PREY SELECTION AND FOOD HABITS OF LARGE CARNIVORES: TIGER *Panthera tigris*, LEOPARD *Panthera pardus* AND DHOLE *Cuon alpinus* IN MUDUMALAI TIGER RESERVE, TAMIL NADU

Thesis Submitted to

Saurashtra University, Rajkot, Gujarat

for

The Award of the Degree of

DOCTOR OF PHILOSOPHY

IN

WILDLIFE SCIENCE

By

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November 2010

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15th November 2010

CERTIFICATE

This is to certify that the thesis titled **"Prey selection and food habits of large carnivores: tiger *Panthera tigris*, leopard *Panthera pardus* and dhole *Cuon alpinus* in Mudumalai Tiger Reserve, Tamil Nadu"** submitted for the award of degree of **Doctor of Philosophy** in Wildlife Science to Saurashtra University, Rajkot is a record of original and independent research work carried out by **Mr. T. Ramesh** under our guidance. No part of this thesis has been submitted in part or full to any other University/Institution for the award of any degree and it fulfils all the requirements laid down by Saurashtra University.

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Acknowledgement

I am extremely grateful to my supervisors, Dr. K. Sankar and Mr. Qamar Qureshi for constantly guiding me throughout project period. Dr. K. Sankar provided the entire administrative support for the project. It was an honour for me to have worked under his supervision. He also played a major role in shaping up thesis, my wildlife career and always encouraged me to perform better to achieve my goal. Mr. Qamar Qureshi has provided me valuable analytical thinking which impressed me for quite long. His understanding and patience in all aspect of statistical analysis and thesis writing has enhanced and enriched my thinking ability thoroughly.

I solicit my humble gratitude to Mr. P. R. Sinha, Director, WII and Dr. V. B. Mathur Dean, FWS, WII for the support and guidance extended to the project.

I would like to thank, former dean Dr. A. J. T Johnsingh for the fruitful discussions that I had with him in the field. Dr. Y. V. Jhala is thanked for his suggestion in the initial stage of the project. All the faculty members of WII, especially Dr. K. Ramesh, Dr. A. J. Johnson and Dr. G. V. Gopi are thanked for their support.

I thank senior researchers Dr. K. Pankaj, Dr. B. Bhaskar Acharya, Dr. K. Saravanan, Mr. Merwyn, Dr. G. Singh, Mr. Abishek Harihar and Mr. John for their kind help at the time of thesis writing.

My wildlife career started with Dr. S. Balachandran, Senior Scientist, BNHS. He along with Mr. Sathya Selvam, SRF, BNHS, are thanked for teaching me bird ecology.

Special thanks to my colleague researcher Ms. Riddhika for her editorial comments on all stages of thesis and her time-less helping tendency. I never felt like she was somebody else as I could discuss my ideas, whims and sorrows freely during my field days and at WII.

I would like to formally thank the Chief Wildlife Warden of Tamil Nadu for granting us permission to work in Mudumalai. I thank the Field Director, Dr. Rajeev Srivastava of Mudumalai Tiger Reserve for providing me logistic support, co-operation in the field and information on large carnivores in Mudumalai landscape. All the Range Officers, other forest staff are thanked for their timeless help. I take back those memories of all my conversations with Anti-poaching Watchers who made my field experiences more thrilling than ever before. Their field support, tendency to share their wild experience and knowledge helped be immensely.

Mr. Vinod Thakur's expertise and valuable assistance in scat analysis and Mrs. Nelanjana, Ms. Swathi and A. Pragatheesh are thanked for their expertise in GIS mapping. I am thankful to the WII library staff and Mr. Virendra Sharma for their necessary help.

I would like to thank WII Researcher N. Sridharan who helped me in the initial days of my field data collection and during my synopsis presentation at the institute.

From Indian Institute of Science, Mr. R. Arumugam is thanked for introducing me to Mudumalai. Other researchers Harish, Datta Raj, Suresh, Kannan, Dr. Prakash, Sumith, Barnaya, Sumitha, Nandita, Geeta, Somuya Prasad are thanked for their cheerful discussions with me and their insight during the course of my field work.

I can never forget Mr. Kumar, for his generosity, courtesy, for being so resourceful, making me a part of his family, with all his hospitality during my stay in Mudumalai.

I would like to thank all my field assistants James, Kethan, Mathan, Kunmari, Manpan, Dharmalingam, Sidhan, Maran, Mohan, Anith, Manchu and Somu for their assistance during field data collection.

I am greatly indebted to my parents and brothers for letting me pursue my wildlife career.

(T. Ramesh)

Executive Summary

A detailed long-term study on prey selection, food habits and population status of three sympatric large carnivores (tiger, leopard and dhole) was documented during the present study. In many protected areas upto date scientific information on this aspect remains negligible. To supplement the current basic information, the present study was conducted in Mudumalai Tiger Reserve, Tamil Nadu from January 2008 to April 2010.

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

Prey species availability was estimated using line transect method in an intensive study area of 107 km^2 comprising of deciduous forest (moist and dry deciduous). The study area was divided into 3x3 km^2 grids and in each grid, a line transect (1.5 to 3.13 km) was laid (n=20). Along the line transects, density of prey species was estimated for a period of two successive years (January 2008 to December 2009). The total length of line transects was 41.3 km. Each line transect was walked three times in the dry season (January to April) and wet season (May to December) which yielded a total effort of 369.45 km. All transects were walked in the early morning between 6.30 am to 8.30 am after sunrise. For every detection, time, species, group size, group composition, animal bearing (using a hand held compass) and the angular sighting distance (using a laser range finder) were recorded. Vehicle transects were used to estimate group size and composition of prey species in the intensive study area. Five vehicle transect routes ranging from 15 to 23 km were monitored. Total transect length of 93.5 km was monitored twice a month in the early morning and late afternoon which resulted in a total effort of 3740 km.

Prey species population was estimated using program Distance 6.0. Analysis was done with fitting different detection functions to the observed data for estimation of densities. The best model was selected on the basis of the lowest Akaike Information Criteria (AIC) values. To get better estimates, a minimum number of observations are required in order to model the detection function whereas sightings were pooled together both the year dry seasons and wet seasons separately as there was no

significant difference (P >0.5) in the angular sighting distance between same dry seasons or wet seasons. Also data was analysed yearly and overall for both the years. Halfnormal Cosine-Binomial model was fitted for the species which was sighted >5 to 15 times. Pooled species estimated strip width (ESW) was used to derive density estimate wherever species which was sighted less than five time presuming that related species have similar visibility w.e.t chital (*Axis axis)* ESW for ungulates species such as wild pig (*Sus scrofa)*, barking deer (*Muntiacus muntjak)*, mouse deer (*Tragulus meminna)*, common langur (*Seminopethicus entellus*) ESW for bonnet macaque (*Macaca radiata*) and grey jungle fowl (*Gallus sonneratti*) ESW for peafowl (*Pavo cristatus*), red spur fowl (*Galloperdix spadicea*), black-naped hare (*Lepus nigricollis*).

In total, 14 prey species were detected on line transects in the study area. The estimated overall prey densities were 95.6 individuals / km^2 which include wild ungulates – 42.2 / km^2, arboreal mammals – 42.32 / km^2, elephant – 5.5 / km^2 and others - 5.7 / km^2. The estimated mean biomass of ungulate prey species was 6145.9 kg / km^2. Half normal detection function with cosine adjustment was the best fit model for ungulates fowls and arboreal mammals during overall analysis while uniform cosine was the best fit model for elephants. Common langur was found to be the major prey species in the study area (35.0 ± 4.4 /km^2) followed by chital (25.4 ± 6.7/ km^2), gaur (9.4 ± 2.5/km^2), sambar (4.5 ± 0.98/km^2) and wild pig (1.3 ± 0.87/km^2). Minor prey species were recorded as follows:- elephant 5.5 ± 0.99 animals/km^2, Indian giant squirrel (4.9 ± 1.2 animals/km^2), grey jungle fowl (3.5 ± 1.5 animals/km^2), peafowl (1.0 ± 0.5 animals/km^2), red spur fowl (1.0 ± 0.7 animals/km^2), barking deer (1.2 ± 0.8 animals/km^2), hare (0.17 ± 0.17 animals/km^2), mouse deer (0.15 ± 0.08 animals/km^2) and bonnet macaque (1.9 ± 1.1 animals/km^2). The mean group size and male: female: fawn ratio of chital was observed to be 13.1 ± 0.5SE and 61.1: 100: 14.8 respectively (Combined data n = 13366 individuals). Sambar mean group size and male: female: fawn ratio was 3.6 ± 0.3SE and 43.9: 100: 18.8 respectively (Combined data n = 1341 individuals). The average mean group size and male: female: calf ratio of gaur was 7.5 ± 0.4SE and 42.1: 100: 25.8 respectively (Combined data n = 2944 individuals). Wild pig mean group size was 3.3 ± 0.4SE and the overall male: female: piglet ratio was 60.4: 100: 113.6 (Combined data n = 381 individuals). The overall mean group size of common langur was 5.3 ± 0.1SE

(Combined data n = 3583 individuals). Barking deer mean group size was 2.1 ± 0.08SE (Combined data n = 70 individuals). The male: female: fawn ratio was 50.8: 100: 14.8 for all the seasons. The estimated overall mean group size and male: female: calf ratio of elephant was 5.2 ± 0.2SE and 17.7: 100: 18.4 respectively.

Prey selection and food habits of large carnivores were studied using two methods i.e by evaluating kills and analyzing scat. Scats were collected whenever encountered in the study area along pre-determined roads and trails. Scats were broken and washed over a sieve of mesh size <1mm in running water and sun dried. Prey remains in scats were observed microscopically and identified with reference slides available in the research laboratory of Wildlife institute of India. Kills of large carnivores were located during the study period by presence of vultures, crows, alarm calls of prey and odour of decomposing carcass. On locating kills, detailed information of age and sex of prey species and the bone marrow condition (solid, semi – solid, liquid) were also recorded.

Scat samples collected were analysed separately season wise (dry and wet season), year wise and overall for both the years using respective densities of available prey during the same period in the study area. Percentage occurrence of different prey species in large carnivore scats was calculated by enumerating the number of scats with remains of a particular prey species out of the total number of scats with prey remains, depicted in the form of percentage. The relative frequency occurrence of a prey species was calculated as the number of occurrence of that prey species divided by the total number of scats analysed and expressed in percentage. The biomass and relative number of prey consumed was calculated in terms of relative numbers of prey species using regression equation (i) $Y_i = 1.98 + 0.035\ X$ for tiger, leopard and (ii) $Y_i = 0.035 + 0.020\ X$ for dhole. In order to account for the exact variability of prey items in scats, sensitivity analysis was done using program SCATMAN by bootstrapping data 1000 times. To assess similarity of food composition between tiger, leopard and dhole, the Pianka's niche overlap index was used. The total prey species killed by tiger, leopard and dhole were 41, 20 and 35 respectively. Percent of each prey species killed by predators was compared with percent occurrence of each prey species found in predator scats.

In total 875 tiger scats, 413 leopard scats and 1070 dhole scats were collected. Scat analysis revealed the presence of 19 prey species in tiger scats, 20 prey species in leopard scats and 13 prey species in dhole scats with a high predominance of medium to large sized ungulates in tiger, leopard and dhole diet. Of the prey species identified from tiger scats, ungulates constituted 96.9% followed by primates (2.3%), cattle (0.9%), buffalo (0.3%) and others (2.3%). Leopard scats contained 84.1% ungulates, 12.8% primates, 1.9% cattle, 0.2% buffalo and 4.8% others. Dhole scats contained 94.4% ungulates followed by 1.6% primates, 0.3% cattle and 5.6% others. The overall biomass composition of large sized prey (>50 kg) in tiger, leopard and dhole scats was found to be 70% , 36.2% and 19.3% respectively, medium sized prey (20 to 50 kg) was 28.2%, 54.4% and 72.4% respectively, while small sized prey (< 20 kg) was 1.8%, 19.4% and 8.3% respectively. Chital and sambar together contributed to the bulk of the diet (>77%) in all the three predators. In addition to this, gaur and wild pig were the important prey for tiger in terms of frequency occurrence while common langur for leopard and black naped hare and mouse deer for dhole. The overall Ivlev’s prey selection index showed that sambar and chital were utilized more than their availability by tiger, leopard and dhole. In comparision to leopard and dhole, tiger utilized chital in less proportion. Common langur was utilized less than its availability by leopard, tiger and dhole. The index of prey selection showed that mouse deer and black naped hare were found to be the most utilized prey among all prey consumed by tiger, leopard and dhole and this may be due to underestimation of their availability data. Wild pig was utilized more than its availability by tiger, equall to the availability by leopard and it was less consumed by dhole. All three predators exhibited significant (P = < 1) selection or avoidance of prey species in the study area. The dietary overlap was 82% between tiger and leopard, 84% between tiger and dhole and 98% between leopard and dhole using percentage occurrence of prey remains in the diet. Out of all tiger kills, gaur (n = 14) was found to be the maximum followed by sambar (n = 12), chital (n = 7), cow (n = 5), wild pig (n = 3), python (n = 1), black naped hare (n = 1) and sloth bear cub (n = 1), while leopard kills comprised of chital (n = 9), domestic fowl (n = 3), common langur (n = 2), Indian giant squirrel (n = 2), sambar (n = 1), wild pig (n = 1), mouse deer (n = 1) and black naped hare (n = 1). Dhole kill contained chital (n = 27), sambar (n = 6) and wild pig (n = 2). Of the total tiger kills, 7.3% comprised of small sized prey, 24.4 % medium and 68.3% large sized prey species. Kills of leopard comprised of 35% small sized prey, 58.8% medium and

5.9% large sized prey species. Dhole kills (n = 35) consisted of 10.3% small sized prey, 74.4% medium and 15.4% large sized prey species. Kill data showed gaur, sambar and chital as important prey for tiger and chital for leopard and dhole. The sambar and chital kills might be underestimated and gaur kills might be overestimated in predator kills. Even though kill data underestimated medium sized prey and overestimated large sized prey for tiger and leopard however both the kill and scat data showed almost similar prey selection pattern by both predators. Dhole kill data showed that chital was the dominant prey which is similar to the finding of scat data since dholes tend to hunt in open areas, the ideal habitat for chital. Analysis revealed that scat samples depict predator diets more accurately while kill data underestimates the presence of diverse prey species and proportions of smaller prey. However kill and scat data showed almost similar prey selection pattern of three predators and kill data was biased towards gaur for tiger. Based on evaluation of bone marrow conditions of prey species killed by all predators, it was found that >95% was with good health conditions.

The analysis of scats and kills confirmed that tiger killed mainly large body sized prey, but dholes and the leopard largely killed medium sized prey. All three large predator scats contained 26 prey species in which major ungulates and one primate species were commonly shared in their diet. These predators largely depend on principle prey species such as sambar, chital, gaur, wild pig and langur > 90% in their diet and coexist in the prey rich tropical forest of Mudumalai. The dietary overlap between predators was high because of shared inclusion of major ungulates by predators in their diet. The landscape of Mudumalai Tiger Reserve is an exceptional case where tiger, leopard and dhole coexist in high density by selecting different sized prey. Even though female biased sex ratio is found in prey species (cervids) population, males were more prone to tiger predation while fawns by dholes.

Scat analysis revealed that chital and sambar were important prey for all three predators though they have wider prey intake. Other prey species such as gaur and wild pig were important prey for tiger while langur was important for leopard and black naped hare and mouse deer for dhole. Domestic livestock presence in all the three predators scat revealed that they were indeed predated on livestock around villages found inside and at the periphery of the Tiger Reserve. The scat data revealed food habits and prey selection patterns of three sympatric carnivores in a better way as compared to kill data. During this study, among total kills recorded, the male biased sambar, chital and gaur kills was recorded high for tiger and both the sex classes (male and female) of chital were utilized equally by leopard. Dhole largely killed chital sub- adults and fawns of both sexes. The selective male predation in adult cervids may be attributed to presence of large sized antlers that may hamper their navigation through thick bushes and solitary habits. The solitary behaviour of males increases their individual probability of encountering predators and keeping them away from group vigilance which make them more vulnerable to predation. In two occasions female gaur chased a dhole pack of five individuals. Leopard scavenging evidences were detected on four occasions on gaur and sambar kill made by tiger. Adult wild pig was predated by tiger on two occasions and piglets were killed by leopard and dhole on three occasions during the study period. Langurs were utilized by all three predators. Livestock predation by all three predators was recorded due to presence of domestic livestock inside the Tiger Reserve. The average mean body weight of prey killed by three predators was 253 kg for tiger, 37 kg for leopard and 44.5 kg for dhole. Though all three predators are capable of killing larger prey, tiger mostly killed larger prey while leopard and dhole killed medium to large sized prey. This showed that carnivores usually prey upon herbivores of about their own size and weight. It is likely that risk of injury during hunting may be the reason underlying the lower preference for large prey by leopard and dhole. Among all the predator kills, more than 95% of them were found in good health condition as revealed by bone marrow analysis. My results support that vertebrate predators would be selective in maximizing energy in prey rich habitats, but would be non - selective number maximizers where large prey were scarce. These sympatric carnivores in Mudumalai largely depend on wild ungulates than domestic livestock.

Camera trapping was conducted for large carnivores between March 2008 and April 2010 in Mudumalai in an intensive study area of 107 km^2 in deciduous forest (moist and dry deciduous). Within the deciduous habitat, each grid (3 x 3 km^2) had at least one pair of camera to ensure uniform distribution of camera locations (n = 20) and trapping was conducted between November and May for three consecutive years with a minimum of 70 days to a maximum of 100 days. Therefore crucial sample design of the whole study area ensured even coverage of camera traps, without leaving gaps large enough to contain an individual’s movements. The camera stations were placed on roads, trails, nullahs or near water holes to maximize tiger, leopard and dhole captures based on observation of indirect signs (pugmark, scat, scrapes and kills) and direct sightings. Each station comprised two pairs of passive infrared cameras (DEERCAM DC 300 or STEALTH CAM^{TM}) to simultaneously photograph both flanks of large carnivores. Cameras were loaded with 36-print, 200 American Standard Association (ASA) 35-mm film. Cameras were set active for 24 hrs with lowest photographic delay (15 seconds in DEER CAM^{TM} and 60 seconds in STEALTH CAM^{TM}). The cameras were mounted on wooden posts at a height of 30–40 cm from the ground and placed at 2–3 m on either side from the centre of the trail or road. In the prey rich forest habitat of Mudumalai, adult female home range of tiger and leopard can be as small as 15 km^2, therefore we placed at least two camera trap stations in an area of this size, which translated to a trap spacing of ca 2-3 km. Each camera was checked every two to three days to replace film and batteries.

Data on population estimation of dhole was collected between January 2008 and December 2009. Five vehicle transect routes ranging from 15 to 23 km were monitored to record dhole sightings. The total length of 93.5 km was monitored twice in a month during early morning and late afternoon which resulted in a total effort of 3740 km. On each sighting of dhole along vehicle transects, the following information was recorded; group size, sex and age classes if possible and perpendicular distance from the road to the centre of initial dhole group sighting. Vehicle transect sighting data was pooled for two years together and further analysis was done to estimate dhole density within the deciduous habitat.

Capture histories in ‘X matrix’ from camera trapping data was analyzed using the software MARK and Program DENSITY using a spatially explicit maximum-likelihood method to estimate density from capture-recapture data. I assessed the relative abundance index of tiger, leopard and dhole by using a camera trap-based abundance index used previously in studies on tigers and their prey. Dhole density was estimated using program Distance 6.0. The best model was selected on the basis of lowest Akaike Information Criteria (AIC) values. To get better estimates of species, a minimum number of observations are required in order to model the detection function and hence sightings from morning and evening vehicle transect data were pooled together for two years (2008 and 2009) and analysed.

A total of 9600 trap nights over a period of three years in the study area yielded independent photographic captures (including right, left and unidentified photos) of 214 tigers and 307 leopards and 164 dhole photographs. Total number of males, females and unidentified individuals of tiger was 9, 25 and 4 respectively based on right flank and 11, 24 and 3 respectively from left flank. Identified male, female and unidentified leopard was 16, 27 and 8 respectively based on right flank and 17, 34 and 2 respectively based on left flank. Based on maximum capture probability of either right or left flank, the identified individuals of tiger and leopard varied from 16 to 22 for tiger and 18 to 27 for leopard from camera trapping in each year and the sampling period varied from 70 to 100 days. The estimated average male: female ratio was 0.41: 1 for tiger and 0.54: 1 for leopard based on both right and left flank. Mh model ranked second as the most appropriate model followed by Mo model for both tiger and leopard in this study. Mh model was best fitted for tiger and leopard in all the years. The population size estimate was computed using Mh jackknife model. Test for population closure was not significant for tiger, indicating that the assumption of demographic closure was not violated during the study period while for leopard, only in 2009 the closure assumption was violated significantly ($P = 0.05$). The capture probabilities for Mh model ranged from 0.06 to 0.09 for tiger and 0.05 to 0.1 for leopard. The estimated population size ranged from 26.7 to 28.9 individuals for tiger and 26.0 to 34.9 individuals for leopard. The present estimate of tiger and leopard density (± SE) / 100 km^2 using 1/2MMDM and MMDM and Maximum Likelihood methods was 17.7 ± 3.3, 12.6 ± 2.9, 11.7 ± 2.9 and 23.6 ± 4.0, 20.7.4 ± 4.1, 14.9 ± 3.5 respectively. The overall mean maximum distance moved (MMDM) by tiger and leopard was 3.2 km and 1.6 km respectively. The average value of relative abundance index (RAI) capture/100 trap night was 2.3 for tiger, 3.2 for leopard and 1.8 for dhole. Estimated dhole density was 43.7 ± 21 / 100 km^2 (excluding pups) with average group size of 5.6 ± 1.0. Totally, 31 dhole sightings were obtained during vehicle transect and number of individuals on each sighting varied from one to 28. Half normal detection function with Hermite adjustment fitted data well for dhole during overall analysis.

Methods like ½ MMDM, Full MMDM are being site specific and strip width based, Maximum Likelihood (ML) method appeared to be more robust as density estimate by this method did not vary over the years and this estimate can be extended to the adjoining areas. Density estimate for tiger and leopard excluded cubs <1yr old during the present study. Dhole density in Mudumalai appeared to be the second highest in India after Bandipur. Camera-trap and vehicle transect studies have showed that high densities of large carnivores in the study area of the Tiger Reserve. The key insight gathered from the present study of large predator population status indirectly delineates habitat quality of persistent forest and prey base availability whereas large predators are vulnerable to habitat fragmentation and depleted prey base. Large predators are conservation dependent species requiring large contiguous forests with less interspersion of undisturbed breeding habitats. It can be expected that larger forest continuity proximal to high population of large predators, have the chance for long-term survival in the Mudumalai landscape.

CHAPTER 1

INTRODUCTION

1.1. Introduction

Species with overlap in resource requirements are assumed to have co-evolved in some way so as to minimize competition between them. Carnivores in general are a good model taxon for the development of a predictive science of conservation (Cardillo et al., 2004). The survival of any predator is directly related to the quality and quantity of its diet (Melville 2004). Co-existence of sympatric carnivore species is considered to be possible through niche differentiation (Pianka 1974). Differential prey selection is one of the principal relationships which permit species to coexist. The patterns of prey selection exhibited by various predators tend to be shaped by a suite of factors, including predator and prey behaviour, morphology, and habitat requirements related to hunting behaviour (Kruuk 1986, Husseman et al., 2003). Predators have evolved strategies to maximize the nutrient intake within different kinds of habitats by selecting different prey species. Prey selection determines spacing patterns and structure of social pattern between predators. Prey selection is critical in understanding life history strategies (Miquelle et al., 1996). The co-existence is probably result of size difference between predators and their hunting strategies, involve selecting different set of prey species (Rosenberg 1966) and one way in which competition can be reduced is when predator occupy different habitats or use the same area at different times (Schaller 1972). A striking feature of Asian tropical forest communities is the high diversity of sympatric mammalian carnivores (Richard 2007). Tiger, leopard and dhole are at the top of the food chain in six out of eight bio geographic zones in India (Karanth 1993). Preservation of these large predators provides an umbrella for the overall plant and animal species diversity within their habitats. The key factors that determine large carnivore habitats are prey abundance, less disturbance, water availability and forest continuity. These biodiversity drivers allow us to explain the track of biodiversity response. The acquirement of food is a fundamental component for every predator’s daily existence; hence knowledge of food selection is critical to understand life history strategies and developing sound conservation recommendation (Miquelle et al., 1996). Crook (1965) suggested that there is a close relationship between the exploitation of food resources and social organization within an animal species. Co-existence between felids and canids is also facilitated through evolution of different anatomical adaptations for prey selection (Biknevicius and Van Valkenburgh 1996). Carnivore guilds of differing morphology have evolved to take prey species of different types (Krebs 1978). The behaviourally dominant tiger and leopard differ in their prey selection by taking different body sized prey species. These two felids have morphologically adapted for leaping and grasping prey with their sharp and retractile claws. Tigers prefer less disturbed habitats where they feed on large sized prey (Karanth and Sunquist 1995). Leopards occur across a wide range of ecosystems and feed opportunistically on a large variety of prey species (Bailey, 1993) whereas dhole as social hunters, are capable of feeding on small to large prey species (Johnsingh 1983, Pole et al., 2004, Grassman et al., 2005). Karanth and Sunquist (1995) argued that predators selectively preyed upon different species, body sizes and age classes that adequate availability of prey of varying size facilitating coexistence among them. Leopards coexist with other carnivores because of their ability to climb trees and reduce spatial and food competition by occupying habitats not favoured by tiger and dhole and by feeding on different sized prey species. In Wilpattu National Park, SriLanka, where leopards are the dominant predators, they rarely place their kills on trees. Instead, they merely feed on the carcasses at the kill site or drag them into nearby cover (Eisenberg and Lockhart 1972). In Kanha, leopards were not permanent residents where tigers were numerous; instead leopards used disturbed habitats near villages at the periphery or outside the park (Schaller 1967). Where tigers are absent or being exterminated, leopards feed on a wider variety of prey (Muckenhirn and Eisenberg 1973) and may even become more numerous (Seidensticker 1986). Where tigers have been extirpated in the tall-grasslands of the Indian Terai, leopards have recolonized (Johnsingh et al., 2004). Seidensticker (1976) noticed that leopards differed from tigers in their activity periods and in their microhabitat usage. In Southern India, Mudumalai-Bandipur-Nagarahole landscape tiger, leopard and dholes occur in high densities because of prey availability and forest continuity (Karanth and Sunquist 2000). The Western Ghats complex historically has good potential for long term tiger survival due to its continuous forest (Qureshi et al., 2006, Jhala et al., 2008). Dholes perform co-operative hunting unlike tigers and leopards which are solitary hunters. Group-hunting can serve to reduce morphological disadvantages such that larger prey can be killed when hunted communally (Rosenzweig 1966, Gittleman1989), while in other predators hunting success rate may determine prey selection patterns through selection of disadvantaged individuals only where prey species are difficult to capture (Temple 1987). Dholes do not have long canines and powerful jaw muscles like in felids and run down their prey by lethal bites and feed while prey is still alive which leads to prey mortality due to severe blood loss and shock. Prey size selected by dholes range from rodents to gaur calves depending upon the habitat and availability of prey species diversity. Usually, they feed on medium sized ungulates (Johnsingh 1983). The hunting success of dhole varies depending on the pack size, prey species and habitat (Johnsingh 1983, Acharya 2007). The role of prey selection in shaping prey communities and their behaviour is of primary interest to wildlife biologists (Schaller 1967, Johnsingh 1983 and Gasaway et al., 1992, Karanth and Sunquist 1995). Stable co-existence occurs when each species can recover from low abundance in the presence of competitors at their stochastic equilibrium abundance (Chesson 2000). Most of the large carnivores are cryptic, nocturnal or crepuscular and often solitary unlike dholes that live in packs and largely diurnal. In general mammalian species particularly, focus on large predators as flagship species would serve to make decisions for overall biodiversity conservation. Large predators help in maintain mesocarnivores diversity and also known to affect diversity of prey and vegetation. Differential hunting strategies and hunting success rates between predators may account for variability in prey selection patterns, even within a given prey species. Such prey selection patterns can be explained by diet, kill and direct observation (Schaller 1967, Johnsingh 1983, Karanth and Sunquist 1995, Biswas and Sankar 2002, Ramesh et al., 2009) Abundance and distribution of large carnivores are fundamentally functioned by densities of different sized ungulate prey (Karanth and Nichols 1998). Real abundance of predators and prey is a fundamental factor to understand prey-predator interaction in the ecosystem as well as enable managers to conserve ecosystem.

1.2. Study species

1.2.1. Tiger

Tigers are highly adaptable species that exhibit tolerance to a wide range of habitats, environments, altered landscapes, and prey bases (Schaller 1967, Sunquist et al., 1999). Tigers are behaviourally flexible and can adapt to a host of alterations in their landscape (O'Brien et al., 2003). Their resilience, a product of adaptability and high fecundity, has allowed tigers to survive massive onslaught and habitat loss in the past century (Kawanishi 2002). It is the largest obligate terrestrial carnivore in all the mammalian assemblages which occurs in Asia (Seidensticker et al., 1999) and lives sympatrically with other co-predators.

Tiger has been studied in its distribution range with respect to its general ecology, home range, habitat use, prey selection and conflicts with local people (Seidensticker et al., 1999). Different aspects of tiger conservation studied in the Indian subcontinent are on general ecology (Schaller 1967, Johnsingh 1983, Seidensticker and McDougal 1993), social organization (Sunquist 1981), population estimation (Karanth 1995, Karanth and Nichols 1998, 2000, 2002, Karanth et al., 2004, Kawanishi and Sunquist 2004, Harihar 2005, Jhala et al., 2008, Sharma et al., 2009, Wegge et al., 2009, Wang and Macdonald 2009), land tenure system (Panwar 1979, Smith et al., 1989, Gogate and Chundawat 1997, Vanak 1997), dispersal and communication (Smith 1984), its effect on prey species (Tamang 1982, Karanth 1993), on tiger reintroduction (Sankar et al., 2010), prey selection and food habits (Schaller 1967, Johnsingh 1983, Johnsingh et al., 1992, Karanth and Sunquist 1995, Stoen and Wegge 1996, Wegge et al., 2009, Sankar and Johnsingh 2002, Biswas and Sankar 2002, Bagchi et al., 2003, Andheria et al., 2007, Avinandan et al., 2008, Ramesh et al., 2009, Wang 2008, Khan 2008) and tiger-leopard interaction (Seidensticker 1976, Wang 2008, Odden et al., 2010). Besides these, a lot of natural history accounts and some short-term studies are also available eg. Corbett (1944), McDougal (1977), Sankhala (1977), Singh (1984), Thapar, (1986, 1989).

1.2.1.1. General description

The supreme predator tiger is the largest of the cats, weighing up to about 250 kg and measuring about 10 ft in length from the tip of the nose to the end of the tail. Average male weight is 180- 230 kg and females are considerably smaller than males up to 185 kg (Prater 2005). It has an elongated body, short neck and a compact head with a shorter muzzle contains formidable set of canine teeth. Their large canines and large hooked claws are meant to hold prey. The monomorphic tiger has an orange coloured pelage with well marked black coloured stripe pattern that differs from individual to individual. It has black ears, muscular limbs armed with powerful paws and a long banded tail (Schaller 1967, Menon 2003). Usually tiger is polygamous and mates with many females. The life span of tiger is estimated to be about 20 years (Prater 2005). The largest of the cats, the tiger is stocky, heavily muscular and a powerful predator. They are extremely agile, and are capable of great feats of strength and are even known to kill elephant calves occasionally.

1.2.1.2. Geographical distribution

Presently tigers occupy only 7% of their historic range (Sanderson et al., 2006). Its geographic range has declined by 40% within a decade (Dinerstein et al., 2007). Tiger numbers in India have dropped down to 1411 individuals (>1.5 years of age) (Jhala et al., 2008). India is home to nearly 50% of the world's wild tiger population. The tiger, which evolved in China and entered the Indian subcontinent through the Assam gateway tens of thousands of years ago, thrived well in the forested habitats of India feeding on cervids, bovids and wild pigs (Johnsingh and Goyal 2005). The late arrival of tiger to southern India showed the absence of tiger in Sri lanka because the Island was cut off from mainland of India by rising sea levels at the beginning of the Holocene (Kitchener and Dugmore 2000). Arachchi et al., (2005) found that tigers appear to have arrived in Sri Lanka during a pluvial period during which sea levels were depressed, evidently prior to the last glacial period (maximum ca. 20,000 years ago). It is commonly stated that the centre of evolution for tigers was northern China (e.g. Mazak 1981, Hemmer 1987, Herrington 1987), Sumatra and Java which are dated from the middle to late Pleistocene but tiger fossils only appeared in Indian Sub- continent, Altai, northern Russia and elsewhere in the late Pleistocene (Lydekker 1886, Brongersma 1935, Loukashkin 1937, Hooijer 1947, Hemmer 1976, 1987). The tiger once had a wide distribution from almost 10^0 latitudes of south equator (Java and Bali) to more than 60^0 north (the Russian Far East) through more than 100 longitudes (Nowell and Jackson, 1996). Since the early 1900s, habitat loss, fragmentation and human persecution have reduced tiger populations from probably over 100,000 in 1900 to fewer than 7,000 free-ranging individuals (Nowell and Jackson 1996, Dinerstein et al., 1997, Kitchener and Dugmore 2000). Most populations consist of less than 120 animals, increasing the risk of local extirpation due to demographic and genetic factors (Smith and McDougal 1991, Dinerstein et al., 1997). There are eight generally accepted tiger subspecies in accordance with their geographic distribution;

Bali (*P. t. balica*), Caspian (*P. t. virgata*), and Javan (*P. t. sondaica*) tiger subspecies got extinct by the 1940s, 1970s, and 1980s respectively. Fifty Amoy or South China tigers (Nowell and Jackson 1996) now exist in captivity only. Today an estimated 3,200–4,500 Indian or Bengal tigers (*P. t. tigris*) exist in Bangladesh, Bhutan, India, western Myanmar and Nepal (Seidensticker et al., 1999). Fewer than 500 Amur or Siberian tigers (*P. t. altaica*) survive in eastern Russia, north-eastern China and Korea (Matyushkin et al. 1999, Miquelle and Pikunov 2003), while *P. t. amoyensis* exists in captivity only (Tilson et al., 2004). An estimated 400–500 Sumatran tigers (*P. t. sumatrae*) occur in Sumatra (Seidensticker et al., 1999) and 1,200–1,800 Indochinese tigers (*P. t. corbetti*) live in Cambodia, Laos, Malaysia, and east Myanmar, Thailand, and Vietnam (Seidensticker et al., 1999). In tropical Asia, tigers inhabit forests of deciduous, evergreen, riverine, swamp and mangrove, showing incredible tolerance to variation in altitude, temperature and rainfall regimes. Currently tigers occupy 21,435 km^2 of forests within the Western Ghat Landscape comprising 21% of the forested area. The current potential tiger habitat in the landscape complex is about 51,000 km^2 (Jhala et al., 2008). Indian species is one of the most adaptable animals and occupies a variety of habitats from the snowline in conifer forests of Himalayas to the tropical dense forest grassland, scrub, spread over the hills and plains of the country and swamps and marshes of the Himalayan foothills and the estuarine island of Sunderban except deserts (Prater 2005).

1.2.1.3. Conservation status

The tiger is critically endangered; the rapid decline of tiger population in the country had resulted in a complete ban on the hunting of the animal during 1970 and the Project Tiger was launched with nine Tiger Reserves in 1973 with international cooperation in the country. Now there are 36 Tiger Reserves in the country. This was one of the biggest conservation efforts in the world. The total ban on tiger hunting, promulgation of the Indian Wildlife Protection Act 1972 and the birth of Project Tiger in 1973 envisioned that reserves protecting the tiger and its habitat would help in the conservation of all species that live alongside the tiger. Dinerstein et al., (1997) identified Tiger Conservation Units level I, II and III in the range of the tiger. The number of sites in the Indian subcontinent can be strengthened by connecting the corridor. It is necessary that it is essential to monitor tigers to evaluate the management interventions and to have scientific information to react adaptively and solve problems (Karanth et al., 2004). The National Tiger Conservation Authority (Project Tiger renamed) and Wildlife Institute of India collaboratively has initiated the biggest task of conducting census of wild populations of tigers, co-predators, prey species and their habitat throughout India using scientifically advanced methods since 2005. This is one of the biggest conservation efforts in the world where large number of people were involved within a short span of time. Tigers are listed as 'endangered' in the 2000 IUCN Red List of Threatened Species and Schedule I of the Indian Wildlife Protection Act 1972.

1.2.1.4. Threats

The first threat to the survival of tiger came with the arrival of the British who brought in matchlocks and rifles as well as health care enabling people to conquer diseases. The resulting rapid increase in human population led to the clearing of vast tracts of forests. However the British also took several measures to protect forests, such as enactment of Forest Act of 1878 which highlighted the urgent need for saving forests and wildlife. Skin and bone of large cats have been used in traditional Chinese medicine where bones are crushed and used in anti-inflammatory drugs for treating rheumatism and arthritis. Hunting for fur is the biggest cause of decline of tigers. Habitat loss and poaching are important threats to the species survival (Kitchner, 1999). One of the current tiger crises in India; the case in Sariska Tiger Reserve, is where tigers have been wiped out due to poaching. Most of the tiger's range is being fragmented due to population explosion. Sometimes large predators can give serious problems to the management by cattle lifting and attacking humans (Corbett 1944, Rabinowitz 1986, McDougal 1987, Seidensticker and Lumpkin 1996) due to fragmentation and over-hunting pressure on prey. The landscape has already lost a large part of its forest cover, and the remaining forests are threatened with ever increasing anthropogenic pressure (Rodgers and Panwar 1988, Qureshi et al., 2006). Although tigers existed in large numbers during the last century, they are now being threatened due to habitat fragmentation, poaching for wildlife trade and decreasing prey populations (Karanth and Sunquist 1995, Jhala et al., 2008). Tigers also perished from human persecution such as deliberate and accidental forest fire, trapping or snaring, poisoning and shooting (McDougal 1977, Karanth 1991). Only 7% of the original tiger habitat remains and conflict with humans poses a significant threat, which if unchecked, could reduce tiger populations beyond recovery (Karanth and Stith 1999, Sunquist et al., 1999, Wang 2008).

1.2.2. Leopard

The generalist nature of this species implies a wide variation in its ecology across its range. Leopard has the ability to adapt to different habitats and prey, and the capacity of individual leopards as compared to other large carnivores, to alter their behaviour in close proximity to humans (Myer 1986, Hamilton 1976). Leopards have been found to be essentially solitary and territorial animals (Hamilton 1976) and rarely seen in social groups where mothers are with cubs and courting pairs (Eisenberg and Lockhart 1972). Scent marking is the primary mode of communication. This includes scraping, marking with scats and spraying urine. Leopards have found to use trails and trail intersections that serve as common boundaries between territories (Smith, et al., 1989). Communication has been speculated to serve several functions, chiefly among those which allow leopards to separate themselves in space and time, to attract the opposite sex during courtship, and to distinguish each other by age, sex and individual status (Bailey 1993). In Nepal the leopard land tenure system was suggested as the one in which the home range of a male is enclosed by home ranges of many females (Seidensticker 1976). Eisenberg and Lockhart (1972) found that till the age of puberty, juveniles were tolerated after which they became transients until they could find a suitable undefended portion of habitat where they could establish and defend their territory.

The leopard has had the reputation of being one of the least studied of the large carnivores despite being the most abundant (Hamilton 1976). Most of the studies on leopards have been conducted in Africa (Schaller 1972, Hamilton 1976, Bertram 1982, Bailey 1993, Jenny 1996, Ray and Sunquist 2001, Uphyrkina et al., 2001, Henschel et al., 2005, Khorozyan et al., 2008). The situation is hardly different even now, in the Indian context. In India, leopards have been studied addressing human-leopard conflicts (Edgaonkar and Chellam 1998, Athreya et al., 2007, Goyal and Chauhan 2006), general ecology (Qureshi and Edgoankar 2006), population estimation (Chauhan et al., 2005, Sankar et al., 2008, Edgaonkar 2008, Harihar et al., 2009a, Riddhika 2009, Wegge et al., 2009, and Wang and Macdonald 2009) and food habits (Johnsingh 1983, Sathyakumar 1992, Mukherjee et al., 1994, Karanth and

Sunquist 1995, Daniel 1996, Ramakrishnan et al., 1999, Edgaonkar and Chellam 1998, Sankar and Johnsingh 2002, Maheshwari 2006, Arivazhagan et al., 2005, Andheria et al., 2008, Ramesh et al., 2009, Wegge at al., 2009). Leopard ecology has also been studied in Java, Indonesia (Santiapillai and Ramono, 1992), China (Johnson et al., 1993), Sri Lanka (Eisenberg and Lockhart 1972, Santipillai and Chambers 1982), Nepal (Seidensticker et al., 1990), Bhutan (Wang 2008) and Thailand (Rabinowitz 1989, Grassman Jr. 1999). The sparse information on leopards in Asia mostly hails from studies which have had the tiger (Sunquist 1981, Karanth and Sunquist 1995), lion (Chellam 1993) or dhole (Johnsingh 1982) as the species of interest.

1.2.2.1. General description

The leopard is one of the most widely distributed and highly adaptable big cats that has pelage hues varying from pale yellow to deep golden or tawny colour and are patterned with black rosettes. Pocock (1932) described four different colouration patterns that correspond to the semi-desert, savannah, rainforest and high mountain leopards. The coat and colour patterns vary widely across various types of habitat. Melanistic forms occur throughout its range, mostly in humid areas (Seidensticker & Lumpkin 1991, Nowell & Jackson 1996). The leopard shows considerable variation in its physical appearance, having black rosettes varying from individual to individual. Melanistic individuals are those in which the rosettes are faintly visible. Average adult weights obtained from Sri Lanka are 56 kg for males and 29 kg for females, while two males from Central India weighed 50 and 70 kg (Nowell and Jackson 1996). The length of upto 8 ft is measured from nose to tail (Daniel 1996). The leopard weighs on an average 58 kg in males and 37.5 kg in females (Bailey 1993). Compared to other members of the Felidae family, the leopard has relatively short legs and a long body with a large skull. It is similar in appearance to the jaguar, but it is smaller and well built. Its fur is marked with rosettes similar to those of the jaguar, but the leopard's rosettes are smaller and more densely packed, and do not usually have central spots as the jaguar's do. Both leopards and jaguars that are melanistic (completely black or very dark) are known as black panthers.

1.2.2.2. Geographical distribution

The leopard occurs across most of sub-Saharan Africa, as remnant populations in North Africa, in the Arabian peninsula, Sinai Judean Desert (Egypt, Israel, Jordan), south-western and eastern Turkey, Southwest Asia and the Caucasus into the Himalayan foothills, India, China and the Russian Far East, as well as on the islands of Java, Sri Lanka, Zanzibar and Kangean (Nowell and Jackson 1996, Sunquist and Sunquist 2002). Leopards occur at sea levels (Africa, Arabia, India, Java), in the foothills, mountains and volcanic areas (Morocco, Turkmenistan, Iran, Russia, Java) (Upherkina et al., 2001). Leopards are found in the Himalayas where they are sympatric with snow leopards up to 5200 m (Uphyrkina et al., 2001). Throughout its range, the leopard feeds on a broad range of prey, including small rodents, birds, different species of ungulates and livestock (Hoogerwerf 1970, Nowell and Jackson 1996, Christen 2000). Leopard's habitat coincides with most of the habitats where lions and tigers also inhabited years ago. Fossil records for the leopard as well as for other *Panthera* cats are controversial. The oldest leopard remains were reported from the Indian Siwaliks approximately 2 Ma. This primitive leopard was similar to jaguar (*P. onca*) and the now extinct *P. gombazogensis* (Hemmer 1976, Kitchener 1991). Teeth of ancient leopards found in southern China dated from the Middle Pleistocene being similar to the recent subspecies *P. p. sinensis* leading to the hypothesis of local evolution in eastern and south-eastern Asia (Hemmer 1976). On the other hand, their presence in Ceylon, where tigers are not found, points to their occupation of peninsular India at an earlier date than tigers, perhaps they invaded India by two routes, south of eastern and western ends of the Himalayas respectively (Daniel 1996). The leopard, along with the lion (*P. leo*), tiger (*P. tigris*), jaguar (*P. onca*) and snow leopard (*P. uncial*) comprise the relatively young felid genus *Panthera* thought to have diverged from a common ancestor 2–3 million years ago (Ma) (Hemmer 1976, O'Brien et al., 1987, Wayne et al., 1993, Johnson and O'Brien 1997).

The Indian subspecies, *Panthera pardus fusca*, is found in all forested habitats in the country, absent only in the arid deserts and above the timber line in the Himalayas (Prater 2005). There is a wide variation in the ecology of the species across its range and in different ecosystems. In Western Ghats, leopard occupied area is 43,353 km^2 (Jhala et al., 2008). Leopards occur widely in forests of the Indian sub-continent, through India and South-east Asia. Leopards are found in all forest types, from tropical rainforests to temperate deciduous, alpine coniferous (up to 5,200 m in the Himalaya), dry scrub and grasslands (Nowell and Jackson 1996). They are not found on the islands of Borneo or Sumatra (Nowell and Jackson 1996). The leopard's extensive geographical distribution, its varied coat colour patterns and morphological characteristics led to the naming of 27 subspecies in early taxonomic treatments (Pocock 1932). Upherkina et al., (2001) confirmed and extended the phylogenetic discrimination of seven phylogeographic groups of leopards to nine revised subspecies from the 27 classical leopard trinomials as one of *P. p. pardus* in Africa, eight Asian subspecies *P. p. nimr* South Arabian, and P. *p. saxicolor* in central Asia, *P. p. fusca* in India, *P. p. kotiya* in Sri Lanka, *P. p. melas* in Java, *P. p. orientalis* in Russian Far East, *P. p. japonensis* in North China and *P. p. delacouri* in South China.

1.2.2.3. Conservation status

Leopards are least studied species in India as compared to the tiger. It is listed as a species of least concern by the 2000 IUCN Red List of Threatened Species. In India, however it is listed in Schedule I of the Indian Wildlife (Protection) Act, 1972, under the highest level of protection. This is because 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. Except for central Africa and India, the leopard is endangered throughout its range (Uphyrkina et al., 2001) and declared as threatened species (IUCN 2010). Hunting of leopards for skin is an alarming issue, therefore leopards are included in the list of Convention of International Trade in Endangered Species (CITES) in 1975 (Bailey 1993).

1.2.2.4. Threats

The leopard is quite adaptable to different habitat and food requirements, being found in intensively cultivated and inhabited areas as well as near urban development (Nowell & Jackson 1996) which leads them to animal-human conflict. Leopards are found very often in villages to prey upon domestic animals and often encountered with man. Leopards are still found throughout most of their historic range, although their numbers have been significantly reduced over the last hundred years due to increasing human population expansion, habitat loss, hunting, and poaching by snares, traps, guns and poisoning. Leopard populations have become heavily fragmented and isolated (Uphyrkina et al., 2001). Loss of habitat is the most serious long-term threat to leopards and their prey. Increasing human population, changing land use practices, soaring demands from our urban population and more recently fast expanding economic activity have started straining the delicate balance at which tigers and leopards survive (Wickramanayake et al., 1998).

1.2.3. Dhole

The dhole or Asiatic wild dog is a canid, hunting in packs and cooperatively raising the young of single breeding females (Cohen 1977, Johnsingh 1982, 1992, Karanth and Sunquist 1995, Venkataraman et al., 1995). Dholes are the only members of the monospecific genus *Cuon* which is post Pleistocene in origin. The animal is closely related to Wolves (Canis lupus), the African wild dog (Lycaon pictus) and the South American bush dog (Speothos venaticus) in their life history behaviour (Johnsing 1982). The factor which governs dhole habitats are prey abundance, water availability, interspersion of forests with grassy openings, minimum human disturbance and potential den sites (Johnsing 1985, Acharya 2007). Mostly dholes are encountered in the thick scrub jungle and dense forest (Krishnan 1972, Davidar 1975) in South India. Dholes are highly social animals and they live and hunt in packs. Usually a clan consists of two or more packs (Johnsingh 1982, Fox 1984, Sheldon 1992) and larger appears to be rare (Johnsingh 1982). They are one of the ferocious hunters in the jungle through their co-operative hunting operation where they run down the prey, give lethal bites leading to blood loss, suffocate the prey and feed while the prey is alive. Usually the pack contains 3 – 15 members, although of up to 40 have been observed on occasion (Davidar 1975). They have an excellent sense of smell and sight allowing them to locate their prey easily. All study conducted in India showed that dholes primarily rely on medium to large ungulates, while also hunting smaller prey as well (Fox 1975, Johnsingh 1983, Acharya 2007 and Jimmy et al., 2009). The territories are marked by latrine at trail and road intersections where all pack members defecate. Dholes are good swimmers and drive their prey sometimes into water. Dholes are bimodal or diurnal in habit, hunting mainly in the morning and evenings (Johnsingh 1983). The pack usually moves in a single file trotting at a gradual pace, often on roads, tracks or forest paths, sniffing and scanning the surrounding area for potential prey (Acharya 2007) and communicating with each other by whistle. Being extremely social, dholes possess a highly developed vocal communication system (Davidar 1975, Cohen 1977, 1985, Johnsingh 1982).

The dhole is the least studied social carnivore in the world. In many forested areas scientific information existing on dhole populations remains negligible. Very few specific long-term studies have been conducted on this species (Johnsingh 1982, 1983, Venkataraman et al., 1995, Karanth and Sunquist 1995, Acaharya 2007). Prey selection and food habits have been studied in Bandipur (Johnsingh 1992), Mudumalai (Venkatraman et al., 1995), Nagarahole (Karanth and Sunquist 1995) along with spatial ecology using radio telemetry in Pench (Acaharya 2007). Short term opportunistic studies on food habits of dhole was carried out in Satpura (Gimmy et al. 2009), in south India (Fox and Johnsingh 1975, Cohen et al., 1978, Arivazhagan et al., 2005, Andheria et al., 2008). Grassman et. al., (2005) studied spatial ecology and diet of dhole using radio-telemetry in Thailand. Iyengar et al., (2005) documented phylogeography, genetic structure, and diversity of dhole. Further information on ecology of dhole would be of relevant conservation value.

1.2.3.1. General description

Dholes are large canids generally appear like domestic dogs weighing between 15- 20 kg, unlike domestic dogs that usually have shorter rusty reddish or brown coat and a darker bushy tail. Usually males are larger than females. Dholes mainly differ from wolves, domestic dogs or jackals in having six molar teeth in the lower jaw while others have seven and 12 – 14 teats as against ten in true dogs (Prater 2005). The ears are triangularly rounded with distinctive red coated body that varies with locality, black tip nose and chest, underside is often whitish. The total body length including the tail is 130 cm (Prater 2005). Pups born with a sooty-brown coat retain till three to four months and the coat gradually changes to rusty red.

1.2.3.2. Geographical distribution

Dhole’s distribution ranged from Siberia in north, India in the west, Java in the south and China in the east (Fox 1984, Johnsingh 1985, Acharya 2007). Oddly, dholes occur in the island of Sumatra and Java but not in Japan and Sri Lanka or Borneo (Pocock 1936, Ellerman and Morrison-Scott 1951, Acharya 2007). The major population of dholes still remain in the forest of south and central India and probably Myanmar (Johnsingh 1985). The fossil remains of dhole from the mid and early Pleistocene found in Europe, the Far East and South East Asia show that the species was widely distributed (Thenius 1954, Johnsingh 1985). Nine subspecies (Ellerman and Morrison-scott 1966) were recognised, *Cuon alpines laniger* (Kashmir and Southern Tibet), *C.a.primaevus* (Himalayan Nepal, Sikkim and Bhutan) *C.a. dukhunensis* (south of Ganges, India) *C.a. infuscus* (South Myanmar, Malaysia, Thailand, Laos, Cambodia and Vietnam), *C.a. adjustus* (North Myanmar and north-east India), *C. a. alpinus* (east of eastern Sayans, East Russia), *C. a. lepturus* (south of Yangze River, China), *C. a. hesperius* (East Russia and China) and *C. a. fumosus* (West Szechuan, China and Mongolia). Johnsingh (1985) reported *C.a. dukhunensis* are seen commonly in south of Ganga in the forest of Central Indian Highlands, Western and Eastern Ghats of Southern India. Like tigers, dholes must have entered India, extended their range to southern part through north-eastern frontiers but unabled to colonise in Sri Lanka (Prater 2005). In India they exist exclusively in dense forests and thick scrub jungles and are not found in open countries (Krishnan 1972, Cohen 1978) and occur in the hills at over 2,000 m. Dhole occupies 46,321 km^2 area in Western Ghats (Jhala et al., 2008). The India, optimal habitats of dholes appeared to be dry deciduous and moist deciduous based on their largest population in those habitats where ungulate biomass is high. In most of the forested areas in India, they overlap with the habitat of tiger and leopard.

1.2.3.3. Conservation status

In India, bounties were paid for carcasses right up until 1972 when dholes were declared as protected species. Dholes are listed as threatened in schedule II of the Wildlife (protection) Act, 1972. Also they are classified as endangered in the IUCN Red List and appendix II of CITES (IUCN 2010). The creation of Project Tiger Reserves in India has provided some protection for populations of the *C. a. dukhunensis* sub species.

1.2.3.4. Threats

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

1.3. Justification of study

A detailed long-term study on prey selection, food habits and population status of three sympatric large carnivores together has not been documented earlier in the country. Even though prey selection and food habits of large carnivores was studied in Nagarahole in detail (Karanth and Sunquist 1995), in many of the well protected areas uptodate scientific information on this aspect remains negligible. To supplement the current basic information the present study was conducted in Mudumalai Tiger Reserve from January 2008 to April 2010.

1.4. Objectives of the study

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

1.5. Organization of the thesis

The thesis is structured into six chapters, each chapter consisting of an introduction of the topic, elaboration of methods and analysis used, results arrived at and discussion of the results and comparisons with earlier studies. First chapter deals with the study species tiger, leopard and dhole, scope of the study and objectives of the study. Chapter 2 describes the study area, Mudumalai Tiger Reserve, Tamil Nadu. Chapter 3 deals with the prey species of large carnivores, their abundance and population structure. Chapter 4 describes prey selection and food habits of large carnivores. Chapter 5 covers population estimation of large carnivores using different methods in the study area.

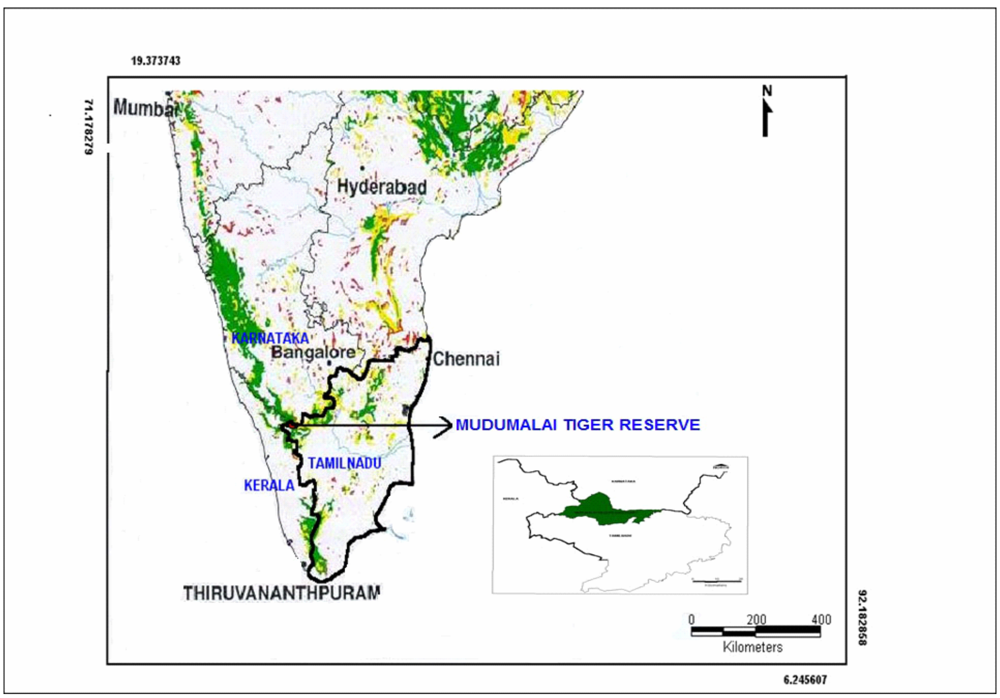
CHAPTER 2

STUDY AREA

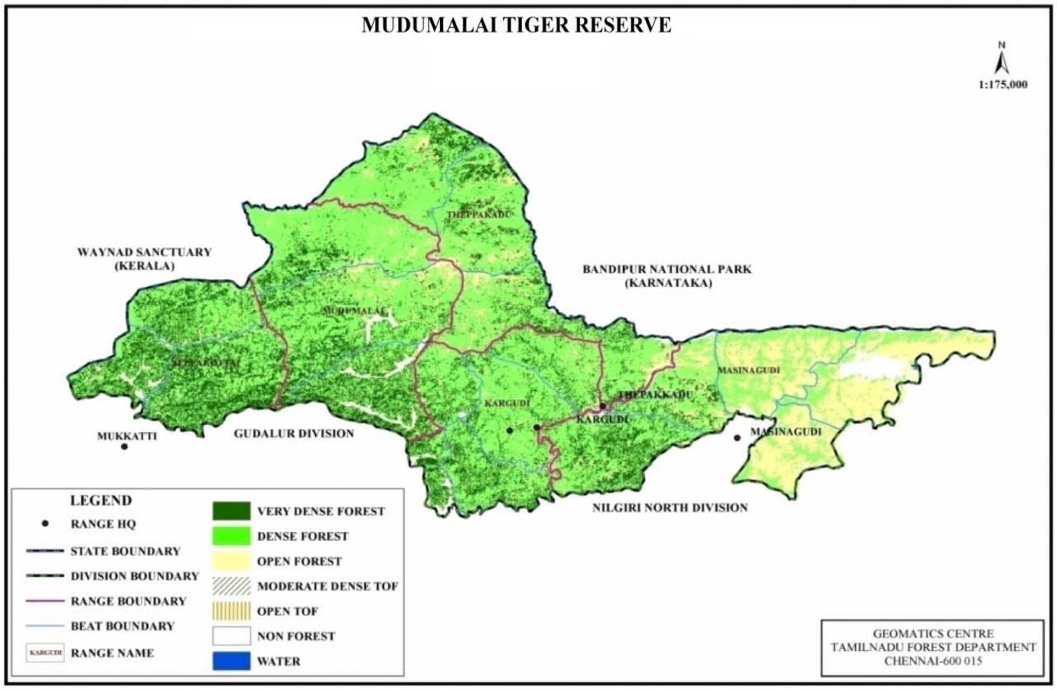
2.1. Location

The study area Mudumalai Tiger Reserve (MTR) (11^0 32' & 11^0 43' N and $76^0$22'& $76^0$45' E) the newly created Tiger Reserve in the country since April 2007 is situated at the tri-junction of Tamil Nadu, Karnataka and Kerala states (Maps 1a and 2b.). It is contiguous with Wayanad wildlife Sanctuary on the north west, Bandipur Tiger Reserve on the north, the south and the east the Singara and Sigur Reserved Forests which forms the boundary of Nilagiri North Division. The MTR is located within the Nilgiri Biosphere Reserve (5,520 km^2).

Map 1a. The location of Mudumalai Tiger Reserve, Tamil Nadu, in Western Ghats.



Map 1b. Mudumalai Tiger Reserve, Tamil Nadu, showing administrative zone



2.2. General information

Mudumalai is one of the few areas in the country with a rich and varied terrain, flora and fauna. Mudumalai plays an important role in biodiversity conservation of especially large mammals, by offering habitat contiguity of about 3300 km^2 with three other protected areas in the region, namely Nagarahole and Bandipur National Park and Wynaad Wildlife Sanctuary through forest corridors between the Western Ghats and Eastern Ghats. Mudumalai has a part of the single largest tiger population in India and acting as source population for the Northern and Eastern parts of the Western Ghat landscape complex and has the highest potential for long-term tiger conservation (Jhala et al., 2008). This area was also being used by the jungle warfare school during the Second World War. The reserve (Sanctuary) was created in 1940, the first in southern India, with an area of 60 km^2. In 1956, it was enlarged to 295 km^2 and later to a further 321 km^2, which is its present extent. The Core Zone of this reserve (100 km^2) has been notified as National Park. The present park was under the control of Thirumalapad kovilagam until late 18th century and in 1914 this area was declared as a Reserved Forest. This park has five ranges (Mudumalai, Theppakadu, Kargudi, Masinagudi and Nelakottai), 18 beats and 35 forest compartments. Later it was declared as Tiger Reserve in April 2007.

2.3. Physical features

2.3.1. Soil

Two types of soils are found in the reserve; black sandy loam soil containing over 50% of sand and gravel and red heavy loam soil (Suresh et al., 1999). The red soil is generally present in the southern part of the Sanctuary, where rainfall is plentiful making the soil fertile. The northern part of the Sanctuary has blackish soil, which does not favour better retention of moisture, and possibly has more infertile mineral. The eastern part of the Sanctuary has gravel soil, with very poor rainfall and poor soil moisture content resulting in stunted growth of trees.

2.3.2. Terrain

The terrain is mostly gently undulating but flat towards the eastern portion with an average elevation ranging from 960 m to 1266 m. Morganbetta of Masinagudi range is the highest peak (1266 m) in Mudumalai. Narathibetta on the western side of the park is the second highest peak (1188 m). The park areas located in Wayanad plateau is characterized by the presence of several swamps and `vayals’ varying in size.

2.4. Climate

The park has a long wet season and a short dry season. It receives rainfall from south-west and north-east monsoons. Two peaks of rainfall can be seen in the eastern part of the reserve, one during the month of June (100-150 mm) and the second peak during October (200 mm). The western part of the Sanctuary receives rainfall almost throughout the year starting from March and the peak rainfall is received during the months from June to October. The south-west monsoon starts by May and ends by August whereas the north- east monsoon starts by September and ends by December. Based on the climate of the area, there are three distinct seasons recognized: dry season (January to April), first wet season (May to August) and second wet season

(September to December) (Varman and Sukumar 1993). There is a decreasing rainfall gradient from the west and south to the east and north (Suresh et al. 1996). The rainfall has a marked east-west gradient, with the eastern areas getting the least amount of heavy rains (1000 to 2000 mm). The temperature ranges from 8^0C in December to 35^0 C in April. Annual rainfall and temperature in deciduous habitat is given in figure 1a. and 1b (Source IISC Bangalore).

2.5. Hydrology

Mudumalai is characterized by the presence of several swamps and vayals varying in size which provide wallowing grounds for herbivores. The central part of the Sanctuary is slightly elevated with seasonal streams and three perennial streams. They are Moyar River; its tributaries drain the Tiger Reserve. The Moyar River, originating from Nilgiri Mountain near Pykara and meanders through the park for a distance of 20 km. On the eastern part of the reserve there is an artificial canal through which water is drawn from Maravakandy reservoir from Masinagudi to Moyar reservoir (about 9 km) for power production and this is the major water source for wildlife. Avarhalla is another perennial water source in the eastern part of the Sanctuary. Throughout the year, seepage water from Maravakandy dam flows through Avarhalla draining the dry thorn forest. Mavanhalla is a perennial stream found in the western side of the sanctuary and about two decades back it had become a seasonal stream due to a check dam that was built across this river to supply water to Bokkapuram and Mavanhalla villages. There are four major perennial artificial waterholes; Ombetta, Game hut, Compartment no.3 check dam and Narathi check dam. The seasonal waterholes include Mavinhalla, Bidharhalla, Segur River, Doddakattihalla, Hebhalla, Imberhalla, Bennahole, Kakkanhalla and Mukkattihole. Water in these seasonal streams flow only during rainy season but water is available for wildlife in puddles throughout the year. During the months of March, April, and May water flow in Moyar gets almost cut off, in situations like this water from Singara power house is released so as to maintain the water flow in the river.

2.6. Vegetation

Champion and Seth (1968) classified the vegetation type in Mudumalai as Southern Tropical dry thorn forest, Southern Tropical dry deciduous forest, Southern Tropical moist deciduous forest, Southern Tropical semi-evergreen, Moist bamboo brakes and Riparian fringing forest.

2.6.1. Southern Tropical dry thorn forest (6A/C)

Tropical dry thorn forest occurs along the foothills of Nilgiris hills on the eastern side of the Sanctuary. This region receives an average annual rainfall of 600-900 mm. The trees are stunted with the following common tree species; *Acacia chundra, A. suma, A. leucopholea, Prema tomentosa, Dalbergia lanceolaria, Anogeissus latifolia, Ziziphus xylopyrus, Ziziphus mauritiana, Sapindus emarginatus, Erythroxylon monogynum, Canthium parviflorum, Acacia pennata, Randia dumetorum* and *Capparis* species.

2.6.2. Southern Tropical dry deciduous forest (5A/C1B and /C3)

Dry deciduous forest occurs over a major portion of the tiger reserve where the rainfall is between 900 mm and 1200 mm. This type of forest extents up to the northern boundary and on the west, dry deciduous forests can be seen up to Game hut. Tall grasses like *Themeda triandra* and *T. cymbaria*, *Heteropogon contortus* and *Cymbopogan flexuous* are found in patches where the canopy is open. The trees found in this habitat shed their leaf during dry season and it is prone to fire during dry season. The common tree species are *Anogeissus latifolia, Grewia tilifolia, Terminalia crenulata, T. tomentosa, and Kydiya calycina and Tectona grandis.* In Doddagatti block there is plentiful growth of *Shorea roxburghii* occur.

2.6.3. Southern Tropical moist deciduous forest (3B/C1C and C2)

Moist deciduous forest is found in regions where the rainfall is between 1600 and 2000 mm. This type of forest is found in Benne, Mudumalai and Theppakadu blocks. The canopy is closed in this forest and the trees are tall. The common tree species in moist deciduous forest includes *Lagerstroemia microcarpa, Terminalia crenulata,* *Tectona grandis* and *Dalbergia latifolia*. The ground vegetation includes several species of Orchids, *Amorphophallus, Zingiber, Curcuma* and *Solanum species.*

2.6.4. Southern Tropical semi evergreen (2A/C2)

A bit of semi evergreen forest is found in the Southwest and Western part of MTR. The rainfall in this region exceeds 2000 mm. The tree species in this habitat includes *Olea dioca, Glochiodion velutinum, Toona ciliate, Elaeocarpus tuberculatus, Casseria ovoides, Litsea mysorensis* and *Cinnamomum malabaricum*. Climbers like *Todalia asiatica, Watakaka volubilis, Gnetum ula, Entada scandens* are also found in semi evergreen forest (Suresh et al., 1999).

2.6.5. Moist Bamboo brakes (2E3)

Bamboo thickets are found amidst dry deciduous, moist deciduous and semi evergreen forests. It is commonly interspersed with semi evergreen habitat in the western side of the reserve. There are two species of bamboo; *Bambusa arundinacea* and *Dendrocalamus strictus.* They are found along the fringes of riparian forests and swamps.

2.6.6. Riparian forest (4E/RS1)

Amongst all habitat types of forest from a vantage point a green strip of riparian forest can be seen along the dry seasonal and perennial streams. Tree species found in this type of forest remain green throughout the year. The plant species found in riparian forests includes *Mangifera indica, Pongamia glabra, Terminalia arjuna, Bischofia javanica, Linociera malabarica, Syzygium cumini, Dalbergia latifolia, Bambusa arundinacea* and *Dendrocalamus strictus.*

2.7. Fauna

Mudumalai Tiger Reserve has got a high diversity of fauna. Thirteen percent of mammal species found in India are present here. There are about 50 species of fishes, 21 species of amphibians, 34 species of reptiles, 227 species of birds and 55 species of mammals reported from the reserve (Dogera 2007). The diversity of mammals is high in the deciduous and dry thorn forest than in the other habitats. Tiger, leopard and dhole are the three major carnivores present in the study area. Mudumalai supports a fabulous assemblage of herbivores (Davidar 1983)) such as chital (*Axis axis),* sambar (*Rusa unicolor),* muntjac (*Muntiacus muntjak),* wild pig (*Sus scrofa),* Indian chevrotain (*Tragulus meminna),* gaur (*Bos gaurus),* Asian elephant (*Elephas maximus),* four-horned antelope (*Tertracerus quadricornis*), black-buck (Antelope cervicapra), black-naped hare (*Lepus nigricollis),* and arboreal mammals such as bonnete macaque (*Macaca radiata),* common langur (*Seminopithecus entellus),* Indian giant squirrel (*Ratufa indica)* and Indian giant flying squirrel (*Petaurista philippensis*) are also found here. The area supports a wide variety of medium to small sized carnivores such as sloth bear (*Melursus ursinus*), jackal (*Canis aureus*), striped hyena (*Hyaena hyaena*), jungle cat (*Felis chaus*), leopard cat (*Prionailurus bengalensis*), rusty spotted cat (*Prionaillurus rubiginosus*), common palm civet (*Paradoxurus hermaphroditus*), small Indian civet (*Viverricula indica*), grey mongoose (*Herpestes erdwardsii*), ruddy mongoose (*Herpestes smithii*) and stripe-necked mongoose (*Herpestes vitticollis*). MTR is also domicile to the Indian porcupine (*Hysterix indica),* and Indian pangolin (*Manis crassicaudata*). There are other small mammals also present such as common house rat (*Rattus rattus),* Indian gerbil *(Tatera indica),* and Blandford's rat *(Cremnomys blanfordi).* Domestic livestock (cattle, buffalo and goat*)* occur in the village areas present inside the Sanctuary. Deciduous forest habitats support the highest small mammal abundance and biomass in the reserve (Venkataraman *et al.*, 2005).

2.8. People and livestock

There are 21 tiny hamlets located within the park. People living in these settlements include Mountain Chetties and tribes; Kattu Naickers, Paniyas, Kurumbas, Irula. Mountain Chetties main occupation is to perform agricultural practices in swamp vayal habitats and rear cattle. The Paniya tribes work in agriculture fields of Chetties and they also collect tuber, honey, and perform fishing operations in the reserve for their sustenance. There are also Kurumba, Kattu Naicker tribes and some Irula living near Theppakadu, Kargudi and Thoraplli. The Kurumbas are basically hunter-gatherers. At present they do not hunt animals. Kurumba, Kattu Naickers and Irula collect tubers, honey, and mushroom and also scavenge on carnivore kills. These people work as fire watchers, tourist guide, mahout and anti-poaching watchers. Moyar is a non-tribal village located as an enclave in the eastern part of the park. This is basically a village with electricity board employees and a few resident Irula tribes, a grazier and agrarian tribal community. Retired electricity board employees have settled in this village. The village has expanded in the last ten years by encroaching and clearing the revenue land adjacent to forest areas. These villagers cultivate ragi, coconut, garlic, cabbage, beans etc. These villagers own large number of livestock. Cattle grazing in the forest occur illegally. There are fairly a few villages abutting the eastern and southwestern part of the park, to name a few; Mavanhalla, Chemmanatham, Masinagudi, Bokkapuram, Singara, Thorapalli and Bospara. These villagers cultivate paddy, tapioca and raise plantations like tea, coffee and pepper.

Figure 1a. Annual rainfall pattern in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to December 2009).

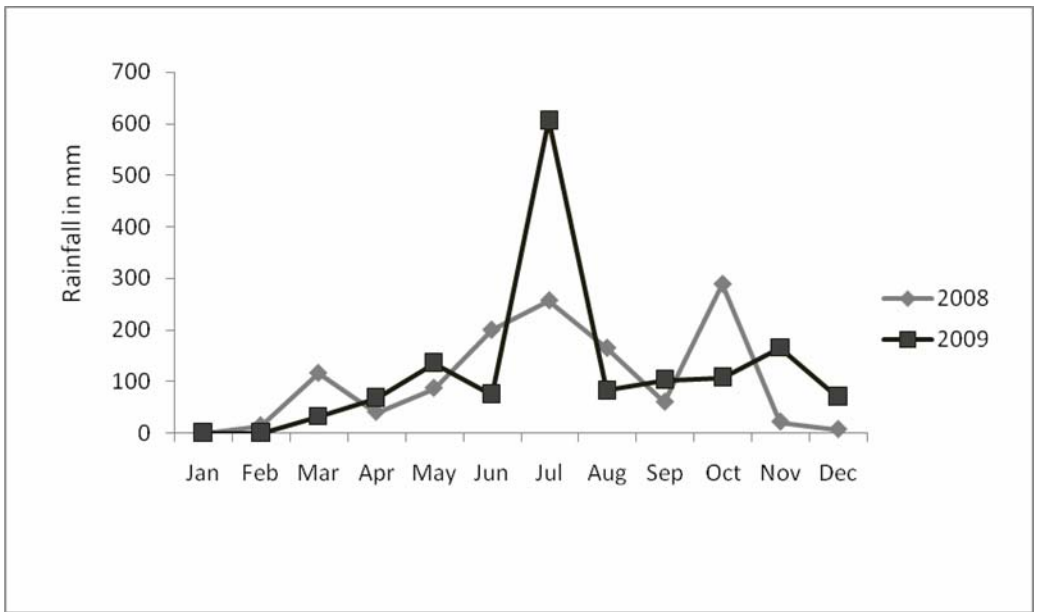
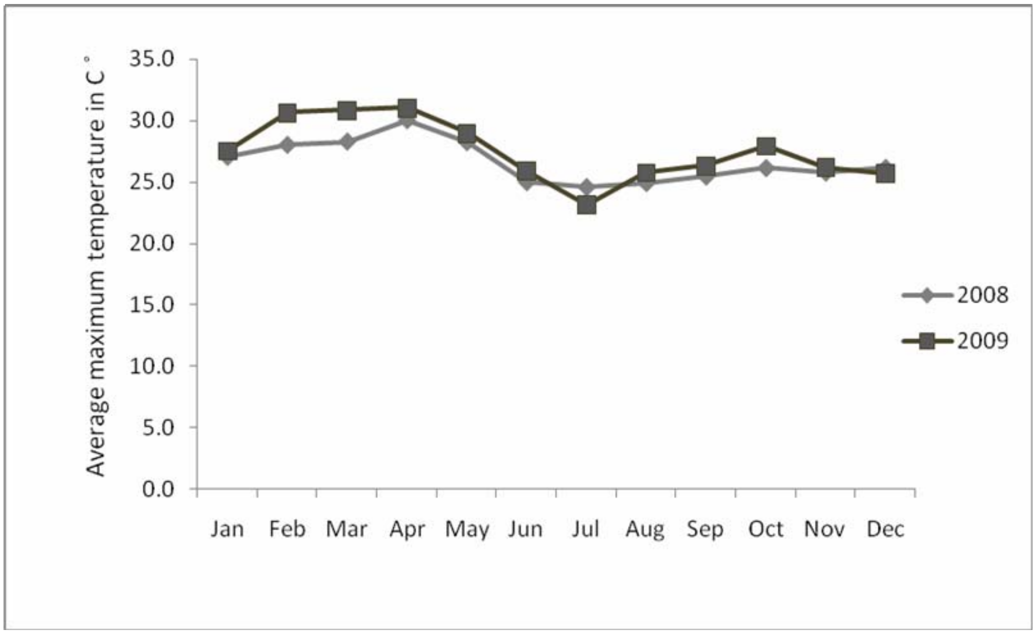


Figure 1b. Annual temperature in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to December 2009).



CHAPTER 3

ESTIMATION OF PREY AVAILABILITY, GROUP SIZE AND COMPOSITION

3.1. Introduction

Conservation and management of large carnivores require reliable knowledge of the number of individuals in an area. Survival of carnivores is dependent on measurable amount of energy that can be potential prey base in a given area. Predator–prey relationships amongst large mammals are complex interactions in system ecology (Gasaway et al., 1983). Prey availability can influence prey selection and hunting success of carnivores (Fuller and Sievert 2001). The resource availability may provide indirect evidence for the likelihood of one species affecting another. An ecological perspective concluded that body size of large carnivores is mainly determined by the frequency distribution of prey available and the presence of species that use similar habitats. The amount of energy in an area is determined by the prey density (Sunquist and Sunquist 1989) and prey biomass. Karanth and Nichols (1998) suggested that the abundance and distribution of large carnivores is principally operated by densities of different sized ungulate prey. Relationships between predator and prey size is associated with increase in mean prey size (Rosenzweig 1966, Gittleman 1985, Carbon et al., 1999) and prey diversity (Gittleman 1985). Ungulates form a major component of carnivore diet (Schaller 1967, Seidensticker 1976, Johnsingh 1983, Karanth and Sunquist 1995, Karanth and Nichols 1998, Biswas and Sankar 2002, Bagchi et al., 2003, Jathanna et al., 2003). Prey species availability is the major source indicator of large predator fitness in an ecosystem. However change in the quality or quantity of available food can have both direct and indirect effect on the ecosystem (Riddhika 2009). Density estimation is one of the parameters for effective management and conservation of wildlife populations (Primack 1993, Sutherland 1996, O'Connell et al., 1999, Carbone and Gittleman 2002, Karanth et al., 2004, Ogutu et al., 2006). Accurate density estimation is vital because resources can get easily wasted if appropriate methods and survey techniques are not followed (Krebs 1999). Ecology generally aims at estimating abundance of organisms (Karanth et al., 2004). Long-term studies have focussed on wild prey of large carnivores in the Indian sub-continent (Schaller 1967, Eisenberg and Lockhart 1972, Berwick 1974, 1976, Seidensticker 1976, Dinerstein 1979, Mishra 1982, Tamang 1982, Johnsingh 1983, Balakrishnan and Easa 1986, Karanth 1992, Sankar 1994, Khan et al., 1996). Line transect method is practical, efficient and relatively inexpensive for many biological populations (Burnham 1980, Buckland et al 1993, Karanth and Sunquist 1992, 1995, Varman and Sukumar 1995, Khan et al., 1996, Karanth and Nichols 1998, 2000, Biswas and Sankar 2002, Avinandan et al., 2008, Bagchi et al., 2003, Jathanna et al., 2003, Harihar 2005, Andheria et al., 2007, Ramesh et al., 2009). A limitation of line transects is that large number of observations are needed to calculate detection function precisely. Prey densities are estimated using distance sampling methods (Burnham 1980, Buckland et al., 2001). Animal counts and associated distance data are used to model visual detection probabilities as a decreasing function of distance from the line transect. The detection probability of an object depends solely on its perpendicular distance from the line. This modelling and the subsequent estimation of prey densities and their variances are accomplished by using program DISTANCE 6.0 (Thomas et al., 2009). Ungulate prey densities can vary from 5.3 to 63.8 animals per km^2 in a wide array of ecological situation (Karanth et al., 2004). Habitat type and quality are among the primary factors affecting spatial distribution of ungulates (Gilpin and Soule 1986). Ramakrishnan et al., (1999), Karanth et al., (2004) and Carbone and Gittleman (2002) were able to predict tiger density as a function of prey density. Predator–prey relationships are so finely tuned and data on prey availability can be used to reliably predict predator densities and abundance (Carbone & Gittleman 2002, Karanth et al., 2004, Khorozyon et al., 2008).

Animals in groups are thought to have lower risks of predation than solitary individuals (Jarman 1974). Most mammalian species often live in groups, the size of which constitute the simplest and most basic elements of their social organization (Eisenberg 1966, Crook et al., 1976). Group size varies widely within and between species (Altman, 1974, Geist 1974, Jarman, 1974, Clutton-Brock and Harvey 1977, Rodman 1981). This variation needs to be explained if it is to be considered as a part of the species adaptation to its environment (Southwell 1984). Ungulates group sizes are determined by food quality, abundance and dispersion of cover density. Individual fitness varies with group size (Rodman 1981) and the group vigilance level thus increases with increase in group size (Sartaj et al., 2010). The most frequently used group size measure is the mean ± SD. This method is only fruitful when the distribution of group size approaches normal distribution (Reiczigel et al. 2007). The normal distribution is rare in mammalian population. Exclusion of highly skewed (aggregated) data such as solitary group and outliers large group from the analyses would cause loss of information with parallel changes in crowding (Reiczigel et al. 2007). Such skewed frequency distributions are complex patterns that cannot be adequately characterized by single descriptive statistics and average group size. Group size is experienced by an average individual (Jarman 1974). Though average individuals come from groups larger than the average group size, Reiczigel et al. (2007) introduced a measure called "crowding" is the group size in which an individual lives or is referred to group size experienced by any individuals. Sex ratio is generally an indicator of the reproduction potential of a species. A high percentage of young as compared to adults generally indicates a fast growing or thriving population in contrast to a relatively small percentage of young usually indicating a listless rate of population increase (Sankar 1994, Sankar and Acharya 2004). A population with more females than males generally has a higher reproductive potential than the one that is predominantly composed of males (Spillet 1966). De and Spillet (1966) suggested that more or less 1:1 sex ratio may usually be found in an area free from selective shooting or predation. Vehicle transects (along road networks) as a substitute to foot transects (Ward et al. 2004, Ogutu et al. 2006, Ramesh et al., 2009) yield larger effort, however, the resulting estimate may be biased towards roads (Varman & Sukumar 1995) since it provide better visibility and result in better estimate of population structure (Karanth 1992) for those species which are attracted to open habitats created alongside roads (Ramesh et al., 2009) while other species may avoid due to disturbance caused by vehicular movement. This depends on the arrangement of the road network in habitat and the species being monitored.

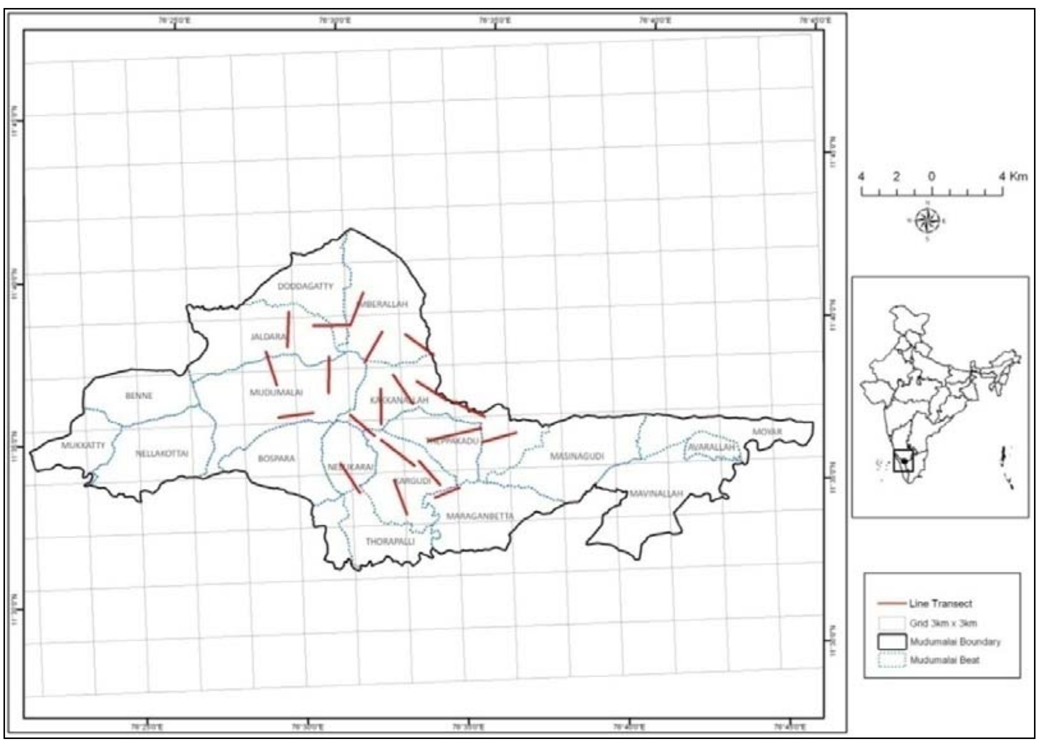
Major prey species of large carnivores such as chital, sambar, gaur, wild pig, and langur have been described here. Chital is the third largest deer in India (Sankar and Acharya, 2004) that has been well studied in Corbett (De and Spillit 1966), Kanha (Schaller, 1967), Bandipur (Johnsingh, 1983), Nagarahole (Karanth and Sunquist 1992), Sariska (Sankar 1994), Gir (Khan et al. 1996), Guindy (Raman 1997), Pench (Acharya 2007, Sartaj et al., 2009), Ranthambore (Bagchi et al. 2003), Chitwan (Mishra 1982), Karnali-Bardia (Dinerstein 1980) in Nepal, and Wilpattu (Eisenberg and Lockhart 1972) in Sri Lanka. Other few studies reported introduced populations from Hawaii (Graf and Nichols, 1966). Sambar, the largest deer in India is widely distributed in the country. Its population biology and habitat requirements have been studied in Kanha (Schaller 1967), Bandipur (Johnsingh 1983), Nagarahole (Karanth and Sunquist 1992), Sariska (Sankar 1994), Gir (Khan et al. 1996), Pench (Acharya 2007), Ranthambore (Bagchi et al., 2003), Mudumalai (Varman and Sukumar, 1993), Karnali-Bardia, Nepal (Dinerstein 1980) and Khao-Yai National Park, (Ngampongsai 1987). Other information comes from introduced populations in Australia (Slee 1984), Prairies, Edwards Plateau regions of Texas (Ables and Ramsey 1974), New Zealand (Semiadi et al., 1995) and Florida (Flynn et al., 1990; Lewis et al., 1990; Shea et al 1990). There are studies on gaur, the largest member of bovidae from central India (Brander 1923), Kanha (Schaller 1967), Palamau (Sahai 1977), Nagarahole (Karanth and Sunquist 1992), Parambikulam (Vairavel 1998), Pench (Sankar et. al., 2001), Noth-east India (Choudhury 2002) and natural history observations (Inverarity 1889, Russell 1900, Sanderson 1912), Wild pig is a widely distributed terrestrial mammal of all the Suiformes. The study i.e, carried out in Indian subcontinent on wild pigs are in Radhanagari (Ahmed 1989, 1991), Punjab (Shafi and Khokhar 1986), Ruhana, Sri Lanka (Santiapillai and Chambers 1980), Periyar (Ramachandran et al., 1986) and elsewhere (Mason 1893, Brander 1923, Ali 1927, Morris 1929, Rao 1957, Prater 2005, Tiwari 1985, Ramdas 1987, Chauhan 2004). Common langur is a colobine monkey found in a wide range of South-Asian habitats and documented by few studies (Agoramoorthy, G. 1986, 1992, Terborgh and Janson 1986, Newton 1984, 1987, Koenig et al., 1998, Chapman & Chapman 2000, Koenig & Borries 2001, Johnson et al., 2002 and Chapman and Pavelka 2005).

3.2. Methods

3.2.1. Line Transects

Using Survey of India Map overlaid with grid cells (3 km x 3 km), an intensive study area of 107 km^2 was selected in the deciduous forest (moist and dry deciduous) of Mudumalai. In each grid at least one line transect was laid to ensure uniform distribution of line transects (n=20) which varied in length from 1.5 to 3.13 km (Map 2). Coordinates of the start and end point of these transects were recorded. All the transect starting and ending points were marked with the help of Global Positioning System (Garmin 72). Along the line transects, density of prey species was estimated using line transect sampling method (Anderson et al., 1979, Burnham et al., 1980, Buckland et al., 1993) for a period of two years (January 2008 to December 2009). The total length of line transects was 41.3 km. Each line transect was walked two to three times in the dry season and long wet season. Transects were walked by two members; an observer and a recorder. All transects were walked in the early morning between 6.30 am and 8.30 am after sunrise. For each detection, the time, species, group size, group composition, animal bearing (using a hand held compass SUNNTO™) and angular sighting distance (using a laser range finder) were recorded. Necessary care was taken while walking on transects to maximise detectability of animals before they flush away.

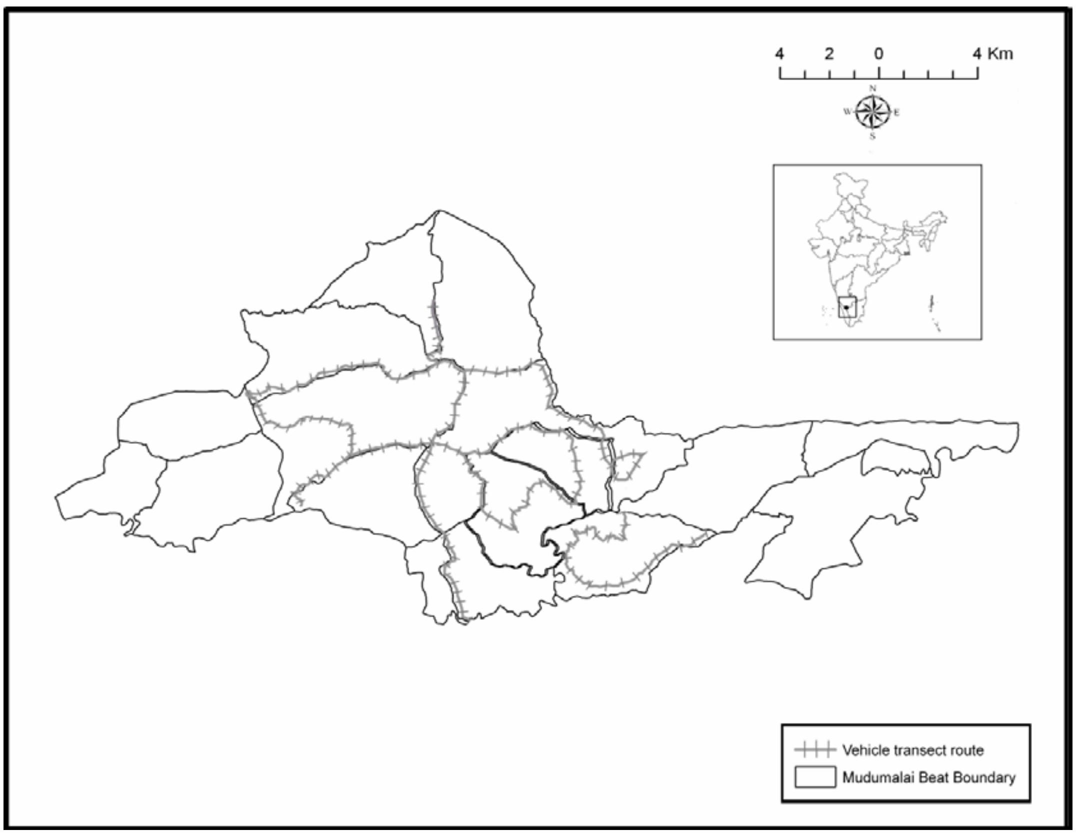
Map 2. Locations of line transects in the study area, Mudumalai Tiger Reserve (2008-2010)



3.2.2. Vehicle transects

Vehicle transects (Hirst 1969, Varman and Sukumar 1995) were used to estimate group size and composition of prey species in the intensive study area (107 km^2) for each season for two years from January 2008 to December 2009. Five vehicle transect routes ranging from 15 to 23 km were monitored (Map 3.). Two observers carefully searched on either side of the road for sightings of prey species. Total transect length of 93.5 km was monitored twice in a month in the early morning and late afternoon hours which resulted in a total effort of 3740 km. On each sighting of prey species, the following information was recorded; group size and composition of prey species and perpendicular sighting distance from the road. Male and female age was classified into adults and sub-adults. Sex ratio was calculated from prey species composition. Fawns were placed in a separate category. Vehicle transect sighting data was analyzed season wise (Dry and Wet) and pooled for each year separately. No attempt was made to age and sex of common langur and Indian giant squirrel.

Map 3. Location of vehicle transects in the study area, Mudumalai Tiger Reserve (2008-2010)



3.3. Analyses

3.3.1. Prey availability

Prey species population was estimated using program Distance 6.0 (Thomas et al. 2009) following line transect method by Burnham et al., (1980), Lancia et al., (1994) and Buckland et al., (2001). Analysis was concerned with fitting different detection functions to the observed data for estimation of densities. The best model was selected on the basis of the lowest Akaike Information Criteria (AIC) values (Buckland et al., 1996, Burnham et al., 1980). This is a more appropriate method for calculating prey density with the associated coefficient of variance (CV %) since it takes into account the temporal variation in species detection (Jathanna et al., 2003). The thumb rule is the difficulty in getting a robust result with less than 40 or 60 observations, although the number depends on the characteristics of the species (Burnham et al., 1980). All density estimates were done after 1% truncation of the farthest sighting data from the line transect. Suitable modifications in right truncation were made so as to ensure a reliable fit of key functions and adjustment terms to the data so as to arrive at density estimate. To get better estimates, a minimum number of observations are required in order to model the detection function whereas sightings were pooled together for both the year dry seasons and wet seasons separately as there was no significant difference (P >0.5) in the angular sighting distance between same dry seasons or wet seasons. Also data was analysed yearly and overall for both the years. Halfnormal Cosine-Binomial model was fitted for the species which was sighted >5 to 15 times. Pooled species estimated strip width (ESW) was used to derive density estimate wherever species which was sighted less than five time presuming that related species have similar visibility w.e.t chital ESW for ungulates species such as wild pig, barking deer, mouse deer, langur ESW for bonnet macaque and grey jungle fowl ESW for peafowl, red spur fowl, black-naped hare.

3.3.2. Group size and composition

Data on group size and composition of prey species was estimated as suggested by Schaller (1967), Johnsingh (1983) and Karanth and Sunquist (1992). Average mean group size was estimated by taking the average of different group sightings and group size was classified into different class intervals for better interpretation between seasons. Earlier studies in the sub continent on wild ungulates did not take crowding into account within their data set. I calculated "crowding" phenomenon and mean group size using program Flocker 1.0 (Reiczigel and Rozsa, 2006) following the crowding measure developed by Reiczigel et al. 2007. Age classification of chital and sambar was followed by Schaller (1967) and Sankar (1994), barking deer - Barrette (2004), gaur - Schaller (1967), Sankar et al., (2001) and elephant - Sukumar (1985) with a few modifications. Age of female chital deer was categorized as follows; full grown > 30 kg as adults while < 30 kg as sub-adults. The male chital deer were classified into; adult (> 2 feet antlers) and sub-adult (spike and < 1 feet antlers). Fawns were considered if the size was equal to the height of the mother's belly. Barking deer was classified into males (adults with antlers having a short brow line, protruded upper canines (whenever possible) >15 kg and sub-adults of approximately 5 - 15 kg), females (adults which were antlerless, >15 kg and sub-adult which were antlerless of approximately 5 - 10 kg) and fawns (sometimes with spotted coat and approximately <5 kg). Gaur was classified into; adult males (shiny black coat with heavy horns sweeping sideways and upwards), sub-adult males (dark brown coat with a conspicuous dorsal ridge and small dewlap hanging below the chin, large drapes between the fore legs), yearlings (10-20 months old), adult females (smaller than adult males, pelage is dark brown with more upright horns corrugated inwards than in adult males), sub-adult females (50 - 75 % size of adult female lacking a conspicuous white stocking), female yearlings (light brown coat which were 25 to 50 percent size of sub-adult females), small calves (light brown coloured coat, approximately < 3 months old of < 30 kg), medium calves (light brown coloured coat of approximately 30 to 100 kg) and large calves (dark brown coloured coat which were half the size of yearling females). Male wild pigs were aged into adult males (well developed tushes and genital organs), sub-adult males (not well developed tushes and half the size of adult males), male yearlings (tushes not visible, genital organ and half the size of sub-adult males) and adult females (tushes not seen), sub-adult females (tushes not seen and half the size of adult females), female yearlings (half the size of sub-adult females). Piglets have brown coloured coat with black stripes on the dorsal region and are classified into small (half the size of large piglet and approximately <3 kg) and large (approximately 3-5 kg). Percentage of male and young ratio to 100 females was calculated from the group composition. Elephants were classified into various age-sex categories based on relative height and morphological characteristics. Young elephants (< 15 years) were compared to the oldest adult female in the group (Eisenberg and Lockhart 1972) based on the height while the older elephants were classified based on their morphological characteristics like degree of ear fold, depression of the buccal cavity and forehead and using tribal mahout's field experience. Elephants were placed in broad age-classes; calves (< 1 year old), juveniles (1-5 years old), sub-adults (5 -15 years) and adults (> 15 years). Males were identified by the presence of tusks while females were tuskless.

3.4. Results

3.4.1. Availability of prey species

Groups and individual density of potential prey species of large carnivores was estimated along with their percent coefficient of variation, effective strip width and their associated standard error are given (Tables 1- 4). Prey species were classified into major (chital, sambar, gaur, wild pig, common langur) and minor (mouse deer, barking deer, elephant, Indian giant squirrel, bonnet macaque, peafowl, grey jungle fowl, red spur fowl, and black-naped hare) based on their significant contribution in the diet of large carnivores. In total 14 prey species were detected on transects over the two year period with a sampling effort of 364.77 km. Even for pooled estimates of seasonal analysis the numbers of observations were less than recommended (40 different observations by Burnham et al., 1980) for some species. Therefore the pooled density of overall analysis would be more reliable. Though desirable level of precision (CV < 15%) was not achieved in some cases even in overall analysis since less sampling effort yielded few observations. The estimated overall prey density was 95.6 / km^2 which include wild ungulates – 42.2 / km^2, arboreal mammals – 42.2 / km^2, elephant – 5.5 / km^2 and others -5.7 / km^2. Major prey species of large carnivores was found to be 76.3/km^2 in study area while minor prey species density was 19.3 km^2.

3.4.1.1. Major prey species

3.4.1.1.1. Chital

Chital density ranged from 20.3 ± 7.1SE to 23.0 ± 5.0SE individuals/km^2 between dry and wet seasons. There was a sudden drop in the individual density of chital in 2009 due to increased forest fire that might have influenced chital to move towards adjacent moist patches. Half normal cosine model was the best fitted for both the seasons. Overall density of chital was 25.4 ± 6.7 / km^2.

3.4.1.1.2. Sambar

Sambar density ranged from 4.6 ± 1.2SE to 4.7 ± 1.6SE individuals/km^2 between dry and wet seasons. Half normal cosine model was the best fitted in the dry season and Halfnormal Hermite in the wet season. Overall sambar density was 4.5 ± 0.98 / km^2.

3.4.1.1.3. Gaur

Seasonal density of gaur ranged from a minimum of 6.3 ± 2.3SE to a maximum of 11.0 ± 4.4SE individuals/km^2 in the deciduous forest. Individual density declined drastically in 2009. This wide variation was seen due to forest fire which might have influenced gaur to move towards moist patches during the dry season in 2009. The model selection was Halfnormal Cosine in the dry season and Halfnormal Hermite in the wet season. On the whole, gaur density was 9.4 ± 2.5SE / km^2.

3.4.1.1.4. Wild pig

Estimated density of wild pig varied between seasons from 0.52 ± 0.31SE to 1.9 ± 0.87SE/km^2. Half normal cosine-Binomial model was the best fitted for both the seasons. On the whole, density of wild pig was 1.3 ± 0.87SE / km^2.

3.4.1.1.5. Common Langur

Individual density of common langur declined drastically in 2009 due to widespread forest fire in the dry season. Density varied between seasons from 20.0 ± 4.1SE to 59.0 ± 11.8SE. Halfnormal cosine model was best fitted model in the dry season and Halfnormal Hermite in the wet season. Common langur was the most abundant prey species (35.0 ± 4.4SE/km^2) in the study area.

3.4.1.2. Minor prey species

3.4.1.2.1. Mouse deer

Mouse deer occurred in low density throughout the study area. They were encountered thrice on transects. Their overall density was 0.15 ± 0.08SE/km^2.

3.4.1.2.2. Barking deer

Throughout the study area, barking deer also occurred in low density like the mouse deer. The estimated overall density of barking deer was 1.2 ± 0.8SE / km^2.

3.4.1.2.3. Elephant

There was not much difference in the elephant density between seasons which ranged from 4.9 ± 1.2SE / km^2 to 5.1 ± 1.3SE / km^2. The data was best fitted with Half normal cosine model in both the seasons. The overall density of elephant was 5.5 ± 0.99SE / km^2 .

3.4.1.2.4. Bonnet macaque

Wide variation was seen in bonnet macaque density between seasons and ranged from 2.2 ± 1.7 to 1.7 ± 1.6SE / km^2. Their overall density was 1.9 ± 1.1SE / km^2 and model selection was similar to that of common langur.

3.4.1.2.5. Indian giant squirrel

Indian giant squirrel was the second most abundant arboreal mammal in the study area. Their overall density was 4.9 ± 1.2SE / km^2. Their individual density seemed to be higher in the wet season than dry season.

3.4.1.2.6. Peafowl

Peafowl density was found to be 1.0 ± 0.5SE / km^2. The peafowl detections were best explained by Half normal cosine model as fitted in grey jungle fowl.

3.4.1.2.7. Grey jungle fowl

Overall estimated density of grey jungle fowl was found to be 3.5 ± 1.5SE / km^2 in the study area. The model selection was Halfnormal cosine in both the seasons.

3.4.1.2.8. Red spur fowl

Red spur fowl was estimated to be 1.0 ± 0.7SE /km^2. The model selection was like that of grey jungle fowl.

3.4.1.2.9. Black-naped hare

Hare density was found to be 0.17 ± 0.17SE / km^2. The model selection was similar to that of grey jungle fowl.

Table 1. Season wise density estimate of major prey species in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons /Years	Species	Number of Observation	Model	ESW	GS±SE	Dg±SE	%CV	D±SE	%CV	Confidence Interval	
										Lower	Upper
Dry 08-09	Chital	44	HC	33.9	6.5±0.82	3.1±1.0	32.6	20.3±7.1	35.2	10.2	40.2
Wet 08-09	Chital	40	HC	43.5	12.1±1.7	2.5±0.67	25.8	23.0±5.0	31.7	12.2	42.3
Dry 08-09	Sambar	32	HC	29.8	1.8±0.17	2.6±0.65	25.2	4.6±1.2	27.2	2.7	7.9
Wet 08-09	Sambar	19	HH	22.4	2.1±0.25	2.3±0.77	32.4	4.7±1.6	35	2.4	9.5
Dry 08-09	Gaur	31	HC	35.8	3.5±0.87	2.0±0.64	30.9	7.4±2.9	39.0	3.4	15.0
Wet 08-09	Gaur	28	HH	40.2	5.5±1.5	2.0±0.75	39.8	11.0±4.4	39.5	5.0	23.1
Dry 08-09	Wild pig*	5	HC	33.9	0.38±0.60	0.38±0.21	56.5	0.96±0.59	61.0	0.29	3.1
Wet 08-09	Wild pig*	5	HC	43.5	1.8±0.37	0.60±0.26	43.3	1.9±0.87	46.2	0.7	4.6
Dry 08-09	Common langur	71	HH	29.3	3.5±0.31	5.8±1.0	17.9	20.0±4.1	20.5	13.1	29.5
Wet 08-09	Common langur	86	HC	22.9	5.4±0.33	9.9±1.8	21.3	59.0±11.8	20.1	40.0	87.0

ESW – Estimated Strip Width, GS – Group Size, SE – Standard Error, Dg – Group density/km^2, D – Individual density/km^2, %CV – Percentage of Co-efficient Variation, * - Pooled species (Chital) ESW used, HC- Halfnormal Cosine, HH – Halfnormal Hermite.

Table 2. Year wise and overall density estimate of major prey species in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Years	Species	Number of Observation	Model	ESW	GS±SE	D g ±SE	%CV	D±SE	%CV	Confidence Interval	
										Lower	Upper
2008	Chital	47	HC	35.7	9.0±1.4	4.0±1.1	28.6	28.0±9.0	33	14.4	52.9
2009	Chital	36	HC	29.9	9.4±1.5	2.9±0.83	28.4	19.0±6.1	32	9.9	35.7
CD 2008-2009	Chital	83	HC	28.9	9.2±0.99	3.8±0.94	24.2	25.4±6.7	26.7	14.9	43.0
2008	Sambar	17	HC	26.4	2.0±0.30	1.9±0.61	31.5	4.0±1.3	34.6	2.0	7.9
2009	Sambar	34	UC	25.3	1.8±0.16	3.2±0.73	23.1	5.9±1.4	24.6	3.6	9.8
CD 2008-2009	Sambar	51	HP	27.3	1.9±0.42	2.5±0.55	22.0	4.8±1.1	23.3	3.0	7.7
2008	Gaur	26	UC	37.1	6.0±1.6	2.1±0.55	26.1	12.8±4.8	38.0	6.1	26.7
2009	Gaur	33	HH	40.0	3.3±0.44	2.0±0.44	30.5	7.0±2.5	38.3	3.1	14.0
CD 2008-2009	Gaur	59	HC	38.3	4.5±0.85	2.0±0.41	19.7	9.4±2.5	27.4	5.4	15.9
2008	Wild pig*	4	HC	35.7	2.0±0.57	0.37±0.29	78.4	0.71±0.59	83.5	0.2	3.2
2009	Wild pig	6	HC-B	16.4	2.2±0.52	0.74±0.41	56.5	1.3±0.80	60.2	0.4	4.3
CD 2008-2009	Wild pig	10	HC-B	8.0	2.1±0.34	0.74±0.45	61.2	1.3±0.87	67	0.3	4.7
2008	Common langur	87	HH	25.1	4.7±0.34	10.5±1.3	13.6	49.7±7.7	15.5	36.5	67.7
2009	Common langur	70	HH	28.6	4.3±0.33	5.9±0.91	15.3	25.6±4.6	18.1	18.0	37
CD 2008-2009	Common langur	157	HH	27.8	4.5±0.24	7.6±0.88	11.5	35.0±4.4	12.7	27.0	45.0

ESW – Estimated Strip Width, GS – Group Size, SE – Standard Error, SE – Standard Error, Dg – Group density/km^2, D –Individual density/km^2, %CV – Percentage of Co-efficient Variation, * - Pooled species (Chital) ESW used, HC – Halfnormal Cosine, HC-B – Halfnormal Binomial, UC – Uniform Cosine, HP - Halfnormal Polynomial, HH – Halfnormal Hermite, CD – Combined data.

Table 3. Season wise density estimate of minor prey species in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 09).

Seasons /Years	Species	Number of Observation	Model	ESW	GS±SE	D g ±SE	%CV	D±SE	%CV	Confidence Interval	
										Lower	Upper
Dry 08 -09	Elephant	35	HC	60.3	3.8±0.54	1.2±0.25	20	4.9±1.2	25	3	8.0
Wet 08-09	Elephant	32	HC	59.5	3.7±0.45	1.5±0.31	20.4	5.1±1.3	25.8	3.1	8.5
Dry 08 -09	Barking deer*	2	HC	33.9	-	0.15±0.10	69.3	0.15±0.10	69.3	0.1	0.56
Wet 08-09	Barking deer*	5	HC	43.5	1.8±0.20	0.60±0.40	66	1.3±0.93	68.6	0.37	4.8
Dry 08 -09	Mouse deer*	1	HC	33.9	-	0.76±0.75	98.5	0.76±0.75	98.5	0.13	0.43
Wet 08-09	Mouse deer*	2	HC	43.5	-	0.24±0.17	70.6	0.24±0.17	70.6	0.2	1.0
Dry 08 -09	Giant squirrel	28	HC	17.3	1.3±0.86	3.9±1.17	29.8	4.7±1.4	30	2.5	8.6
Wet 08-09	Giant squirrel	37	HC	25.9	1.4±0.10	3.8±1.1	29.2	5.8±1.7	30	3.2	10.6
Dry 08 -09	Bonnet macaque#	4	HC	29.3	9.3±2.9	0.32±0.18	56	2.2±1.7	78	0.32	14.9
Wet 08-09	Bonnet macaque#	2	HC	22.4	8.0±5.0	0.22±0.15	69.1	1.7±1.6	93.2	0.21	14.1
Dry 08 -09	Grey jungle fowl	10	HC	18.4	1.3±0.15	1.3±0.64	48.9	1.8±0.93	50.4	0.7	4.8
Wet 08-09	Grey jungle fowl	8	HC	11.2	1.6±0.26	2.2±1.1	50.2	2.7±1.4	53.1	0.97	7.4
Dry 08 -09	Peafowl^	2	HC	18.4	-	0.26±0.19	75.2	0.26±0.19	75.2	0.26	1.0
Wet 08-09	Peafowl^	2	HC	11.2	-	0.56±0.42	75.2	1.1±0.84	75.2	0.28	4.4
Dry 08 -09	Red spur fowl^	1	HC	18.4	-	0.26±0.26	100	0.26±0.26	100	0.26	1.5
Wet 08-09	Red spur fowl^	2	HC	11.2	-	0.56±0.56	100	1.1±1.1	100	1.0	6.6
Dry 08 -09	Black-naped hare^	1	HC	18.4	-	0.13±0.13	100	0.13±0.13	100	0.13	0.22

ESW - Estimated Strip Width, GS – Group Size, SE – Standard Error, SE – Standard Error, Dg – Group density/km^2, D – Individualdensity/km^2, %CV – Percentage of Co-efficient Variation, * - Pooled species (Chital) ESW used, # - Pooled species (Langur) ESW used, ^- Pooled species (Grey jungle fowl) ESW used, a - No sighting, HC – Halfnormal Cosine, - - not derived.

Table 4. Year wise and overall density estimate of minor prey species in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 09).

Years/ Seasons	Species	Number of Observation	Model	ESW	GS±SE	D g ±SE	%CV	D±SE	%CV	Confidence Interval	
										Lower	Upper
2008	Elephant	35	UC	60.3	3.6±0.36	1.8±0.38	21.6	5.8±1.4	25.0	3.5	6.6
2009	Elephant	32	HC	59.2	3.8±0.63	1.3±0.27	20.7	5.0±1.4	27.4	2.6	8.5
Combined	Elephant	67	UC	60.8	3.7±0.35	1.4±0.22	17.9	5.5±0.99	17.9	3.2	8.4
2008	Barking deer*	1	HC	35.7	-	0.89±0.89	100	0.89±0.89	100	0.15	0.8
2009	Barking deer	6	HC-B	7.0	1.7±0.21	1.0±0.90	82.6	1.8±1.5	85.0	0.31	10.6
Combined	Barking deer	7	HC-B	10.1	1.5±0.20	0.80±0.53	67.1	1.2±0.82	68.8	0.33	4.3
2009	Mouse deer*	3	HC	28.9	-	0.27±0.15	54.7	0.27±0.15	54.7	0.94	0.8
Combined	Mouse deer*	3	HC	28.9	-	0.15±0.08	54.5	0.15±0.08	54.5	0.14	0.8
2008	Giant squirrel	25	UC	7.6	1.3±0.13	7.1±2.1	30.4	9.0±3.3	33.1	5.1	19.2
2009	Giant squirrel	40	HH	28.6	1.4±0.78	3.6±1.0	30	4.73±1.4	30.7	2.5	8.6
Combined	Giant squirrel	65	HH	27.9	1.3±0.71	3.6±0.86	24	4.9±1.2	24.5	2.9	8.0
2008	Bonnet macaque#	4	HH	25.1	8.5±2.9	0.48±0.28	58.6	2.6±1.9	72.1	0.63	10.5
2009	Bonnet macaque#	1	HH	28.6	-	0.85±0.85	100	0.85±0.85	100	0.14	4.8
Combined	Bonnet macaque#	5	HH	27.8	8.8±2.2	0.48±0.25	51.8	1.9±1.1	60	0.62	6.2

Contd…..

Years/ Seasons	Species	Number of Observation	Model	ESW	GS±SE	D g ±SE	%CV	D±SE	%CV	Confidence Interval	
										Lower	Upper
2008	Grey jungle fowl	5	HC	13.2	1.5±0.34	1.3±0.88	64	2.0±0.81	67.9	0.58	7.3
2009	Grey jungle fowl	12	HC-B	7.5	1.4±0.14	3.5±1.59	44.8	5.1±2.3	46.0	2.1	12.7
Combined	Grey jungle fowl	17	HC	8.3	1.4±0.15	2.8±1.2	41.8	3.5±1.5	43.0	1.5	8.1
2008	Peafowl^	1	HC	13.2	-	0.23±0.23	100	0.46±0.49	100	0.46	0.74
2009	Peafowl^	3	HC	7.5	1.3±0.33	0.97±0.57	58.6	1.2±0.82	63.0	0.38	4.3
Combined	Peafowl^	4	HC	8.3	1.5±0.28	0.70±0.34	48.5	1.0±0.54	52.0	0.38	2.9
2008	Red spur fowl^	1	HC	13.2	-	0.23±0.23	100	0.46±0.46	101	0.83	2.7
2009	Red spur fowl^	2	HC	7.5	-	0.64±0.66	101	1.2±1.3	101	0.23	7.5
Combined	Red spur fowl^	3	HC	8.3	-	0.52±0.39	74.3	1.05±0.78	74.0	0.26	4.2
2009	Black- naped-hare^	1	HC	7.5	-	0.32±0.32	100	0.32±0.32	100	0.32	1.8
Combined	Black- naped-hare ^	1	HC	8.3	-	0.17±0.17	101	0.17±0.17	101	0.3	1.0

ESW – Estimated Strip Width, GS – Group Size, SE – Standard Error, Dg – Group density/km^2, D – Individualdensity/km^2, %CV – Percentage of Co-efficient Variation, ^- Pooled species (Grey jungle fowl) ESW used, HC – Halfnormal Cosine, HC-B - Halfnormal Cosine – Binomial, UC – Uniform Cosine, - - not derived.

3.4.2. Group size and composition of prey species

3.4.2.1. Major prey species

3.4.2.1.1. Chital

Formation of large chital groups (> 35 individuals) occurred throughout the year. The seasonal group size varied from 1 to 131 individuals with a mean group size (± SE) was observed to be 13.1 ± 0.5 and overall mean crowding 33.3 (Combined data, n = 13366 individuals) (Table 5.). Fourty percentage individuals was observed under group size of <5 for the overall season. During seasonal analysis, the mean group size varied from 9.3 ± 0.8SE in the second dry season to 16.5 ± 1.0SE in the second wet season. Chital new-born fawns were seen throughout the year with a fawning period from March to April in 2008 and March to May in 2009. The average male:female:fawn ratio in chital was 61.1:100: 14.8 (combined data, n = 13366). Average male and female ratio did not vary considerably between seasons. Average fawn ratio in the first dry season varied from the first year wet season while the second year fawn ratio did not vary much between seasons (Table 6). The average chital sub-adult, male and female was half the percentage to adult male and female population (Table 7.).

3.4.2.1.2. Sambar

In Mudumalai, seasonal group size of sambar varied from 1 to 45 individuals with a mean (±SE) group size of 3.6 ± 0.3SE and overall mean crowding was 11.0 (Combined data, n = 1341) (Table 8.). More than 75 percent of sambar groups were observed with the group size ranging from 1 to 5 individuals. The largest aggregation of 36 to 45 individuals was observed in swampy grasslands during the months of July in the wet season for both the years. During the seasonal analysis, mean group size varied from 4.1 ± 0.9SE in the first year dry season to 3.7 ± 0.8SE in the first year wet season while the mean group size in the second year dry season varied from 2.7 ± 0.3SE to 4.2 ± 0.5SE in the wet season. On several occasions (n = 14) > 15 individuals were seen between April to October around swampy grasslands. Sambar new-born fawns were seen throughout the year with a peak fawning period (> 25%) from April to July in the first year and May to August in the second year. Fawning ratio did not vary between seasons in the first year but the fawn ratio varied drastically between seasons in the second year. The average male: female: fawn ratio in sambar was 43.9:100:18.8 (n = 1341) (Table. 9.). Males were sighted more often in the dry season. Average male ratio did not show much variation between seasons in the first year while male ratio varied between seasons in the second year. Sambar sub-adult males were 70% to adult male population while female sub-adult was 26% to female adult population (Table 10).

3.4.2.1.3. Gaur

Group size of gaur ranged from 1 to 42 individuals among seasons over a period of two years with an average mean group size of 7.5 ± 0.4SE and overall mean crowding was 17.5 (Combined data, n = 2944) (Table 11.). There was no major difference observed in the mean group size between seasons except for second year dry season. More than 70% of gaur groups were observed between the group size ranging from 1-10 individuals. The average male: female: fawn ratio in gaur was 42.1: 100: 25.8 (n = 2944) (Table 12.). The average age composition of gaur is as follows: female 59.6% (Adult – 39.5%, sub-adult – 10.8% and yearling – 9.3%), male 25.1% (Adult – 15.2 %, sub-adult – 6.1% and yearling – 3.8%) and calves 15.4% (small – 4.8%, medium 4.1% and large 6.5%) (Table 13.).

3.4.2.1.4. Wild pig

Largest group of wild pig comprising 29 individuals was observed in the first year wet season. The overall mean group size of wild pig was observed to be 3.3 ± 0.4 and overall mean crowding was 9.2. The average mean group size varied among seasons from 1.9 to 5.4 (Table 14.). More than 70% of wild pig group comprised of 1 to 5 individuals. Wild pigs showed peak seasonality in littering from June to August and no piglets were recorded in the dry seasons in both the years. The overall male: female: piglet ratio was 60.4: 100: 113.6 (n = 381 individuals) (Table 15.). The piglet ratio exceeded female ratio in the first year wet season (Table 16).

3.4.2.1.5. Common Langur

As common langur sex could not be classified with certainty, only group size classification was carried out. The overall mean group size was 5.3 ± 0.1 and mean crowding 7.8 (n = 3583 individuals) (Table 17). The mean group size of common langur was much similar between the seasons for both years. More than 89% of the group size had < 10 individuals.

3.4.2.2. Minor prey species

3.4.2.2.1. Barking deer

Solitary individuals of barking deer (>80%) were sighted mainly in the wet season and their average mean group size was 2.1±0.08 and overall mean crowding was 1.4 (n = 70 individuals) (Table 18.). Moreover barking deer are not group living species (Barrette 2004) hence their mean group size did not vary between seasons. The estimated male: female: fawn ratio was 50.8: 100: 14.8 for all the seasons (Table 19.). Fawn ratio was found to be higher in the first year dry season but in the second year, fawns were not sighted in the wet season. In the second year there was an increase followed by a sudden drop in the male ratio between dry and wet seasons as compared to the first year. The age structure of barking deer is given in table 20.

3.4.2.2.2. Elephant

A maximum of 21 elephant individuals were recorded in the first year dry season and 22 in the second year wet season. Mean group size ranged from 3.8 to 5.3 and did not vary considerably during the study period with an exception of a slight variation in the first year. This variation was seen because more than 80 percent of the group size ranged from 1 to 5 individuals. The overall mean group size seemed to be 4.6 ± 0.2 and overall mean crowding was 6.8 (n = 1710 individuals) (Table 21.). Elephant calves were seen throughout the year but the calf ratio was more in the first year dry season than in the wet season and during the second year calve ratio drastically declined in the dry season. The overall male: female: calf ratio was 17.7: 100: 18.4 (n = 1710 individuals) (Table 22). The average age structure of elephant is as follows: female 74.3% (Adult – 51.2%, sub-adult – 9.6% and juvenile – 13.5%), male, 13% (Adult – 5.4 %, sub-adult – 4.4% and juvenile – 3.2%) and calves 13.5% (Table 23.).

Table 5. Season and year wise grouping pattern of chital in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Season	NG	NA	Si	Lgo	Mc	Mdgs	Mgs	SE	Group Size in %							
									1 - 5	6 - 10	11- 15	16-20	21-25	26 - 30	31-35	>35
Dry - 2008	102	1165	5	67	23.7	7.5	11.4	1.2	33.8	23.4	14.1	6.0	9.2	5.9	2.6	5.0
Wet - 2008	362	4330	34	98	30.5	7.0	12.0	1.5	48.1	19.1	12.4	6.7	5.3	4.6	0.0	3.9
CD - 2008	464	5495	39	98	29.0	7.0	11.8	0.7	43.4	20.5	12.9	6.5	6.6	5.0	0.9	4.2
Dry - 2009	183	1710	18	70	21.6	9.3	9.3	0.8	52.0	23.1	7.7	5.6	2.1	4.2	1.6	3.6
Wet - 2009	373	6161	21	131	40.3	9.0	16.5	1.0	34.1	21.3	11.6	6.4	6.1	4.8	2.4	13.3
CD - 2009	556	7871	39	131	36.2	8.0	14.1	0.7	40.1	21.9	10.3	6.1	4.8	4.6	2.2	10.1
CD - 08 - 09	1020	1366	78	131	33.3	7.0	13.1	0.5	41.7	21.2	11.6	6.3	5.7	4.8	1.5	7.1

Si – Solitary individuals, Lgo – Largest group observed, SE – Standard Error, Mgs – Mean group size, NG –No. of groups, NA – No. of animals, Mc – Mean crowding, Mdgs – Median group size, CD – Combined data.

Table 6. Season and year wise sex ratio and female: fawn ratio of chital in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 09).

Seasons/Years	Male	Female	Fawn	Total number of individuals classified
Dry - 2008	74.4	100	22.1	1165
Wet - 2008	68.1	100	11.7	4330
Combined data - 2008	69.3	100	13.7	5495
Dry - 2009	61.5	100	17.7	1710
Wet - 2009	54.2	100	15.0	6161
Combined data - 2009	55.7	100	15.6	7871
Combined data - 2008 - 2009	61.1	100	14.8	13366

Table 7. Season and year wise age structure of chital in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/ Years	Adult Male		Sub Adult Male		Adult Female		Sub Adult Female		Fawn		TNC
	No.	%	No.	%	No.	%	No.	%	No.	%	
Dry - 2008	321	27.6	120	10.3	444	38.1	149	12.8	131	11.2	1165
Wet - 2008	1179	27.2	461	10.6	1713	39.6	696	16.1	281	6.5	4330
CD - 2008	1500	27.3	581	10.6	2157	39.3	845	15.4	412	7.5	5495
Dry - 2009	436	25.5	151	8.8	627	36.7	327	19.9	169	9.9	1710
Wet - 2009	1272	20.6	701	11.4	2252	36.6	1390	22.6	635	8.9	6161
CD - 2009	1708	21.7	852	10.8	2879	36.6	1717	21.8	715	9.1	7871
CD - 08 - 09	3208	24.0	1433	10.7	5036	37.7	2562	19.2	1127	8.4	13366

CD – Combined data, TNC - Total number of individuals classified

Table 8. Season and year wise grouping pattern of sambar in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/years	NG	NA	Si	LG	Mc	Mdgs	Mgs	SE	1-5	6-10	11-15	>16
Dry - 2008	32	133	13	27	10.9	2.0	4.1	0.9	81.3	6.3	9.4	3.1
Wet - 2008	86	316	26	45	11.7	2.0	3.7	0.8	88.4	4.7	4.2	2.3
CD - 2008	118	449	39	45	11.4	2.0	3.8	0.5	86.4	5.1	5.9	2.5
Dry - 2009	136	365	55	13	7.8	2.0	2.7	0.3	91.2	6.6	1.5	0.7
Wet - 2009	123	527	42	36	12.7	2.0	4.2	0.5	78.0	13.0	4.9	4.1
CD - 2009	259	892	97	36	10.9	2.0	3.4	0.3	84.9	9.7	3.1	2.3
CD - 08 - 09	377	1341	136	45	11.0	2.0	3.6	0.3	85.4	8.2	4.2	2.4

Si – Solitary individuals, Lg – Largest group observed, SE – Standard Error, Mgs – Mean group size, CD – Combined data, NG –No. of groups, NA – No. of animals, Mc – Mean crowding, Mdgs – Median group size.

Table 9. Season and year wise sex ratio and female: fawn ratio of sambar in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons	Male	Female	Fawn	Total number of individuals classified
Dry - 2008	40.7	100	24.7	133
Wet - 2008	42.3	100	24.9	316
Combined data - 2008	41.9	100	24.8	449
Dry - 2009	55.5	100	10.5	365
Wet - 2009	38.0	100	19.5	527
Combined data - 2009	44.9	100	15.9	892
Combined data- 2008 - 2009	43.9	100	18.8	1341

Table 10. Season and year wise age structure of sambar in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons	Adult Male		Sub Adult Male		Adult Female		Sub adult Female		Fawn		TNC
	No.	%	No.	%	No.	%	No.	%	No.	%	
Dry - 2008	16	12.0	17	12.7	69	51.8	12	9.0	20	14.2	133
Wet - 2008	41	13.0	39	12.3	154	48.7	35	11.1	47	14.9	316
CD - 2008	57	12.7	56	12.5	223	49.7	47	10.5	67	14.7	449
Dry - 2009	65	17.8	57	15.6	184	50.4	36	9.9	23	6.3	365
Wet - 2009	91	17.3	36	6.8	248	47.1	86	16.3	65	12.5	527
CD - 2009	156	17.5	93	10.4	432	48.5	122	13.7	88	9.9	892
CD - 08 - 09	213	15.9	149	11.1	655	48.8	169	12.6	155	11.6	1341

CD – Combined data, TNC – Total number of individuals classified

Table 11. Season and year wise group size of gaur in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Season/year	No. of groups	No. of animals	Si	Lgo	Mc	Mdgs	Mgs	SE	Group Size in %					
									1-5	5-10	11-15	16-20	21-25	>26
Dry - 2008	65	515	24	41	19.1	3.0	7.9	1.1	71.9	7.8	6.3	3.1	4.7	6.3
Wet - 2008	119	940	25	42	16.1	4.0	8.0	0.7	50.8	25.4	9.0	6.6	4.1	4.1
CD - 2008	184	1455	49	42	17.1	2.0	7.9	0.6	58.1	19.4	8.1	5.4	4.3	4.8
Dry - 2009	73	442	32	32	15.5	2.0	6.0	0.9	68.9	9.5	6.8	9.5	1.4	4.1
Wet - 2009	133	1047	49	41	17.5	4.2	8.0	0.7	53.5	16.9	12.7	5.6	6.3	4.9
CD - 2009	206	1489	81	41	16.9	3.0	7.2	0.6	58.8	14.4	10.6	6.9	4.6	4.6
CD -2008 -2009	390	2944	127	42	17.5	4.0	7.5	0.4	57.4	17.1	9.7	6.4	4.6	4.8

Si – Solitary individuals, Lgo – Largest group observed, SE – Standard Error, Mgs – Mean group size, CD – Combined data, Mc – Mean crowding, Mdgs – Median group size.

Table 12. Season and year wise sex ratio and female: calf ratio of gaur in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/years	Male	Female	Calves	Total number of individuals classified
Dry - 2008	42.3	100	22.8	515
Wet - 2008	38.8	100	28.5	940
Combined data - 2008	40.0	100	26.4	1455
Dry - 2009	54.6	100	31.1	442
Wet - 2009	40.2	100	23.1	1047
Combined data - 2009	44.1	100	25.3	1489
Combined data - 2008 - 2009	42.1	100	25.8	2944

Table 13. Season and year wise age structure of gaur in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/years	Males						Females						Calves						TNC
	Adult		Sub Adult		Yearlings		Adult		Sub Adult		Yearlings		Small		Medium		Large		
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	
Dry - 2008	86	16.7	30	5.8	16	3.1	216	41.9	62	12.0	34	6.6	24	4.7	22	4.3	25	4.9	515
Wet - 2008	134	14.3	51	5.4	33	3.5	380	40.4	92	9.8	90	9.6	64	6.8	45	4.8	51	5.4	940
CD- 2008	220	15.1	81	5.6	49	3.4	596	41.0	154	10.6	124	8.5	88	6.0	67	4.6	76	5.2	1455
Dry - 2009	85	19.2	30	6.8	15	3.4	155	35.1	43	9.7	40	9.0	18	4.1	21	4.8	35	7.9	442
Wet - 2009	142	13.6	69	6.6	47	4.5	411	39.3	120	11.5	110	10.5	35	3.3	33	3.2	80	7.6	1047
CD - 2009	227	15.2	99	6.6	62	4.2	566	38.0	163	10.9	150	10.1	53	3.6	54	3.6	115	7.7	1489
CD- 2008 - 2009	447	15.2	180	6.1	111	3.8	1162	39.5	317	10.8	274	9.3	141	4.8	121	4.1	191	6.5	2944

TNC – Total number of individuals classified, CD – Combined data

Table 14. Season and year wise group size of wild pig in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/Years	No. of Groups	No. of animals	Si	Lgo	Mc	Mdgs	Mgs	SE	Group size in %			
									1 - 5	6 -10	11 - 15	>16
Dry - 2008	13	25	9	10	4.8	1.0	1.9	0.7	82.4	17.6	0.0	0.0
Wet - 2008	33	178	17	29	14.9	1.0	5.4	1.3	69.7	6.1	12.1	12.1
CD- 2008	46	203	30	29	13.7	1.0	4.4	0.9	74.0	10.0	8.0	8.0
Dry - 2009	25	54	10	6	2.9	2.0	2.2	0.3	96.0	4.0	0.0	0.0
Wet - 2009	45	124	22	9	5.0	2.0	2.7	0.3	84.8	15.2	0.0	0.0
CD - 2009	70	178	32	9	4.2	2.0	2.5	0.2	88.73	11.27	0.0	0.0
CD - 2008 - 09	116	381	62	29	9.2	2.0	3.3	0.4	82.6	10.7	3.3	3.3

Si – Solitary individuals, Lgo – Largest group observed, SE – Standard Error, Mgs – Mean group size,
Mc – Mean crowding, Mdgs – Median group size.

Table 15. Season and year wise sex ratio and female: piglet ratio of wild pig in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/years	Male	Female	Piglet	Total number of individuals classified
Dry - 2008	66.6	100	0.0	25.0
Wet - 2008	45.5	100	259.1	178
Combined data - 2008	50.8	100	193.2	203
Dry - 2009	86.2	100	0.0	54
Wet - 2009	56.9	100	86.3	124
Combined data - 2009	67.5	100	55.0	178
Combined data - 2008- 2009	60.4	100	113.6	381

Table 16. Season and year wise age structure of wild pig in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/years	Male						Female						Piglet				TNC
	Adult		Sub Adult		Yearlings		Adult		Sub Adult		Yearlings		Small		Large		
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	
Dry - 2008	6	24.0	2	8.0	2	8.0	10	40.0	5	16.0	1	4.0	a	a	a	a	25
Wet - 2008	17	9.6	1	0.6	2	1.1	32	18.0	11	6.2	1	0.6	52	29.2	62	34.8	178
Combined data - 2008	23	11.3	3	1.5	4	2.0	42	20.7	16	7.4	2	1.0	52	25.6	62	30.5	203
Dry - 2009	21	38.9	1	1.9	3	5.6	17	31.5	10	18.5	2	3.7	a	a	a	a	54
Wet - 2009	26	21.0	1	0.8	2	1.6	30	24.2	16	12.9	5	4.0	25	20.2	19	15.3	124
Combined data- 2008 -2009	47	26.4	2	1.1	5	2.8	47	26.4	26	14.6	7	3.9	25	14.0	19	10.7	178
Combined data- 2008- 2009	70	18.4	5	1.3	9	2.4	89	23.4	41	10.6	9	2.4	77	20.2	81	21.3	381

a – No sighting, TNC – Total number of individuals classified

Table 17. Season and year wise group size of common langur in Mudumalai Tiger Reserve, (January 2008 – December 2009).

Seasons/ Years	NG	NA	Si	Lgo	Mc	Mdgs	Mgs	SE	1 - 5	6 -10	>11
Dry - 2008	67	346	6	16	7.7	4.0	5.1	0.4	62.9	28.6	8.6
Wet - 2008	258	1297	34	20	7.4	4.0	5.0	0.2	62.8	29.9	7.3
CD - 2008	325	1643	40	20	7.5	4.0	5.0	0.2	63.0	29.7	7.3
Dry - 2009	164	991	19	20	8.5	5.0	6.0	0.3	54.3	34.8	11.0
Wet - 2009	183	949	24	20	7.6	5.0	5.1	0.3	64.0	30.6	5.4
CD - 2009	347	1940	43	20	8.1	5.0	5.6	0.2	60.0	32.5	7.5
CD - 08 - 09	672	3583	84	20	7.8	5.0	5.3	0.1	61.3	30.8	7.9

Si – Solitary individuals, Lgo – Largest group observed, SE – Standard Error, Mgs – Mean group size, CD – Combined data, Mc – Mean crowding, Mdgs – Median group size.

Table 18. Season and year wise group size of barking deer in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Season/Years	NG	NA	Si	Lgo	Mc	Mdgs	Mgs	SE	Group size in %		
									1-3	01	2-3
Dry - 2008	12	16	8	2	1.5	1.0	1.1	0.1	100	66.7	33.3
Wet - 2008	13	15	11	2	1.2	1.0	1.1	0.1	100	84.6	15.4
CD - 2008	25	31	19	2	1.4	1.0	1.2	0.08	100	76.0	24.0
Dry - 2009	12	16	9	3	1.6	1.0	1.3	0.8	100	75.0	25.0
Wet - 2009	19	23	16	2	1.3	1.0	1.2	0.09	100	84.2	22.6
CD - 2009	31	39	25	3	1.5	1.0	1.2	0.09	100	76.8	23.2
CD - 08 - 09	56	70	44	3	1.4	1.0	1.2	0.06	100	78.6	21.4

Si – Solitary individuals, Lgo – Largest group observed, SE – Standard Error, Mgs – Mean group size, CD – Combined data , NG –No. of groups, NA – No. of animals, Mc – Mean crowding, Mdgs – Median group size.

Table 19. Season and year wise sex ratio and female: fawn ratio of barking deer in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/years	Male	Female	Fawn	Total number of individuals classified
Dry - 2008	55.6	100	22.2	16
Wet - 2008	55.6	100	11.1	15
Combined data - 2008	55.6	100	16.7	31
Dry - 2009	62.5	100	37.5	16
Wet - 2009	35.3	100	0.0	23
Combined data - 2009	44.0	100	12.0	39
Combined data - 2008 - 09	50.8	100	14.8	70

Table 20. Season and year wise age structure of barking deer in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons /years	Adult male		Sub Adult male		Adult female		Sub Adult female		Fawn		TNC
	No.	%	No.	%	No.	%	No.	%	No.	%	
Dry - 2008	2	12.5	3	18.8	7	43.8	2	12.5	2	12.5	16
Wet - 2008	3	20.0	2	13.3	7	46.7	2	13.3	1	6.7	15
CD - 2008	5	16.1	5	16.1	14	45.2	4	12.9	3	9.7	31
Dry - 2009	4	25.0	1	6.3	6	37.5	2	12.5	3	18.8	16
Wet - 2009	4	17.4	2	8.7	12	52.2	5	21.7	0	0.0	23
CD - 2009	8	20.5	3	7.7	18	46.2	7	17.9	3	7.7	39
CD -08 -09	13	18.6	8	11.4	32	45.7	11	15.7	6	8.6	70

CD – Combined data, TNC - Total number of individuals classified

Table 21. Season and year wise group size of elephant in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons /Years	NG	NA	Si	Lg	Mc	Mdgs	Mgs	SE	Group size in %		
									1-5	6-10	>10
Dry - 2008	46	173	7	10	5.0	3.0	3.8	0.3	80.4	19.6	0.0
Wet - 2008	123	602	13	21	7.0	4.0	5.0	0.3	62.6	31.3	6.1
CD - 2008	169	775	20	21	6.6	4.0	4.6	0.2	67.7	28.0	4.3
Dry - 2009	72	379	9	22	8.4	4.0	5.3	0.5	69.4	18.1	12.5
Wet - 2009	129	556	14	13	6.2	4.0	4.3	0.3	64.8	29.5	5.7
CD - 2009	201	935	23	22	7.1	4.0	4.7	0.2	66.5	25.3	8.2
CD -08- 09	370	1710	43	22	6.8	4.0	4.6	0.2	67.0	26.5	6.5

Si – Solitary individuals, Lgo – Largest group observed, SE – Standard Error, Mgs – Mean group size, CD – Combined data, NG –No. of groups, NA – No. of animals, Mc – Mean crowding, Mdgs – Median group size.

Table 22. Season and year wise sex ratio and female: calf ratio of elephant in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons/years	Male	Female	Calves	Total number of individuals classified
Dry - 2008	17.1	100	30.8	173
Wet - 2008	16.8	100	21.9	602
Combined data - 2008	16.9	100	23.8	775
Dry - 2009	19.0	100	9.5	379
Wet - 2009	17.8	100	17.5	556
Combined data - 2009	18.3	100	14.2	935
Combined data- 2008- 2009	17.7	100	18.4	1710

Table 23. Season and year wise age structure of elephant in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons /years	Male						Female						Calves		Total number of individuals classified
	Adult		Sub Adult		Juvenile		Adult		Sub Adult		Juvenile				
	NO	%	NO	%	NO	%	NO	%	NO	%	NO	%	NO	%	
Dry – 2008	9	5.2	8	4.6	3	1.7	91	52.6	8	4.6	18	10.4	36	20.8	173
Wet – 2008	24	4.0	29	4.8	20	3.3	303	50.3	58	9.6	73	12.1	95	15.8	602
Combined data – 2008	33	4.3	37	4.8	23	3.0	394	50.8	66	8.5	91	11.7	131	16.9	775
Dry – 2009	27	7.1	14	3.7	15	4.0	193	50.9	45	11.9	57	15.0	28	7.4	379
Wet – 2009	32	5.8	24	4.3	17	3.1	288	51.8	54	9.7	69	12.4	72	12.9	556
Combined data – 2009	59	6.3	38	4.1	32	3.4	481	51.4	99	10.6	126	13.5	100	10.7	935
Combined data – 2008 - 2009	92	5.4	75	4.4	55	3.2	875	51.2	165	9.6	217	12.7	231	13.5	1710

3.5. Discussion

3.5.1. Prey availability

The line transect technique proved to be an effective and reliable method in estimating density of ungulates and other mammalian species in the study area. The high variances associated with the density estimates were likely to be an outcome of the relatively low sample sizes. Though the estimates of density are accompanied by high coefficient of variance, it is important to note that the estimates of coefficient of variation obtained by pooling the variance across transects has a better representation of spatial and temporal variation in the distribution of prey species. Common langur was the most abundant prey species in the study area. This high density may be attributed to the canopy continuity of the forest and availability of food plants throughout the year in the study area (Ramesh et al., 2009). Langur was the most affected prey species in the dry season followed by gaur and chital because of increased forest fire. Chital was found to be the second most abundant prey species and the reason for the same may be attributed to the availability of open habitat with edible short grasses. Chital density was low during the second year due to increased forest fire in 2009 dry season. After the end of the forest fire, with the onset of wet season gave rise to fresh young grass sprout caused sudden increase in the chital group size and chital density in the study area. It was reported that fire plays a major role in maintaining habitat productivity for ungulates in savanna woodlands (Rodgers 1977). The estimated sambar density was high during 2009 since the understory vegetation got burnt due to forest fire thereby increasing the visibility and frequented sambar's visitation towards burnt vegetation and ashes in the dry season. Abundance and distribution of sambar in the study area was influenced by dense cover, water and swampy vayals. The high density gaur was influenced by availability of grass shoots of *Themeda* sp. and clearings in the moist zones of the forests. Sometimes gaur were seen feeding on young *Lantana camara* as observed earlier by Karanth and Sunquist (1992) in Nagarhole. Wild pig occured in low density throughout the study area and and the reason for the same is not known. Since mouse deer is largely nocturnal in habits, only a few sightings of this species on line transects were obtained in the morning hours. They were often sighted along the stream under bamboo clumps or bushes during the dry season. The low density of barking deer in Mudumalai may be attributed to the solitary nature and territorial spacing mechanisms between them (Karanth and Sunquist 1992). The estimated elephant density was high in the study area. Elephants were largely sighted in habitats having tall *Themeda* sp. and *Apluda mutica* species in deciduous forests. Sivaganesan and Johnsingh (1995) found that *Themeda* grasses and *Apluda mutica* species often frequented in the diet of elephants in deciduous forests. Bonnet macaques were seen close to human habituation and a few places inside the park. Their density was low in deciduous forest. The high abundance of Indian giant squirrel may be attributed to the availability of thick canopy and nesting or roosting trees. This species is a generalist w.r.t habitat and food which is also found in deciduous and riparian forests, consuming a wide variety of plant parts, including seeds, leaves, flowers and bark (Borges 1992, Sushma and Singh 2006 and Sridhar et al., 2008). The observed black-naped hare densities are low in the study area and the reason for the same may be attributed to nocturnal habitas of this species. Densities of all three fowls were found to be low. All ungulate species showed considerable variation in their spatial abundance within the study area due to variation in cover, habitat structure, and food availability. Forest fire increased the forage availability in burnt areas in the following winter. Forest fire may also stimulate primary productivity in subsequent years, resulting in improved forage quantity, quality and palatability. The density of ungulates in the present study is much similar to the earlier study in Mudumalai (Varman and Sukumar 1995). Though the output of the earlier study is similar to the present study, their density value may not be representative of the deciduous forest since their data was collected from deciduous and dry thorn forests.

To compare the density of different ungulate species in different areas, it is important to note that the methodology for estimating population density in those areas should be similar. Different methods can yield different results even in the same study site (Karanth and Sunquist 1992). Still, for many protected areas in the Indian sub-continent the status of prey is unknown from distance sampling methods. Density estimates of prey species in the study area was compared with other available tropical areas (Table 24). As many studies used different body weight of single prey species for biomass calculation, biomass of ungulates and arboreal mammals was calculated for all the sites using a single standard body weight taken from Schaller (1967), Karanth and Sunquist (1992) and Prater (2005). In comparison of overall ungulate density and biomass to other study sites, it is clear that the biomass of ungulates in Mudumalai was the highest after Nagarahole, Ranthambhore and Chilla even though the estimated ungulates density was 42.2 individuals /km^2. This high biomass of ungulates in our study area is attributed to the presence of high density of megaherbivore, gaur, while it is found in low density and not present in most of the sites. Rinderpest disease heavily suppressed the population of gaur in Bandipur and Mudumalai in 1968 and Peryiar in 1974-75 (Ranjitsinh 1997). In Western Ghats Wynaad – Nagarhole – Mudumalai – Bandipur complex has the most extensive existing stronghold of gaur in good numbers (Ranjitsinh 1997, Sankar et al., 2001). In terms of arboreal prey biomass, Mudumalai is one of the highest after Pench because of the canopy continuity of the forest and availability of food plants throughout the year in the study area (Ramesh et al., 2009).

Table 24. Comparison of prey densities (individuals/km^2) and ungulate biomass from protected areas in India subcontinent.

Species/biomass	PS	MTR	NGH	BDP	BTR	PNCH	KNH	WPT	BRD	RNP	GIR	STR	CNP	KZP	CHL
Common langur	35.4	-	23.8	7.5	22.6	77.16	-	2.8	2.3	21.75	-	14.13	3.6	-	-
Chital	25.4	25.03	50.6	40	4.5	80.75	49.7	5.8	77.7	31	57.3	27.62	61.8	NP	56.21
Gaur	9.4	14.38	9.6	0.5	1.48	0.34	0.7	-	NP	-	NP	NP	-	-	NP
Elephant	5.5	4.41	3.3	5	-	NP	NP	0.1	-	NP	NP	NP	-	-	-
Sambar	4.8	6.61	5.5	7	0.89	6.09	1.5	1.2	-	17.15	3.5	8.44	20	-	24.25
Wild pig	1.3	-	4.2	2.5	-	2.6	2.5	0.3	8.8	9.77	-	1.64	3.6	2.6	6.06
Nilgai	NP	NP	NP	NP	NP	0.43	NP	NP	1.9	11.3	0.58	5.19	NP	NP	4.28
Chowsingha	-	-	-	-	-	0.29	-	NP	-	-	0.42	-	NP	-	NP
Muntjac	1.2	-	4.2	1	3.64	-	0.6	0.4	1.7	-	-	NP	-	-	-
Bonnete macaque	1.9	-	5.5	-	-	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
Barasingha	NP	NP	NP	NP	NP	NP	3	NP	1.4	NP	NP	NP	NP	14.2	NP
Wild buffalo	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	2.7	NP
Hog deer	NP	NP	NP	NP	NP	NP	NP	NP	7.7	NP	NP	NP	NP	38.6	NP
Chinkara	NP	NP	NP	NP	NP	NP	NP	NP	NP	5.6	-	-	NP	NP	NP
Total Ungulates	42.25	46.02	74.1	56	10.51	87.56	58	7.8	99.2	74.82	61.8	42.89	32.7	58.1	90.8
Ungulate Biomass	6145.9	8539.8	7684.3	3165	1070.4	4952.4	3350.4	454	4852.3	6244.7	3278.4	3434.1	5741.7	4703.8	6916.3
Arboreal Biomass	295.5	-	226.1	60	180.8	617.3	-	22.4	18.4	174	-	113.04	28.8	-	-

PS - present study; NP – Not present; - information unavailable; - - Not available, MTR (Mudumalai) – Varman and Sukumar 1995; NGH (Nagarhole) - Karanth and Sunquist 1992; BDP (Bandipur) - Johnsingh 1983; BTR (Bhadra) - (Jathanna et al., 2003); PNCH (Pench) - Biswas and Sankar 2002; KNH (Kanha) – Karanth and Nichols (1998); WPT (Wilpattu) – Eisenberg and Lockhart (1972); BRD (Barida) - Stoen and Wegge (1996); RNP (Ranthambore) – Bagchi et al., 2003; GIR – Khan et al., 1996; STR (Sariska) - Avinandan (2003); CHL (Chilla) – Harihar 2005; CNP (Chitwan) - Sunquist (1981), KZP(Kaziranga) - (Karanth and Nichols, 1998).

3.5.2. Group size and composition

Living as a part of a group can increase foraging ability. Schaller (1967) and Eisenberg and Lockhart (1972) reported that chital and sambar do not remain in permanent social groups. Group composition of chital was observed to change frequently during feeding periods (Dinerstein1980). In Mudumalai, average mean group size of chital differed marginally between seasons in first year due to availability of food throughout the year. Moreover in the second year there was a sudden drop in the mean group size in the dry season compared to wet season due to widespread forest fire. Smaller group sizes in forest habitats are presumably a consequence of food being more dispersed and scattered throughout the habitat (Jarman 1974, Mishra 1982, Johnsingh 1983, Karanth and Sunquist 1992). Even though chital densities increased substantially in the forest during the dry season, large aggregations of chital were noticed to form and feed on locally abundant food sources such as fallen fruits and leaves, often in communal association with bonnet macaques and langur. The mean group size is a more sensitive measure of changes in group size due to the individuals remaining solitary or joining groups (Barrette 1991, Sankar and Acharya 2004). Widespread forest fire and roadside clearings created open areas which resulted in increase group size increase in chital because of emerging young sprouting grasses. Chital mean group size in the second year dry season varied from the wet season due to the increased forest fire that leaded to more grouping of chital in the second wet season after monsoon. Ramesh et al., (2009) observed that roads and fire lines created a mosaic of openings is an optimal habitat for chital. The observed mean group size of chital in Mudumalai was lower than Pench (Acharya 2007) and higher than Wilpattu, Sariska and Chitawan (Mishra 1982, Sankar 1994). In Sariska the absence of open grassy patches might have prevented formation of larger groups in chital (Sankar and Acharya 2004). Sartaj et al., (2010) reported that chital group size was more in open areas. Chital group size may vary from 1 to 150 individuals or more depending upon circumstances (De and Spillit 1966, Schaller 1967, Eisenberg and Lockhart 1972, Krishnan 1972, Fuchs 1977, Balasubramaniam et al., 1980). Mishra (1982) reported a higher percentage of chital group size between 5 to 10 individuals with a mean group size of 7.5 in Royal Chitawan National Park. Acharya (2007) reported a mean group size of 22.6 ± 2.2 in Pench Tiger Reserve. Chital group size in Karnali - Bardia (Dinerstein 1980) varied from 1 to 91 individuals with a mean group size of 10.7, while in Sariska, chital group size varied from 1 to 88 individuals with mean group size 7.8 ± 8.3 (Sankar 1994). Barrette (1991) reported that chital group size varied from 2 to 125 individuals in Wilpattu with a mean group size of 6. Group size in chital in Mudumalai decreased during peak rainfall as most of the individuals took shelter from heavy rains under dense vegetation cover especially thick *Lantana camara* bushes that might have resulted in their low sightings along vehicle transects.

Chital male: female sex ratio was 0.77: 1 in Hawaii (Graf and Nichols 1966); 0.69: 1 in Corbett and 0.70: 1 in Kanha (Schaller 1967), 0.72: 1.0 in Nagarahole (Karanth and Sunquist 1992) and 1: 0.2 in Gir (Khan et al., 1996). The average male: female: fawn ratio was 0.57: 1: 0.53 in Royal-Karnali Bardia (Dinerstein 1980), 0.66: 1: 0.49 in Bandipur (Johnsingh 1983), 0.47: 1: 0.22 in Sariska (Sankar 1994) and 0.50: 1: 0.27 in Pench (Acharya 2007). The observed average male: female: fawn ratio in chital was 0.61: 1: 0.15 in Mudumalai. The average fawn ratio was lower in Mudumalai than other areas such as Royal-Karnali Barida, Bandipur, Sariska and Pench (Dinerstein 1980, Johnsingh 1983, Sankar 1994, Acharya 2007) This is may be due to low visibility because of dense *Lantana camara* cover in the study area or chital fawns were more prone to predation by dhole as reported by Johnsingh (1983), Karanth and Sunquist (1995), Venkatraman et al., (1995) and Sankar and Acharya (2004). Chital fawning was >25% in April 2008 but got extended till May in 2009 due to delay in onset of monsoon and forest fire. The fawning ratio in chital was low in second dry season as compared to first dry season due to increased forest fire. In Sariska, Sankar (1994) observed that drought affected the reproduction rate of chital in summer which resulted low fawning ratio. Chital sex ratio (male:female) in Mudumalai was skewed towards females and similar findings were reported by other studies (Graf and Nichols 1966, Schaller 1967, Dinerstein 1980, Johnsingh 1983, Karanth and Sunquist 1992, Khan et al. 1995, Acharya and Sankar 2004).The proportion of chital adult male and adult female and sub adult male did not show major changes between seasons.

In sambar, group size was small, numbering fewer than 6 individuals (Jerdon 1874, Schaller 1967). The characteristic social unit is one hind and one fawn or one hind, one yearling and one fawn (Schaller 1967, Kelton 1981, Downes 1983). Family groups usually travel in a single file led by the adult female (Kelton 1981). On a few occasions two hard antlered individuals together with hinds were seen during the rutting season in Mudumalai. Lewis et al., (1990) recorded that during the rut, dominant stags were frequently seen with hinds and occasionally with other stags who may challenge the dominant stag for breeding rights. This smaller group size of 1-5 individuals was recorded >70 percent throughout the year in Mudumalai. Eisenberg and Lockhart (1972) commented that water holes are places where sambar populations come together in late evenings to form temporary aggregations before dispersing for food. In Mudumalai large aggregations were seen near water holes, swampy grasslands, salt licks and burnt areas. Johnsingh (1983) also recorded large association of sambar near water holes and feeding sites in Bandipur. Sambar mean group size in 2009 dry season was lower than the wet season reason and this may be due to forest fire. During the present study, the mean group size of 3.6 ± 0.3 was recorded for sambar which was much similar to 4.0 ± 2.3 in Sariska (Sankar 1994), 3.7 in Ranthambore (Bagchi et al., 2003) and higher than 3.1 in Mudumalai (Varman and Sukumar 1993), 3.1 ± 0.2 in Pench (Acharya 2007) and 1.7 in Nagarahole (Karanth and Sunquist 1992). This may be attributed to large aggregation of sambar in and around swampy grasslands that provide feeding and wallowing grounds throughout the year.

In Mudumalai, the observed sambar male: female ratio was 0.44: 1 and female: fawn ratio was 1: 0.19. The observed sambar low male ratio might be due to selective predation by tiger on male sambars as reported in other studies (Johnsingh 1983, Schaller 1967, Karanth and Sunquist 1992). In south Asian ungulates, solitary habits, proneness to injuries from intra-specific aggression, lack of antlers during rut, and dispersal behaviour have been considered as some of the factors which make males more vulnerable to selective predation (Johnsingh 1983, Schaller 1967, Karanth and Sunquist 1992). Sambar male: female sex ratio was higher in Mudumalai than 0.29: 1 in Kanha, 0.27: 1 in Mudumalai, 0.11: 1in Sariska, 0.22: 1 in Pench (Schaller 1967, Varman and Sukumar 1993, Sankar 1994, Acharya 2007), similar to 0.5: 1 in Gir (Khan et al., 1996) and lower than 1.2: 1 in Wilpattu (Eisenberg and Lockhart, 1972), 102: 1 in Texas (Richardson 1972), 0.73: 1 in Flordia (Flynn et al., 1990) and 83: 1 in Ranthambore (Bagchi et al., 2008). In Kanha, sambar fawns were seen from April to December and the peak fawning period was observed in May and June (Schaller 1967). The female: fawn ratio in sambar was 1: 0.27 in Texas (Richardson 1972), 1:

0.41 in Bandipur (Johnsingh 1983), 1: 0.22 in Flordia (Flynn et al., 1990), 1: 0.12 in Mudumalai (Varman and Sukumar 1993), 1: 0.27 in Sariska (Sankar 1994), 1: 0.1 in Gir, (Khan et al., 1996) and 1: 0.30 in Pench (Acharya 2007). The observed sambar fawn ratio in Mudumalai was lower than Bandipur, Sariska, Pench and Texas (Jonsingh 1983, Karanth and Sunquist 1992, Acharya 2007, Richardson 1972) and the reason for the same could be as earlier stated for chital. Fawning season in sambar in the study area got delayed for a month in the second year as compared to the first year from the usual fawning season due to delay in onset of monsoon. More number of fawns were seen in Mudumalai during the rainfall as compared to chital due its adaptability to environmental conditions and delayed rutting season. Observed fawn ratio was very low in 2009 dry season compared to 2008 dry season and this may be due to increased forest fire. In Sariska, drought affected the reproductive rate of sambar in summer and resulted low fawn ratio (Sankar 1994).

A typical group in gaur consists of cows and few calves, one to two adult bulls and sub adults (Sankar et al., 2001). The group size ranged from 1 to 43 in Mudumalai, 2 to 19 in Pench (Sankar et al., 2001), 2 to 40 in Kanha (Schaller 1967) and 1 to 70 in Jaldapara (Bhattacharyya et al., 1997). The estimated mean group size of gaur in Mudumalai was 7.5 ± 0.4 which is similar to Kanha (8.8 ± 0.74) (Schaller 1967), Mudumalai (6.8 ± 1.47) (Varman and Sukumar 1993), Nagarahole (3.9 to 7.47) (Karanth 1992), Palamau (5 to 7) (Sahai 1977), Parambikulam (6.0) (Vairavel 1998), Pench (4.62 ± 0.29) (Sankar et al., 2001), Bhadra (2.31) (Jathanna et al., 2003) and Burma (10 to 20) (Peacock 1933). The largest group of gaur comprising 42 individuals was recorded in Mudumalai. More than 50 gaur individulas were observed in Bandipur (Johnsingh 1983) and Jaldapara (Bhattacharyya et al., 1997). The largest group of gaur (n = >15) mostly frequented grassland areas dominated by *Themeda* species close to water sources in the morning and evening and near teak plantations where they fed mainly on fallen leaves. Calving season in gaur indicated that there was no distinct seasonality but a peak observed in the first year in July, October and November and for the second year in March, April and December. In Jaldapara WLS, young calves were observed with the herd mostly during November and December (Bhattacharyya et al., 1997) and in Kanha calving period was recorded from early Sepember to mid March with a peak in December and January and sometime in April, May, June and July (Schaller 1967). In Pench, calving season was observed throughout the year with peak between March and May (Sankar et al., 2001). Twice, a cow with two calves was seen separately from the herd and once, two calves were seen suckling milk from a single cow in a herd in Mudumalai. The overall gaur male: female ratio was 0.42: 1 in Mudumalai which is similar as reported from Kanha (0.38: 1) (Schaller 1967), Parambikulam (0.45: 1) (Vairavel 1998) and Tadoba (0.47: 1) (Dubey 1999) but lower than as reported from Pench (0.6: 1) (Sankar et. al. 2001). The female: calf ratio was 1:0.26 in Mudumalai which is comparable to Pench (1:24) (Sankar et al., 2001), lower than Kanha (1:0.46) (Schaller 1967) and higher than Parambikulam (1: 0.16) (Vairavel 1998). Morris (1937) recorded the rutting period of gaur in southern India from November to March. During the present study on several occasions two or more bulls were seen with a herd size of > 20 individuals. Krishnan (1972) has never seen two or more mature bulls in a gaur herd in south India. Calf ratio in gaur did not vary much in the population for both seasons in Mudumalai.

A maximum of 29 wild pig individuals were observed in a group in Mudumalai during wet season and this is lesser as reported in Bandipur (32 individuals) (Johnsingh 1983) and other areas (Prater 2005, Sankar 1994). The mean group size of wild pig (3.3 ± 0.4) in Mudumalai was lower than Pench (4.23) (Biswas and Sankar 2002), Ranthambhore (7.22 ± 0.87) (Bagchi et al., 2003) and higher than Nagarhole (2.23) (Karanth and Sunquist 1992), and Mediterranean forest, Rome (1.9±0.7) (Focardi et al., 2002). Increased group size in wild pig was recorded only in the wet season and this may be attributed to food availability and peak littering period. The basic social group in wild pigs includes one or more females and their last litters (Chauhan 2004). The male: female ratio of wild pig (0.64: 1) in Mudumalai was higher than Nagarahole i.e. 0.53: 1 (Karanth and Sunquist 1992). In Mudumalai, the piglets were seen only from June to August for the both years indicating their peak seasonality. Johnsingh (1983) also made similar observation in Bandipur. Wild pig peak oestrous activity has been recorded during the wetter months i.e. November and December in Sri Lanka (Santiapillai and Chambers 1980). The reproductive activity in pigs tends to be seasonal and positively correlated with the relative availability of food or climatic factors (Chauhan 2004). On one occasion a mother was seen with 10 piglets. The observed piglet ratio was higher than adult male female ratio in Mudumalai. This shows that they are prolific breeders. Though the piglet ratio was higher than female, their yearling and sub-adult ratio were lower than adult.

The abundance of food resources played a major role in grouping of the folivore langur. Predation risk tends to increase the size of primate groups, so they benefit from increased vigilance (Van Schaik and Horstermann 1994). Population of common langur are also subjected to extreme seasonality, with great fluctuations in climate and vegetation between arid and rainy seasons (Newton 1987). The observed mean group size in common langur in Mudumalai (5.3 ± 0.1) is comparable with Nagarahole (5.73) (Karanth and Sunquist 1992), lower than Kanha (14) (Newton 1987), Ranthambhore (9.18 ± 0.63) (Bagchi et al., 2003), Pench (6.12) (Biswas and Sankar 2002) and higher than Bhadra (4.04) (Jathanna et al., 2003). The mean group size of common langur increased in the wet season when plenty of young sprouting foliage on trees was available. More than 80% of the group size was seen between 1 to 10 individuals with more number of solitary individuals seen in the dry season. This may be due to scattered food availability or less young leaves availability in the study area.

The muntjac or barking deer is a solitary, forest living species (Barrette 2004). In Mudumalai, it was mostly observed solitary. The estimated mean group size of barking deer was 1.2 ± 0.06 in Mudumalai was lower than other areas such as Bandipur (2.24 ± 0.21) (Johnsingh 1983) and similar to Nagarhole (1.17) (Karanth and Sunquist 1992) and Bhadra (1.04) (Jathanna et al., 2003). More than 75 percent of barking deer were sighted solitarily. It was reported that over 65% animals are solitary in Wilpattu (Eisenberg and Lockhart 1972) and Chitwan (Seidensticker 1976). A maximum of upto three individuals were seen together on a single occasion but upto four individuals were seen in four different occasions by Johnsingh (1983) in Bandipur. Barrette (1977a) recorded the largest group of four and these groups are temporary. Two fawns with a mother was sighted once in Mudumalai. Muntjacs breed and give birth throughout the year (Barrette 1977b, Chapman et al., 1997). Fawns were seen both in the dry and wet season in the first year but only in wet season for the second year. Barette (2004) stated that adult females were least solitary and are usually accompanied by one fawn. Only two studies reported male and female ratios in muntjac; 0.64: 1 in Bandipur (Johnsingh 1983), and 0.76: 1 in Nagarhole (Karanth and Sunquist 1992), which are high as compared to the present study (0.51: 1). The female: fawn ratio of munjtac (1: 0.15) in Mudumalai is lower than as reported in Bandipur (1: 0.41) (Johnsingh 1983).

The basic unit of elephant is the family consisting of an adult cow and her immature offsprings (Sukumar 2006). The mega herbivore elephant lives in matriarchal groups of five to 20 individulas that interact with other family units in the area (Sukumar 2006). Group size of elephant ranged from 1 to 22 individuals with mean group size of 4.6 ± 0.2 in Mudumalai. Majority of group size (>60%) was recorded between 1 and 5 category. The elephant group size typically ranged from five to 20 animals and may vary with season (Sukumar 2006). In other studies, the mean group size recorded was 6 to 12.5 in Bandipur (Johnsingh 1983), 3.59 in Nagarahole (Karanth and Sunquist 1992) which is comparable to 4.6 ± 0.2 in Mudumalai. In the second year, the elephant calves ratio in Mudumalai (1:0.095) drastically declined in the dry season due to increased forest fire. The overall female: calve ratio for elephant in Mudumalai was 1: 0.18 which is similar to 1: 0.19 in Rajaji (Williams 2004) and higher than earlier studies in Mudumalai (1:0.11) (Arivazhagan 2005), Nagarahole (1:0.11) (Arivazhagan 2005) and Periyar (1:0.09) (Arivazhagan 2005). The mean male: female ratio for elephant in Mudumalai (0.25: 1) was much similar to earlier study in Mudumalai (0.18:1) (Arivazhagan 2005), BR hills (0.20:1) (Sukumar 1985) and lower than Uttar Pradesh (0.58: 1 – 0.78: 1) (Singh 1993), Gaioya (0.40: 1) (Mckay 1973), Lahugala (0.42: 1) (Mckay 1973), Yala (0.31: 1) (Kurt 1974). During the present study 14 Makhnas were sighted. The reported male: female ratio was very low in Mudumalai as compared to other study sites. The major reason for this could be increased vulnerability of male to poaching for ivory. Between 2007 and 2009 four adult male tuskers were killed by poachers in and around Mudumalai. Male elephant in southern India is severely affected by ivory poaching (Sukumar 1989, Arivazhagan 2005).

CHAPTER 4

PREY SELECTION AND FOOD HABITS OF LARGE CARNIVORES

4.1. Introduction

A predator's choice of prey serves as a primary link connecting the dynamics of species on different levels in the ecosystem. The predator's prey choice or selections depend on different prey size, habitat, activity pattern and differential use of space. The mean of "selection" cover either preference greater than expected under random utilization of prey species or avoidance less than expected usage of particular types of prey (Alldrege and Ratti 1986). When ecologically similar species evolve as sympatric, competition theory predicts that there should be a shift in the morphological characters that relate proximately to the way in which they compete (Dayan 1992). Competitive interactions among species operating within predator guilds may generate selective pressures which are causally related to differences in body size, dentition, shape and other traits (Dayan & Simberloff 1994, Van Valkenburg & Robert 1994). The competition led predators to evolve different strategies in selection of diverse sized prey at different times of the day or in different habitats and fit them in the varied ecological condition. Predatory strategies are shaped and refined by natural selection to maximize nutrient intake within the bound of a wide range of ecological constraints (e.g. prey density, habitat) that may differ dramatically for the same species at the extremes of its geographical distribution (Sunquist and Sunquist 1989). Such differences in activities separate niches, reduce competition, and presumably allow the coexistence of sympatric living species. An efficient predator will accept all potential prey encountered when food is scarce or unpredictable and depict greater selectivity when food is common and adequate (Sunquist and Sunquist 1989). Sympatric large carnivores share similar prey in most of the forested habitats of Indian subcontinent. Large carnivores can recover from substantial losses as long as the habitat and prey populations remain intact. Most of the felids are nocturnal, hunting under the cover of darkness while diurnal canids hunt in open places. They share prey species ranging from small to large body-sized animals. Interaction among large carnivores influences prey choice. Among predators, two basic types of encounter strategies commonly used are ambush (sit-and-wait) and coursing tactics (move to locate prey). Felids generally stalk prey and rely more upon cover to remain concealed prior to a chase; the absence of a prolonged pursuit in felids should favour random choice of individuals from a prey population (Rosenzweig 1966). Canids are coursing predators, and thus typically exhibit prolonged pursuit of prey through relatively open terrain (Schaller 1972). These patterns imply that when canids and felids are sympatric, they rely upon the same prey base. Both predators should select prey having different demographic or physical attributes (Husseman et al., 2003). Tiger and leopard almost invariably kill their prey before consuming it, for instance by biting the victim on the neck and severing the spinal cord and strangulation through a throat bite or suffocation by biting across the mouth (Schaller 1967). Leopards drag kills upon trees only in areas where other competitive scavengers are there. But dholes do not kill their prey before feeding whereas they bite the victim’s body randomly anywhere. Tiger and leopard are solitary hunters unlike dholes that live and hunt in packs. Behavioral factors likely to contribute to the coexistence of tiger, leopard and dhole were investigated in tropical forests of Nagarahole, Southern India (Karanth 1993, Karanth, and Sunquist 1995, 2000) which showed that three predators selectively killed different prey types in terms of species, size and age-sex classes and to some extent temporal separation in their activity facilitating their coexistence through ecological separation. Leopard is an opportunist i.e attempt to kill any prey they encounter. The prey range utilized by leopard varies from large ungulates, small carnivores, and rodents to arthropods such as crickets and scorpions (Bailey 1993).

Large carnivores play a relatively major role in shaping prey communities in the stable environments of tropical forests (Karanth and Sunquist 1995). Studies on their prey selection have been scarce in these habitats (Schaller 1967, Johnsingh 1983, Rabinowitz and Nottingham 1986, Emmons 1987, Rabinowitz 1989, Griffiths 1975). There has been relatively only one long-term study particularly on prey selection and food habits of sympatric large carnivores in a tropical forest (Karanth and Sunquist 1995) while other studies collected information out of their single species focus, either on dhole (Johnsingh 1983) or leopard (Edaongar 2008) and a short-term study on these three species (Andheria et al., 2008). Another study gives information on prey selection and food habits of sympatric large carnivores by studying their ecological interaction (Wang 2008). These predators selectively killed different prey types in terms of species, size and age-sex class, facilitating their coexistence through ecological separation (Johnsingh 1992, Karanth, and Sunquist 2000). In tropical forest habitats of southern Asia, tiger, leopard and dhole form a predator assemblage over a large area (Karanth and Sunquist 2000). All three species are morphologically specialized for killing prey larger than themselves; and in most places their prey base consists of cervids, bovids, suids and primates thereby enabling them to coexist sympatrically in most of their range. Tigers and leopards exploit this common suite of prey species as solitary, stalk-ambush hunters, whereas dholes are coursing pack hunters (Schaller 1967, Seidensticker 1976, Sunquist 1981, Johnsingh 1983, Karanth 1993). Large carnivore prey selection pattern in tropical forests are poorly understood (Karanth and Sunquist 1995). Past studies pertained to ecology of carnivores based on direct observations of incidence of hunting and baiting experiments (Schaller 1967). Study of mammalian carnivore diet is difficult if the species is solitary and elusive because of difficulties in elusive predator’s hunting and feeding. Since elusive species are secretive and not easily seen, direct observation of prey capture is rarely possible. Owing to that researchers resort to collection of data from scats and kill sites (Johnsingh 1983, Karanth and Sunquist 1995).

4.2. Methods

Prey selection and large carnivore food habits were evaluated from January 2008 to December 2009. Feeding ecology of carnivores are usually studied using different methods such as field observation, stomach content analysis, identifying kills and scat analysis. Of these methods, scat analysis is considered the most suitable method since it is non-invasive, cost and time effective (Schaller 1967, Kruuk 1972, Sunquist 1981, Johnsingh 1983, 1992, Karanth and Sunquist 1995). Though kills are supposed to be one of the best estimates of carnivore diet if field conditions are quite favorable, it was not possible to obtain effective number of kills to estimate prey selection by tiger, leopard and dhole in my study. However the diet of large carnivores was estimated using two methods i.e by evaluation of kills and analysing scats.

4.2.1. Scat

Scat collection and laboratory analysis

Scats were collected whenever encountered in the study area and associated signs (scrapes, tracks, rake, scent, etc.) were recorded along pre-determined roads and trails in the deciduous forest from January 2008 to December 2009. More than a month old predator scats were not collected. Date, location, scat condition (fresh or old), associated predator signs and substrate type were also recorded. These large predators are known to move mostly along forest roads and trails where scats are usually deposited (Johnsingh 1983). Thus the presence of good network of forest roads in the study area facilitated collection of representative predator scats. Tiger and leopard scats were distinguished from one another by size and diameter of scats and presence of ancillary signs like pugmarks (Johnsingh 1983, Karanth and Sunquist 1995 and Biswas and Sankar 2002), with other supplementary evidences such as scrapes and rake marks. Tiger scrape marks were much deeper and broader than those of the leopard. Both species scrape marks were found usually along with scats deposited on grassy strips along either side of the road or trail and in the middle of motorable road. Tiger scats were found to be less coiled and having larger distance between two successive constrictions within a single piece of a scat, when compared to the leopard which was mostly coiled having similar distance between constrictions (Johnsingh 1983). Dhole scats are much smaller than tiger and leopard scats, which were often, found in clusters with a characteristic odour deposited at the intersection of trails or roads and wheel tracks on bare or exposed soil (Johnsingh 1983, Karanth and Sunquist 1995, Acharya 2007). Only a single dhole scat was collected from a group of scats to avoid over representation of the kill. If the scat appeared to have different prey species composition, then more number of scats were taken to ensure smaller prey like hare, rodent and bird represented in the scats. Scats that were not identifiable in the field with certainty were discarded. Scats were broken and washed over a sieve of mesh size <1 mm in running water and after sun-drying, stored in paper bags, individually labelled with date, GPS location and species for further analysis.

Hair of the prey is relatively undamaged in carnivore scat that can be used to identify prey species eaten (Ramakrishnan et al., 1999). At least, 20 hairs were picked up randomly from each scat for preparation of slides. A combination of hair characteristics like hair width, medullary and cuticular structure of hair (Mukherjee et al., 1994) of the prey from each scat collected was observed microscopically and compared with reference slides made by me using hair samples collected from kills of large carnivores and reference samples available in the research laboratory of Wildlife institute of India, Dehra Dun.

4.2.2. Kill

Dietary study using scats is an unbiased method for prey species consumed by carnivore. Hence, it does not provide information on physical condition, sex-age class and body size of the killed prey animal. Large carnivores kill study is useful to document age and sex classes of prey that is killed (Johnsingh 1983, 1992, Karanth and Sunquist 1995). Kills of carnivores are crucial for understanding predation ecology of large carnivores (Schaller 1967, Sunquist 1981, Johnsingh 1992, Acharya 2007). Because of dense *Lantana camara* cover and tall grasses found in the study area, the carcasses of prey killed were difficult to locate. Kills of large carnivores were located during the study period by the presence of vultures, crows, alarm calls of prey and odour of decomposing carcass. On locating kills, detailed information of prey age (based on antler height (cervids), sex, approximate weight, percentage of meat eaten and physical health condition of prey (bone marrow state i.e solid, semi – solid, liquid) were recorded. Tiger kill was differentiated from leopard and dhole kills, by the deep canine and long claw marks on the prey's body with the rump portion eaten, dragging impressions on the soil of large body sized prey to a long distance and other associated evidences. Leopard kill were differentiated by narrow claw marks, on the body, parts of the body eaten randomly and kills dragged up the tree. Felids (tiger and leopard) usually bite the throat region of medium to smaller sized prey unlike canids (dholes). Dhole kills were identified based on the typical evidences of excessive blood spilled around the carcass, eye portion eaten and many lethal bites all over the body. When the carcass of prey species was not identified with certainty, it was not recorded.

4.3. Analysis

4.3.1. Scat

Scat samples collected were analysed separately season wise (dry and wet season), year wise and overall for both the years using respective densities of available prey during the same period. Sample adequacy analysis was carried out to ensure sufficiency of collected scat samples for each season following the standardized protocol by Mukherjee at al., (1994). Minimum sample adequacy of scats to study food habits of predators for each season was calculated by selecting random sets of five scats each until all scats within a season were analysed. This was plotted cumulatively to reach an asymptote which was considered sufficient to quantify the diet of predator.

Percentage occurrence of different prey species in large carnivore scats was calculated by enumerating the number of scats with remains of a particular species out of the total number of scats with prey remains, depicted in the form of a percentage figure (Reynolds and Aebischer 1991). The frequency of occurrence of a prey species was calculated as the number of occurrence of that prey species divided by the total number of scats analysed (Ackerman et al., 1984) and expressed in percentage. While frequency of occurrence indicates how often a prey species occurs in carnivore diet, percentage occurrence provides an idea of prey intake. According to Ackerman et al., (1984), the relative frequency occurrence provides a better index of prey consumed because it accounts for scats containing remains of more than one species. However, they also point out that if more than one prey species regularly occurs in scats, relative number and biomass of different prey species must be estimated in the predator's diet (Ackerman et al., 1984, Putman 1984).

When prey species of different body sizes are consumed, frequency of occurrence does not adequately represent the proportion of different prey species. As a result, smaller prey species with more hair per unit body weight, produce more scats per unit prey weight, and consumption may be overestimated in carnivore diets (Floyd, et al., 1978; Ackerman, et al., 1984). As digestive system and degree of utilization of a prey animal by tiger and leopard are comparable to that of the cougar (*Felis concolor*) and dhole would be similar to those for the wolf (*Canis lupus*). To correct this bias, biomass and relative number of prey consumed was calculated in terms of relative numbers of prey species using regression equations Yi = 1.98 + 0.035 X(i) (Ackerman et al., 1984) for tigers, leopards and Yi = 0.035 + 0.020 X(i) (Floyd et al., 1978) for dholes and this was further successfully used in other studies (Karanth and Sunquist, 1995, Biswas and Sankar, 2002, Bacghi, et al., 2003, Andheria, et al., 2007) where Xi represents the live weight of the prey species i and Yi is the weight of prey i in one collectable scat Y. The average number of collectable scats (λi) produced per prey species i is given as λi = XiYi and the relative biomass and number of each prey killed were computed. The expected proportion of scat availability (fi) was calculated using the formula fi = [λi * di] Σ [λi * di] where di is density of prey species. The relative proportion of biomass consumed (D = [A x Yi] Σ [A x Yi]) was computed using the relative frequency of occurrence (A) of a species and correction factor (Yi) and depicted into percentage value. The relative proportion of number of prey individuals consumed (E = [DXi] Σ [DXi]) was calculated using average unit weight of each prey species (Xi) and the relative proportion of biomass consumed (D). The unit body weight of prey species was taken from available studies (Schaller 1967, Karanth and Sunquist 1995). To depict prey selection of large carnivores, the Ivlev's Index (PI) (Ivlev 1961) was used:

$$PI = \frac{(U - A)}{(U + A)}$$

Where U = utilized scat proportion of predators.

A = expected scat proportion in the environment of predator.

The utilized scat proportion (U) was obtained from relative frequency occurrence of prey remains in predator scats and the expected scat proportion (U) from fi. The positive or negative value would indicate preference or avoidance of that prey type utilized by predators.

Link and Karanth (1994) cautioned that variability in density estimates for each prey species and the number of scats produced from a particular kill of any prey species may increase the chance of type I error. To alleviate this problem, I used 1000 bootstrap iterations in SCATMAN (Hines 2002). Prey selectivity was then assessed by a multinomial likelihood ratio test (Link and Karnath, 1994, Biswas and Sankar, 2002, Bagchi, et al., 2003) between the observed (raw frequency of occurrence in the scat) and expected (individual prey species density with standard error derived from line transect) contribution by each prey species at $\alpha = 0.05$ and using a correction factor. Since the exact variability of prey items in scats was not known, in order to account for this, sensitivity analysis was done by changing coefficient of variance from 10% to 40% (Link and Karanth, 1994). Program SCATMAN (Hines 2002) was used for this analysis and sensitivity analysis was done by 1000 bootstraps. Chi-square values or probability value at 95% confidence interval in the output indicates that observed frequencies whether significantly different from expected or not and the presence of selectivity of prey.

To assess similarity of food composition between tiger, leopard and dhole, the Pianka's niche overlap index was used (Pianka, 1973). The index distributes between 0 and 1, the similarity is higher as the index is close to 1.

$$\text{Pianka index} = \frac{\Sigma pij * pik}{\sqrt{(\Sigma_i (pij)^2 * \Sigma_i (pik)^2)}}$$

Pij = percentage of prey items i of predator j.

Pik = percentage of prey items i of predator k.

4.3.2. Kills

The total prey species killed by tiger, leopard and dhole were 41, 20 and 35 respectively. Since the kill data collected during the present study is comparatively low, the age-sex class of each major prey species from kill data could not be compared to the corresponding population of age-sex distribution observed from vehicle transects to make statistical inference of predator's selection for a particular age-sex class of each prey. Instead, percent availability of each prey species killed by predators was compared with percent occurrence of each prey species found in predator scats. Importantly, kills on smaller prey might have been underestimated w.r.t number of successful hunts because large carnivores are known to consume the entire small bodied prey. Physical condition of prey species killed was categorized as solid (good), semi-solid (moderate) and liquid (bad).

4.4. Results

4.4.1. Prey composition of predator diets

In total 875 tiger scats, 413 leopard scats and 1070 dhole scats were collected during the study period. Scat analysis revealed the presence of 19 prey species in tiger scats, 20 prey species in leopard scats and 13 prey species in dhole scats with a high predominance of medium to large sized ungulates in tiger, leopard, and dhole diet. Tiger scats contained 97.4% single prey species, 2.5% two prey species and 0.1% three prey species. Leopard scats contained 96.2% single prey species, 3.6% two prey species and 0.2% three prey species, while dhole scats contained 98% single prey species and 2% two prey species. Of the prey species identified from tiger scats, relative frequency occurrence of ungulates constituted 96.9%, followed by primates (2.3%), cattle (0.9%), buffalo (0.3%) and others (2.3%). Leopard scats constituted 84.1% ungulates, 12.8% primates, 1.9% cattle, 0.2% buffalo and 4.8% others. Dhole scats contained, 94.4% ungulates, followed by primates (1.6%), cattle (0.3%) and others (5.6%). The percent biomass of prey species consumption and number of prey species found in the scats of tiger, leopard and dhole are given in Tables 25 to 31. The overall biomass composition of large sized prey (>50 kg) in tiger, leopard and dhole scats was found to be 70% , 36.2% and 19.3% respectively, medium sized prey (20 to 50 kg) was 28.2%, 54.4% and 72.4% respectively while small sized prey (<20 kg) was 1.8%, 19.4% and 8.3% respectively. In terms of individual prey species consumption, tiger and dhole largely fed on chital and sambar, whereas leopard fed on chital and common langur. There was a wide variation in the frequency occurrence, biomass and relative number of individuals consumed by three predators between seasons. Chital and sambar together contributed to the bulk of the diet (> 77%) in all the three predators. In addition to this, gaur and wild pig were the important prey for tiger in term of frequency occurrence while common langur for leopard and black naped hare and mouse deer for dhole.

Table 25. Prey species utilization by tiger as shown by scat data season wise in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Prey species	Prey remains		% Frequency occurrence		% Occurrence		% Biomass consumed		% Individuals consumed	
	I (N = 384)	II (N = 491)	I	II	I	II	I	II	I	II
Sambar	191	192	49.7	39.1	48.2	38.2	54.5	46.7	30.9	22.4
Chital	138	229	35.9	46.6	34.8	45.5	21.3	30.1	34.6	41.5
Gaur	23	27	6.0	5.5	5.8	5.4	17.4	17.4	2.9	2.5
Wild pig	11	21	2.9	4.3	2.8	4.2	1.6	2.5	3.1	4.3
Common langur	12	8	3.1	1.6	3.0	1.6	1.2	0.7	11.0	5.3
Cow	6	2	1.6	0.4	1.5	0.4	2.1	0.6	0.9	0.2
Buffalo	2	1	0.5	0.2	0.5	0.2	1.0	0.4	0.3	0.1
Mouse deer	4	11	1.0	2.2	1.0	2.2	0.4	0.9	5.6	11.1
Barking deer	0	1	0.0	0.2	0.0	0.2	0.0	0.1	0.0	0.3
Black – naped hare	3	5	0.8	1.0	0.8	1.0	0.3	0.4	9.5	11.5
Sloth bear	1	0	0.3	0.0	0.3	0.0	0.3	0.0	0.2	0.0
Porcupine	1	1	0.3	0.2	0.3	0.2	0.1	0.1	0.9	0.8
Tiger cub	1	0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Bird	2	1	0.5	0.2	0.5	0.2	0.0	0.2	0.0	0.0
Monitor lizard	1	0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Snake	0	1	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0
Indian flying squirrel	0	1	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0
Mongoose	0	1	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0
Rodent	0	1	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0

I – Dry season, II – Wet season

Table 26. Prey species utilization by tiger as shown by scat data year wise in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – Dec. 09).

Prey species	Prey remains			Relative frequency occurrence			% Occurrence			% Biomass consumed			% Individual consumed		
	2008 (N=420)	2009 (N=455)	CD (N=875)	2008	2009	CD	2008	2009	CD	2008	2009	CD	2008	2009	CD
Sambar	196	187	383	46.7	41.1	43.8	45.3	40.1	42.6	52.1	48.7	50.4	28.7	23.6	26.0
Chital	169	198	367	40.2	43.5	41.9	39.0	42.5	40.8	24.3	27.9	26.1	38.5	38.8	38.6
Gaur	25	25	50	6.0	5.5	5.7	5.8	5.4	5.6	17.6	17.2	17.4	2.9	2.5	2.7
Wild pig	12	20	32	2.9	4.4	3.7	2.8	4.3	3.6	1.6	2.6	2.1	3.1	4.4	3.8
Common langur	12	8	20	2.9	1.8	2.3	2.8	1.7	2.2	1.1	0.7	0.9	10.0	5.7	7.7
Mouse deer	7	8	15	1.7	1.8	1.7	1.6	1.7	1.7	0.6	0.7	0.6	8.9	8.8	8.8
Cow	3	5	8	0.7	1.1	0.9	0.7	1.1	0.9	1.0	1.6	1.3	0.4	0.6	0.5
Black - naped hare	2	6	8	0.5	1.3	0.9	0.5	1.3	0.9	0.2	0.5	0.3	5.8	14.9	10.7
Buffalo	3	0	3	0.7	0.0	0.3	0.7	0.0	0.3	1.4	0.0	0.7	0.4	0.0	0.2
Porcupine	1	1	2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.8	0.7	0.8
Barking deer	0	1	1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.1	0.0	0.3	0.2
Sloth bear	1	0	1	0.2	0.0	0.1	0.0	0.0	0.1	0.3	0.0	0.1	0.1	0.0	0.1
Unidentified Bird	2	1	3	0.5	0.2	0.3	0.2	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Snake	0	1	1	0.0	0.2	0.1	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Monitor lizard	0	1	1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Tiger cub	0	1	1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Indian flying squirrel	0	1	1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mongoose	0	1	1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Rodent	0	1	1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0

CD – Combined data

Table 27. Prey species utilization by leopard, as shown by scat data season wise in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Prey species	Prey remains		% Frequency occurrence		% Occurrence		% Biomass consumed		% Individuals consumed	
	I	II	I	II	I	II	I	II	I	II
Sambar	32	24	14.6	12.4	14.0	12.1	21.4	20.5	6.0	4.6
Chital	135	127	61.6	65.5	59.0	63.8	48.9	58.5	39.4	37.7
Gaur	8	3	3.7	1.5	3.5	1.5	14.2	6.8	1.2	0.5
Wild pig	4	3	1.8	1.5	1.7	1.5	1.3	1.3	1.3	1.0
Common langur	32	21	14.6	10.8	14.0	10.6	7.2	6.0	34.2	22.9
Mouse deer	4	6	1.8	3.1	1.7	3.0	0.9	1.6	6.5	10.0
Cow	5	3	2.3	1.5	2.2	1.5	4.1	3.2	0.9	0.5
Hare	2	0	0.9	0.0	0.9	0.0	0.4	0.0	7.4	0.0
Buffalo	1	0	0.5	0.0	0.4	0.0	1.2	0.0	0.2	0.0
Snake	3	0	1.4	0.0	1.3	0.0	0.0	0.0	0.0	0.0
Porcupine	0	2	0.0	1.0	0.0	1.0	0.0	0.6	0.0	2.2
Brow-palm civet	0	2	0.0	1.0	0.0	1.0	0.0	0.5	0.0	7.2
Four-horned antelope	1	0	0.5	0.0	0.4	0.0	0.3	0.0	0.5	0.0
Small Indian civet	1	0	0.5	0.0	0.4	0.0	0.2	0.0	2.6	0.0
Tiger cub	1	0	0.5	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Indian flying squirrel	0	1	0.0	0.5	0.0	0.5	0.0	0.3	0.0	3.9
Indian giant squirrel	0	2	0.0	1.0	0.0	1.0	0.0	0.5	0.0	7.9
Jungle cat	0	1	0.0	0.5	0.0	0.5	0.0	0.3	0.0	1.5
Mongoose	0	1	0.0	0.5	0.0	0.5	0.0	0.0	0.0	0.0
Rodent	0	3	0.0	1.5	0.0	1.5	0.0	0.0	0.0	0.0

I - Dry Season (N = 219), II - Wet Season (N = 194)

Table 28. Prey species utilization by leopard, as shown by scat data year wise in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Prey species	Prey remains			Relative Frequency occurrence			% Occurrence			% Biomass Consumed			% Individual consumed		
	2008 (N=209)	2009 (N=204)	Cmb.dat. (N=413)	2008	2009	Overall	2008	2009	Comb. data	2008	2009	Comb. data	2008	2009	Comb. data
Sambar	37	19	56	17.7	9.3	13.6	16.8	9.1	13.1	26.0	15.5	21.0	7.3	4.1	5.3
Chital	122	140	262	58.4	68.6	63.4	55.5	67.0	61.1	46.4	61.7	53.1	37.1	47.1	38.6
Gaur	6	5	11	2.9	2.5	2.7	2.7	2.4	2.6	11.2	10.8	10.9	0.9	0.9	0.8
Wild pig	5	2	7	2.4	1.0	1.7	2.3	1.0	1.6	1.7	0.8	1.3	1.7	0.8	1.2
Common langur	30	23	53	14.4	11.3	12.8	13.6	11.0	12.4	7.1	6.3	6.7	33.4	28.3	28.6
Cow	5	3	8	2.4	1.5	1.9	2.3	1.4	1.9	4.3	3.0	3.7	0.9	0.6	0.7
Buffalo	1	0	1	0.5	0.0	0.2	0.5	0.0	0.2	1.2	0.0	0.6	0.2	0.0	0.1
Porcupine	2	0	2	1.0	0.0	0.5	0.9	0.0	0.5	0.5	0.0	0.3	2.2	0.0	1.1
Black - naped hare	2	0	2	1.0	0.0	0.5	0.9	0.0	0.5	0.4	0.0	0.2	7.7	0.0	3.7
Mouse deer	5	5	10	2.4	2.5	2.4	2.3	2.4	2.3	1.1	1.3	1.2	8.5	9.4	8.2
Brown palm civet	2	0	2	1.0	0.0	0.5	0.9	0.0	0.5	0.0	0.0	0.2	0.0	0.0	3.6
Four-horned antelope	0	1	1	0.0	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.1	0.0	0.0	0.3
Small Indian civet	0	1	1	0.0	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.1	0.0	0.0	1.3
Indian flying squirrel	0	1	1	0.0	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.1	0.0	0.0	2.0
Indian giant squirrel	0	2	2	0.0	1.0	0.5	0.0	1.0	0.5	0.0	0.5	0.2	0.0	8.9	3.9
Jungle cat	0	1	1	0.0	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.1	0.0	0.0	0.8
Tiger cub	0	1	1	0.0	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Mongoose	0	1	1	0.0	0.5	0.2	0.0	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Snake	3	2	4	1.4	0.5	1.0	1.4	0.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Rodent	0	3	3	0.0	1.5	0.7	0.0	1.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0

Table 29. Prey species utilization by dhole, as shown by scat data season wise in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Prey species (N =182)	Prey remains		% Frequency occurrence		% Occurrence		% Biomass consumed		% Individuals consumed	
	I (N = 503)	II (N = 567)	I	II	I	II	I	II	I	II
Sambar	108	85	21.5	15.0	21.1	14.7	44.2	32.0	20.5	14.2
Chital	347	424	69.0	74.8	67.8	73.4	50.6	56.9	67.3	72.5
Gaur	3	7	0.6	1.2	0.6	1.2	4.1	8.7	0.6	1.2
Wild pig	3	1	0.6	0.2	0.6	0.2	0.4	0.1	0.6	0.2
Common langur	15	2	3.0	0.4	2.9	0.3	0.4	0.1	3.4	0.4
Cow	0	3	0.0	0.5	0.0	0.5	0.0	1.5	0.0	0.5
Mouse deer	5	27	3.2	4.8	1.0	4.7	0.1	0.5	1.3	6.0
Hare	16	14	1.0	2.5	3.1	2.4	0.2	0.1	5.5	4.2
Small Indian civet	1	2	0.4	0.4	0.2	0.3	0.0	0.0	0.3	0.5
Brow-palm civet	2	1	0.2	0.2	0.4	0.2	0.0	0.0	0.7	0.3
Bird	2	3	1.8	0.5	0.4	0.5	0.0	0.0	0.0	0.0
Rodent	9	8	0.4	1.4	1.8	1.4	0.0	0.0	0.0	0.0
Insect	1	1	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0

I – Dry Season, II – Wet Season

Table 30. Prey species utilization by dhole as shown by scat data year wise in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Prey species	Prey remains			% Frequency occurrence			% Occurrence			% Biomass consumed			% Individual consumed		
	2008 (n =755)	2009 (n=315)	Comb. data (n=1070)	2008	2009	Comb. data	2008	2009	Comb. data	2008	2009	Comb. data	2008	2009	Comb. data
Sambar	136	57	193	18.0	18.1	18.0	17.7	17.7	17.7	38.9	35.6	37.9	17.0	17.4	17.1
Chital	542	229	771	71.8	72.7	72.1	70.6	71.1	70.7	55.2	51.0	53.9	69.4	71.6	70.1
Gaur	5	5	10	0.7	1.6	0.9	0.7	1.6	0.9	4.7	10.3	6.5	0.6	1.5	0.9
Wild pig	3	1	4	0.4	0.3	0.4	0.4	0.3	0.4	0.2	0.2	0.2	0.4	0.3	0.4
Common langur	15	2	17	2.0	0.6	1.6	2.0	0.6	1.6	0.3	0.1	0.2	2.3	0.7	1.8
Cow	0	3	3	0	1.0	0.3	0.0	0.9	0.3	0.0	2.5	0.8	0.0	0.9	0.3
Mouse deer	28	4	32	3.7	1.3	3.0	3.6	1.2	2.9	0.40	0.1	0.3	4.7	1.6	3.8
Black - naped hare	21	9	30	2.8	2.9	2.8	2.7	2.8	2.8	0.17	0.2	0.2	4.8	5.0	4.8
Small Indian civet	1	2	3	0.1	0.6	0.3	0.1	0.6	0.3	0.01	0.0	0.0	0.2	1.0	0.4
Brown palm civet	3	0	3	0.4	0.0	0.3	0.4	0.0	0.3	0.02	0.0	0.0	0.7	0.0	0.5
Unidentified bird	2	3	5	0.3	1.0	0.5	0.3	0.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Rodent	11	6	17	1.5	1.9	1.6	1.4	1.9	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Insect	1	1	1	0.1	0.3	0.1	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0

Table 31. Derived correction factors to estimate prey biomass consumption per scat produced by tiger, leopard and dhole for different prey species, using regression from Ackerman at al.,(1984) and Floyd et al., (1978)

Prey species	Weight (Xi)	Correction factor for tiger & leopard (λi = XiYi)	Correction factor for dhole (λi = XiYi)
Sambar	135	6.7	2.7
Chital	47	3.6	1.0
Gaur	450	17.7	9.0
Wild pig	38	3.3	0.8
Common langur	8	2.3	0.2
Cow	180	8.3	3.6
Buffalo	273	11.5	0.0
Porcupine	8	2.3	0.0
Black - naped hare	2.1	2.1	0.1
Mouse deer	5	2.2	0.1
Barking deer	20.0	2.7	0.0
Brown palm civet	2.2	2.1	0.1
Four-horned antelope	20	2.7	0.0
Sloth bear	135	6.7	0.0
Small Indian civet	3	2.1	0.1
Indian flying squirrel	2	2.1	0.0
Indian giant squirrel	2	2.1	0.0
Jungle cat	5.5	2.2	0.0

Minimum sample size required to study food habits of tiger, leopard and dhole was 80 to 90 scat samples (Figures 2 to 3.). Scat samples collected for all the three predators were sufficient to document prey selection pattern of the species.

Figure 2. Sample adequacy for analyses of predator scats during dry season in Mudumalai Tiger Reserve, Tamil Nadu (January – April 2008 and 2009).

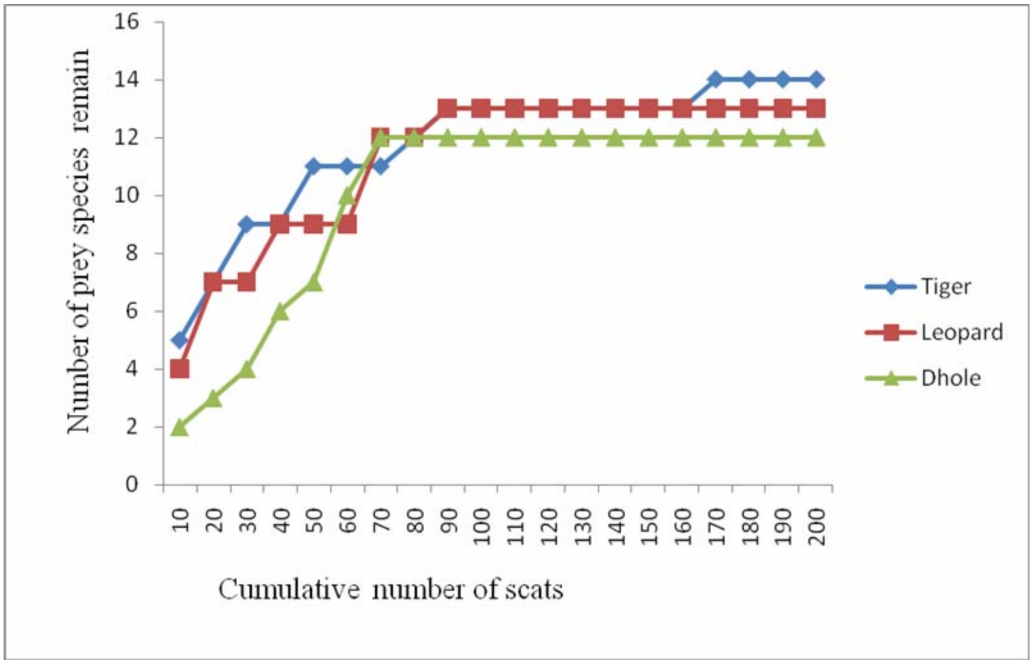
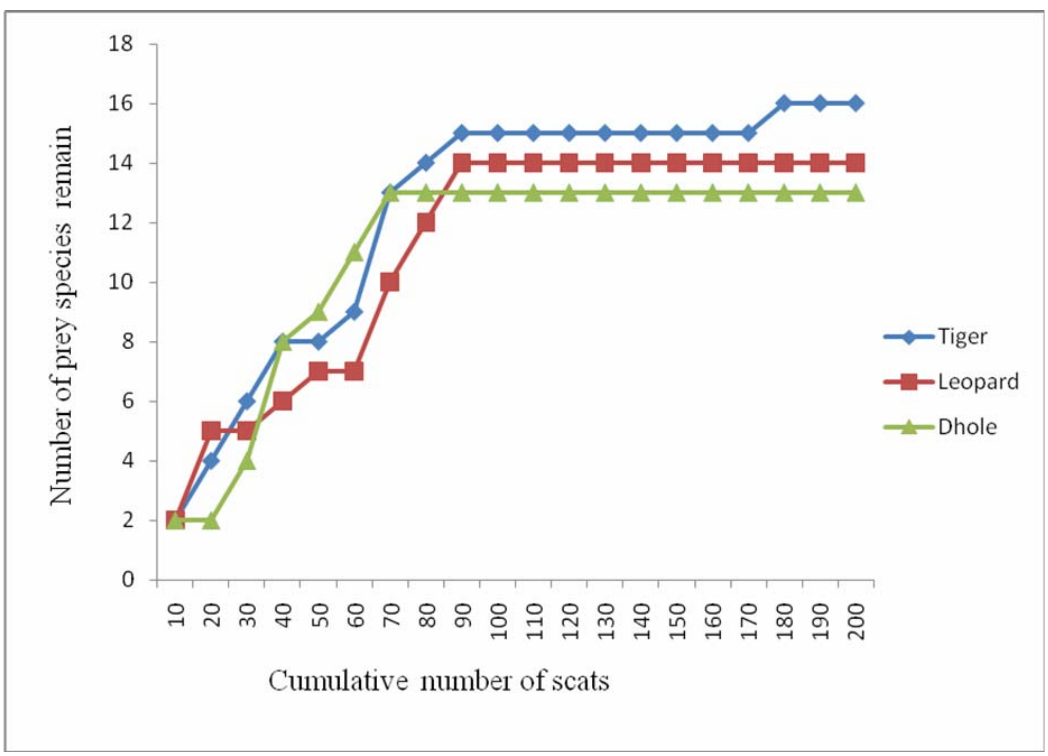


Figure 3. Sample adequacy for analyses of predator scats during wet season in Mudumalai Tiger Reserve, Tamil Nadu (May – December 2008 and 2009).



4.4.2. Prey selectivity of predators

The Ivlev's prey selection index showed that sambar and chital were utilized more than their availability by tiger, leopard and dhole (Tables 32 to 34). In comparision to leopard and dhole, tiger utilized sambar in more proportion and chital in less proportion. Common langur was marginally less utilized than its availability by leopard whereas less utilized more by tiger and dhole. The index showed that mouse deer and black naped hare were found to be the most utilized prey among all prey consumed by tiger, leopard and dhole and this may be due to underestimation of their availability data. Wild pig was more utilized by tiger, equally to the availability by leopard and less consumed by dhole than its availability.

Season wise analysis of Ivlev's prey selection index showed that tiger utilized sambar and wild pig more than its availability for both dry and wet seasons while wide variation was seen in utilization of chital between seasons (Tables 32 - 34). When tiger and dhole utilized sambar more than its availability in less proportion in the dry season, leopard utilized sambar less than its availability as compared to wet season. Common langur was utilized more than its availability by leopard during the dry season but less ultilized than its availability in the wet season. All the three predators consumed gaur less than its availability in all seasons. Chital was utilized more than its availability in both the dry and wet seasons by leopard and dhole whereas tiger utilized chital less than its availability in the dry season.

Multinomial likelihood ratio test indicated random selection preference for certain prey species by tiger, leopard and dhole using individual density for both the years (Tables 32 - 34). All three predators exhibited significant preference and avoidance of a particular prey species. However, tiger exhibited a significant preference (P = < 0.1) for sambar, chital, wild pig, mouse deer, black naped hare and significantly avoided (P = < 0.1) gaur, common langur and barking deer. Leopard showed a significant preference (P = < 0.1) towards chital, sambar, mouse deer and black naped hare, no significant preference for wild pig (P = 0.32) and no preference (P = < 0.1) for common langur, gaur and Indian giant squirrel. Dhole revealed a significant preference (P = < 0.1) for prey species in the following order; sambar > chital > mouse deer > black naped hare and avoidance for gaur and common langur (P = < 0.1). Preference of wild pig by dhole was P = 0.22.

Table 32. Prey selection of tiger in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons	Prey species remain	Adjusted p – value # at 10%	Adjusted p – value # at 40%	U-A/ U+A*
Dry	Sambar	0.000	0.000	0.52
	Chital	0.007	0.029	-0.10
	Gaur	0.000	0.000	-0.63
	Wild pig	0.000	0.000	0.48
	Common langur	0.000	0.000	-0.48
	Mouse deer	0.361	0.373	0.56
	Black - naped hare	0.000	0.000	0.94
Wet	Sambar	0.000	0.000	0.58
	Chital	0.000	0.000	0.18
	Gaur	0.000	0.000	-0.69
	Wild pig	0.000	0.000	0.29
	Common langur	0.000	0.000	-0.87
	Mouse deer	0.000	0.000	0.95
	Barking deer	0.205	0.214	0.68
2008	Sambar	0.000	0.000	0.70
	Chital	0.000	0.000	0.03
	Gaur	0.000	0.000	-0.70
	Wild pig	0.000	0.000	0.54
	Common langur	0.000	0.000	-0.73
2009	Sambar	0.000	0.000	0.41
	Chital	0.000	0.000	0.10
	Gaur	0.000	0.000	-0.65
	Wild pig	0.000	0.000	0.34
	Common langur	0.000	0.000	-0.76
	Mouse deer	0.000	0.000	0.90
	Barking deer	0.074	0.088	-0.80
	Black - naped hare	0.000	0.000	0.93
Combined data	Sambar	0.000	0.000	0.62
	Chital	0.000	0.000	0.06
	Gaur	0.000	0.000	-0.71
	Wild pig	0.000	0.000	0.49
	Common langur	0.000	0.000	-0.75
	Mouse deer	0.000	0.000	0.95
	Black - naped hare	0.000	0.000	0.95
	Barking deer	0.055	0.066	-0.81

- Multinomial likelihood ratio test, * - Ivelev's Index, < 0.1 – Significant difference in use

Table 33. Prey selection of leopard in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons	Prey species	Adjusted p - value at 10%	Adjusted p - value at 40%	UA/ U+A
Dry	Sambar	0.191	0.241	-0.03
	Chital	0.000	0.000	0.17
	Gaur	0.000	0.000	-0.76
	Wild pig	0.032	0.034	0.29
	Common langur	0.431	0.481	0.11
	Mouse deer	0.035	0.038	0.72
	Black - naped hare	0.000	0.000	0.95
Wet	Sambar	0.001	0.003	0.11
	Chital	0.000	0.000	0.35
	Gaur	0.000	0.000	-0.90
	Wild pig	0.763	0.766	-0.20
	Common langur	0.000	0.000	-0.34
	Mouse deer	0.000	0.000	0.96
	Indian giant squirrel	0.194	0.206	0.27
2008	Sambar	0.000	0.000	0.37
	Chital	0.000	0.000	0.23
	Gaur	0.000	0.000	-0.84
	Wild pig	0.000	0.000	0.49
	Common langur	0.011	0.025	-0.10
2009	Sambar	0.037	0.060	-0.01
	Chital	0.000	0.000	0.22
	Gaur	0.000	0.000	-0.81
	Wild pig	0.199	0.205	0.03
	Common langur	0.196	0.240	0.03
	Mouse deer	0.000	0.000	0.92
	Indian giant squirrel	0.004	0.006	-0.16
Combined data	Sambar	0.000	0.000	0.09
	Chital	0.000	0.000	0.25
	Gaur	0.000	0.000	-0.83
	Wild pig	0.294	0.320	0.01
	Common langur	0.001	0.008	-0.06
	Mouse deer	0.000	0.010	0.98
	Black - naped hare	0.009	0.000	0.85
	Indian giant squirrel	0.008	0.012	-0.07

- Multinomial likelihood ratio test, * - Ivelev's Index, < 0.1 – Significant difference in use

Table 34. Prey selection of dhole in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Seasons	Prey species	Adjusted p - value at 10%	Adjusted p - value at 40%	U-A/ U+A
Dry	Sambar	0.000	0.000	0.39
	Chital	0.000	0.000	0.26
	Gaur	0.000	0.000	-0.91
	Wild pig	0.603	0.608	-0.26
	Common langur	0.213	0.252	-0.84
	Black - naped hare	0.000	0.000	0.91
	Mouse deer	0.000	0.000	-0.08
Wet	Sambar	0.000	0.000	0.49
	Chital	0.000	0.000	0.51
	Gaur	0.000	0.000	-0.81
	Wild pig	0.064	0.075	-0.84
	Common langur	0.000	0.000	-0.99
	Mouse deer	0.000	0.000	0.92
2008	Sambar	0.000	0.000	0.61
	Chital	0.000	0.000	0.42
	Gaur	0.000	0.000	-0.91
	Wild pig	0.736	0.740	-0.30
	Common langur	0.000	0.001	-0.91
2009	Sambar	0.082	0.166	0.27
	Chital	0.000	0.000	0.38
	Gaur	0.000	0.000	-0.90
	Wild pig	0.140	0.153	-0.69
	Common langur	0.004	0.009	-0.90
	Mouse deer	0.000	0.000	0.20
	Black - naped hare	0.000	0.000	0.59
Combined data	Sambar	0.000	0.000	0.45
	Chital	0.000	0.000	0.34
	Gaur	0.000	0.000	-0.87
	Wild pig	0. 224	0.245	-0.65
	Common langur	0.000	0.000	-0.93
	Mouse deer	0.000	0.000	0.90
	Black - naped hare	0.000	0.000	0.91

- Multinomial likelihood ratio test, * - Ivelev's Index, < 0.1 – Significant difference in use

4.4.3. Dietary overlap

The estimated dietary overall overlap was 82% between tiger and leopard, 84% between tiger and dhole and 98% between leopard and dhole using relative frequency occurrence of prey remains in the diet. The estimated dietary overlap between leopard and dhole in all seasons was consistently very high (>98%) (Table 35).

Table 35. Dietary overlap between predators based on relative frequency occurrence of prey remains in predators scats in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Season	Tiger x Leopard	Tiger x Dhole	Leopard x Dhole
Dry	75 %	80 %	98 %
Wet	86 %	87 %	99 %
2008	83 %	81 %	97 %
2009	80 %	86 %	98 %
Combined data	82 %	84 %	98 %

4.4.4. Kill of predators

Of the tiger kills (n = 41), 7.3% comprised of small sized prey, 24.4 % medium and 68.3% large sized prey species. Kills of leopard (n = 20) comprised of 35% small sized prey, 58.8% medium and 5.9% large sized prey species. Dhole kills (n =35) consisted of 10.3% small sized prey, 74.4% medium and 15.4% large sized prey species (Table 36.) Kill data showed that gaur, sambar and chital were the important prey for tiger and chital for leopard and dhole. The sambar and chital kills might have been underestimated and gaur kills might have been overestimated in predator kills (Figures 4 to 6.). Even though kill data underestimated medium sized prey and overestimated large sized prey for tiger and leopard, both the kill and scat data showed almost similar prey selection pattern by tiger and leopard. Dhole kill data showed that chital was the dominant prey which is similar to the finding of scat data since dholes tend to hunt in open areas, the ideal habitat for chital. Analysis revealed that scat samples depict predator diets more accurately while kill data underestimates the presence of diverse prey species and proportions of smaller prey. However kill and scat data showed almost similar prey selection pattern of three predators and kill data was biased towards gaur for tiger. Based on evaluation of bone marrow conditions of prey species killed by all predators, it was found that >95% was found with good health conditions.

Table 36. Prey species utilization by predators as shown by kill data in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).

Predators	Prey species	No. of Kill	% Kill	Adult Male	Adult Female	Sub adult Male	Sub adult Female	Fawn
Tiger	Sambar	11	26.8	8	1	1	1	0
	Chital	7	17.1	3	2	1	1	0
	Gaur	12	29.3	7	2	1	1	0
	Cow	5	12.2	0	5	0	0	0
	Wild pig	3	7.3	2	1	0	0	0
	Python	1	2.4	0	0	0	0	0
	Sloth bear cub	1	2.4	0	0	0	0	1
	Black - naped hare	1	2.4	0	0	0	0	0
Leopard	Sambar	1	5.0	0	0	1	0	0
	Chital	9	45.0	3	3	2	1	0
	Wild pig	1	5.0	0	0	0	0	1
	Mouse deer	1	5.0	0	0	0	0	0
	Black - naped hare	1	5.0	0	0	0	0	0
	Indian giant squirrel	2	10.0	0	0	0	0	0
	Domestic fowl	3	15.0	2	0	0	0	0
	Common langur	2	10.0	0	0	0	0	0
Dhole	Sambar	6	17.1	0	2	2	1	1
	Chital	27	77.1	3	5	9	8	9
	Wild pig	2	5.7	0	0	0	0	2

Figure 4. Prey utilization by tiger as shown by scat and kill data in Mudumalai Tiger Reserve, Tamil Nadu (Jan. 2008 – Dec. 2009).

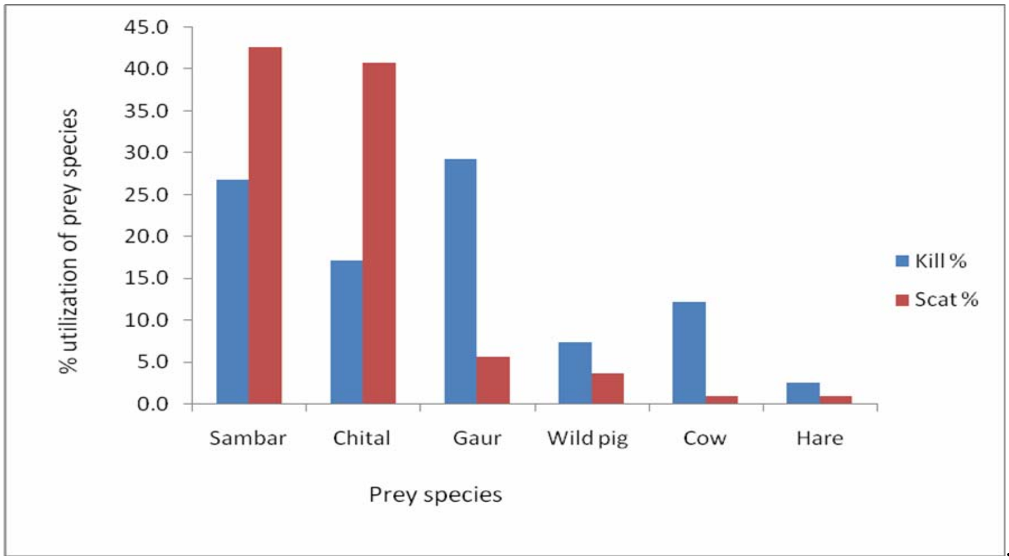


Figure 5. Prey utilization by leopard as shown by scat and kill data in Mudumalai Tiger Reserve, Tamil Nadu (Jan. 2008 – Dec. 2009).

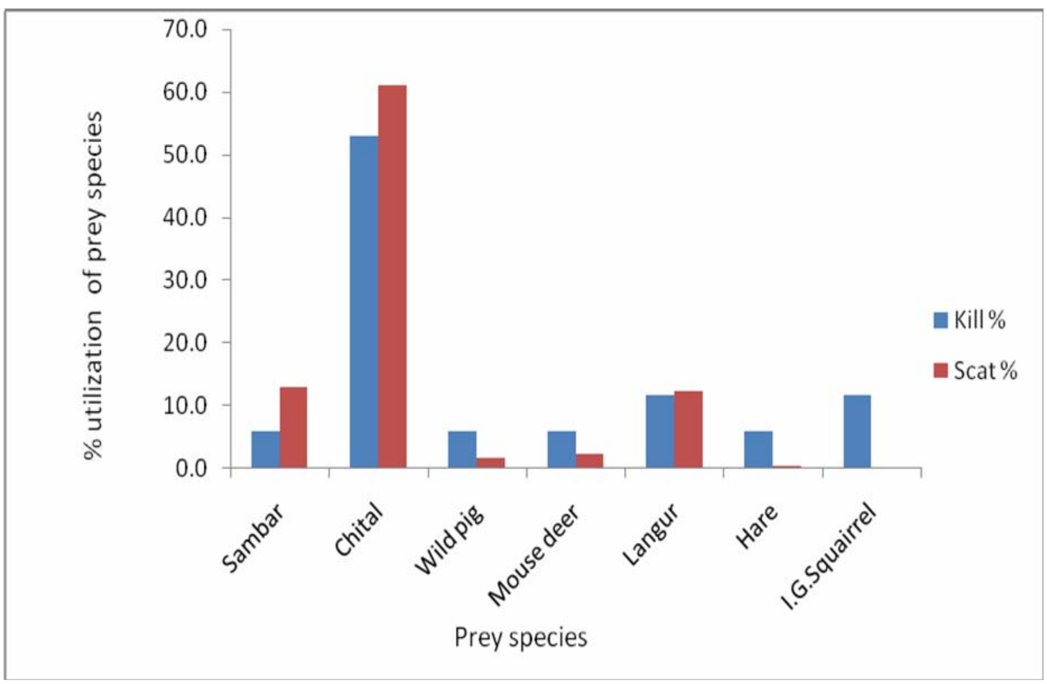
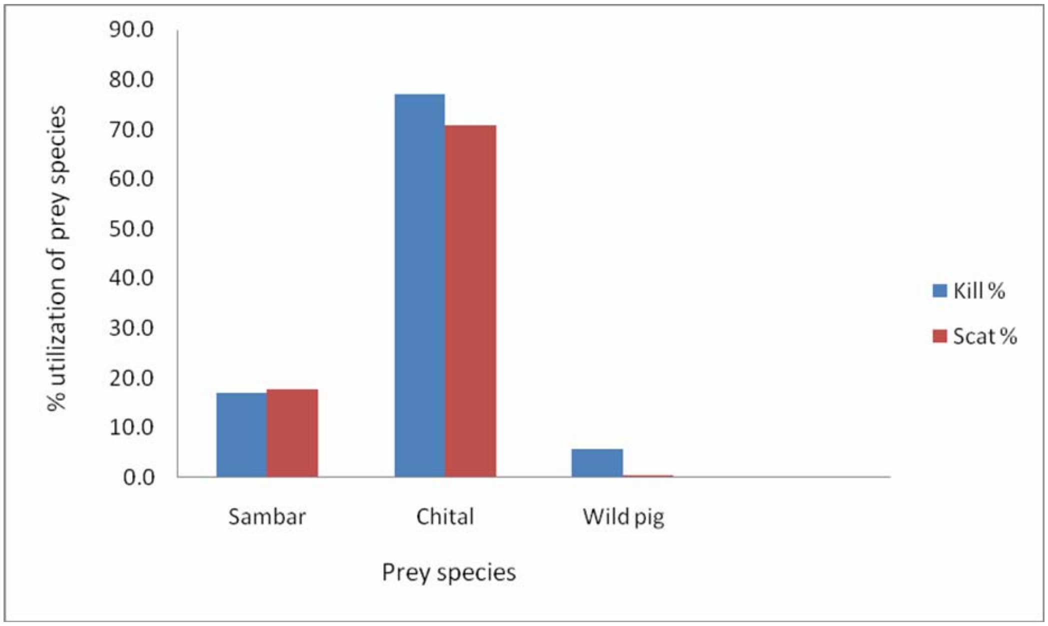


Figure 6. Prey utilization by dhole as shown by scat and kill data in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 – December 2009).



4. 5. Discussion

An increase in predator size is associated with increased intake of mean prey size and prey diversity (Gittleman 1985). The analysis of scats and kills confirmed that tiger killed mainly large body sized prey, but dholes and the leopard largely killed medium sized prey. In addition to this tiger utilized negligible amount of medium sized prey meanwhile leopard and dhole consumed large and small body sized prey. All three large predators showed significant level of preference towards utilization of prey species (P = < 0.1). All three large predator's scat contained 26 prey species in which major ungulates and one primate species were commonly shared in their diet. These predators largely depend on principle prey species such as sambar, chital, gaur, wild pig and langur > 90% in their diet and coexist in the prey rich tropical forest of Mudumalai. The dietary study in Mudumalai revealed that large carnivores can also utilize whatever prey they can catch including barking deer, mouse deer, four-horned antelope, domestic livestock, porcupine, sloth bear, jungle cat, monitor lizard, mongoose, civet, bird, rodent, snake, squirrel and insect. To understand the prey selection pattern of these species a minimum of 80 to 90 scat samples are required to be analysed for the study area in Mudumalai. These samples were sufficient in the present study to document food habits of predators. Clearly, large predators discriminate between potential prey types on the basis of functional characteristics such as size, defensive ability, escape behaviour, group structure and habitat affinity. Advancing the importance of competition in structuring guilds is a measurable overlap in resource use. Resource overlap is commonly used to assess the potential for competition (Schoener 1983). Overlap in carnivore diets may increase when resources are too abundant for little competition. In Mudumalai, dietary overlap between predators was very high because of shared inclusion of major ungulates by predators in their diet. Tiger's diet overlapped >80% with that of the leopard and dhole because of shared inclusion of major prey species. The idea that competition leads to character divergence dominates on coexistence between mammalian carnivores. Previous studies on diet of sympatric carnivores showed that diets of large carnivores are very similar when prey species are abundant (Schaller 1967, Johnsingh 1983, Sunquist and Sunquist 1989, Karanth and Sunquist 1995, Andheria et al., 2007). Environment changes pattern seasonally and annually leading to fluctuating levels of inter-specific competition. Leopards are more successful than tigers because of their ability to live in different environmental conditions with a flexible diet (Johnsingh 1983). The wide geographic distribution of leopard attributed to their ability to coexist with other large carnivores (Bailey 1993). The ability of the tiger to hunt prey ranging from rodent to elephant calf indicates that tiger takes a much wider spectrum of food resources. These evidences suggest that large carnivores can prey on broader size ranges of prey due to their prey handling capabilities (Gittleman 1985). Usually when tigers are abundant in an area, leopards become scarce and vice versa (Schaller 1967). The landscape of Mudumalai Tiger Reserve is an exceptional case where tiger, leopard and dhole coexist in high density by selecting different sized prey. Because of high large carnivore density, tigers are known to out-compete leopards and dholes, the capacity of which includes killing both the species. However in some way, intraguild competition occurs; in two cases where the tiger had killed a leopard when it was scavenging on the tiger's kill (sambar) in the study area. In one case, two dhole pups were killed by the tiger while in another case a leopard was harassed by a pack of dholes in Mudumalai (Arumugam per.comm. 2009). Moreover on one occasion tiger killed an adult male dhole in adjacent dry thorn forest. In India there are records of tigers killing leopards (Biscoe 1895); leopards were twice observed being chased and `treed' by dholes (Karanth and Sunquist 2000). Dhole remains were found in leopard scats in Nagarhole (Karanth and Sunquist 1995). Such agitating interactions are frequent and related to diet overlap (Donadio and Buskirk 2006). In Mudumalai, cannibalism was recorded in the tiger from its scat that contained a claw and hair of a tiger cub. Leopard killing tiger cubs as evidence was recorded in a leopard scat by the presence of a claw and hair of tiger cub. In Chitwan radio-tracking studies on tiger and leopard movements indicate that leopards avoid areas frequented by tigers (Seidensticker, 1976) and tiger killed six leopards over a 21-month period in Chitwan (McDougal 1977); tiger killing a leopard cub and leopard killing dhole pups were reported in Bandipur (Johnsingh 1983) and two instances of leopards escaping from a tigress by climbing trees was observed in Nagarhole (Karanth and Sunquist 2000). Dholes were seen killing panther and tiger as reported by Prater (2005). Sometimes even though female biased sex ratio is found in prey species (Cervids) population, males were more prone to tiger predation and fawns by dholes. In Mudumalai, tribes as well non-tribes stealing kills of large carnivores seems to be a significant threat to the predator community.

4.5.1. Scat

The large predator, tiger being large body sized maximizes its energy by tending preferably towards large body sized prey followed by medium sized prey while medium body sized leopard and dhole maximize their energy by feeding on medium followed by large and smaller sized prey. Scat analysis revealed that chital and sambar was the important prey for all three predators though they have wider prey intake. Other prey species such as gaur and wild pig were important prey for tiger while langur was important for leopard and black naped hare and mouse deer for dhole. Domestic livestock presence in all the three predator’s scats revealed that they were indeed livestock lifting from villages found inside and at the periphery of the Tiger Reserve. High dietary overlap should facilitate killing encounters because species searching for similar prey should occupy similar habitats, thereby increasing encounter rates (Polis et al. 1989). The influence of prey availability on prey selection or more utilization is clear from the seasonal difference in consumption of prey in the study area. The scat data revealed food habits and prey selection patterns of three sympatric carnivores in a better way as compared to kill data. They are discussed species wise as follows:

Tiger

The dietary analysis revealed that tiger utilized overall 19 prey species, from the smallest prey (bird) to the largest prey (gaur). The index of prey selection by tiger showed that sambar is an important prey in the study area. Sambar's preference by tiger could be attributed to its large body weight (Johnsingh 1983, Karanth and Sunquist 1995, Avinandan et al., 2008) and wide distribution across the study area and higher frequency of encounter since both the species are crepuscular in habits (Johnsingh 1983). The biomass of sambar, chital and gaur constituted more than 80% to tiger diet. Tiger utilized chital as an important secondary prey due to its high availability. Tiger's diet contained high percentage of domestic livestock than the leopard and dhole. This is attributed to tiger's large body sized prey preference.

When data was examined on a seasonal basis, there appeared to be some evidences of prey switching. In the dry season, when sambar remains were found more in tiger scats, chital and wildpig remains were found in less proportion which was opposite to the wet season. This showed that dense cover preference of sambar and cover availability during the wet season which might have reduced sambar encounter rate to tiger predation. In Mudumalai, sambar is in rut mostly from November to May thereby increasing its movement rate making them more vulnerable to high tiger predation during the dry season. Gaur predation not seemed to be fluctuating between seasons. This may be an opportunistic behaviour of tiger. Wild pig predation could be an opportunistic by tiger as they occur in low density in the study area. Common langur usually forage on the ground during the dry season when all the deciduous trees shed their leaves which increased the chance of their predation by tiger.

I used frequency occurrence of prey remains in tiger scats and compared with other studies (Table 37.). The frequency occurrence of chital in tiger diet in Mudumalai (41.9%) is comparable with Bandipur, Nagarahole and Ranthambhore (Johnsingh 1983, Karanth and Sunquist 1995, Bagchi et al., 2003) but lower than Pench, Kanha, Bardia, Chitwan and Sundarban (Biswas and Sankar 2002, Schaller 1967, Stoen and

Wegg 1996, Sunquist 1981, Khan 2008) and higher than Sariska, Srisailam and Satpura (Avinandan et al., 2008, Reddy et al., 2004, Edgaongar 2008). The proportion of sambar remains in tiger diet is also comparable to Bandipur, Nagarahole, Sariska and Ranthambhore (Johnsingh 1983, Karanth and Sunquist 1995, Avinandan et al., 2008, Bagchi et al., 2003) but higher than Pench, Kanha, Srisailam, Chitwan and Singye Wangchuck (Biswas and Sankar 2002, Schaller 1967, Redd et al., 2004, Sunquist 1981, Wang 2008) and lower than Satpura and Rajaji (Edgaongar 2008, Harihar 2005). However, tiger predation also occurs on other large deer species such as barasingha in Kanha and Barida and Nilgai in Sariska, Ranthambhore and Srisailam. Gaur remains in tiger diet in Mudumalai (5.7%) is comparable to Kanha and Bandipur (Schaller 1967, Johnsingh (1983) but lower than Bandipur and Nagarhole (Andheria et al., 2007 and Karanth and Sunquist 1995). Karanth and Sunquist (1995) suggested that high percentage of gaur remains in the tiger diet is a trait could be acquired through learning behaviour. However, this was not observed in Mudumalai. Wild pig remains in tiger diet as recorded during the present study were similar to Bandipur and Chitwan (Johnsingh 1983, Sunquist 1981) and lower than Bandipur, Nagarahole, Srisailam, Pench, Rajaji, Bardia, Sundarban and Singye Wangchuck (Andheria at al., 2007, Karanth and Sunquist 1995, Biswas and Sankar 2002, Harihar 2005, Stoen and Wegg 1996, Khan 2008, Wang 2008). This shows that tiger mainly feeds on large to medium sized prey.

Table 37. The frequency occurrence of prey species remains in tiger scats in the Indian Subcontinent

Species	P. Study	Bdp	Bdp*	Ngle	Ss	Pench	Kanha	Rajaji	Sariska	Rbh	Stp	Cht	Bda	SE	SW
Chital	41.9	39.0	38.0	33.6	21.3	53.0	52.2	11.3	17.24	45.6	4.3	61.8	77.7	108.0	NP
Sambar	43.7	30.5	25.9	26.8	18.4	13.7	10.4	75.0	45.9	36.8	78.5	20.0	a	NP	13.8
Langur	2.2	a	2.6	4.2	1.7	3.6	6.2	a	4.5	4.8	7.5	3.6	2.3	NP	a
Gaur	5.7	5.5	27.8	18.7	a	NP	8.3	NP	NP	NP	a	a	1.9	NP	NP
Wildpig	3.6	5.5	10.5	10.1	33.1	8.8	0.8	6.8	1.1	2.8	2.2	3.6	8.8	16.0	6.9
Cattle	0.89	5.5	0.4	NP	5.8	4.3	5.9	25.0	11.4	2.8	5.3	1.8	a	a	27.6
Buffalo/Yak*	0.34	a	a	a	a	2	1.7	6.8	5.7	2.6	a	a	a	a	13.8*
Mouse Deer	1.7	a	1.5	3.3	a	NP	NP	a	NP	NP	NP	NP	NP	NP	NP
Munjac	0.11	a	a	6.6	a	5.3	a	a	NP	NP	a	a	a	a	17.2
Chowsingha/	a	a	a	a	10.0	2.6	a	a	a	NP	a	NP	NP	NP	NP
Barasingha	NP	NP	NP	NP	NP	NP	8.6	NP	NP	a	NP	NP	1.7	NP	NP
Nilgai	NP	NP	NP	NP	3.6	a	a	a	13.7	3.2	a	a	a	NP	NP
Chinkara/Hog deer*	NP	NP	NP	a	1.2	a	NP	NP	a	0.58	a	NP	7.7*	NP	NP
Hare	0.91	a	a	0.2	2.3	a	a	a	a	a	a	a	a	a	a
Porcupine	0.23	5.5	a	0.2	2.3	a	a	a	a	a	a	a	a	8	a
Miscellaneous	1.1	8.5	a	4.7	2.9	6.3	6.1	a	a	a	4	9.0	5.2	16.9	6.9

P.Study – Present study, Bdp – Bandipur (Johnsingh 1983), Bdp*- Bandipur (Andheria et al., 2008), Ngle – Nagarhole (Karanth and Sunquist 1992), Ss – Srisailam (Reddy et al., 2004), Pench (Biswas and sankar 2002) , Kanha (Schaller 1967), Sariska (Sankar and Johnsing 2002), Rbh Ranthambhore (Bagchi et al., 2003), Stp – Satpura (Edgaongar 2008), Cht – Chitwan (Sunquist 1981), Bda – Bardia (Stoen and Wegg 1996), SE – Sundarban East (Khan 2008), SW - Singye Wangchuck(Wang 2008), a – Absent, NP – Not present.

Leopard

Leopard utilized overall 20 prey species from smallest prey (bird) to the largest prey (gaur). More than 75% of leopard diet constituted biomass of chital and sambar. The index of prey selection indicated that chital and sambar were the main prey species for leopard in the study area. However leopard scat contained remains of sambar much lower than chital. This may be due to leopard's inability to kill adult sambar which are much larger in size than leopard. Unlike tiger, leopard is found to use moderate cover and open places where chital congregate more. In addition gaur was an additional important prey for leopard. The presence of gaur remains in leopard scats may be due to scavenging behaviour of leopard on tiger kill in Mudumalai as observed by me. Relative number of individual prey killed by leopard include more chital followed by langur in the study area. This showed wider dietary pattern of leopard influenced by habitat diversity and species abundance. Leopard differed from tigers in their activity periods and microhabitat use (Seidensticker 1976). When tiger increased its intake of medium sized prey then leopard increased its diet intake to smaller prey in the present study.

Seasonal dietary pattern of leopard food habits appeared to be fluctuating where intake of sambar increased or decreased alternatively. Increased intake of chital was noticed when intake of sambar reduced. This is an indicative of leopard's adaptability as per the prey movement and availability. The utilization of gaur was more in the dry season compared to wet season and this may be related to the seasonal movement of gaur. Predation rate on common langur was high during the dry season. The reason for the same is attributed to availability of common langur on the ground during dry months. Wild pig and cattle predation by leopard seemed to be opportunistic intake.

The leopard food habits from Mudumalai with regard to chital and sambar contribution is comparable with studies from Bandipur, Nagarhole, Kanha (Johnsingh 1983, Andheria et al., 2007, Karanth and Sunquist 1995, Schaller 1967) and lower than Kalakad – Mundanthurai, Satpura, Sariska, Gir and Singye Wangchuck (Ramakrishnan et al., 1999, Edgaongar 2008, Sankar and Johnsingh 2002, Maheswari 2006, Wang 2008) where either tiger occurs in low density or it is not present which led leopard to utilize these prey species as per the prey availability (Table 38.).

Common langur was utilized less than their availability in leopard diet during the present study and the results were comparable with studies from Bandipur, Nagarhole and Satpura (Johnsingh 1983, Andheria et al., 2007, Karanth and Sunquist 1995, Edgaongar 2008). Gaur remains in leopard diet were found higher in adjacent study areas; Bandipur (Andheria et al. 2007) and Nagarhole (Karannth and Sunquist 1995). Other species contribution in leopard diet in Mudumalai was very less and the reason for the same was attributed to their low occurrence.

Table 38. The frequency occurrence of prey species remains found in leopard scats in Indian Subcontinent.

Species	P. study	Mdu*	Bdp	Bdp*	Ngle	KMTR	Sariska	Gir	Kanha	Stp	SW
Chital	63.4	67.2	51.0	54	48.7	24.3	20.8	26	59.0	20.2	NP
Sambar	13.6	11.6	14.0	7.2	15.0	9.0	20.0	28.3	9.0	52.8	16.8
Common langur	12.8	2.7	10.0	10.8	7.9	0.9	6.4	2.6	27.0	10.9	4.4
Gaur	2.7	0.5	a	10.8	8.1	a	NP	NP	a	a	NP
Wildpig	1.7	1.1	a	9.9	5	3.7	a	1.7	a	2.1	5.3
Cattle	1.9	6.1	6.0	a	a	8.3	a	7.0	a	1.6	25.7
Buffalo/Yak*	0.2	a	a	a	a	a	a	1.7	a	a	6.2*
Mouse Deer	2.4	a	a	1.8	7.9	4.6	NP	NP	a	a	NP
Muntjac	a	2.2	a	1.8	8.3	a	NP	NP	a	a	8.8
Chowsingha	0.2	a	a	3.6	0.4	a	a	a	a	a	NP
Nilgai/ Barasingha*	NP	NP	NP	NP	NP	NP	7.2	a	4.5*	a	NP
Nigiri langur/Goral*	NP	NP	NP	NP	NP	8.3	NP	NP	NP	NP	8*
Hare	0.5	3.3	11.2	a	1.3	a	2.4	7.9	a	5.7	a
Porcubine	0.5	0.56	a	a	a	6.4	a	a	9.0	3.1	a
Miscellaneous	3.9	7.6	7.5	a	6.5	3.7	78.4	21.0	a	6.7	12.4

P. Study – Present study, Mdu* - Mudumalai (Ramakrishnan et al.,1999), KMTR –Kalakadu Mundanthurai (Ramakrishnan et al.,1999) Bdp – Bandipur (Johnsingh 1983), Bdp*- Bandipur (Andtheria et al., 2008), Ngle – Nagarahole (Karanth and Sunquist 1992), Gir – (Maheswari – 2006), Kanha (Schaller 1967), Sariska (Sankar and Johnsing 2002), Stp – Satpura (Edgaongar 2008), SW - Singye Wangchuck (Wang 2008), a – Absent, NP - Not present.

Dhole

Dhole diet composed of 13 prey species from smallest prey, beetles to largest prey gaur. Chital and sambar were the most important prey of dhole in Mudumalai, which contributed >90% biomass in the diet of dhole in which chital contribution was 53.9%. The prey selection index depicted sambar and chital were the most selected prey species than their availability. The greater contribution of chital in dhole diet may be due to since both species are diurnal as well as chital tend to live in open areas which make them more vulnerable to dhole predation. The herding behaviour and congregation by chital is not an effective strategy against a diurnal, coursing predator (Edgaonkar 2008). Mouse deer and hare were one of the supportive prey species for dhole. Other species were appeared to be less important in dhole's diet. In terms of percent individual prey species killed by dhole, chital was found to be the primary prey, followed by sambar, hare and mouse deer. This showed that dhole fed largely on medium sized prey.

Dhole food habits revealed wide variation between seasons. Chital biomass was consumed (44.5%) almost equal to sambar in the dry season and increased intake of chital was observed in wet season. The predation rate on gaur and langur by dhole was probably an opportunistic intake. Dhole predation on langur was recorded very low during present study.

The dhole food habits in Mudumalai when compared with other available studies, (Table 39.) revealed that the major prey species such as chital and sambar contribution is similar to earlier study in Mudumalai (Venkatraman et al., 1995). Chital remains in dholes diet in Mudumalai were found similar to as reported from Bandipur (Andheria et al., 2007) and higher than Nagarhole, Nilgiri plateau, Pench and Satpura (Cohen et al., 1978, Acharya 2007, Edgaongar 2008). Sambar remains in dhole's diet during the present study was found lower than Satpura, Pench and Singye Wangchuck (Edgaongar 2008, Acharya 2007, Wang 2008), almost similar to studies reported from Nilgiri plateau, Bandipur (Cohen 1978, Johnsingh 1983) and higher than Nagarhole and Bandipur (Karanth and Sunquist 1995 and Andheria et al., 2007).

Table 39. The frequency occurrence of prey species remains found in dhole scats in Indian Subcontinent.

Species	P.study	MTR*	Bdp	Bdp*	Ngle	NP	Pench	Stp	SW
Chital	72.1	70.4	52	66.8	54.1	18.7	50.5	41.9	NP
Sambar	18.0	21.7	14.0	8.8	11.1	14.7	40.6	48.1	60.9
Langur	1.6	a	a	0.45	0.4	24.1	2.6	6.2	0.7
Gaur	0.9	*	a	0.5	2.2	0.7	0.1	*	NP
Wildpig	0.4	*	a	6.6	8.6	11.3	0.1	2.1	0.7
Cattle	0.3	4.3	a	a	NP	2.0	1.7	a	9.4
Buffalo/Yak*	a	a	a	a	a	a	0.1	a	7.2*
Mouse Deer	3.0	a	a	0.5	4.7	1.3	NP	NP	NP
Muntjac	a	a	a	2.2	24.0	2.0	a	a	22.5
Goral	NP	NP	NP	NP	NP	NP	NP	NP	14.5
Hare	2.8	3.5	14	a	a	a	1.9	3.7	a
Chowsingha	a	a	a	a	0.7	a	a	a	NP
Dhole	a	a	a	a	0.4	a	a	a	a
Miscellaneous	2.8	a	20.0	a	2.8	25.3	0.5	a	2.2

P. Study – Present study, Mdu* - Mudumalai (Venkatraman et al.,1995), Bdp – Bandipur (Johnsingh 1983), Bdp*- Bandipur (Andheria et al., 2007), NP – Nilgiri Plateau (Cohen et al., 1978), Ngle – Nagarhole (Karanthe and Sunquist 1992), Pench (Acharya et al., 2007), Stp – Satpura (Edgaongar 2008), SW - Singye Wangchuck (Wang 2008), a – Absent, NP – Not present.

4.5.2. Kill

Sex and age classes of prey

During this study, among the total kills recorded the male biased sambar, chital and gaur kills in the diet of tiger were high and both the sex classes (male and female) of chital were utilized equally by leopard. Dhole killed mostly chital sub adult and fawn of both sexes than adult. Male classes of all larger prey species were found to be more susceptible to predation by tiger. Leopard predated on both the sex classes of adult chital and dhole largely predated on chital sub adult and young ones. This male predation may be attributed to presence of large size antlers in deers that may hampur their navigation through thick bushes and solitary habits during the rut. The solitary behaviour of males increases their individual probability of encountering predators and keeping them away from group vigilance which make them more vulnerable to predation. Tamang (1982) observed male biased predation on chital in Chitwan.

Schaller (1967) and Sunquist (1981) made similar observation that tiger killed male sambar frequently than female in the population. Leopard did not show any selective predation on male chital in Mudumalai. Similar observation was reported by Karanth (1993) and Johnsingh (1983). Usually tiger and leopard drag their kill into dense cover for eating and protecting it from scavenging animals (Schaller 1967, Sunquist 1981, Karanth1993). In few incidents the kill of leopard on top of the tree was observed not only in the open place and even in dense semi evergreen forest in Mudumalai. In Chitwan, leopard pulled about half of their kill up on trees (Seidensticker 1976). Dhole predation rate on deer fawns appeared to be high in Mudumalai. Johnsingh (1983), Venkatraman et al., (1995) and Acharya (2007) recorded high fawn predation by dhole, since young prey animals have less chance to escape from the predators than adults (Curio 1976). I did not see any male biased predation on chital by dhole in contrary to the data available from earlier studies (Karanth 1993 and Acharya 2007) but my findings were in accordance with previous study in Mudumalai (Venkatraman et al., 1995) and Bandipur (Johnsingh 1983). In one occasion a medium sized gaur calf was killed by dhole in adjacent semi evergreen forest and on two occasions a female gaur chased a dhole pack of five individuals in the study area. Leopard scavenging evidences were detected on four occasions on gaur and sambar kills made by tiger. Wild pig being an aggressive prey and can retaliate viciously whereas they are in low chance of predation by leopard and dhole but the piglets are vulnerable to predation. Adult wild pig was predated by tiger on two occasion and piglets were killed by leopard and dhole on three occasions during the study period. Karanth (1993) observed male biased tiger predation on wild pig. Though the kill data underestimated the smaller prey occurrence, it illustrated that body size of large carnivores can determine the body size of prey choice. My kill samples for other species were very low to examine it in details. The scavenging behaviour of predators was seen especially in leopard on kill of tiger and dhole. Along with that incidence of tiger (n = 5) and leopard (n = 2) scavenging on dead elephant carcasses and leopard (n = 6) on tiger kill were observed. But the behaviour of scavenging on other predator’s kill was not seen in dhole while one incidence of scavenging on dead elephant carcass by dhole was noticed. Johnsingh (1983) recorded that an elephant calf was killed and eaten by a tiger in Bandipur. Also in Northern Congo, leopard killing elephant calf was recorded (Blake 2004).

Prey size

The average mean body weight of prey killed by three predators was 253 kg for tiger, 37 kg for leopard and 44.5 kg for dhole. Though all three predators were capable of killing larger prey, tiger mostly killed larger body sized prey. This showed that carnivores usually prey upon herbivores of about their own size and weight. It is likely that risk of injury during prey capture may be the reason underlying the lower preference for large body sized prey by leopard and dhole.

Heath condition of prey species

Among all the predator kills, more than 95% of them were found in good health condition as revealed by bone marrow analysis. Karanth and Sunquist (1995) reported that 13 to 23% of the prey species kills in Nagarahole were in poor health condition.

Overall, tiger kills on sambar (26.8%) from this study, was similar to as reported in Nagarahole (28.6%) (Karanth and Sunquist 1995), Kanha (24.6%) (Schaller 1967) and lower than Bandipur (36.8%) (Johnsingh 1992). The kill of tiger on chital was 17.1% in Mudumalai which was lower than as reported from Kanha (43%) (Schaller 1967), Bandipur (26.3%) (Johnsingh 1992) and higher than Nagarahole (10.4%) (Karanth and Sunquist 1995). The reported gaur kills in the study area (29.3%) was found higher than as reported from Kanha (6.1%) (Schaller 1967) and lower than Nagarahole (44.8%) (Karanth and Sunquist 1995). Tiger kill on wild pig in Mudumalai was 7.3% which was lower than as reported from Nagarahole (14.3%) (Karanth and Sunquist 1995), Bandipur (21%) (Johnsingh 1992) and higher than Kanha (4.4%). Other prey species killed by tiger formed a minor proportion.

Leopard kills on sambar was 5% in Mudumalai which was similar to studies available from Bandipur (5%) (Johnsingh 1992) and lower than Nagarahole (9.6%) (Karanth and Sunquist 1995). Common langur predation by leopard was 10% in Mudumalai which was lower than the findings from Nagarahole (17%) (Karanth and Sunquist 1995) and higher than Bandipur (1.2%) (Johnsingh 1992).

During the present study, 17.1% kills by dhole on sambar was similar to as reported from Bandipur (18.5 %) (Johnsingh 1992), higher than Nagarahole (3.0%) (Karanth and Sunquist 1995), Pench 13.1% (Acharya 2007) and lower than earlier report in Mudumalai (31.2%) (Venkatraman 1995). Dhole kills on chital in Mudumalai was 77.1%, which is similar to the findings from Bandipur 79% (Johnsingh 1992), Pench 81.8% (Acharya 2007) while predation on wild pig was higher than as reported from Pench (1.5%) (Acharya 2007) and Nagarahole (1.0%) (Karanth and Sunquist 1995).

My results support the prediction of Giffths (1975) and Karanth and Sunquist (1995) that vertebrate predators would be selective energy maximizers in prey rich habitats, but would be non selective number maximizers where large prey were scarce. The heterogeneous habitat and diverse ungulate prey species biomass allowed the predator's to coexist in the study area. The findings are related to foraging theory which suggests that predators may select species containing the most profitable prey by the ratio of energy gain to handling time (Scheel 1993). Present food habits study results are in accordance with those from other available studies in India (Johnsingh 1983, Karanth and Sunquist 1995, Venkatraman et al., 1995, Andheria et al., 2007). Prey species larger than predator size make a greater dietary contribution than prey species smaller than the predator, because of greater biomass. Leopards and dholes are selective towards larger ungulate prey when they are available, although predation on some large ungulates is limited only to young individuals (Karanth & Sunquist, 1995). Over all these predators depend largely on wild ungulates than domestic livestock in the study area, which enhanced their long – term survival in Mudumalai.

CHAPTER 5

POPULATION ESTIMATION OF LARGE CARNIVORES

5.1. Introduction

Population estimation of large carnivores such as tiger, leopard and dhole is a main stream tool in ecological studies where these species are sympatric in similar habitats, serving as umbrella species across a wide array of habitats and are functionally important components of the ecosystem. Umbrella species are those 'species with large area requirements, which if given an area of sufficient protected habitat, will bring many other species under protection' (Noss 1990, Caro 2003). The decline and extirpation of top carnivores from fragmented ecosystems may generate tropic cascades that alter the structure of ecological communities, so the persistence of these keystone species can indicate levels of ecosystem health (Crooks 2002). Populations of predators, particularly obligatory meat-eating carnivores, depend on prey resources. Having high dietary overlap between these species in their diet in a prey rich habitat and co-existence with each other, are by selecting different sized prey. The loss of habitat, poaching for trade, declining prey populations and conflicts with humans primarily provoked by predation on livestock has overall endangered tiger and threatened dhole and leopard populations (Sunquist 1981, Nowell and Jackson 1996, Wang and Macdonald 2009). The Western Ghats landscape has already lost a large part of its forest cover and the remaining forests are threatened with ever increasing anthropogenic pressure (Rodgers and Panwar 1988). This necessitates strict conservation measures to prevent further loss of biodiversity and ecosystem processes (Jhala et al., 2008). It is also necessary to come up with management oriented issues especially for sympatric large carnivore population status. Large terrestrial carnivores are difficult to monitor because they are shy, solitary and nocturnal with wide ranging patterns confounding efforts to obtain reliable populations. Without careful consideration of population dynamics across habitats, conservation efforts may be poorly applied, thus delaying species ecological understanding. Complete counts of carnivore numbers are often impractical, expensive, and time-consuming. An alternative sampling measure was developed to estimate the abundance of tiger and leopard population based on pugmark census (Choudhary 1970, 1971, Panwar 1979, Sawakar 1987, Sharma 2001). This method was found to be error prone and lacked statistical rigor (Karanth et al., 2003). The mark-recapture method has long been used to estimate biological populations (Otis et al., 1978). Karanth (1995) and Karanth and Nichols (1998) developed a method to estimate tiger population using photographic capture–recapture analysis in Nagarhole, India. Following which it has been widely used to estimate population of tiger (Karanth and Nichols 1998, 2000, 2002, Karanth et al., 2004, Edgaongar 2008, Jhala et al. 2008, Harihar et al. 2009, Sharma et al., 2009, Riddhika 2009, Wegge et al., 2009, Wang and Macdonald 2009) and leopard in the Indian Sub-continent (Chauhan et al., 2005, Sankar et al., 2008, Edgaonkar 2008, Harihar et al., 2009, Riddhika 2009, Wegge et al., 2009 and Wang and Macdonald 2009), tiger in other countries (O'Brien et al., 2003, Kawanishi and Sunquist 2004, Johnson et al., 2006, Linkie et al., 2006), leopard in other countries (Balme et al., 2007, Henschel 2008, Khorozyan et al., 2008) and other species such as, snow leopard, ocelot, jaguar and puma, bobcat and Geoffroy's cats (Trolle and Kerry 2003, Wallace et al., 2003, Maffei et al., 2004, Silver et al., 2004, Bitetti et al., 2006, Cuellar et al., 2006, Harmsen 2009, Heilbrun et al., 2006, Jackson et al., 2006, Soisalo and Cavalcanti 2006, Dillon and Kelly 2007, Kelly et al., 2008). This method requires identification of individual animals (from photographic evidence) by their natural markings (i.e., stripe and spot patterns). Individual identification of species is necessary in order to create individual capture histories and perform mark–recapture analysis to estimate abundance.

Although the principles underlying camera trap surveys are statistically robust, few studies have validated their results against independent abundance estimates. Further, when providing a density estimate, size of the sampled area must be determined as precisely as possible (Karanth and Nichols 2002). Size of the sampled area is not necessarily equal to the area enclosed by the outer traps because home ranges of some individuals may extend beyond borders of the survey area (Wilson and Anderson 1985). It is therefore customary to add a boundary strip onto the survey area. Karanth and Nichols (1998) used a boundary strip equivalent to half the mean maximum distance moved (1/2MMDM) by tigers photographed on >1 occasion as a proxy of home range radius. Subsequently, numerous authors have suggested that using 1/2MMDM from photographic recaptures underestimates actual distances moved and thus overestimates the resulting population density estimates (Sharma et al., 2009). A boundary strip calibrated is calculated using independent estimates of home range size obtained from radio-telemetry data would be more appropriate (Soisalo and Cavalcanti 2006). Many studies (Dillon & Kelly 2008, Soisalo & Cavalcanti 2006, Sharma et al., 2009) suggested that actual density of tigers from Full MMDM and spatial likelihood estimate are close to radio collared tiger estimates calculated by home-range radius. A relatively new maximum likelihood method would explicitly account for the spatial nature of this mark-recapture study design in population estimation studies (Borchers and Efford 2008). Given the increasing use of camera-trap surveys, it is essential that these issues are addressed. Accurate estimates of populations obtained through mark–recapture data collected from recognizable individuals over the entire population range are rarely available (Cabone et al., 2002).

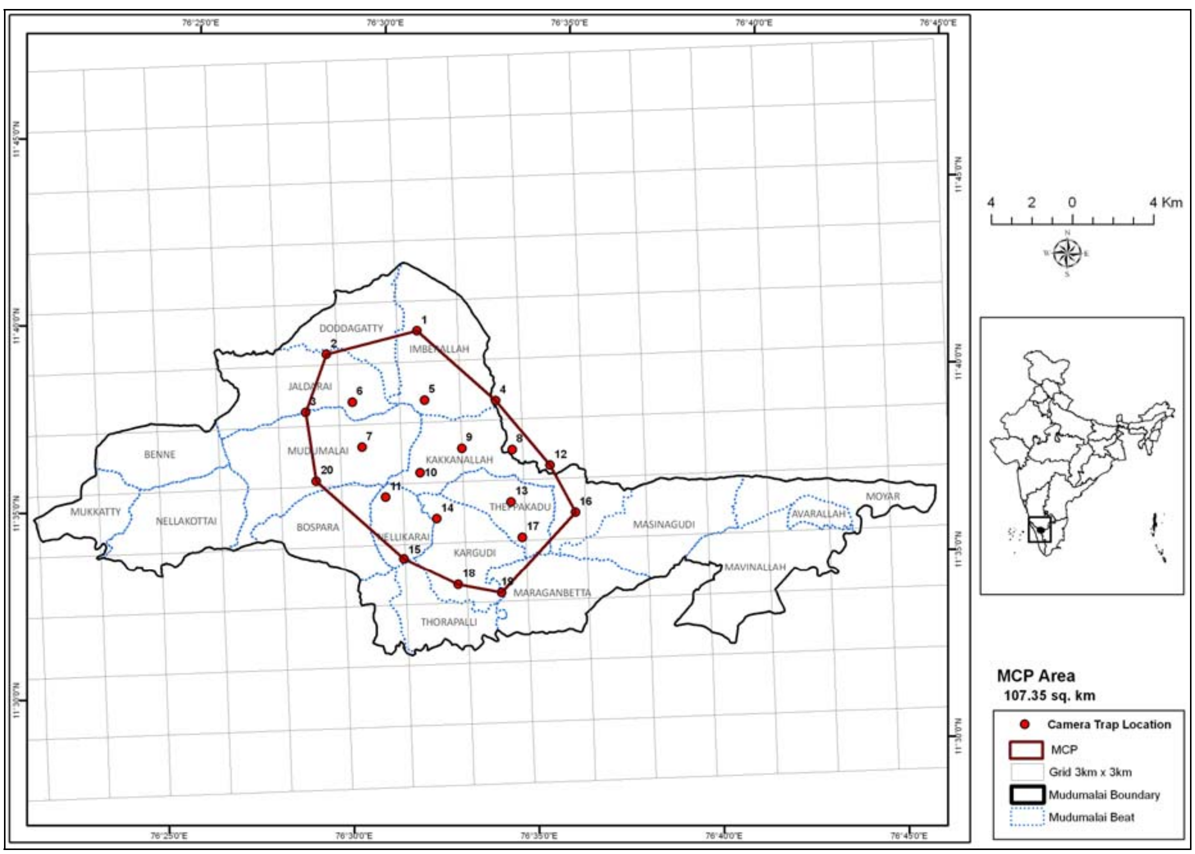
Studies sampling multiple species indicate that results are biased towards different species when using different sampling methods or different sampling designs. Camera trapping seemed to be appropriate for tiger and leopard unlike dholes as the latter cannot be individually identified to derive their true abundance. Besides individual identification or population estimation, camera trapping can also provide other biologically relevant information such as temporal variations (Karanth and Sunquist 2000, Maffei et al., 2004, Di Bitetti et al., 2006). Activity patterns in mammals can be influenced by foraging, prey behavior, predator avoidance, physiological traits, cover and climate (Seidensticker 1976). Camera trapping technique could provide a useful index of animal abundance; especially for species that cannot be individually recognized from their markings and rate based indices should only be used where more rigorous methods cannot be implemented (Carbone et al., 2002, O'Brien et al., 2003, Johnson et al., 2006, Datta et al., 2008, Rowcliffe et al., 2008). The use of statistically robust indices to monitor population trends have been suggested, such as camera trapping rates (Carbone et al. 2001, Karanth & Nichols 2002) or occupancy models (MacKenzie and Nichols 2004), but these methods are unable to provide an estimate of the number of individuals in the carnivore occupied landscapes. Besides, methods involving photographic rates may not be an advisable method for pack living dholes as cameras are unable to detect all members in a pack. Different species will have different microhabitat preferences and therefore there is no reason to expect that different species have similar capture probabilities along different trails. Dhole population was estimated in India by dhole pack monitoring (Johnsingh 1982, Venkatraman et al., 1995) and radio-telemetry (Acharya 2007). Since my study site has good network of roads, vehicle transects were considered to be a convenient method for estimating population of dhole. Vehicle transect frequently used along road networks act as a substitute to foot transects for prey species count (Ogutu et al., 2006, Ward et al., 2004, Ramesh et al., 2009). These yield larger effort at the same time. However, the resulting estimate may be biased as roads are not randomly laid with respect to animals (Varman and Sukumar 1995). Some species are attracted to open habitats created (Ramesh et al., 2009) along roads while other species may avoid this disturbance. This is depending on the arrangement of the road network within the habitat and the species being monitored whereas dholes are often found travelling as a pack along roads for locating prey species because of more visibility. In this study, I believe that density estimation and temporal separation of tiger, leopard and dhole would be an important phenomenon in prey–predator community study because they inhabit similar habitats, selecting morphologically similar prey bases at diverse levels with different hunting strategies in areas having high prey base. Reliable count of sympatric species which are closely related or ecologically similar may contribute to a better understanding of animal ecology. Estimates of large carnivore density from a single location over the years can yield estimates of trends in population change.

5.2. Methods

5.2.1. Camera trapping

Camera trapping was conducted for large carnivores between March 2008 and April 2010 in Mudumalai. The study area of 321 km^2 of Mudumalai was overlaid with grid cells of 3 km x 3 km (Map 4.). After initial preliminary sign survey for large carnivore presence, 107 km^2 area of deciduous forest (moist and dry deciduous) of Mudumalai was selected as the intensive study area. Within the deciduous habitat, each grid had at least one pair of camera to ensure uniform distribution of camera locations (n=20) and trapping was continued between November and May for three consecutive years with a minimum of 70 days to a maximum of 100 days. Therefore crucial sample design of the whole study area ensured even coverage of camera traps, without leaving gaps large enough to contain an individual's movements. The camera stations were placed usually on roads, trails, nullahs or near water holes to maximize tiger, leopard and dhole captures based on observation of indirect signs (pugmark, scat, scrapes and kills) and direct sightings. Each station comprised two pairs of passive infrared cameras (DEERCAM^{TM} DC 300 or STEALTH CAM^{TM}) to simultaneously photograph both flanks of large carnivores. Cameras were loaded with 36-print, 200 American Standard Association (ASA) 35-mm film.

Map 4. Location of camera trap sites in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).



Cameras were active 24 hrs with lowest photographic delay (15 seconds in DEER CAM and 60 seconds in STEALTH CAM) between pictures to avoid large herds of ungulates or other group living species in exhausting the film rolls. Initially for two years (2008 - 2009) only DEER CAM were used while in the third year 50% of them were replaced with STEALTH CAM. I had set up the date and time option to provide information needed for estimation of activity patterns. This date and time setting option together was not available in STEALTH CAM while only date: month: year option was set in STEALTH CAM in the third year. The cameras were mounted on wooden posts at a height of 30–40 cm from the ground placed at 2–3 m on either side from the centre of the trail or road so as to protect cameras from weather and animal damage. Camera traps that are triggered by heat and motion sensors are set at a high sensitivity level to increase the detection level. Variation in trap spacing has shown to have a strong impact on density estimates (Wegge et al., 2004, Contractor 2008). In the prey rich forest habitat of Mudumalai, adult female home range of tiger and leopard can be as small as 15 km^2, therefore I placed at least two camera trap stations in an area of this size, which translated to a trap spacing of ca. 2 to 3 km. Each camera was checked every two to three days to replace film and batteries. We restricted the duration of camera trapping from 70 to 100 days at study sites, because capture-recapture models applied in this study assume demographic closure of the study population and in prior studies on large cats it was suggested that trapping periods of 2-3 months would be sufficiently short to assume that no population change occurred during the study (Karanth 1995, Karanth and Nichols 1998, Silver et al., 2004). Camera trapping was conducted in the driest months of the year, as heavy rain was found to result in technical failures of the camera units and other operational difficulties during monsoon. Each camera unit was given a unique ID number (eg. CT1A, CT2A…….CT20A) and each film roll was marked e.g. CT 1A/Roll1, CT 2A/Roll1, enabling me to correctly note the date, time and location of the photographs resulting from each photograph. Every tiger and leopard captured was given a unique identification number e.g. for tigers TL1 (left flank) and TR1 (right flank) whereas for leopards LL1 (left flank) and LR1 (right flank) after examining the stripe and rosette patterns on the flanks, limbs and fore-quarters. Individual tigers and leopards were identified from photographs using variations in their pelage patterns. I used both sides left and right flanks separately for further analysis.

5.2.2. Vehicle Transect

Data on population estimation of dhole was collected between January 2008 and December 2009. Five vehicle transect routes ranging from 15 to 23 km were monitored to record dhole sightings (Map 3.). The total length of 93.5 km was monitored twice in a month during early morning and late afternoon which resulted in a total effort of 3740 km. On each sighting of dhole along vehicle transects, the following information was recorded; group size, sex and age classes if possible and perpendicular distance from the road to the centre of initial dhole group sighting. To get desirable level of precision in the result, vehicle transect sighting data was pooled for two years and and analysed to estimate dhole density within the study area.

5.3. Analysis

5.3.1. Camera trapping

5.3.1.1. Capture and recapture frame work

Individual tiger and leopard can be identified relatively easily by means of their unique stripe and rosette pattern and this natural marking permits the application of capture-recapture models for such species where recaptured individuals can be readily recognized following the method developed for tigers in India (Karanth 1995, Karanth and Nichols 1998, Karanth and Nichols 2002). Population sizes can be estimated statistically if some of the animals can be individually identified and periodically recaptured (White et al., 1982). For each site, after identification of all tigers and leopards, left and right flanks separately and either right or left flank was chosen for further analysis based on maximum number of photographic capture rate. Further capture history was created for each individual by assigning either “1”, or “0”, depending on if the individual was captured on each occasion, where each trap day represented a separate capture occasion. To use closed population models, I assumed demographic and geographic closure. The short sampling periods (minimum 40 days to maximum 100 days) relative to a carnivore's long life and high survival will most likely not violate the demographic closure assumption. To test our closure assumption, Stanley & Burnham closure test was used by program Close Test (Stanley and Richard 2005) that tests a null model allowing for time-specific variation in capture probabilities (Stanley and Burnham 1999). To satisfy the closure requirement, reduce no capture of blank space between trapping days matrix and to achieve an adequate capture probability for analyses, I defined a sampling occasion as five successive trap nights, resulting in 14 to 20 sampling occasions for the entire 70 to 100 days survey in three years time. Capture histories were stored as an 'X matrix' for each site separately and were analyzed using the software MARK (White and Burnham 2000). MARK offers seven different estimators of population size to account for differences in capture probability between different individuals and sampling occasions, variations over time or as a reaction to prior capture, and several combinations of these. It is also possible to select all estimators of population size and MARK will assign scores from 0.0 to 1.0 for each potential model, where the highest score represents the best fit (Otis et al., 1978). A Jackknife estimator (Otis et al., 1978), successfully used in earlier photographic capture studies (Karanth 1995, Karanth and Nichols 1998) was used to estimate capture probabilities (P) and tiger or leopard population size (N). Model Mh assumes heterogeneity among individuals in their capture probabilities, expected behavioural differences among individuals and their unequal access to camera traps. I used Mh model which was the best-fit model in many studies as it takes care of heterogeneity in the data set. Hence I preferred using the model Mh with jackknife estimator. For each selected model MARK produces an estimate of capture probability and a resulting population size with confidence limits and standard error. The actual population density is then obtained by dividing the resulting population size by the size of the effectively sampled area. This is defined as the area covered with camera traps plus a boundary strip around the outer traps to account for an additional area from which individuals may enter the trapping polygon (White et al., 1982). The width of this strip should be equivalent to the radius of an average home range, and for trapping studies the mean maximum distance moved (MMDM) by animals that were captured on more than one occasion can be used as an approximation of home range diameter (Wilson & Anderson 1985). Consequently, ½ MMDM was used to define boundary strip width of the study site. Recently Sharma et al., (2009) suggested that the actual density of tigers from Full MMDM and spatial likelihood estimate are close to radio collared tigers estimated by home-range radius while density based on ½ MMDM is likely to produce overestimates. Therefore I used Full MMDM by adding individuals to the boundary strip width. Both the methods were used to calculate density of tiger using buffer width in the study area. However, statistical analysis of passive detections is not straightforward because not all individuals are detected and not all detected animals live within the perimeter of the array, resulting in both uncertainity about the area sampled and heterogeneity in the detection probabilities of individuals called as edge effects (Efford et al., 2009). Conventional methods do not address the problems caused by edge effects. Capture–recapture methodology has been extended recently to spatially explicit capture–recapture so that it provides direct estimates of population density unbiased by edge effects (Efford et al., 2009). Density was also calculated using these alternative approaches *viz* simple spatial explicit capture–recapture model which does not restrict the density to the sampled area but makes it global (Efford 2004). This model considers point process where animal home range centers are distributed across the study area as point processes in space with density (D). During a closed population study each animal is assumed to occupy a home range centered at an unknown location and the traps are set at known locations and catch at least one animal. Considering only one animal per trap, capture probability of the animal is a declining function of distance (d) between the range centre and the trap, which is analogous to the detection function g(d) in distance analysis (Borchers and Efford 2008). This function requires parameters g0 for overall magnitude and α for the spatial scale over which the density declines. These parameters along with D define the individual based model of capture process. Consider a distribution of point process with density D, the expected number of such processes in two-dimension by simply multiplying density D with the Area A (N = D.A), but in reality the actual number varies depending on the spatial variance associated with each point process. Inverse prediction incorporates this variance into the uncertainty of the estimate of the number of such process. This is appropriate for the generalization of entire spatial process rather than the conventional method of restricting to the measure of density of one realization obtained in the vicinity of the trap grid. It is also more appropriate to incorporate this spatial variance into the estimate as the animal distribution in nature is a Poisson process. Such Poisson distribution is assumed and animal density estimates are obtained through simulation as spatially explicit maximum-likelihood. Program DENSITY (Efford 2004) uses a spatially explicit maximum-likelihood method to estimate density from capture-recapture data. This approach uses the trap locations of each individual animal detected to fit a spatial model of the detection process to obtain estimates that are unbiased by trapping-grid edge effects (Efford 2007). The necessary calculation for the above mentioned methods were carried out using software DENSITY 4.1 (Efford 2004). Data was analyzed year wise following the same methodology. To achieve an adequate capture probability for analyses, collapsing 5 days to a sampling occasion still maintains the original data structure and also makes it possible for software packages to produce precise estimates. Therefore I provided different density estimates for the study site year wise using the following methods; 1/2 MMDM, Full MMDM and spatially explicit maximum-likelihood method.

In addition, photographic rate seemed to correlate well with animal abundance making it more useful for non-identifiable species (Carbone et al., 2001). I assessed the relative abundance index of tiger, leopard and dhole by using a camera trap-based abundance index used previously in studies on tigers and their prey (O'Brien et al., 2003, Kawanishi and Sunquist 2004, Johnson et al., 2006). The relative abundance index (RAI) was calculated for tiger, leopard and dhole for the entire study area by dividing total number of photographs from total trap nights and depicted in the form; number of photographs/100 trap nights. Total photographs included both right and left flank along with unidentified pictures of individuals. But a repeated photograph of the same individual within 30 seconds was discarded from analysis. This analysis was done year wise.

5.3.1.2. Temporal activity pattern

Photographs provide information on the date and hour of the picture taken and can be used to study daily activity patterns of wild animals. Sometimes individuals were photographed from only one of the two cameras operating at a single camera station. The event of capturing an individual animal, whether it was photographed by two camera traps or one, was considered to be a record of that animal. On rare occasions, an individual was captured more than once at a camera station during a short period of time (<1 minute) and to avoid pseudo-replications I only considered the first capture of that animal as a record. Activity levels were calculated from the date and time imprinted on photographs. Photos without time were discarded from analysis. The percentage of activity level was used to indicate whether large carnivores are nocturnal or diurnal. The time of capture was used to create a 24 hrs activity pattern for three species. The number of photographs was summed within two hours each for eg; 0100–0300 h, 0301–0500 h … etc. and converted to percentage of captures within an hour to facilitate comparisons between the three species. Temporal activity pattern for tiger, leopard and dhole was documented from 2008 to 2009.

5.3.2. Vehicle transect

Camera trapping method was relatively straight forward for well-marked species (tiger and leopard) unlike non-identifiable species (dhole). Though, animal population is estimated based on perpendicular sighting distance following the line transect method (Burnham et al., 1980, Lancia et al., 1994 and Buckland et al., 2001), I used dhole sightings and their perpendicular distances from vehicle transects, and their density was estimated using program Distance 6.0 (Thomas et al., 2009). The best model was selected on the basis of lowest Akaike Information Criteria (AIC) values (Buckland and Burnham 1997, Burnham et al., 1980). Suitable modifications with right truncation were made to ensure a reliable fit of key functions and adjustment terms to the data so as to arrive at density estimates. To get better estimates of species, a minimum number of observations are required in order to model the detection function and hence sightings from morning and evening vehicle transect data were pooled together for two years (2008 and 2009) and analyzed.

5.4. Result

5.4.1. Camera trapping

5.4.1.1. Capture and recapture framework

A total of 9600 trap nights over a period of three years in the study area yielded independent photographic captures (including right, left and unidentified photos) of 214 tigers and 307 leopards and 164 dhole photographs (Table 46.). Total number of males, females and unidentified individuals of tiger was 9, 25 and 4 respectively based on left flank and 11, 24 and 3 respectively from right flank (Table. 45). Identified male, female and unidentified leopard was 16, 27 and 8 respectively based on right flank and 17, 34 and 2 respectively based on left flank (Table 45.). Based on maximum capture probability of either right or left flank, the identified individuals of tiger and leopard varied from 16 to 22 for tiger and 18 to 27 for leopard from camera trapping in each year and the sampling period varied from 70 to 100 days (Table 42 and 43.). Tiger capture rate declined in the first and second year and gradually increased during third year. Leopard capture rate gradually increased from second year onwards. In 2009, capture rate of tiger and dhole declined drastically as compared to leopard. The estimated male: female ratio was 0.41: 1 for tiger and 0.54: 1 for leopard based on both right and left flank. Mh model ranked second as the most appropriate model following by Mo model for both tiger and leopard in this study. Although the null model (Mo) ranked higher, the estimator based on this model was not robust to violations of the underlying assumption that capture probabilities do not vary between individual tigers. Mh model ranked second as the most appropriate model followed by Mo model for both tiger and leopard in the study. Mh model was chosen because tiger and leopard would have heterogeneous capture probabilities. Mh model was best fitted for tiger and leopard for all the years. Mh model is known to be a robust model (Otis et al., 1978). To generate parameter estimates under the Mh model, I used the jackknife estimator (Burnham & Overton 1978, Otis et al., 1978) implemented in MARK, which had performed well in earlier photographic capture studies of tigers in the same landscape (Karanth 1995, Karanth & Nichols 1998). Therefore the population size estimate was computed using Mh jackknife model. Test for population closure was not significant for tiger, indicating that the assumption of demographic closure was not violated during the study interval while for leopard, only in 2009 the closure assumption was violated significantly (P = 0.05) (Table 44.). The capture probabilities for Mh model ranged from 0.06 to 0.09 for tiger and 0.05 to 0.01 for leopard. Density D (±SE) and effective trapping area ETA was calculated by different methods using program DENSITY 4.4 is given in Table 42 and 43. The estimated population size ranged from 26.7 to 28.9 individuals for tiger and 26.0 to 34.9 individuals for leopard. Since spatially explicit models ML estimate had low coefficient variation compared to IP, ML method result was considered. The present estimate of tiger and leopard density (±SE)/100 km^2 using 1/2MMDM and MMDM and Maximum Likelihood methods in deciduous habitat was 17.7 ± 3.3, 12.6 ± 2.9, 11.7 ± 2.9 and 25.5 ± 4.2, 19.4± 3.7, 18.2 ± 4.0 respectively. The overall mean maximum distance moved (MMDM) by tiger and leopard was 3.1 km and 2.3 km respectively (Table 40 and 41.). The mean maximum distances moved were fairly constant across the study duration for tiger while for leopard it showed decrease in 2009. The average value of relative abundance index (RAI) capture/100 trap night was 2.3 for tiger, 3.2 for leopard and 1.8 for dhole (Table 46.). When tiger and leopard density was correlated with RAI index of a particular species in each year, there was some relation between RAI and tiger and leopard density (Figure 10 and 11.). The tiger and leopard density did vary w.r.t RAI in each year.

Table 40. Camera trapping details of tiger in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

Years	Sampling days	Traps	Trap days	Right Flank	Left Flank	Mt+1	Total no. of capture	d bar	MMDM
2008	70	20*2	2800	0	1	16	25	3.34±1.19	3.38±1.56
2009	100	20*2	4000	1	0	19	42	1.85±0.459	3.63±0.855
2010	70	20*2	2800	0	1	22	42	2.38±0.589	2.54±0.725

Mt+1 - No. of individuals caught, d bar - Mean capture distance, MMDM – Mean Maximum Distance moved, 1 – Either right or left flank taken for further analysis, 0 – Either right or left flank taken for further analysis.

Table 41. Camera trapping details of leopard in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

Years	Sampling days	Traps	Trap Night	Right Flank	Left Flank	Mt+1	Total no. of capture	d bar	MMDM
2008	70	20*2	2800	0	1	18	27	1.53±0.675	1.97±0.798
2009	100	20*2	4000	1	0	23	55	0.502±202	1.02±0.402
2010	70	20*2	2800	0	1	27	62	1.35±0.283	1.88±0.448

Mt+1 - No. of individuals caught, d bar - Mean capture distance, MMDM – Mean Maximum Distance moved, 1 – Either right or left flank taken for further analysis, 0 – Either right or left flank taken for further analysis.

Table 42. Density estimates of tiger using different methods in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

Years	Model	Mt+1	N	SE	P hat	Method	ETA	Density /100KM^2	SE
2008	Mh Jacknife	16	27.4	7.0	0.06	1/2MMDM	182.9	16.0	5.2
						MMDM	276.3	11.1	4.6
						IP		11.2	7.1
						ML		10.0	3.7
2009	Mh Jacknife	19	26.7	4.7	0.059	1/2MMDM	189.3	14.1	3.0
						MMDM	291.9	9.2	2.3
						IP		8.3	5.9
						ML		9.2	3.0
2010	Mh Jacknife	22	28.9	4.5	0.09	1/2MMDM	162.5	17.7	3.3
						MMDM	227.7	12.6	2.9
						IP		12.5	3.7
						ML		11.7	2.9

N – Population size, Mt+1 - No. of individuals caught, SE – Standard error, P hat – Capture probability, 1/2MMDM – Half Mean Maximum Distance Moved, MMDM - Mean Maximum Distance Moved, IP – Inverse Prediction, ML – Maximum Liklihood, ETA – Effective Trapping Area.

Table 43. Density estimates of leopard using different methods in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

Years	Model	Mt+1	N	SE	P hat	Method	ETA	Density /100 KM^2	SE
2008	Mh Jacknife	18	34.9	8.8	0.051	1/2MMDM	149.4	23.4	6.5
						MMDM	197.5	17.6	5.8
						IP		19.5	12.5
						ML		15.2	5.6
2009	Mh Jacknife	23	30.0	4.6	0.086	1/2MMDM	125.5	23.6	4.0
						MMDM	145.0	20.7	4.1
						IP		16.2	3.9
						ML		14.9	3.5
2010	Mh Jacknife	27	26.0	2.5	0.097	1/2MMDM	147.3	25.5	4.2
						MMDM	192.8	19.4	3.7
						IP		16.7	6.0
						ML		18.2	4.0

N – Population size, Mt+1 - No. of individuals caught, SE – Standard error, P hat – Capture probability, 1/2MMDM – Half Mean Maximum Distance Moved, MMDM - Mean Maximum Distance Moved, IP – Inverse Prediction, ML – Maximum Liklihood, ETA – Effective Trapping Area.

Table 44. Stanley & Burnham closure test result for tiger and leopard using program Close Test in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

Years	Tiger		Leopard	
	Chi square Value	P- Value	Chi square Value	P- Value
2008	4.9	0.89	10.5	0.31
2009	12.2	0.51	26.2	0.05
2010	9.7	0.64	7.4	0.83

Table 45. Photographic capture of individual male and female tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

Years	Tiger Right Flank			Tiger Left Flank			Leopard Right Flank			Leopard Left Flank		
	M	F	Un	M	F	Un	M	F	Un	M	F	Un
2008	5	9	0	6	10	0	7	7	2	8	9	1
2009	5	15	1	5	11	0	8	14	1	12	18	1
2010	6	13	3	6	13	3	12	15	4	9	17	1

M- Male, F – Female, Un - Unidentified

Table 46. Relative abundance index (RAI) for tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

Years	Trap Night	Tiger		Leopard		Dhole	
		Total Capture	RAI	Total Capture	RAI	Total Capture	RAI
2008	2800	57	2.0	53	1.9	53	1.9
2009	4000	68	1.7	126	3.2	40	1.0
2010	2800	89	3.2	128	4.6	71	2.5

Figure 7. Cumulative number of tiger and leopard photographs in Mudumalai Tiger Reserve, Tamil Nadu (January to April 2008).

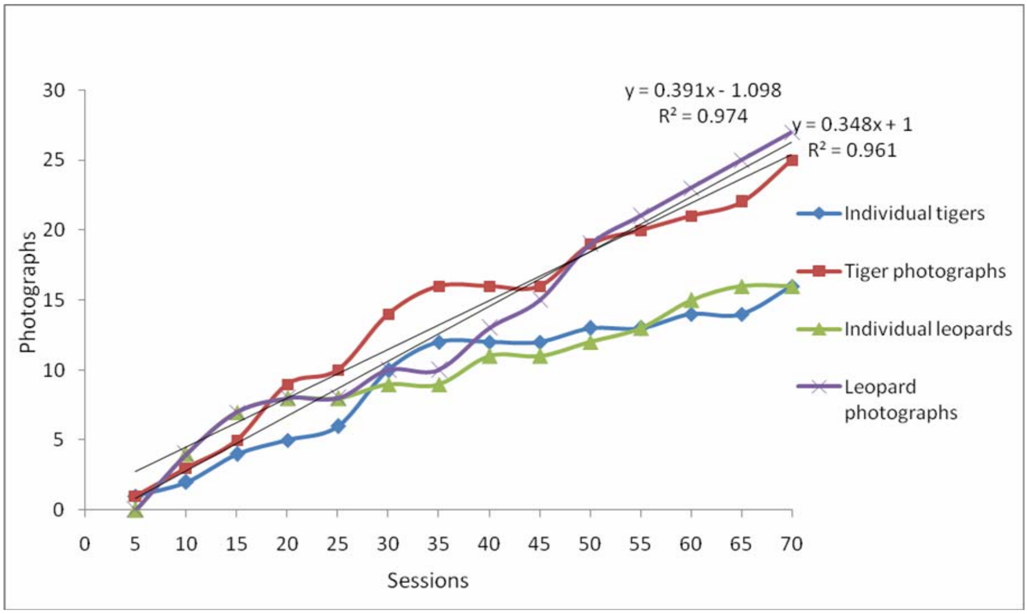


Figure 8. Cumulative number of tiger and leopard photographs in Mudumalai Tiger Reserve, Tamil Nadu (January to April 2009).

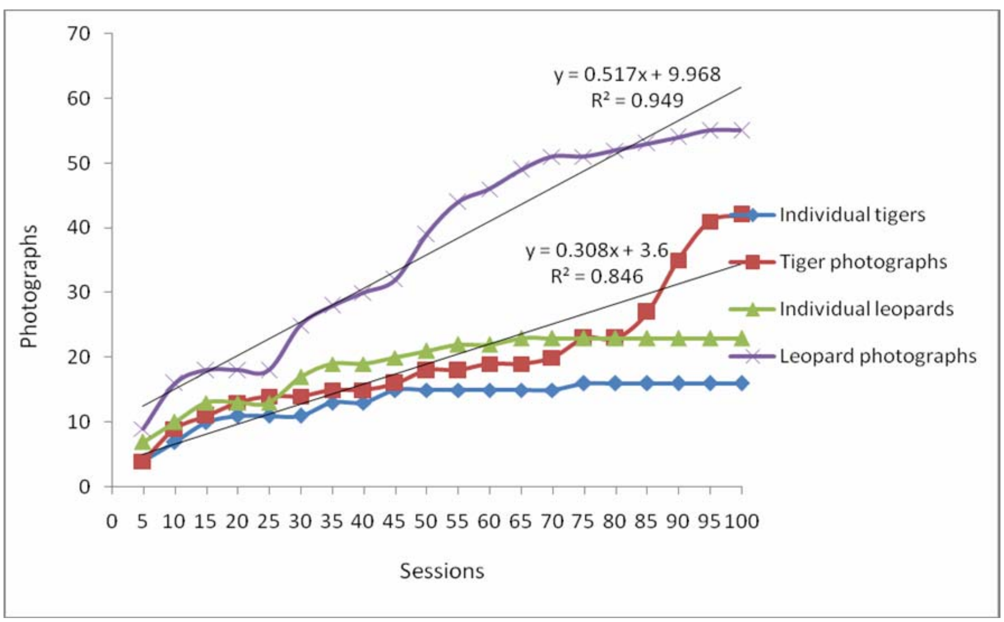


Figure 9. Cumulative number of tiger and leopard photographs in Mudumalai Tiger Reserve, Tamil Nadu (January to April 2010).

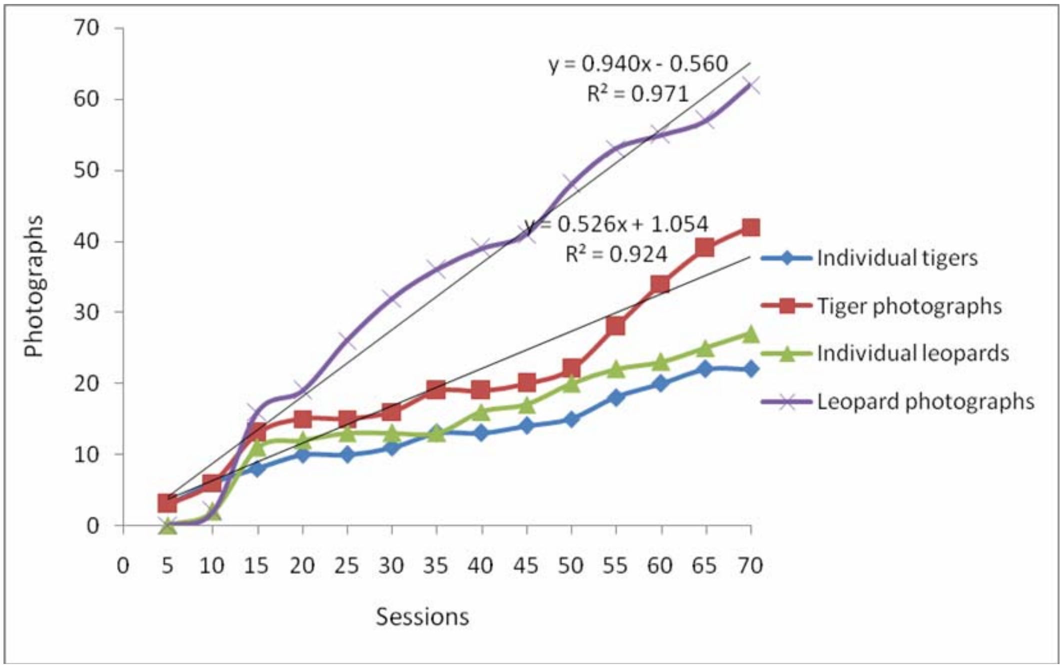


Figure 10. Correlation between tiger density and RAI value in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).

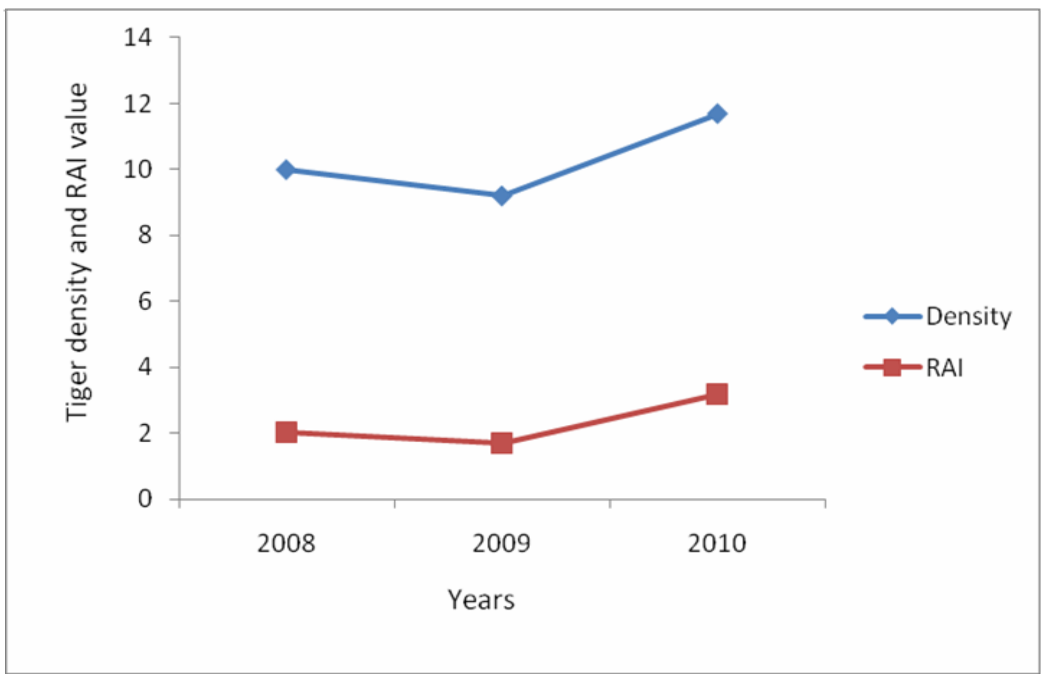
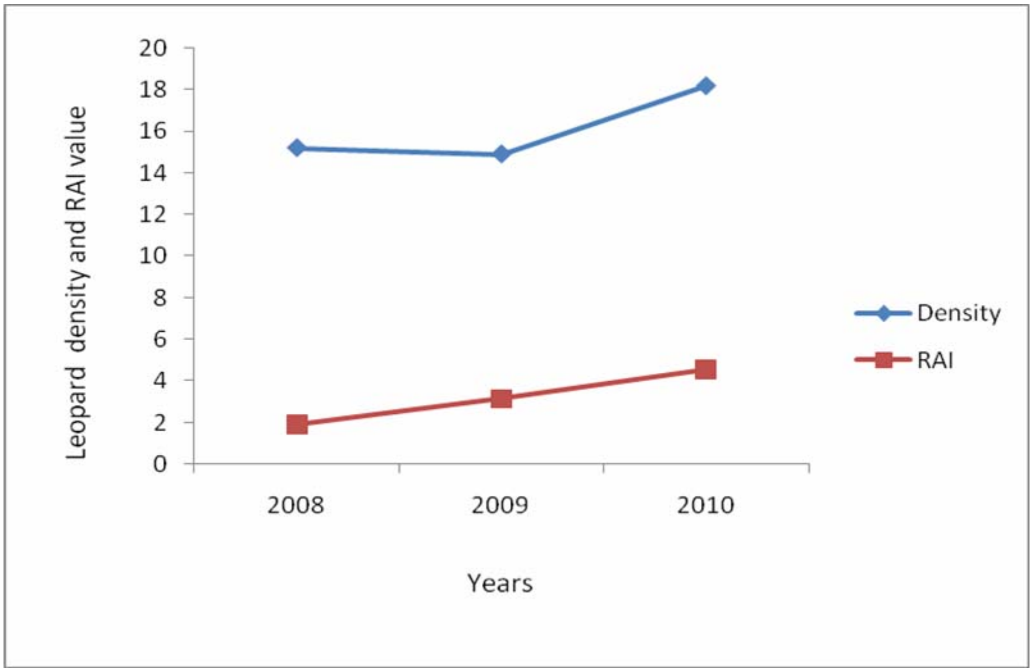


Figure 11. Correlation between leopard density and RAI value in Mudumalai Tiger Reserve, Tamil Nadu (January 2008 to April 2010).



The number of new individual tiger and leopard captures stabilized after 70 days in 2009 when number of days increased and hence the possibility of capturing more new individuals may not be possible in these years (Figure 8.). Species accumulation curve did not appear to reach a plateau after 50 days in 2008 and 2010 suggesting that few additional individuals would have been detected with increasing trapping effort or increasing number of cameras to reduce inter-trap distance (Figure 7 and 9.).

5.4.1.2. Activity patterns

Tigers showed two peaks of activity, one after midnight and the other just after sunset and dholes were found active in the early mornings just after sunrise and evening and showed reduced activity during the hottest parts of the day in 2009 (Figure 12.). Leopard's activity was more or less similar throughout the day in 2009. Moreover all three species were captured more in the morning in 2008, their peak activity differed at different times and the frequency of all predator captures dropped suddenly in the evening (Figure 13.). Tiger and leopard showed some activity in the evening and mid-night while dhole was more active after sunrise in 2008.

Figure 12. Activity pattern of tiger, leopard and dhole based on camera trap photo captures in Mudumalai Tiger Reserve, Tamil Nadu. (January to April 2008).

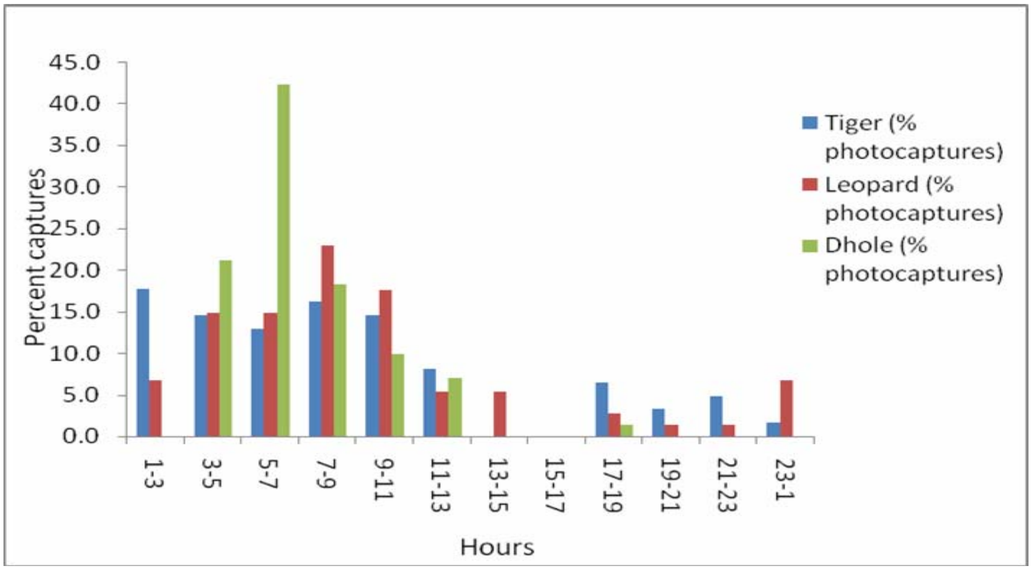
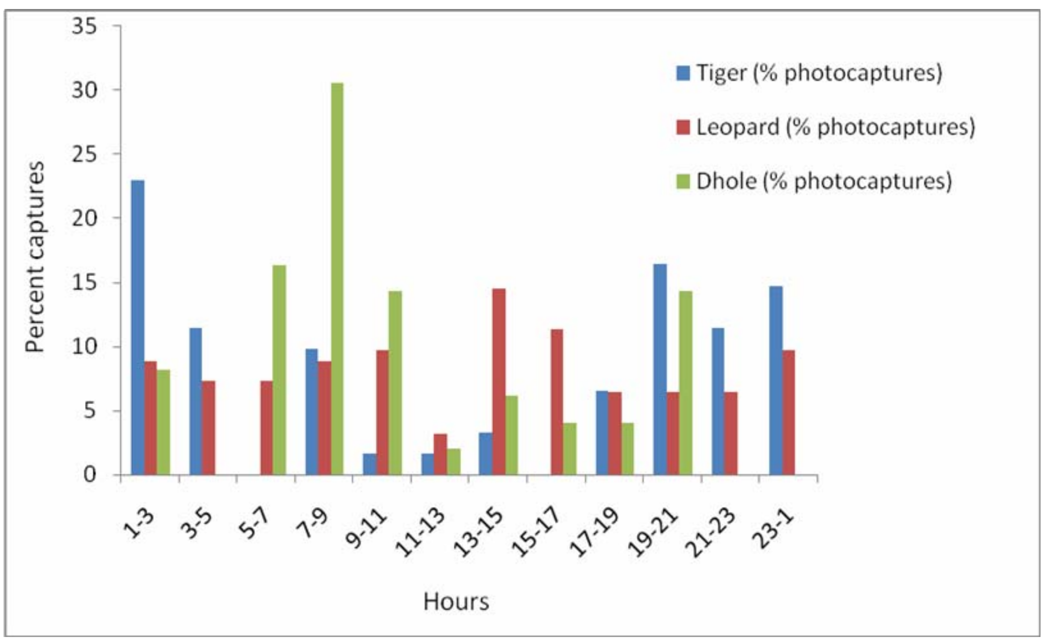


Figure 13. Activity pattern of tiger, leopard and dhole based on camera trap photo captures in Mudumalai Tiger Reserve, Tamil Nadu. (January to April 2009).



5.4.2. Vehicle transect

Estimated dhole density in the deciduous habitat was 43.7 ± 21/100 km^2 (excluding pups) with average group size of 5.6 ± 1.0. In total, 31 dhole sightings were obtained during vehicle transect and number of individuals on each sighting varied from one to

28. Usually more than 20 individuals in a pack were sighted during the monsoon. Uniform detection function with Cosine adjustment fitted data well for overall analysis (Table 47). Based on my personal observation, 93 dholes were seen in the Tiger Reserve which composed of six different packs. Deciduous habitats contained four packs in which a pack kept moving to the adjacent dry thorn forest, moreover dry thorn habitat had another pack which contained 15 members that operated at the border of the reserve near Sigur river side and a pack with 14 members was seen in semi-evergreen habitat.

Table 47. Density estimates of dhole using vehicle transect in Mudumalai Tiger Reserve, Tamil Nadu. (January 2008 to December 2009).

Years	Observation	Model	ESW	D g ±SE	%CV	GS±SE	D±SE	%CV
2008 -2009	31	Uniform polynominal	29.3	13.0±6.0	45	5.4 ±1.0	43.0±21.0	48

5.5. Discussion

5.5.1. Population of large carnivores

Understanding the variation in population density among different species within habitats and within species across habitat is of central importance in wildlife ecology and critical to conservation efforts of threatened and endangered species (Andrewartha and Birch 1954, Pulliam 1988). Over the course of study, camera trapping was successful in population estimation of tiger and leopard and since individual recognition of dhole is not possible based on photographs, vehicle transect was used to estimate the abundance of dhole in the study site. The systematic sampling made to derive population estimation of large predators in Mudumalai would be important for making management oriented decision. Methods like ½ MMDM, Full MMDM are being site specific and strip width based Maximum Likelihood (ML) method appeared to be more robust as density estimate by this method did not vary over the years and this estimate can be extended to the adjoining areas. ML method does not restrict to the sampled area as it is not dependent on strip width unlike 1/2MMDM and Full MMDM. The best approach of ML in the absence of telemetry-based home-range data is to use the spatial capture histories of camera traps in a likelihood-based density estimation framework (Borchers & Efford 2008, Efford et al., 2009). Because the spatial likelihood approach does not depend on adding a buffer to the trapping polygon for estimating effective trapping area, the resultant estimates are least biased by trap layout and density (Efford 2004). Dillon and Kelly (2007) and Sharma et al., (2009) found that the actual density of animal (tigers and Puma) from Full MMDM and spatial likelihood estimate are close to radio collared individuals estimated by home-range radius while density based on ½ MMDM is likely to produce overestimates. Another Correlated radio-collared and camera trap study on Jaguar suggested that the ½ MMDM method consistently overestimated and Full MMDM under-estimated the density of jaguars at the site over two yearly surveys (Soisaloa and Cavalcanti 2006). However since MMDM methods either over estimated or under estimated the real population, ML estimate was more robust. From the present study, it is suggested that the density estimates from ML estimates are more biologically accurate than estimates from MMDM methods. Distance between trap locations and trap night can considerably influence the result of camera trap study in a high density area (Wegge et al., 2004, Dillon and Kelly 2007, Contractor 2008). During the camera trapping study an asymptote in the cumulative number of individuals identified was not reached in 2008 and 2010 and the rate of new encounter showed no decline till the 70 days sampling occasion for tigers and leopard due to increased inter-trap distance and less number of cameras. Moreover when number of sampling days was extended in 2009, capture of new individual tigers and leopards stabilized. The stabilization of individual capture not occurred or occurred late may be due to forest continuity around the study site. Capture probability of tiger was low due to constraints in the number of camera traps, trap shyness and presence of track plots in the study site. As well as the capture rate of tiger and dhole drastically declined more in 2009 as compared to the leopard. This was due to widespread forest fire in the study area which might have reduced the movement of tiger and dhole in burnt areas while leopard usage was more at burnt sites. Seidensticker (1976) observed that the burnt areas were used more frequently by leopard than tiger in Chitwan. When the cumulative number of tiger and leopard did not reach asymptote during the sampling period it is possible that I would have captured more individuals if the inter-trap distance was reduced. Since camera density played a major role in the capture rate of individual tiger and leopard it was necessary to use less inter-trap distance (1.2-2 km) between camera trap locations. Minimum of 40 trap nights are required to obtain reliable estimates of carnivore population (Carbone et al., 2001, Contractor 2008) whereas in 2009 due to increased sampling days, an asymptote curve was achieved for tiger and leopard. This minimum requirement may vary with respect to habitat continuity and camera trap density. Even though cameras were replaced in nearby locations (within 250 m from original location), I found only trivial improvement in capture rate. In many instances, tiger avoiding camera traps was noticed from the presence of pugmark behind cameras and by photographic detection by the opposite camera, but the trap shyness was not observed much in leopard. In some cases photographic evidences appeared to be showing leopards scrolling their body and resting in front of the camera for a long time. Karanth et al., (2006) found that tiger abundance in Nagarahole fluctuated from year to year and estimates had relatively wide variances. This is because of model explicitly incorporated uncertainties arising from factors related to tiger ecology as well as sampling issues (Karanth et al., 2006). During the study, two leopard cubs in 2009 and a leopard cub with mother in 2008 were photographed. This suggests that camera traps are poor at detecting cubs as cubs are restricted to a small area and rarely accompany mothers and this same was reported from other areas as well (Karanth and Sunquist 1998, 2004). Density estimate for tiger and leopard excluded cubs <1yr old during the present study. Karanth and Stith (1998) predicted using demographic models that cub may form 25% of the normal wild tiger population.

Population estimation would be demographically closed since individual tigers less than 1 year of age were not taken into account for population estimation. As tiger and leopard are territorial animals, the assumption of geographical closure was mostly achieved in my study but in 2009 population closure was not achieved for leopard. Soisalo and Cavalcanti (2006) recommended that population closure was difficult to ascertain in biological populations especially in uncontrolled situations. Also population closure is affected by trap shyness when animal becomes trap shy and undetected; it is difficult to differentiate it from death or emigration of the animal. But it is essential to meet the population closure assumption. However, geographic closure, especially in contiguous habitats is much more difficult to attain (Wilson and Anderson 1985). The results of the closure test suggested that the maximum capture period of two to three months was sufficient to meet the assumption of a closed population during the survey period.

Frequency of capture of animal in photo-capture may not be true correlates of their abundance (Jenelle et al., 2002, Edgaongar 2008). This may not be a better correlate especially in the case of dholes because of their pack living habits; it underestimates all the members in a pack. Moreover photographic correlates particularly useful for non- identifiable species (Corbone et al., 2001), camera trap data was directly related to independent density estimates even in areas where poaching occurred (O'Brien et al., 2003) and camera trap-based abundance indices have consequently been used in a number of studies to measure the impact of hunting on populations of large carnivores and their prey (Kawanishi and Sunquist 2004, Johnson et al., 2006, Datta et al., 2008). During the present study the RAI increased w.r.t to increase in tiger and leopard density every year. This may be due heterogeneity in capture probability of each species. However, when better population estimate is available where RAI may not be required.

Dhole density in Mudumalai appeared to be the highest in India. Result from vehicle transect method may not be extrapolated to areas outside the study area, but it provided density values of dhole over the years where population density estimate from other methods were not applicable.

Camera-trap and vehicle transect studies have showed that high densities of large carnivores in the intensive study area of the Tiger Reserve and these thrive in similar habitat types across. These are excellent models of species abundance estimates for exploring parts of mechanisms of coexistence between large sympatric carnivores. Any extrapolation of these density results outside the study area boundaries would be sensible where there are not much anthropogenic pressure, difference in vegetation cover and prey base around the Tiger Reserve. Thus, camera-trapping furnishes an important non-invasive tool for assessing patterns of abundance throughout space and time, and their link with activity patterns, habitat use and reproductive information, which are key elements for wildlife conservation.

Maffei & Noss (2008) found that camera trapping in a small survey area leads to lower buffer values and overestimates of density, whereas the present density estimate from maximum survey area of 107 km^2 of latest survey years (2010). Since population estimation of tiger and leopard using 1/2MMDM method is available from most of the earlier studies, ½ MMDM density estimate was used to compare with other available studies in the Indian Sub continent. Prior camera trapping studies suggest that bias may occur if trapping polygons are too small to capture animals' true maximum distances moved (Maffei and Noss 2008). In Mudumalai sampling area was large compared to earlier studies. For dhole, though there was no similar method available to compare with other studies, inorder to understand the species abundance in different protected areas, density of dhole using vehicle transect from Mudumalai was compared with other protected areas.

The estimated tiger density per 100/ km^2 in the Indian sub – continent ranged from 0.36 to 19.3. Tiger density 17.7/100km^2 in Mudumalai was lower than Barida, Nepal (Wegge et al., 2009), and Corbett (Contractor 2008) higher than Kaziranga (Karanth et al., 2004), Nagarahole (Karanth et al., 2004), Bandipur (Karanth et al., 2004), Kanha (Sharma et al 2009), Ranthambore and Pench (Karanth et al., 2004), Panna (Karanth et al., 2004), Melghat (Karanth et al., 2004), Bhadra (Karanth et al., 2004), Tadoba (Karanth et al., 2004), Chilla (Harhar 2005), Pakke (Chauhan et al., 2006), Jigme Singye Wangchuck, Bhutan (Wang 2008) and Hukuang, Myanmar (Lynam et al 2009). The results showed that Mudumalai has potential habitats with high prey base to support the present tiger density like other prey rich areas in the sub – continent (Table 48.). Estimates for leopard population was 25.5/100 km^2 in Mudumalai which is higher than Chilla (Harihar et al., 2009), Satpura (Edgaongar 2008), Sariska (Sankar et al., 2008) and Jigme Singye Wangchuck, Bhutan (Wang 2008). The density of leopard/100 km^2 ranged from 1.0 to 25.5 individuals in the Indian sub- continent (Table 49.). The estimated dhole density i.e. 43.0/100 km^2 in Mudumalai was lower than Bandipur (Johnsingh 1983) and higher than Pench (Acharya 2007), Mudumalai (Venkatraman et al., 1995) and Nagarahole (Karanth 1993) (Table 50.). Observed pack range in the present study was also higher than other studies (Cohen et al., 1978, Johnsingh 1983, Venkatraman et al., 1995, Karanth 1993, Acharya 2007).

Table 48. Comparison of tiger densities using 1/2MMDM method from different protected areas in Indian subcontinent.

Location	Trap Nights	ETA	M_{t+1}	P – hat	N±SE	D±SE/100 km^2
Mudumalai 2010 (Present study)	1400	162.5	22	0.096	28.9±4.5	17.7±3.3
Hukuang (Lynam et al., 2009)	1062-1328	275-536	2	0.11-0.31	2.0 -3.0 ±0.05-1.3	0.36 - 1.0 ±-
Jigme Singye Wangchuck (Wang 2008)	4050	1506	8	0.04	8.0±2.1	0.52±2.1
Pakke (Chauhan et al., 2006)	718	158	4	0.044	4.0±2.56	1.1±0.8
Chilla (Harihar 2005)	895	133	4	0.35	4.0±0.08	3.0±0.71
Tadoba (Karanth et al., 2004)	706	367	10	0.174	12.0±1.97	3.3±0.59
Bhadra (Karanth et al., 2004)	587	263	7	0.22	9.0± 1.93	3.4±0.84
Pench - MP (Karanth et al., 2004)	788	122	5	0.22	6.0±1.41	4.9±1.37
Ranthambore (Chauhan et al., 2005)	358	141	12	0.047	21.0±6.1	5.8±2.01
Melghat (Karanth et al., 2004)	896	360	15	0.058	24±6.09	6.7±1.85
Panna (Karanth et al., 2004)	914	418	11	0.039	29.0±9.65	6.9±3.23
Pench – MR (Karanth et al., 2004)	715	274	14	0.108	20.0±4.41	7.3±2.54
Ranthambore (Karanth et al., 2004)	840	244	16	0.115	28.0±7.29	11.5±4.20
Kanha (Sharma et al 2009)	462	111	12	0.234	13.0±1.19	11.7±1.74
Nagarahole (Karanth et al., 2004)	938	243	25	0.12	29.0±3.77	11.9±1.7
Bandipur (Karanth et al., 2004)	946	284	16	0.055	34.0±9.9	11.9±3.71
Kaziranga (Karanth et al., 2004)	544	167	22	0.19	28.0± 4.51	16.8±2.96
Corbett (Contractor 2007)	7865	562	103	-	108±4.5	19.2±1.6
Bardia (Wegge et al., 2009)	563	129.4	21	-	-	19.3±2.2

ETA – Effective trapping area, Mt+1 –Number of individuals captured, P-hat – Capture probability, N±SE – Population size with standard error, D±SE – Density/100 km^2 with standard error.

Table 49. Comparison of leopard densities using 1/2MMDM method from different protected areas in Indian subcontinent.

Location	Trap Nights	ETA	M_{t+1}	P – hat	N±SE	D±SE/100 km^2
Mudumalai (Present study)	1400	147.3	27	0.097	26.0±2.5	25.5±4.2
Satpura (Edgaonkar et al., 2008)	660-1216	119 - 152	8 - 11	0.02-0.07	9-14± 2.6-6.9	7.3 - 9.3± 2.1-5.1
Chilla (Harihar et al., 2009)	450	86.72	8	0.053	13.0±6.9	14.9 ±6.9
Sariska (Sankar et al., 2008)	896	213.8	14	0.083	14.0±0.2	7.0±0.2
Jigme Singye Wangchuck (Wang 2008)	4040	1506	16	0.042	16.0±2.9	1.0±2.9

ETA – Effective trapping area, Mt+1 –Number of individuals captured, P-hat – Capture probability, N±SE – Population size with standard error, D±SE – Density/100 km^2 with standard error.

Table 50. Comparison of dhole densities (individuals/100 km^2) from different protected areas in Indian subcontinent.

Locations	Density/ 100 km^2	Pack Size Range	Method
Mudumalai (Present study- 2010)	43.0±21.0	1 - 28	Vehicle Transect
Mudumalai (Venkatraman et al., 1995)	31.2±-	4 - 25	Direct observation
Bandipur (Johnsingh 1983)	35-90±-	7 - 18	Direct observation
Nagarhole (Karanth 1993)	14.0±-	3 - 10	Direct observation
Pench (Acharya 2007)	29.0±2.0	1 - 14	Radio Telemetry
Nilgiri Plateau (Cohen et al.,1978)	-	1 - 5	Direct observation

The high density of large predators suggests that the study area is acting as a source population for the surrounding area. Jhala et al., (2008) stated that Mudumalai tiger population is a part of the single largest tiger population in India and it acts as a source for populating the Northern and Eastern parts of the Western Ghat landscape complex. This tiger population is capable of existing at reasonably high density due to the deciduous nature of its forests. Carnivore densities are positively correlated with prey biomass (Hanby et al. 1995, Carbone and Gittleman 2002, Karanth et al., 2004). A high level of prey availability causes an increase in the presence of transient or immigrant animals and may also increase reproduction and survival of neonates and juveniles from within the population. Regardless of the effect on the greater population, it is clear that habitat quality and high prey base, remains high for source populations of large predators to exist at high density in Mudumalai.

5.5.2. Activity patterns

Several authors (Schaller 1967, Seidensticker 1976, Sunquist 1981, Karanth and Sunquist 2000) have previously observed that tiger and leopard are more active at dusk and dawn than during the day. However, the observed activity patterns of tiger and leopard during the present study was mostly different. Differences in time use, either temporally or spatially, have been recognized as behavioural characteristics that may promote coexistence. Seidensticker (1976) and Sunquist (1981) have found that sympatric tiger and leopard are able to coexist by selecting different habitats. Temporal time separation has been proposed as a strategy adopted by sympatric tiger, leopard and dhole to allow coexistence (Karanth and Sunquist, 2000). The higher level of activity at night of tiger and leopard is probably associated with the activity patterns of their prey (Sunquist 1981). Though the peak activity of tigers, leopards and dholes were at different times, there was considerable overlap between species observed. There was an evidence of significant temporal segregation between the two cats (within 3-h intervals) and inter-specific spatial overlap was high on a coarse scale.

The comparison of activity patterns showed that leopards were relatively more active in the day time than tigers. This activity pattern may be possible due to leopard's predation on prey species like chital and langur during day hours. Leopards and tigers were active throughout the day unlike dholes that were active in the day time. Karanth and Sunquist (2000) observed that leopards were relatively more diurnal than tigers in Nagarahole. The generalist nature of leopard implies an activity pattern throughout the day in its ecology across its range. Dhole largely showed diurnal activity in Mudumalai which is similar to other reported studies (Johnsingh, 1983, Venkataraman et al., 1995, Karanth and Sunquist 2000, Austin 2002 and Grassman et al., 2005). However, these studies (Johnsingh 1983, Venkataraman et al., 1995, Karanth and Sunquist 2000) were based on only diurnal observations. Some nocturnal activity of dhole was recorded in 2009 during my study.

Activity pattern within a species varies depending on geographical location, climate and the distribution of prey and interaction with other species (Leuthold 1977). Tiger and leopard frequently showed maximal activity declining to a minimum at midday (Sunquist

1981). In Wilpattu National Park, Sri Lanka, where leopards are the top carnivores, they are often active during the day in open habitats (Eisenberg and Lockhart 1972). Though large predator guild feed on similar food resources in different proportion by utilizing different sized prey, having high degree of dietary overlap may lead to competition among them. One way to minimize this competition would be to partition their activity patterns. The activity pattern exhibited for three predators appeared to minimize the chances of interaction between each other. But Karanth and Sunquist (2000) stated that temporal activity patterns of predators may be driven primarily by prey activity patterns, rather than by the need to avoid other predators in Nagarahole. Some of the differences observed in activity patterns among sites could result from different methodologies used to study the species. Camera trapping has proven to be a useful complement to telemetry study in documenting 24 hrs temporal activity pattern of large predators in Mudumalai. Camera trapping can augment the detail of spatio-temporal patterns of multiple individuals simultaneously with less effort than telemetry study.

A photographic capture-recapture survey has been successfully used to estimate tiger and leopard populations and vehicle transect for dhole in Mudumalai. High tiger density appears to depress leopard density in Chitwan and in Rajaji (McDougal 1977, Harihar et al., 2009). Leopards avoided areas where tiger density was high (Schaller 1967), instead residing at the peripheries of the park between the high-density tiger areas and croplands (Seidensticker 1976). In contrast to Chitwan and Rajaji, the present study documented a high density of large predators due to availability of abundant prey base in a diverse range of size classes. Similar finding was made in the same landscape by Karanth and Sunquist (2000) in Nagarahole. Many studies have found that sympatric carnivores are able to coexist by selecting different habitats (Seidensticker 1976, Schaller & Crawshaw 1980, Fedriani et al., 1999). The stronghold of carnivores to areas of high prey density has been noted in other sympatric species (Palomares et al., 1996, Durant 1998, Scognamillo et al., 2003). The Western Ghats landscape comprises 21% of the forested area in India (Jhala et al., 2008). Mudumalai landscape has good potential for long term tiger survival due to its large extent of contiguous forest and the single largest population of tigers in India, which is a part of larger landscape comprising Nagarhole-Bandipur-

Waynad encompassing the states of Karnataka, Tamil-Nadu and Kerala (Jhala et al., 2008). However, the results of this study indicate that abundance of diverse body sized prey and temporal separation from their activity at different times are important factors in promoting the coexistence of high density of tiger, leopard and dhole in the study site. The key insight gathered from the present study of large predator population status indirectly delineates habitat quality of persistent forest and prey base availability whereas large predators are vulnerable to habitat fragmentation and depleted prey base. Large predators are conservation dependent species requiring large contiguous forests with less interspersion of undisturbed breeding areas. It can be expected that larger forest continuity proximal to high population of large predators have the chance for long-term survival in Mudumalai landscape.

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APPENDICES

Appendix 1. Habitat overview of the intensive study area in Mudumalai Tiger Reserve.

Dry Deciduous forest　　　　　　　　Moist Deciduous forest

Appendix 2. A vehicle transect in the study area.

Appendix 3. Forest fire during the dry season – 2009 in the study area.

Appendix 4. Major prey species of large carnivores in Mudumalai Tiger Reserve.

Sambar

Chital

Gaur

Wild Pig

Common Langur

Appendix 5. Tiger on a gaur kill

Appendix 6. Chital killed by leopard

Appendix 7. Dholes on a sambar kill

Appendix 8. Camera trap housed in wooden log

Appendix 9. Two tigers showing unique stripe patterns based on left flank.

(A)

(B)

Appendix 10. Two tigers showing unique stripe patterns based on right flank.

(A)

(B)

Appendix 11. Two leopards showing unique rossette pattern based on left flank.

(A)

(B)

Appendix 12. Two leopards showing unique rosette pattern based right flank.

(A)

(B)

Appendix 13. Locations of line transects in the study area, Mudumalai Tiger Reserve.

LT No.	Length	Place	Start lat.	End Long.	Start lat.	End Long.
1	2	Dodagatty Bridge	11.652222	76.513889	11.669194	76.519833
2	2	Kaniallam	11.639777	76.481722	11.657694	76.481639
3	2.03	Northey betta Road	11.637138	76.470611	11.619889	76.476972
4	2	Onargatty	11.638555	76.557806	11.648750	76.542556
5	2	Imbrellah Junction	11.633444	76.522056	11.649472	76.530583
6	2.11	Jaldhari	11.652138	76.513917	11.651139	76.494611
7	2.12	Mudumalai-Northey Road	11.635555	76.503528	11.617000	76.504056
8	2	Link Road Junction	11.615527	76.565500	11.624667	76.549556
9	2	Theppakad-Ponagiri Road	11.613055	76.547917	11.627500	76.537083
10	2	TMR Junction	11.602111	76.531972	11.620111	76.530944
11	2	Cheenakoli	11.594333	76.530750	11.606111	76.515611
12	2.03	Link Road gate	11.607916	76.585528	11.615167	76.568500
13	3.13	Theppakad Block Line	11.594388	76.556528	11.602028	76.583944
14	2.52	S.Bend	11.595694	76.529889	11.581472	76.550222
15	2	Thorapalli Block Line	11.566444	76.522361	11.581028	76.511694
16	2	Circular Road	11.594861	76.584611	11.600361	76.602139
17	1.8	Kalallah Junction	11.583972	76.552306	11.572167	76.563722
18	2.06	Ombetta	11.573583	76.539778	11.556500	76.547083
19	1.5	Morgenbetta	11.571055	76.573833	11.565500	76.561306
20	2	Church Road	11.603416	76.478417	11.606500	76.496500

Appendix 14. Location of camera traps in the study area, Mudumalai Tiger Reserve.

Camera No.	Place	Lat. in dec.	Long. In deg.
1	Dodagatty Bridge	11.652222	76.513889
2	Kaniallam	11.639777	76.481722
3	Northey betta Road	11.637138	76.470611
4	Onargatty	11.638555	76.557806
5	Imbrellah Junction	11.633444	76.522056
6	Jaldhari	11.652138	76.513917
7	Mudumalai-Northey Road	11.635555	76.503528
8	Link Road Junction	11.615527	76.565500
9	Theppakad-Ponagiri Road	11.613055	76.547917
10	TMR Junction	11.602111	76.531972
11	Cheenakoli	11.594333	76.530750
12	Link Road gate	11.607916	76.585528
13	Theppakad Block Line	11.594388	76.556528
14	S.Bend	11.595694	76.529889
15	Thorapalli Block Line	11.566444	76.522361
16	Circular Road	11.594861	76.584611
17	Kalallah Junction	11.583972	76.552306
18	Ombetta	11.573583	76.539778
19	Morgenbetta	11.571055	76.573833
20	Church Road	11.603416	76.478417

PUBLICATION

BVG Trust

J. Sci. Trans. Environ. Technov. 2009, 2(3): 170-181

Scientific Transactions in Environment and Technovation

Food habits and prey selection of tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu, India

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Abstract

Food habits and prey selection of tiger (*Panthera tigris*) and leopard (*Panthera pardus*) in Mudumalai Tiger Reserve, Tamil Nadu were assessed from January to August 2008. Chital, *Axis axis* was the most common prey species in the study area with a density of 55.3 ± 6.28 animals/km^2 followed by common langur *Presbytis entellus* with 25.9 ± 3.59 animals/km^2 and gaur *Bos gaurus* with 11.4 ± 2.14 animals/km^2.The estimated mean biomass of the potential prey species was 8365.02 kg/km^2. A total of 179 tiger scats and 108 leopard scats were collected and the prey remains were analyzed. Sambar and chital were the principle prey species for tiger and leopard, respectively, as inferred from the relative biomass consumption of prey remains in tiger and leopard scats. The preferred prey species of leopard and tiger were sambar, common langur, wild pig and cattle. The dietary overlap between these two predators was 82% in terms of percentage frequency of occurrence of prey remains in the scats. In terms of biomass consumed, the estimated dietary overlap between tiger and leopard was 72%.

Keywords : food habits, line transect, *Panthera pardus*, *Panthera tigris*, prey availability, scat analysis, sympatric carnivores, vehicle transect

INTRODUCTION

Tiger (*Panthera tigris tigris)* and leopard (*Panthera pardus fusca)* are the two large felids found in Mudumalai Tiger Reserve, Tamil Nadu, South India. Tiger is the largest of all the felids and is found in diverse habitat types including dry deciduous, moist deciduous, semi evergreen, wet evergreen, riverine, swamp and mangrove forests. They are socially dominant over other sympatric carnivores (Karanth *et al*., 2004). Both felids are territorial and wide ranging, but the effective size of the territory is the function of density and biomass of larger prey species in its habitat (Sunquist 1981; Karanth, 1991). They show remarkable tolerance to variation in altitude, temperature and rainfall regimes (Sunquist *et al*., 1999). Tigers prey upon the large ungulates in all the ecosystems in which they occur (Seidensticker 1997; Karanth, 2003). They can potentially hunt prey varying from small mammals to the largest of the bovids with the mean weight of the species hunted is reported to be 60 kg (Biswas and Sankar, 2002). Although tiger do kill smaller prey, ranging from peafowl to prawns, they cannot survive and reproduce if a habitat does not support ungulates with adequate densities (Sunquist and Sunquist, 1989).

The leopard is the most adaptable and widely distributed among all the big cats (Bailey 1993; Nowell and Jackson, 1996). According to Hamilton (1976) the leopard had the reputation of being one of the least studied of the large carnivores despite being the most abundant. This species is known for its use of habitat edges and its ability to live in close to human habitation (Seidensticker *et al*., 1990). Leopard shows plasticity in changing behaviour as conditions changes (Daniel, 1996). Leopard's ability to feed on a broad spectrum of prey makes them the most successful predator among big cats and its size gives the ability to feed on a variety of prey species ranging in size from the smallest rodent to a young buffalo (Eisenberg and Lockhart 1972; Santiapillai *et al*.; 1982, Johnsingh, 1983, Rabinowitz 1989; Seidensticker *et al*. 1990, Bailey 1993; Karanth and Sunquist, 1995; Daniel 1996; Edgaonkar and Chellam 1998; Sankar and Johnsingh 2002; Goyal and Chauhan 2006; Qureshi and Advait 2006; Andheria *et al*. 2007; Arivazhagan *et al*. 2007; Ahmed and Khan, 2008). Tiger and leopard co-exist by feeding large to small size animals (Johnsingh 1983; Karanth and Sunquist, 1995; Sankar and Johnsingh 2002; Andheria *et al*. 2007). The adaptations in the food habits of tiger and leopard are the major indications for the successful co-existence of these sympatric large carnivores (Sidensticker, 1976; Johnsingh, 1983; Karantha and Sunquist, 2000).

STUDY AREA

Mudumalai Tiger Reserve (MTR) (110 32′ & 110 43′ N and 76022′& 76045′ E) is a newly created Tiger Reserve in the country (established in April 2007) and situated at the tri-junction of Tamil Nadu, Karnataka and Keraia states. It is contiguous with Wayanad Wildlife Sanctuary on the west, Bandipur Tiger Reserve on the north and in south and east with the Singara and Sigur Reserved Forests which forms the boundary of Nilgiri North Division. The MTR is located within the Nilgiri Biosphere Reserve. The area of the reserve is 321 km^2. The Core

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Zone of this Sanctuary (100 km^2) has been notified as National Park. The intensive study area (107 km^2) constituted central area of the park including some parts of the Core Zone. The general terrain of this Tiger Reserve is gentle undulating. The elevation ranges from 960 m to 1266 m.

The vegetation types (Champion and Seth, 1968) found in Mudumalai are: Southern Tropical Dry Thorn forest, Southern Tropical Dry Deciduous forest, Southern Tropical Moist Deciduous forest, Southern Tropical Semi-Evergreen forest, Moist Bamboo Brakes and Riparian forest. The climate of the Mudumalai is moderate. There is a decreasing rainfall gradient from the west and south to the east and north (Venkataraman *et al.*, 2005). Mudumalai experiences cold weather during the month of December or the beginning of January and hot weather during March and April. The average maximum and minimum temperature is 32°C and 8°C, respectively.

Tiger , leopard and dhole *(Cuon alpinus)* are the three major carnivores present in the study area. The potential ungulate prey species of the tiger and leopard in the Tiger Reserve are chital (*Axis axis)*, sambar (*Cervus unicolor)*, muntjac (*Muntiacus muntjak)*, wild pig (*Sus scrofa)*, Indian chevrotain (*Tragulus meminna)* and gaur (*Bos gaurus)*. Asian elephants (*Elephus maximus)* are distributed throughout the park. Black naped hare (*Lepus nigricollis)*, bonnet macaque (*Macaca radiate)*, common langur (*Presbytis entellus)*, Indian porcupine (*Hysterix indica)*, Malabar giant squirrel (*Ratufa indica)* and peafowl (*Pavo cristatus)* are the other prey species found. Domestic livestock (cattle, buffalo and goat) occur in the village areas present inside the Sanctuary.

METHODS

Estimation of prey availability

Transect method (Burnham *et al.* 1980, Buckland *et al.*, 1993, Sunquist and Sunquist 1989) was used to estimate densities of prey species in the study area. This method has been widely applied to estimate densities of prey species in tropical forests (Karanth and Sunquist 1992, 1995; Khan *et al.*, 1996; Biswas and Sankar 2002; Bagchi *et al.*, 2003; Jathanna *et al.*, 2003; Karanth *et al.*, 2004).

Twenty foot transects varying in length from 2 to 3 km were laid in the study area covering all major vegetation types (Figure 1). The total transect length of 82.82 km was monitored two times during the beginning of the day and late after noon resulting in 165.64 km of total effort. For each prey species sighting on a transect, the following were recorded: (1) total number of individuals, (2) animal bearing and (3) angular sighting distance. In addition to foot transects, five vehicle transects ranging from 15 to 23 km were monitored in the study area (Figure 1). The total length of 93.5 km was monitored by a four-wheel drive vehicle twice during the beginning of the day and late afternoon, resulting in 187 km of total effort. On each sighting of prey species along the vehicle transects, the following were recorded: (1) total number of individuals and (2) perpendicular sighting distance.

The density of all prey species was calculated using the Distance program *Version 5.0* (Laake *et al.* 1994) by pooling the line and vehicle transect data. The best model was selected on basis of the lowest Akaike Information Criteria (AIC) (Burnham *et al.* 1980; Buckland *et al.* 1993). All the density estimates were done after 1% truncation of the farthest sighting data from transect. While estimating the density of prey species for the study area, half normal key function with cosine adjustment gave the best fit for all the prey species.

Reconstruction of diet

Tiger and leopard scats were collected where ever encountered in the intensive study area. A total of 179 scats of tiger and 108 scats of leopard were collected and analyzed. Tiger and leopard prefer to use roads or animal trails as travel routes and are likely to leave scats and tracks on such routes (Smith *et al.*, 1989; Karanth and Nichols, 2000). To maximize overall capture effort, tiger scats were collected by walking on predetermined forest roads once in a month. Total length walked was 908 km. In addition to this, animal trails were also sampled for scat collection. Tiger and leopard scats were distinguished from one another by the size of the scats and the presence of ancillary signs like pugmarks (Sunquist 1981; Karanth and Sunquist 1995; and Biswas and Sankar, 2002), and other supplementary evidences such as the diameter of scat, scrapes, claw marks etc., Tiger scats are found to be less coiled and having larger distance between two successive constrictions within a single piece of scat, when compared to leopard which were mostly coiled and have similar distance between constrictions (Johnsingh pers.comm.).

The hair of the prey is relatively undamaged in carnivore scat and can thus be used to identify the prey species eaten (Mukherjee *et al.*, 1994a; Ramakrishnan *et al.*, 1999). Thus these undigested prey hairs which remain in the scat after washing were used for the identification of prey species. At least, 20 hairs were picked up randomly from each scat for the preparation of the slides. A combination of hair characteristics like hair width, medullary structure, and the ratio of medulla width to hair width (Mukherjee *et al.*, 1994b) of the prey hairs of each scat collected were observed microscopically and were compared with the reference slides available in the laboratory of Wildlife institute of India, Dehra Dun.

Estimation of biomass and number of prey consumed by tiger and leopard from scat analysis, using a correction factor

The biomass and the number of individuals of the prey consumed by tiger and leopard was estimated using the

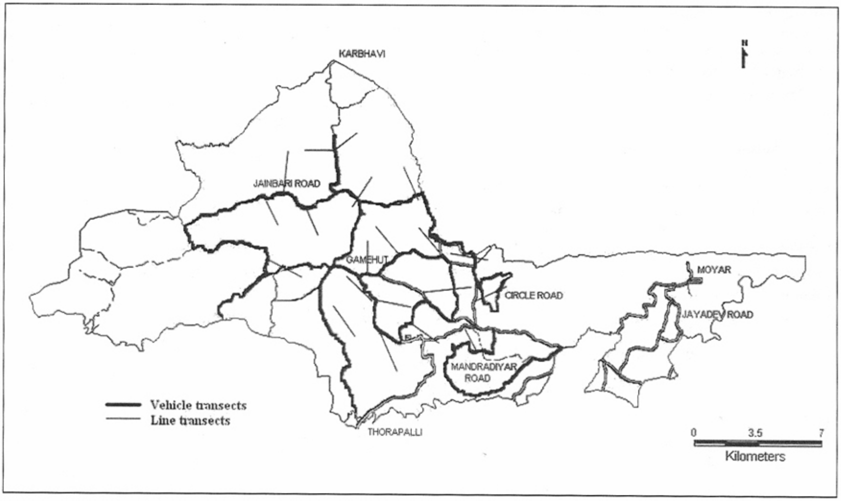

Figure 1. Study area showing the location of line and vehicle transects utilized for the present study

following Ackerman's equation (Ackerman *et al.*, 1984) to get a more accurate estimate of prey consumption.

$Y = 1.980 + 0.035X$

X= Average weight of a particular prey type

Y=Kg of prey consumed per field collectable scat (Ackerman *et al.*, 1984).

This method has already been used in various studies for the estimation of prey consumption by tigers (Karanth and Sunquist 1995; Biswas and Sankar 2002; Sankar and Johnsingh 2002) and leopard (Henschel *et al.*, 2005; Sankar and Johnsingh, 2002; Andheria *et al.*, 2007). The assumption for extrapolation of the above equation is that the tigers and cougars have similar utilization and digestibility (Karanth and Sunquist, 1995). We also presume that the scats containing various prey items have similar decay rate and their detection is equally probable.

Estimation of prey selectivity

Prey selectivity by tiger and leopard was estimated for each species by comparing the proportion of the prey species utilized from scats with the expected number of scats 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):

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

fi= expected scat proportion in the environment.

di= density of i th species

Σ di—dn= sum of the density of all species.

$\lambda i = X/Y$ = the average number of collectable scats produced by tiger from an individual of i th prey species.

X = Average Body weight of the species

Y = Ackerman's equation

The prey selection was measured by using Ivelev's index (Ivelev, 1961)

$E = (U - A) / (U + A)$, where

U = relative frequency occurrence of prey items in predator scats.

A = expected scat proportion in the environment.

and multinomial likelihood ratio test (Chesson 1978; Reynolds and Aebischer 1991; Link and Karanth 1994; Karanth and Sunquist, 1995). The exact variability of prey items in scats is not known and in order to account for that sensitivity analysis was done by changing coefficient of variance from 10% to 40% (Link and Karanth, 1994). Program SCATMAN (Link and Karanth, 1994) was used for this analysis and sensitivity analysis was done by bootstrapping data 1000 times.

Dietary overlap index

To asses the similarity of food composition between tiger and leopard, the Pianka's niche overlap index was used (Pianka, 1973). Where:

$$\text{Pianka index} = \frac{\Sigma pij * pik}{\Sigma_i (pij)\, 2 * \Sigma_i (pik)^2}$$

Pij = percentage of prey items i of predator j.

Pik = percentage of prey items i of predator k.

The index distributes between 0 & 1; the similarity is higher as the index is close to 1.

RESULTS

Availability of prey species

The individual prey densities were estimated for all prey animals (Table 1). The estimated mean biomass of the potential prey species was 8365.02 kg/km^2.

Composition of tiger and leopard diet

The analysis of 179 tiger scats and 108 leopard scats revealed the remains of eleven and ten prey species, respectively, with a high predominance of medium to large sized ungulates in both tiger and leopard diets (Table 2 and 3). Ninety five percent of tiger and leopard scats contained single prey species and 5% contained two prey species. No scat had remains of multiple prey species (> 2). Of the prey species identified from the tiger scats, sambar constituted 59.79%, chital 22.75%, common langur 5.29%, wild pig 4.23%, gaur 2.65%, cattle 2.12%, buffalo 1.06%, hare 0.53%, sloth bear 0.53%, porcupine 0.53% and unknown bird species 0.53% (Table 2). The leopard diet comprised of 37.72% of chital, 28.95% of sambar, 17.54% of common langur, 3.51% of wild pig, 3.51% of cattle, 2.63% of gaur, 2.63% of unknown snake species, 1.75 % of hare, 0.88 % of buffalo, and 0.88 % of mouse deer as inferred from the prey remains (Table 3). The total available prey biomass in the study area was estimated to be 8365.02 kg. The estimated mean biomass/sq.km of different prey species in the study area was chital 2488.5 kg, gaur 5130 kg, sambar 350 kg, common langur 207.2 kg, wild pig 15.2 kg and cattle 167.4 kg. The dietary overlap between these predators was 82% in terms of percentage of frequency occurrence of prey remain in the diet. In terms of percentage of biomass consumed, the estimated dietary over lap between tiger and leopard was 72%.

Estimation of prey selectivity

Sambar and wild pig were consumed by tiger more than the availability of individuals (Table 4 and Figure 2). Cattle were consumed in proportion to their availability. Common langur, chital and gaur were consumed less in comparison to their availability. The index of prey selection by tiger at individual species level was in the

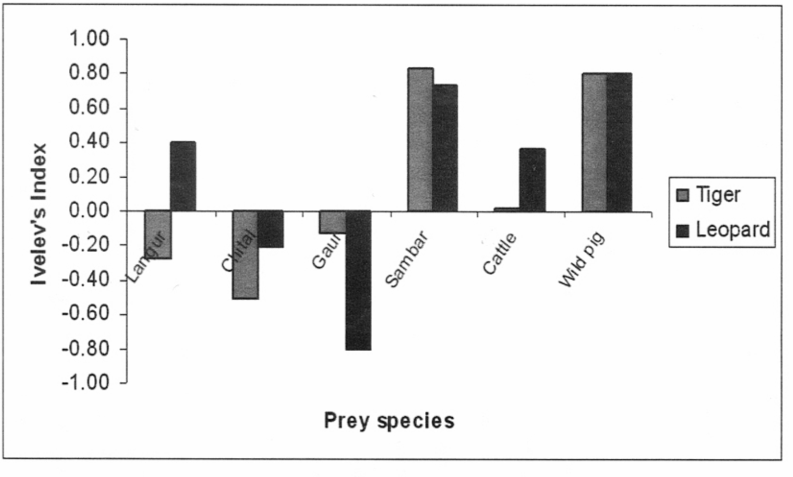

Figure 2: Prey selection of tiger and leopard in Mudumalai Tiger Reserve, Tamil Nadu (January to August 2008)

Table 1. Density of prey species in Mudumalai Tiger Reserve, Tamil Nadu (January to August 2008)

Species	Density/ sq km	SE	CV (%)	Mean group size	SE	Detection probability	No. of Observations	No. of individuals
Common langur	25.9	3.59	13.8	4.8	0.21	13.3	222	1080
Chital	55.3	6.28	11.3	13.2	0.88	14.4	334	4426
Gaur	11.4	2.14	19.4	7.3	0.71	4.9	118	863
Elephant	4.9	1.7	34.4	4.2	0.32	31.2	106	446
Bonnet macaque	3.4	0.94	31.5	7.6	1.02	2.6	19	145
Sambar	2.8	0.49	17.6	4.11	0.75	5.9	77	317
Peafowl	3.7	0.53	14.0	1.5	0.10	17.4	85	133
Cattle	0.93	0.34	37.0	3	0.77	1.3	21	63
Goat	0.74	0.58	78.0	5	----	0.3	1	5
Wild pig	0.40	0.15	37.3	1.5	0.18	1.3	18	27
Barking deer	0.32	0.73	22.3	1.2	0.10	3.7	18	22
Indian giant squirrel	1.6	0.37	22.5	1.1	0.45	5.2	61	70
Sloth bear	0.29	0.17	60.2	1	----	0.5	2	2
Grey jungle fowl	1.1	0.25	22.9	1.8	0.26	6.5	21	39
Red spurfowl	0.25	0.17	48.8	2.2	0.43	1.4	4	9

Table 2. Composition of tiger diet (n=179) and relative biomass contribution of different prey species in Mudumalai Tiger Reserve, Tamil Nadu (January to August 2008)

Species	Frequency of Occurrence	Percent frequency of occurrence (A)	Average Body Weight (kg) (B)	Correction Factor (kg/scat) (C)	Relative proportion of Biomass consumed (D)	Relative proportion of Individuals consumed (E)
Sambar	113	59.79	125.0	6.355	0.660	0.400
Chital	43	22.75	45.0	3.555	0.140	0.230
Common langur	10	5.29	8.0	2.260	0.0210	0.190
Wild pig	8	4.23	38.0	3.310	0.024	0.048
Cattle	4	2.12	180.0	8.280	0.030	0.012
Gaur	5	2.65	450.0	17.730	0.082	0.013
Hare	1	0.53	2.1	2.050	0.0019	0.680
Buffalo	1	1.06	273.0	11.535	0.0210	0.005
Sloth bear	1	0.53	135.0	6.705	0.0062	0.030
Porcupine	1	0.53	14.0	2.470	0.0022	0.010
Bird (unknown)	1	0.53	-----	-----	-----	-----

A) Percent frequency of occurrence
B) Estimated mean live weight (kg) of individuals consumed
C) Estimated weight of prey consumed per collectable scat produced, when such prey is the only item in a scat
D) = $(A*C)/\Sigma(A*C)$
E) = $(D/B)/\Sigma(D/B)$

Table 3. Composition of leopard diet (*n* =108) and relative biomass contribution of different prey species in Mudumalai Tiger Reserve, Tamil Nadu (January to August 2008)

Species	Frequency of Occurrence	Percent frequency of occurrence (A)	Average Body Weight (kg) (B)	Correction Factor (kg/scat) (C)	Relative proportion of Biomass consumed (D)	Relative proportion of Individuals consumed (E)
Chital	43	37.72	45.0	3.555	0.380	0.180
Sambar	33	28.95	125.0	6.355	0.290	0.051
Common langur	20	17.54	8.0	2.260	0.180	0.480
Wild pig	4	3.51	38.0	3.310	0.036	0.020
Cattle	4	3.51	180.0	8.280	0.036	0.004
Gaur	3	2.63	450.0	17.730	0.027	0.001
Snake	3	2.63	-----	------	-----	------
Hare	2	1.75	2.1	2.0535	0.018	0.185
Buffalo	1	0.88	273.0	11.535	0.009	0.0007
Mouse deer	1	0.88	3.0	2.085	0.009	0.064

A) Percent frequency of occurrence
B) Estimated mean live weight (kg) of individuals consumed
C) Estimated weight of prey consumed per collectable scat produced, when such prey is the only item in a scat
D) = (A*C)/Σ(A*C)
E) = (D/B)/Σ(D/B)

following order: sambar > wild pig > cattle > chital > gaur > common langur (Table 4).

For leopard, common langur, sambar, wild pig and cattle were preferred more than their availability (Table 5 and Figure 2). Chital and gaur were consumed less than their availability. The index of prey selection by leopard at individual species level was in the following order: wild pig > sambar > common langur > cattle > gaur > chital (Table 5).

DISCUSSION

Availability of prey species

The high abundance 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 semi evergreen forests, availability of food plants, water resources and forest protection. Chital, which were observed to be the most abundant prey species in the study area, were largely found in forest edges having palatable grass species as undergrowth. The study area has good network of roads and fire lines creating a mosaic of openings, an optimal habitat for chital. Chital is known to prefer ecotone or forest edges (Schaller 1967; Johnsingh and Sankar, 1991). The densities of chital in the study area are comparable with sites such as Kanha (Schaller, 1967) and Pench (Biswas and Sankar, 2002) and Nagarahole (Karanth and Sunquist, 1992) Tiger Reserves (Table 1 and 6). The common langur had the second highest abundance in the study area (25.9 individuals/ km^2) and this may be attributed to the canopy continuity of the forest types and availability of food plants through out the year. The densities of common langur in the study area are comparable with Nagerhole (Karanth and Sunquist, 1992) (Table 1 and 6). The barking deer is a shy animal and occurs in low densities across its present distributional ranges (Schaller 1967; Barrette, 2004). Though peafowl and Indian giant squirrel were distributed throughout the study area, their density was 3.7 individuals/km^2 and 1.6 individuals/km^2, respectively, on transects. The domestic livestock were not seen inside the National

Table 4. Prey selection by tiger in Mudumalai Tiger Reserve based on availability of individuals and utilization based on scat data (January to August 2008)

Species	Chi-Square value	Adjusted p-value 10% cv	Adjusted p-value 40% cv	Ivlev's index
Langur	6.7626	0.0112	0.0200	-0.272
Chital	18.8883	0.0001	0.0006	-0.513
Gaur	109.6599	0.0001	0.0001	-0.124
Sambar	1826.6754	0.0001	0.0001	0.830
Cattle	0.5299	0.4761	0.4821	0.018
Wild pig	0.6304	0.4274	0.4340	0.803

Table 5. Prey selection by leopard in Mudumalai Tiger Reserve based on availability of individuals and utilization based on scat data (January to August 2008)

Species	Chi-Square value	Adjusted p-value 10% cv	Adjusted p-value 40% cv	Ivlev's index
Langur	4.8454	0.0303	0.0406	0.403
Chital	0.0111	0.9151	0.9252	-0.204
Gaur	65.9241	0.0001	0.0001	-0.799
Sambar	229.5148	0.0001	0.0001	0.732
Cattle	3.4312	0.0668	0.0691	0.361
Wild pig	48.2768	0.0001	0.0001	0.807

Table 6. Comparison of densities (individuals/km^2) of prey species from different areas in India

Species	PS	MTR	NGH	BDP	PNCH	KNP	STR
Common langur	25.9	-	23.8	7.5	77.16	46.2	14.13
Spotted deer	55.3	25.03	50.6	40.0	80.75	3.2	27.62
Gaur	11.4	14.38	9.6	0.5	0.34	0.7	NP
Elephant	4.9	-	0.92	5.0	NP	NP	NP
Bonnet macaque	3.4	-	5.5	-	-	-	-
Sambar	2.8	6.61	5.5	7.0	6.09	0.9	8.44
Wild pig	0.40	-	4.2	2.5	2.59	0.5	17.52
Muntjac	0.32	-	4.2	1.0	-	0.4	NP

PS - present study area; **MTR (Mudumalai)** - Varman and Sukumar 1995; **NGH (Nagarahole)** - Karanth and Sunquist 1992; **BDP (Bandipur)** - Johnsingh 1983; **PNCH (Pench)** - Biswas and Sankar 2002; **KNP (Kanha)** - Schaller 1967; **STR (Sariska)** - Avinandan 2003

Park area but encountered only in Sanctuary. Since sloth bear is nocturnal (Schaller, 1967) the two sightings obtained on sloth bear during the study period may be a chance encounter. Though the overall prey species density recorded in the study area was one of the highest in the Indian sub-continent, the estimated overall biomass of the prey species in the study area (8365.02 kg/km^2) was high as compared to Kanha (Schaller, 1967), Bandipur (Johnsingh, 1983), Nagarahole (Karanth and Sunquist, 1992) and Pench (Biswas and Sankar, 2002).

Prey selection by tiger and leopard

Sambar was observed to be the principle prey species for tigers as inferred from the percentage occurrence of prey remains in tiger scats (Table 2). Sambar also contributed to highest biomass of prey consumed by the tiger and was consumed more than the availability of individuals (Table 5 and Figure 2). Sambar's preference by tiger could be attributed to the larger body weight and wide distribution of sambar across the study area and hence there could have been higher frequencies of encounter since both the species are crepuscular in habits (Johnsingh, 1983). Similar results were obtained by other studies in the country (Schaller 1967; Karanth and Sunquist 1995; Biswas and Sankar, 2002). Chital constituted 22.75% of the tiger diet during the present study which is less than that was reported from other areas *i.e.*, Pench- 53.01% (Biswas and Sankar, 2002), Kanha-52.2% (Schaller, 1967), Nagarahole- 31.2% (Karanth and Sunquist, 1995) and Bandipur- 39% (Johnsingh, 1983).

Leopard in the study area fed on 10 different prey species. Chital, sambar and common langur constituted 84.2% of leopard's diet (Table 3) which is similar to the findings reported from Nagarahole (Karanth and Sunquist, 1995). In Sariska (Sankar and Johnsingh, 2002), chital, sambar and common langur constituted only 47.2% of the leopard's diet. However in Sariska, Sankar and Johnsingh, (2002) reported a high percentage of (45.6%) rodent remains in leopard scats and the reason for the same was attributed to the high rodent availability. On the contrary, during the present study no rodent remains were recorded in the leopard scats.

The leopard preferred common langur, sambar and wild pig in the study area (Figure 2). It was observed that both tiger and leopard showed preference for sambar in the study area. Since leopard is nocturnal and tiger is crepuscular in habits (Prater, 1980) they may show preference for the same prey species but their utilization might be in different times (hours) of a day.

The observed high dietary overlap (>72%) for the utilized prey species in terms of percentage of frequency occurrence of prey remain in the diet and percentage of biomass consumed by tiger and leopard may be attributed to high prey availability in the study area.

Conservation of tiger and leopard in Mudumalai

In Mudumalai tiger and leopard are found in very high densities (Jhala *et al.*, 2008). These two species co-exist in areas where there is a high prey base availability (Sankar and Johnsingh, 2002). However, the ecological separation between tiger and leopard lies in leopard's ability to survive on multiple prey species as well as small bodied prey. The high density of tiger and leopard in Mudumalai may be due to the availability of high prey base, continued forest cover (in the west with Wynad Wildlife Sanctuary, Kerala, Bandipur Tiger Reserve, Karnataka in the north and in south with Nilgiri North forest division) and forest protection. Thus, protection of the habitat along with regular monitoring of these large carnivores and their prey population using comparable scientific methods is essential for Mudumalai to emerge as one of the most important areas for tiger and leopard conservation in Western Ghats.

ACKNOWLEDGEMENT

We thank Tamil Nadu Forest Department for granting permission to work in Mudumalai, as part of 'Sympatric carnivore studies' conducted by Wildlife Institute of India (WII). We thank the Director and Dean, WII for their encouragement and support provided for the study.

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2. ADDITIONAL NOTES ON THE DIET OF SLOTH BEAR *MELURSUS URSINUS* IN MUDUMALAI TIGER RESERVE AS SHOWN BY SCAT ANALYSIS

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The Sloth Bear *Melursus ursinus* is a widely distributed omnivore, endemic to the Indian subcontinent. It is a medium-sized mammal weighing between 127 and 145 kg (Prater 1965). Very few studies on its food habits in the Subcontinent have been carried out; Mudumalai (Baskaran *et al*. 1997; Desai *et al*. 1997), Mundanthurai plateau (Gokula *et al*. 1995), Bandipur Tiger Reserve (Johnsingh 1981), Neyyar Wildlife Sanctuary (Srikumaran and Balakrishnan 2002), Panna Tiger Reserve (Yoganand *et al*. 2005), Bandhavgarh Tiger Reserve (Gopal 1991), Chitwan National Park (Laurie and Seidensticker 1977; Joshi *et al*. 1997) and Wilpattu National Park (Eisenberg and Lockhart 1972). The Sloth Bear is a well-known seed disperser, which influences the regeneration of some plant species (Srikumaran and Balakrishnan 2002). Consequently, its movement depends largely on the density and distribution of its key food availability in the area. Sloth Bear population is declining in many parts of its range due to deterioration and loss of habitat (Johnsingh 2003).

Mudumalai Tiger Reserve (11º 32'-11º 43' N; 76º 22'-76º 45' E) is situated at the tri-junction of Tamil Nadu, Karnataka, and Kerala states at an elevation that varies from 960 to 1,266 m. This 321 sq. km reserve is bounded by Wayanad Wildlife Sanctuary on the west, Bandipur Tiger Reserve in the north, and in the south by Nilgiri North Forest Division. According to Champion and Seth (1968), the vegetation types found in Mudumalai are classified into Southern Tropical Dry Thorn Forest, Southern Tropical Dry Deciduous Forest, Southern Tropical Moist Deciduous Forest, Southern Tropical Semi-Evergreen Forest, Moist Bamboo Brakes and Riparian Forest. Earlier studies on food habits of

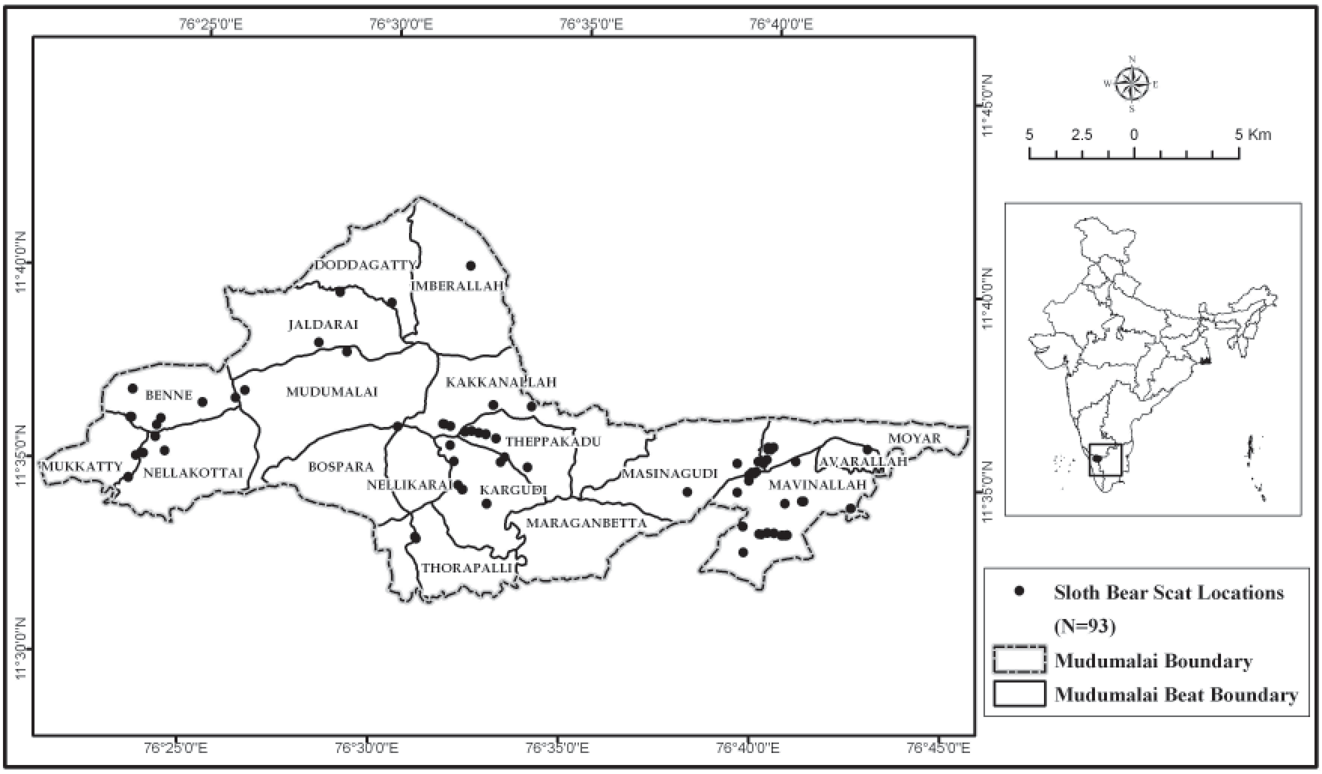

Fig. 1: Locations of Sloth Bear scats collected in Mudumalai Tiger Reserve (January-May 2009)

Table 1: Frequency and percent occurrence of food items found in Sloth Bear scats in Mudumalai Tiger Reserve (January-May 2009)

Plants	Frequency of occurrence	Percent occurrence
Albizzia odoratissma	2	1.0
Anogeissus latifolia	2	1.0
Artocarpus heterophyllus	2	1.0
Cassia fistula	26	13.83
Cordia oblique	12	6.38
Ficus sp.	2	1.0
Grewia tilifolia	4	2.1
Lagerstromia microcarpa	1	0.5
Lantana camara	4	2.1
Mangifera indica	1	0.5
Olea glandulifera	1	0.5
Semicarpus anacardium	1	0.5
Syzygium species	2	1.0
Zizyphus mauritiana	16	8.51
Zizyphus oenoplia	2	1.0
Zizyphus rugosa	2	1.0
Heteropogon contortus	1	0.5
Seteria intermedia	2	1.0
Unidentified fruit	1	0.5
Others		
Family: Formicidae (Red Ant)	30	15.9
Family: Formicidae (Black Ant)	12	6.3
Odontotermes sp.	33	17.5
Order: Coleoptera (Beetle)	6	3.1
Apis sp. and wax	18	9.5
Cervus unicolor	5	2.6

Sloth Bear in Mudumalai (Baskaran *et al*. 1997; Desai *et al*. 1997) were conducted in deciduous and scrub habitats. The present study was carried out in the entire Park covering deciduous, scrub and semi-evergreen habitats in Mudumalai.

Ninety-three Sloth Bear scats were collected along forest roads and trails in the Park encountered from January to May 2009. The location of scats collected is given in Fig. 1. The scats were distinguished by their size, shape, composition of seeds and animal remains, and by using indirect evidences (track, signs). Each scat sample was taken in a separate polythene bag with details of date, place, condition (fresh, old), habitat, and GPS location. The scats were washed in running water using a mesh sieve (1 x 1 mm) and sun dried to recover seeds and animal matter. The plant remains were compared with seeds obtained from plants in the field and identified in the herbarium of the Wildlife Institute of India. Animal remains (bone, hair, insect parts) were identified in the laboratory of the Wildlife Institute of India. The percentage occurrence of various plant and animal remains were assessed.

The frequency and percent occurrence of food items found in Sloth Bear scats is given in Table 1. Thirty-five scats contained plant matter along with animal remains, 40 scats contained only animal matter, and 18 scats contained bee wax remains. A total of 18 plant species were recorded in scats. *Cassia fistula*, *Zizyphus mauritiana*, and *Cordia obliqua* constituted the bulk of the diet with each species contributing 13.83, 8.51 and 6.38% respectively. Two grass species, *Heteropogon contortus*, *Seteria intermedia*, and an unidentified fruit was also recorded. Animal matter in the scats composed mainly of red and black ants (Formicidae), termites *Odontotermes* sp. and bees *Apis* sp. with wax, which constituted 15.9, 6.3, 17.5 and 9.5% respectively. Beetles (Coleoptera) and Sambar *Cervus unicolor* remains (bone, hair) formed a small fraction, 3.2 and 2.7% respectively (Table 1).

The present study documented eight new plant species including a grass species, *Albizzia odoratissma*, *Artocarpus heterophyllus*, *Ficus* sp., *Lagerstromia microcarpa*, *Mangifera indica*, *Olea glandulifera*, *Syzygium* sp., and *Heteropogon contortus*, which were not reported from earlier studies in Mudumalai (Baskaran *et al*. 1997; Desai *et al*. 1997). The percent occurrence of animal matter was found higher than plant matter as compared to previous studies (Gokula *et al*. 1995; Baskaran *et al*. 1997; Desai *et al*. 1997). The occurrence of Sambar remains in Sloth bear scats may be attributed to scavenging behaviour over decayed carcass of wild animals, which has already been recorded by Gopal (1991).

ACKNOWLEDGEMENTS

We thank the Tamil Nadu Forest Department for giving us permission to work in Mudumalai Tiger Reserve. Special thanks to Riddhika for her comments for the improvement of the manuscript. We thank Mr. K. Vinay Bhargav for his help in identification of insects, Mr. M.M. Babu for plant identification and Ms. Nelanjana for preparing the map. We are indebted to our field assistants C. James, M. Kethan, S. Mathan and T.M. Manpan for their extensive help in the field.

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3. MYSTERIOUS CHARACTERS RECORDED IN BLACK-HEADED IBIS *THRESKIORNIS MELANOCEPHALUS* DURING BREEDING SEASON

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On May 23, 2008, while on a visit to a breeding site of Black-headed Ibis at Paldi village, situated 8 km north of Visnagar, Gujarat, India, we observed three pairs of the Bird busy selecting their nesting site. On approaching closer, we observed red coloration on the bare hind neck of one bird (Fig. 1). Similar coloration was recorded on May 29, 2008, in a bird in a flock of 44 birds at a breeding site at Ralisana village. On June 14, 2008, we observed two birds with red lores and scattered red spots on the throat, besides a red hind neck and mantle, building their nest at Civil Hospital, Visnagar.

Fig. 1: Black-headed Ibis with mysterious characters

During the breeding season, we observed 93 pairs, out of which 17 birds with a red hind neck and mantle, and 3 birds with red lores and scattered red spots on the throat were recorded. The breeding plumage of Black-headed Ibis is well described in literature (Grimmett *et al.* 1998; Gadhvi 2001; Ali 2002; Kumar *et al.* 2005) and there is no mention of any red coloration on body parts during the breeding season.

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