Deviance**
{S(t), γ"(.), γ'(.), π(.), p(t), N(t)}	946.6241	0.0000	0.4598	1.0000	18	921.8214
{S(t), γ"(t), γ'(t), π(t), p(t), N(t)}	951.5024	4.8783	0.0401	0.0872	20	921.8119
{S(t), γ"(t), γ'(t), π(.), p(t), N(t)}	951.5024	4.8783	0.0401	0.0872	20	921.8119
{S(.), γ"(.), γ'(.), π(.), p(.), N(t)}	992.2614	45.6373	0.0000	0.0000	7	992.5677
{S(t), γ"(.), γ'(.), π(.), p(.),N(t)}	995.7322	49.1081	0.0000	0.0000	9	991.6839
{S(t), γ"(t), γ'(t), π(.), p(.),N(t)}	999.2781	52.6540	0.0000	0.0000	11	990.7849
{S(t), γ"(t), γ'(t), π(t), p(.),N(t)}	999.2781	52.6540	0.0000	0.0000	11	990.7849

Table 5. 6. Estimation of survival rates of leopard in the study area between 2007 and 2010.

Primary Period	**No. of Secondary Period**	**No. of leopards caught**	**Survival rate with Robust Design**
1 (2007)	44	19	--
2 (2008)	59	17	0.67 (0.11)
3 (2009)	65	14	0.58 (0.12)
4 (2010)	43	8	0.45 (0.07)
Overall			**0.57 (0.07)**

Notes: Values in parentheses are estimated standard errors. Leopard survival rate was not estimated for the year 2007 since it was the beginning of study.

5. 5. DISCUSSION

5. 5. 1. Estimation of population and density of leopard in the study area

The population and density of leopard in the study area was estimated using Mh model and jackknife estimator as every individual has different capture probability depending upon their movement pattern, access to trap sites and response to photographic flash. Looking at the capture history data (X matrix) it was evident that some individuals became trap shy after being captured once. Poor recapture rates of some individuals during the present study, can affect population estimation and it was understandable that larger number of recaptures will result in more accurate and precise population estimates. Effort required in terms of sampling occasions suggested that a minimum of 80-90 days are required in an area of 250 km^2 to get reliable density estimates for leopard in the study area while for tigers in Corbett

Tiger Reserve it varies from 30 to 40 days to get reliable density estimates (Contractor 2007).

Although photographic capture-recapture sampling methodology has been used to estimate the density of tigers in many protected areas throughout India (Karanth and Nichols 1998, Karanth *et al.* 2004), similar density estimates of leopards are only available from Rajaji National Park (Harihar *et al.* 2009, Mondal 2006), Pench Tiger Reserve (WII, ongoing study) and Mudumalai Tiger Reserve (Kale *et al.* 2011). The leopard population estimate in the present study based on the capture-recapture framework is lower than the density estimated from the moist deciduous forests of Rajaji National Park, Pench Tiger Reserve and Mudumalai Tiger Reserve (table 5.6). A comparison of camera trapping results in the present study with similar studies conducted at other sites on leopard showed that the density estimate in 2007 (10.7/ 100 km^2) was comparatively similar to estimates obtained from other studies (table 5.6). The density estimate in 2010 (3.1/ 100 km^2) in the study area was found comparatively lower than the other studies (table 5.7). However, in the absence of comparable density estimates from across representative habitats within India, it is difficult to identify the regulators of relative abundance of leopards.

Table 5. 7. Estimated leopard densities in different protected areas.

Study Site	**Density/ 100 km^2**	**Author**
Present Study (2007)	10.7	--
Present Study (2010)	3.1	--
Satpura National Park	7-10	Edgaonkar (2008)
Rajaji National Park (West)	9.8	Mondal (2006)
Rajaji National Park (East)	14.9	Harihar *et al.* (2009)
Mudumalai TR	14.9	Kale *et al.* (2011)
Pench TR		WII**,** ongoing study (2006-11)
Mera Poh, Malayasia	6	Kawanishi and Sunquist (2004)
Phinde Reserve, SA	7.1	Balme *et al.* (2009)
Mkhuze Reserve, SA	10.7	Balme *et al.* (2009)
Ngorongoro NP	7.5	Kruuk (1972)
Hwange, Zimbabwe	2.1	Wilson (1975)
Lake Manyara, Tanzania	11	Schaller (1972)
Serengeti NP, Tanzania	5.6	Schaller (1972)
Nairobi NP, Kenya	8.5	Rudnai (1974)
Kruger NP, South Africa	5.1	Pienaar (1969)

Two more studies were available on leopard population estimation using camera traps from a smaller study area (68 to 91 km^2) in Sariska Tiger Reserve (Chauhan *et al.* 2005, Edgaonkar 2008). Both the studies reported a high leopard density in the sampled area (13 to 16 individuals/ km^2). Whereas the present study which had been conducted in a large area and over a longer period estimated the leopard population more effectively. Comparisons among the three studies indicated that density estimation tends to be high and less precise with less effective sampled area. Both the previous studies (Chauhan *et al*. 2005, Edgaonkar 2008) had less effective trapping area and smaller sampling sessions, thus came with high densities with high standard error (Table 5.8).

Table 5. 8. Estimated Leopard density in the study area by different studies

Study	**Year of study**	**Effective trapping area**	**Leopards captured**	**Density (SE)**
Chauhan *et al*. (2005)	2005	68 km^2.	9	16 (6.8)
Edgaonkar *et a*l. (2007)	2005	91.4 km^2.	9	13.1
Present study	2007	213.8 km^2.	19	10.7 (1.8)

5. 5. 2. Estimation of survival rate of leopard in the study area

Long-term studies of leopards based on either radio-telemetry (Bailey 1993, Balme *et al.* 2009) or visual identification of individual (Daniel 1996) have classified leopard in a population as "residents" (breeding adults that defend stable home ranges), pre-dispersal offspring (cubs and juveniles), and "transients" (post dispersal animals that are not "residents"). Such categorization of residents and transients was subjective and was based on the detection histories themselves in the present study. The probability of individual leopard not being detected despite their presence during some sampling period was not considered in such classifications.

The present study estimated the overall annual survival rate for leopard in the study area as 57%. The complement of this annual survival estimate was 43%, which includes deaths and permanent emigration out of the study area. Although the bulk of this annual loss of leopards was likely to be from mortalities and emigration, which includes an unknown fraction of animals that permanently emigrated out of the study area as dispersing sub-adults or as evicted residents as observed by Smith (1993) in tiger population of Royal Chitwan National Park. Karanth and Stith (1999) hypothesized that although tiger populations have high mortality rates from natural and anthropogenic causes, they can be demographically viable if supported on an abundant prey base. This hypothesis can also be implemented on leopard population as both tiger and leopard occupy the same top position in food chain (Schaller 1967). As observed, in the present study the annual survival rate of leopard in the study area declined from 67% (2007-08) to 58% (2008-09) and 45% (2009-10). Subsequently, the estimated leopard population (Mo estimator) in the study area was also declined from 19 individuals in 2007 to 17 in 2008, 14 in 2009 and 8 in 2010. It was also recorded that the wild prey density in the study area also declined from 133 individuals/ km^2 in 2007 to 103 individuals/ km^2 in 2008, 86 individuals/ km^2in 2009 and 38 individuals/ km^2 in 2010. Hence, considering the hypothesis by Karanth and Stith (1999), the depletion of wild prey species may be one of the reasons for the decline of leopard population as well its survival rate in the study area.

The re-introduction of tiger in the study area may also have contributed to the decline of leopard population. After the extermination of tiger in Sariska, leopard took over the entire tiger habitat, which was the best habitat available in Sariska TR and became the top predator (Sankar *et al.* 2009). The density estimates for leopard in 2007 and 2008 were comparatively higher, when there was no tiger in the study area. Six tigers were re-introduced in the study area between 2008 and 2010 and after that leopard population declined significantly in the study area. The present study showed that there was 18% decrease in leopard population after tiger release. In areas of high tiger density, tigers are known to out-compete leopards (McDougal 1988, Schaller 1967, 1972). Radio-tracking studies on tiger and leopard movements indicate that leopards avoid areas frequented by tigers (Seidensticker 1976). In Sariska, leopard were found everywhere in the study area before tiger release. But after the tiger release, leopard avoided those valley areas which were frequented by tigers. They largely occupied the peripheral hilly areas close to human population, which are less frequented by tigers in the study area.

After the re-introduction of tigers, the photo-capture rate of leopard and tiger from camera trapping per 100 trap nights in each grid was calculated and projected on Sariska beat map through color gradient. It was found the grids with maximum tiger photo-captures were largely avoided by leopard and selected the grids where tiger occurrence was less. Photo capture rates of leopard and tiger were shown in grey-scale color gradient in figure 5.6. Site utilization of both the species was estimated with site-wise capture records. Site utilization of leopard and tiger were 0.55 and 0.53 respectively in the absence of either species, while that of both leopard and tiger together was 0.51. The detection probability of leopard was 36% in the absence of tiger and it was 6% when tiger was present.

The estimated overall survival rate of leopard in the study area was comparatively low (57%) compared to other studies (Balme and Hunter 2004, Balme *et al*. 2009). This may be attributed to permanent or temporary emigration of leopard from the study area due to tiger re-introduction, as avoidance of competitor species apparently increases fitness of one species, which is a basic phenomenon of animal behavior (Schaller 1972).

Figure 5. 6. Spatial distribution of tiger and leopard based on camera trap photo-captures in the study area.

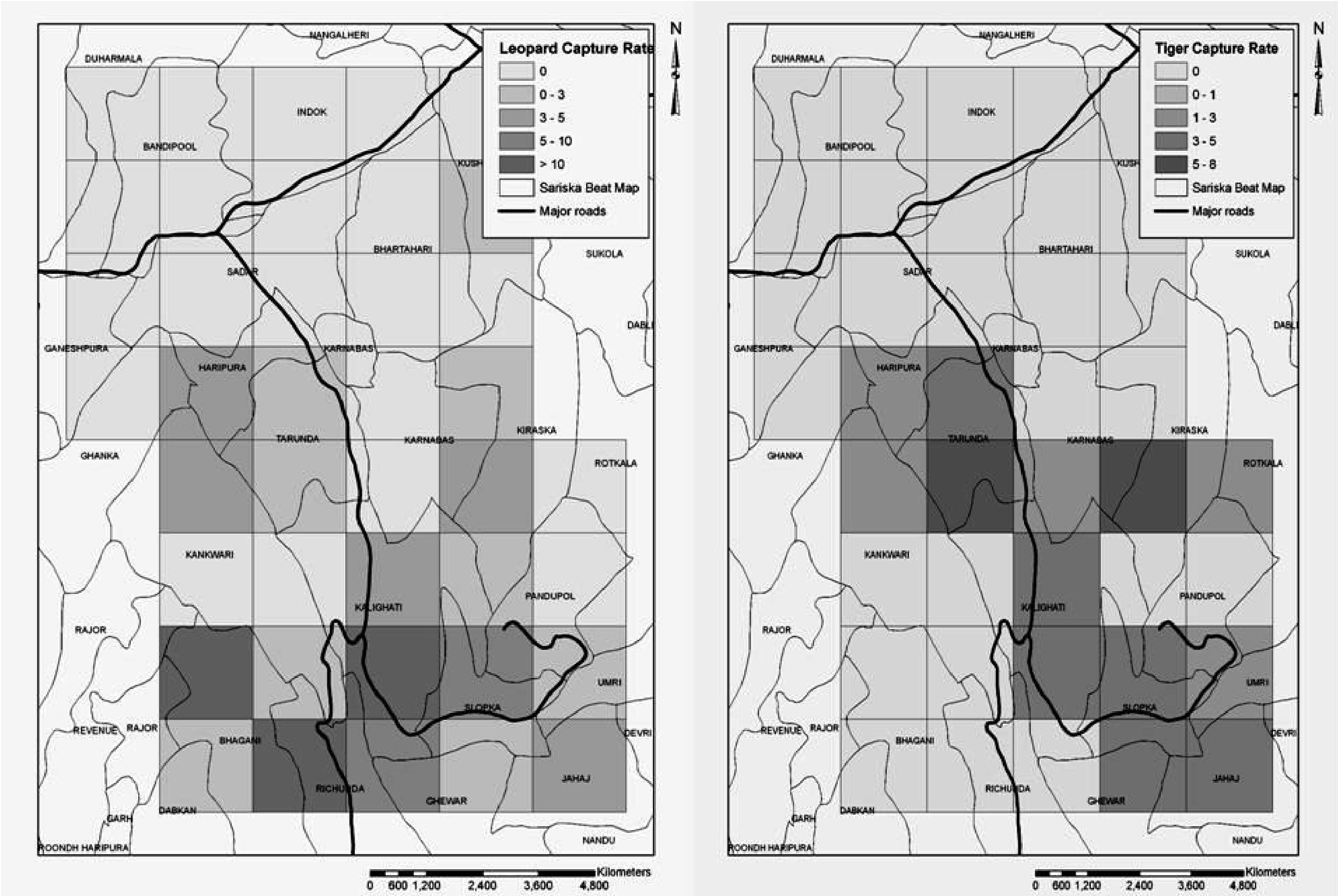


Plate 6a. Camera trap photo of L6 (Male leopard)

Plate 6b. Camera trap photo of L12 (Female leopard)

Chapter 6

HOME RANGE AND HABITAT USE OF LEOPARD

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6. 1. INTRODUCTION

Knowledge of the distribution and habitat requirements of a species are essential to formulate conservation strategies. While some species are considered habitat generalists, they are still vulnerable to habitat loss and fragmentation. These factors along with prey depletion and poaching are responsible for the decline of the tiger (*Panthera tigris*) across its geographic distribution (Sunquist *et al.* 1999). It has been estimated that the tiger exists in only seven percent of its historical range (Dinerstein *et al.* 2007). The leopard is a wide-ranging large carnivore that is less susceptible to disturbance, is a generalist with respect to habitat requirements, and can survive on a wide range of prey species (Sunquist and Sunquist 2002). Unlike the tiger, which needs a high biomass of large-sized prey (Karanth and Sunquist 1995), the leopard has been known to survive on domestic dogs and rodents in the absence of wild prey populations (Edgaonkar and Chellam 2002). The dramatic reduction in tiger populations (Jhala *et al.* 2008) in India has also meant that there is increasing poaching pressure on the leopard to meet the demands of the skin and bone trade. This has been borne out by seizures of hundreds of skins in recent years. In spite of this, very little information is available on the ranging pattern and resource selection of leopard populations in India. Conserving leopards in the semi-arid landscape of Sariska Tiger Reserve will require a quantification of resource use and resource selection of leopard and identification of potential habitat availability thorough habitat suitability model.

6. 2. LITERATURE REVIEW

Leopards are solitary, and other than a female and her young or a consorting pair, they seldom associate with one another. In 1947, Jim Corbett wrote that “male leopards are very resentful of intrusion of others of their kind in the area they consider to be their own”. Fifty years later, radio-tracking studies have confirmed that animals of the same sex seldom share their home areas.

Like all large carnivores, leopards maintain home ranges that must be large enough to provide them with sufficient prey year round. The land tenure system of leopards is broadly similar to that of many other cats and adult males typically occupy large areas that overlap with home areas of one or more adult females. Female ranges are usually smaller than those of males. The home range size of female leopards in Chitawan, Tsavo, northern Serengeti, Kenya, Kruger and Thailand are remarkably similar in size, varying from 6 to 18 km^2. Male home ranges in these areas varied between 17 to 76 km^2 and usually overlapped the ranges of one or more females (Bailey 1993, Hamilton 1976, Bertrum 1982, Mizutani and Jewell 1998, Stander *et al.* 1997, Norton and Lawson 1985, Norton and Henley 1987 and Seidensticker 1976). In Arid areas or other sites of low primary productivity, the home range sizes of leopard are much larger and range overlap for the same-sex animals is more common (Jenny 1996). In the Israeli desert, female home ranges averaged 84 km^2, whereas those of males measured 137 km^2 (Ilany 1981). Two adult females in the Russian Far East had ranges of 33 and 63 km^2 and an adult male home range was 280 km^2 (Miquelle *et al.* 1996). In northeastern Namibia male ranges were even larger (mean=451 km^2; range

210-1164 km^2), and female ranges measured 183 to 194 km^2 (Stander *et al.* 1997). Jenny (1996) placed radio collars on one male and two female leopards in the Taï NP, Ivory Coast, and found that the home range was 86 km^2 for the male, and for the females 29 km^2 and 22 km^2, respectively. In between sexes there can be a complete overlap of home ranges (Jenny 1996), and even for home ranges of individuals of the same sex, there can be some degree of overlap (Rabinowitz 1989, Grassman 1999). To understand the complex system of ranging pattern of leopard, the study area should ideally be large enough to contain at least parts of the home ranges of several individuals.

Resource selection by animals is a hierarchical process of behavioral responses to particular environmental characteristics (Horne *et al.* 2008). Establishment of a home range within a landscape and the movement of individuals within a home range may be influenced by different environmental factors and scales, and therefore animal- landscape relationships should be examined across a range of scales (Johnson 1980, Anderson *et al.* 2005; Boyce 2006). This is particularly important when examining the resource selection dynamics of species inhabiting fragmented or human- dominated landscapes (Anderson *et al.* 2005). An animal's movements determine a trajectory through space and time; its habitat use is the proportion of the trajectory contained within each habitat type (Aebischer *et al.* 1993). Animal location data approximate the trajectory by sampling it at discrete intervals. If sampling is representative and sufficiently frequented to record little-used habitat types, then the proportion of animal locations in each habitat estimates the proportion of the trajectory in each habitat (Aebischer *et al.* 1993). Resource selection by animals is a scale-dependent hierarchical process of behavioral responses to environmental factors. Lack of information on such habitat selection dynamics can affect the conservation management of species and habitats. For example, little is known about the space-use patterns of leopard in the semi-arid landscape of Western India. Leopard, one of the top carnivores of the Indian subcontinent, represents an example of such lack of information. Based on anecdotal observations, leopards have been described as tolerant of human disturbance and are reported to be found near agricultural fields and human habitations (Prater 1980, Daniel 1996). However, leopard is largely resident in protected forest areas rather than disturbed human dominated areas and depends on a variety of wild prey base (Bailey 1990). In the present study, resource selection of leopard was examined comparing different vegetation types in the study area and agricultural lands.

Habitat Suiatbility maps are basically computed by fitting relevant statistical or numerical model on environmental data and species distribution data. Classical methods (e.g. logistic regression, discriminant analysis, GLM, etc.) need both species presence and absence data; presences attest a good habitat and absences attest a bad habitat. An “absence” (=lack of observation) may have three causes: 1) the species is present but was not detected (false absence), 2) the habitat is suitable, but the species is not yet/no more present (false absence) and 3) the habitat is actually not suitable (true absence) (Hirzel *et al.* 2002).

Categorizing suitable leopard habitat requires information at multiple scales. First-order selection (Johnson 1980) refers to the distribution of a species with respect to geographical space. This information is used to derive a probability of species presence at each location. Leopards are not only rare and secretive, they are also crepuscular (Sunquist and Sunquist 2002) and without intensive effort there is a high likelihood of non-detections in areas where leopards are actually present, contaminating the absence data. Presence-only models are a way of dealing with this problem. The present study used maximum entropy model (Phillips *et al.* 2004), a presence-only environmental habitat based method to create habitat suitability maps for leopard in Sariska Tiger Reserve and surrounding 5 km buffer area.

The maximum entropy model requires a set of geographic coordinates where the species has been observed. In addition, the data on a number of environmental variables, such as vegetation types, NDVI, elevation, etc., which are to be measured or estimated across a geographic region of interest. The goal is to predict which areas within the region satisfy the requirements of the species' ecological niche, and thus form part of the species' *potential distribution* (Anderson and Martinez-Meyer 2004). The potential distribution describes where conditions are suitable for survival of the species, and is thus of great importance for conservation. It can also be used to estimate the species' *realized distribution*, for example by removing areas where the species is known to be absent because of deforestation or other habitat destruction. Although a species' realized distribution may exhibit some spatial correlation, the potential distribution does not, so considering spatial correlation is not necessarily desirable during species distribution modeling (Phillips *et al*. 2004).

The idea of maximum entropy habitat modeling (MaxEnt) is to estimate the target distribution by finding the distribution of maximum entropy (i.e., that is closest to uniform) subject to the constraint that the expected value of each feature under this estimated distribution matches its empirical average. This turns out to be equivalent, under convex duality, to finding the maximum likelihood Gibbs distribution (i.e., distribution that is exponential in a linear combination of the features). For species distribution modeling, the occurrence localities of the species serve as the sample points, the geographical region of interest is the space on which this distribution is defined, and the features are the environmental variables (Phillips *et al*. 2004). Hence, in the present study, habitat suitability model (based on maximum entropy approach) can be used as a tool to explain or predict important ecological parameters for leopard in semi-arid landscape, including its distribution and habitat quality (Heglund 2002, Philips *et al.* 2004).

6. 3. METHODLOGY

6. 3. 1. Estimation of home range of leopard

Radio-telemetry technique was followed to estimate the home range and habitat use of leopard as this technique is found to be the most updated and useful practice to gather information on home range, daily and seasonal movement pattern of big cats (White and Garrot 1990, Karanth *et al.* 2006). To capture leopard in the study area a couple of iron double door trap cage was deployed using goat, domestic dog, meat and chicken as bait in the cage. Rotten meat (cat-lure), eggs and fresh blood were also used to lure leopard inside the cage. The dimension of the trap cage was 9 ft X 2.5 ft X 3 ft including the bait cage. A number of 148 trap nights in 2009 and 115 trap nights in 2010 were deployed in different locations in the study area following leopards' signs and trails. In spite of these efforts, no adult leopard got trapped in the trap cages. On two occasions, <1 year old cubs got trapped inside the trap cages but escaped due to malfunction of traps. To understand the ranging pattern of leopard, two male leopards were captured from conflicted areas outside Sariska TR and released in the study area.

The first male leopard (SP1) was captured from a village near Shahpura 50 km away from Sariska TR on 24th December 2008. After capturing, the animal was kept in Jaipur zoo. On 27th March 2009, SP1 was immobilized using HBM mixture of

Xylazine and Ketamine drug, fitted with Telonics made VHF radio-collar and released in the study area (Kalighati). The weight of SP1 was 40 kg and estimated age was two and half years at the time of collaring.

The second male leopard (SP2) was rescued from a 96 ft deep dry well at Madhogarh fort which is 100 km away from Sariska TR (Mondal *et al.* 2010). The animal was immobilized using HBM mixture of Xylazine and Ketamine, fitted with Telonics made VHF radio-collar and released in the study area (Kalighati) on 28th October 2009. The weight of SP2 was around 65 kg and estimated age was four years at the time of collaring.

Radio-locations of each collared animal were determined by ground tracking through VHF signal following 'homing in' and 'triangulation' techniques (White and Garrot 1990). Telonics made TR-4 receiver along with 'Yagi' and 'H' antenna were used to track the radio-collared animals. Four to six locations every week per collared animal were recorded in different time of day. The first male leopard (SP1) was monitored from 27th March 2009 to 18th December 2009 (266 days) till the animal died due to liver and lungs congestion. In total, 148 locations were collected from the first male leopard (SP1). The second male leopard (SP2) was monitored from 28th October 2009 to 18th August 2010 (292 days) till the animal was lost. In total, 268 locations were collected from the second male leopard. For the first male leopard (SP1), in total 74 locations were recorded in summer, 36 locations in monsoon and 38 locations in winter. For the second male leopard (SP2), in total 98 locations were recorded in summer, 54 locations in monsoon and 116 locations in winter.

Information on major vegetation type, terrain type, distance to nearest water source, distance to nearest human habitation and road were recorded on each radio-collared leopard location. Co-ordinates for the all radio-location points were determined with the help of Global positioning system (GPS) and later plotted in Mapsource (Garmin Ltd. 1999) and ArcGIS 9.2 (ESRI 2006) to estimate home ranges of leopard. Two methods of home range analysis were used in the present study i.e. minimum convex polygon method (Mohr 1947) and kernel method (Katajisto and Moilanen 2006). Since both the animal were captured outside of the Sariska TR and later released in the study area, they took around two months to explore the area and establish their home ranges in Sariska TR. Hence, the locations of initial two months were excluded from the home range analysis. Program CALHOME (Kie 1994) and ArcGIS 9.2 (ESRI 2006) with Hawth's tool and HRT tool was used to estimate home ranges in different methods.

6. 3. 2. Habitat use and selection of leopard

As habitat use by a population is that of the 'average' member, it should be estimated from the trajectories of a random sample of individuals from the population. The sample size is the number of tracked individuals. The numbers of radio locations are relevant only in affecting the accuracy of reconstructed trajectories (Aebischer *et al.* 1993). The extreme case of one radio location per animal may be compensated for by increasing the number of animals (equivalent to estimating habitat use by a point count of individuals in terms of direct sightings or camera trap records) (Neu *et al.* 1974). Consideration of one individual yields no information about population habitat use; however numerous the radio locations are (Aebischer *et al.* 1993). Since, radio-collaring data from two individual is a very small sample size to understand the habitat use of leopard, *ad libitum* data of seven individually indentified leopards (three males and four females) were also added to the analysis. The *ad libitum* data collected from those individuals, who were repeatedly captured in the camera traps in different sites and frequently sighted during the field work in the study area during four year study period. The details of the individual leopards, numbers of locations used for resource selection analysis are given in table 6.1.

Table 6. 1. Details of the individual leopards with number of locations collected for resource selection analysis between 2007 and 2010.

Individual leopard and sampling period	Sex	Number of locations collected
SP1 (March 2009-December 2009)	Young Male	148
SP2 (October 2009-August 2010)	Young Male	268
L2 (January 2007-June 2010)	Male	61
L4 (January 2007-April 2010)	Female + 3 cubs	44
L6 (February 2007-February 2010)	Old Male	65
L8 (February 2007-April 2010)	Young male	54
L14 (January 2007- June 2007)	Old female + 3 cubs	48
L17 (January 2008-May 2009)	Young female	21
L26 (February 2009-June 2010)	Young female	39

Second order resource selection function was evaluated to understand the habitat selection of leopard in the study area. The second order of selection is the selection of home-range within a geographic range and third order is selection of habitats within the home-range (Johnson 1980). Due to small sample size, the selection of habitat was measured within the (global) geographic range. The extent of the geographic range (412.4 km^2) was defined by calculating a minimum convex polygon around the collective home-ranges of all the study animals (figure 6.1). A multispectral (Landsat 7 ETM+), high resolution (28.5m) satellite imagery from the Global Land Cover Facility, NASA was used to generate a landuse/ landcover map of the study area (figure 6.2). Details of the satellite imagery used are given in table 6.2. From the landuse/ landcover map, it was determined that the intensive available geographic area consisted of 25.5% *Anogeissus* dominated forest, 21.9 % scrubland, 20.5% agricultural land, 10.2% *Boswellia* dominated forest, 5.9 % *Butea* dominated forest, 5.9% *Zizyphus* mixed forest, 5.3% barren land and 4.8% of *Acacia* mixed forest (table 6.6). Individual Utilization Distribution (UD) grids were overlaid on a GIS layer derived from the landcover map for the study area within ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, CA, USA). Compositional analysis (Aebischer *et al.* 1993) was followed to determine the resource selection of leopard in the study area, but with a modification that assigns values based on the Utilization Distribution of each animal in the study area (UD) (Millspaugh *et al.* 2006). In this way, an individual's use of the habitat is defined by the proportion of UD volume in each habitat type within the overall geographic range combining the home ranges of all animals (Millspaugh *et al.* 2006). The program Resource Selection for Windows (RSW) was used to conduct the compositional analysis (Leban 1999).

Table 6. 2. Details of satellite imagery used to evaluate habitat use of leopard in Sariska Tiger Reserve (Sankar *et al.* 2009)

Satellite	Landsat 7
Sensor	ETM+
FCC bands	4, 3, 2 (RBG)
Projection	Universal Transverse Mercator (UTM)
Datum	Geo-coded
Resolution	28.5 meters
Path	147
Row	041
RMS Error	7 m

Source: (http://glcf.umiacs.umd.edu/index.shtml)

6. 3. 3. Habitat suitability model of leopard

Camera trapping method was adopted to collect presence/absence information along with direct sighting data of leopard in the intensive study area from January 2007 to June 2010. A total of 65 locations were selected for the placement of camera traps in the intensive study area and adjoining areas inside Sariska National Park. Each camera trap location was considered as the representative of leopard presence/absence data. Records on presence /absence of leopard were converted into digital data in GIS using program ArcGIS (Environmental Systems Research Institute, Redlands, CA, USA), and were stored on the base map prepared for Sariska Tiger Reserve and adjoining 5 km areas. The entire map was divided into 2 x 2 km^2 grids (n=574) and the records were plotted as presence information on each grid. If leopard was detected at least once at a site over the entire sampling duration then it was recorded as present '1' or '0' otherwise. Spatial data which was generated for Sariska TR (Sankar *et. al.*, 2009) was used for preparing spatial layers on habitat features relevant for each species. Total of 11 macro habitat characteristics and variables considered for the analysis which are given in **table 6.3**. Information of five prey species in the study area was also included as variables. Due to high auto-correlation (90%), information of nilgai and livestock were excluded. Topographical variables include elevation (DEM), anthropogenic variables (includes Euclidean distance from villages and roads), habitat variable (includes vegetation types) and Normalized Differential Vegetation Index (NDVI) and hydrological variables (include Euclidean distance to water). These variables were chosen on the basis of field knowledge and information on leopard biology (Prater 1982, Schaller 1967).

Mapping of vegetation types was done earlier in Sariska based on remotely sensed data of Landsat -7 – ETM+ imagery for the month of September 2007 Geo-coded False Color Composite (FCC) on 1:50,000 scale for entire Sariska TR and adjoining 5 km area was procured and different color tones for 30 classes was prepared (Sankar *et. al.,* 2009). The color classes were merged depending on the similarity in vegetation types based field collected vegetation data. The map was further improved using supervised maximum likelihood classifier to incorporate unclassified and misclassified data. Nine vegetation and land cover classes were delineated and mapped with 80% accuracy (Sankar *et. al.* 2009). Area occupied by each vegetation type was extracted grid wise (2 X 2 km^2) from vegetation map. A separate layer was prepared for each vegetation type thereby computing the area for each habitat variables. Digital data on contour and drainage were used to create Digital Elevation Model (DEM) on the basis of interpolation. All village locations and water points were recorded using Global Positioning System (GPS) during the field work. The locations were further downloaded and Euclidean distance was calculated for each grid center from the nearest water sources and villages. Information on presence of prey species were collected from beat-wise line transect data and later extracted into grids (2 X2 km^2). All the habitat variable characteristics were then converted into grid-wise (2 X2 km^2) ASCII (American Standard Code for Information Interchange) layers. The data was analyzed using program MaxEnt (Phillips *et al.* 2006). MaxEnt is a program for modeling species distributions from presence-only species records, which minimizes the relative entropy between two probability densities (one estimated from the presence data and one, from the landscape) defined in covariate space. MaxEnt's predictive performance is consistently competitive with the highest performing methods (Elith *et al.* 2006). Since becoming available in 2004, it has been utilized extensively for modeling species distributions. Published literature cover diverse aims (finding correlates of species occurrences, mapping current distributions, and predicting to new times and places) across many ecological, evolutionary, conservation and bio-security applications (Tinoco *et al.* 2009, Young *et al.* 2009, Monterreso *et al* . 2009).

Table 6. 3. List of the variables used in MaxEnt analysis.

Variables	Variables type	Source
1. Habitat	*Anogeissus* dominated forest	Land use and land cover map from Landsat -7 – ETM+ data (source: Sankar *et. al*. 2009)
	Boswellia dominated forest	
	Zizyphus mixed forest	
	Butea dominated forest	
	Acacia dominated forest	
	Scrubland	
	Barren land	
	Agricultural land	
	Water body	
	NDVI (summer)	Wildlife Institute GIS cell
	NDVI (winter)	
2. Prey information	Chital	Line transect data (2007)
	Sambar	
	Wild pig	
	Common langur	
	Peafowl	
3. Anthropogenic	Distance from village	Village and road map, WII
3. Topographical	DEM	Wildlife Institute GIS cell
4. Hydrological	Distance from water	Field data, WII

Flow chart 1. The process followed to build model and preparation of habitat suitability map for leopard

Field data (Presence/ absence data)

Spatial maps of habitat features

Digitization and grid on spatial map (1 x 1 km)

PRESENCE /ABSENCE (O and 1)

1	1	1	0	0	1
0	1	0	1	0	1
0	1	0	0	1	0
1	0	1	1	1	0
0	0	1	0	1	0
0	0	1	0	1	0

NDVI, DEM, WATER, LANDCOVER, VILLAGE

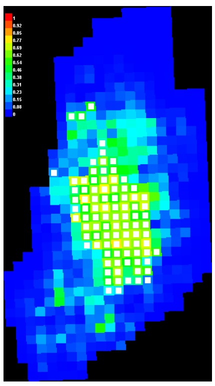
230	25	42	111	0.02	0.30
64	11	19	112	0.6	.045
29	16	24	145	0.9	0.15
43	78	49	128	1.7	0.46
21	93	76	198	1.9	0.46
88	46	25	142	1.8	0.55

Conversion of Vector to Raster and ASCII

Data Extraction

IDs	Lat	Long	Chital	Sambar	NDVI	DEM	WATER	BOS	ZIZ
27	-	-	1	0	124.23	0.003	123	0.023	0.055
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
n	Xn	Yn	N	n	n	n	n	n	n

Maximum Entropy habitat modeling



6. 4. RESULTS

6. 4. 1. Estimation of home range of leopard

Home range of leopard was estimated following minimum convex polygon method (Mohr 1947) and kernel method (Katajisto and Moilanen 2006). The exploration period of two months was excluded from the analysis of home range of both the leopards. With 100 % MCP, the home range of SP1 male leopard was 84.3 km^2 and that of SP2 male leopard was 170.1 km^2 (table 6.4). The estimation of home ranges with 95% MCP and 90% MCP of both the individuals are given in table 6.4. With 90% Kernel, the estimated home range of SP1 was 72.4 km^2 and that of SP2 was 54.6 km^2. The home range estimate with 50% Kernel, which was the core-area within home range, was 12.2 km^2 for SP1 and 7.9 km^2 for SP2. With 95% harmonic mean method, the estimated home range of SP1 was 67.3 km^2 and that of SP2 was 140.6 km^2. The estimation of home ranges with 90% and 50% harmonic mean of both the individuals are given in table 6.4.

The seasonal home ranges were also estimated for both the individuals following minimum convex polygon method (Mohr 1947). The summer home range of SP1 was 67.8 km^2 and that of SP2 was 56.9 km^2. The monsoon home ranges were 57.8 km^2 and 13.6 km^2 for SP1 and SP2 respectively. The winter home ranges were 29.6 km^2 and 170.1 km^2 for SP1 and SP2 respectively (table 6.5).

Table 6. 4. Estimation of overall home range of leopard using different methods in Sariska Tiger Reserve.

Methods	SP1*	SP2*
100% MCP	84.3	170.1
95% MCP	66.3	138.6
90% MCP	58.9	130.8
95% KERNEL	92.5	153.6
90% KERNEL	72.4	54.6
50% KERNEL	12.2	7.9
95% Harmonic mean	67.3	140.6
90% Harmonic mean	58.7	67.6
50% Harmonic mean	9.4	5.9

* Home range in km^2

Table 6. 5. Estimation of seasonal home range of leopard in Sariska Tiger Reserve.

Season	Estimated Home Range using MCP (km^2)			
	SP1		SP2	
	Home Range	Total number of locations	Home Range	Total number of locations
Summer	67.8	74	56.9	98
Monsoon	57.8	36	13.6	54
Winter	29.6	38	170.1	116

6. 4. 2. Habitat use of leopard

From January 2007 to June 2010, the locations of nine individual leopards were used for estimation of habitat use. Out of nine animals, two animals were fitted with radio-collar and locations of rest of the individuals were recorded through camera trapping and direct sighting. Though I have recorded the presence of 34 individual leopards in four years in study area, location data of more than 20 points were collected from seven individuals, which were considered in the habitat use analysis. The minimum convex polygon of locations collected from all the nine individual leopards are given in figure 6.1. Multi-spectoral (landsat 7 ETM+) high resolution (28.5 m) satellite imagery from GLCF was obtained for the study area to generate a GIS landcover/ landuse map (figure 6.2). By joining all the MCP of nine leopards, a geographic range was delineated as the available habitat for compositional analysis. The total area of available geographic range was 412.4 km^2 and eight landcover/ landuse classes were identified within that comparing with ground collected vegetation data. The area of different landcover classes within the geographic range is given in table 6.6.

Figure 6. 1. Minimum convex polygons of leopards in Sariska Tiger Reserve.

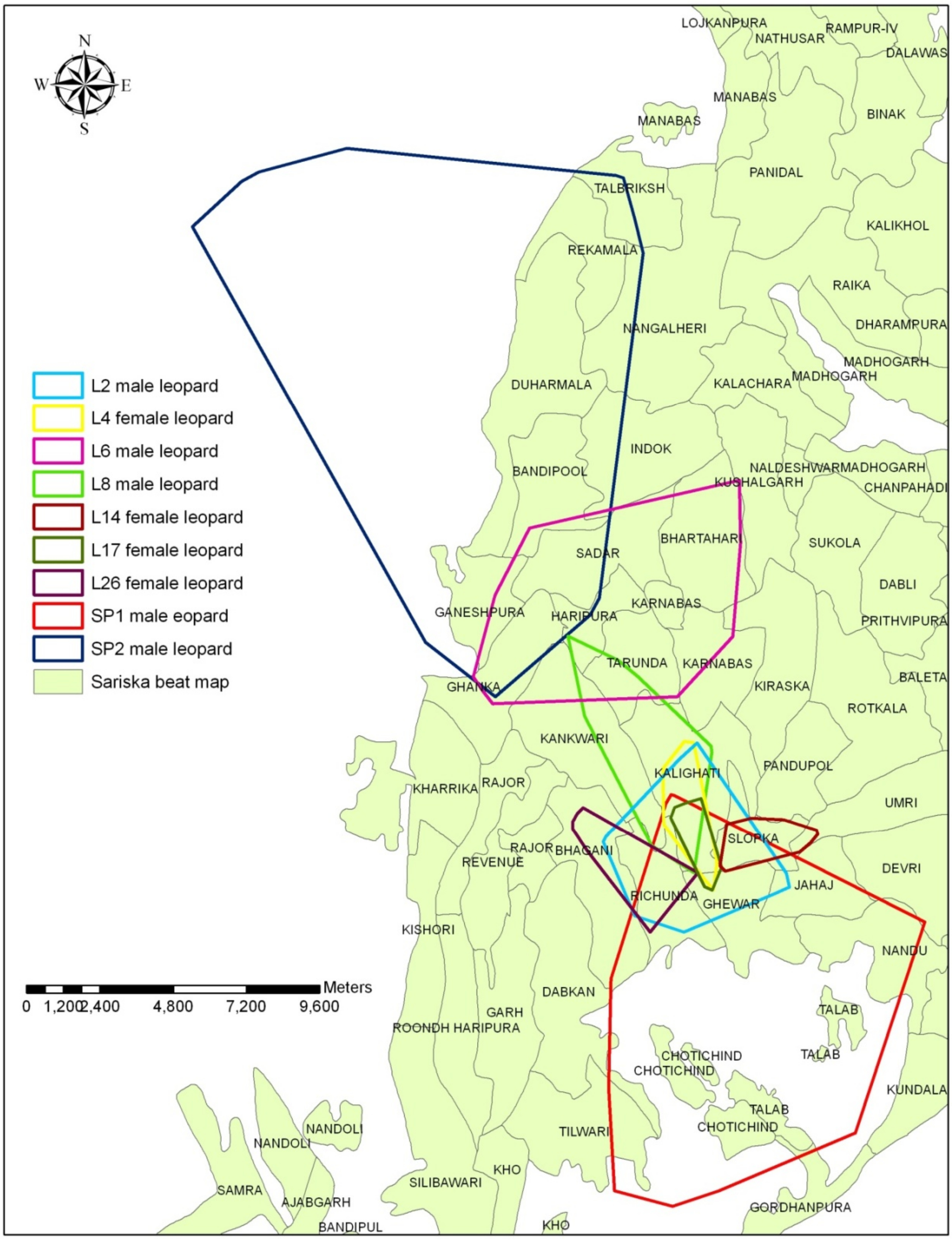


Figure 6. 2. Landuse and landcover map of Sariska Tiger Reserve with 5 km buffer.

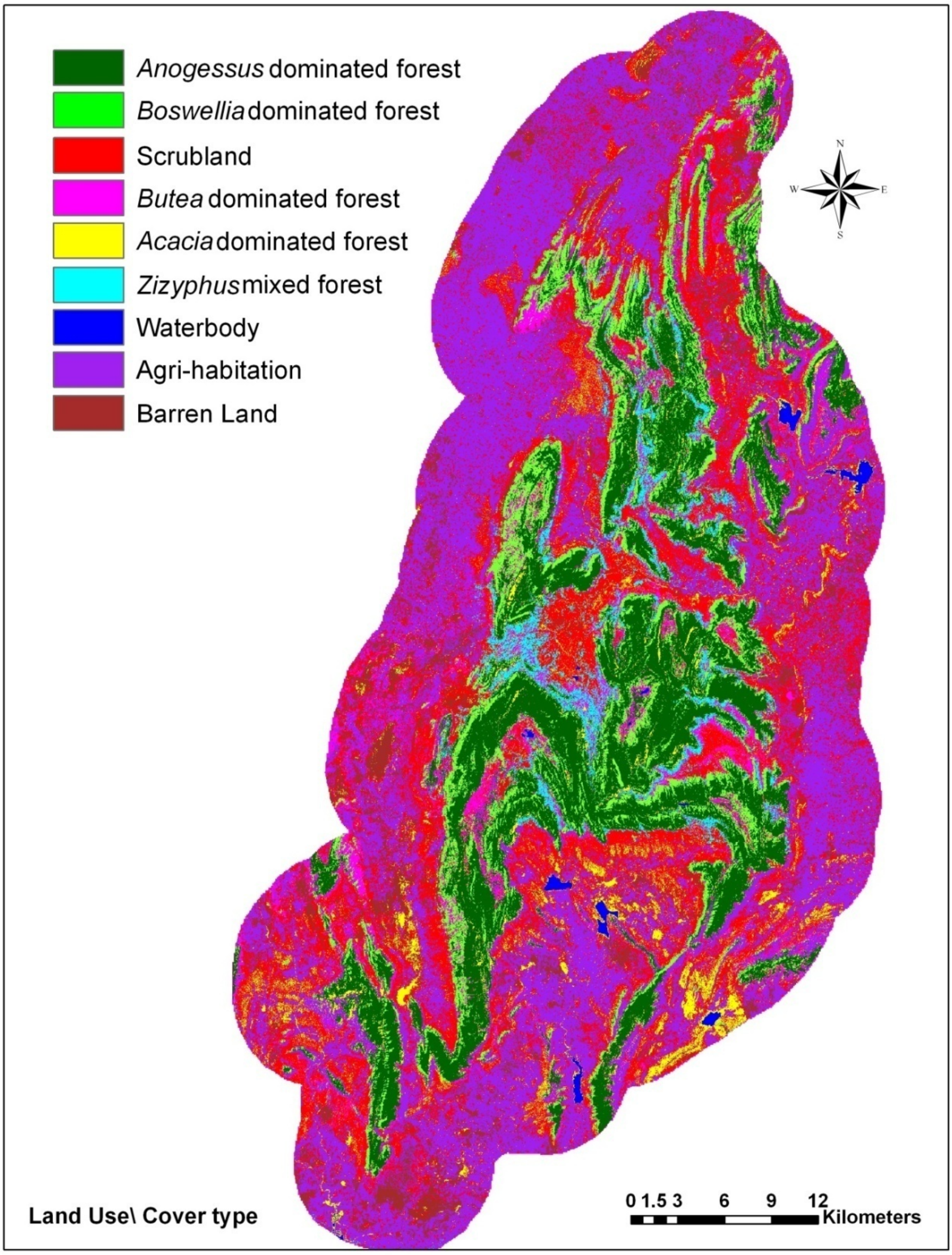


Table 6. 6. Vegetation and land cover classes in available geographic range in Sariska Tiger Reserve.

Vegetation/Landcover type	**Area (km^2)**	**Percentage**
Anogeissus dominated forest (Ano dom)	105.01	25.46
Boswellia dominated forest (Bos dom)	41.99	10.18
Butea dominated forest (But dom)	24.57	5.96
Zizyphus mixed forest (Ziz mix)	24.23	5.88
Acacia mixed forest (Aca mix)	19.79	4.80
Scrubland (Scrblnd)	90.42	21.92
Agriculture/Habitation (Agri lnd)	84.44	20.47
Barren land (Bar lnd)	21.99	5.33
Total	412.44	100.00

The available (total geographic range joining all the MCP) and utilized (kernel utilization distribution of each animal) habitat components were transformed to log-ratios y_0 and y using the proportion of *Boswellia* dominated forest as the denominator (table 6.7) and then the difference ($d = y - y_0$) was calculated (table 6.8). The residual matrix R_2 is the matrix of raw sums of squares and cross products calculated from d; R_1 is the matrix of mean corrected sums of squares and cross-products calculated from d.

R_1 =

109.292	5.0222	91.2376	75.8427	15.1006	19.5993	-7.2134
5.0222	4.8952	1.9255	7.2825	3.9337	1.3477	0.6414
91.2376	1.9255	95.8257	68.5393	12.8255	16.5872	-7.5582
75.8427	7.2825	68.5393	64.1099	14.9585	15.4966	-3.3487
15.1006	3.9337	12.8255	14.9585	4.7508	3.2029	-0.2191
19.5993	1.3477	16.5872	15.4966	3.2029	9.3054	0.3053

R_2 =

210.1612	-24.103	196.11	136.289	2.4105	1.9295	-10.947
-24.1030	13.3049	-28.356	-10.171	7.5978	6.4497	1.7194
196.1199	-28.356	204.86	131.384	-0.3681	-1.7838	-11.44
136.2886	-10.171	131.384	100.332	7.3539	4.908	-5.5859
2.4105	7.5978	-0.3681	7.3539	6.3473	5.4259	0.2506
1.9295	6.4497	-1.7838	4.908	5.4259	12.4007	0.9593
-10.9468	1.7194	-11.44	-5.5859	0.2506	0.9593	1.9778

Then, LAMBDA = $[R_1]/ [R_2]$ = (106.1668/ 81558.1171) = 0.0013,

Which yielded $P < 0.001$ when compared to X^2 (59.7965) with 7 degree of freedom. Inspection of *d* shows (table 6.8) that its distribution is not multivariate normal, however, the level of significance obtained by randomization was $P < 0.001$. This clearly showed that the habitat use by leopard was non-random.

Table 6. 7. Log ratios of utilized habitats for comparing habitat use based on kernel home ranges of each individual leopard with availability in the total study area of Sariska Tiger Reserve.

Individual leopard	Log-ratios of utilized habitat (y)						
	Bar lnd/ Bos dom	**Zizy-mix/ Bos dom**	**Agri-land/ Bos dom**	**scrblnd/ Bos dom**	**But-dom/ Bos dom**	**Aca-mix/ Bos dom**	**Ano dom/ Bos dom**
1	-5.6505	-1.3818	-5.0314	-3.2923	-1.7243	-2.0911	1.2305
2	-9.6678	-0.4125	-5.064	-3.702	-1.1191	-1.4875	1.407
3	-1.5082	1.2649	-3.1176	1.4938	0.52	-0.1674	1.5264
4	-6.9556	-0.4941	-5.3462	-3.0638	-1.1626	-1.181	1.9812
5	-5.3066	-0.6981	-4.6135	-4.6135	-1.672	-0.5921	1.1775
6	-9.7734	-1.0331	-9.7734	-6.3833	-2.0638	-2.4738	1.4174
7	-5.1436	0.0122	-3.0233	-2.0576	-0.7102	-2.4656	1.3121
8	0.2156	-1.1286	1.6228	1.8352	-0.7111	0.7039	1.1974
9	-0.414	-0.619	1.0575	0.3806	-0.6349	-1.6248	0.1698

Table 6. 8. Difference in log-ratios of utilized habitats for comparing habitat use based on kernel home ranges of each individual leopard with availability in the total study area of Sariska Tiger Reserve.

Individual leopard	Difference in log-ratios ($d = y - y_0$)						
	Bar lnd/ Bos dom	**Zizy-mix/ Bos dom**	**Agri-land/ Bos dom**	**scrblnd/ Bos dom**	**But-dom/ Bos dom**	**Aca-mix/ Bos dom**	**Ano dom/ Bos dom**
1	-4.0867	0.0838	-4.8133	-3.1426	-0.2722	-0.2402	0.0856
2	-8.104	1.0531	-4.8459	-3.5523	0.3329	0.3633	0.2621
3	0.0556	2.7304	-2.8995	1.6435	1.972	1.6835	0.3815
4	-5.3918	0.9714	-5.128	-2.9141	0.2895	0.6698	0.8363
5	-3.7429	0.7674	-4.3953	-4.4638	-0.2199	1.2587	0.0326
6	-8.2096	0.4325	-9.5552	-6.2336	-0.6117	-0.623	0.2725
7	-3.5799	1.4778	-2.8052	-1.9079	0.7419	-0.6148	0.1672
8	1.7794	0.3369	1.8409	1.9849	0.741	2.5548	0.0525
9	1.1498	0.8465	1.2756	0.5304	0.8172	0.226	-0.9751

To rank the habitat types in order of use by leopards, a matrix of the mean and standard error of all the habitats was calculated over all for nine leopards (table 6.9). The final outcome was obtained when the mean values were replaced by its sign in a simplified was as given in table 6.10.

The final simplified matrix (table 6.10) ranked leopard use of habitat in the following order: *Zizyphus* mixed forest> *Acacia* mixed forest> *Butea* dominated forest> *Anogeissus* dominated forest> *Boswellia* dominated forest> Scrubland> Barren land> agricultural land. There were no detectable differences between selection of *Acacia* mixed forest, *Butea* dominated forest, *Anogeissus* dominated forest and *Boswellia* dominated forest, but each habitat showed greater use then remaining habitat types.

Table 6. 9. Ranking matrix of means and standard errors obtained by averaging each habitat overall for nine leopards in Sariska Tiger Reserve.

Resource	Bar lnd	Ziz mix	Agri lnd	Scrblnd	But dom	Aca mix	Ano dom	Bos dom
Bar lnd		-4.3144	0.1329	-1.3416	-3.769	-3.9342	-3.4717	-3.3478
SE		1.2027	0.5608	0.5492	1.0791	1.0501	1.3206	1.232
Ziz mix	4.3144		4.4473	2.9728	0.5455	0.3802	0.8427	0.9666
SE	1.2027		1.1599	0.8695	0.1572	0.3997	0.2752	0.2607
Agri lnd	-0.1329	-4.4473		-1.4745	-3.9018	-4.0671	-3.6046	-3.4806
SE	0.5608	1.1599		0.5634	1.0201	0.9997	1.2516	1.1537
Scrblnd	1.3416	-2.9728	1.4745		-2.4273	-2.5926	-2.1301	-2.0062
SE	0.5492	0.8695	0.5634		0.7354	0.7676	1.0045	0.9436
But dom	3.769	-0.5455	3.9018	2.4273		-0.1653	0.2973	0.4212
SE	1.0791	0.1572	1.0201	0.7354		0.326	0.3124	0.2569
Aca mix	3.9342	-0.3802	4.0671	2.5926	0.1653		0.4625	0.5864
SE	1.0501	0.3997	0.9997	0.7676	0.326		0.3825	0.3595
Ano dom	3.4717	-0.8427	3.6046	2.1301	-0.2973	-0.4625		0.1239
SE	1.3206	0.2752	1.2516	1.0045	0.3124	0.3825		0.1598
Bos dom	3.3478	-0.9666	3.4806	2.0062	-0.4212	-0.5864	-0.1239	
SE	1.232	0.2607	1.1537	0.9436	0.2569	0.3595	0.1598	

Table 6. 10. Simplified ranking matrix of leopard based on comparing the utilization distribution of radio-locations for each animal in each habitat type with proportion of total available habitat types.

Resource	Bar lnd	Ziz mix	Agri lnd	Scrblnd	But dom	Aca mix	Ano dom	Bos dom	Rank
Bar lnd		-3	1	-3	-3	-3	-3	-3	**1**
Ziz mix	3		3	3	3	1	3	3	**7**
Agri lnd	-1	-3		-3	-3	-3	-3	-3	**0**
Scrblnd	3	-3	3		-3	-3	-1	-1	**2**
But dom	3	-3	3	3		-1	1	1	**5**
Aca mix	3	-1	3	3	1		1	1	**6**
Ano dom	3	-3	3	1	-1	-1		1	**4**
Bos dom	3	-3	3	1	-1	-1	-1		**3**

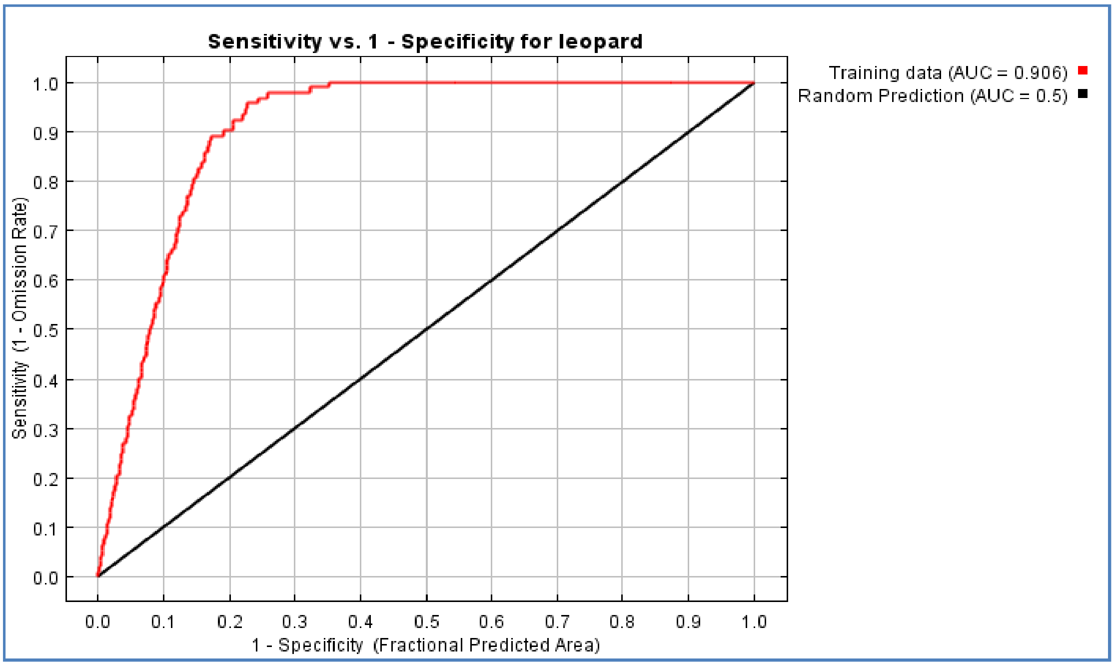
* Each mean element in the matrix was replaced by its sign. A (-3) represents significant deviation from random at $p<0.05$.

6. 4. 3. Habitat suitability of leopard

The habitat suitability model of leopard in Sariska TR and surrounding 5 km areas was predicted using MaxEnt model. The hypothesis in the present model was 'leopard is present when the area is suitable'. The hypothesis was validated with the area under curve (AUC), which is the probabilistic ratio between sensitivity and specificity of the hypothesis. The probability of rejecting the hypothesis, when it is actually true, is known as type I error (α); whereas, the probability of not rejecting the hypothesis, when it is actually false, is known as type II error (β). Hence, the specificity of the hypothesis is the probability of not rejecting the hypothesis, when it is actually true ($1-\alpha$) and the sensitivity of the hypothesis is the probability of rejecting the hypothesis, when it is actually false ($1-\beta$). In the present study, the receiver operating characteristic (ROC) (figure 6.3) curve predicted the area under curve (AUC) with the present data and random prediction The receiver operating characteristic (ROC) curve is a statistical accuracy measure of a model given by the type I error (probability of rejecting the hypothesis, when it is actually true, α) probability vs. 1- type II error (probability of rejecting the hypothesis, when it is actually false, 1-β) or power of the analysis. The main advantage of ROC analysis is that the area under the ROC curve (AUC) provides a single measure of model performance and independent of any particular choice of threshold. ROC analysis has recently been applied to a variety of classification problems in the evaluation of models of species distributions (Elith, 2002; Fielding and Bell, 1997). In the present study, the ROC curve showed that the MaxEnt model could predict a site as unsuitable when it is actually unsuitable with a power (1-β) of 0.9 while the probability of committing an error of not predicting it as unsuitable is 0.2.

MaxEnt predicted model gave the details of variables, which matter most for the leopard distribution in Sariska TR and adjoining 5 km areas (table 6.11). While the MaxEnt model is being trained, it keeps track of which environmental variables are contributing to fitting the model. Each step of the MaxEnt algorithm increases the gain of the model by modifying the coefficient for a single feature; the program assigns the increase in the gain to the environmental variable(s) that the feature depends on. The percent contribution of each variable to the leopard distribution model is given in table 6. 11.

Figure 6. 3. The prediction of area under receiver operating characteristic (ROC) curve (AUC) for habitat suitability model of leopard in Sariska Tiger Reserve.



The responses of leopard to the variables, which contributed most (> 5%) for predicting habitat suitability model for leopards, were given in figure 6.4 to 6.11. Each figure (figure 6.4 to 6.11.) represents a different MaxEnt model created using only the corresponding variable. These plots reflect the dependence of predicted suitability of leopard on the selected variable in Sariska TR and adjoining areas. The distances to water from leopard presence locations contributed maximum (19.8%) to the habitat suitability model for leopard. From the response curve of leopard (figure 6.4), it was observed that the probability of leopard presence was negatively correlated with the distance to water. In other words, the probability of presence of leopard in a location decreased with the increasing distance of water from such location. Amongst the prey species, distribution of peafowl (11.9%) and chital (11.5%) contributed maximum to the habitat suitability model for leopard followed by livestock (7%), sambar (5.9%), wild pig (5.2%) and common langur (0.8). The predicted distribution model of leopard was positively dependent on distribution of peafowl, chital, sambar and wild pig. The probability of presence of leopard increased with increasing encounter rate of peafowl, chital, sambar and wild pig (figure 6.5, 6.6, 6.10 and 6.11). Initially, the probability of presence of leopard decreased with increasing encounter rate of domestic livestock but further increased with increase of encounter rate of domestic livestock (figure 6.9).

Table 6. 11. Percent contribution of each bio-geographical variable in leopard distribution model in Sariska Tiger Reserve.

Variable	**Percent contribution**	**Permutation importance**
Dist to water	19.8	13.6
Peafowl	11.9	18.9
Chital	11.5	0.7
Zizyphus mixed forest	8.4	3.8
NDVI (summer)	8.1	6.4
Livestock	7	4.2
Sambar	5.9	12.3
Wild pig	5.2	0
Elevation	4.8	6
Boswellia dominated forest	4.7	5.7
Agricultural land	4.4	8.9
Anogeissus dominated forest	2.8	10.3
Scrubland	1.5	2.1
Acacia dominated forest	1.5	3.2
Barren land	1.3	0.9
Common langur	0.8	0.4
Butea dominated forest	0.4	2.5

Amongst the vegetation types, *Zizyphus* mixed forest contributed most (8.4%) for leopard's distribution followed by *Boswellia* dominated forest (4.7%), agricultural land (4.4%), *Anogeissus* dominated forest (2.8%), scrubland (1.5%), *Acacia* dominated forest (1.5%), barren land (1.3%) and *Butea* dominated forest (0.4%) (Table 6.11). It was found that the probability of presence of leopard increased with increasing area of *Zizyphus* mixed forest patches (figure 6.7). Normalized difference vegetation index (NDVI) in summer, directly contributed to leopard distribution. It was observed that the probability of presence of leopard increased with increasing NDVI in summer (figure 6.8).

Figure 6. 4. Response of leopard to the distance of water, as shown by in habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.

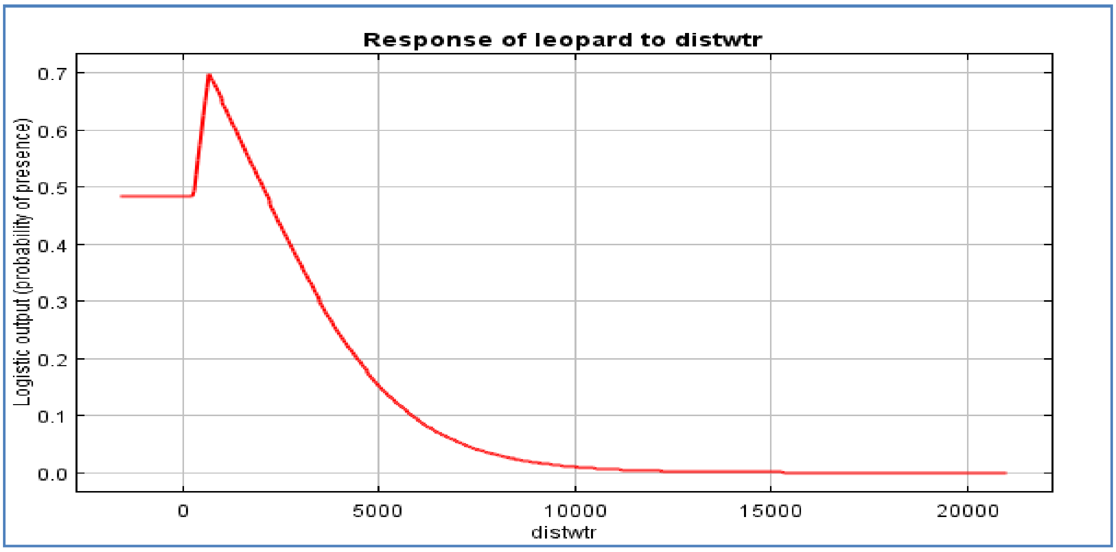


Figure 6. 5. Response of leopard to the distribution of peafowl, as shown by habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.

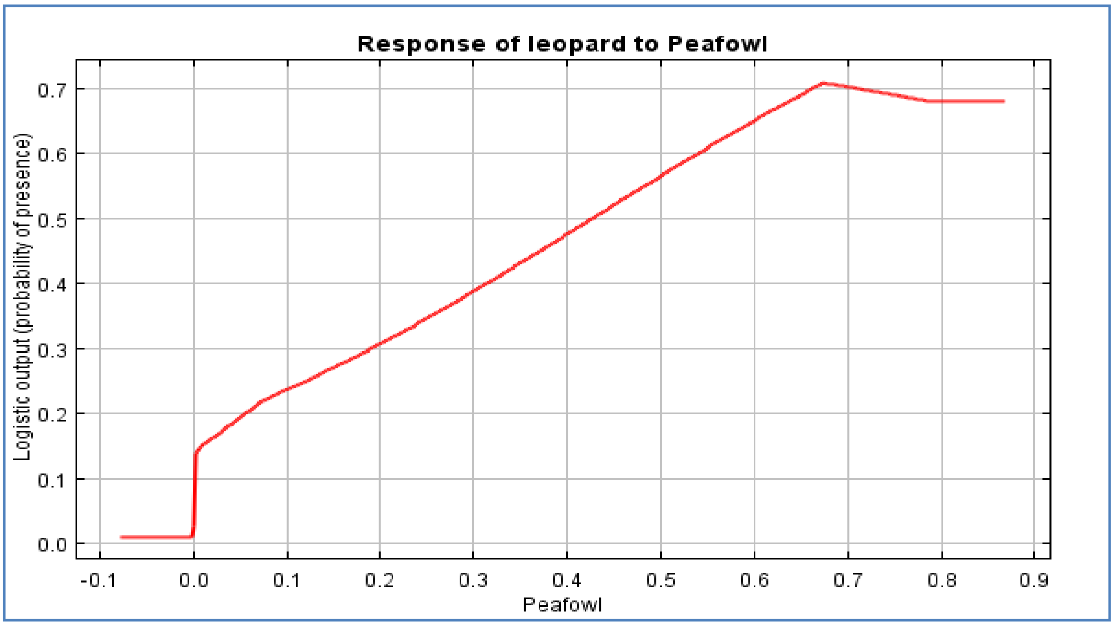


Figure 6. 6. Response of leopard to the distribution of chital, as shown by habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.

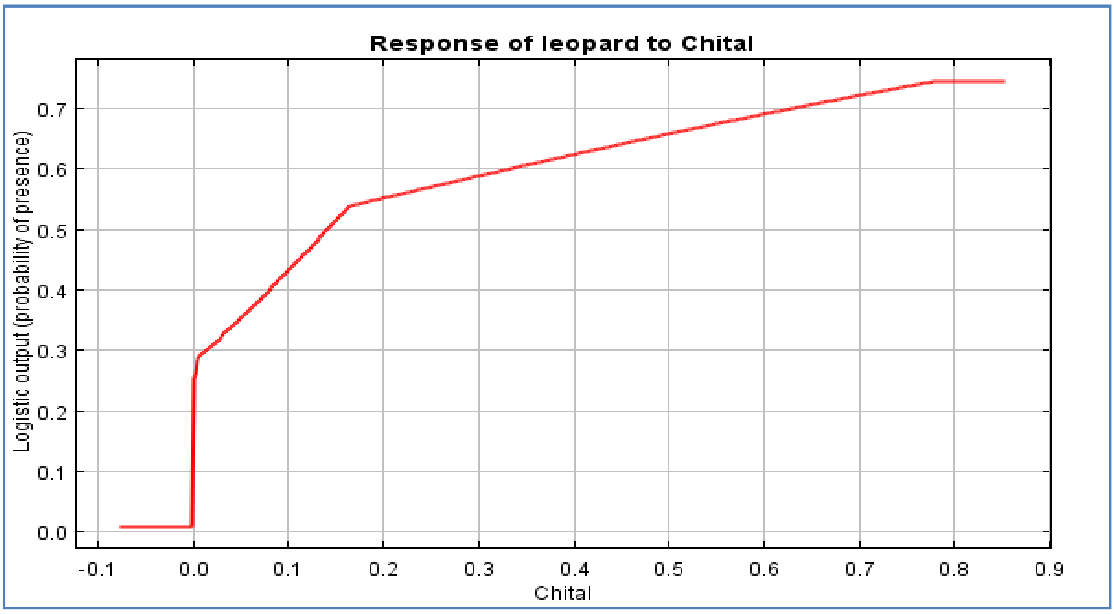


Figure 6. 7. Response of leopard to the distribution of *Zizyphus* mixed forest, as shown by habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.

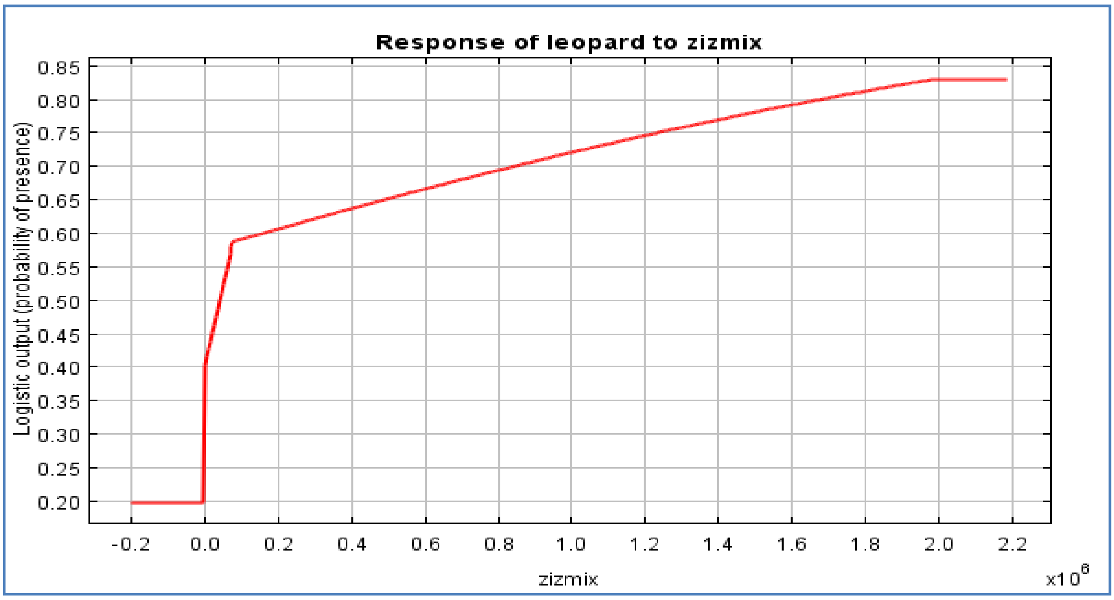


Figure 6. 8. Response of leopard to the NDVI (summer), as shown by habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.

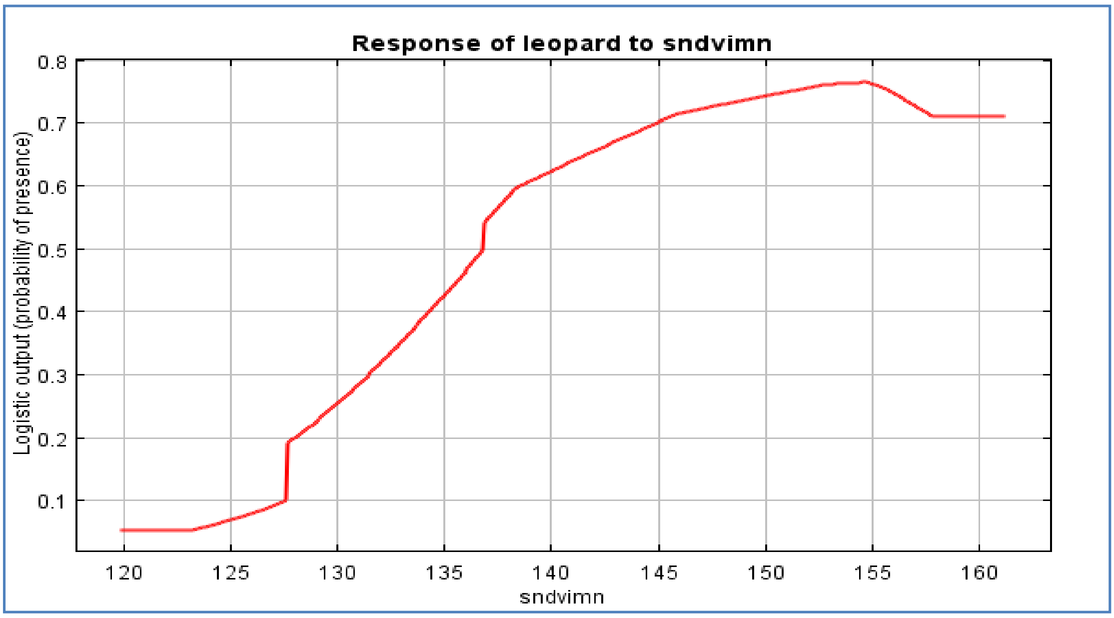


Figure 6. 9. Response of leopard to the distribution of livestock, as shown by habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.

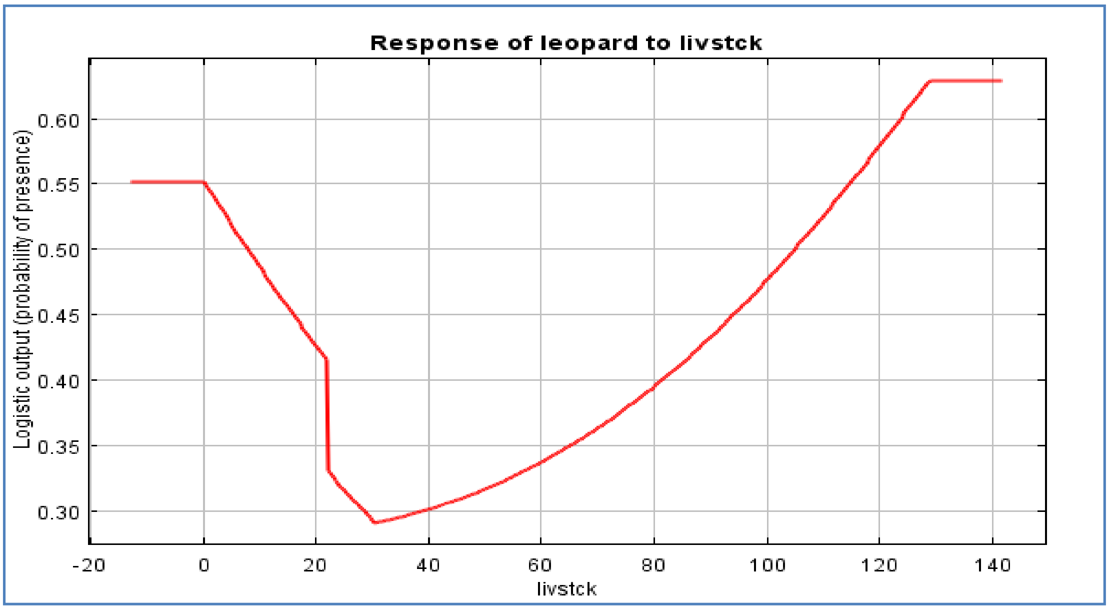


Figure 6. 10. Response of leopard to the distribution of sambar, as shown by habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.

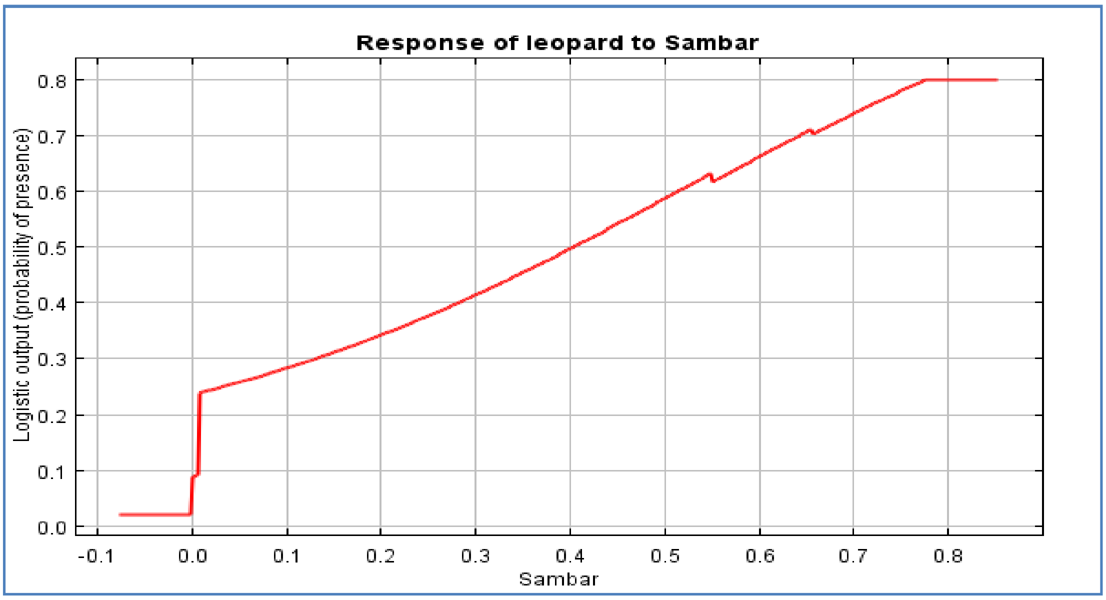
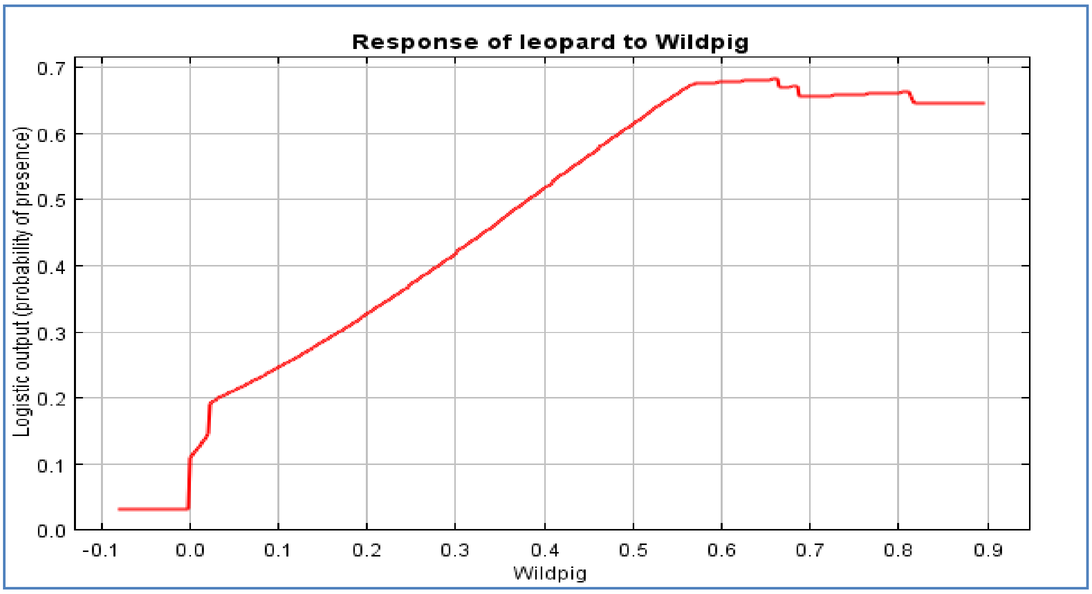
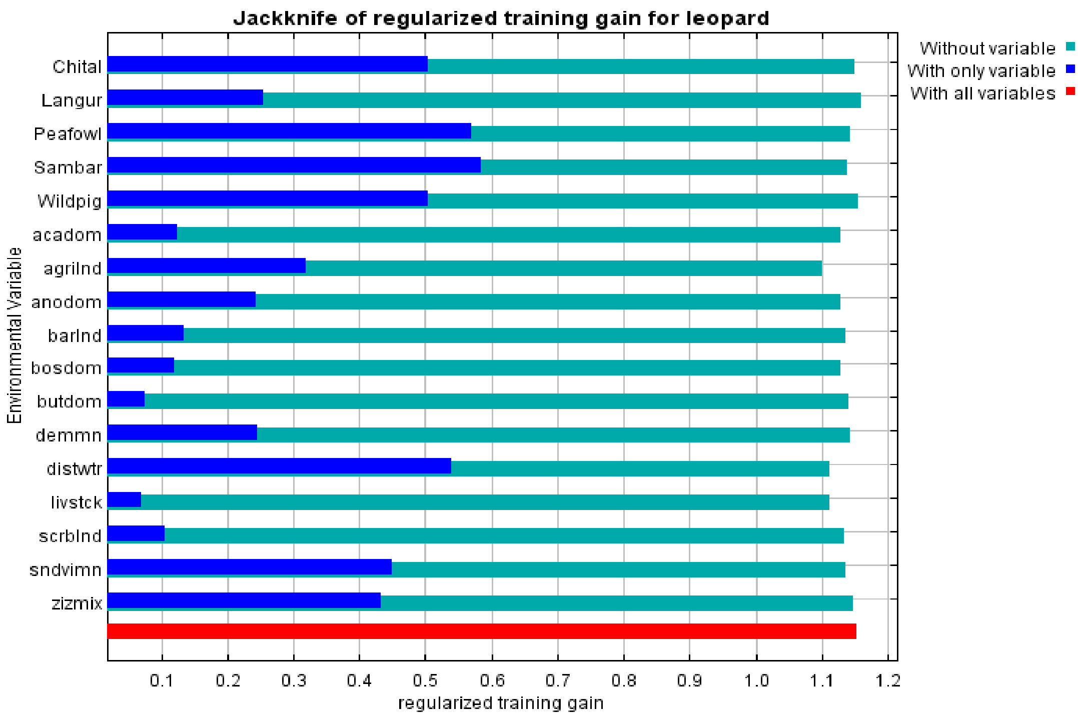


Figure 6. 11. Response of leopard to the distribution of wild pig, as shown by habitat suitability model in Sariska Tiger Reserve and adjoining 5 km areas.



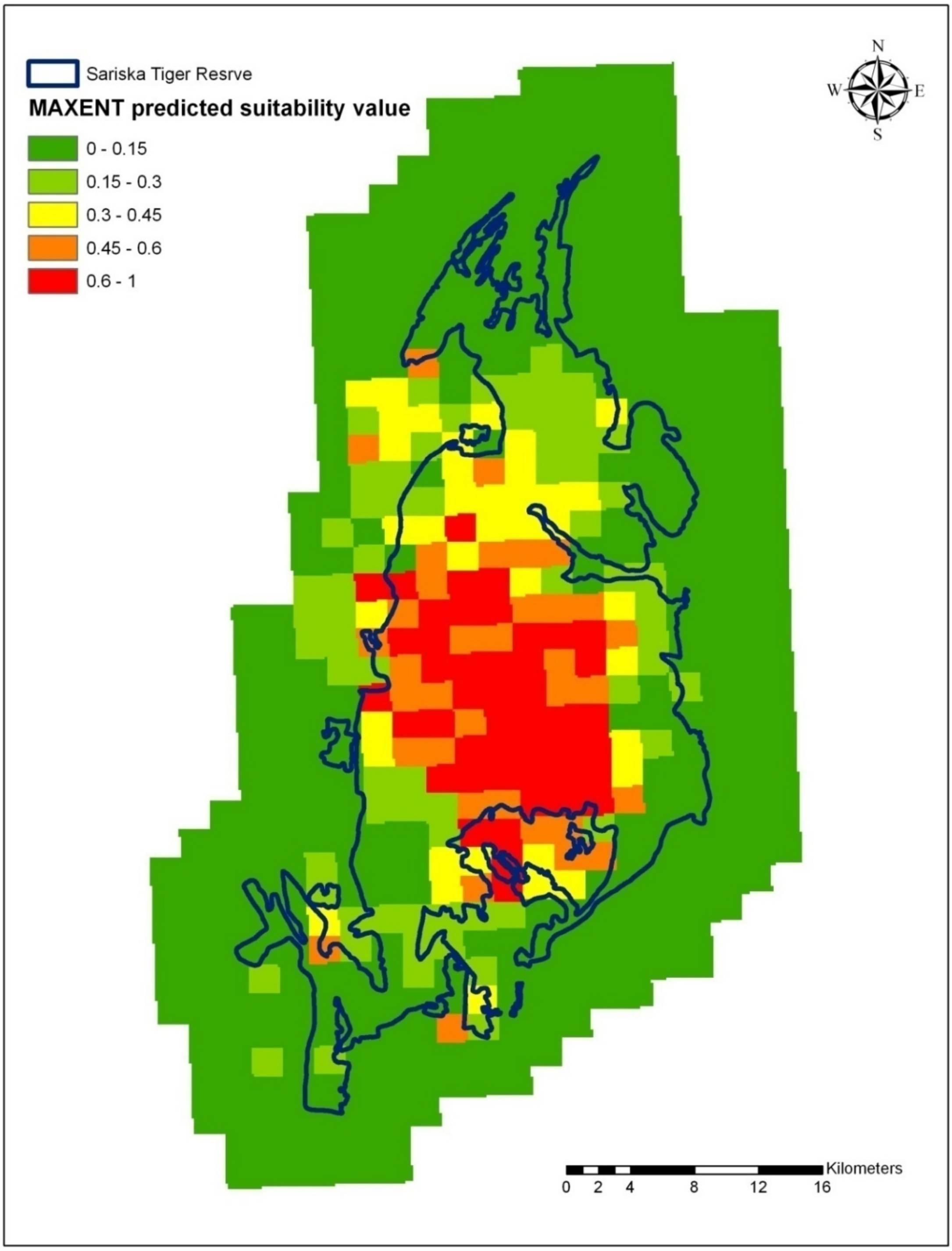
To understand the importance of each eco-geographic variable for predicting the distribution of leopard in Sariska TR and adjoining areas, a jackknife test was performed. The role of each variable (with or without) was examined in the jackknife test against the MaxEnt prediction gain (figure 6.12). It was observed that the eco-geographic variable with the highest gain when used in isolation was sambar, which therefore appeared to have most useful information by itself for prediction of leopard's distribution. The eco-geographic variable that decreased the gain most when it was omitted was agricultural land, which therefore appeared to have the most information that was not present in other variables. Agricultural land was found to be negatively correlated with the probability of presence of leopard and habitat use analysis revealed that agricultural land was most avoided habitat type by leopard in Sariska TR and adjoining 5 km areas.

Figure 6. 12. Jackknife test of eco-geographic variables against MaxEnt prediction gain.



Considering the contribution of each eco-geographic variable for the prediction of leopard's distribution, a composite habitat suitabality value was obtained for each grid by the program MaxEnt, which was then represented as MaxEnt habitat suitability model for leopard in Sariska TR and adjoining 5 km areas (figure 6.13).

Figure 6.13. Habitat suitability map of leopard for Sariska Tiger Reserve and adjoining 5 km areas.



6. 5. DISCUSSION

6. 5. 1. Estimation of home range of leopard

Leopards (*Panthera pardus*) are endangered in South East Asia and yet little is known about their resource needs which are to be secured for long-term conservation. The present study used radio telemetry to investigate home range size and habitat selection of Leopards in Sariska Tiger Reserve. Considering the leopard's elusive nature and occurrence in low densities, radio telemetry is probably the best available means to investigate both habitat selection and home range size (Bailey 1993). This technique has been used extensively in the leopard's African range (Norton and Lawson 1985, Bailey 1993, Jenny 1996, Mizutani and Jewell 1998, Marker and Dickman 2005). In Asia it has been used in Nepal (Seidensticker 1976, Sunquist 1981, Odden and Wegge 2005), India (Karanth and Sunquist 1995, 2000) and Thailand (Rabinowitz 1989, Grassman 1999).

In the present study, two male leopards were radio-collared to study the ranging pattern. Since both the male leopard were rescued from outside of Sariska TR, then collared and released inside Sariska TR, initially they explored larger areas to establish their home ranges. Both the animal took nearly two months explore the habitat and to settle down. Therefore, the locations from initial two months were excluded from home range and habitat use analysis. Before the release of these two male leopards, three tigers were re-introduced in the Sariska National Park area. Though both the leopards were initially released in the tiger occupied area, later they established their home ranges outside tiger occupied areas in Sariska TR. Since both the leopards were rescued from conflicted areas, they were more familiar with human dominated landscapes. Even after establishment of their home ranges, a large proportion of their home ranges were found outside the protected area. The annual home range of first male leopard (SP1) was calculated to be 84.3 km^2, out of which only 36.5 km^2 areas was found inside Sariska TR boundary. Similarly, the annual home range of second male leopard (SP2) was 170.1 km^2, out of which 64.4 km^2 areas was found inside Sariska TR boundary. A few cases of un-guarded livestock predation (N=7) were observed by these two leopards in the study period outside the protected area.

In the present study, the home range of leopard was estimated following different estimator, such as Minimum Convex Polygon (100%, 95%, and 90%), adaptive kernel (95%, 90%, and 50%) and harmonic mean (95%, 90%, and 50%). But, the estimate using 100% MCP method was considered to be the final estimate in this study. The MCP method, which has frequently been used as home range estimator in other leopard studies, is criticized for its sensitivity to small sample sizes, and because it usually incorporates large areas that are rarely used (Powell 1987, White and Garott 1990). Mitzutani and Jewell's (1998) study confirmed that relatively large samples sizes (>40) were required to produce reliable home range estimates. Bothma *et al.* (1997) concluded that the home range sizes of all nine leopards tracked in their study were underestimated when using MCP due to limited sample sizes. In the present study, a number of 148 and 268 locations were collected from first and second male leopards respectively, which gave better home range estimate with MCP method. Subsequently, MCP method allows to compare the estimate with previous studies. The home range estimate (100% MCP) of leopard from the present study was compared with other studies conducted in a wide variety of habitats in different parts of Africa and South-east Asia (table 6.12a), and it was evident that the home ranges estimated in the study area were amongst the largest reported in the literature (table 6.12a). Estimates from various regions were made using a variety of techniques, which probably accounts for a large degree of variation, but even when analyses were restricted to those made using the 100% MCP technique, estimates of home range size varied from 9.8 km^2 to 451 km^2. These studies were performed in a wide diversity of different habitats, with large variation in prey abundance, rainfall, vegetation and leopard density, as well as disparities in other factors such as whether the study was conducted in a protected area and whether larger sympatric carnivores were present in the area. The estimate of adult male home range size calculated using the 100% MCP method in the present study was comparable with other studies. Some of the studies specified that they used the 95% MCP or 95% kernel method to estimate adult male home range size, and hence the estimates could not be compared statistically with the present study. Comparing with other studies it was found that the home ranges of leopard in tropical forest are lesser than the dry deciduous forest or savanna forest (Rabinowitz 1989, Karanth and Sunquist 2000, Eisenberg and Lokhart 1972). Most of the African studies on leopard home range reported larger home ranges in woodland savanna or dry thorn forest (Stander *et al.* 1997, Bailey 1993, Zeiss 1997, Bothma and LeRiche 1984). The home range estimate in the present study was similar to the estimates in African studies as the habitat of Sariska TR falls under dry deciduous forest (with some savanna patches) and dry thorn forest.

The home range estimate of leopard in the present study was compared with different study sites of Africa and South-east Asia along with leopard density, prey biomass and rainfall of the respective area (table 6.12b). It was observed that the increase of home range of male leopard was negatively correlated with increase in prey biomass (Spearman correlation test; $r = -0.750$, $n = 7$, $p = 0.026$) among the different study sites. Several authors have described an inverse relationship between food availability and territory size in territorial animals (Ebersole 1980, Hixon 1980, Saitoh 1991). This relationship seems evident when reviewing previous leopard studies conducted in Africa, where the drier habitats with a sparser prey distribution produce extremely large home ranges and the more humid and prey rich habitats produce smaller home ranges. It was also found that the increase of home range was negatively correlated with increase in leopard density (Spearman correlation test; r = -0.547, n = 10, p = 0.051) in respective study area.

Despite of the fact that the increased rainfall was linked to higher prey biomass in an area (Spearman correlation test; r = 0.806, n = 5 p = 0.050), it had no significant impact on home ranges of male leopard (Spearman correlation test; r = 0.494, n = 9 p = 0.088) or on leopard densities across the study sites (Spearman correlation test; r = 0.450, n = 7 p = 0.155). The presence of large predators (tiger, lion or cheetah) in a particular area did not appear to have a significant impact on home range of male leopard (f = 0.523, p = 0.485).

There were major differences between the home ranges of two male leopards in different seasons. The first male leopard (SP1) occupied 67.8 km^2 areas in summer, which may be attributed to difficulties for obtaining water and wild prey species in peripheral areas of Sariska TR in summer. His home range decreased to 57.8 km^2 in monsoon and 29.6 km^2 in winter season centering two dams (Mansarovar and Mangalsar) which attracts a number of wild prey species in dry period. The second male leopard (SP2) occupied larger home range (170.1 km^2) in winter, which decreased to 56.9 km^2 in summer and 13.6 km^2 in monsoon. The home ranges in monsoon season were comparatively smaller for both the leopards, which may be attributed to easy availability of water and tall grass height, which helps leopard to stalk and kill prey animal with less effort (Bailey 1993).

Table 6. 12a. Estimated home ranges of leopard in different study sites.

Study area	Habitat type	Method	Mean Home Range size (male) (km^2)	Author
Present Study, Sariska TR, India	Dry deciduous/ thorn forest	100% MCP	127.1	
Kaeng Krachen NP, Thailand	Forested Hills	100% MCP	17.7	Grassman 1999
Kaudom Game Reserve, Namibia	Woodland Savanna	100% MCP	451.2	Stander *et al.* 1997
Kruger NP, South Africa	Woodland Savanna	100% MCP	76.2	Bailey 1993
Cape Province, South Africa	Fynbos/ plantation	100% MCP	388	Norton and Lawson 1985
Tai NP, Ivory Coast	Tropical forest	100% MCP	85.6	Jenny 1996
Waterberg Plateau Park, Namibia	Thorn bush savanna	100% MCP	118.7	Zeiss 1997
Hula Kha Kueng WLS, Thailand	Dry tropical forest	-	32	Rabinowitz 1989
Kalahari Gemsbok NP, SA	Desert/ grassland	95% Kernel	2182	Bothma and LeRiche 1984
Nagarhole NP, India	Tropical forest	95% MCP	21.7	Karanth and Sunquist 2000
Serengeti NP, Tanzania	Plans/ woodland	Sightings	57.5	Schaller 1972
Sabie river, Kruger NP, SA	Woodland Savanna	100% MCP	27.7	Bailey 1993
Wilpattu NP, SriLanka	Tropical forest/ scrubland	-	9.5	Eisenberg and Lokhart 1972

Table 6. 12b. Estimated leopard home range, density, prey biomass and rainfall in different study sites.

Study area	Mean Home Range size (male) (km^2)	Estimated prey biomass (kg/km^2)	Estimated leopard density/ 100 km^2	Presence of large predator	Mean Annual rainfall
Present Study, Sariska TR, India	127.1	8209.1	6.2	Yes	650
Kaeng Krachen NP, Thailand	17.7	-	-	No	1000
Kaudom Game Reserve, Namibia	451.2	34.9	1.5	Yes	450
Krugar NP, South Africa	76.2	3851.7	9.5	Yes	665
Cape Province, South Africa	388	-	0.9	No	1500
Tai NP, Ivory Coast	85.6	-	9	No	1700
Waterberg Plateau Park, Namibia	118.7	-	-	No	-
Hula Kha Kueng WLS, Thailand	32	-	4	Yes	-
Kalahari Gemsbok NP, SA	2182	-	0.6	Yes	200
Nagarhole Np, India	21.7	9856	-	Yes	1250
Serengeti NP, Tanzania	57.5		4	Yes	-
Sabie river, Kruger NP, SA	27.7	4559.6	16.4	Yes	665
Wilpattu NP, SriLanka	9.5	476	3.4	No	-

(-) = Data not available

6. 5. 2. Habitat use by leopard

Radio-telemetry is one of the most powerful tools available to the wildlife biologist because of its potential for providing unbiased data on animal's use of time and space. However, the analysis of habitat use is not straightforward, owing to the problem of sampling level, unit-sum constraint, differential use and definition of availability (Aebischer *et al.* 1993). In the present study, an animal's habitat use was determined by its trajectory, sub-sampled by radio-telemetry, camera trapping photographs and directs sightings. Although the number of locations per animal determines the accuracy with which its habitat use was estimated, it was the number of animal monitored that determined the sample size upon which to base and test hypotheses concerning habitat use by population. For each animal, habitat use was given by a set of proportions describing habitat composition and habitat availability was given by the proportion of habitat composition of a global area summing the MCPs of all the leopards. The recourse selection analysis was done by a second order compositional analysis (Vanak and Gompper 2010) and also related to Johnson's (1980) rank based method. Although habitat selection for leopards is covered by some studies (Bailey 1993, Marker and Dickman 2005), information is lacking for Asia. A camera trap study in Kaeng Krachen National Park in Thailand found that leopard habitat use increased with distance from human habitation (Ngoprasert *et al.* 2007). However, no study in Indian sub-continent has conclusively identified, leopard's selection of other geographical features likely to influence their distribution, such as forest type, topography or water availability.

In the present study, the order of preference of habitat selection of leopard in the study area was in the following order: *Zizyphus* mixed forest> *Acacia* mixed forest> *Butea* dominated forest> *Anogeissus* dominated forest> *Boswellia* dominated forest> Scrubland> Barren land> agricultural land. Though the area of *Anogeissus* forest within each animal's home range was higher than any other habitat categories, *Zizyphus* forest was found to be the preferred habitat by leopard. Compositional analysis is a comparison of used habitat types against available habitat. The area of *Zizyphus* forest is less (6%) in the total available habitat, but considering kernel utilization distribution *Zizyphus* forest was used more than its availability, thereby ranked as most preferred habitat by leopard in the study area. Ecologically, the *Zizyphus* forest always plays a key role in the ecosystem of a tropical dry deciduous forest. As the major *Zizyphus* forest patches were inside the Sariska National Park area, which is happened to be the tourism zone also, a number of artificial water holes were constructed in *Zizyphus* woodland by the Park authority. The Zizyphus patches allow palatable grasses to grow under it, such as *Chloris dolychostachya, Heteropogon contortus* and *Cynodon dactylon*. These grass species along with fallen *Zizyphus mauritiana* leaves and fruits which contain high protein (Sankar 2007), influenced assemblage of a number of prey species of leopard (ungulate and bird) in the study area. Hence, the resource available to an individual leopard in terms of food and water in *Zizyphus* forest may have influenced its higher rank in resource selection by leopard.

Though there was a preference order of habitats by leopard in the study area, but there was no significance difference observed in the selection of *Acacia* mixed forest, *Butea* dominated forest, *Anogeissus* dominated forest and *Boswellia* dominated forest. But leopard significantly avoided barren land and agricultural land ($p < 0.05$). Scrubland was selected more than barren land and agricultural land, as these provide no cover to a large carnivore. The present study proved, leopard being an elusive, secretive top predator prefers moderate to thick vegetation cover rather than open forest types in dry deciduous landscape.

6. 5. 3. Habitat suitability of leopard

In the present study, the habitat suitability model for leopard in the Sariska TR and surrounding area was predicted using presence only data. Systematic biological survey data tend to be sparse and/or limited in coverage. Species records are available though in the form of presence-only records in literature records, herbarium and museum databases. Many of these databases represent well over a century of public and private investment in biological science and are an important source of species occurrence data. The desire to maximize the utility of such resources has spawned an array of Species Distribution Models (SDM) methods for modeling presence-only data. MaxEnt (Phillips *et al*. 2006, Phillips and Dudık 2008) is one such method followed in the present study. Expanding use of presence-only data for modeling species distributions has prompted wide discussion about the sorts of distributions (e.g., potential vs. realized) that can be modeled with presence-only data in contrast to presence-absence data (Hirzel and Le Lay, 2008, Soberon and Nakamura 2009, Lobo *et al.* 2010). As mentioned in several of these articles, the subject is complex because of the interplay of data quality (amount and accuracy of species data; ecological relevance of predictor variables; availability of information on disturbances, dispersal limitations and biotic interactions), modeling method and scale of analysis (Elith *et al.* 2011).

Habitat models of ‘generalist’ big cats demonstrate associations with certain elevations, aspects, ruggedness and vegetation types, and negative correlations with proximity to roads and human density (Ortega-Huerta and Medley 1999, Hatten *et al.* 2005, Carroll and Miquelle 2006, Linkie *et al*. 2006). In comparison with these models, the present study showed similar findings even in a smaller landscape. Water found to be the most important factor contributed (19.8%) for the leopard distribution in Sariska TR and adjoining areas. Water is always known as the limiting factor and plays an important role in dry deciduous habitat for species distribution (Schaller 1972, Kruuk, 1972). In Sariska TR, the central part or the National Park area holds more number of water points (artificial and natural) than the peripheral areas, which reflected to more leopard presence in that area and therefore, the most suitable habitat for leopard.

Carnivore distribution and densities are clearly linked to prey distribution and abundance (Carbone and Gittleman 2002). Amongst the prey species, distribution of peafowl (11.9%) and chital (11.5%) contributed maximum to the habitat suitability model for leopard followed by livestock (7%), sambar (5.9%), wild pig (5.2%) and common langur (0.8). Peafowl was the most abundant prey species in the entire Sariska TR. The density of peafowl in the entire Sariska TR was 60.2/ km^2 and in the National Park area it was 100.7-121.4/ km^2, which was predicted as the most suitable habitat for leopard. The densities of chital and sambar in the National Park area were comparatively higher than the peripheral area and the MaxEnt predicted leopard distribution was positively correlated with both chital and sambar. In the present study, it was found that the chital and sambar contributed maximum in leopard's diet and were the most preferred prey species in the study area (chapter four). Evidently, the distribution of chital and sambar was found to be the key factors for the prediction of suitable habitat for leopard in Sariska TR and adjoining 5 km areas. Though, wild pig was consumed by leopard less than its availability, leopard's habitat suitability model showed positive correlatation with the distribution of wild pig, because of its distribution was limited to National Park area. The distribution of livestock and nilgai were auto-correlated (Pearson correlation = 0.017, p = 0.673), hence the distribution of nilgai was removed from the habitat suitability analysis. The distance to nearest village was also highly auto-correlated with the distribution of livestock (Pearson correlation = 0.000, p = 0.991) and hence it was removed from the analysis. Though, the distribution of livestock contributed 7% for the prediction of leopard's suitability model, it showed no significant trend. As there are 31 villages located inside the Sariska TR, the distribution of leopard was influenced by neither presence of village nor the distribution of livestock.

In the present study, normalized difference vegetation index (NDVI) in summer season contributed 8.1% for the prediction of suitability model of leopard in Sariska TR and adjoining 5 km area and revealed a positive correlation with leopard presence. Various studies have shown that NDVI integrates the influence of climatic variables (e.g. rainfall and evapo-transpiration) and other environmental factors (Cihlar *et al.* 1991) and is related to the distribution of both plant and animal species diversity (Walker *et al.* 1992). NDVI correlates directly with photosynthetically active biomass or vegetation productivity (Tucker and Sellers 1986, Reed *et al.* 1994), hence it accounts for biomass of wild ungulates and other herbivores in forested areas (Andersen *et al.* 2004, Loe *et al.* 2005, Pettorelli *et al.* 2005a, b). The NDVI in different seasons were auto-correlated, hence NDVI only in summer was taken into analysis. In a dry deciduous area like Sariska TR, NDVI in summer is more important than the other season, because the available vegetation biomass and productivity come to a critical point in peak summer and drought period. Thus, NDVI values indicated the presence of food (i.e. herbivores) and water for leopard, as well as cover (shrubs and trees) as important for thermal protection, reproduction, escape and stalking prey.

Amongst the different habitat types, *Zizyphus* mixed forest contributed most (8.4%) for the prediction of leopard's distribution followed by *Boswellia* dominated forest (4.7%), agricultural land (4.4%), *Anogeissus* dominated forest (2.8%), scrubland (1.5%), *Acacia* dominated forest (1.5%), barren land (1.3%) and *Butea* dominated forest (0.4%). As it was previously mentioned that the *Zizyphus* forest plays a key role in the ecosystem of a tropical dry deciduous forest. *Zizyphus* mixed forest with combination of several edible grass species, allow assemblage of ungulates throughout the year, which in turn helps leopard to stalk and kill. The availability of *Zizyphus* mixed forest was very limited to the valley areas of Sariska National Park (only 7% of the total habitat of Sariska TR), but it was used more than its availability ($p < 0.05$) by leopard. From the habitat use analysis it was found that *Zizyphus* mixed forest was the most preferred habitat by leopard, and had positive correlation with leopard distribution. Though *Boswellia* dominated forest and *Anogeissus* dominated forest contributed 4.7% and 2.8% respectively for predicting the suitable habitat of leopard, showed negative correlation with leopard's distribution. The availability of *Boswellia* dominated forest and *Anogeissus* dominated forest was throughout the Sariska TR and adjoining 5 km areas, but considering the other eco-geographical factors (preybase, NDVI), the most suitable habitat of leopard was predicted in Sariska National Park area. From the habitat use analysis, it was also observed that *Boswellia* dominated forest and *Anogeissus* dominated forest were not much preferred by leopard, thus had no significant contribution to determine suitable habitat for leopard in Sariska TR. Agricultural land and barren land contributed 4.4% and 1.3% respectively for predicting the suitable habitat of leopard, but showed negative correlation with leopard's presence, as it was observed from habitat use analysis of leopard, agricultural land and barren land were highly avoided. Though scrubland contributed very less (1.5%) to determine suitable habitat for leopard, it showed slight positive correlation with leopard's presence, as scrubland provides day time refuge and cover for leopard in dry deciduous thorn forest (Kruuk 1972). *Acacia* dominated forest and *Butea* dominated forest contributed less (1.5% and 0.4% respectively) for predicting the suitable habitat of leopard, and hence showed no detectable correlation with leopard's presence.

Considering the contributions of prey species and availability of different habitat types for the prediction of leopard's distribution, it was found that, leopards at Sariska TR selected habitats that were easier to catch prey rather than where prey was more common. However, in contrast to expectations, the apparent 'catchability' of prey was not directly proportional to the amount of cover present within a vegetation type. Leopards are widely perceived to favor the densest habitats available for hunting (Hes 1991; Sunquist and Sunquist 2002; Bailey 2005). For example, of 50 kills recorded in the Kruger National Park (Bailey 2005), 46% were found in dense riparian vegetation, 44% in medium to dense thorn-bush thickets and 10% in open habitats. Hayward *et al.* (2006) suggested a similar trend, with leopards preferring to hunt in dense environments. But in the present study, out of 82 kills recorded, 60 were in *Zizyphus* mixed forest, *Butea* mixed forest and scrubland. However, results in this study showed that the probability of presence of leopard was higher in habitat types with intermediate cover levels, even though areas with the denser vegetation may have higher abundance of available prey. Leopards are visual hunters, relying heavily on sight and to a lesser extent on hearing to detect prey (Sunquist and Sunquist 2002, Bailey 2005). Thicker habitat types on Sariska TR (riparian forest, *Anogeissus* forest with *Grewia* understory or *Acacia* forest with *Adathoda* understory) may have reduced the chance of an encounter with prey sufficiently to negate any benefits accrued from increased cover for stalking. Additionally, even if prey is successfully detected, increased vegetation density may not always benefit a stalking predator. Very thick cover can either impede the progress of a stalk by obstructing a clear view of the target, or increase the chance of detection by prey (because of a noisier approach by the predator), and may hamper the final chase even if a predator gets within charging distance (Leyhausen 1979).

Although the leopard has the widest habitat tolerance of any large felid and is more resilient than other, sympatric large cat species in the face of anthropogenic threats (Sunquist and Sunquist 2002), the widely held perception that leopards are 'super-generalists' with little need for dedicated conservation action is increasingly viewed with suspicion (Spong *et al.* 2000, Balme and Hunter 2004, Ray *et al.* 2005*). The* results in the present study indicated that leopards show some degree of specialization, at least in their choice of habitat.

Plate 7a. Radio-collaring of leopard

Plate 7b. First radio-collared male leoprd (SP1)

Chapter 7

CONSERVATION OF LEOPARD IN SARISKA TIGER RESERVE

Little is known about the conservation status of leopard in human dominated Aravalli landscape. The presence of leopard is reported from 16 Protected Areas (PA) in Rajasthan that includes two National Parks (NP) and 14 Wildlife Sanctuaries (WS). In addition, they are also found in Reserved Forest areas. Despite their wide distribution in the State, it is one of the least studied species. In last two decades leopard has been vanished from Keoladeo NP, Bandh Baratha WS, Ramgarh Vishdhari WS and Shergarh WS. The largest number of leopard was reported from Kumbhalgarh WS (87) followed by Sitamata WS (43), Sariska TR (38), Mount Abu WS (35), Ranthambore (29) and Todgarh Rawali WS (21). These PA's have better chances of survival of leopard as they hold large areas with adequate wild prey base. PA's having <100 km^2 areas and with <10 leopards may not sustain leopard population in the long run because of heavy biotic interference. In these PA's the availability of wild prey species is found low which results in leopard preying upon domestic livestock (cattle and goats) and dogs thus leading to human-leopard conflicts.

There has long been an assumption that leopards can cope in human-dominated landscapes and persevere despite pressures such as habitat fragmentation due to their great adaptability. However, conservation scientists agree that leopards may be more vulnerable to extinction than previously thought. On either side of the argument, very little research has been done which can direct successful conservation strategies for leopards.

The present study estimated the prey availability and prey consumption, population and survival rate and the home ranges and resource selection of leopard in

Sariska Tiger Reserve. It was found that the population of leopard declined significantly from 22.2 ± 3.6 in 2007 to 9.0 ± 1.5 in 2010 in the study area. Only eight individual leopards were photo captured in 2010, whereas 19 individuals were captured in 2007. When the survival rate of the leopard population in the study area was examined, it was found that the survival rate was also declined from 65% in 2008 to 47% in 2010. Several eco-geographic and anthropogenic factors may have contributed to this decline in the study area.

A small population of tigers (10-12 individuals) got exterminated in Sariska due to poaching in 2004. After that, leopard took over the entire tiger habitat, which was the best habitat available in Sariska TR and became the top predator (Sankar *et al.* 2009). A number of three tigers were re-introduced in the study area 2008-2009 and another three in 2009-2010. It was observed that the leopard population declined significantly (18%) after re-introduction of tiger in the study area in 2009 and decline was even more (41%) in 2010. The re-introduced tigers established their home ranges in the study area, which was the best available habitat in Sariska National Park which was previously occupied by leopards. Being a larger cat, the dominance of tiger in the Sariska- Kalighati- Pandupole valley may have out-competed leopards to the peripheral areas. In regions of high tiger density, tigers are known to out-compete leopards (McDougal 1988, Schaller 1967, 1972). Radio-tracking studies on tiger and leopard movements indicate that leopards avoid areas frequented by tigers (Seidensticker 1976) occurring the periphery of parks near human settlements. Interestingly, though the forest leopards in the study area might have moved towards the peripheral region, the cases of human-leopard conflict are comparatively less in Sariska TR than the other protected areas. There were a few incidence of livestock lifting (n=6) from the villages inside and outside Sariska TR during the study period.

The present study showed that sambar and chital were the most preferred prey species by leopard throughout the study period and these two cervids contributed more than 50% in leopard diet. A few studies have reported about the livestock lifting and incidences of lifting dogs by leopards from the villages in the forest periphery where the prey base is less abundant (Edgaonkar and Chellum 2002, Athreya *et. al.* 2004, Chauhan *et al.* 2005). Those leopards, in a sense, became urban leopard due to extensive habitat degradation and prey base depletion. But in Sariska TR, though there are ten villages inside the study area, the predation of goats and dogs by leopard were negligible. The predated cattle by leopard were largely unguarded feral cattle in the forested area. Even in past, when there were 15 to 20 tigers in the study area, leopard consumed largely rodents (more than 40%) and other wild ungulate species, but didn't depend on domestic livestock (Sankar and Johnsingh 2002). Unlike the study of Arivazhagan *et al.* (2007) and Seidensticker and Lumpkin (1996), where leopards are more likely to move through open terrain and raid villages for domestic prey and tigers depend upon large ungulate prey, in Sariska leopard utilized largely wild ungulate species. Leopard's ability to consume wide range of prey species and adapt in any habitat or terrain type helped them to survive on wild prey species than domestic livestock, even in the presence of sympatric competitor species, the tiger.

The prey base of leopard also declined significantly in the study area. The overall density of wild ungulates declined from 133 animals/ km^2 in 2007 to 39 animals/km^2 in 2010. The wild ungulate prey biomass declined from 13582 kg/ km^2 in 2007 to 4188 kg/ km^2 in 2010. As mentioned earlier, a large number of prey species died in the study area due to heat stroke and food and mouth disease during the summer 2009 and 2010 in the study area. Seventy sambar were trans-located to Kumbhalgarh Wildlife Sanctuary from the study area by the park authorities during summer 2009. Nevertheless, fragmentation and loss of habitat and its quality usually result in loss of prey availability. Inadequate prey base affect leopard's reproductive success and its survival. The predation by tiger may have also contributed to decline in wild prey base in the study area. All these reasons contributed to the decline of prey base in the study area, which may indirectly have led to decline in leopard population.

The overall survival rate of leopard in the study area was 57 %, and the rest 43% represented the deaths and emigration of leopard from the study area. In total eleven leopard deaths were recorded in the study area. After analyzing the cause specific mortality model, it was found that more than 13% leopard deaths were due to road accidents and poisoning. A proportion of 7% leopard deaths were due to inter-guild fight with tigers, which can be considered as the natural cause obeying the theory of carnivore competition (Kruuk 1972). Evidently, 13% leopard deaths due to anthropogenic causes also contributed to the decline in leopard population. In the other parts of Aravalli landscape (where presence of leopard is reported), availability of wild prey species is found low resulting in leopard predating largely on domestic livestock (cattle and goats) and dogs thus leading to human-leopard conflicts. Further, rapid decline in forest resources (fuel wood, fodder) in these areas are reported due to heavy dependency by local people. The increasing human population, changing land use practices, soaring demands from our urban population and more recently fast expanding economic activity have started straining the delicate balance at which leopard survive. Leopard being a large territorial animal require large spaces and in small and isolated protected areas they frequently venture out and come in direct conflict with local people and experience high mortality.

In the present scenario, if the anthropogenic causes for leopard deaths are decreased and habitat continuity is maintained with adjoining forest areas in north with Alwar forest division and in south Jamwa Ramgarh Wildlife Sanctuary, the existing leopard population in Sariska TR will survive for more than 100 years (probability of extinction 0.06). Considering the adaptive capability of leopard throughout its range, the leopard population in Sariska may survive, for longer period with better habitat management, forest protection and closing of State Highways (SH 13 - Alwar-Sariska-Jaipur and SH 29A – Alwar-Sariska-Tehla-Dausa) for vehicular traffic during the night hours.

References

Ackerman, B.B., Lindzey, F.G and Herker. T.P. 1984. Cougar food habits in southern Utah. *J. Wildlife Manage. 48:* 147-155.

Aebischer, N.J., Peter, A.R., Robert, E.K., Robertson, P.A. and Kenward, R.E. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74, 1313–1325.

Ahmed, K. and Khan, J.A. 2008. Food habits of leopard in Tropical Moist Deciduous Forest of Dudhwa National Park, Uttar Pradesh, India. International Journal of Ecology and Environmental Sciences 34(2): 141-147, 2008.

Ajith Kumar C.R. and Sankar K. 1993. Ichthyo-fauna of Sariska Wildlife Sanctuary. Journal Bombay Nat. Hist. Soc. 1993; 90:299-300.

Anderson, D.R., Burnham, K.P. and Crain, B.R. 1978. A Log Linear Model Approach to Estimation of Population Size using the Line Transect Sampling Method. *Ecology*, 59: 190-193.

Anderson, D.R., Laake, J.L., Crain B.R. and Burnham, K.P. 1979. Guidelines For Transect Sampling of Biological Populations. *Journal of Wildlife Management*, 43(1): 71-79.

Anderson, R.P. and Martınez-Meyer, E. 2004. Modeling species' geographic distributions for preliminary conservation assessments: an implementation with the spiny pocket mice (*Heteromys*) of Ecuador. Biol. Conser. 116, 167–179.

Anderson, P., Turner, M.G., Forester, J.D., Zhu, J., Boyce, M.S., Beyer, H. and Stowell, L. 2005. Scale-dependent summer resource selection by reintroduced elk in Wisconsin, USA. J. Wildl. Mgmt. 69, 298–310.

Andheria, A.P., Karanth K.U., and Kumar N.S. 2007. Diet and prey profiles of three sympatric large carnivores in Bandipur Tiger Reserve, India. Journal of Zoology 273:169-175.

Avinandan, D., Sankar K. and Qureshi Q. 2008. Prey selection of tiger (*Panthera tigris tigris*) in Sariska tiger reserve, Rajasthan. Journal of the Bombay Natural History Society 105:247-254.

Bagchi, S., Goyal S.P. and Sankar K. 2003. Prey abundance and prey selection by tigers (*Panthera tigris*) in a semi arid, dry deciduous forest in western India. *Journal of Zoology* 260: 285-290.

Bailey, T.N. 1993. The African Leopard: Ecology and behavior of a solitary felid. Columbia University Press, New York

Bailey, T.N. 2005. The African Leopard: Ecology and Behavior of a Solitary Felid. 2nd edn. Caldwell, New Jersey: Blackburn Press.

Ballard, W. B., Whitman, J. S. and Gardner, C. L. 1987. Ecology of an exploited wolf population in south-central Alaska. Wildlife Mono- graphs 98:1-54.

Balme, G.A. and Hunter, L.T.B. 2004. Mortality in a protected leopard population, Phinda Private Game Reserve, South Africa: a population in decline? CCAfrica Ecological Journal, 6, 5e11.

Balme, G., Slotow, R. and Hunter, L. 2009. Edge effects and the impact of nonprotected areas in carnivore conservation: leopards in the Phinda-Mkhuze Complex, South Africa. Animal Conservation. (2010) 1–9.

Banerjee, K. 2005. Estimating the ungulate abundance and developing the habitat specific effective strip width models in Kuno Wild Life Sanctuary, Madhya Pradesh. Masters Thesis, Forest research Institute. Deemed University. 185pp.

Beecham, J.J. 1983. Population characteristics of black bears in west central Idaho. Journal of Wildlife Management 47:405-412.

Bergerud, A.T. and Ballard, W.B. 1988. Wolf predation on caribou: the Nelchina herd case history: a different interpretation. Journal of Wildlife Management 2:344-357.

Bertram, B.C.R. 1978. Living in groups: predators and prey. Pages 64-96 in J. R. Krebs and N. B. Davies, eds. Behavioral ecology: an evolutionary approach. Sinauer, Sunderland, Mass.

Bertram, B.C.R. 1982. Leopard ecology as studied by radio tracking. Symp. Zool. Soc. Lond: 41-352

Berwick, S.H. and Jordan, P.A. 1971. First Report of The Yale-Bombay Natural History Society Studies of Wild Ungulates at the Gir Forest, Gujarat, India. *Journal of Bombay Natural History Society* 68: 412-423.

Biswas, S. and Sankar K. 2002. Prey abundance and food habit of tigers (*Panthera tigris tigris*) in Pench National Park, Madhya Pradesh, India. Journal of Zoology 256:411-420.

Bodendorfer, T., Hoppe-Dominik, B., Fischer, F. and Linsenmair, K.E. 2006. Prey of the leopard (*Panthera pardus*) and lion (*Panthera leo*) in the Comoe and Marahoue National Park, Cote d'Ivoire, West Africa. Mammalia 35: 231–246.

Boitani, L., Corsi, F., De Biase, A., Carranza, I. D., Ravagli, M., Reggiani, G., Sinibaldi, I. and Trapanese, P. 1999. A databank for the conservation and management of the African mammals. Instituto di Ecolgia Applicata. Roma, Italy.

Borchers, D.L. and Efford, M.G., 2008. Spatially Explicit Maximum Likelihood Methods for Capture–Recapture Studies. Biometrics 64:377-385.

Bothma, J.D.P., and Le Riche E.A.N. 1984. Aspects of the ecology and the behavior of the leopard *Panthera pardus* in the Kalahari Desert. Koedoe 27:259-279.

Bothma, J.D.P. and Le Riche, E.A.N. 1986. Prey preference and hunting efficiency of the Kalahari Desert leopard. In Cats of the world: biology, conservation and management: 381–414. Miller, S.D. and Everett, D.D. (Eds). Washington, DC: National Wildlife Federation.

Bothma, J.D.P. and E.A.N. Le Riche. 1990. The influence of increasing hunger on the hunting behavior of southern Kalahari leopards. *J. Arid Environ.* 18:79-84.

Bothma, J.duP., Knight, M.H., Le Riche, E.A.N. and Van Hensbergen, H.J. 1997. Range size southern Kalahari leopards. South African Journal of Wildlife Research 27(3):94-99

Bowen, W.D. 2000. Reconstruction of pinniped diets: accounting for complete digestion of otoliths and cephalopod beaks. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 898–905.

Boyce, M.S. 2006, Scale for resource selection functions. Diversity and Distributions, 12: 269–276.

Brander, D.A.A. 1923. *Wild animals in central India.* London: Edward Arnold.

Buckland, S.T. 1985. Perpendicular Distance Models for Line Transect Sampling. *Biometrics,* 41: 177-195.

Buckland, S.T. 1992. Fitting Density Functions with Polynomials. *Applied Statistics*, 41: 63-76.

Buckland, S.T. and Turnock, B.J. 1992. A robust line transect method. Biometrics, 48: 901–909.

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. Distance Sampling: Estimating Abundance of Biological Populations. Chapman and Hall, London. Pp 446.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thonas, L. 2001. In Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press. P 432.

Burnham, K.P and Anderson, D.R. 1976. Mathematical Models for Non Parametric Inferences from Line Transect Data. *Biometrics*, 32: 325-336.

Burnham, K.P. and Overton, W.S. 1979. Robust estimation of population size when capture probabilities vary among animals. Ecology 60:927–936

Burnham, K.P., Anderson, D.R. and Laake, J.L. 1980. Estimation of density from line transect sampling of biological populations. Wildl. Monogr. 72: 202 pp.

Carbone, C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg, J.R., Griffiths, M., Holden, J., Kawanishi, K., Kinnaird, M., Laidlaw, R., Lynam, A., Macdonald, D.W., Martyr, D., McDougal, C., Nath, L., O'Brien, T., Seidensticker, J., Smith, D.J.L., Sunquist, M., Tilson, R. and Shahruddin, W.N. 2001. The use of photographic rates to estimate densities of tigers and other cryptic mammals. *Animal Conservation 4*: 75–79.

Carbone. C. and Gittleman, J. L. 2002. A Common rule for scaling of carnivore density. Science 295, 2273-76.

Carroll, C. and Miquelle, D.G. 2006. Spatial viability analysis of Amur tiger *Panthera tigris altaica* in the Russian Far East: the role of protected areas and landscape mat

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

Champion, F.W. 1992. *With a camera in tiger-land*. London: Catto and Windus.

Chauhan, D.S. and Goyal, S.P. 2001. A study on distribution, relative abundance and food habits of leopard (*Panthera pardus*) in Garhwal Himalayas. Technical Report, 2001, Wildlife Institute of India.

Chauhan, D.S., Harihar, A., Goyal, S.P., Qureshi, Q., Lal, P. and Mathur, V.B. 2005. Estimating leopard population using camera traps in Sariska Tiger Reserve, Wildlife Institute of India, Dehradun, India, pp 23.

Chellam, R. 1993. The ecology of the Asiatic lion (*Panthera leo persica*). Saurashtra University, Rajkot.

Chundawat, R.S. 2001. Tiger conservation in dry tropical forests of India. Report: Jan 2000 to June 2001, submitted to Centre for Wildlife Studies, Bangalore, India

Chundawat, R.S., Gogate, N. and Johnsingh, A.J.T. 1999. Tigers in Panna: preliminary results from an Indian tropical dry forest. In Riding the tiger: tiger conservation in human-dominated landscapes: 123–129. Seidensticker, J., Christie, S. and Jackson, P. (Eds). Cambridge: Cambridge University Press.

Cihlar, J., St-Laurent, L. and Dyer, J.A. 1991. The relation between normalized differences vegetation index and ecological variables. *Remote Sensing of Environment*, 35, 279–298.

Contractor, D. 2007. Evaluating the effects of design and sampling intensity on estimating tiger (*Panthera tigris*) population and density, M.Sc thesis submitted to Wildlife Institute of India, Dehra Dun 64pp.

Corbet, G.B. and Hill, J.E. 1992. The mammals of the Indo-malayan region. Oxford: Oxford University Press.

Corebett. J. 1947. The man eating leopard in Rudraprayag. Oxford University Press. London.

Corbett, L.K. 1989. Assessing the diet of dingoes from feces: a comparison of 3 methods. *Journal of Wildlife Management* 53: 343–346.

Crumpacker, D.W., Hodge, S.W., Friedley, D.F. and Gregg, Jr.W.P. 1988. A preliminary assessment of the status of major terrestrial and wetland ecosystems on federal and Indian lands in the United States. Conservation Biology 2:103-115.

Cueller, E.L., Arispe M.R. and Noss A.J. 2006. Geoffroy's cat at the northern limit of their range: activity patterns and density estimates from camera trapping in Bolivian dry forests. Stud *Neotrop Fauna Environ* 41:169-178.

Cutler, T.L. and Swann. D.E. 1999. Using remote photography in wildlife ecology: a review. *Wildlife Society Bulletin* 27:571-581.

Daniel, J.C. 1996. The leopard in India- A natural history. Natraj Publishers. Dehradun.

Das, S. 2006. Food Habits of Leopard (*Panthera pardus*) in different Human-Leopard conflict categories in Pauri Garhwal, Uttaranchal. Masters Thesis. Forest Research Institute (Deemed University). Dehradun. Pp 83.

Desai, J.H. 1975. Observations on the reproductive biology and early postnatal development of the panther, *Panthera pardus* L. in captivity. *J. Bombay Nat. Hist. Soc.* 72: 293-304.

Dinerstein, E., Loucks, C., Wikramanayake, E., Ginsberg, J., Sanderson, E., Seidensticker, J., Forrest, J., Bryja, G., Heydlauff, A., Klenzendorf, S., Leimgruber, P., Mills, J., O'Brien, T. G., Shrestha, M., Simons, R. and Songer, M. 2007. The fate of wild tigers. Bioscience 57:508-514.

Dobroruka, L.J. 1968. A note on the gestation period and rearing of young in the leopard. *Int. Zoo. Yrbk.* 8: 65.

Dorazio, R.M. and Royle, J.A. 2005. Estimating size and composition of biological communities by modeling the occurrence of species. Journal of the American Statistical Association 100:389–398.

Drummer, T.D. and McDonald, L.L. 1987. Size Bias in the Line Transect Sampling. *Biometrics*, 43: 13-21.

Drummer, T.D. 1991. SIZETRAN: Analysis of Size-biased Line Transect Data. *Wildlife Society Bulletin*, 19: 117-118.

Eberhardt, L.L. 1978. Appraising variability in Population Studies. *Journal of Wildlife Management*, 42: 207-238.

Eberhardt, L.L. 1979. Line Transects based on Right-angle Distances. *Journal of Wildlife Management*, 43: 768-774.

Ebersole, S.P. 1980. Food density and territory size: An alternative model and test on the reef fish Eupomacentrus leucostius. American Naturalist 115:492-509.

Edgaonkar, A. and Chellam, R. 1998. A preliminary study on the ecology of the leopard *(Pathera pardus fusca)* in the Sanjay Gandhi National Park, Maharashtra. RR-98/002. Pp 33. Wildlife Institute of India, Dehra Dun.

Edgaonkar, A. and Chellam, R. 2002. Food habit of the leopard, *Panthera pardus*, in the Sanjay Gandhi National Park, Maharashtra, India. Mammalia 66:353-360.

Edgaonkar, A. 2008. Ecology of the Leopard (*Panthera pardus fusca*) in Satpura National Park and Bori Wildlife Sanctuary. Ph.D Thesis, Saurashtra University, Rajikot.

Efford, M.G. 2004. Density estimation in live trapping studies. *Oikos* 106: 598-610.

Efford, M.G. 2007. DENSITY 4.1: software for spatially explicit capture–recapture. Department of Zoology, University of Otago, Dunedin, New Zealand.

Efford, M.G., Dawson, D.K. and Borchers, D.L. 2009. Population density estimated from locations of individuals on a passive detector array. Ecology 90:2676-2682.

Eisenberg, J.F. 1986. Life history strategies of the felidae: Variations on a common theme. Pages 293-303 in S. D. Miller, and D. D. Everett, editors. Cats of the World of the World: Biology, Conservation, and Management. National Wildlife Foundation, Washington, D.C.

Eisenberg, J.F. and Lockhart, M.C. 1972. An ecological reconnaissance of Wilpattu Park, Ceylon. Smithsonium Contributions to Zoology 101: 1- 118.

Elith, J., Graham, C.H. and Anderson, R.P. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography, 29, 129–151.

Ellith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, Y.E. and Yates, C.J. 2011. A statistical explanation of Maxent for ecologists. Diversity and Distributions. 17, 43-57

ESRI, 2006. Arc Map 9.2. Environmental systems Research Institute Inc.

Foreman, D. 1992. Developing a regional wilderness recovery plan. Wild Earth (special issue):26-29.

Franklin, J.F., Cromack, K., Denison, W., McKee, A., Maser, C., Sedell, J., Swanson, F. and Juday, G. 1981. Ecological characteristics of old- growth Douglas-fir forests. General technical report PNW-1 18. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon

Fuller, T.K. 1989. Population dynamics of wolves in north-central Minnesota. Wildlife Monographs 105.

Fuller, T.K. 1995. An international review of large carnivore conservation status. Pages 410-412 in J. A. Bissonette and P. R. Krausman, editors. Integrating people and wildlife for a sustainable future. The Wildlife Society, Bethesda, Maryland

Gates, C.E., Marshall, W.H. and Olson, D.P. 1968. Line Transect Method of Estimating Grouse Population densities. *Biometrics*, 24: 135-145.

Grassman, LI.Jr. 1999. Ecology and behavior of the Indochinese leopard in Kaeng Krachan National Park, Thailand. Nat. HIST. Bull. Siam Soc. 47: 77-93.

Griffiths, M.G. and Van Schaik, C.P. 1993. Camera-trapping: a new tool for the study of elusive rain forest animals. *Trop. Biodiv.* 1: 131–135.

Gupta, S., Mondal, K., Sankar, K. and Qureshi, Q. 2009. Record of Desert cat (*Felis selvestris*) in Sariska Tiger Reserve, Rajasthan *Indian Forester* Vol 135, No 10:1446-1448

Hamilton, P.H. 1976. The Movements of Leopards in Tsavo National Park, Kenya as Determined by Radio-tracking. M.Sc. thesis, University of Nairobi.

Haque, Md.N. 1990. Study on the Ecology of wild Ungulates of Keoladeo National Park, Bharatpur, Rajasthan. Ph.D. Thesis. Centre for Wildlife and Ornithology, Aligarh Muslim University, Aligarh. 308 pp.

Harihar, A. 2005. Population, Food Habits and Prey Densities of Tiger in Chilla Range, Rajaji National Park, Uttaranchal, India.

Harihar, A., Pandav, B. and Goyal S.P. 2009. Density of leopard (*Panthera pardus*) in Chilla Range of Rajaji National Park, Uttarakhand, India. *Mammalia* 73: 68.71.

Harihar, A., Ghosh, M., Fernendes, M., Pandav, B. and Goyal S.P. 2010. Use of photographic capture-recapture sampling to estimate density of Striped Hyena (*Hyaena hyaena*): implications for conservation. Mammalia 74 (2010): xxx-xxx

Harrison, D.L. and Bates, P.J.J. 1991. The mammals of Arabia. 2nd ed. Sevenoaks, England: Harrison Zoological Museum.

Harvey, J.T. 1989. Assessment errors associated with harbor seal (*Phoca vitulina*) faecal sampling. *Journal of Zoology (London)* 219: 101–111

Hatten, J.R., Averill-Murray, A. and Van Pelt, W.E. 2005. A spatial model of potential jaguar habitat in Arizona. *Journal of Wildlife Management*, 69, 1024–1033.

Hayne, D. W. 1949a. Calculation of size of home range. Journal of Mammalogy 30:1-18.

Hayne, D.W. 1949b. An Examination of the Strip Census Method for Estimating Animal Abundance. *Journal of Wildlife Management*, 13: 145-147.

Hayward, M.W., Henschel, P., O'Brien, J., Hofmeyr, M., Balme, G. and Kerley, G.I.H. 2006. Prey preferences of the leopard (*Panthera pardus*). Journal of Zoology 270:298-313.

Heglund, P. 2002. Foundations of species-environment relations. In Predicting Species Occurrences. (J. Scott, P. Heglund, M. Morrison, J. Haufler, M. Rapheal, W. Wall and F. Samson eds.). Island Press. Washington D.C 45.51 pp.

Hemmer, H. 1979. Gestation period and postnatal development in fields. *Carnivore* 2: 90-100.

Henschel, P., Abernethy, K.A. and White, L.J.T. 2005. Leopard food habits in the Lope' National Park, Gabon, Central Africa. African journal of ecology, Afr. J.Ecol., 43 21-28.

Hes, L. 1991. The Leopards of Londolozi. Cape Town: Struik Winchester.

Hirzel, A.H., Hausser, J., Chessel, D. and Perrin, N., 2002. Ecological niche factor analysis: how to compute habitat-suitability maps without absence data? Ecology 87, 2027–2036.

Hirzel, A.H. and Le Lay, G. 2008. Habitat suitability modeling and niche theory. Journal of Applied Ecology, 45, 1372– 1381.

HIxon, M.A. 1980. Food production and competitor density as the determinants of feeding territory size. American Naturalist 115:510-530.

Hoppe-Dominik, B. 1984. Etude du spectre des proies de la panthere, *Panthera pardus,* dans le Parc National de Tai en Cote d' Ivoire (Prey frequency of the leopard, *Panthera pardus,* in the Tai National Park of the Ivory Coast). Mammalia 48(4): 477-87.

Horne, J.S., Garton, E.O. and Rachlow, J.L. 2008. A synoptic model of animal space use: simultaneous estimation of home range, habitat selection, and inter/intra-specific relationships. Ecol. Model. 214, 338–348.

Hornocker, M.G. 1969. Winter territoriality in mountain lions. Journal of Wildlife Management 33:457-464.

Hornocker, M.G. 1970. An analysis of mountain lion predation upon mule deer and elk in the Idaho Primitive Area. Wildlife Monographs 21.

Hornocker, M.G. and Bailey. T. 1986. Natural regulation in three species of felids. Pages 211-220 in S. D. Miller and D. D. Everett, editors. Cats of the world. The National Wildlife Federation Institute for Wildlife Research, Washington, D.C.

Ilany, G. 1981. The leopard of the Judean desert. *Israel — Land Nat.* 6: 59–71.

Ilany, G. 1986. Preliminary observations on the ecology of the leopards (*Panthera pardus jarvisi*) in the Judean desert. In: S.D. Miller and D.D. Everett (Eds), Cats of the world: biology, conservation and management. National Wildlife Federation, Washington, D.C.

Ivelev, V.S. 1961. Experimental ecology of the feeding of fishes. Yale University press, New Haven, Conn., USA, pp. 302.

Jackson, R.M., Roe J.D., Wangchuk R. and Hunter D.O. 2006. Estimating snow leopard population abundance using photography and capture-recapture techniques. *Wildl Soc Bull* 34: 772-781.

Jathanna, D. 2001. Density, Biomass and Habitat Occupancy of Ungulates in Bhadra Tiger Reserve, Karnataka. Masters Dissertation. Saurashtra University, Rajkot. India.pp71.

Jennelle, C.S. Runge, M.C. and Mackenzie, D.I. 2002. The use of photographic rates to estimate densities of tiger and other cryptic mammals: a comment on misleading conclusions. *Animal Conservation* 4: 75 – 79.

Jenny, D. 1996. Spatial organization of leopards *Panthera pardus* in Tai National Park, Ivory Coast: Is rain forest habitat a 'tropical haven'? Journal of Zoology 240:427-440.

Jerdon, T.C. 1867. The mammals of India: a natural history of all the animals known to inhabit continental India. Roorkee: Thomason College Press.

Jhala, Y.V. and Qureshi, Q. 2004. Monitoring Tiger Status and Habitat Part-I. A Field Guide. A Technical Publication of Project Tiger Directorate.

Jhala, Y.V., Gopal R., and Qureshi Q. 2008. Status of the Tigers, Co-predators, and Prey in India. Page 151. National Tiger Conservation Authority, Govt. of India, New Delhi, and Wildlife Institute of India, Dehradun.

Johnsingh, A.J.T. 1983. Large mammalian prey--predators in Bandipur. Journal of the Bombay Natural History Society 80:1-57.

Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Johnson, K.G., Wei, W., Reid, D.G. and Jinchu, H. 1993. Food habits of Asiatic leopards (*Panthera pardus fusca*) in Wolong Reserve, Sichuan, China. J. Mammal. 74, 46–650.

Kale, R., Ramesh, T., Qureshi, Q. and Sankar, K. 2011. Density of tiger and leopard in a tropical deciduous forest of Mudumalai Tiger Reserve, southern India as estimated using photographic capture-recapture sampling. Acta Theriologica. DOI 10.1007/s13364-011-0038-9

Karanth, K.U. 1995. Estimating Tiger *Panthera tigris* populations from camera-trap data using capture-recapture models. Biological Conservation 71:333-338.

Karanth, K.U. and. Sunquist, M.E. 1992. Population structure density and biomass of large herbivores in the tropical forests of Nagarahole, India. Journal of Tropical Ecology.8:21-35.

Karanth, K.U. and Sunquist M.E. 1995. Prey selection by tiger, leopard and dhole in tropical forests. Journal of Animal Ecology 64:439-450.

Karanth, K.U. and Sunquist, M.E. 2000: Behavioral correlates of predation by tiger (*Panthera tigris*), leopard (*Panthera pardus*) and dhole (*Cuon alpinus*) in Nagarhole, India.

Karanth, K.U. and Nichols J.D. 1998. Estimation of tiger densities using Photographic captures and recaptures. *Ecology 79 (8)*: 2852-2862.

Karanth K.U. and Nichols, J.D. 2000. Ecological status and conservation of tigers in India. Centre for Wildlife Studies, Bangalore

Karanth, K.U and Nichols J.D. 2002. Monitoring tigers and their prey: a manual for researchers, managers and conservationists in tropical Asia. Centre for Wildlife Studies, Bangalore, India.

Karanth, K.U., Nichols J.D., Kumar N.S., Link W.A. and Hines J.E. 2004. Tigers and their prey: Predicting carnivore densities from prey abundance. Proceedings of the National Academy of Sciences of the United States of America 101:4854-4858.

Karanth, K.U., Nichols, J.D., Kumar, N.S. and Hines, J.E. 2006. Assessing tiger population dynamics using photographic capture-recapture sampling. Ecology, 87, 2925–2937.

Karanth, K.U. and Stith, B.M. 1999. Prey depletion as a critical determinant of tiger population viability. Pages 100 113 in J. Seidensticker, S. Christie, and P. Jackson, editors. Riding the tiger: tiger conservation in human dominated landscapes. Cambridge University Press, Cambridge, UK.

Katajisto, J. and Moilanen, A. 2006. Kernel based home range method for data with irregular sampling intervals. Ecological Modeling 194 2006), 405-413.

Kawanishi, K. and Sunquist. M.E. 2004. Conservation status of tigers in a primary rainforest of Peninsular Malaysia. Biological Conservation 120:329–344

Kendall, W.L., Pollock, K.H. and Brownie, C. 1995. A likelihood-based approach to capture-recapture estimation of demographic parameters under the robust design. Biometrics 51: 293–308

Kendall, W., Nichols, J.D. and Hines, J. 1997. Estimating temporary emigration using capture–recapture data with Pollock's robust design. *Ecology*, 78, 563– 578.

Khan. J.A., Chellam, R. and Johnsingh, A.J.T. 1995. Group Size and Age Sex Composition of Three Major Ungulate Species in Gir Lion Sanctuary, Gujarat, India. *Journal of Bombay Natural History Society*. Vol 92 (3): 295-302.

Khan, J.A., Chellam, R., Rodgers, W.A. and Johnsingh, A.J.T. 1996. Ungulate Densities and Biomass in the Tropical Dry Deciduous Forests of Gir, Gujarat, India. *Journal of Tropical Ecology* 12: 149-162.

Kidwai, Z., Sankar, K., Qureshi, Q. and Khan, J.A, 2009. Population and habitat use of Galliformes in Sariska Tiger Reserve, Rajasthan. M. Sc. Dissertation submitted to Aligarh Muslim University, Aligarh.

Kie, J.G. 1994. CALHOME. Forestry Sciences Lab. Fresno, California.

Kingdon. J. 1977. East African mammals. Vol. 3A, Carnivores. Chicago. Chicago University Press.

Korchgen, L.K. 1980. Procedure for food habits analysis. *Wildlife management techquies manual*. The Wildlife Society, Washington, D.C.113-112.

Kruuk, H. and Turner, M. 1967. Comparative notes on predation by lion, leopard, cheetah and hunting dog in the Serengeti area, East Africa.- Mammalia 31, p. 1-27.

Kruuk, H. 1972. The spotted Hyena. Chicago. The University of Chicago Press.

Kucera, T.E. and Barrett, R.H. 1993. The trailmaster camera systems for detecting wildlife. *Wildlife Society Bulletin* 21: 505–508.

Laake, J.L., Buckland, S.T., Anderson, D.R. and Burnham, K.P. 1993. *DISTANCE user's guide, Version 2.0.* Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, Colorado, USA.

Laake, J., Thomas L., Strindberg S., Marques F.F.C., Borchers D.L., Buckland S.T., Anderson D.R., Burnham K.P., Hedley S.L. and Pollard J.H. 2001. Distance

User's Guide (Research Unit for Wildlife Population Assessment, Univ. Of St. Andrews, St. Andrews, U.K.), Ver. 5.0, Pp. 185.

Landres, P.B., Verner, J. and Thomas. J.W. 1988. Ecological uses of vertebrate indicator species: a critique. Conservation Biology 2: 316-328.

Leban, F.A. 1999. Resource selection for windows 1.00. Moscow: University of Idaho.

Leyhausen, P. 1979. Cat Behavior: the Predatory and Social Behavior of Domestic and Wild Cats. New York: Garland STPM Press.

Link W.A. and Karanth K.U. 1994. Correcting for overdispersion in tests of prey selectivity. Ecology 75: 2456- 2459.

Linkie, M., Chapron, G., Martyr, D.J., Holden, J. and Leader-Williams, N. 2006. Assessing the viability of tiger subpopulations in a fragmented landscape. *Journal of Applied Ecology*, 43, 576–586.

Litivaitis, J.A. 2000. Investigating food habits of terrestrial vertebrates. Research techniques in animal ecology: controversies and consequences (L. Boitani and T. K. Fuller, eds.). Columbia University Press, New York 165-190.

Lobo, J.M., Jimenez-Valverde, A. and Hortal, J. 2010. The uncertain nature of absences and their importance in species distribution modeling. Ecography, 33, 103–114.

MacKenzie, D.I., Nichols, J.D., Sutton, N., Kawanishi, K. and Bailey. L.L. 2005. Suggestions for dealing with detection probability in population studies of rare species. Ecology 86:1101–1113.

MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L.A. and Hines, J.E. 2006. Occupancy modeling and estimation. Academic, San Diego, CA.

Marker, L.L. and Dickman, A.J. 2005. Factors affecting leopard (*Panthera pardus*) spatial ecology, with particular reference to Namibian farmlands. South African Journal of Wildlife Research 35:105-115.

Mathur, V.B. 1991. The ecological interaction between habitat composition, habitat quality and abundance of some wild ungulates in India. D.Phil. Thesis. University of Oxford, United Kingdom. 279 Pp.

McDougal, C. 1977. The face of the tiger. Rivington Books, London

McDougal, C. 1988. Leopard and tiger interactions at Royal Chitwan National park, Nepal. J Bombay Nat Hist Soc 85:609–610

Millspaugh, J.J., Nielson, R.M., Mcdonald, L., Marzluff, J.M., Gitzen, R.A., Rittenhouse, C.D., Hubbard, M.W. and Sheriff, S.L. 2006. Analysis of resource selection using utilization distributions. J. Wildl. Mgmt. 70, 384–395.

Miquelle, D.G., Smirnov, E.N., Hornocker H.G. Nikolaev I.G. and Matyushkin E.N. 1996. Food habits of Amur tigers in Skhote-Alin Zapovednik and the Russian Far East and implications for conservation. J. Wildl. Res. 1: 138-147.

Mizutani, F. and Jewell, P.A. 1998. Home-range and movements of leopards (*Panthera pardus*) on a livestock ranch in Kenya. J. Zool., Lond. 244: 269–286.

Mohr, C.O. 1947 Table of equivalent populations of North American small mammals. *American Midland Naturalist*, 37, 223-249.

Mondal, K. 2006. Leopard and ungulate abundance estimation in Rajaji National Park, Uttaranchal. Masters Thesis. Forest Research Institute (Deemed University). Dehradun. Pp 95.

Mondal, K., Qureshi, Q. and Sankar, K. 2010. A spot of trouble. Sanctuary Asia. August 2010.

Mondal, K., Gupta, S., Qureshi, Q. and Sankar, K. 2011. Prey selection and food habits of leopard (*Panthera pardus fusca*) in Sariska Tiger Reserve, Rajasthan, India. Mammalia, 75 (2011): 201–205

Monterroso, P., Brito, J.C., Ferreras, P. and Alves, P.C. 2009. Spatial ecology of the European wildcat in a Mediterranean ecosystem: dealing with small radio-tracking datasets in species conservation. Journal of Zoology, 279, 27– 35.

Muckhenirn, N.A. and Eisenberg, J.F. 1973. Home range and predation of Ceylon leopard *The World Cats*, Vol 1: 142-175.

Mukherjee, S., Goyal, S.P. and Chellam, R. 1994. Standardisation of scat analysis techniques for leopards (*Panthera pardus*) in Gir National Park, Western India. *Mammalia* 58: 139-143.

Murie, D.J. and Lavigne, D.M. 1986. Interpretation of otoliths in stomach content analyses of phocid seals: quantifying fish consumption. *Canadian Journal of Zoology* 64: 1152–1157

Murray Bertram G. 1979. Population Dynamics- alternative models. Academic Press. New York.

Neu, C.W., Byers, C.R. and Peek, J.M. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 42:172-174.

Nichols, J.D. and Conroy, M.J. 1996. Estimation of species richness. *in* D. Wilson *et al.*, editors. Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution Press, Washington, DC. Pages 227–234.

Nichols, J.D., Boulinier, T., Hines, J.E., Pollock, K.H. and Sauer. J.R. 1998. Inference methods for spatial variation in species richness and community composition when not all species are detected. Conservation Biology 12:1390–1398.

Nichols, J.D. and Karanth. K.U. 2002. Statistical concepts; assessing spatial distribution. *In* K.U. Karanth and J.D. Nichols, editors. Monitoring tigers and their prey. Centre for Wildlife Studies, Bangalore, India.

Norton, P.M. and Henley, S.R. 1987. Home range and movements of male leopards in the Cedarberg Wilderness Area, Cape Province.S. Afr. J. Wildl.Res. 17: 41–48.

Norton, P.M., Lawson, A.B., Henley, S.R. and Avery, G. 1986. Prey of leopards in four mountainous areas of the South-Western Cape Province. S. Afr. J. Wildl. Res. 16 (2):41-48.

Norton, P.M. and Lawson, A.B. 1985. Radio tracking of leopards and caracals in the Stellenbosch area, Cape Province. S. Afr. J. Wild. Res. 15: 17–24.

Noss, R.F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4:355-364.

Noss, R.F. 1995. Maintaining ecological integrity in representative re- serve networks. World Wildlife Fund Canada and World Wildlife Fund U.S., Toronto and Washington, D.C.

Noss, R.F., LaRoe, E.T.III and Scott, J.M. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological report 28. National Biological Service, Washington, D.C.

Noss, R.F., Quigley, H.B., Hornocker, M.G., Merrill, T. and Paquet, P. 1996. Conservation biology and carnivore conservation. Conserv. Biol. 10:949-963.

Nowell, K. and Jackson, P. 1996. Wild Cats: status survey and Conservation Plan, Gland, Switzerland.

O'Brien, T.G., Kinnaird, M.F. and Wibisono, H.T. 2003. Crouching tigers, hidden prey; Sumatran tiger and prey populations in a tropical forest landscape. *Animal Conservation* 6: 131-139.

O'Connell, A.F.Jr., Talancy, N.W., Bailey, L.L., Sauer, J.R., Cook, R. and Gilbert, A.T. 2006. Estimating site occupancy and detection probability parameters for meso and large mammals in a coastal ecosystem. Journal of Wildlife Management 70:1625–1633

Odden, M. and Wegge, P. 2005. Spacing and activity patterns of leopards *Panthera pardus* in the Royal Bardia National Park, Nepal. Wildlife Biology 11:145-152.

Ortega-Huerta, M.A. and Medley, K.E. 1999. Landscape analysis of jaguar (*Panthera onca*) habitat using sighting records in the Sierra De Tamaulipas, Mexico. *Environmental Conservation*, 26, 257–269.

Otis, D.L., Burnham, K.P., White, G.C. and Anderson, D.R. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monographs* 62: 1-135.

Panwar, H.S. 1979. A Note on the Tiger Census Technique Based on Pugmark Tracings, International Symposium on Tiger, New Delhi, Feb.22-24, 1979, also published in Indian Forester Special Issues: 70-77 pp.

Panwar, H.S 1987. Project Tiger: The reserves, the tiger and their future. Pp 110-117 in Tilson, R.L; and Seal, U.S (Eds). Tigers of the world. Noyes Publications Park Ridge.

Parmer, P.J. 1985. Contribution of flora of Sariska Tiger Reserve, Alwar, District, Rajasthan. Bull. Bot. Surv. India. 27: 29-40

Pascoe, E.H. 1950. Manual of the geology of India and Burma. Govt of India, Monoger of Publ; Calcutta, Vol 1: 1-483

Peladeau, N. 2000. *Simstat v 2.0 (software)*. Montreal, Canada: Provalis Research.

Phillips, S.J., Dudık, M. and Schapire, R.E. 2004. A maximum entropy approach to species distribution modeling. In: Proceedings of the 21st International Conference on Machine Learning, ACM Press, New York, pp. 655–662.

Phillips, S.J. 2005. Maxent software for species distribution modeling. Website: http://www.cs.princeton.edu/schapire/maxent/.

Phillips, S.J., Anderson, R.P. and Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling, 190, 231–259.

Phillips, S.J. and Dudik, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography, 31, 161–175.

Pienaar, U.V. 1969. Predator-prey relationships amongst the larger mammals of the Kruger National Park. Koedoe 12:108-176.

Pollock, K.H. 1982. A capture-recapture design robust to unequal probability of capture. Journal of Wildlife Management 46, 752{757.

Powell, R.A. 1987. Black bear home range overlap in North Carolina and the concept of home range applied to black bears. International Conference on Bear Research and Management 7: 235-242.

Prater, S.H. 1980. The book of Indian animals. Bombay Natural History Society, Bombay.

Putman, R.J. 1984. Facts from faeces. *Mammal Review* 14:79–97.

Quang, P.X. 1991. A Nonparametric Approach to Size Biased Line Transect Sampling. *Biometrics*, 47: 269-279.

Quigley, H.B., Koehler, G.M. and Hornocker. M.G. 1989. Dynamics of a mountain lion population in central Idaho over a 20-year period. Page 54 (abstract) in R.H. Smith, editor. Proceedings of the 3rd mountain lion workshop. The Wildlife Society, Arizona Chapter, Phoenix.

Rabinowitz, A. R. 1989. The density and behavior of large cats n a dry tropical forest in Huai Kha Khaeng Wildlife Sanctuary, Thailand. Natural History Society Bulletin Siam Society 37:235-251.

Ramakrishnan, U., Coss, R.G. and Pelkey, N.W. 1999. Tiger decline caused by the reduction of large ungulate prey: evidence from a study of leopard diets in southern India. Biol. Conserv. 89: 113–120.

Ramesh, T., Snehalatha, V., Sankar, K. and Qureshi, Q. 2008. Food habits and prey selection of tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu, India. Journal of Scientific Transactions in Environment and Technovation 2:170-181.

Ray, J.C. and Sunquist, M.E. 2001. Trophic relations in a community of African forest carnivores. Oecologica 127, 397-408.

Ray, J.C., Hunter, L.T.B. and Zigouris, J. 2005. Setting Conservation and Research Priorities for Larger African Carnivores. WCS Working Paper 24. New York: Wildlife Conservation Society.

Reed, B.C., Brown, J.F., VanderZee, D., Loveland, T.R., Merchant, J.W. and Ohlen, D.O. 1994. Measuring phenological variability from satellite imagery. *Journal of Vegetation Science*, 5, 703–714.

Rexstad, E. and Burnham, K.P. 1991. *User's guide for interactive program CAPTURE.* Fort Collins: Colorado State University 30pp.

Reynolds, J.C., and Aebischer, H.S. 1991. Comparison and quantification of carnivore diet by faecal analysis: a critique, with recommendations, based on a study of Fox (*Vulpes vulpes). Mammal Review* 21: 97-122.

Reuther, R.T. and Doherty, Y. 1968. Birth seasons of mammals at San Francisco Zoo. *Int. Zoo. Yrbk.* 8: 97-101.

Riddhika K. 2009. Estimation of tiger (*Panthera tigris*) and leopard (*Panthera pardus*) abundance in Mudumalai Tiger Reserve, Tamil Nadu. M.Sc. Thesis, Bharathidasan University, Coimbatore.

Robbins, N. 2005. http://www.infohub.com/forums/archive/index.php?t-3656.html

Robinette, W.L., Loveless, C.M. and Jones, D.A. 1974. Field Tests of Strip Census Methods. *Journal of Wildlife Management,* 38: 81-96.

Rodgers, W.A. 1985. The vegetation of Sariska Tiger Reserve. Wildlife Institute of India, Dehradun

Rodgers, W.A. and Panwar, H.S. 1988. Planning a Wildlife Protected Area Network in India. Vol I and II. Wildlife Institute of India, Dehra Dun.

Routledge, R.D. and Fyfe, D.A. 1992. Confidence Limits for the Line Transect Estimates based on Shape Restrictions. *Journal of Wildlife Managment*. 56: 402-407.

Royle, J.A. and Dorazio, R.M. 2008. *Hierarchical Models and Inference in Ecology: The Analysis of Data from Populations, Metapopulations and Communities.* Academic Press, 444 pp. Bullington, MA, USA.

Rudnai, J.A. 1974. The pattern of lion predation in Nairobi Park. E. Afr. Wildl.J. 12:213-225.

Sadleir, R.M.F.S. 1966. Notes on reproduction in the larger Felidae. *Int. Zoo. Yrbk.* 6: 184-187.

Saitoh, T. 1991. The effects and limits of territoriality on population regulation in grey re-backed voles, *Clethrionomys rufocanus bedfordiae.* Research on Population Ecology 33:367-386.

Sankar, K. 1994. Ecology of three large sympatric herbivores (Chital Sambar, Nilgai) with reference to reserve management in Sariska Tiger Reserve, Rajasthan. Ph.D. Thesis, University of Rajasthan, Jaipur, India.

Sankar, K. and Johnsingh A.J.T. 2002. Food habits of tiger (*Panthera tigris*) and leopard (*P. pardus*) in Sariska Tiger Reserve, Rajasthan, India, as shown by scat analysis. *Mammalia*, 66(2), 285-289.

Sankar, K, Johnsingh A.J.T. and Mathur R. 2007. Food habits of three major ungulate species in a semi-arid zone of Rajasthan, India. Cheetal 44 (3 and 4): 18-39.

Sankar, K., Qureshi, Q., Mondal, K., Worah, D., Srivastava, T., Gupta, S and Basu, S. 2009. Ecological studies in Sariska Tiger Reserve, Report submitted to National Tiger Conservation Authority, Govt of India, New Delhi and Wildlife Institute of India, Dehra Dun 145pp.

Sankar, K., Qamar, Q., Nigam, P., Malik, P.K., Sinha, P.R. Mehrotra, R.N., Gopal, R., Bhattacharjee, S., Mondal, K. and Gupta, S. 2010. Monitoring of reintroduced tigers in Sariska Tiger Reserve, Western India: preliminary findings on home range, prey selection and food habits. Journal of Tropical Conservation Science Vol.3 (3):301-318, 2010

Santiapillai, C. and Ramono, W.S. 1992. Status of the leopard (*Panthera pardus*) in Java, Indonesia. Tiger Paper. 19, 1-5.

Santiapillai, C., Chambers, M.R. and Ishwaran, N. 1982. The leopard *Panthera pardus fusca* (Meyer 1794) in the Ruhuna National Park, Sri Lanka and observations relevant to its conservation. Biological Conservation, 23:5-14.

Sathyakumar, S. 1992. Food habits of leopard (*Panthera pardus*) on Mundanthurai plateau, Tamil Nadu, India. Tiger Paper 20:8-9.

Schaller, G.B. 1967. The Deer and the Tiger. University of Chicago Press.

Schaller, G.B. 1972. The Serengeti lion. University Chicago Press, Chicago.

Scott, T.G. 1941. The methods of computation in faecal analysis with reference to the red fox. Iowa State Coll. *J. Sci.15*: 279-285.

Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., Anderson, J., Caicco, S., D'Erchia, F., Edwards, T.C., Ulliman, J. and Wright. R.G. 1993. Gap analysis: A geographical approach to protection of biological diversity. Wildlife Monographs 123.

Seager, S.W.J. and Demorest, C.N. 1978. Reproduction of captive wild carnivores. In *Zoo and wild animal medicine,* ed. M. E. Fowler, 667-706. Philadelphia: W.B. Saunders.

Seber, G.A.F. 1973. The estimation of animal abundance and related parameters, Griffin, London, pp 506.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. Second ed. Macmillan Publ. Co. Inc., New York, N.Y. 654pp.

Seber, G.A.F. 1992. A Review of Estimating Animal Abundance II. *International Statistical Review,* 60,129-166.

Seidensticker, J., Hornocker, M.G., Wiles, W.V. and Messick, J.P. 1973. Mountain lion social organization in the Idaho Primitive Area. Wildlife Society Monograph 35:1-60.

Seidensticker, J. 1976. On the Ecological Separation between Tigers and Leopards. Biotropica 8:225-234.

Seidensticker, J.C., Sunquist, M.E. and McDougal, C.W. 1990. Leopards living at the edge of Royal Chitawan National Park, Nepal. Pp.415-423.In:J.C. Daniel and J.S. Serraro (eds): Conservation in developing countries: problems and prospects. Bombay Natural History Society, Bombay, India and Oxford University Press.

Seidensticker, J. 1997. Saving the tiger. Wildlife Society Bulletin 25:6-17.

Sen, A.R., Tourigney, J. and Smith, G.E.J. 1974. On the Line Transect Sampling Method. *Biometrics,* 30: 329-341.

Sharma S., Jhala, Y.V. and Sawarkar, V.B. 2005. Identification of individual tigers (*Panthera tigris*) from their pugmarks. Journal of Zoology, 267, pp 9-18

Sharma, R.K., Jhala, Y.V., Qureshi, Q. Vattakaven, J. Gopal, R. and Nayak, K. 2009. Evaluating capture–recapture population and density estimation of tigers in a population with known parameters. Animal Conservation 13:94-103.

Silver, S.C., Ostro, L.E., Marsh, L.K., Maffei, L., Noss, A.J. and Kelly, M.J. 2004. The use of camera traps for estimating jaguar (*Panthera onca*) abundance and density using capture/ recapture analysis. *Oryx* 38: 148–154.

Singh, P., Gopalaswamy, A.M., Royle, A.J., Kumar, N.S. and Karanth, K.U. 2010. SPACECAP: A program to estimate animal abundance and density using Bayesian spatially explicit capture-recapture models. Version 1.0. Wildlife Conservation Society - India Program, Centre for Wildlife Studies, Bangaluru, India.

Skinner, J.D. and Smithers, R.H.N. 1990. The mammals of the southern African sub-region. - University of Pretoria Press, Pretoria.

Slobodkin, L.B., Smith, F.E. and Hairston, N.G. 1967. Regulation in terrestrial ecosystems, and the implied balance of nature. Amner. Natur. 101:109-124.

Smith, R.M. 1977. Movement patterns and feeding behavior of leopard in the Rhodes Matopos National park, Rhodesia. *Arnoldia Rhodesia* 8: 1-16.

Smith, J.L.D. 1993. The role of dispersal in structuring the Chitwan tiger population. Behavior 124:165-195.

Smithers, R.H.N. 1983. *The mammals of the Southern African subregion.* Pretoria: University of Pretoria.

Soberon, J. and Nakamura, M. 2009. Niches and distributional areas: concepts, methods, and assumptions. Proceedings of the National Academy of Sciences USA, 106, 19644–19650.

Soni, R.G. 2000. Management Plan of Sariska Tiger Reserve. Forest Department, Government of Rajasthan, Jaipur.

Soule, M.E. 1985. What is conservation biology? Bioscience 35:727- 734.

Spalding, D.J. 1964. Comparative feeding habits of the fur seal, sea lion and harbor seal on the British Columbia coast. *Fisheries Research Board of Canada Bulletin* 146: 1–47.

Spong, G., Hellborg, L. and Creel, S. 2000. Sex ratio of leopards taken in trophy hunting: genetic data from Tanzania. Conservation Genetics, 1, 169e171.

Stander, P.E., Haden, P.J., Kaqece and Ghau. 1997. The ecology of sociality in Namibian leopards. J. Zool., Lond. 242: 343–364.

Stuart, C.T. 1981. Notes on the mammalian carnivores of the Cape Province. South Africa. Bontebok 1: 1-58

Sunquist, M.E. 1981. The Social Organization of Tigers (*Panthera tigris*) in Royal Chitawan National Park, Nepal. Smithsonian Institution Press.

Sunquist, M.E. and Sunquist, F. 1989. Ecological Constraints on Predation by Large Felids. In Carnivore Behav. *Ecology and Evolution*: 283-301. Gittleman, J.L. (Ed.). New York: Cornell Univ. Press.

Sunquist, M.E., and Sunquist, F. (editors). 2002. Wild cats of the world. University of Chicago Press.

Sunquist, M.E., Karanth, K.U., and Sunquist, F. 1999. Ecology, behavior and resilience of tiger and its conservation needs. In riding the tiger: tiger conservation in human dominated landscapes: 5-18. Seidensticker, J., Christie, S., and Jackson, P. (Eds). Cambridge: Cambridge University Press.

Thomas, L. and Karanth, K.U. 2002. in *Monitoring Tigers and Their Prey: A Manual for Researchers, Managers and Conservationists in Tropical Asia*, eds. Karanth, K. U. and Nichols, J. D. (Centre for Wildlife Studies, Bangalore, India), pp 121–138.

Tiger Task Force. 2005. Joining the dots. Union Ministry of Environment and Forests (Project Tiger).

Tinoco, B.A., Astudillo, P.X., Latta, S.C. and Graham, C.H. 2009. Distribution, ecology and conservation of an endangered Andean hummingbird: the Violet-throated Metaltail (*Metallura baroni*). Bird Conservation International,19, 63–76.

Tobler, M.W., Carrillo-Percastegui, S.E., Pitman, R.L., Mares, R. and Powell, G. 2008. An evaluation of camera-traps for inventorying large and medium-sized terrestrial rainforest mammals. Animal Conservation 11:169–178

Tollit, D. J., Heaslip, S., Zelelin, T., Joy, R. Call, K. and Trites, A.W. 2004. A method to improve size estimates of walleye pollock and Atka mackerel consumed by pinnipeds using digestion correction factors allied to bones and otoliths recovered in scats. *Fishery Bulletin* 102: 498–508.

Trolle, M. and Kery. M. 2003. Estimation of ocelot density in the Pantanal using capture recapture analysis of camera trapping data. *Journal of Mammalogy* 84: 607-614.

Tucker, C.J. and Sellers, P.J. 1986. Satellite remote sensing of primary production. *International Journal of Remote Sensing*, 7, 1133–1135.

Turnbull-Kemp, P. 1967. *The Leopard*. Capetown: Howard Tummins.

Turnock, B.J. and Quinn, T.J.II. 1991. The Effect of Responsive Movement on Abundance Estimation using Line Transect Sampling. *Biometrics*, 47: 701-715.

Vanak, A.T. and Gompper, M.E. 2010. Multi-scale resource selection and spatial ecology of the Indian fox in a human-dominated dry grassland ecosystem J.of Zoology 281: 140–148

Varman, K.S. and Sukumar, R. 1995. The Line Transect Method for Estimating Densities of Large Mammals in A Tropical Deciduous Forest: An Evaluation of Models and Field Experiments. *Journal Bioscience*, 20920, pp73-287.

Walker, R.E., Stoms, D.M., Estes, J.E. and Cayocca, K.D. 1992. Relationships between biological diversity and multi-temporal vegetation index data in California. *ASPRS ACSM, Albuquerque, New Mexico, 3–7 March 1992*,

Wang, S.A. and Macdonald D.W. 2009. The use of camera traps for estimating tiger and leopard populations in the high altitude mountains of Bhutan. Biological Conservation 142: 606-613.

Warren, R.J. 1991. Ecology justification for controlling deer populations in Eastern National Parks. Transactions of the North American Wildlife and Natural Resources Conference 56:56-66.

Waseem, Md. 2008. Monitoring of common leopard (Panthera pardus) and its prey in Northern Pakistan. WWF.

Wegge, P., Pokheral, C. and Jnawali, S.R. 2004. Effects of trapping effort and trap shyness on estimates of tiger abundance from camera trap studies. *Animal Conservation* 7: 251-256.

White, G.C. 1996. NOREMARK: Population Estimation from Mark-Resighting Surveys. *Wildlife Society Bulletin* Vol. 24, No. 1 (Spring, 1996), pp. 50-52

White, G.C. and Garrot, R.A. 1990. Analysis of radio tracking data. Academic Press.

White, G.C. and Burnham, K.P. 1999. Program MARK: survival rate estimation from both live and dead encounters. Bird Study 46(suppl.):S120–S139.

Williams, B.K., Nichols, J.D. and Conroy, M.J. 2002. *Analysis and Management of Animal Populations*. Academic Press, San Diego, CA. USA.

Wilson, D.S. 1975. The adequacy of body size as a niche difference. Am. Nat. 109: 769-784.

Winderberg, L.A. and Mitchell, C.D. 1990. Winters diet of coyotes in relation to prey abundance in southern Texas. *Journal of Mammalogy* 71: 439-447

Yadav, A.S. and Gupta, S.K. 2006. Effect of micro-environment and human disturbance on the diversity of woody species in the Sariska Tiger Project in India, Forest Ecology and Management 225: 178-189

Young, B.F., Franke, I., Hernandez, P.A., Herzog, S.K., Paniagua, L., Tovar, C. and Valqui, T. 2009. Using spatial models to predict areas of endemism and gaps in the protection of Andean slope birds. Auk, 126, 554–565.

Zabala, J., and I. Zuberogoitia. 2003. Badger, (*Meles meles*) Mustelidae, Carnivora, diet assessed through scat-analysis: a comparison and critique of different methods. *Folia Zoologica* 52: 23–30.

Zeiss, B. 1997. Waterberg leopard project. Albert-Ludwigs-Universitat Freiburg, Germany and the Ministry of Environment and Tourism, Namibia. Pp 38.

Zuckerman, S. 1953. The breeding of mammals in captivity. *Proc. Zool. Soc. Lond.*122: 827-950.