A STUDY ON PREDATION ECOLOGY OF LARGE CARNIVORES WITH SPECIAL REFERENCE TO HUMAN-CARNIVORE CONFLICT IN PENCH TIGER RESERVE, MADHYA PRADESH, CENTRAL INDIA

A THESIS

Submitted by

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For the award of the Degree of

DOCTOR OF PHILOSOPHY
IN
WILDLIFE SCIENCE

Under the guidance of

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January – 2022

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I declare that the thesis entitled "**A Study on Predation Ecology of Large Carnivores with Special Reference to Human-carnivore Conflict in Pench Tiger Reserve, Madhya Pradesh, Central India**" submitted by me for the degree of Doctor of Philosophy is the record of research work carried out by me during the period from **2013 to 2016** under the guidance and supervision of Dr. K. Sankar, Q. Qureshi and Dr. Y. V. Jhala. The work has not formed the basis for the award of any degree, diploma, associate ship, fellowship, titles in this or any other University or other institution of higher learning. I further declare that the material obtained from other sources has been duly acknowledged in the thesis. I shall be solely responsible for any plagiarism or other irregularities, if noticed in the thesis.

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EXECUTIVE SUMMARY Apex predators like tigers and leopards play a crucial role in structuring ecosystems and maintaining community dynamics through resource exploitation and top-down effects. Naturally low densities of these predators make their conservation challenging. On top of that,

populations of many **large carnivores are restricted to** small sized **protected areas**

and only a handful of them harbor demographically viable population. Interactions between such carnivore populations in a small area can be limiting to survival of one the interacting species and they become more vulnerable to extinction. Hence, understanding the population dynamics along with the intraguild relationship between these predators is essential as a means of achieving the goal of conservation. Recent advances in camera trapping have enabled researchers to study different population parameters of rare and elusive carnivores like tigers and leopards. These kinds of estimates are integral for guiding required management and conservation strategies. I used

spatially explicit capture-recapture method **to estimate the** abundance and **density** of tigers **and**

leopards in Pench Tiger Reserve (PTR), Madhya Pradesh. Estimated abundances of tigers were 69 (SE 6), 56 (SE 5) and 59 (SE 5) in 2013-14, 2014-15 and 2015-16 respectively. Spatially explicit densities of tigers were 5.73 (SE 0.88), 4.85 (SE 0.8) and 5.15 (SE 0.82) in 2013-14, 2014-15 and 2015-16 respectively. Detection probabilities of female tigers were higher than males. The detection corrected sex-ratio (pmix) of tigers were slightly female biased in the first two years but became male biased during the last year. Estimated abundances of leopards were 56 (SE 13), 50 (SE 7) and 57 (SE 7) in 2013-14, 2014-15 and 2015-16 respectively. Spatially explicit densities of leopards were 3.76 (SE 0.92), 4.45 (SE 0.85) and 4.97 (SE 0.88) in 2013-14, 2014-15 and 2015-16 respectively. Both male and female leopards showed similar probability of detection for the first two years. The detection corrected sex ratio was male biased in the first year but later became dominated by females in the following years. I also compared the spatial scale of detection – σ for different intra and inter species combinations of tigers and leopards. Estimates were similar for female tigers and leopards as well as male tigers and leopards. On the other hand, male tigers movement parameter was at least two times higher than that of female tigers and in case of leopards, the movement of males were 1.3

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Dedicated to my Jethu, Mr. Srikumar Chattopadhyay

ACKNOWLEDGEMENT

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EXECUTIVE SUMMARY

Apex predators like tigers and leopards play a crucial role in structuring ecosystems and maintaining community dynamics through resource exploitation and top-down effects (Linnell and Strand, 2000; Cardillo *et al*., 2004, Ripple *et al*., 2014). Naturally low densities of these predators make their conservation challenging. On top of that, populations of many large carnivores are restricted to small sized protected areas and only a handful of them harbor demographically viable population (Jhala *et al*., 2020). Interactions between such carnivore populations in a small area can be limiting to survival of one the interacting species and they become more vulnerable to extinction (Caro and Stoner, 2003; Durant et al., 2010). Hence, understanding the population dynamics along with the intraguild relationship between these predators is essential as a means of achieving the goal of conservation.

Recent advances in camera trapping have enabled researchers to study different population parameters of rare and elusive carnivores like tigers and leopards. These kinds of estimates are integral for guiding required management and conservation strategies. I used spatially explicit capture-recapture method to estimate the abundance and density of tigers and leopards in Pench Tiger Reserve (PTR), Madhya Pradesh. Estimated abundances of tigers were 69 (± SE 6), 56 (± SE 5) and 59 (± SE 5) in 2013-14, 2014-15 and 2015-16 respectively. Spatially explicit densities of tigers per 100 sq. km. were 5.73 (± SE 0.88), 4.85 (± SE 0.8) and 5.15 (± SE 0.82) in 2013-14, 2014-15 and 2015-16 respectively. Detection probabilities of female tigers were higher than males. The detection corrected sex-ratio (p_{mix}) of tigers were slightly female biased in the first two years but became male biased during the last year. Estimated abundances

of leopards were 56 (± SE 13), 50 (± SE 7) and 57 (± SE 7) in 2013-14, 2014-15 and 2015-16 respectively. Spatially explicit densities of leopards were 3.76 (± SE 0.92), 4.45 (± SE 0.85) and 4.97 (± SE 0.88) in 2013-14, 2014-15 and 2015-16 respectively. Both male and female leopards showed similar probability of detection for the first two years. The detection corrected sex ratio was male biased in the first year but later became dominated by females in the following years. I also compared the spatial scale of detection – σ for different intra and inter species combinations of tigers and leopards. Estimates were similar for female tigers and leopards as well as male tigers and leopards. On the other hand, male tiger's movement parameter was at least two times higher than that of female tigers and in case of leopards, the movement of males were 1.3 times higher than that of the females. Tiger captures were concentrated near the central part of the study area whereas leopard captures were more near the peripheries and areas of low tiger occurrence. So, it becomes clear that leopards respond to tiger abundance by using areas less frequented by tigers.

Seven years of data (2008 – 2015) resulted in phot-capture of 96 unique individual tigers in the study area. The estimated survival rate of individual tigers was high. Survival of female tigers were higher than that of the male tigers but the range was overlapping. Apparent survival and transitional probabilities were best explained by gender specific models. Survival constant was selected as the best model for estimating growth rate of tigers. Calculated annual growth rate was 13% with no observed sex bias.

Conservation of large carnivores is hugely dependent on a viable population of their principal prey species. In PTR chital (*Axis axis*), sambar (*Rusa unicolor*) and wild

pig (*Sus scrofa*) were identified as major contributor of the diet of tigers and leopards which is why I focused on the population parameters of these three species only. Line transect based density estimation has been established as a robust method for monitoring prey population to understand the trend. In addition to wild ungulates, domestic livestock contributes substantially to the diet of large carnivores. Attack on domestic livestock by large carnivores is a major challenge globally and poses a threat for their conservation. A trade-off can be established by grazing the livestock in areas where the probability of them being attacked by livestock goes down. In order to achieve that, mapping their distribution and grazing pattern is crucial.

Estimated densities using the line transect surveys were highest for chital with a range of 44 – 52 individuals per sq. km. over the entire study period and remained stable. Sambar density also remained stable over the study period with a range of 5 – 8 individuals per sq. km. Density of wild pigs could only be estimated for the session of 2013-14 because of lack of observation on the line transect. Estimated density for that period was 12 wild pigs per sq. km. Distribution of chital was concentrated near the submergence area and the northern boundary of the core zone. Sambar occurrence were higher in rugged areas whereas wild pig captures were higher near the edges of the study area bordering crop fields. Domestic livestock were found all over the buffer zone and no cattle is allowed inside the core zone. From the average time herds of domestic livestock spend in area, it was seen that they didn't stay stationary at one place for long. I also found a very slight trend indicating grazing livestock tend to spend lesser time in densely forested areas.

Understanding the activity patterns of the key components of an ecological community is crucial for understanding their dynamics. Temporal partitioning can mediate coexistence among sympatric predators which necessitates looking into their temporal activity patterns and extent of overlap. It is also essential to look into the extent of overlap of the predators with their preferred prey for a holistic understanding. Investigating the activity pattern of wild ungulates can elaborate on their time investment in different activities like foraging, thermoregulation and predator avoidance.

Both tigers and leopards were crepuscular in nature with bimodal activity peaks. The extent of overlap between their activity pattern was 87%. Extent of overlap was maximum (88%) in high tiger density areas and lowest (73%) in low tiger density areas. However, no difference in the peak activity period was observed which means that these two sympatric predators do not segregate on the temporal axis. Investigation of extent of temporal overlap between these two sympatric felids and their principal prey revealed that for both tigers and leopards the maximum overlap was with sambar. Extent of overlap between these predators and their prey also varied along the disturbance gradient. In moderately disturbed areas, highest overlap was between sambar and tiger and in case of leopards highest overlap was with wild pigs. In disturbed areas the predators did not show any alteration in their activity patterns but ungulates were more diurnal. The presence of humans in the vicinity might act as a deterrent which would ultimately increase their chances of survival.

The maximum number of groups seen during behavioural sampling had 4 to 7 chital individuals. In all the three predator density categories (high, medium and low),

proportional vigilance of chital decreased with increase in group size but predator density had no effect on it as their proportional vigilance remained similar across all categories. In both high and medium predator density area, vigilance interval was shortest for smaller groups, increased as the group size increased to 15 individuals. Vigilance interval dipped again when groups comprised of 20 individuals and increased subsequently with increase in group size. In low predator density areas shortest vigilance interval as observed in smallest groups and it increased subsequently. Sambar were mostly solitary or with just another individual. Proportional vigilance of sambar did not vary with group size or changing predator density. I also found that both chital and sambar alter their behavioral pattern in response to habitat cues. The proportional vigilance of chital and sambar increased with the increase in cover density.

Although intraguild interactions amongst large carnivores impact the population dynamics of sympatric predators, their spatial distribution and social organization are also governed by availability of food to a great extent. The abundance and dispersion of prey have been known to influence individual predatory behaviour. In addition to availability of prey, habitat features play a major role in determining the nature of prey-predator interactions.

A total of 105 predation events of wild ungulates were used for identifying their predation hotspots. In case of wild ungulates, the predation hotspots were observed mostly in Karmajhiri range and northern part of Gumtara range. The best model showed that probability of predation increased with abundance of chital and increase in cover density. To model the predation hotspots of domestic livestock, a

total of 111 predation events were used. The best model demonstrated that the probability of predation of domestic livestock increased with increase in predator density and declined with increase in elevation and cover density.

Loss of livestock to tigers and leopards is one of the major factors of negative human-wildlife interactions. Another crucial factor is crop raiding by wild ungulates as it results in huge economic loss. Response of the local people towards such interactions are influenced by these losses in addition to their religious, cultural and social values. In PTR, the minimum average annual cost incurred was INR 33665.78 (± SE 6809.96). Average annual benefit ranged from INR 17265.51 (± SE 4115.4) to 36353.15 (± SE 2922.81). Mean annual benefit increased significantly with increase in dependence on NTFPs and productive land. Net loss decreased significantly with increase in number of earning members in a family and increased with increase in forest cover. Increase in stay duration resulted in a significant decrease of cost : benefit ratio.

Ninety six percent of the local residents could successfully identify tigers followed by more than 80% positive identification of sloth bears, wild dogs and leopards. More than 95% of the respondents positively identified common langur, rhesus macaque and gaur. The rate of identification was more than 75% for chital and wild pigs. Respondents' attitude was positive towards all large carnivores except for wolves. Majority of them think that both livestock and crop raiding has gone up in the last five years because of the protection received. Land owners and panchayat members perception were significantly different. Although majority of the respondents agreed that all wild animals should be protected, 20% of the respondents think that

authorities should grant them the permission to hunt wild ungulates without any limitation. Similar proportion of respondents think that these 'problem animals' should be translocated elsewhere. The caste of the respondent had an impact on their respective attitude towards wildlife and conservation. Thirty one percent of the respondents chose only field and a house as a preferred place to stay followed by a scenario here house, livestock, field and access to fuel wood is seen. Next the most preferred scenario of living as with house, field, livestock and access to fuel wood. None of the respondents chose the scenario with wild ungulates present in the photograph as a preferred place to stay. Educational status of the respondent and the cost incurred by them significantly influenced their choice of the preferred place to stay. Seventy nine percent of the local residents think that formation of protected area was not at all beneficial for them. Mostly people said that they receive no benefit and their right to the forest has been curbed additionally. However, 72% of the interviewees responded that it is beneficial for them to stay near PTR in spite of all the troubles faced.

Spatially explicit densities of tigers of the study remained stable over the entire study period which implies stability in the population. Carrying capacity based on prey density (Jhala et al., 2020) was estimated at 6.96 to 8.86 tiger per 100 sq. km. My results suggest that the predators in PTR are attaining carrying capacity. Leopards coexist with tigers here by segregating spatially. No temporal segregation was observed between these sympatric predators. Predator density, chital density, cover density, elevation and ruggedness were the determining factors of predation by tigers and leopards. This kind of predation risk modelling can be beneficial for formulating

effective management strategies as it pinpoints areas where domestic livestock can be more vulnerable to predation. Grazing routes can be manoeuvred to avoid such areas, thereby avoiding the risk of depredation. The economic loss of lost livestock was significantly lesser that the loss owing to crop raiding. Such extensive losses have made people hostile towards wild ungulates and local authorities. Lack of compensation for lost crop has further aggravated their attitude. Taking cognizance of this matter along with profit sharing mechanism has the potential of garnering the locals support for conservation. Such support is essential as having inviolate space without presence of humans is impossible in current situation and harmonious co-existence between people and wildlife can make conservation a success.

CHAPTER – 1: INTRODUCTION AND LITERATURE REVIEW

1.1. Introduction

Large carnivores at the apex of the trophic pyramid inherently occur at low densities, compete with human interests and are therefore one of the most difficult taxa to conserve (Cardillo *et al*., 2004; Ripple *et al*., 2014). Large carnivores play a crucial role in structuring ecosystems and form an important element of intact functional systems (Linnell and Strand, 2000; Ripple *et al*., 2001; Durant *et al*., 2010). Higher trophic positioning of large carnivores not only shapes the predator guild but also control the demography and distribution of sub-dominant species via resource exploitation and top-down effects (Palomares and Caro, 1999; Elmhaghen and Rushton, 2007; Hoeks *et al*., 2020). They also regulate prey population as well as evolution of prey (Minta *et al*., 1999; Terborgh *et al*., 2001; Buskirk and Zielinski, 2003; Zielinski *et al*., 2005). Absence of large predators leads to mesopredator release where the increased abundance of medium-bodies predators potentially affects prey population along with smaller predators (Soule´ *et al*., 1988; Crooks and Soule´, 1999).

Being so important in maintaining the proper functioning of ecosystem they are especially vulnerable to population decline and extinction (Newmark, 1995; Wennergren *et al*., 1995; Woodroffe and Ginsberg, 1998, Zielinski *et al*.2005). According to the Red Data List (IUCN 2000) 27.4% of the carnivore species are listed as vulnerable, endangered, critically endangered or recently extinct. Populations of many large carnivores are restricted to protected areas that are of limited size and very few of such protected areas harbour a viable population (Jhala *et al*., 2020). Due to small populations, restricted to protected areas often inter-carnivore interactions can become a limiting factor for the survival of some carnivore populations (Creel, 2001;

Caro and Stoner, 2003; Durant *et al*., 2010). In multi-large carnivore systems understanding the mechanisms that permit their coexistence among competing carnivores in time and space (Miller *et al*., 2018) are essential for formulating effective conservation strategies (Estes *et al*., 2011; Wilman *et al*., 2014; Di Minin *et al*., 2016).

Species assemblage in a system is governed by niche partitioning between different species (Begon, Harper and Townsend, 1990; Mayhew 2006). Different factors such as habitat requirements, body size, behavioural adaptations and density determine the way interspecific interactions will take place among sympatric species (Thompson, 1988). The outcome of such interactions can range from intraguild killing and kleptoparasitism (Palomares and Caro, 1999; Pereira *et al.*, 2014; Prugh and Sivy, 2020) to coexistence by differential usage of resources (Paquet, 1992; Johnson and Franklin, 1994, Murray *et al.*,1994) segregating on spatial (Voigt and Earle, 1983), temporal and/or spatio-temporal scale or varying in their foraging strategies (Kozlowski *et al.*, 2008; Vanak *et al.*, 2013). The subordinate species has been observed to coexist with the dominant one by investing more energy including residing in inferior quality habitat or travelling more (Caro and Stoner, 2003).

Dominant predators have been observed to significantly influence the population of the less dominant species through interference interactions (Palomares and Caro, 1999; Linnell and Strand, 2000; Donadio and Buskirk, 2006). On contrary, if the apex predators' population declines, secondary predators can benefit by expanding their population rapidly and affecting the entire ecosystem through cascading mechanism (Prugh *et al.*, 2009; Ritchie and Johnson, 2009; Estes *et al.*, 2011; Ripple *et al.*, 2014; Suraci *et al.*, 2016). In the past, few studies have looked into

the dynamics of carnivore coexistence patterns on a large geographical scale (*e.g.*, Mills, Freitag and van Jaarsveld, 2001; Loyola *et al.* 2009**).** Lately several studies have focused on exploring the mechanisms of the varied coexistence patterns within landscapes and species (Durant, 1998; Elmhagen and Rushton, 2007; Elmhagen *et al.*, 2010; Swanson *et al.*, 2016; Farris *et al.*, 2020). The importance of such studies lies in the fact that forces of natural selection are directed towards individuals within specific ecosystems and not the entire species across their range of distribution. Whilst looking at a large geographical area, very often distinct patterns of niche differentiation and distribution among sympatric species fail to emerge and vice-versa. Thus, choosing the proper geographical scale in order to understand mechanisms governing species coexistence is essential (Rahbek and Graves, 2001; Shriner, Wilson and Flather, 2006; Davies *et al.*, 2007; Anderson *et al.*, 2009; Durant *et al.*, 2010). Interactions between tigers (*Panthers tigris* L.) and leopards (*Panthera pardus* L.) are a perfect fit for understanding how such mechanism can affect the structuring and functioning of large carnivore guilds.

1.2. Literature Review

Tiger (*Panthera tigris* L.) is the largest of all living cats and acts as an apex predator in most of Asia's forest ecosystems (Jhala *et al*., 2020). The mean length of the Bengal tiger is about 3 meters from the tip of the nose to the end of the tail. Adult males weigh 200–260 kg (440–570 lb). Adult females are slightly smaller and lighter, weighing approximately 100–160 kg (220–350 lb). The typical coat pattern of golden and yellow makes them elusive in the wild facilitating its stalking behavior (Sunquist, 2010). Although historically they were distributed from Turkey in the west to Russia in the east (Nowell and Jackson, 2006), their distribution has been reduced drastically

over the last century. Over the past 100 years, tiger have disappeared from southwest and central Asia, from two Indonesian islands (Java and Bali) and from large areas of Southeast and Eastern Asia along with large scale decline over the rest of their range of occurrence (Sunquist *et al*., 1999; Sanderson *et al*., 2006; Dinerstein *et al*., 2007, Wikramayanke *et al*., 2010, Jhala *et al*., 2021).

Leopards (*Pathera pardus* L.) is the most widely distributed felid (Nowell and Jackson, 2006). Male leopards usually weigh 58 kg and the weight of female leopards is around 37.5 kg (Bailey, 1993). Starting from Africa it is distributed through most of Asia up to the Amur valley in Russia. They are suited to almost every kind of habitat ranging from the rainforest of the tropics to desert and temperate regions (Kitchner, 1991). The Indian subspecies, *Panthera pardus fusca*, is found in all forested habitats in the country, except for the arid deserts and areas beyond the timber line in the Himalayas (Prater, 1980). They have adapted surprisingly in terms of habitat and food requirements; they thrive in intensively cultivated and inhabited areas as well as near urban development (Nowell and Jackson 2006). Habitat destruction, depletion of prey base, poaching for skins, bones and claws, and poisoning carcasses of livestock killed by leopards bear a significant threat to the species (Edgaonkar, 2008; Mondal, 2011).

In spite of the large-scale decline of tigers and constriction of geographical range to approximately 10% of the historical range over the last century (Dinerstein *et al*., 2007), they are the apex predators in majority of the tiger reserves in India (Jhala *et al*., 2020). Leopards are susceptible to intraguild competition and predation by tigers to a greater extent due to their taxonomic similarity, overlapping diet spectrum as well as difference in body size. As a result of this leopards might avoid tiger to increase

their chances of survival (Polis *et al*., 1989; Palomares and Caro, 1999; Donadio and Buskirk, 2006). Sympatry between tigers and leopards is observed across their range of occurrence in Asia (Odden *et al*., 2010). The mechanism for coexistence between these two species ranges from differential prey selection depending on size-class of prey (Johnsingh, 1992; Karanth and Sunquist, 1995; 2000; Majumder *et al*., 2013) to expansion of diet niche of leopards which comprises of small mammals, birds and domestic livestock in areas of high density of tigers (Odden *et al*., 2010; Harihar *et al*., 2011). Few studies have also reported shift in spatial use of habitats along with low abundance and occupancy of leopards as a response to presence of tigers in the area (Odden *et al*., 2010; Harihar *et al*., 2011; Mondal *et al*., 2012). Leopards were also known to significantly increase their density in areas of low tiger density (Kumar *et al*., 2019) and change their activity pattern to reduce competition (Mondal *et al*., 2012; Ramesh *et al*., 2012; Karanth *et al*., 2017; Li *et al*., 2018).

1.3. Rationale of the study

In order to get an all-encompassing idea of intra-predator relationships, one needs to study the population dynamics of the target species. Monitoring a population over a specific time period reveals the change in population size which is integral for their conservation. Impact of management strategies can also be understood by monitoring populations. Studies which look into factors like density-dependent growth rate, prey-predator interactions also need to examine the population dynamics of the study species (Williams *et al*., 2002). Size of a population can be demonstrated by either abundance (total number of individuals in a population at a specific time in the study area) or density (abundance/area). Density of a population is more advantageous as it helps one compare estimates over space and time (Caughley, 1977; Roy, 2019).

For elusive, wide-ranging large carnivores; direct observations to study their population dynamics is nearly impossible. Recent advances in technology have not only helped to estimate the population abundance and density of such carnivores using camera trap based photo-captures but also helped to assess their annual survival, growth rate, sex-ratio as well as recruitment pattern (Karanth *et al*., 2004, Bisht *et al*., 2019; Kumar *et al*., 2019).

Carnivore density have been positively linked with prey biomass (Carbone and Gittleman, 2002). Their importance in maintaining the ecosystem equilibrium and productivity is significant (McNaughton, 1979; Crawley, 1983). Hence, to conserve large carnivore populations, monitoring their prey population is also essential. For such monitoring exercises robust estimates of population abundance and distribution is essential.

These kind of robust estimates of prey population dynamics can be attained from line-transect based density estimation (Karanth and Sunquist, 1995; Biswas and Sankar, 2002; Jhala *et al*., 2020). This method overcomes the shortcomings of previously used techniques by incorporating detection probability in the sampled area along with modelling the width of the line depending on the detectability (Buckland *et al*., 2015). Spatial distribution pattern is also another major parameter of interest for such monitoring exercises which has studied by using camera trap based counts extensively (Carter *et al*., 2012; Kafley *et al*., 2019; Jhala *et al*., 2020).

Another key feature of community dynamics is understanding their diel activity patterns as species interactions happen both on spatial and temporal scale (Lashley *et al*., 2018). Predators with similar morphological characteristics and

feeding habits become competitors in nature (Donadio and Buskirk, 2006; Harmsen *et al*., 2009). Even when availability of resource is not constrained, interference interactions between the predators can result in direct death of one of the concerned predators (Polis *et al*., 1989; Polis and Holt, 1992; Holt and Polis, 1997; Linnell and Strand, 2000). Such interactions are frequent in nature and the competing predators segregate their niche spatially, temporally or spatio-temporally (Schoener, 1971; Pianka, 1973; Durant, 1998; Palomares and Caro, 1999; Linnell and Strand, 2000; Harrington *et al*., 2009).

However, an inclusive idea of community dynamics can only be achieved after looking into prey-predator interactions which entails studying the temporal activity patterns of both prey and predators. Understanding activity patterns of wild ungulates reveal the time they spend in foraging, thermoregulation and predator avoidance. On one hand, vigilance behaviour of these ungulates increases their chances of survival by avoiding the predators. But on the other hand, it reduces their allotted time for other regulatory activities like foraging and grooming (Lima and Dilll, 1990; Ghuman *et al*., 2010).

Prey-predator interactions are a dynamic process and it needs information on predation pattern in addition to information on their spatial distribution pattern and temporal activity pattern. Depredation of livestock by tigers and leopards is common India. But very few studies have been able to quantify the contribution of domestic livestock in the diet of large carnivores (e.g., Bagchi and Mishra, 2006; Suryawanshi *et al*., 2013; Johansson *et al*., 2015; Miller *et al*., 2016). Improper understanding of

predation risk on domestic livestock can lead to biased management strategies which ultimately affects conservation efforts negatively.

Predation risk modelling is an effective tool for visualising the predation risk. Their efficacy in enumerating hotspots of predation and predict is well established (Hebblewhite *et al*., 2005; Miller, 2015). One of the major factors for determining predation risk is the density of the predators (Miller, 2015). Relative abundance of ungulate species also plays a key role in determining the preference of prey where most abundant one is usually selected (Jaworski *et al*., 2013). It can be said that encounters between the predator and its prey is positively linked with density of the specific prey but the rate of encounter is random in nature (Holling, 1959; Arditi and Ginzburg 1989, Becker 2008).

Holt (1977) suggested that increased availability of one prey has the potential to increase or decrease the predation level on the other. This is base of the framework of the functional response (Holling, 1959). Functional response provides the theoretical framework of 'prey switching' which suggests that predators modify their 'attack rate' by responding to the changes in prey abundance (Solomon, 1949). But in a natural system, there are other factors than prey densities which affect the functional responses of predators. It can be predator dependent as well where both the predator and prey population have an impact on it or 'multispecies dependent', in which case species except for the 'focal predator and its prey species' affect the same (Abrams and Ginzburg, 2000). But prey and predator are not the only factors which determine predation risk. As both tigers and leopards are ambush predators, they need good cover

for a successful hunt. That is why factors like habitat structure, cover density play a very important role in determining the nature of predation risk.

Livestock depredation by tigers and leopards is frequent in the protected areas of India as they are forced to share resources with one of highest human and livestock density population of the world (Jhala and Giles, 1991; Banerjee *et al*., 2010, Athreya *et al*., 2011). Such increased interface between people and wildlife enhances the probability of conflict because of the extensive economic loss (Meriggi and Lovari, 1996; Mishra, 1997; Madhusudan and Mishra, 2003; Treves and Karanth, 2003; Muhly and Musiani, 2009; Tamang and Baral, 2010; Dhungana *et al*., 2019). As a result, understanding the costs and benefits of people living in and around protected areas bears a great significance to achieve the goal of balancing conservation priorities and needs of local people (Terborgh and Peres, 2002; Naughton-Treves *et al*., 2005; Shahabuddin and Rangrajan, 2007; Bruyere *et al*., 2009; Karanth and Defries, 2010; Karanth and Nepal, 2011). Loss of livestock is not the only cost local people bear due to staying near protected areas. A significant amount of crop damage is experienced by them because of crop raiding by wild ungulates in addition to occasional injury or even death (Karanth and Nepal, 2011). That is why to calculate the total cost of living near protected areas monetary values of both lost livestock and crop need to be taken into consideration.

Nevertheless, protected areas do not only cost money to the local people. People reap significant benefits from forested areas in terms of fuel wood, fodder and other minor forest produces. Employment opportunities from tourism and forest department along with access to materials for their social and religious purposes add

to those benefits. Existing policies provide compensation for lost livestock which has the capability of offsetting the loss incurred. So, it is important to calculate both the cost and benefit of staying near protected areas to understand the economics (Kruger, 2005; Spiteri and Nepal, 2006; Banerjee *et al*., 2013; Karanth *et al*., 2013, Tolbert *et al*., 2019).

These kinds of negative interactions between people and wild animals give rise to hostile attitude towards wildlife and conservation (Karanth *et al*., 2013). That is why a proper understanding of people's perception of risk associated with living in proximity of wildlife is essential to investigate the complicated phenomenon of human-wildlife interaction and designing sustainable management policies (Dickman, 2010). But economics is not the sole factor in determining people's attitude and perception towards conservation and management strategies. Religious beliefs, traditions, cultural values, economic status, source of income and educational status also contribute majorly in shaping the perception of risk and their consequences (Boholm, 1998; Sjoberg, Moen and Rundmo, 2004; Bagchi and Mishra, 2006; Dickman, 2010; Banerjee, 2012). The exponentially increasing human population makes it impossible to have protected areas free of human presence. For conservation to succeed, co-existence of people and wild animals is imperative which can only be achieved through positive attitude. So, it is important to assess their attitude and perception of wildlife, their conservation and existing management practices.

1.4. Objectives

To address the aforementioned issues, I proposed the following objectives for my thesis:

1. Understanding the response of tigers and leopards to wild and domestic prey availability

   a. Assessing the density and distribution pattern of prey and predator in the study area

      Leopards are sympatric with tigers in the study area. Hence, to understand the response of leopards to the presence of tigers I looked into their spatial distribution pattern and densities. Additionally, abundance and spatial distribution of predators and prey determine their predation pattern which is why I estimated the density and spatial distribution pattern of their principal prey as well.

   b. Understanding the temporal activity patterns of predator and prey

      Temporal segregation is also seen as a mechanism of coexistence of sympatric predators which is why I looked into their temporal activity pattern. Their activities are also known to be governed by activities of their principal prey species which led me to estimate the temporal activity of chital and sambar and the extent of overlap amongst the prey and predator.

   c. Assessing the patterns of predation of wild ungulates and domestic livestock by tigers and leopards

      Predation of prey has been known to be positively associated with their density. So, I looked into the predation pattern of both wild ungulates and domestic livestock by tigers and leopards in the study area. Habitat features also

play a major role in determining the predation pattern which led me to assess their impact on the predation hotspots.

2. Understanding the perception of people about wildlife and conservation in terms of actual loss due to human-wildlife interface and the ethics of conservation

a. Assessing the cost: benefit ratio of the losses and benefits respectively of people living around the forested area

Co-existence between people and wild animals can be facilitated if the trade-off between losses incurred and benefits gained by people are economically favourable. This led me to calculate the cost: benefit ratio of losses incurred and benefit received by people living near the study area over a gradient of distance from the core zone.

b. Assessing the perception and awareness of local people towards wildlife and conservation

Positive attitude of local people towards wildlife can be enhanced by minimal to no loss, free accessibility to natural resources, positive religious enforcement towards species, less livelihood dependencies on natural resources and educational level. Therefore, I assessed people's attitude and perception of wild animals, conservation and management strategies and looked into the effects of the aforesaid factors on the same.

CHAPTER – 2: STUDY AREA

Pench Tiger Reserve in the state of Madhya Pradesh is part of one of the major Tiger Conservation Units in India (Wikramayanke *et al*., 1998). The adjoining forest tract provides connectivity with Kanha Tiger Reserve and Satpura Tiger Reserve (Figure 2.1), making it an important source population for both tigers and leopards (Jhala *et al*., 2020; 2021). This merits a detailed description of the features of the area.

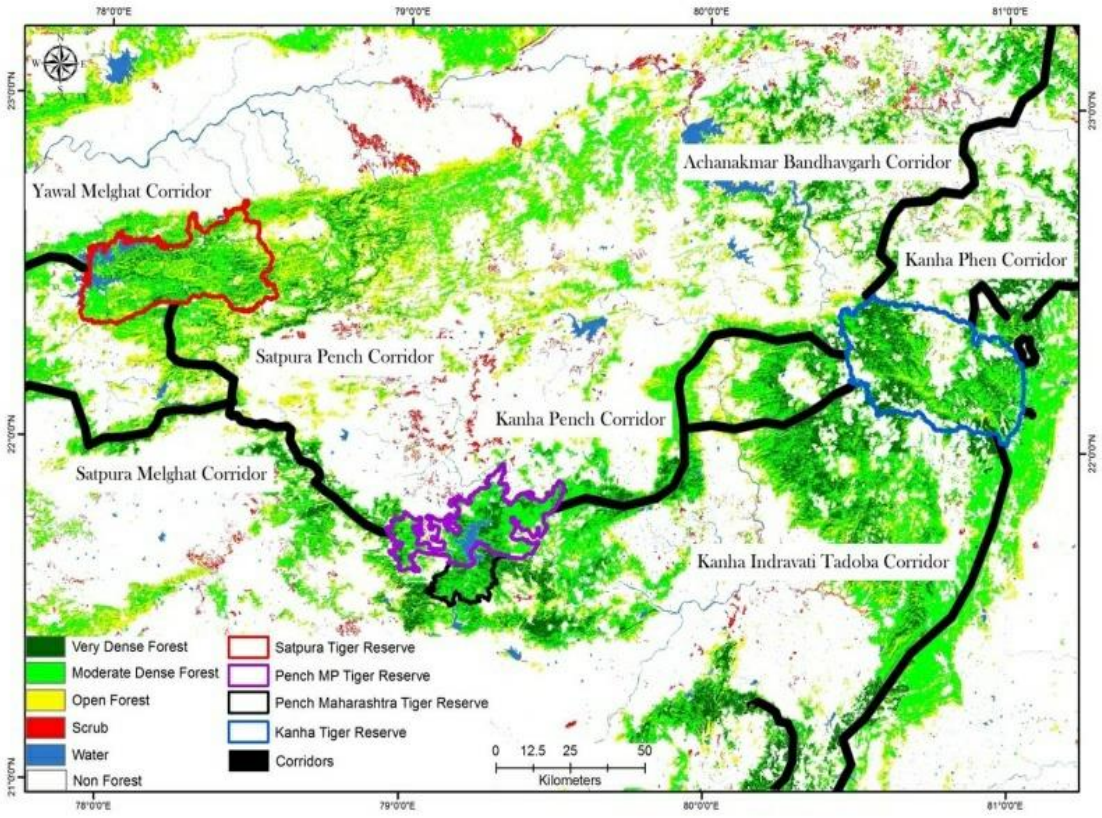

Figure 2.1: Location of Pench Tiger Reserve, Madhya Pradesh in the Central Indian tiger landscape along with its corridors with the surrounding protected areas *(Source: Qureshi et al., 2014)*

2.1. Location

The study area lies in the south-western region of Madhya Pradesh located on the border of Maharashtra. The core zone of Pench Tiger Reserve (hereafter PTR) is comprised of Indira Priyadarshini Pench National Park and Pench Mowgli Sanctuary

within the co-ordinates of 78º 55’ to 79º 35’ in the East and 21º 40’ N to 21º 57’ in the North. Total area of the core zone is 411.330 sq. km. Surrounding buffer zone has an area of 768.30 sq. km. and has six ranges – Ari, Rukhad, Ghatkohka, Khawasa, Kumbhpani and Khamarpani. PTR comes under the biogeopgraphic province of 6A Deccan Peninsula – Central Highlands (Rodgers and Panwar, 1988). It is under the jurisdiction of South Seoni forest division and South and East Chindwara forest divisions. The demarcation between two districts, Seoni and Chindwara, is formed by Pench River within the national park. This river is the main source of water and the name Pench is derived from the river. Near the southern end of the river a dam was constructed in 1987 for hydroelectricity and irrigation which resulted in a highly productive submergence area of 54 sq. km. in the National Park (Sankar *et al*., 2013; 2017).

2.2. Geology

PTR is within the peninsular foreland of the peninsular division geo-morphologically. It is an extension of the Satpura-Mahadeo-Maikal slopes. The terrain of PTR is gently undulating which is crisscrossed by seasonal streams and nullahs. General slope is from Southwest to Northeast. Mean altitude above sea level is around 550 meters. Highest altitude of 625 meters is seen on the hills of ‘Kalapahar’. These hills are characterized by gradual to steep slopes with flat tops (Sankar *et al*., 2017).

Dominant soil type in PTR is sandy loam. This is a result of weathering of Granitic gneisses. In all the elevated areas red soil is found. Areas near the foothill have less tress cover and the gaps in the forested area are comprised of *Kankar* and saline soil. Main features of this soil are large proportion of silica and orthoclase quartz with low water holding capacity. This type of soil is usually mineral deficient and less

productive. Alluvial soil is found in valleys, riverbeds and Pench riverbank (Sankar *et al*., 2017).

2.3. Climate

Four distinct seasons, summer; monsoon; post-monsoon and winter, are observed in PTR. Huge variation in temperature is seen in this region. In peak summer the temperature goes up to 40-45˚C whereas the average temperature falls to 9.1˚C in winters. Monsoon in PTR starts near the middle of the month of June and lasts till September. Ninety percent of total annual rainfall is seen during this time of total annual rainfall of 1300 mm to 1400 mm. Pre-monsoon rains are experienced in April and May and September, October and November receives a little of the post-monsoon showers. December to March is relatively dry in this region with no significant rainfall (Sankar *et al*., 2017).

2.4. Floral Diversity

Major forest types of PTR (Champion and Seth, 1968) (Figure 2) are

i. Tropical moist deciduous Forest – Type 3B/C_{1c} Slightly moist teak forest and

ii. Tropical dry deciduous forest which is further classified into

   a. Type 5A/C_{1b} Dry teak forest and

   b. Type 5A/C_3 Southern dry mixed deciduous forest

Other vegetation types include southern moist mixed deciduous forest and Boswellia forest (Figure 2.2).

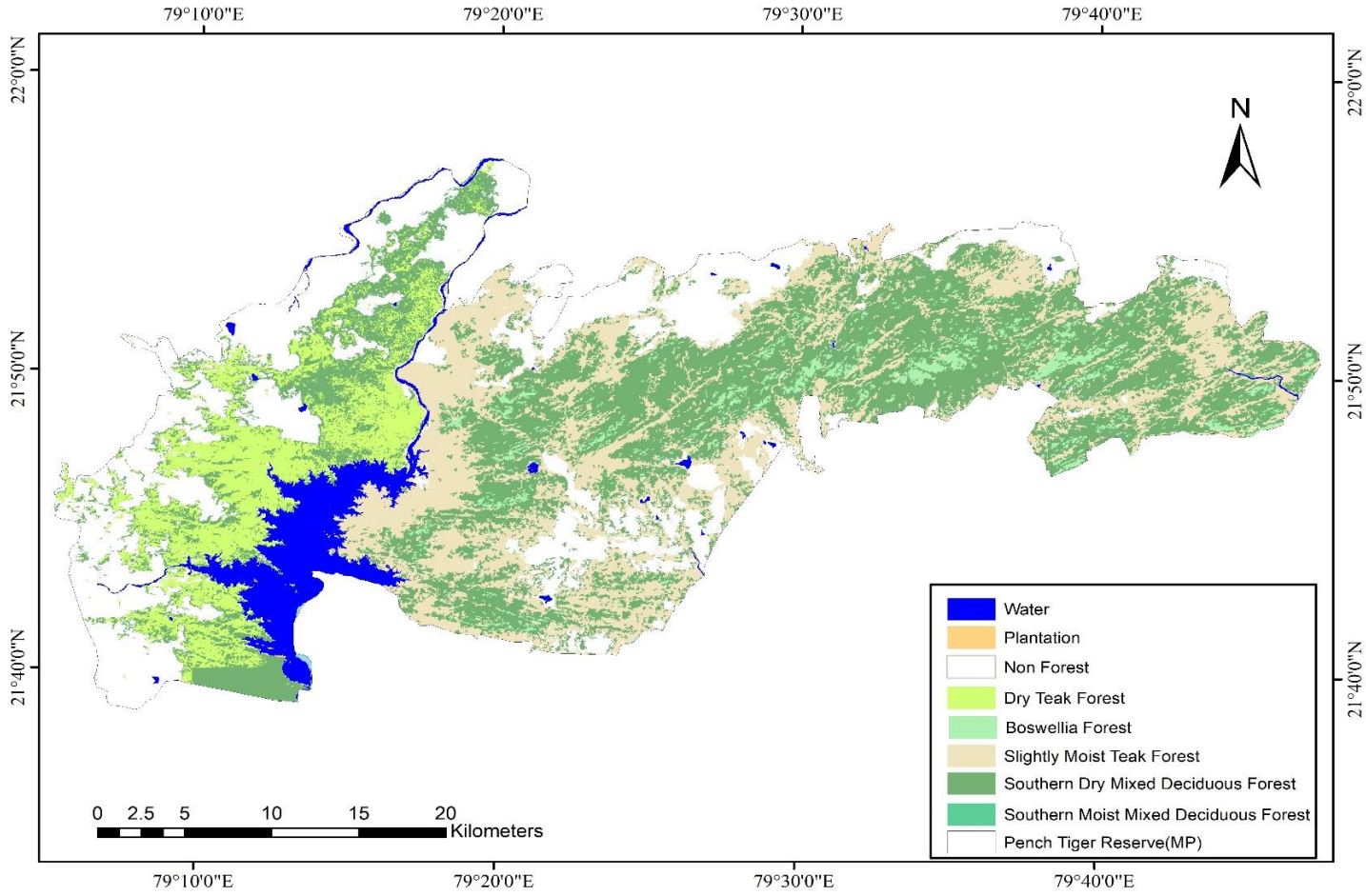

Figure 2.2: Depiction of major forest types found in Pench Tiger Reserve, Madhya Pradesh. Major vegetation types are slightly moist teak forest, dry teak forest and southern dry mixed deciduous forest.

Teak (*Tectona grandis*) is the dominant tree species in PTR. The associated species of teak here are *Madhuca indica, Diospyros melanoxylon, Terminalia tomentosa, Buchanania lanzan, Lagerostroemia parviflora, Ougeinia dalbergoides, Miliusa velutina* and *Lannea coromandelica* which occur in the almost flat terrain. *Boswellia serrata* and *Anogeissus latifolia* mixed forest patches are found on the hill slopes with undulating terrain. *Sterculia urens* and *Gardenia latifolia* are also found sporadically on the rocky slopes. Dendrocalamus strictus patches are frequent along the riverbeds and some hilly slopes. The open patches of PTR are covered with tall grasses along with some *Butea monosperma* and *Ziziphus mauritiana*. Along the river banks and nullahs evergreen species like *Terminalia arjuna, Syzygium cumini* and *Ixora parviflora* are seen. *Cleistanthus collinus* is seen as a dominant species in some scattered patches. Shrub cover is mainly comprised of *Lantana camara*. *Bauhinia vahlii* and *Butea superba* are two major climbers of this region.

2.5. Faunal Diversity

PTR is a part of the Oriental realm zoogeographically. In addition to tigers (*Pathera tigris tigris*) and leopards (*Pathera pardus fusca*), the major large carnivore roaming this area is Asiatic Wild dog or dhole (*Cuon alpinus*). Wolves (*Canis lupus*) are also found along the edges of the reserve. Smaller carnivores of this area include Golden Jackal (*Canis aureus*), Jungle cat (*Felis chaus*), Common palm civet (*Paradoxurus hermaphrodites*), Ratel (*Mellivora capensis*) and Small Indian civet (*Viverricula indica* Rasse). Two main species of mongoose are seen here - common mongoose (*Herpestes edwardsii*) and ruddy mongoose (*Herpestes smithii*). The sole bear

species of PTR is Sloth bear (*Melursus ursinus*). Indian fox (*Vulpes bengalensis*) have also been reported near the fringes of the reserve (Sankar *et al*., 2017).

Wild ungulates of PTR are Chital (*Axis axis*), Sambar (*Rusa unicolor*), Gaur (*Bos gaurus*), Nilgai (*Boselaphus tragocamelus*), Wild pig (*Sus scrofa*), Barking deer (*Muntiacus muntjac*) and Chowsingha (*Tetraceros quadricornis*). All over the study area chital, sambar, nilgai and wild pigs are found albeit their abundance. The distribution of gaur here is largely governed by availability of water sources where they come down from the hills and occupy areas near the Pench River during the dry season and move back up to the hills during monsoon. The distribution of barking deer is confined to the moist riverine patches and chowsingha occur near the undulating areas. Another ungulate, Chinkara (*Gazella bennetti*) are sometimes seen near the open areas of the buffer zone. Primates of PTR are the common langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mulatta*). Other fauna of this region includes Indian porcupine (*Hystrix indica)*, black-naped hare (*Lepus nigricollis*), flying fox (*Pteropus giganteus*), flying squirrel (*Petaurista petaurista*), three stripped squirrels (*Funambulus palmarum*) and Indian pangolin (*Manis crassicaudata*) (Sankar *et al*., 2017).

2.6. People of Pench Tiger Reserve

Presence of people from the 'Gond' tribe is prevalent in the Central Highland zone. They were the rulers of most of this region in the early 17th century (Rangrajan, 1996). They share the same lineage of the Dravidians of south India which can be seen from the linguistic similarity between the gond and Tamil (Forsyth, 1871). Initially they were hunter-gatherers staying in the hilly forested tracts but later they established as an agrarian society. In case of PTR, they mostly reside in the ninety-nine villages that

surround the reserve. As per the last census, the population stands at 61000 (Census of India, 2011). Presently, they form more of an agro-silvicultural community. Dependence on natural resources is seen but their major professions are farming or daily wage labor (Sankar *et al.*, 2017).

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CHAPTER 3: POPULATION DYNAMICS OF TIGERS AND LEOPARDS

3.1. Introduction

"A population is a biological unit at the level of ecological integration where it is meaningful to speak of a birth rate, a death rate, a sex ratio and an age structure in describing the properties of the unit" (Cole, 1957; Caughley, 1977). Studying population trend of a species is important as it looks into the fluctuations in different attributes over time. It takes into account both density dependent and independent factors i.e., environmental factors to be precise to further investigate the population parameters. Environment affects the population by influencing fecundity at each age class and survival of individuals. To summarise, it can be said that the dynamics of a population is the sum of the demographic responses of each individual in a given area (Caughley, 1977).

In any large carnivore population dynamics study, it is essential to know how individuals are surviving over the period (Karanth *et al.*, 2004). According to Schaub *et al.* (2006) "Understanding changes in population growth rate is one of the basic aims of population ecology and central to the field of conservation". A recent study on cheetah showed importance of long-term monitoring that follow multiple generations in gaining a full understanding of the factors affecting reproductive success (Pettorelli and Durant, 2007). Karanth (1995) estimated the density of tigers using camera trap-based capture-recapture framework for the very first time in India. Sadhu *et al.* (2017) used eight years data in Ranthambhore to understand the population demography of tigers. Bisht *et al.* (2019) outlines the importance of long-term population monitoring of large carnivores to establish conservation priorities for source populations in order

to bring forward plausible large carnivore recovery programs on a global scale. Importance of long term monitoring of tigers and leopards to understand their population dynamics is also outlined by another recent study in Kanha in Central India (Kumar *et al.*, 2019).

Success of most of the conservation efforts mainly depends on how good are the available scientific data on ecology, biology and population dynamics and habitat use of the concerned species. In view of enhancing science based large carnivore conservation efforts across its range, studies were undertaken addressing habitat use, food habits, ranging patterns, population estimation (Seidensticker, 1998) and population dynamics (Karanth *et al.*, 2006). Life history parameters are studied to draw inferences on population regulation (Stearns, 1980; Barbault and Maury, 1981; Soulé, 1987) and community structure (Noble and Slatyer, 1980; Crawley and May, 1987). Major challenge is to monitor large felid populations over long period, as they are elusive and nocturnal or disperse over large areas (Smith, 1993). Today, most of the surviving tiger populations occur in patches and at a low density across its distributional range, ranging between less than 20 and 200 breeding animals spanning over 1.5 million sq. km areas across Asia (Dinerstein et al., 2007).

However, the number of studies conducted on tiger population dynamics is extensive (Karanth and Nichols, 1998; Kawanishi and Sunquist, 2004; Karki *et al*., 2015; Aziz *et al.*, 2017; Bisht *et al.*, 2019). On contrary paucity of available literature on the population dynamics of leopards (except – Harihar *et al*., 2011; Kalle *et al.*, 2011; Williams *et al.*, 2017; Kumar *et al*.,2019) makes prioritizing conservation efforts for leopards even more challenging. Leopard is the most widely distributed large

carnivores across Asia and Africa. In spite of their distribution and varied diet spectrum, their population status is dwindling because of habitat fragmentation, loss and poaching (Bailey, 1993). Additionally, leopards thrive near human habitation extensively which makes them even more vulnerable to probable conflict situations (Edgaonkar and Chellam, 2002; Singh, 2005; Athreya, 2006). Hence, it is essential to investigate their population trend over a long period to get detailed insights into their ecological roles as well as formulating conservation priorities.

Recent advances in technology have enabled field biologists to carry out robust estimates of various population parameters. Camera trapping based mark-recapture studies to estimate abundance, densities, survival, sex-ratio and recruitment pattern have gained much importance in the last decade because of the robustness of the data (Kucera and Barrett, 1993). Capture-recapture was originally developed for animals to be caught and marked with tags after capturing them physically. But this is also applicable for animals with natural marking like stripe or rosette pattern. (Karanth and Nichols, 1998). Initially camera trap based capture-recapture framework abundance estimation was non-spatial in nature (Otis *et al.*, 1978; Karanth and Nichols, 1998). Density estimation based on traditional capture-recapture framework can be biased as it involves estimation of an effective sampling area using an ad-hoc buffer (Soisalo and Cavalcanti, 2006). Borchers and Efford (2008) developed spatially explicit capture recapture (SECR) models to estimate spatially explicit densities through a spatial point process which omits the need of estimating the effective sampling area, thereby reduce bias. Lately, these models have been developed to model sex-specific heterogeneity (Sollmann *et al.*, 2011) and effects of trapping session (Efford, 2018). Estimation of

survival poses difficulties under field conditions as it is difficult to ascertain the time of death (Clobert *et al.,* 1990). However, data collected under mark-recapture framework using a rigorous sampling design over multiple years can be effectively used to estimate demographic parameters of the target population (Majumder *et al.*, 2017; Bisht *et al.*, 2019). High capture probabilities coupled with sufficient number of recaptures allows me to calculate various demographic parameters meticulously for tigers (Skalski *et al.* 2005, Jhala *et al.* 2011, Sadhu *et al.*, 2017, Bisht *et al.*, 2019).

In this chapter, I use spatially explicit densities of tigers and leopards in Pench Tiger Reserve which has been identified as a major source population for these two predators in the Central Indian and Eastern Ghats landscape (Jhala *et al.*, 2020; 2021). Data for my doctoral dissertation was collected under the umbrella of the long-term project of understanding ecology of tigers in the study area. This enabled me to estimate various demographic parameters of tigers in PTR. Dearth of information of leopard population in the study area hampered estimation of such parameters.

3.2. Methods

I used camera trap-based capture framework (Jhala *et al.*, 2008) to estimate spatially explicit densities of tigers and leopards (Borchers and Efford, 2008) and demographic parameters of tigers in Pench Tiger Rerve (Bisht *et al.*, 2019).

3.2.1. Field Methods

Study design and equipment

Occupancy surveys for carnivore signs (Yumnam *et al.*, 2014) were carried out taking at beat level (lowest administrative boundary, area 10 – 30 sq. km.) as the lowest sampling unit. Efforts varied from three walks to tally 10-15 kilometers in each beat.

These walks were mainly on forest roads, animal tracks and dry riverbeds. With this, I identified possible camera locations with high probability of capture.

I used active and passive infrared-triggered camera traps. Active infrared trail monitoring system consists of two units: a transmitting unit that sends an infrared beam, and a receiving unit which is set across the target area. A picture is taken when the infrared beam is broken. Passive infrared systems are single units that use heat and motion detector to trigger the camera. Infrared digital cameras were used throughout the study period. The minimum distance between two camera locations varied between 1.5 and 2 km (Sharma *et al.,* 2010) covering an area of 410 sq. km. (n = 82, 84 and 82 camera traps in 2013-14, 2014-15 and 2015-16 respectively) (Figure 3.1) ensuring there are no 'sampling holes'. Camera trapping devices were placed one opposite to another to photograph simultaneously both flanks of an animal. To eliminate mutual flash interference, the two cameras were not positioned directly facing each other.

Each photograph of an individual represented a capture occasion. Individual identification of tiger and leopard was done based on examination of the position and shape of stripes and rosettes on the flanks, limbs and forequarters and tail (Schaller, 1967; McDougal, 1977; Karanth, 1995; Jhala *et al.,* 2008). The sex of the individual was determined by its relative body size and genitalia as suggested by Sadhu *et al.* (2017). My aim was to maximize the capture and recaptures of individual during the camera trapping session. So, I properly camouflaged all the cameras to reduce trap avoidance by animals. I also regularly changed the placement of the camera maintaining a fluid design in a radius of 100 meters from the original location to lessen the probability of trap shyness ('Contagion of Catchability', Otis *et al.*, 1978) and

increase the probability of capture. Due to logistics constrains, I carried out the exercise in two different blocks in 2015 and 2016 maintaining the closure assumption (Otis *et al.*, 1978).

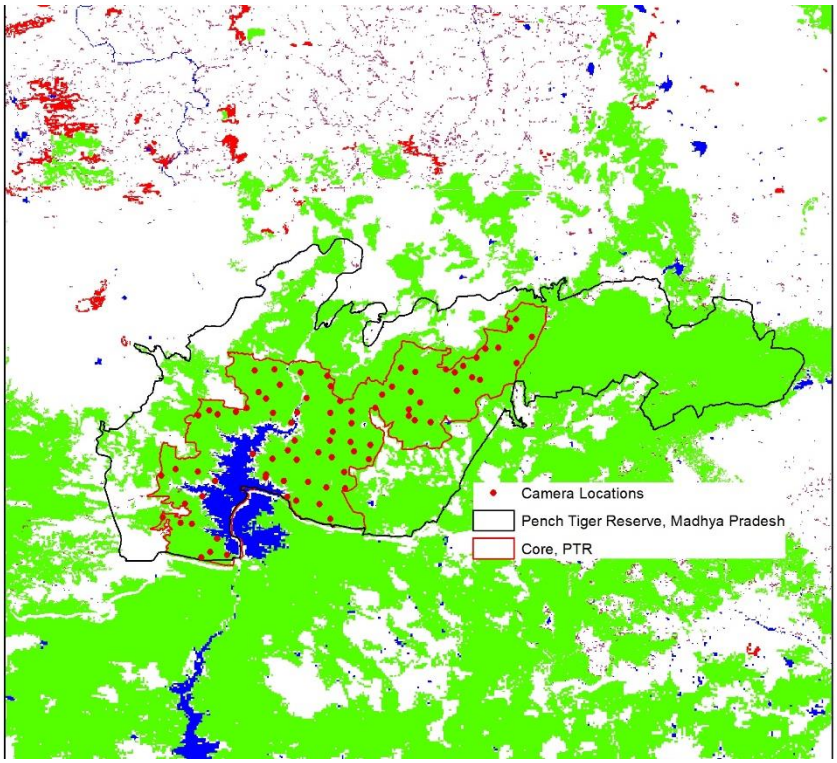

Figure 3.1: Study design at Pench Tiger Reserve, location of camera traps during the study period (n = 82 in 2013-14, n = 84 in 2014-15 and n = 82 in 2015-16)

3.2.2. Analytical Methods

i. Density and Distribution pattern of tigers and leopards

Individuals who are more than one year old were taken into account to conduct the analyses as high mortality rate and low capture probability of younger individuals can possibly reduce the robustness of the estimates (Karanth and Nichols, 1998).

Maximum-likelihood based spatially explicit capture recapture framework (hereafter MLSECR) (Efford 2004, Borchers and Efford 2008) was used to estimate the abundance, density and spatial distribution pattern of the target species. MLSECR uses the capture history of individuals and the interwoven spatial information,

bypassing the estimation of 'Effective Trapping Area' (hereafter ETA) as opposed to the traditional mark-capture-recapture models. SECR uses assumptions of traditional capture-recapture models i.e., demographic closure and marks retaining and accurately recorded for the sampling process. Additionally following assumptions are crucial for a fundamental SECR model:

i. Home range centres are distributed across a landscape randomly following a spatial Poisson point process with density D and

ii. Home ranges and individual activity centres remain constant during the sampling session (Efford 2004, Borchers and Efford 2008, Ivan *et al.* 2013).

The spatial data is used to calculate parameters of interest. The fundamental parameters of interest in this modelling framework are, i) detection probability (**g0**), ii) spatial scale of detection (σ). The spatial information of captures and recaptures of an individual over multiple detectors is used to estimate detection probability because detection probability declines as one moves further away from the home range centre of an individual. Hence, the capture probability is a decreasing function of distance ***d*** between the activity centre and the detector. Distribution pattern is modelled with a homogeneous spatial point process (Efford *et al.*, 2009). Usually, a half-normal function is fitted to describe the model. Activity centres of individuals are unknown but assumed to follow a Poisson distribution with density D (Efford, 2004).

I estimated the parameters of interest, detection probability (**g0**) and the spatial scale of detection (σ), by using different model combinations. Modelling was done assuming constant detection probability (g0 null), influenced by heterogeneous movement (h2) as two groups (Roy *et al.*, 2016). Sunquist and Sunquist (2002)

demonstrated that movement of large cats vary according to sex which has the potential to induce variability in the capture probability of individuals (Efford and Mowat, 2014). This latent variability was accounted for by modelling detection probability and spatial scale of detection as a function of gender. Individuals who could not be assigned to either gender owing to lack of identifiable features in their photos were placed in gender classes based on g0 and σ values using hybrid mixture models; *pmix* in this model denotes the mixing parameter of two sexes which is used to model the detection function as a 2-class mixture. It provided the detection corrected sex ratio of the target species (Kumar *et al.*, 2019). Best model was selected with minimum AICc values (Burnham and Anderson, 2002). Best models were used to estimate abundance of tigers and leopards using region.N argument. Estimated spatial density of both the species was used to predict the spatial distribution pattern in the study area using ArcMap ver. 9.3.1. However, the density surface described by the selected model is actually the realized capture process unless modelled with habitat covariates (Efford, 2018). Data processing was carried out in MS Excel ver. 2007 and analyses were carried out using the 'secr' package (Efford, 2015) in program R ver. 3.1.3 (R Core Team 2015). Next, I extracted the density values of both tigers and leopards at 1 sq. km. grids. I used this information to plot leopard density contours against that of tigers in NCSS statistical software (2018) ver. 21.0.3 to check their spatial segregation.

ii. Estimation of survival rate of tiger

Pollock's (1982) recommendation for the robust design was a two-stage analysis: 1) Abundance was to be estimated using closed-population models with capture history data across secondary periods within each primary period and 2) Survival was then to be estimated by combining data across secondary periods to

indicate whether or not an animal had been caught at least once during a primary period, and then analyzing the resulting capture histories using open models across all primary periods (Karanth *et al.*, 2006). My study was for a time span of three years only which restricted estimation of survival of the species with such a short dataset as three years is a small timeframe as compared to tiger's natural history (Sunquist 1981, Smith 1993). So, I included photocaptures of individuals from previous trapping sessions (carried out in same trapping area) to get an unbiased estimate of survivorship and other parameters. As the sampling area was same over the years, use of this dataset did not introduce any error in the parameter estimation. The study consisted of seven "primary periods" or sessions of sampling covering eight years (2008-09, 2009-10, 2010-11, 2012-13, 2013-14, 2014-15, 2015-16). As reported by Karanth *et al.* (2006), the tiger population was expected to be open to gains and losses between these primary periods. There were multiple ''secondary sampling periods'' within each primary period, and the population was assumed to be closed to gains and losses among these secondary periods. Pollock's robust design model accounts for transitional probabilities between being available and not for capture (temporary emigration). Only those individuals who were older than one year were included in this analysis.

Huggins robust design as used to analyse this dataset. These conditional likelihood based models can estimate sex-specific survival and detection probability. I used this modelling approach to estimate sex-specific survival probability (φ), temporary emigration probabilities (γ', γ''), capture probability (p) and recapture probability (c). Here φ represents the apparent survival as permanent emigration from the study area is not accounted for. γ'' represents the probability of a marked individual not being available for capture during one or more primary sampling period in spite of

being alive and a part of the super-population during the previous primary sampling period because of temporary emigration. On the other hand, γ' represents the probability of an individual being part of the super-population but being unavailable for capture during the primary sampling period. Among all model combination best fitted model was selected based on the lowest AIC_c value. Program MARK *ver* 8.1 (Cooch and White, 2006) was used for data analysis.

iii. Population growth rate

Population growth rate of tiger was estimated using the equation, growth rate (λ) = N_{t+1}/N_t where N_{t+1} is the estimated abundance of year two and N_t is the estimated abundance for year one (Karanth *et al.,* 2006; Mondol *et al.,* 2012; Sankar *et al.,* 2013).

3.3. Results

The overall (2013-2016) effort of 28472 trap nights (9072 in 2013-14, 10080 in 2014-15 and 9320 in 2015-16) was a result for carrying out the exercise for 55-60 days in 82-84 camera trap stations (Table 3.1). I got 1656, 2109 and 2694 identifiable photographs of tigers in 2013-14, 2014-15 and 2015-16 respectively. In case of leopards, I got 511, 689 and 684 identifiable photographs in 2013-14, 2014-15 and 2015-16 respectively. The total effort of 28742 trap night over (Table 3.1) the entire sampling period yielded photographs of 28 male tigers, 27 female tigers, 21 male leopards and 30 female leopards (individuals over the years) (Table 3.2). In case of few individuals gender could not be determined.

Session	Total number of camera traps	MCP1* (sq km)	Total trap nights	Number of identifiable photographs	
				Tiger	Leopard
2013-14	82	410	9072	1656	511
2014-15	84	410	10080	2109	689
2015-16	82	410	9320	2694	684

*Table 3.1: Camera trapping efforts in Pench Tiger Reserve, Madhya Pradesh during 2013-16, [1 * MCP = Minimum Convex Polygon]*

Session	Species	Age-class	Male	Female	Cubs	Unidentified Gender	Total
2013-14	Tiger	Adult	11	19	NA	3	33
2014-15	Tiger	Adult	10	15	NA	0	25
2015-16	Tiger	Adult	10	13	NA	1	23
2013-14	Tiger	Sub-Adult	6	6	NA	0	12
2014-15	Tiger	Sub-Adult	8	5	NA	0	13
2015-16	Tiger	Sub-Adult	11	5	NA	0	16
2013-14	Tiger	Cubs	NA	NA	1	0	1
2014-15	Tiger	Cubs	NA	NA	7	0	7
2015-16	Tiger	Cubs	NA	NA	25	0	25
2013-14	Leopard	Adult	6	12	NA	4	22
2014-15	Leopard	Adult	9	9	NA	4	22
2015-16	Leopard	Adult	19	13	NA	2	34
2013-14	Leopard	Sub-Adult	3	0	NA	0	3
2014-15	Leopard	Sub-Adult	8	3	NA	0	11
2015-16	Leopard	Sub-Adult	6	2	NA	0	8
2013-14	Leopard	Cubs	NA	NA	1	0	1
2014-15	Leopard	Cubs	NA	NA	3	0	3
2015-16	Leopard	Cubs	NA	NA	3	0	3

Table 3.2: Details of camera trap based photographs of individually identified tigers and leopards over the entire study period (2013-16)

3.3.1. Density of Tigers and Leopards

Densities of these sympatric predators were estimated for each sampling year. Estimated tiger density ranged from 4.8 to 5.7 per 100 sq. km. during the study period with overlapping confidence intervals (Table 3.3). Estimates of density of leopards varied from 3.76 to 4.9 per 100 sq. km. Estimated abundance (Realized N) of tigers was highest in 2013-14 at 69 (±SE 6) and lowest in 2014-15 at 56 (±SE 5) (Table 3.4). In case of leopards, highest abundance was observed in 2015-16 at 57 (SE 6) and lowest in 2014-15 at 50 (±SE 7) (Table 3.4). The detection corrected sex-ratio (p_{mix}) of tigers were slightly female biased in the first two years but became male biased during the last year. On the other hand, leopards were male biased in the first year which later became dominated by females in the following years (Table 3.3). My data displayed variation in detection probability and sigma according to gender. Detection probabilities of female tigers were higher than males whereas both male and female leopards showed similar probability of detection for the first two years (Table 3.3). I found similar estimates of sigma for female tigers and leopards were similar and for male tigers and leopards (Table 3.5). Male tigers moved at least two times more than female tigers whereas in case of leopards, the movement of males were 1.3 times higher than that of the females (Table 3.5).

Session	Species	Model Parameters	Density (SE) / 100 Sq. Km.	g0 (SE) (Female)	g0 (SE) (Male)	Sigma (σ) (SE) (Female)	Sigma (σ) (SE) (male)	Sex-ratio (M:F) (SE)
2013-14	**Tiger**	g0[h2]s[h2]	5.73 (0.88)	0.04 (0.004)	0.025 (0.003)	2.237 (0.108)	3.989 (0.224)	0.956 (0.078)
2014-15		g0[h2]s[h2]	4.85 (0.8)	0.05 (0.005)	0.026 (0.003)	2.063 (0.099)	4.404 (0.235)	0.9 (0.081)
2015-16		g0[h2]	5.15 (0.82)	0.07 (0.005)	0.039 (0.003)	2.714 (0.068)	2.714 (0.068)	1.091 (0.082)
2013-14	**Leopard**	s[h2]	3.76 (0.92)	0.004 (0.001)	0.004 (0.001)	2.697 (0.435)	4.129 (0.592)	1.194 (0.123)
2014-15		g0[h2]s[h2]	4.45 (0.85)	0.03 (0.004)	0.025 (0.006)	1.912(0.158)	3.918 (0.29)	0.495 (0.092)
2015-16		g0[h2]s[h2]	4.97 (0.88)	0.02 (0.003)	0.042 (0.005)	2.402 (0.209)	3.133 (0.236)	0.647 (0.086)

Table 3.3: Estimated density per 100 sq. km. along with sex-specific detection probability (g0), sex-specific spatial scale of detection (σ, in km) and detection corrected sex-ratio (male: female) of tigers and leopards in PTR, MP during the study period (2013-16)

Session	Species	M_{t+1}*	E.N.*	SE*	R.N.*	SE
2013-14	Tiger	44	69	11	69	6
2014-15	Tiger	38	56	9	56	5
2015-16	Tiger	40	59	9	59	5
2013-14	Leopard	21	56	15	56	13
2014-15	Leopard	29	50	10	50	7
2015-16	Leopard	34	57	10	57	7

Table 3.4: Estimated abundances of tigers and leopards in Pench Tiger Reserve during the study period (2013-14). [M_{t+1} = total unique individuals photographed, E.N. = Expected N (volume under a fitted density surface) and R.N. = Realized N (number of individuals within the region for current realization of the process (Johnson et al., 2010)., S.E. = Standard Error].

Session	Female (Tiger : Leopard)	Male (Tiger : Leopard)	Male Tiger : Female Tiger	Male Leopard : Female Leopard	Male Leopard : Female Tiger	Male Tiger : Female Leopard	Overall tiger : overall leopard
2013-14	0.83	0.97	1.78	1.53	1.85	1.48	0.97
2014-15	1.08	1.1	2.13	2.05	1.90	2.30	1.12
2015-16	0.97	0.90	1.21	1.30	1.34	1.18	0.87

Table 3.5: Intraspecies and interspecies comparison of estimated sigma of male and female tigers and leopards in Pench Tiger Reserve during the study period (2013-16)

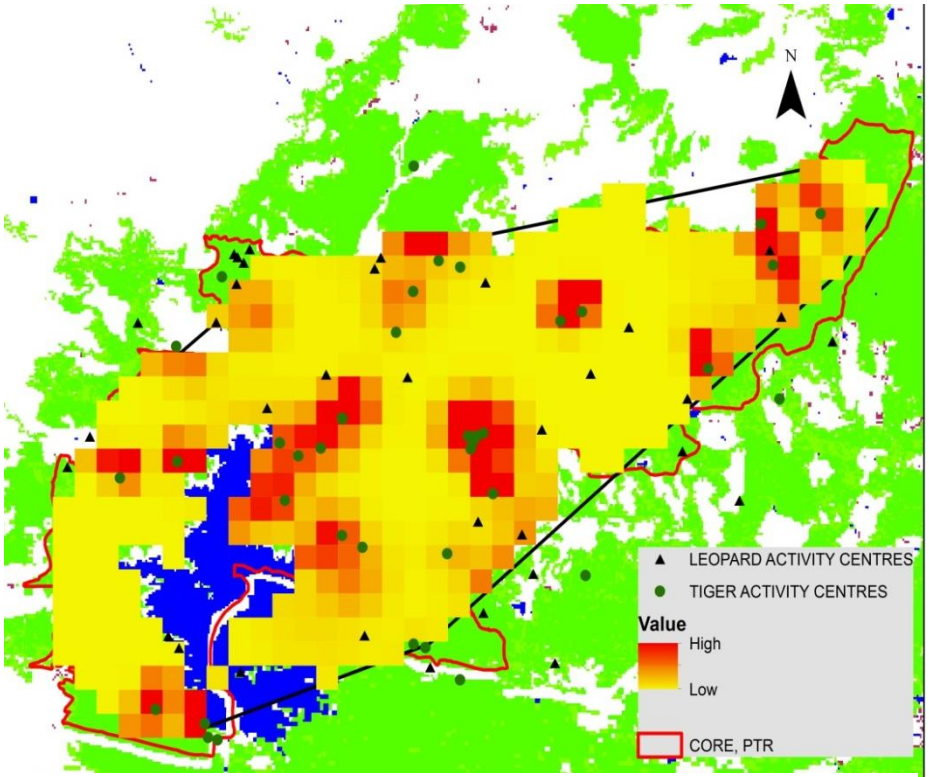

Figure 3.2: Spatial distribution pattern of tigers in Pench Tiger Reserve during the study period (2013-16) where captures of tigers were higher in the central part of the study area

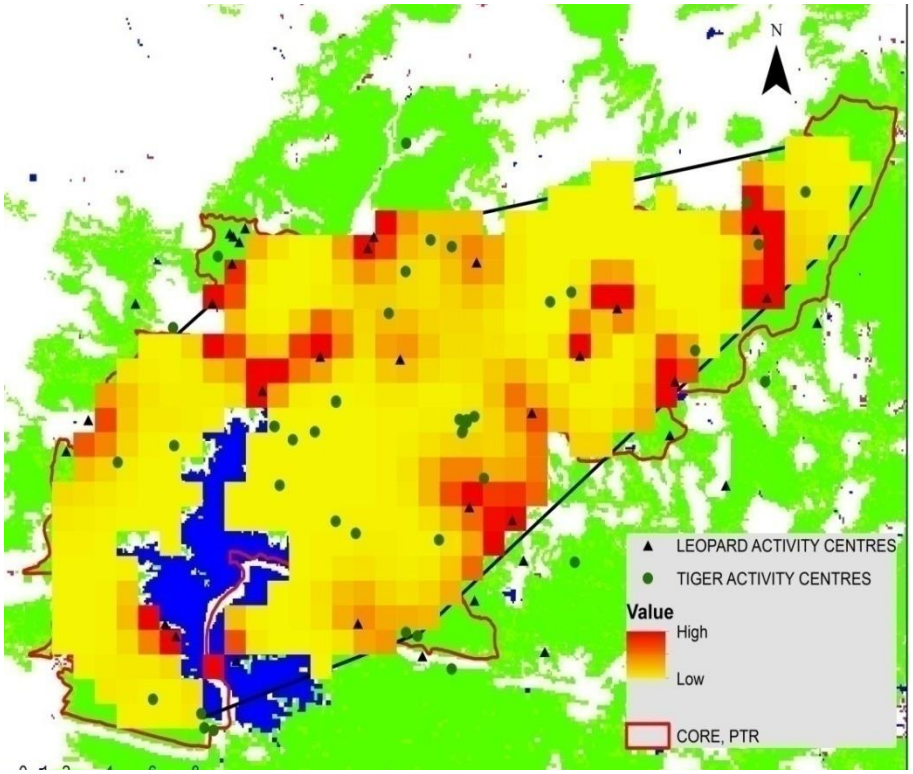

Figure 3.3: Spatial distribution pattern of leopards in Pench Tiger Reserve during the study period (2013-16) where captures of leopards were higher in the peripheries and areas of lower tiger occurrence of the study area

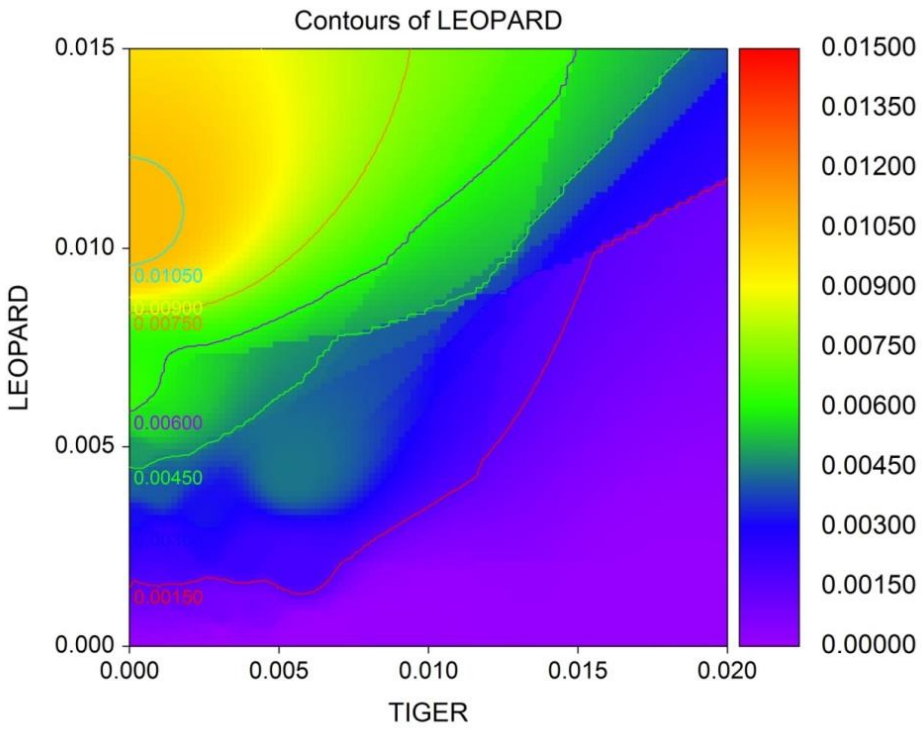

Figure 3.4: Diagrammatic representation of higher leopard density contours against tiger density areas in the Pench Tiger Reserve here the bar on the right hand side of the image represents density contours of leopards

Tigers were concentrated mostly in the central region of the study area whereas leopards were mostly found near the edges in the periphery of human habitation (Figures 3.2 and 3.3). The probabilities of each pixel having spatial abundance values were plotted in this graph to see the spatial response of tigers and leopards. Pixels containing higher values for tigers have low leopard occurrence values (Figure 3.4). Leopards respond to tiger abundance by using areas not or less occupied by tigers.

Male tigers' space usage overlapped completely or partially with that of minimum 1 and maximum 5 females and the overlap with males ranged between 1 and 3 individuals. Females space usage partially overlapped with males mostly, number of individuals ranging from 1 to 3 and minimal overlap near the periphery with other females was observed (Figure 3.5 and 3.6).

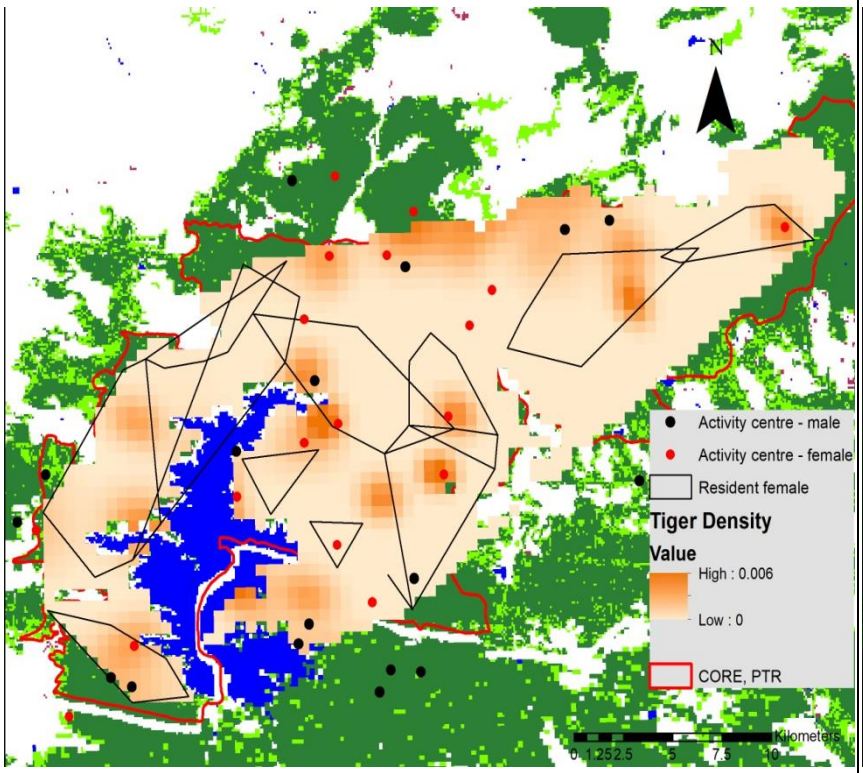

Figure 3.5: Distribution pattern of male tigers in Pench Tiger Reserve where the polygon represents minimum space usage by female tigers

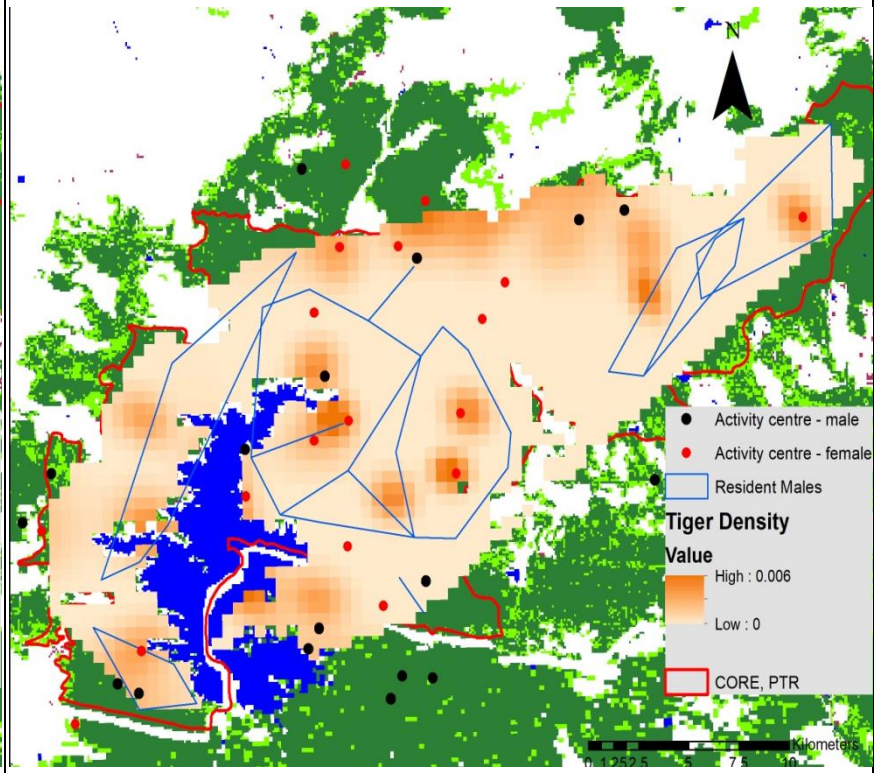

Figure 3.6: Distribution pattern of female tigers in Pench Tiger Reserve where the poygons represent minimum space usage by male tigers

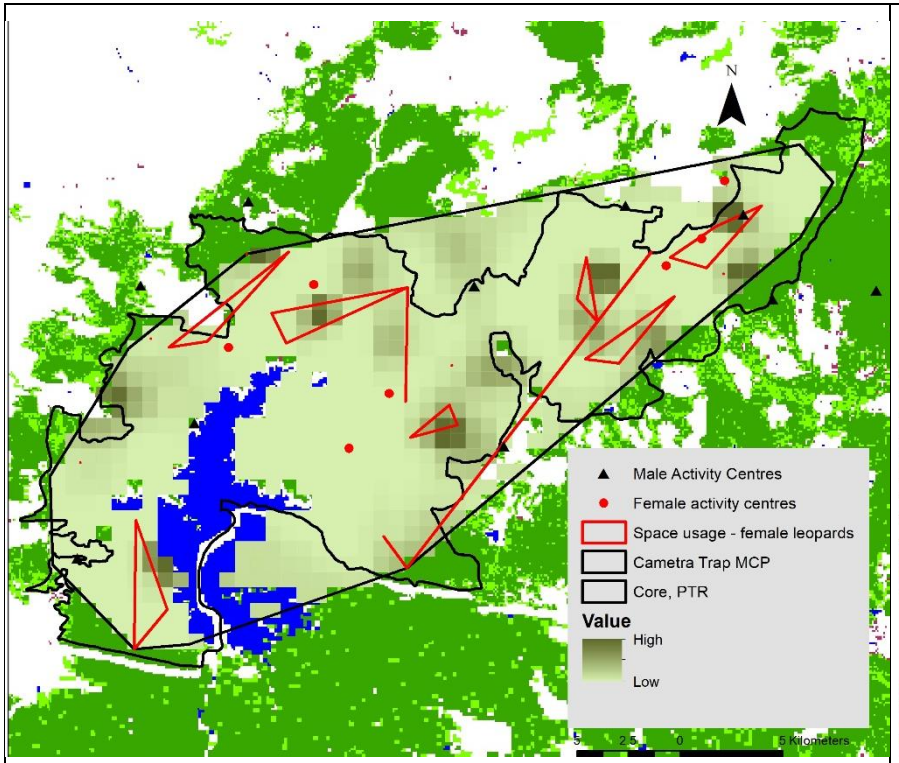

Figure 3.7: Distribution pattern of male leopards in Pench Tiger Reserve where the polygon represents minimum space usage by female leopards

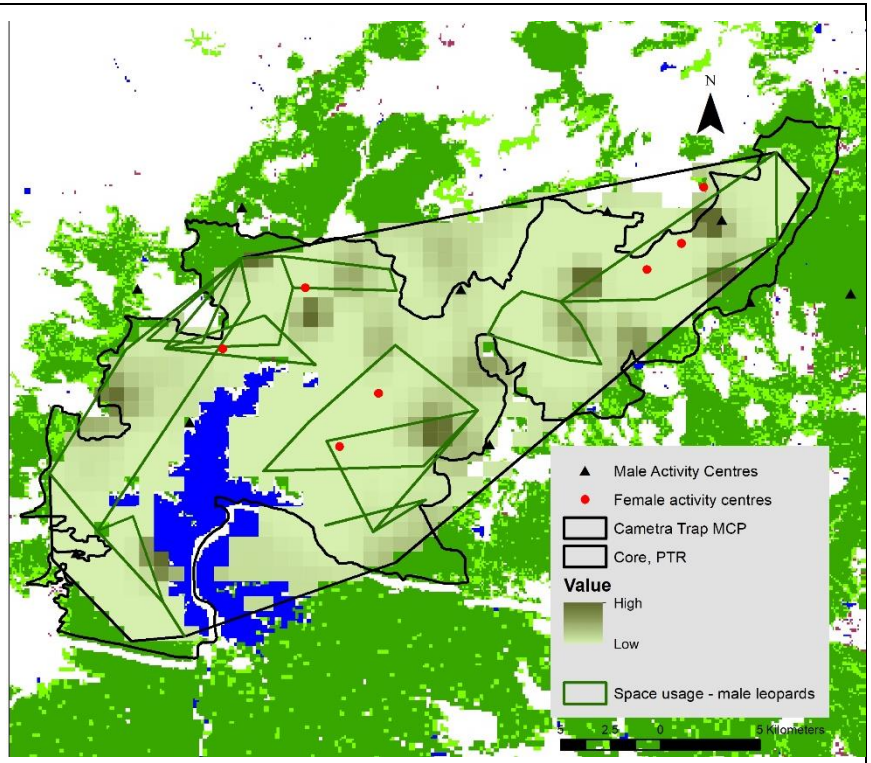

Figure 3.8: Distribution pattern of female leopards in Pench Tiger Reserve where the polygon represents minimum space usage by male leopards

Although leopards showed a 1:1 sex-ratio, the space usage could only be calculated for individuals who were captured at minimum three different locations to create the MCP. Overlap between space usage of both males and females ranged from 0 to 3 individual (both partial and complete). Female space usage was exclusive in terms of overlapping with other females (Figures 3.7 and 3.8).

3.3.2. Survival rate of tiger

A total of 96 individuals were taken into consideration for analysis of which 56 were female tigers and 40 were males during 7 years (2008 – 2015) of monitoring the population. The estimated survival rate of all tiger (n=109) was 72.6%, whereas for all male tiger (n=40) it was 73% and for all female tiger (n=456) it was 82.7% (Table 3.6). Although the survival estimate of females was higher than males, the 95% confidence intervals were overlapping. Apparent survival (φ) and transitional probabilities (γ', γ'') were best explained by gender specific models. Estimated transitional probabilities of females were also higher than males (Table 3.4). This analysis was done only for tigers as long-term data to conduct the analysis was absent for leopards.

3.3.3. Population Growth Rate

I maintained the same trapping area for estimation of annual growth rate. Survival constant model i.e. S (.) was found to be the best fitted model while estimating growth rate using both Pradel and Pollock's Robust Design model The overall growth rate was 12.7%, whereas the growth rate of females and males were 20.1% and 12.3% respectively (Table 3.7). This analysis was done only for tigers as long-term data to conduct the analysis was absent for leopards.

	Selected model	Survival estimate (SE)	95% CI		Trasitional probability (SE)	95% CI	
			Upper	Lower		Upper	Lower
Female	φ(.)γ''=γ'(.)	0.827 (0.044)	0.723	0.897	0.228 (0.092)	0.096	0.451
Male	φ(.)γ''=γ'(.)	0.73 (0.06)	0.597	0.832	0.075 (0.073)	0.011	0.386

Table 3.6: Estimated sex-specific survival and transitional probabilities obtained from Robust Design analysis using camera trap based mark-recapture data of 96 individual tigers in Pench Tiger Reserve (2008 – 2015).

	Lambda (λ)	SE	95% CI	
			Upper	Lower
Overall	1.127	0.044	1.040	1.213
Female	1.201	0.061	1.081	1.321
Males	1.123	0.070	0.986	1.261

Table 3.7: Estimated annual growth rate (λ) (using Pradel Model) of tigers in Pench Tiger Reserve, Madhya Pradesh (2008 – 2015).

3.4. Discussion

Research has been conducted in Pench Tiger Reserve for a long term to monitor the population of tigers. Very few protected areas in India possess such kind of intensive dataset, especially on a large carnivore like tigers. The observed trend based on long term data can be useful to formulate viable conservation strategies and management interventions for long term survival of tigers in this landscape. The Central Indian landscape and Eastern Ghats harbours the largest population of both tigers and leopards in India with high genetic diversity of which PTR is an integral part and has been identified as one of the major source populations of this landscape (Jhala *et al.*, 2020, 2021). Hence, long-term population monitoring studies for both tigers and leopards in this landscape bears significance for conservation success.

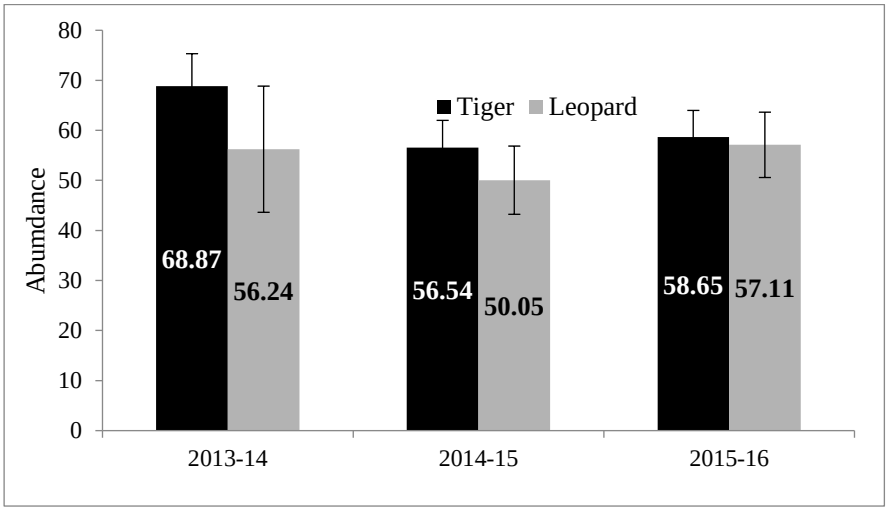

Figure 3.9: Comparison of estimated abundances of tigers and leopards in Pench Tiger reserve during the study period (2013 – 2016)

Estimated abundances of both tigers and leopards remained similar across the year implying stability in the population (Figure 3.9). The sampling during 2014-15 commenced later and continued till summer which might be the reason of obtaining fewer photographs of the target species. Forest type of Pench Tiger Reserve is dry deciduous, with severely hot summers (Sankar *et al.* 2013). Commencing the sampling in such a hot weather can be the probable causes of reduced capture rate in the 2014-15 trapping session which probably led to the dip in the mean abundance of these two species. Estimated densities of both tigers and leopards remained stable over the years (Figure 3.10).

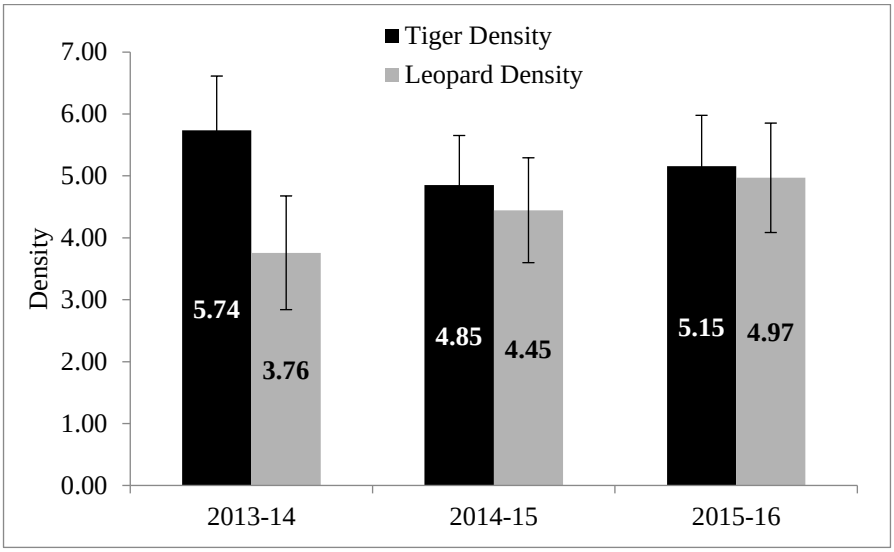

Figure 3.10: Comparison of estimated densities of tigers and leopards in Pench Tiger Reserve during the study period (2013 – 16)

The density estimates of tigers were found to be similar to Kanha whereas densities of leopards were lower (Kumar *et al.*, 2019). A number of studies have showed that densities of large carnivores are positively correlated with prey biomass (Odden *et al.*, 2010; Mitchell *et al.*, 2012; Carter *et al.*, 2015). Majumder *et al.* (2012) reported overall biomass of principal prey species (chital, sambar, nilgai, gaur, wild pig and common langur) in PTR as 6890 (kg/ km²). Estimation of prey density based carrying capacity (Jhala *et al*., 2020) tells us that the carrying capacity of the study area varies between 6.96 and 8.86 tigers per 100 sq. km. As per our findings and the latest estimates of tiger and leopard densities in the area (Jhala *et al.*, 2020), it can be safely said that predators are about to attain carrying capacity in PTR, MP.

I also found clear spatial segregation between these two predators as expected. Photographic captures of leopards were higher near the peripheral edges of the study area where captures of tigers were lower. This realized capture pattern showcases intensive usage of areas by leopards which are less frequented by tigers. Both Odden

et al. (2010) and Harihar *et al.* (2011) reported similar findings from Bardia National Park, Nepal and Rajaji National Park, India where leopards are pushed towards the edges as a result from interference interactions from tigers. They also reported shift in prey choice of leopards in response to interspecific competition albeit significant dietary overlap. Majumder *et al.* (2012) reported significant dietary overlap between tigers and leopards in PTR which puts leopards more at risk towards exploitative competition with tigers as shared prey leads to enhanced competitive interactions.

Felids are supposed to show a typical 1:1 sex ratio at birth (Seifert, 1985). In case of tigers, the population remained female-biased during the first two years but became male dominated during the last trapping session (Table 3.3). On contrary, photocaptures of male leopards were comparatively higher during the first two sampling sessions (Table 3.3). Minimum space usage by tigers (Figures 3.5 and 3.6) shows that the resident tigers have held their territories. Average land tenure for female tigers was calculated at 6.9 (±SE 0.41) years whereas the same for males was 5.3 (± SE 0.64) years. No infanticide was recorded during the study period which has been designated as a major cause of cub mortality for both tigers in Chitwan (Smith and McDougal, 1991) and Asiatic lions (*Panthera leo persica*) in Gir (Banerjee and Jhala, 2012). Stability in male tenures probably enabled the new recruitments to reside near their natal territories because of lack of hostile takeover by new males. As seen from the data even sub-adult males resided near their natal territories for long to grow in body size and being able to find areas devoid of resident individuals to establish their territories (Sadhu *et al.*, 2017).

Resident male tigers encompass areas with more than one resident breeding female to enhance their breeding success and defend their territories actively (Smith and McDougal, 1991). Intra-species overlap between males is rare as every individual needs to focus their energy expenditure to enhance their overall fitness and defending a territory in the presence of another dominant resident male can be energetically expensive. Females reside in areas with ample resources and ability to defend their territories. They usually establish their territories near the natal home range and mothers have been known to shift their ranges to accommodate their female cubs (Sunquist, 1981). In this study, the maximum overlap amongst females was found to be with their kins. Females are also known to move more when cubs younger than dispersing age are present (McDougal, 1977; Sunquist, 1981; Smith *et al.*, 1989; Smith and McDougal, 1991). Females which had larger home ranges during the study period were with litters. On the contrary, non-reproductive females (adult female with no litter during the entire study period) had smaller territories than sub-adult females.

On the other hand, I found high turn-over of leopards in the study area. 30-40% of the captured individuals were not captured in the previous trapping seasons and the rate was even higher in case of males. The data points towards the males being transient. Individuals might be dispersing through the study area while trying to establish territories. Resident male leopards were fewer in number in the study area. Female leopards have been found to be maintaining their established territories and breeding. As fewer resident individuals are present in the study area more individuals can be accommodated. Females can stay close to their natal territory which is available and the cue to the population to become skewed towards males is most likely not in

action. A viable population can be sustained for long term if a minimum of twenty breeding units are present in the population (Jhala *et al.,* 2008). The data suggests good proportion of breeding individuals in the leopard population which is probably why the population shows an increasing trend as the resident females have the scope to recruit new females in the population in terms of availability of space.

Parameters	Pench*	Kanha*1	Corbett*2	Nagarhole*3	Huai Kha Khaeng*4
Apparent survival (Overall)	0.73 (0.04)	Not reported	0.68 (0.02)	0.77 (0.05)	0.8 (0.08)
Apparent Survival - Female	0.83 (0.04)	0.84 (0.04)	0.79 (0.05)	Not reported	Not reported
Apparent Survival - Male	0.73 (0.06)	0.78 (0.06)	0.6 (0.04)	Not reported	Not reported
Temporary emigration - Female	0.228 (0.092)	0.03 (0.09)	0.2 (0.08)	0.1 (0.07)	Not reported
Temporary emigration - male	0.075 (0.073)	0.06 (0.02)	0	0.1 (0.07)	Not reported
Density/100 sq. km.	5.15 (0.82)	5.21 (0.55)	14 (3.0)	9.7(1.8)	1.68 (0.69)

*Table 3.8: Comparative review of camera trap based open mark-studies of tigers across their range of occurrence (*present study, *1- Kumar, 2019, *2 – Bisht et al., 2019, *3 – Karanth et al., 2006, *4 - Duangchantrasiri et al., 2016)*

The estimated survival using camera trap based open mark-recapture framework is an estimate of the apparent survival as the model can't distinguish between death and permanent emigration. Estimated survival varied between genders where apparent survival of females (0.83) was significantly higher than that of the males (0.73). Overall estimated survival rate (0.73) of tigers in the present study is comparable with the same of tigers in Nagarahole Tiger Reserve (Karanth *et al.* 2006) and higher than that of Corbett National Park (Bisht *et al.*, 2019) (Table 3.8). Estimated gender-specific apparent survival was similar to the estimates of tigers in Kanha National Park (Kumar, 2019) (Table 3.8). As females are philopatric and tend to stay close to their natal

territories, higher survival is a possible reflection of that. On the other hand, male tigers are more wide-ranging and are the ones who usually disperse further away from their natal territories and have inherent low survival which is also seen in my study (Smith, 1993).

Breeding tigresses might adopt a strategy to protect her cubs from infanticide, utilizing different temporal activity period with female without cubs and transient male tigers. The high survival rate of resident male might have influenced the high survival rate of cubs in the study area. Barlow *et al.* (2009) observed that loss of resident males increases cub mortality substantially through infanticide and temporarily limits the supply of individuals available for replacing deceased residents.

The overall growth rate of tiger population in the present study is higher than that of Amur Tigers (Goodrich *et al.*, 2008), Ranthambhore Tiger Reserve (Jhala *et al.* 2012) and lower than Kanha Tiger Reserve and Mudumalai Tiger Reserve (Jhala *et al.* 2008). Although the population showed an annual growth rate of 12%, the resident population in the study area has been stable over the years. The continued immigration and emigration of transient individuals from the superpopulation to the studied population and vice-versa was mainly responsible for this pattern. Studies have shown that high survival of breeding individuals can ensure long term survival of a population in-spite low survival of dispersing and transient individuals (Karanth *et al.* 2006, Chapron *et al.* 2008).

There is a chance that the population of tigers harbours more males so that they can disperse from the source. We still don't know how these environmental cues work, yet the same can be suggested for the target tiger population. I have got photographic

evidences of individuals establishing their territories as far as Nagzira-Navegaon Tiger Reserve in Maharashtra apart from other tiger reserves such as Pench Tiger Reserve, Maharashtra, Kanha Tiger Reserve, Madhya Pradesh. Tiger population in PTR shows typical characteristics of a source population. To ensure long-term survival of this population it becomes necessary to properly maintain the forest cover surrounding PTR for their dispersal, establishment and maintenance of territory. High turn-over rate of leopards also suggests this area being a part of the metapopulation structure for leopards as well and putting management interventions in place to protect their population bears equal importance to maintain the integrity of the ecosystem. To achieve long term survival for both these species, maintaining connectivity between the remaining habitat patches is essential. This connectivity will allow the population to maintain the genetic diversity by introducing new genes through new individuals having different genotype from populations belonging to different areas which is also crucial for their survival. Genetic inbreeding is a major cause of extinction and can be prevalent in small populations (Jhala *et al.*, 2008). Hence, exchange of genetic information via movement of individuals from one place to another is highly desirable. Current conservation and management strategies are to be targeted towards this maintenance of connectivity. So, it can be summarised that to guarantee their survival proper mitigation measures and conservation strategies are required to maintain the superpopulation of which Pench Tiger Reserve forms an integral part.

CHAPTER – 4: POPULATION DYNAMICS OF PRINCIPAL PREY SPECIES OF TIGERS AND LEOPARDS

4.1. Introduction

The importance of large herbivores comprising of primates and ungulates with a body weight of more than equal to 5 kg., has been well documented in ecological studies. They can influence the forest structure, composition, productivity of the ecosystem, soil composition and succession in a tropical ecosystem to a significant extent (McNaughton, 1979; Crawley, 1983). More importantly they form majority of the prey base of large carnivore diet worldwide (Schaller, 1967; Karanth and Sunquist, 1995; Biswas and Sankar, 2002; Wang *et al*., 2010). Hence, in the face of the global challenge of declining large carnivore population understanding the population dynamics of the major prey species of these carnivores is pivotal. Robust scientific estimates of population abundance and distribution of these species are fundamental for such monitoring exercises.

Population monitoring is crucial to evaluate existing management strategies and formulation of future methods (Jathanna *et al.* 2003). Although, reliable estimates of prey densities in Asian tropical ecosystems were rare previously, as they used methods like belt transects, vehicle transects, block counts, roadside and platform counts [India (Schaller, 1967; Berwick, 1974), Nepal (Seidensticker, 1976; Dinerstein, 1979; Tamang, 1983) and Sri Lanka (Eisenberg and Lockhart, 1972)]. As these methods lack strong theoretical framework, the estimated abundance and density tend to be biased. In most cases one cannot ensure the inclusion of all the animals in such counting process. The fact these animals are naturally unmarked makes them susceptible to double counting and population closure cannot be assured (Jathanna *et al., 2003*; Buckland *et al*., 2015; Roy, 2019).

Recent studies (e.g., Karanth and Sunquist, 1992; Khan *et al.*, 1996; Raman, Menon and Sukumar, 1995; Biswas and Sankar, 2002) have progressed in this manner. Distance sampling which includes both line transect and point counts tend to address such shortcomings by incorporating detection probability. Line transect based distance sampling assumes that all animals on the line are detected at their initial locations and the observer moves faster than the animals detected (Burnham *et al*., 1980; Buckland *et al.*, 2001; Roy, 2019). The breadth of the line is estimated by modelling the detection of animals instead of a predetermined strip width (Buckland *et al*., 2015, Roy, 2019).

In addition to wild ungulates, domestic livestock contributes substantially to the diet of large carnivores. Attack on domestic livestock by large carnivores is a major challenge globally and poses a threat for their conservation (Sillero-Zubiri and Laurenson, 2001; Treves and Karanth, 2003; Woodroffe *et al*., 2005, Miller, 2015). The cost associated with losing a livestock often impels the owners to resort to lethal measures which hinder the entire conservation process (Woodroffe *et al*., 2005; Ripple *et al*., 2014; Miller, 2015). A trade-off can be established by grazing the livestock in areas where the probability of them being attacked by livestock goes down (Treves *et al*., 2011). In order to achieve this, counting the numbers of domestic livestock present in the area and mapping their grazing pattern is extremely important.

Domestic livestock has been known to be sympatric and potential competitors of wild ungulates in vast tracts of Indian forests (Kothari *et al*., 1989; Dave and Jhala, 2011). Pench Tiger Reserve in the state of Madhya Pradesh is surrounded by 99 villages with a significant population of domestic cattle. The large predators, namely tigers and leopards can attack livestock and their anti-predator response is almost non-

existent. Although Miller (2015) found evidence of anti-predator response in domestic livestock using predator cues, without such elements their vigilance mechanism is poor. This in turn makes them even more susceptible to predator attacks. This further paves the way of these people being more hostile without proper financial incentives to compensate such losses. Hence, it is essential to quantify the availability of domestic livestock in an area to formulate effective management and conservation strategies to mitigate these kinds of negative interactions between wildlife and local people.

In light of this, I aimed to estimate the abundance and distribution of wild ungulates and domestic livestock in and around the study area.

4.2. Methods

4.2.1. Field Methods

i. Estimation of wild prey and domestic livestock abundance

Wild prey abundance was evaluated by line transect based density estimation method (Burnham *et al*., 1980) and camera trap-based encounter rate (Carbone *et al*., 2001).

In the core zone, each beat (n=44) was taken as sampling unit (Figure 4.1). I used the line transects in PTR established in 2005 and previously used for "Monitoring of tigers, co-predators, prey and their habitat" research project to estimate densities of prey species of tigers and its co-predators (Jhala *et al.,* 2005) and "estimation of prey availability of tigers" for the first phase of the project from 2006 – 2013 (Sankar *et al.,* 2013). Line transects were laid in each beat, each consisting of 2 km. in length and were walked at least two times in a month during winter and summer in morning hours between 0600 – 0900 hours to ensure maximum detection as ungulates are most active during this time period (Schaller, 1967). All the line transects were laid in North-South

direction to avoid glare and maximise detection of animals. Animal clusters were used as the analytical unit since individual data tends to underestimate true variance (Southwell and Weaver, 1993). For each detection, the GPS co-ordinates, the exact time, species, group size, group composition (age classes and sex, whenever possible) sighting angle and the sighting (radial) distance from the transect line were recorded.

The population of the domestic livestock was estimated using total count method. I radio-tracked 5 to 10 individuals of each domestic livestock species (cows and buffaloes) using track loggers to observe the route and distance they traverse. In order to do this, I fitted the animals with a cloth belt around the neck and made sure the belt did not move as the animal moved. I tracked these animals with informed consent from the villagers and the herders. Areas where I did not get the consent could not be sampled. I fitted the animals with the track-loggers in the morning before they left to graze and collected those in the evening after they came back to the village. The loggers were set to record the point every five seconds and create a track as it goes along. I also used camera traps to estimate encounter rate using captures per 100 trap nights (Carbone *et al*., 2001).

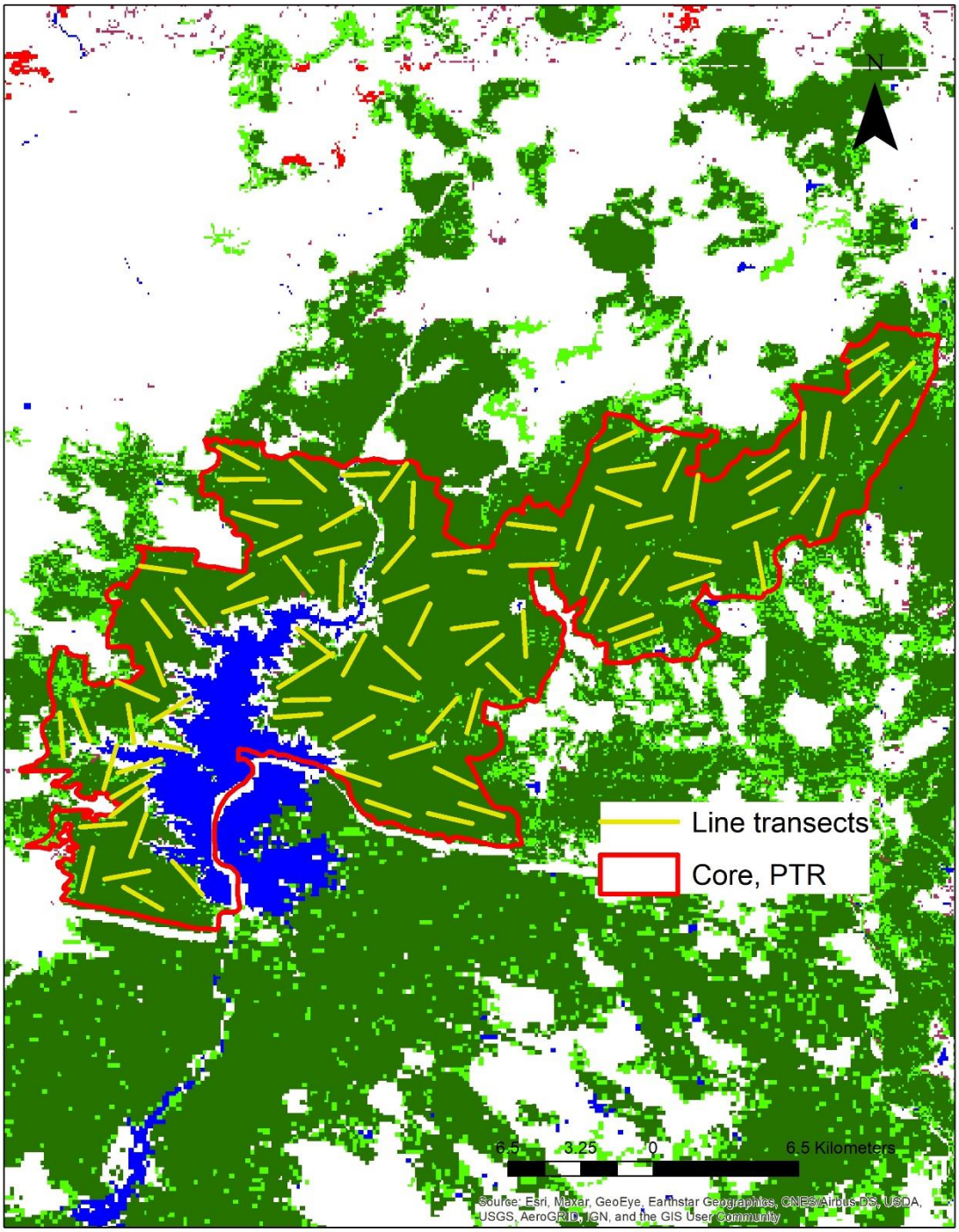

Figure 4.1: Location of 44 line transects in Pench Tiger Reserve, Madhya Pradesh during the study period (2013 – 16)

4.2.2. Analytical Methods

i. Prey density and distribution pattern

Density of each species was estimated separately for each session (2013-16). The distribution of the data was first examined by assigning very small cut-off points to the distance intervals during the curve fitting, to detect evidences of evasive movements by the animals or heaping of data were truncated at suitable distances from the line. Most parsimonious model was selected after applying different set of parameters. The best model was selected based on their AIC values (Burnham and Anderson, 2002) and by visually judging the fit of the proposed model to the observed distance data close to the transect line. Average detection probability of detection (p), group density (Dg), group size (Sg), animal density (Dind), and effective strip width (ESW) were estimated using the selected model in program DISTANCE version 6.0. The detections in the line transect were analysed by grouping them into distance classes and fitting a decay model (eg. Half-normal, Uniform cosine, etc.) into them. Analysing this data helped to come up with the effective strip width (ESW) in which the detectability becomes nearly hundred percent. The population densities and other parameters of interest were calculated with respect to this effective strip width (Buckland *et al.*,2001; Qureshi *et al.*2014).

Data on number and demographic structure of the livestock belonging to each village were recorded. The spatial distribution of both the prey species were estimated using Krigging (Oliver and Webster, 1990) in ArcMap 9.3. using the camera trap based encounter rates. I also mapped the routes usually followed by the livestock from the target villages. I then used these track points to calculate the linear time density of domestic livestock. I also calculated the kernel density of domestic livestock around

the tiger reserve. ArcMap 10.6.1 (Esri Inc., Redlands, CA) was used to conduct this analysis. I also looked into the relationship between average time spent by a grazing herd and the forest type of that area using Pearson's correlation coefficient (Zar, 1999). I also looked into the relationship between livestock grazing hotspots and distribution of tigers and leopards.

4.3. Results

4.3.1. Prey density and distribution pattern

In total 12 potential prey species were recorded on these line transects. There were seven ungulate species (chital, sambar, nilgai, wild pig, gaur, chausingha and barking deer), two primate (common langur and rhesus macaque), two birds (Indian peafowl and red spur fowl) and one small mammal (black naped hare). Estimated density was highest for Langur (pooled estimate – 52.1 $\pm$ 6.56) followed by chital (pooled estimate – 51.4 $\pm$ 9.5). Density of wild pigs could only be estimated for the session of 2013-14 because of lack of observation on the line transects (Table 4.1).

Species	Year	Total no. of observations	Selected models	Chi-p	Density per/ sq km (SE)	Group Density/ sq. km. (SE)	ESW in metres (SE)	Cluster Size (SE)
Chital	2013-14	264	Half-Normal Cosine	0.705	54.12 (12.27)	7.9 (1.66)	63.98 (4.22)	6.85 (0.57)
Chital	2014-15	192	Half-Normal Cosine	0.986	52.75 (7.57)	9.94 (1.42)	50.88 (3.18)	5.48 (0.1.)
Chital	2015-16	121	Half-Normal Cosine	0.956	44.56 (9.82)	8.71 (1.65)	31.44 (2.93)	6.29 (0.65)
Chital	Pooled	577	Half-Normal Cosine	0.948	51.4 (9.5)	10.97 (2.03)	48.23 (3.0)	4.68 (0.00)

Species	Year	Total no. of observations	Selected models	Chi-p	Density per/ sq km (SE)	Group Density/ sq. km. (SE)	ESW in metres (SE)	Cluster Size (SE)
Sambar	2013-14	79	Uniform Cosine	0.97	7.68 (1.58)	2.73 (0.51)	53.65 (4.57)	1.76 (0.31)
Sambar	2014-15	51	Uniform Cosine	0.95	4.64 (1.01)	2.37 (0.49)	59.64 (6.62)	2.16 (0.23)
Sambar	2015-16	48	Uniform Cosine	0.95	6.75 (1.57)	3.59 (0.78)	38.94 (4.76)	1.88 (0.15)
Sambar	Pooled	178	Uniform Cosine	0.98	6.64 (1.11)	2.90 (0.48)	53.36 (4.67)	1.75 (0.00)
Langur	2013-14	237	Half-Normal Simple Polynomial	0.96	70.36 (10.75)	9.69 (1.3)	46.34 (2.99)	7.25 (0.53)
Langur	2014-15	104	Half-Normal Simple Polynomial	0.89	67.44 (10.94)	7.83 (1.15)	35.48 (2.87)	8.9 (0.41)
Langur	2015-16	72	Half-Normal Simple Polynomial	0.90	45.57 (8.92)	6.94 (1.2)	26.57 (8.92)	5.55 (0.45)
Langur	Pooled	413	Half-Normal Simple Polynomial	0.97	52.1 (6.56)	11.54 (1.48)	40.18 (1.79)	4.51 (0.00)
Wild Pig	2013-14	40	Hazard Rate Cosine	0.84	12.21 (4.12)	2.08 (0.52)	41.11 (6.86)	5.87 (1.34)

Table 4.1: Year-wise and pooled individual density, group density, cluster size and effective strip width (ESW) for chital, sambar, langur and wild pig (2013-14 only) throughout the entire study period (2013-16)

Two of the principal prey species (chital and sambar) of these two sympatric felids showed uniform spatial distribution with chital preferring open areas (Figure 4.2) and sambars were found more near the undulating terrain with miscellaneous

dry deciduous forest (Figure 4.3). Another principal prey, wild pigs were found more near the edges of the study area, and staying close to the crop fields might be the reason that they were not detected much on the line transects (Figure 4.4). Livestock grazing is prohibited in the core region of PTR, MP which was reflected in the spatial distribution pattern of domestic livestock who were seen near human habited areas and the buffer zone where anthropogenic disturbance is higher (Figure 4.5).

I could only estimate the grazing routes of domestic livestock near the northern, eastern and south-eastern part of the study area. In the western parts of PTR, some villagers practice stall feeding only and or others I could not get the consent of the owner for tracking their livestock. A total of 141 tracks could be used to conduct further analyses. My results showed that livestock did not spend a lot of time stationary in one place. A maximum of 31% of the total time spent grazing was spent in one place (Figure 4.6). No significant relationship was found between average time spent in grazing and forest type except for the very dense forest. My results showed a pattern of reduction in mean time spent grazing with an increase in proportion of very dense forest in the grid ($R = -0.33$, $p = 0.057$) (Figure 4.7). I didn't

find any significant relationship between the distribution of tigers and leopards and the grazing hotspots of domestic livestock around the study area.

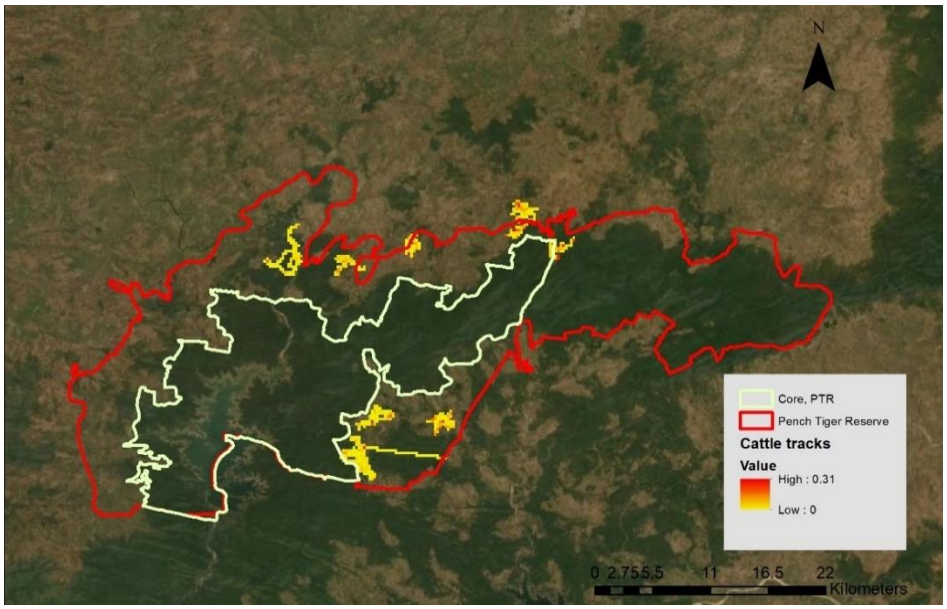

Figure 4.6: Estimated linear time density of domestic livestock around Pench Tiger Reserve, MP where the red points represent higher density

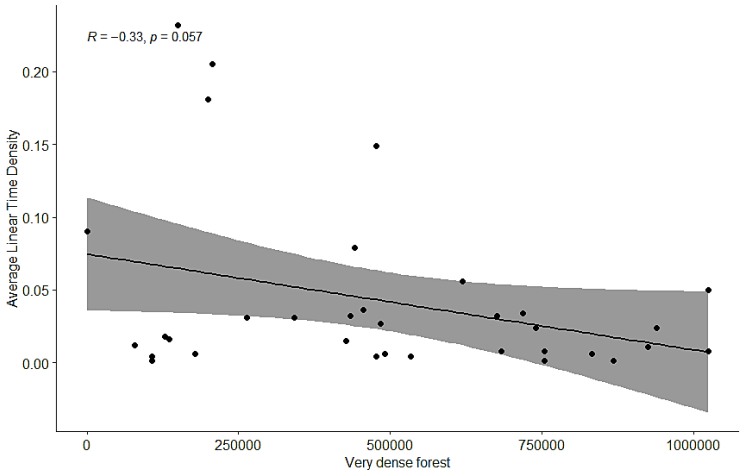

Figure 4.7: Relationship between average time spent grazing by domestic livestock and proportion of very dense forest in a grid around Pench Tiger Reserve, Madhya Pradesh

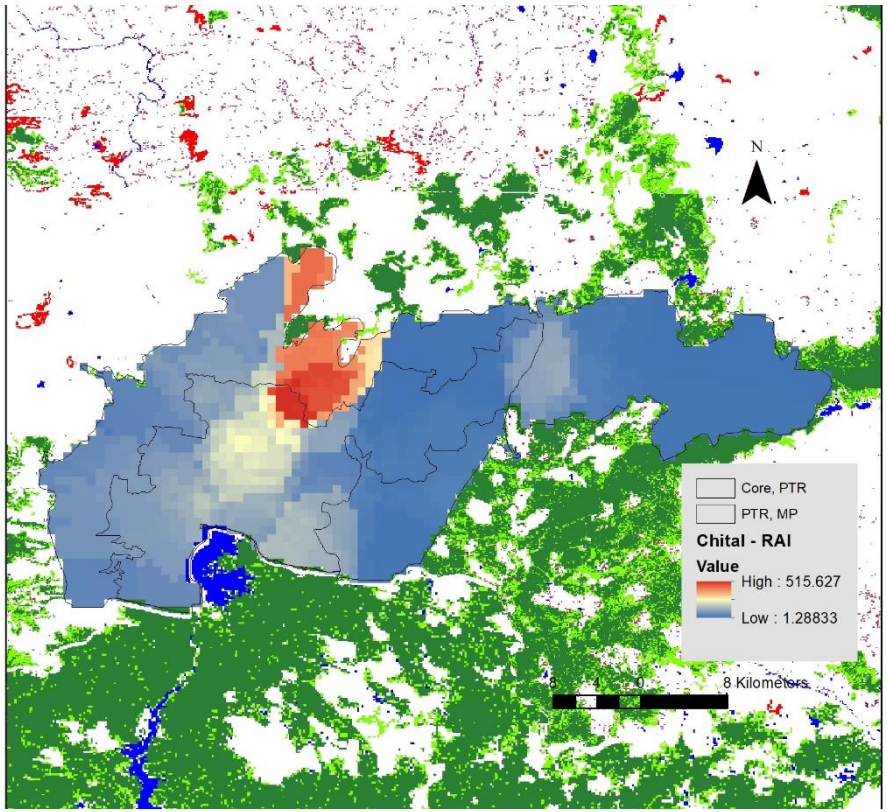

Figure 4.2: Estimated spatial distribution pattern using camera trap based photos of a principal prey species (chital) of tigers and leopards, chital in PTR, MP

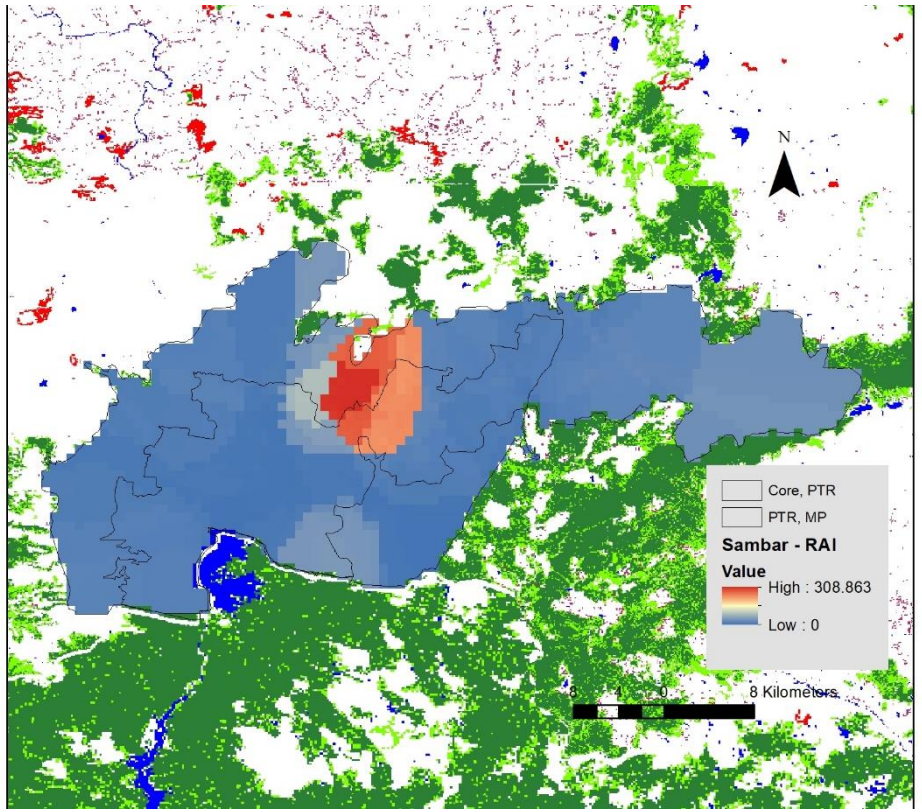

Figure 4.3: Estimated spatial distribution pattern using camera trap based photos of a principal prey species (sambar) of tigers and leopards, sambar in PTR, MP

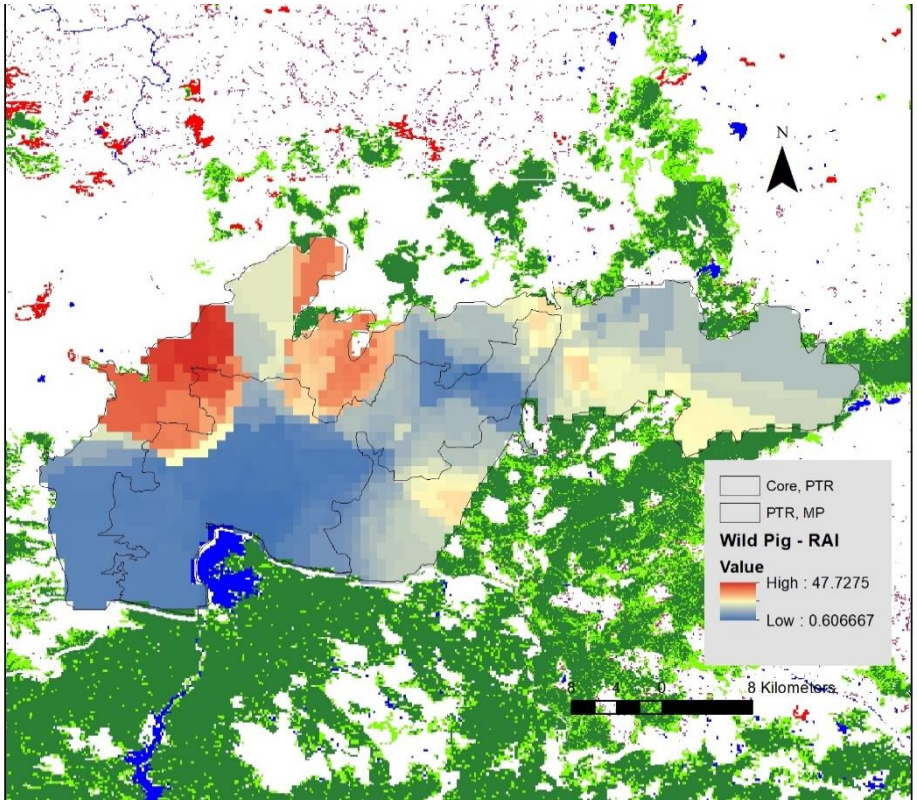

Figure 4.4: Estimated spatial distribution pattern using camera trap based photos of a principal prey species (wild pigs) of tigers and leopards, wild pigs in PTR, MP

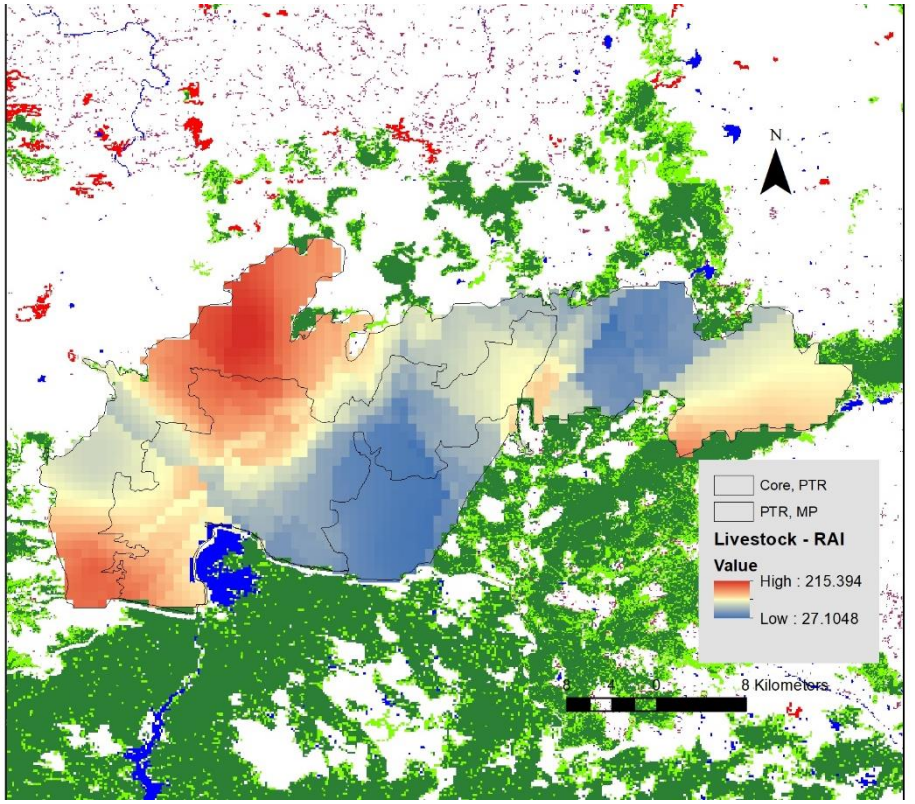

Figure 4.5: Estimated spatial distribution pattern using camera trap based photos of domestic livestock in PTR, MP

4.4. Discussion

Use of line transect based distance sampling have been well established for prey population estimation of tigers as well as other large carnivores (Biswas and Sankar, 2002; Bagchi *et al.*, 2003; Ramesh *et al*., 2010; Sankar *et al.*, 2013). Data did not show any sign of heaping or evasive movements (Buckland *et al.*, 2002). Major variation in the data was from encounter rate of individuals on line transects. The encounter rate of animals on a line transect was hugely dependent on different habitat features like visibility, terrain and presence of *Lantana* spp. During these surveys, very few juveniles/fawns/calves of identified prey species were detected on the lines. This might be because of the overall visibility and the increased predation pressure on them from not only tigers and leopards but also smaller carnivores like jackals, jungle cats.

PTR being a part of the Satpura-Maikal landscape offers heterogeneity in landscape features. This diversity from grassland to moist deciduous forest (Sankar *et al*., 2013; 2017) is very well suited for the survival of both grazers and browsers (Eisenberg and Seidensticker, 1976; Sankar *et al*., 2013). The abundance of *Cynodon* spp. which is preferred by both chital and wild pigs in the study area and water resources have most likely resulted in the high density of the wild ungulates.

Although the density estimate of Langurs was the highest during the study period, Chital was found to be the most abundant ungulate here. Sambar were principally a dense forest dwelling species and their congregation was seen near the rugged areas. Except for the first year, very few wild pigs were detected on the line transects. The distribution of wild ungulates from camera trap based photographs showed that wild pigs were mostly near the edges bordering the crop fields. My study

did not target those areas for prey estimation which is the reason for such low detection of wild pigs during the line transect surveys. Sambars being a habitat specialist mostly reside in dense forested areas. In PTR, I have mostly observed solitary male sambars. Sambar females (both adult and sub-adult), juveniles and fawns were mostly found in groups.

The group living structure of wild ungulates is also extremely variable as they maintain a fission-fusion group structure (Schaller, 1967; Eisenberg and Lockhart, 1972; Ghuman *et al*., 2010). The group size is mostly a result of the surrounding habitat feature. Larger groups of chital were seen in open areas. Forested areas provide disjoint food sources which might be responsible for their smaller group sizes. Additionally, bigger group sizes in open areas provide them the option of 'many-eyes' which increases the group size. In contrast, bigger groups in dense forested area will obstruct their field of vision which is detrimental for detecting predators. The predation pressure on Langurs was minimal in the study area (Biswas and Sankar, 2002). As a result of this and abundance food resources, the recruitment rate of langur was high (Manjumder *et al*., 2011) which probably resulted in the high density throughout the study period. I also compared the density estimates of Chital and Sambar from areas with similar habitat features. According to the latest estimated densities (Jhala *et al*., 2020), the individual and group densities of Chital were highest in Pench Tiger Resrve, Madhya Pradesh. The estimated group density of Sambar during the present study was also higher than Kanha Tiger Reserve, Bandhavgarh Tiger Reserve and the adjacent Pench Tiger Reserve in the state of Maharashtra and at par with Ranthambhore Tiger Reserve and Sariska Tiger Reserve (Figure 4.8).

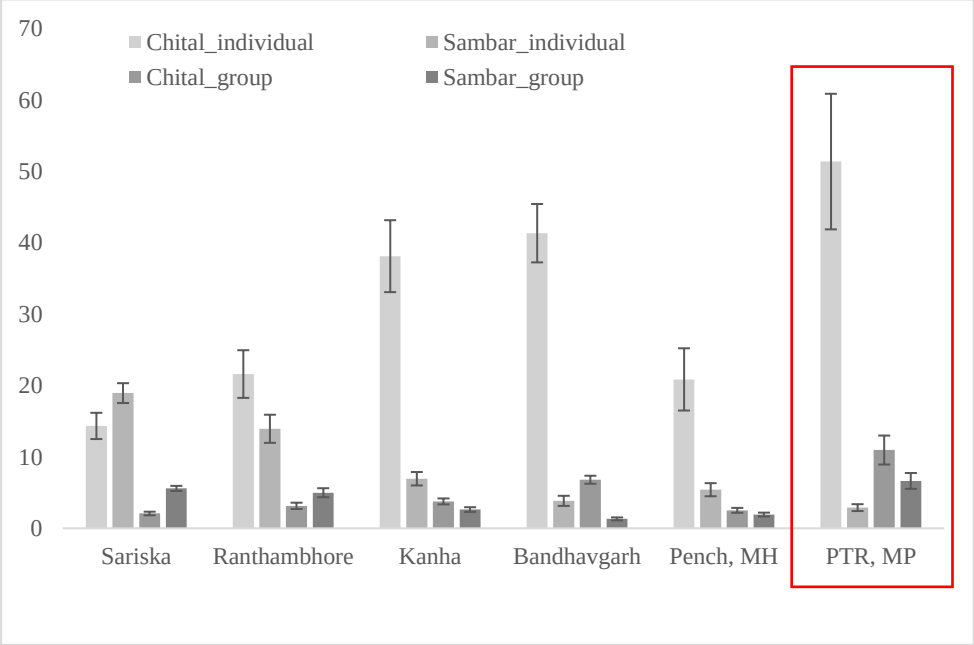

Figure 4.8: Comparison of individual and group density estimates of Chital and Sambar of PTR, MP with that of Sariska TR*, Ranthambhore TR, Kanha TR, Bandhavgarh TR and Pench TR, Maharashtra. Present study is highlighted in red box. (*TR = Tiger Reserve).

Almost all of the protected areas in India face certain levels of anthropogenic pressure in terms of grazing, lopping or grass-cutting. Although the core zone of PTR, MP is free from such activities, local people do graze their livestock outside the core, within the buffer of the reserve. My study provides the first ever estimate of grazing hotspots of cattle using real time data. This kind of data is extremely useful for conservation of large carnivores as it can pinpoint areas where livestock is more vulnerable to predation from large carnivores.

My results showed that livestock movements in the study area did not show any kind of affinity to any type of habitat. The cattle in this area are mostly grazed in presence of a herder. These herds are seldom kept stationary anywhere. The estimated linear time density of the grazing paths showed that a maximum of 30% of

the grazing time is spent in one place. This might be because of the availability of pastures as well avoidance of predators.

There are no designated pasturelands in the buffer zone of PTR. Hence the grazing livestock need to keep on moving to look for food. Additionally, I also found a trend of these cattle avoiding very dense forest. Dense forest is often used by these ambush predators as a hunting cover which might be the reason for such avoidance. A closed canopy rarely allows the understory to be dense which are usually the food materials of these grazers. The avoidance may partly be because of this as well.

I also found no relationship between the distribution pattern of tigers and leopards and that of domestic livestock. The results showed that grazing hotspots were not coinciding with that of the distribution hotspots of tigers and leopards, point to the fact that these predators do not actively search for cattle to feed on. The high abundance of wild ungulates in the study area is the most probable reason for such pattern. So, if the domestic livestock is grazed in similar pattern in the near future, more depredation of domestic livestock by them can be avoided. However, it is important to take cognizance of the fact that the distribution pattern of these predators can change. If that happens, grazing should be diverted to areas where the presence of predators is lower. Incentivized stall feeding for domestic livestock can also give positive results.

CHAPTER-5: TEMPORAL ACTIVITY PATTERNS OF TIGERS, LEOPARDS AND THEIR PRINCIPAL PREY SPECIES

5.1. Introduction

Investigating and inferring about a community revolves around imploring some key features one of which is understanding the diel activity patterns (Lashley *et al.*, 2018). Movement ecology governs physiological processes and in turn impacts the growth of a population (Werner and Anholt, 1993). Comprehending activity pattern of a species can affectively lead to the fundamentals of movement ecology by informing the hour of peak activity of the target species (Lashley *et al.*, 2018).

Interaction within the members of a carnivore community can be on spatial as well as temporal scale. Investigating the pattern of temporal interactions is imperative (Pianka, 1973) especially for carnivores having similar body size and overlapping diet pattern (Farris *et al.*, 2014). When two predator species have similar morphology although of different sizes and overlapping diet pattern, their resource use tend to be similar which makes them competitors in nature(Donadio and Buskirk, 2006; Harmsen *et al.*, 2009). Interference intraguild interactions can result in direct death of one of the competitors even when resource availability is not constrained (Polis *et al.*, 1989; Polis and Holt, 1992; Holt and Polis, 1997; Linnell and Strand, 2000). These kind of interactions are of frequent occurrence in nature and it has been observed that the contending species need to segregate their niche either spatially or temporally or both spatio-temporally (Schoener, 1971; Pianka, 1973; Durant, 1998; Palomares and Caro, 1999; Linnell and Strand, 2000; Harrington *et al.*, 2009).Temporal niche partitioning

between competing predators can make coexistence possible and promote a more diverse community(Kronfeld-Schor and Dayan, 2003; Farris *et al.*, 2014).

Evidence exists on temporal niche partitioning in case of African sympatric carnivores where African wild dogs (*Lyacon pictus*) and Cheetahs (*Acinonyx jubatus*) segregate their resources temporally from the dominant lions (*Panthera leo*) and spotted Hyena (*Crocuta crocuta*) (Hayward and Slotow, 2009). Although contradicting results have been found in Okovango delta, where temporal overlap between these sympatric carnivores were extensive (Cozzi *et al.*, 2012). Two other sympatric predators, Jaguar (*Panthera onca*) and Puma (*Puma concolor*) have showed high temporal overlap in their diel activity patterns (Scognamillo *et al.*, 2003; Silveira 2004; Harmsen *et al.*, 2009; Paviolo *et al.*, 2009). Several studies have also suggested that activity patterns of felids are principally dominated by their principal prey species (Schaller and Crawshaw, 1980; Rabinowitz, 1986; Emmons, 1987; Karanth and Sunquist, 2000; Sunquist and Sunquist, 2002; Mendes Pontes and Chivers, 2007; Carrillo, Fuller and Saenz, 2009). Leopards are sympatric with tigers in several places in Asia (Odden *et al*., 2010) and their nature of co-occurrence varies significantly throughout which they either segregate spatially or temporally or exploit different size of food resources(Karanth and Sunquist, 1995, 2000; Odden *et al*., 2010; Harihar et al., 2011; Ramesh *et al.*, 2012; Carter *et al.*, 2015).

In order to achieve an all-encompassing idea of the community dynamics of an area, it is essential to understand the predator-prey interactions. For such successful understanding of an ecological process knowing the activity patterns of both components, predator and prey, is essential. Investigating activity pattern of ungulates

also hints towards the trade-offs animals might be making in terms of foraging, thermoregulation as well as predator avoidance. Predator avoidance behavioural mechanism of prey has the capability of reducing the overall fitness of the species by affecting its resource acquirement (Sih, 1982; Downes, 2001; Suselbeek *et al.*, 2014). 'Anti-predator vigilance' behaviour is often displayed by prey species to avoid the predator and increase their chances of survival which in turn reduces their investment in other regulatory activities (Lima, 1990; Ghuman *et al*., 2010).

Prey animals try to balance between energy investments to avoid fitness and increase their overall fitness(Périquet *et al.*, 2010). Solitary individuals face greater risk as they have to establish a trade-off between foraging and being vigilant (Fairbanks and Dobson, 2007). This trade-off acts as the deciding factor in deciding area and duration of foraging and time invested in anti-predatory vigilance behaviour (Hebblewhite, Pletscher and Paquet, 2002). When animals congregate and they attempt to establish the same trade-off, the collective vigilance level goes up and duration of foraging also goes up without enhancing the risk of exposure to a predator(Bertram, 1980; Townsend, Zöttl and Manser, 2011).

Residing in a group enable the prey animals to detect predators easily (Pulliam, 1981; Lima, 1990) and because of the 'many-eyes' (Lima, 1990) present, available duration of foraging increases (Townsend, Zöttl and Manser, 2011). Additionally group living has the ability to 'confuse' the attacking predator (Neill and Cullen, 1974). If the predator is unable to capture more than a single individual during a hunting attempt, presence of more number of individuals 'dilutes' the individual risk (Foster and Treherne, 1981; Hebblewhite and Pletscher, 2002). In contrast, large

groups may compete for resources if they are limited and very large groups can also attract predators (Pulliam, 1981). Hence predator avoidance behaviour is impacted by a number of factors like group size, predator presence, time of day, distance from cover, group size and demography, potential competitors and resource availability (Hamilton, 1971; Elgar, 1989; Yáber and Herrera, 1994; Rose and Fedigan, 1995; Burger, Safina and Gochfeld, 2000; Hebblewhite and Pletscher, 2002; Ghuman *et al*., 2010). Predators have also been found to implement measures to deal with this anti-predatory behaviour by increasing number of attacks on larger groups or hunt from a smaller group for a successful attempt (Bertram, 1980).

Chital or spotted deer (*Axis axis*) and Sambar (*Rusa unicolor*) have been identified as the major contributor of diet for both these large felids in the study area(Majumder *et al.*, 2013; Sankar *et al.*, 2013). Chital is an endemic ungulate species of south Asia mainly occurring in India, Nepal, Bangladesh and Sri Lanka (Prater, 1934; Schaller, 1967). Under the Wildlife Protection Act, 1972 India they are listed as Schedule III species. Chital is a habitat generalist, residing in a variety of habitats starting from moist, dry deciduous forest to scrublands. They do not prefer evergreen forests and open semi-desert or desert(Sankar *et al.*, 2013; Duckworth *et al.*, 2015). They are listed as least concern under the IUCN Red Data List (2015). They form social groups in wild in a 'fission-fusion' manner while performing routine physiological activities like foraging, and migration. Their behavioural pattern is governed by resource availability, animal density and social and environmental cues (Clutton-Brock, Albon and Harvey, 1980; Shankar Raman, 1997; Ghuman *et al*., 2010).

Sambar is a large deer native to South-east Asia namely India, Sri Lanka, Pakistan, Nepal, Myanmar, Thailand, Cambodia and the Malay Peninsula. They are also distributed throughout southern China, Taiwan and the islands of Sumatra and Borneo (Prater, 1934; Schaller, 1967). Sambar is listed as a Schedule-III species under Wildlife Protection Act, India (1972) and Vulnerable in IUCN Red Data List (2015). They are the most widely adapted ungulate to different forest types and climatic conditions (Schaller, 1967). They can survive in thorn forest as well as deciduous and dry deciduous forests, pine and oak forest and in moist evergreen forest as well (Sankar and Acharya, 2004). They are also found in temperate woodlands and alpine forests of Taiwan (Yen, Wang and Ou, 2014). This generalist nature arises from the broad spectrum of its diet and can both graze or browse depending upon the available resource(Schaller, 1967; Richardson, 1972; Dinerstein, 1979; Kelton and Skipworth, 1987; Johnsingh and Sankar, 1991; Sankar, 1994).

Investigating the activity patterns of a vertebrate community not only provide insights on predator-prey interaction and its effects on prey fitness, but can also be used to find answers to questions regarding intra and inter-specific competition (Foster *et al.*, 2013; Ross *et al.*, 2013; Delibes-Mateos *et al.*, 2014).

5.2. Materials and Methods

5.2.1. Field methods

i. Activity patterns of tigers, leopards and their principal prey species

Camera trap-based photographs were used to estimate the activity patterns of tigers, leopards and their principal prey species and the extent of overlap amongst them. Details of camera trapping exercises are given in the first chapter. All these

photographs were time-stamped, hence could be used for generating the required data set (Linkie and Ridout, 2011).

ii. Vigilance behaviour of prey species (chital and sambar)

"The method of direct observation plays a curious and unique role in behavioural sciences. It is at once the necessary link between laboratory research and "real-world" behaviour, and the bane of our aspirations for more accurate, more objective information about behaviour."(Altmann, 1974). I used direct observation methods to study the vigilance behaviour of chital and sambar as they are the principal prey species of both tigers and leopards in the study area (Sankar *et al.*, 2013)

I used instantaneous scan sampling and focal sampling to document their behavioural pattern(Altmann, 1974). Individuals were categorized as adult, sub-adult, juvenile and fawn based on the body size, color of coat and branching of antler (in case of males). Gender of the individual was deciphered using presence of antlers. In case of male chital, spike male (Sankar, 1994) category was added. During the scan, I recorded the activity of each individual and their position in the group. Before commencing the sampling, I recorded the distance and sighting angle of the left-most and right-most individual of the group. A specific individual within the group was chosen for focal sampling right after finishing the scan. Selected individual was observed and behavioural patterns were recorded for 5 minutes or until the individual was with visual range. The age and gender of the neighbouring animals as well as their activities were also recorded. The same sequence was repeated after an interval of 5 minutes and continued till the group moved out of sight (Ghuman *et al*., 2010; Ghosal and Venkataraman, 2014). Sampling was carried out in all different habitat

types: open grassland, teak dominated forest, teak mixed forest and mixed deciduous forest (Sankar *et al.*, 2013) The grass height, canopy cover and type of dominant vegetation were recorded using standard protocols (Jhala *et al*., 2014).

Recorded activities were categorized into 8 major types(Ghuman *et al*., 2010):

i. Feeding: grazing on forest floor, head bent

ii. Looking for food: individual moving in search for food, head bent

iii. Travelling: individual/group of individuals moving in a direction, head at right angle

iv. Alert: individual was looking steadily at a direction, head at right angle, ears up, tail down

v. Scanning: individual scanning the surrounding to detect risk, head at right angle to shoulder, ears erect and tail down

vi. Grooming: Licking self or any neighbouring individual

vii. Resting: individual sitting and looking around, often masticating

Additionally, if the animal got disturbed by the observer's presence or any tourist vehicle, if any juvenile was prancing or playing around, those were also noted down.

5.2.2. Analytical Methods

i. Activity patterns of tigers, leopards and their principal prey species

A temporal capture history was prepared for all the study species based on the camera trap based time stamped images. Only the photographs which were at least 15 minutes apart from each other were taken for this analysis to maintain the independence of the events occurred at the same camera location (Linkie and Ridout, 2011; Ramesh *et al.*, 2012). Temporal overlap was also calculated along the gradient

of human disturbance. Disturbance was defined based on the human activities observed in the area. No disturbance designates areas where local people were not allowed inside the forest, low disturbance where human activities were present but minimal and medium disturbance areas where human disturbance was found to be higher than the previous category.

A von Mises kernel density estimate, corresponding to circular distribution function (Ridout and Linkie, 2009) was used to generate the activity pattern for each species. Activity peaks were identified depending on the maximum number of captures in a specific time period (Linkie and Ridout, 2011; Foster *et al.*, 2013) The co-efficient of overlap (Δ) is denoted by the area under the density curve. I calculated the extent of temporal overlap from the co-efficient of overlap and its 95% confidence interval using 10000 bootstrap samples (Meredith and Ridout, 2017). The extent of overlap varies from 0 (no overlap) to 1 (100% overlap, identical activity pattern) (Ridout and Linkie, 2009). Extent of temporal overlap among the two predators and their principal prey was investigated along the disturbance gradient. Statistical analysis was done in the 'overlap' package (Meredith and Ridout, 2017) in R (R Development Core Team, 2015).

I also looked into the temporal segregation of leopards and tigers at each camera location. Temporal information of photo-captures of tigers and leopards at each camera location was transformed to Julian format for analysis. I first collated independent photo-captures of tigers. I consider a photo-capture as independent event if the same individual tiger or leopard was photo-captured at the same location after an interval of 30 minutes. A relative abundance index (RAI) for tigers was computed for each camera trap location as the sum of total independent tiger photo-captures

divided by camera trap effort (time that a camera was operational); expressed as photo-captures per 100 trap nights. Camera traps were then categorised into five RAI categories for tigers. Category 1 being the lowest quartile, category 2 being the second quartile, category 3, 4 and 5 based on the third, fourth and fifth quartiles respectively. At each camera trap location where both tigers and leopards were photocaptured, I calculated the time difference between the detection of tigers (hereafter 'reference detection', (Cusack *et al.*, 2017) and the closest detection of leopards following the reference detection (hereafter 'proximal detection', (Cusack *et al.*, 2017). This time difference between the reference and proximal detections is hereby termed as 'minimum lag'. I took into account all the photocaptures of leopards after the reference detection of tigers at a specific camera location till another independent detection of a tiger. The average time difference between the reference detection of a tiger and all the captures after the proximal detection of a leopard was estimated and hereafter termed as 'overall lag'. Both minimum lag and overall lag were regressed and plotted against the encounter rate classes of tigers. All analyses were carried out using Microsoft Excel (ver. 2007) and Program R (ver. 3.1.3).

ii. Vigilance behaviour of prey species (chital and sambar)

Group composition of both chital and sambar were calculated. Groups of chital were divided into eight categories based on their group size. Groups with 1-2 individuals were classified in one group. Groups with 2 – 5 individuals were in the next group. The next group classifications were with 5 – 10, 10 – 15, 15 – 20, 20 – 30, 30 – 40 and more than 40 individuals respectively. Sambar groups were divided into three categories based on their group size. I looked at the time spent in anti-predatory

behaviour in varying predator density areas, with varying group sizes and how it was varying in different habitat types.

I calculated the proportion of vigilance in each chital group by dividing the number of vigilant individuals by the total group size and termed it as 'proportional vigilance' of the group. I used this data to see how proportional vigilance changes with the change in group size. After that I divided the data into three predator density categories based on the locations they were sampled in. I used Kolmogorov-Smirnoff test (KS test) to compare the change in vigilance with change in group size and predator density. Pearson's and Spearman rank correlation was used to calculate the effect of density of the predators and different habitat features on the mean time spent by these two species being vigilant (Zar, 1999).

To analyse the proportion of vigilance from the focal sample, I calculated the vigilance intervals. I calculated the time difference between two vigilance events in the same sample and calculated how they vary with group size and predator density in a GLM framework using Gaussian distribution. I also looked if there was any effect of position of the focal individual and vigilance. All analyses were carried out in Microsoft excel and R version 3.2 (R Development core team, 2015).

5.3. Results

5.3.1 Activity patterns of tigers, leopards and their principal prey species

Both tigers and leopards in the study area are crepuscular in nature with bimodal activity peaks. Tigers were found be more active during dusk (1800 – 2000 hrs) whereas leopards were more active during dawn (0400 – 0800 hrs). The extent of overlap between these two sympatric predators while taking the whole study area into consideration was 87% (Figure 5.1).

In areas where tiger density was higher, the extent of overlap was maximum (88%) (Figure 5.2). Observed extent of overlap between these two felids was 83% in medium density and 73% in low density areas (Figure 5.3 and 5.4 respectively). Extent of temporal overlap between these two predators was different along the disturbance gradient. In low disturbance area the co-efficient of overlap was 78% whereas in high disturbance it was calculated at 51% (Figure 5.5 and 5.6). However no difference in the peak activity period was observed.

Investigation with respect to extent of temporal overlap between these two sympatric felids and their principal prey revealed that for both tigers and leopards the maximum overlap was observed with sambar (Figure 5.7a, 5.8a) followed by wild pig (Figure 5.7b, 5.8b) and chital (Figure 5.7c, 5.8c) (Table 1). Extent of overlap between these predators and their prey also varied along the disturbance gradient (Figure 5.9, 5.10 – low disturbance area, Figure 5.11, 5.12 – medium disturbance area).

Prey species	**No Disturbance**		**Low Disturbance**		**Medium Disturbance**	
	Tiger	**Leopard**	**Tiger**	**Leopard**	**Tiger**	**Leopard**
Sambar	$\Delta = 86\%$	$\Delta = 88\%$	$\Delta = 59\%$	$\Delta = 51\%$	$\Delta = 73\%$	$\Delta = 57\%$
Wild Pig	$\Delta = 70\%$	$\Delta = 77\%$	$\Delta = 61\%$	$\Delta = 67\%$	$\Delta = 55\%$	$\Delta = 62\%$
Chital	$\Delta = 61\%$	$\Delta = 68\%$	$\Delta = 51\%$	$\Delta = 48\%$	$\Delta = 41\%$	$\Delta = 31\%$

Table 5.1: Extent of temporal overlap between tiger, leopard and their principal prey species where Δ is co-efficient of overlap (Ridout and Linkie 2009)

Average minimum lag between successive captures of tigers and leopards ranged from 52 minutes (± SE 26.19) to 6.67 hours (± SE 1.87) (Figure 5.13). My data

showed that the average overall lag and average minimum lag decreased with increase in the tiger encounter rate in a linear manner ($R^2 = 0.87$)

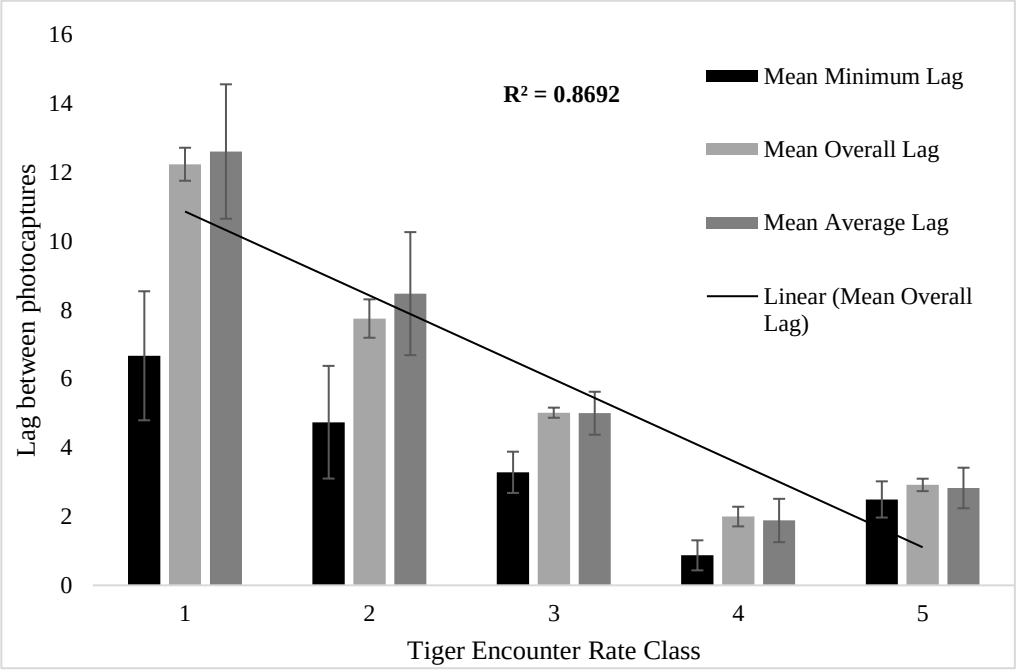

Figure 5.13: Relationship between average minimum, overall and mean lag between photo-capture of a leopard, after a tiger has been photographed. Columns represent the average encounter rate of tigers (classified 1 as lower quantile or least encounter rate and 5 as upper quantile or maximum encounter rate of tiger).

5.3.2. Vigilance of prey species (chital and sambar) in the study area

The maximum number of groups seen during the behavioural sampling had 4 to 7 chital individuals (Figure 5.14). In all the three predator density categories (high, medium and low), proportional vigilance of chital decreased with increase in group size ($p<0.05$). Proportional vigilance was highest in groups with 1-2 individuals (Figure 5.15 a, b, c). Proportional vigilance decreased significantly with the increase in group size (Figure 5.16). Position of the focal animal in the group also had no effect on their anti-predator behavioral mechanism. No significant relationship was found between predator density and proportional vigilance. In high predator density area

vigilance interval was shortest for smaller groups, increased as the group size increased to 15 individuals. Vigilance interval dipped again when groups comprised of 20 individuals and increased subsequently with increase in group size (Figure 5.17). In medium predator density areas, vigilance interval was found to be lowest for groups with 10 – 15 individuals (Figure 5.18). In low predator density areas shortest vigilance interval was observed in smallest groups (Figure 5.19). Although mean vigilance interval changed significantly with group sizes ($p<0.05$), extent of vigilance did not vary significantly with changes in group size. I also observed that proportional vigilance of chital increased with increase in tree density ($p<0.05$) (Figure 5.20).

Sambar were recorded mostly as solitary or with just another individual (Figure 5.21). Solitary individuals were classified as group 1, groups containing 2 – 3 individuals were classified as group 2 and more than 3 individuals were grouped into category 3. Proportional vigilance was similar in group category 1 and 2 and it decreased in category 3 (Figure 5.22). Proportional vigilance did not show any significant change with changing predator density (Figure 5.23). In contrast, the time spent in being vigilant by sambar increased with the increase in the tree density ($p = 0.030$) (Figure 5.24).

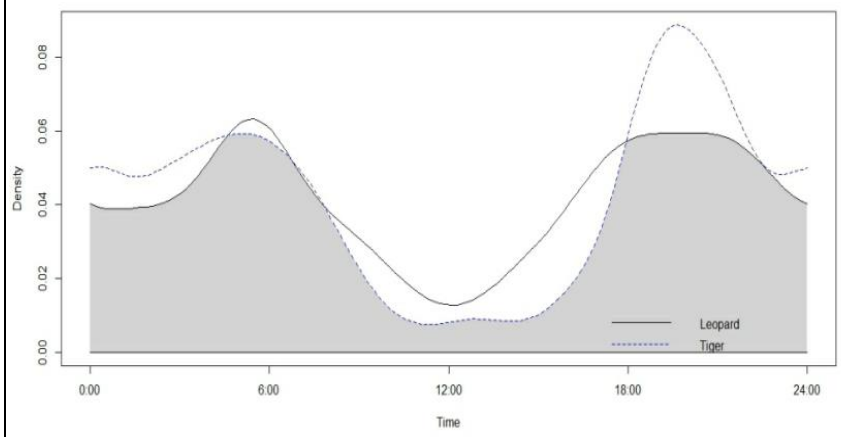

Figure 5.1: Activity curves and extent of overlap between tigers and leopards in core area of Pench Tiger Reserve, Madhya Pradesh

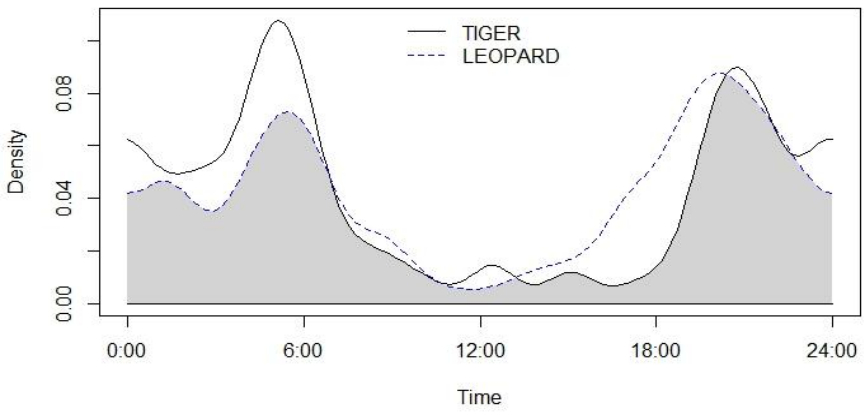

Figure 5.2: Extent of temporal overlap between tigers and leopards in high tiger density areain core area of Pench Tiger Reserve, Madhya Pradesh

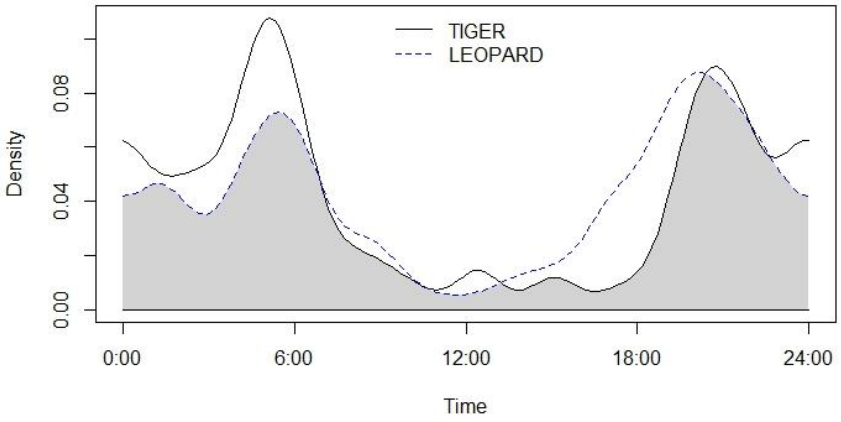

Figure 5.3: Extent of temporal overlap between tigers and leopards in medium tiger density area in core area of Pench Tiger Reserve, Madhya Pradesh

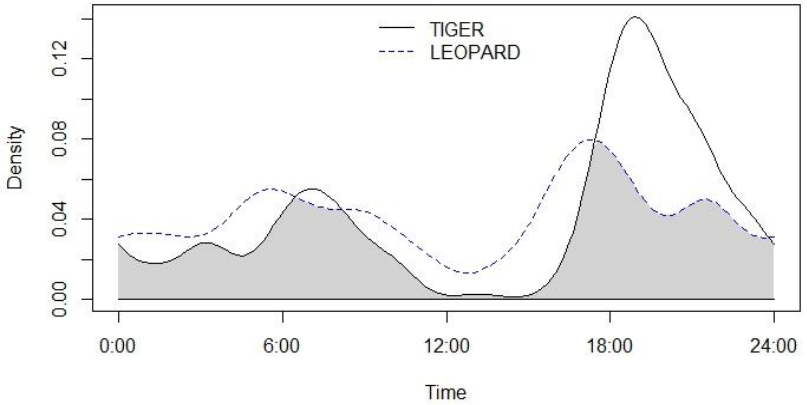

Figure 5.4: Extent of temporal overlap between tigers and leopards in low tiger density area in core area of Pench Tiger Reserve, Madhya Pradesh

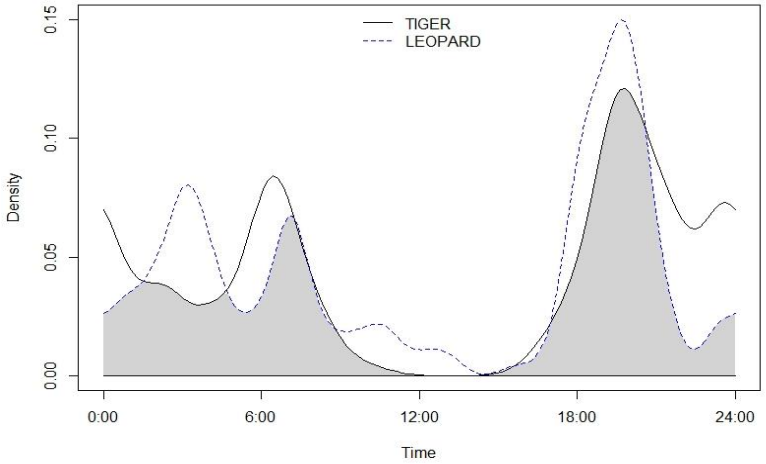

Figure 5.5: Extent of temporal overlap between tigers and leopards in low disturbance area in the buffer zone of PTR, MP

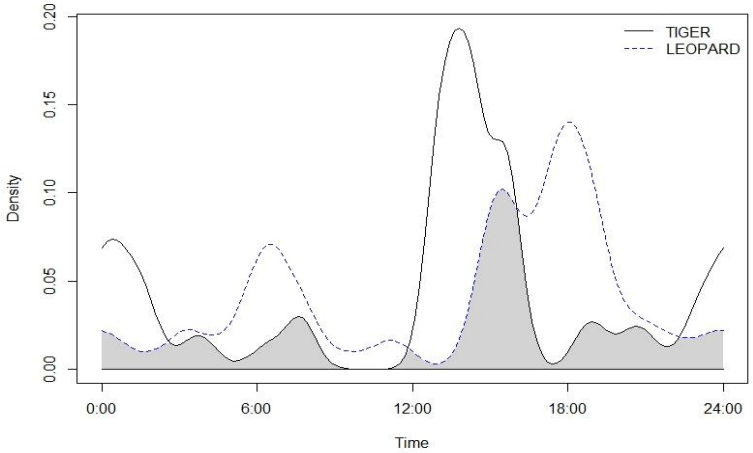

Figure 5.6: Extent of temporal overlap between tigers and leopards in medium disturbance area in the buffer zone of PTR, MP

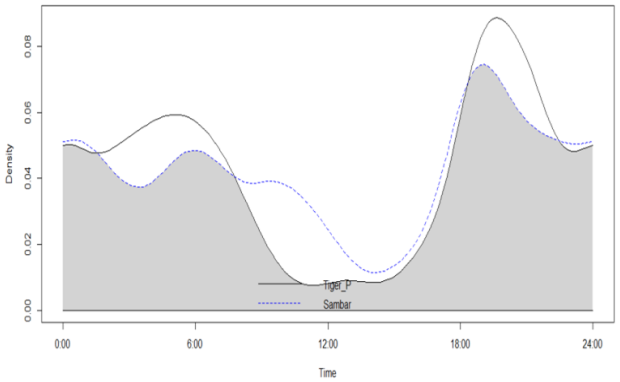

Figure 5.7a: Activity curves and extent of overlap between tiger and sambar in the core zone of PTR, MP

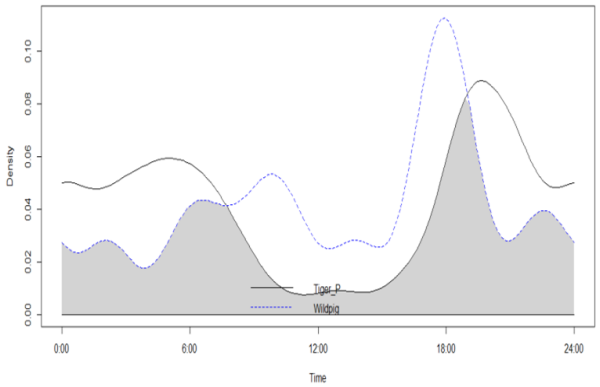

Figure 5.7b: Activity curves and extent of overlap between tiger and wild pig in the core zone of PTR, MP

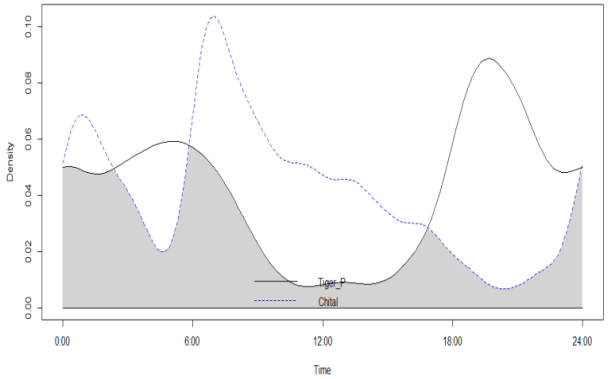

Figure 5.7c: Activity curves and extent of overlap between tiger and chital in the core zone of PTR, MP

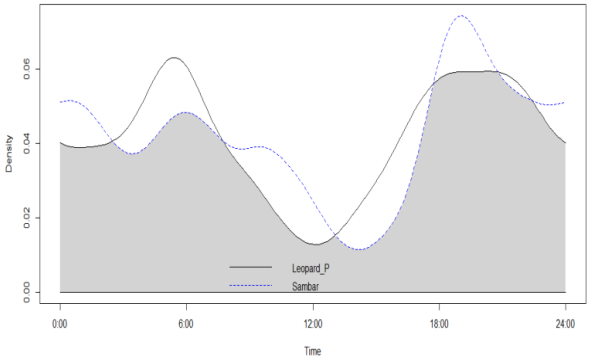

Figure 5.8a: Activity curves and extent of overlap between leopard and sambar in the core zone of PTR, MP

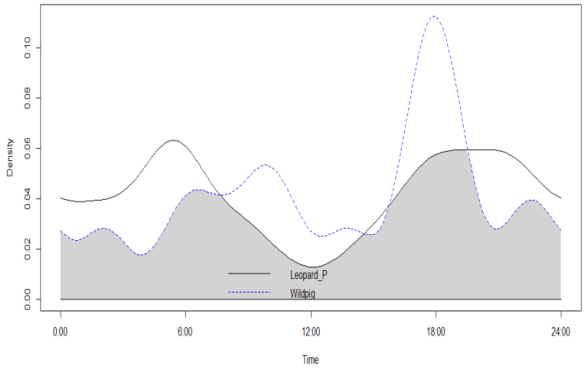

Figure 5.8b: Activity curves and extent of overlap between leopards and wild pig in the core zone of PTR, MP

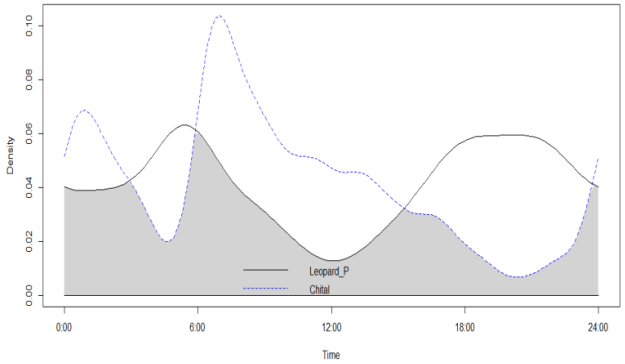

Figure 5.8c: Activity curves and extent of overlap between leopard and chital in the core zone of PTR, MP

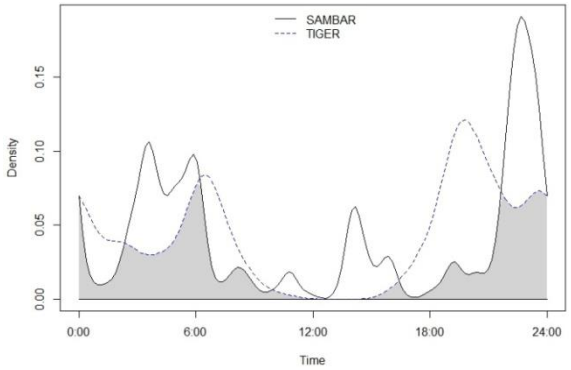

Figure 5.9a: Activity curves and extent of overlap between tiger and sambar in low disturbance area in the buffer zone of PTR, MP

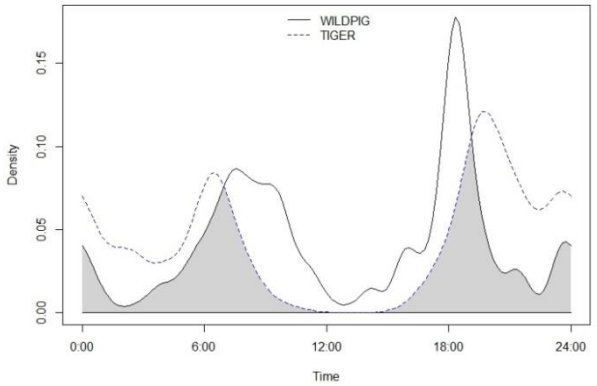

Figure 5.9b: Activity curves and extent of overlap between tiger and wildpig in low disturbance area in the buffer zone of PTR, MP

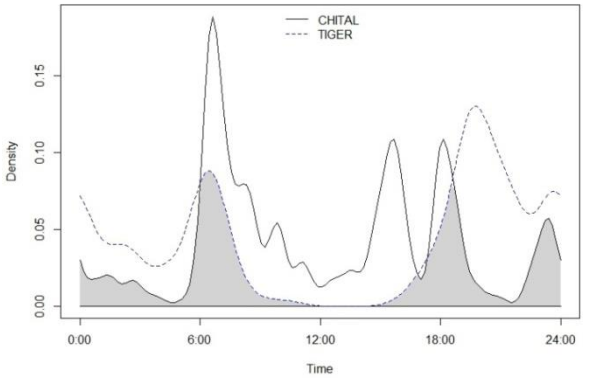

Figure 5.9c: Activity curves and extent of overlap between tiger and chital in low disturbance area in the buffer zone of PTR, MP

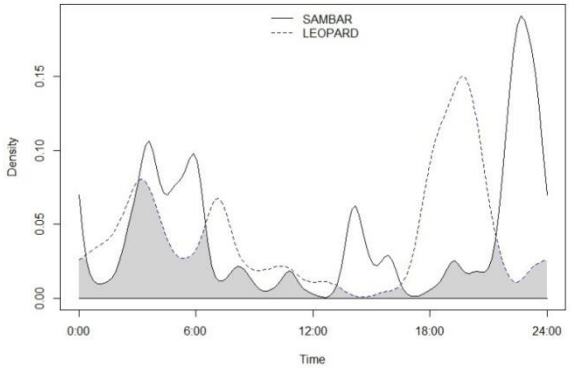

Figure 5.10a: Activity curves and extent of overlap between leopard and sambar in low disturbance area in the buffer zone of PTR, MP

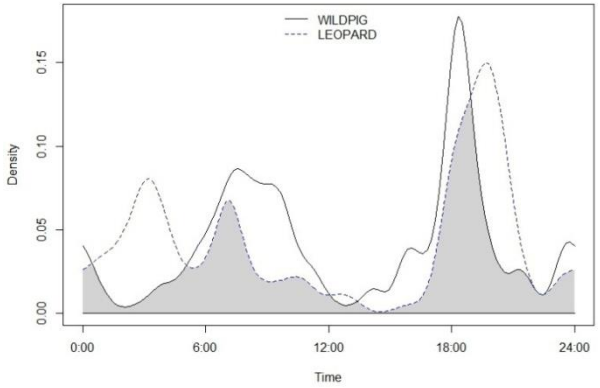

Figure 5.10b: Activity curves and extent of overlap between leopard and wildpig in low disturbance area in the buffer zone of PTR, MP

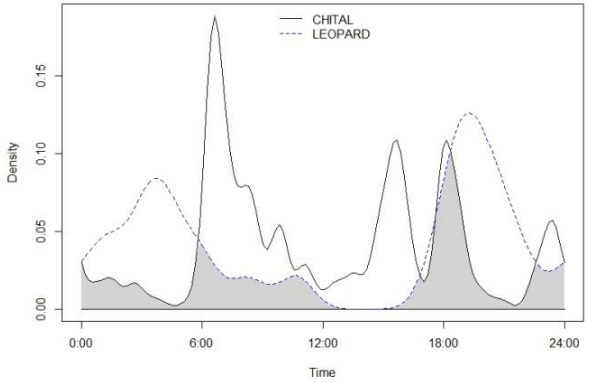

Figure 5.10c: Activity curves and extent of overlap between leopard and chital in low disturbance area in the buffer zone of PTR, MP

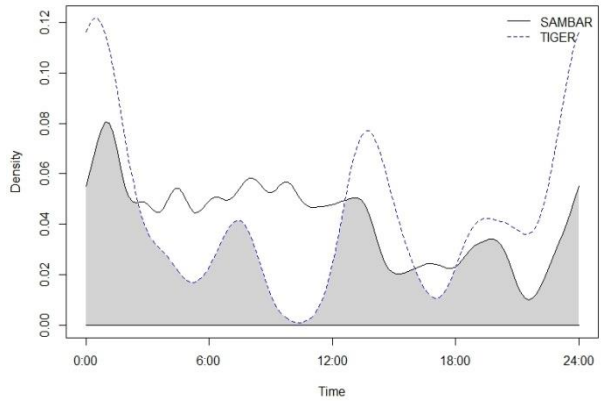

Figure 5.11a: Activity curves and extent of overlap between tiger and sambar in medium disturbance area in the buffer zone of PTR, MP

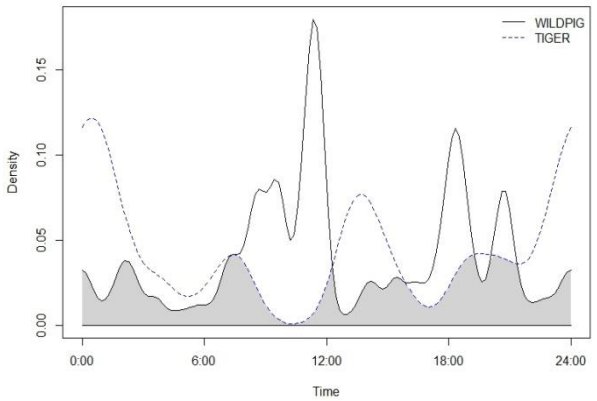

Figure 5.11b: Activity curves and extent of overlap between tiger and wildpig in medium disturbance area in the buffer zone of PTR, MP

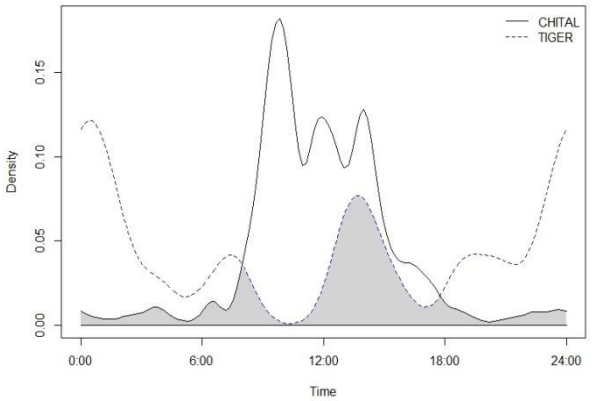

Figure 5.11c: Activity curves and extent of overlap between tiger and chital in medium disturbance area in the buffer zone of PTR, MP

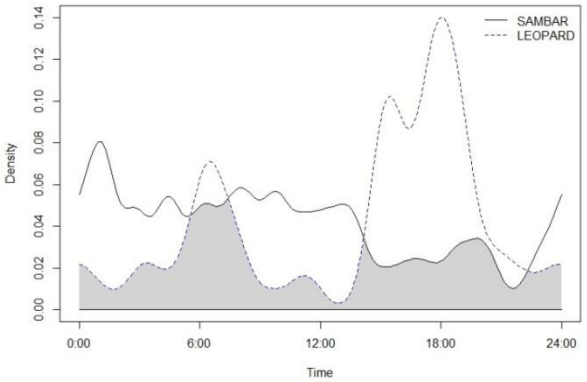

Figure 5.12a: Activity curves and extent of overlap between leopard and sambar in medium disturbance area in the buffer zone of PTR, MP

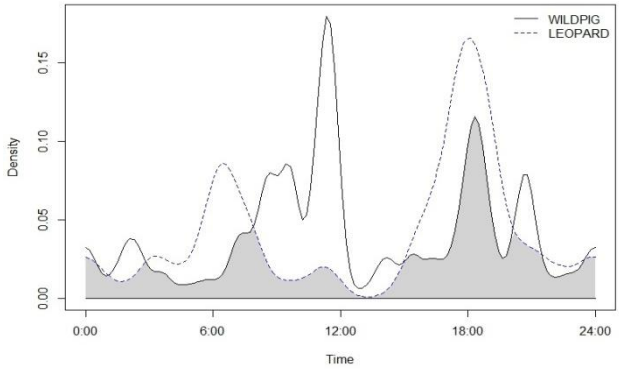

Figure 5.12b: Activity curves and extent of overlap between leopard and wildpig in medium disturbance area in the buffer zone of PTR, MP

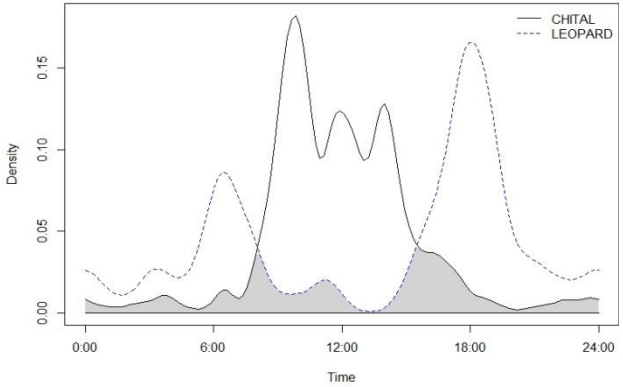

Figure 5.12c: Activity curves and extent of overlap between leopard and chital in medium disturbance area in the buffer zone of PTR, MP

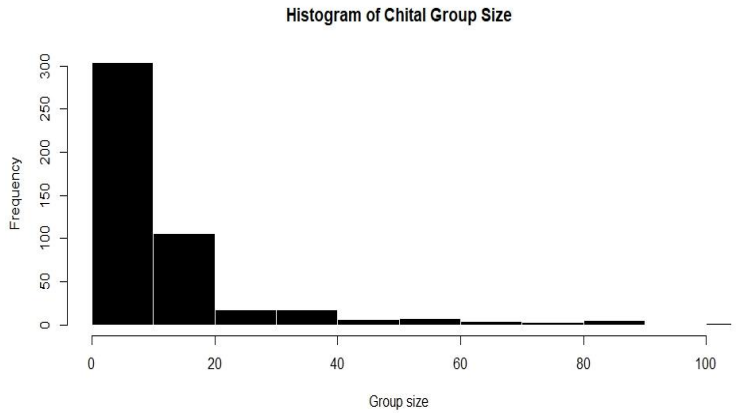

Figure 5.14: Group size of Chital in Pench Tiger Reserve, Madhya Pradesh

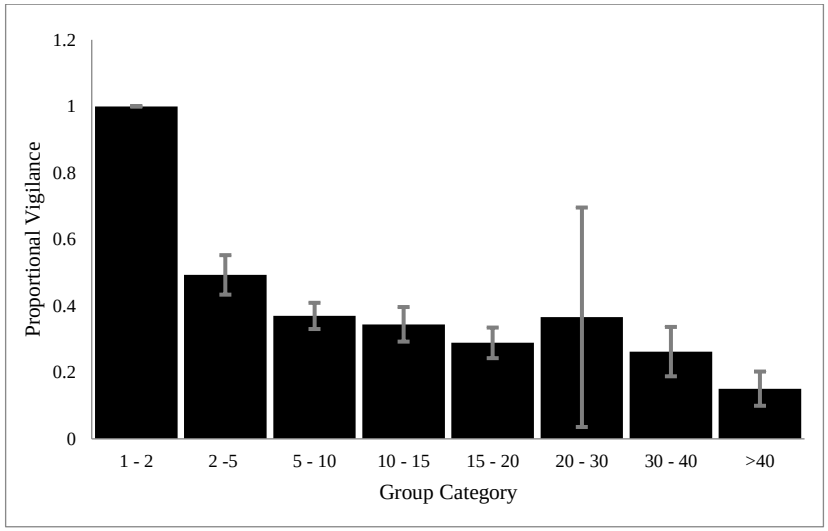

Figure 5.15a: Proportional vigilance of chital with increase in group size in high predator density areas

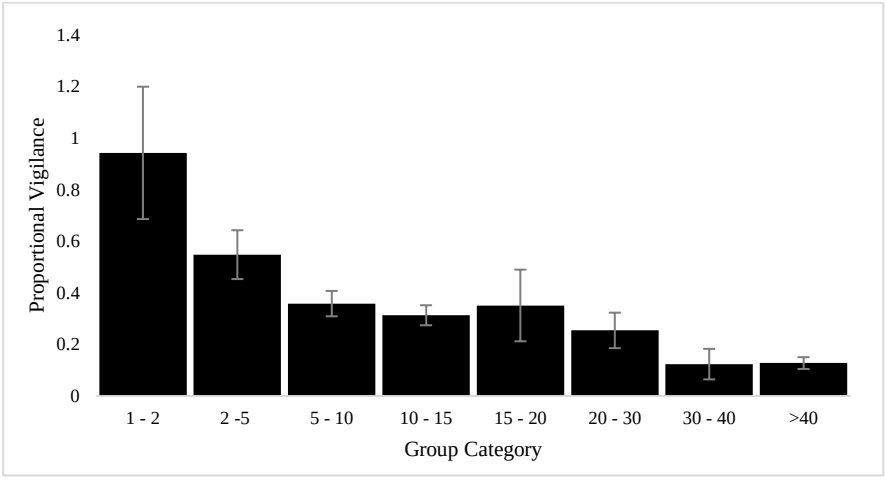

Figure 5.15b: Relationship between proportional vigilance of chital with increase in group size in medium predator density areas

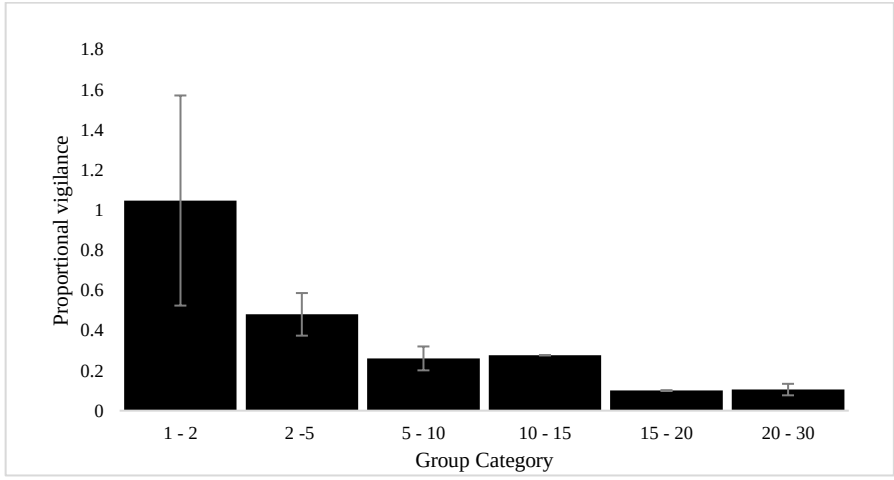

Figure 5.15c: Relationship between proportional vigilance of chital with increase in group size in low predator density areas

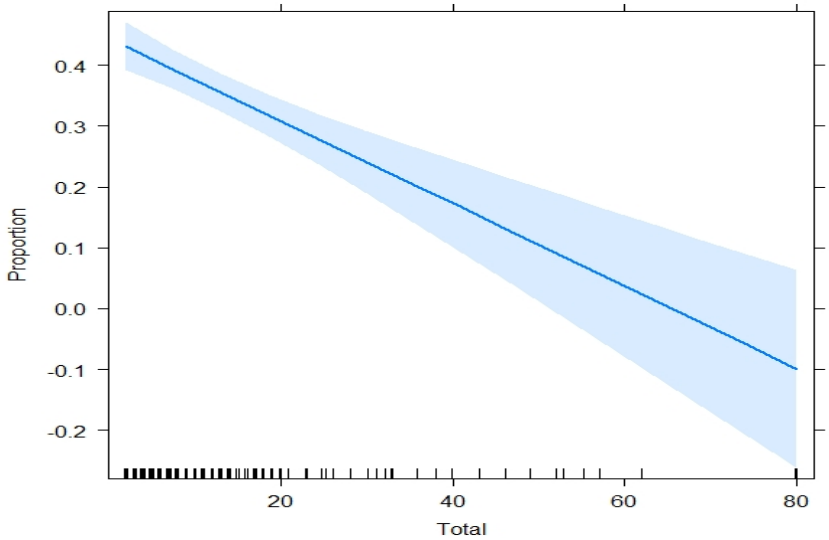

Figure 5.16: Diagrammatic representation of decline in proportional vigilnace with increase in group size

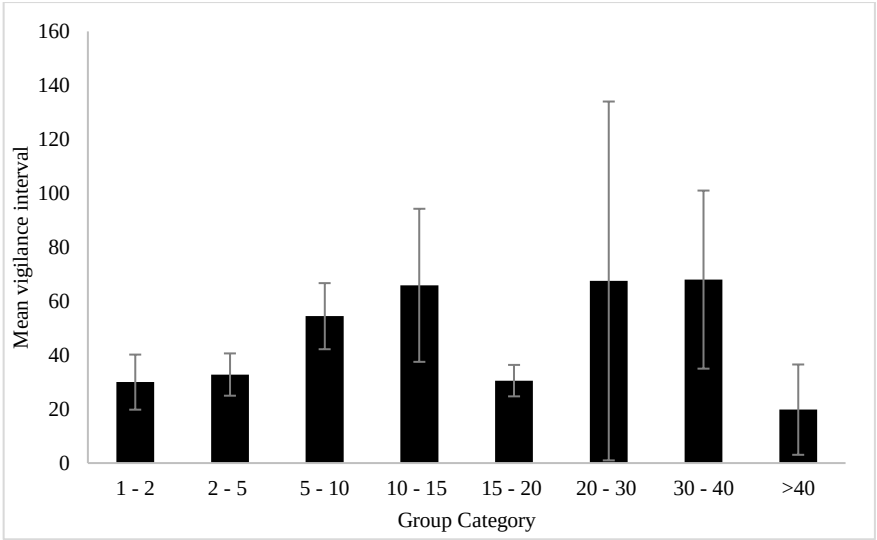

Figure 5.17: Change in average vigilance interval of chital with changing group size in high predator density areas

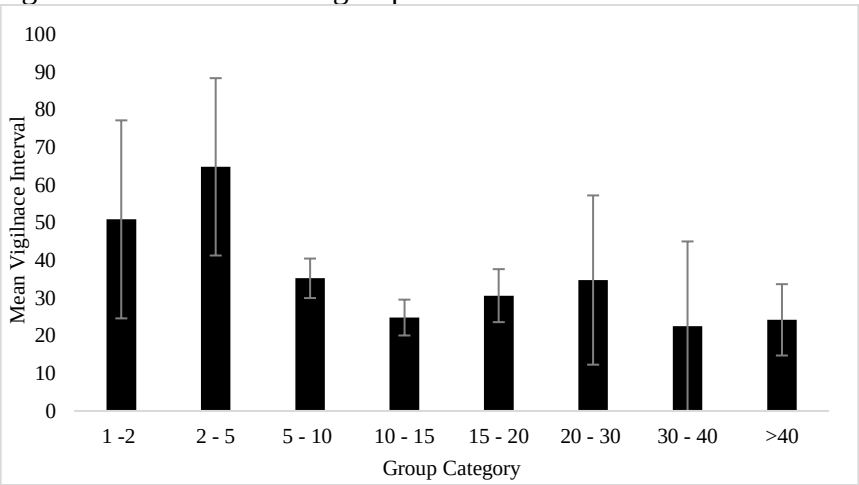

Figure 5.18: Change in average vigilance interval of chital with changing group size in medium predator density areas

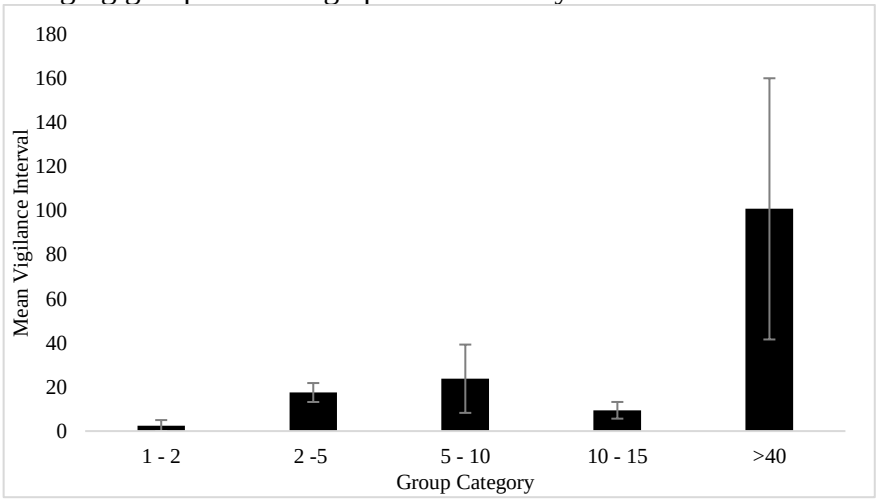

Figure 5.19: Change in average vigilance interval of chital with changing group size in low predator density areas

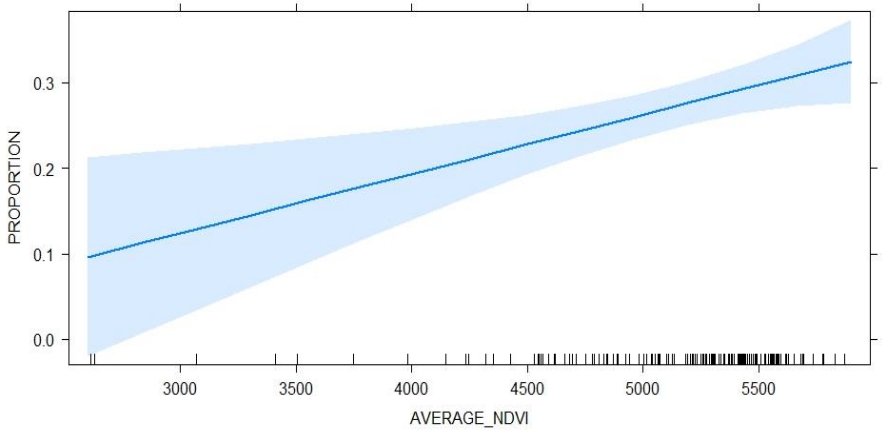

Figure 5.20: Relationship between average time spent in anti-predator behaviour by chital and tree density in PTR,MP

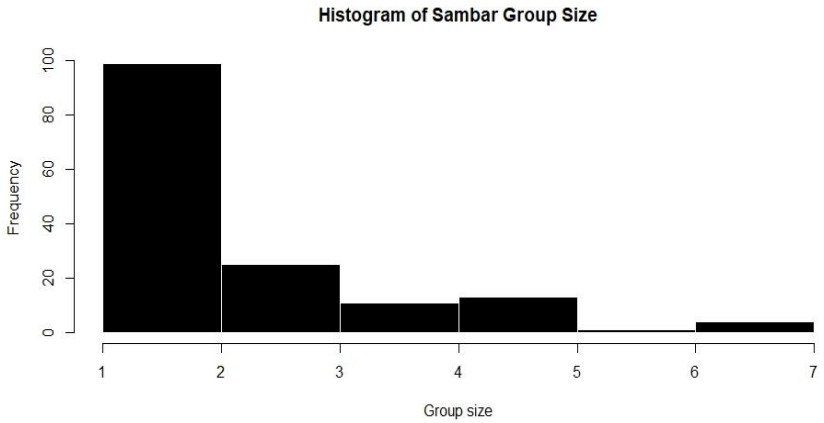

Figure 5.21: Histogram of group size of Sambar in Pench Tiger Reserve, Madhya Pradesh

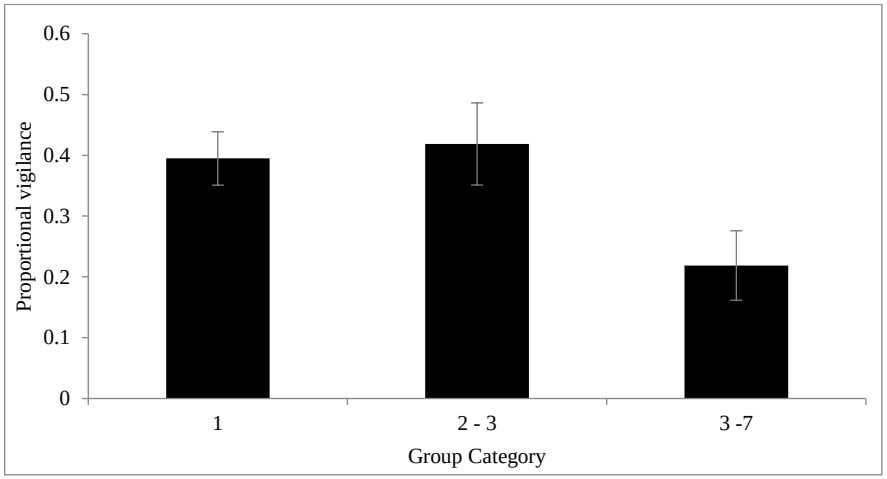

Figure 5.22: Chage in proportional vigilance of Sambar with change in group size

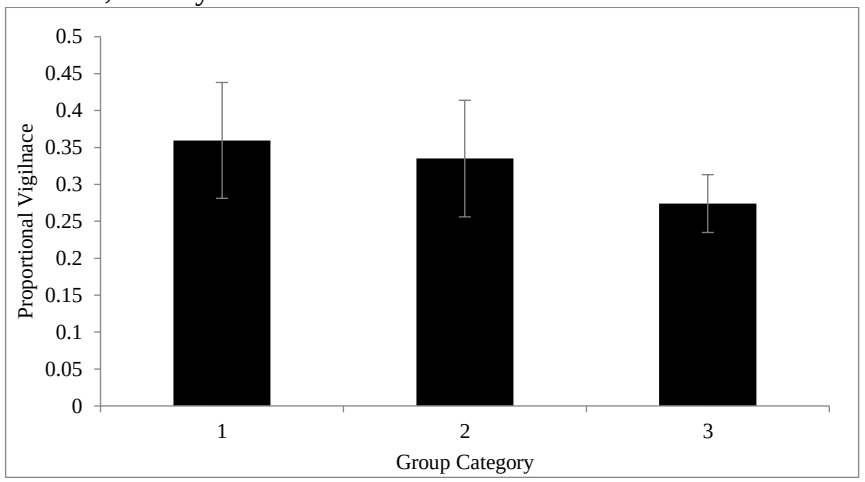

Figure 5.23: Change in proportional vigilance of Sambar with changes in predator density where 1 is low predator density and 3 is high predator density

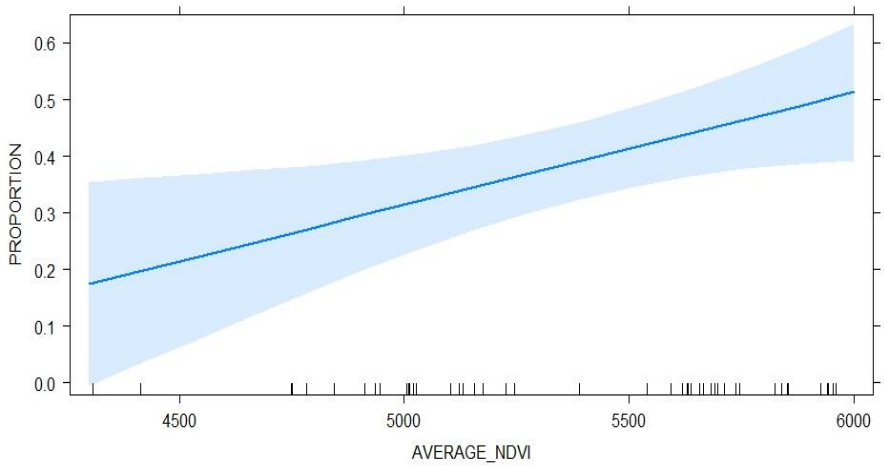

Figure 5.24: Relationship between average time spent in anti-predator behaviour by sambar and tree density in PTR, MP

5.4. Discussion

Estimation of activity curves is a fundamental part of understanding the ecology of a particular species. Camera traps can effectively estimate activity pattern of a species when placed following a robust sampling framework (Lashley *et al.*, 2018). My data clearly indicates that these two sympatric felids, tigers and leopards do not segregate on the temporal niche axis in Pench Tiger Reserve, Madhya Pradesh. The study area harbours very high density of the principal prey species of these two predators. During a simultaneous study, it was seen that this area harbours 51.405 ($\pm$ SE 9.5) chital and 6.64 ($\pm$ SE 1.11) sambar per sq. km. (Chapter – 4) which is one of the highest reported densities throughout India (Jhala *et al*., 2020).

Carnivore population dynamics, movement and distribution pattern have been known to be positively correlated with prey density and distribution pattern (Carbone and Gittleman, 2002). Temporal separation among potential competitor carnivores have been rarely reported (Palomares and Caro, 1999) and segregation on the spatial or prey is more common (Schoener, 1971; Ramesh *et al.*, 2012). Evidence exists on the fact that even the fiercest predators modify their activity pattern depending on

human disturbance (Ordiz *et al*., 2011; Gaynor *et al.*, 2018). "In a humanized biosphere (e.g., Vitousek *et al.*, 1986), man has become a universal predator" (Ordiz *et al*., 2011). Anthropogenic activities have the potential to disrupt the population dynamics or the 'eco-ethological' characteristics and no animal is immune to man's greed to hunt or destruction of habitat for developmental activities (Blanc *et al.*, 2006).

Several studies also point towards the fact that activity patterns of carnivores are principally governed by the activity pattern of their principal prey (Emmons, 1987; Karanth and Sunquist, 2000). It has also been seen that high density of prey species can make successful co-existence between two potentially competing carnivores feasible (Karanth and Sunquist, 2000; Linkie and Ridout, 2011; Karanth *et al.*, 2017). Hence understanding the activity pattern of prey is equally important to grasp the dynamics of prey-predator interactions. Prey-predator interactions have been well known to drive evolutionary behavior. But human disturbance have the potential to act as a stimuli which is equivalent to predation risk when looked at it from an evolutionary perspective (Frid and Dill, 2002).

Large carnivores need significant space to survive which makes them reside and roam in multiple-use landscapes to a great extent (Noss *et al.*, 1996). A considerable proportion of adult large carnivore mortality in human dominated areas is due to anthropogenic pressure (Woodroffe and Ginsberg, 1998). Prey can reduce their perceived risk and fear of predation by adapting several behavioral and morphological mechanisms to the same extent as predator behavior increases the perception of risk in them (Martín and López, 2004; Stankowich and Blumstein, 2005; Ordiz *et al*., 2011). Similarly, large carnivores can also undertake behavioral or 'eco-ethological' modifications to reduce the perceived risk i.e. reducing the interface with humans.

They can avoid peak periods of human activity, areas with high human presence or take refuge in densely vegetated areas to avoid detection (Boydston *et al.*, 2003; Ordiz *et al.*, 2011; Gaynor *et al.*, 2018).

During the present study, tigers signs were seen mostly found inside the study area i.e. further away from human (chapter 3) whereas leopards more frequently encountered near the edges. Leopards have been known to survive in the 'backyards' of people (Athreya *et al.*, 2013) The extent of temporal overlap between tigers and human were estimated at 33% (Figure 5.25) and at 43% between human and leopards (Figure 5.26). However, I didn't find any significant difference between the activity patterns of tiger and leopards in disturbed and undisturbed areas. The extent of overlap between these two sympatric predators and humans might be due to active avoidance behavioral mechanism of the predators or staying active during the peak activity period of their principal prey or a combination of both and is difficult to tease apart. Hence, understanding the activity pattern of the major prey species of tigers and leopards bears equal significance in understanding the prey predator interaction.

Part of Satputa-Maikal landscape, Pench provides heterogeneous habitat structures, varying from open grassland to moist deciduous forests (Sankar *et al.*, 2013). This kind of habitat heterogeneity enabled both browsers and grazers to thrive equally well (Eisenberg and Seidensticker, 1976; Sankar *et al.*, 2013). The *Cynodon* spp. is favored by ungulates like chital and wild pigs and ample water sources have enabled these species to proliferate in the study area (Sankar *et al.*, 2013). Extent of temporal overlap was highest between sambar and tiger and leopard. The co-efficient of overlap decreased in disturbed areas. Lowest overlap was seen between chital and leopards in the moderately disturbed areas. In areas without any anthropogenic

disturbance, both the predator and the prey roam without any hindrance. However, in disturbed areas the predators most likely alter their activity pattern. Although my data did not show any such alteration, all the prey species in the disturbed areas were mostly diurnal. They might also alter their behavioral mechanism to avoid the predator. The presence of humans in the vicinity might also act as a deterrent which would ultimately increase their chances of survival. It is difficult to pinpoint which factor might be contributing the most in such patterns.

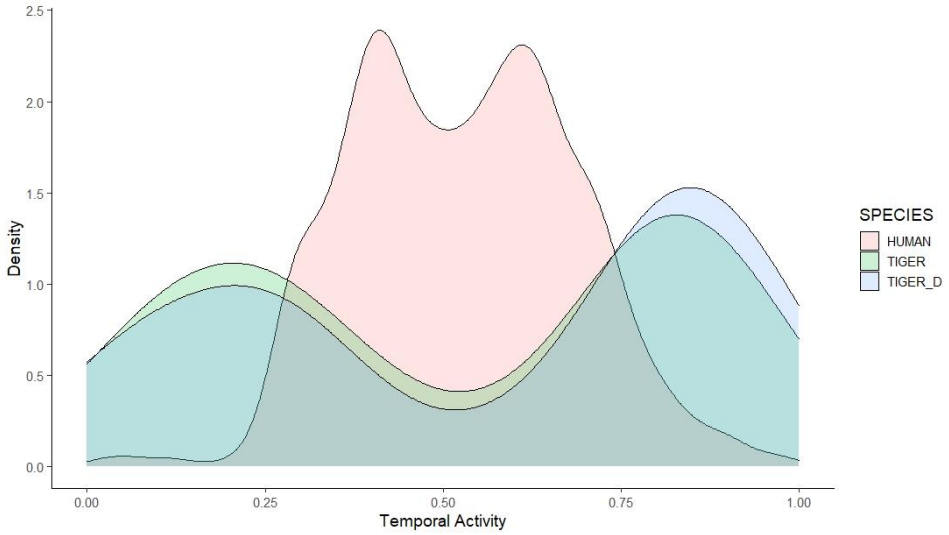

Figure 5.25: Extent of temporal overlap between tigers and human where TIGER represents photo-captures in the core zone and TIGER_D represents photo-captures in the buffer zone of the reserve

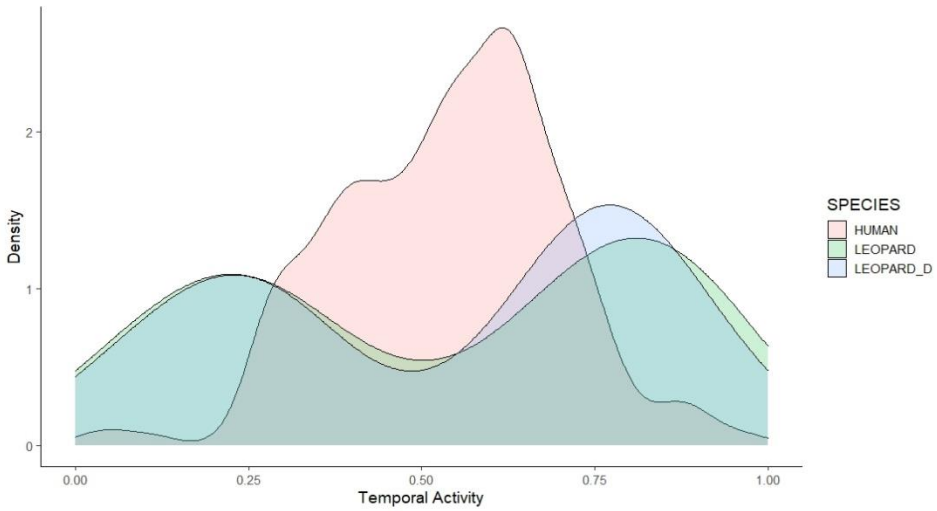

Figure 5.26: Extent of temporal overlap between leopards and human where LEOPARD represents photo-captures in the core zone and LEOPARD_D represents photo-captures in the buffer zone of the reserve

Competition acts as a major driving force in structuring communities in ecosystems with multiple predators because of their behavioural and morphological adaptations to hunt successfully (Creel, 2001; Donadio and Buskirk, 2006; Balme *et al.*, 2017). While looking at the spatio-temporal interaction between tigers and leopards, I found that the minimum time difference between two successive photo-captures of these two large cats varied 52.27 (± SE 26.19) minutes to 6.67 (± SE 1.87) hours at a specific camera location. Both the species were captured at almost all the trapping sites, but their rate of captures varied. Hence, it can be said that I found adaptive evidence of spatio-temporal avoidance of tigers by the sub-dominant predator, leopard. It is not necessary that they encounter each other while foraging as their spatial distribution pattern differ significantly with widely spaced activity centres as seen in the map (Chapter – 3).

Prey behavioral mechanism in response to the perceived predation risk act as a crucial component of investigating prey-predator dynamics. To enumerate the

magnitude of caution, several factors such as flight distance (Blumstein, 2006), activity pattern in absence of the predator (Stoks, McPeek and Mitchell, 2003), modifying resource selection (Kotler, Brown and Hasson, 1991), proportion of vigilant behavior (Blumstein, 2007), group size (Heard, 1992), position of focal animal in the group (Périquet *et al.*, 2010) have been taken into account. Present study showed that even in areas of low predator density, both chital and sambar spent equal amount of time in anti-predatory behavior. They did not take presence of predator in the habitat as a cue to alter their behavioral mechanism to invest more energy in physiological processes which contributes to increase in overall fitness. Highest proportional vigilance was seen in smallest of groups as they are more vulnerable to predation than in larger groups (Creel *et al*., 2014). Moreover, in case of chital, my results showed a trend of decline in the proportion of vigilant individuals in a group with increase in the herd size (Figure 5.15). As the group size increased, the proportion of individuals being vigilant decreased. As 'many-eyes' (Lima, 1990) are present, available duration of foraging increases (Townsend, Zöttl and Manser, 2011) and can 'confuse' the attacking predator (Neill and Cullen, 1974). Both tigers and leopards are ambush predator and usually capture a single individual during one capture attempt, presence of more number of individuals 'dilutes' the individual risk (Foster and Treherne, 1981; Hebblewhite, Pletscher and Paquet, 2002; Creel, Schuette and Christianson, 2014). However, when the group contains more than 40 individuals, the observed vigilance interval decreases again. This might be a point of breakdown where individuals start relying less on the associated animals for detection of a threat.

Results showed that variation in group size of chital was largely governed by the surrounding habitat features. With increase in canopy cover, chital herd size decreased

(Figure 5.19). Their group size as significantly large in the first category where canopy cover as the sparsest. As tree density increased, the group sizes also decreased significantly. Detection probability of a potential threat is easier in open areas. Thus, when large number of individuals congregate in these kinds of locations it is mostly because of the enhanced visibility of the surrounding. With increase in visibility, the chance of detecting a predator increases, resulting in reduction in the perceived predation risk. This finding is similar to a study previously conducted in the same study area (Ghuman *et al*., 2010) which also found that large number of chitals congregate in open grassland areas more frequently. In line with findings of the same study, the size of most frequent encountered chital group had 4 – 7 individuals. In contrast to open areas, the detection probability of a predator decreases with reduction in visibility and congregation of large number of individuals in such areas can increase the risk for all the individuals in the group. Hence, this data points towards 4-7 individuals being the optimum group size for chital to reduce the perceived predation risk in a dry deciduous forest. The open grasslands of Pench Tiger Reserve, Madhya Pradesh are mostly inundated areas with increased preferred resource availability of chital (Sankar *et al.*, 2013) which also contribute such aggregation of both grazers and browsers. Although it is difficult to distinguish which factor contributed to such congregation of individuals.

Investigation of temporal activity pattern and extent of overlap is only a subset of understanding the prey-predator dynamics of an ecosystem. Obtaining the overall depiction of prey-predator interactions in a system depends on gathering information on their spatial distribution and overlap pattern, pattern of predation and spatio-temporal interaction between the members of carnivore guild. In case of large

carnivores, gathering information during their resting phase is difficult as they are sparsely distributed naturally and mostly solitary, elusive and nocturnal in nature (Ordiz *et al*., 2011). Formulation of effective conservation strategies largely depends on detailed knowledge of animals ecological as well as adaptive mechanisms (Morris *et al.*, 2009). Despite all the constrains in directly observing large carnivores' behavioral mechanism, understanding their feeding ecology or activity pattern or movement ecology is relatively easier and has been well-documented in the past (Ordiz *et al*., 2011; Carter *et al.*, 2015; Karanth *et al.*, 2017). Such useful insights into carnivore behavioral mechanisms on a long term can help in effective strengthen existing conservation and management strategies.

CHAPTER – 6: PREY-PREDATOR INTERACTIONS OF TIGERS AND LEOPARDS

6.1. Introduction

Interactions among different species are essentially spatial and behavioural as animals must keep moving in an area both in search of food to consume as well as to evade being predated upon (McCann *et al*., 2005; Amarasekare, 2007; Schmitz *et al*., 2017). However, prey-predator interactions are seldom too straight forward because several other factors such as interspecific competition in a multi-predator system, intraspecific completion (both exploitative and apparent), intraguild predation, keystone predation, habitat features (McCann *et al*., 2005; Amarasekare, 2007; Schmitz, 2007; Barraquand and Murrell, 2013; Schmitz *et al*., 2017) also contribute a lot to these interactions.

In a multi-predator system, sympatry among the large carnivores has been seen worldwide. Sympatry is mediated by allometric differences, differential prey selection, habitat usage and changing their activity patterns (Palomares *et al*., 1996; Lovari *et al*., 2015; Sugimoto *et al*., 2016; Bocci *et al*., 2017). Competition between the sympatric species becomes more likely if available gamut of resources is scarce (Peiman and Robinson, 2010; Bocci *et al*., 2017). Leopards are sympatric with tigers across their entire range of occurrence in Asia and their coexistence follows similar mechanisms. They can be segregated spatially (Odden *et al*., 2010; Harihar *et al*., 2011), temporally (Karanth *et al*., 2017) or partition their preferred prey either by species or health condition (Ramesh *et al*., 2012; Majumder *et al*., 2012).

Although intraguild interactions amongst large carnivores impact the population dynamics of sympatric predators, their spatial distribution and social

organization are also governed by availability of food (Macdonald, 1983; Sandell, 1989). Density of large carnivores is widely influenced by density of wild ungulates (Carbone and Gittleman, 2002; Karanth *et al*., 2004). The abundance and dispersion of prey have been known to influence individual predatory behaviour (Litvaitis *et al*., 1986; Powell *et al*., 1997). However, ungulate abundance is not the single factor governing the catching of prey by large predators. Body size, profit gained from the prey, chances of encounter, ease of access or vulnerability, probability of successful capture rate, capacity of useful feeding, anti-predatory behaviour and defences, resulting risk of injury and also extent of habitat overlap between these interacting species influence the range of prey normally taken by predators (Meriggi *et al.*, 1996; Garrot *et al.*, 2007; Jaworski *et al.*, 2013).

Keeping all of these factors and optimal foraging theory (MacArthur and Pianka, 1966) in mind, it should imply that predators should be selecting domestic livestock over wild ungulates because of reduced search effort (known locations of pastures resulting in clumped distribution of resources and alleviating aggregation response by predators), greater successful catchability of prey as they are not able to detect and avoid predators (due to domestication) and less chances of escape owing to lack of availability of refugia. But practically the human interference involved with the domestic ungulates in turn reducing the chances of survival, can make them less profitable for predators (Meriggi *et al.*, 1996). The dependence on reliable prey base is necessary for social organisation among carnivores and 'the ontogeny of search images and prey recognition concerning livestock' can also probably negatively affect the catchability of domestic ungulates (Moa *et al.*, 2006).

Preference of prey by predators depends largely on the relative abundance of the prey in the system, skewed positively towards the most abundant and negatively for the rarest prey (Jaworski *et al.,* 2013). This implies that the prey selection by a specific predator is principally governed by the probability of encounter between them. Hence encounter rate of a prey is random in nature (Holling, 1959) but also directly proportional to their density (Arditi and Ginzburg, 1989; Becker 2008). In a study carried out in Northern Italy (Meriggi *et al.,* 1996), it has been observed that as the density of wild prey decreases, domestic ungulates are used as an alternate prey by wolves. Meriggi and Lovari (1996) observed a statistically significant inverse correlation between the proportional contribution of wild prey and domestic livestock in wolves' diet. Evidences also suggest lynx and wolves predated on livestock more in areas of high local wild prey abundance (Stahl *et al.,* 2001; Treves *et al.,* 2004; Moa *et al.,* 2006; Odden *et al.,* 2008). This may be due to the increased chances of encounters between predators and domestic livestock in areas where wild ungulates are also abundant (Odden *et al.,* 2013).

In addition to the availability of prey in terms of both wild ungulates and domestic livestock, habitat characteristics also play a major role in determining the nature of prey-predator interactions. Habitat structure has been seen to be an important factor in explaining the variation in predation risk. Hunting success of lions was seen to be positively influenced by bush and grass cover (Orsdol, 1984). A long-term study of pumas (*Puma concolor*) and mule deer (*Odocoileus hemionus*) demonstrated that the predator was more successful in killing a prey near the forest edges whereas in the open areas the success rate went down significantly. Juniper-pinyon habitats were also

identified as important ‘cache points’. Presence of higher tree density and higher diameter at breast height of the trees at the cache points in comparison to the kill points demonstrates the importance of cover in the hunting success of an ambush predator (Laundré and Hernández, 2003).

In addition to prey density and habitat features, prey behavioural characteristics play an important role in determining the results of prey-predator interactions. It has been observed that wild ungulates alter their behavioural strategies in different habitat types as per the predation risk in spite of fewer feeding opportunities in cases. A study of the foraging behaviour showed that perceived predation risk of mule deer was higher in Douglas-fir forest which in turn affected their food intake (Altendorf *et al*., 2001). A significant change in willow regeneration was seen in Southwestern Montana after reintroduction of wolves. The high perceived predation risk of elks in narrow regions of Willow patches led to this cascading effect (Ripple and Beschta, 2004). Elks in Yellowstone National Park moved more in aspen forests in low wolf-usage areas in comparison to high usage areas (Fortin *et al*., 2005). As wolves thrive well near human habitation, elks were also more vulnerable to predation near the edges (Bergman *et al*., 2006). Because of the habitat heterogeneity of a landscape predation risk fluctuates spatially as a predator is not a successful hunter in all the habitat types. These examples thus adequately illustrate how the variation in predation risk because of habitat heterogeneity is used optimally by the wild ungulates to increase their fitness.

Prey-predator interaction can be visualised as a two-player game in which a responsive predator tries to catch a prey which is trying to avoid the predation (Brown, 1999; Laundre *et al*., 2010). In the landscape it is analogous to a game of stealth and

fear (Brown, 1999). “Fear” is defined as “an unpleasant often strong emotion caused by anticipation or awareness of danger” by Merriam-Webster. When prey scamper at the sight of an approaching predator; the response is from the fear of being predated upon. Nevertheless, the response is not confined to the event taking place and prey need to anticipate the risk of getting killed by a predator (Laundré *et al*., 2010). Naturally it is nearly impossible for a prey animal to be aware of the location of a possible predator and they seldom detect the presence of a nearby predator. Hence, to maintain its overall fitness, the prey retains a specific level of fear of predation or of the risk of exposure to a predator (Brown, 1999). Being afraid is the way to survive for prey and if an animal lacks fear of the risk of predation, it becomes more prone to predation thus hampering its overall fitness (Boissy, 1995; Laundré *et al*., 2010).

Aldo Leopold (1966) brands fear as an essential ingredient of the predator-prey interactions: *“As a deer herd lives in mortal fear (our emphasis) of its wolves, so does a mountain live in mortal fear of its deer.”* That is why fear has been an important behavioural component towards understanding this fundamental interaction (Laundré *et al*., 2010). Fear manoeuvres prey behaviour with response to risk of predation, thus governing predator actions in search of prey and becomes the key component of this two-component board game (Brown, 1999; Holmes and Laundré, 2006; Laundré *et al*., 2010).

In this game of stealth and fear (Brown, 1999), habitat patches can be considered as the ‘squares’ of the play board in which both the predator and the prey reside as well as roam around. Prey aims to select patches with abundant resources along with facilitating behavioural strategies to augment the overall fitness while

avoiding being predated upon. On the other hand, a predator opts to stay in patches where hunting success can be maximum while locating a suitable prey. However, the caveat of this entire selection process is that not all habitat patches offer similar resource availability, low risk of predation, fitness opportunities or successful hunting prospect for predators. Hence like all board games, in this game of stealth and fear the central scheme is the decision making by both prey and predator to roam around in between these patches for resource exploitation to strengthen their respective chances of survival.

This landscape of fear encompasses information on predation risk, prey refugia as well as the efficiency of the predator. Refugia are the areas where the predation risk remains low. Hence risk of predation varies throughout the landscape because of these refugia, where higher the numbers of these refugia lower the predation risk (Lima and Dill, 1990; Chapman *et al*., 1996; Laundré *et al*., 2001; Creel and Christianson, 2008). The visual model – landscape of fear, integrates variation in predation risk and prey behavioural responses to fear ultimately leading to change in space usage pattern in the area of interest. Therefore, in the landscape of fear (seen from a three-dimensional point of view) the troughs and crests represent the varying predation risk with changing habitat structure owing to predator lethality (Laundré *et al*., 2010).

I hypothesised that the predation hotspots of wild ungulates and domestic livestock are determined by density and distribution of these prey species and the density of tigers and leopards. Habitat features like proportion of dense forest; visibility will also play a major role in determining the predation hotspots.

6.2. Methods

6.2.1. Field Methods

To evaluate the predation pattern, I located kills made by both tiger and leopards, systematically and opportunistically during the study period (2013-16). For systematic sampling of kills of wild prey, I carried out carnivore sign survey in each forest circle for eight to ten kilometres once in a month. Carnivore sign surveys (Jhala *et al.,* 2004) were conducted in each beat of the study area covering an area of approximately 1100 sq. km. Total 56 beats were surveyed. A total effort of 15 km walk was made along trails, dirt roads, dry riverbeds in each beat (lowest sampling unit, administrative boundary) recording carnivore signs such as pugmarks, rake marks, scrape marks, scent markings, scats, kills and also direct sightings.

For opportunistic sampling prime indicators of the presence of kills like predators in the vicinity, the calls of jungle crows and hovering or descending vultures were used. The locations of the kills were identified by the sighting of the feeding carnivores or scavengers, by the odour of the decomposing carcass and occasionally, the signs of dragging of the carcass. All the beat-guards and watchers were also requested to inform me if they get any information on any kill made by large carnivores. I also collected information on predation events from their daily patrol logs. Predator was identified by looking at the pugmarks and other signs near the kill. I collected the information on livestock depredation from the events reported to the forest department for compensation. I only used information on predation of compartments where effort in terms of locating those predation events was similar. All the data were collated at compartment level and habitat covariates were extracted at the same level to carry out further analysis.

6.2.2. Analytical Methods

I calculated kill density based on number of kills detected in each compartment divided by compartment area. For this calculation, I only took into account the kills inside the core zone as the effort to locate these kills was uniform. A hotspot map was created using Getis-ord Gi* statistic (a spatial clustering technique) for density of predation events of both wild ungulates and domestic livestock in ArcMap 10.3.1. This helps to identify statistically significant clusters of an event using z-score. Higher value of z-score represents higher clustering of such events (Baruch-mordo *et al.*, 2008; Ruda, Kolejka and Silwal, 2018).

I used Generalised Linear Model (GLM) to examine the relationship between spatial clustering of predation events and habitat variables. Prey and predator density values were also extracted at compartment level. I used percentage of different forest types and forest cover areas in each compartment as habitat covariates. Normalised Difference Vegetation Index (NDVI) values were also extracted at compartment level. I then used the estimated linear time density (Chapter – 4) of domestic livestock grazing in the buffer zone to see if they impact the depredation hotspots. I also calculated proportion of different forest types in each compartment in ArcMap 10.3.1 (2018, Esri, Redlands, CA). All of these variables were then scaled using z-transformation in R 4.0.3 (R development core team, 2015). I ran different combinations of GLM using a Gaussian error distribution with identity link function. Model with lowest AIC values were selected as best models (Burnham and Anderson, 2002).

6.3. Results

A total of 105 predation events of wild ungulates and 111 predation events of domestic livestock were used for identifying their predation hotspots. In case of wild ungulates, the predation hotspots were mostly in Karmajhiri range and northern part of Gumtara range (Figure 6.1). Predation hotspots of domestic livestock were mostly found adjacent to northern boundary of the core zone (Figure 6.2).

The probability of predation of wild ungulates in a compartment increased with increase in abundance of chital and increase in the value of NDVI i.e., increase in cover density (Table 6.1) (Figure 6.3a, b). The same decreased with increase in ruggedness in the compartment (Table 6.1) (Figure 6.3c).

Parameters	Estimate	Standard Error (±)	t value	Pr(>|t|)
Intercept	-0.039	0.106	-0.37	0.712
Chital Abundance	0.256	0.115	2.213	0.029*
NDVI	0.601	0.123	4.893	0.000003***
Ruggedness	-0.274	0.127	-2.167	0.032*

Table 6.1: Variables influencing predation of wild ungulates based on best fitted Generalised Linear Model (GLM). The best model is comprised of abundance of chital, NDVI (cover density) and ruggedness in the compartment.

On the other hand, the best model for depredation of domestic livestock showed that the probability of depredation in a compartment increased with increase in predator density (Table 6.2) (Figure 6.4a). The model also demonstrated that the probability declines with increase in elevation and NDVI (cover density) (Table 6.2) (Figure 6.4b, c).

Parameters	Estimate	Standard Error	t-value	Pr(>|t|)
Intercept	-0.055	0.078	-0.702	0.483
Predator Density	0.181	0.082	2.212	0.028*
Elevation	-0.258	0.081	-3.196	0.002**
NDVI	-0.273	0.091	-3.011	0.003**

Table 6.2: Variables influencing depredation of domestic livestock based on best fitted Generalised Linear Model (GLM). The best model is comprised of density of predators, elevation and NDVI (cover density) in the compartment.

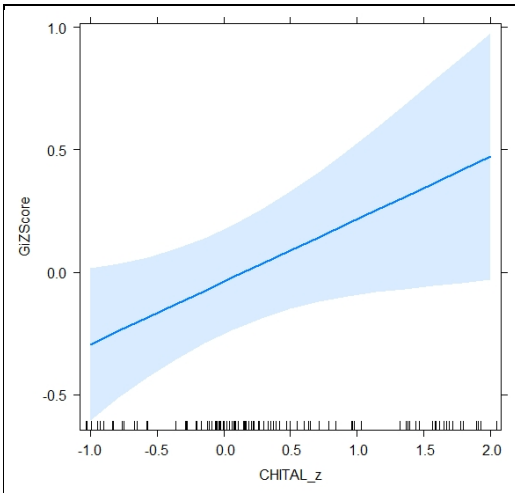

Figure 6.3a: Effect plot of GLM depicting increase in probability of predation of wild ungulates with increase in chital abundance

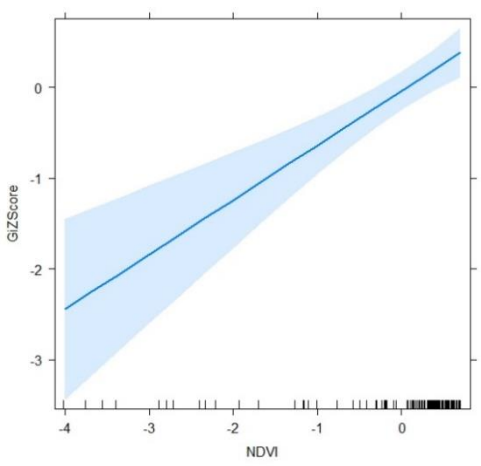

Figure 6.3b: Effect plot of GLM depicting increase in probability of predation of wild ungulates with increase in NDVI (cover density)

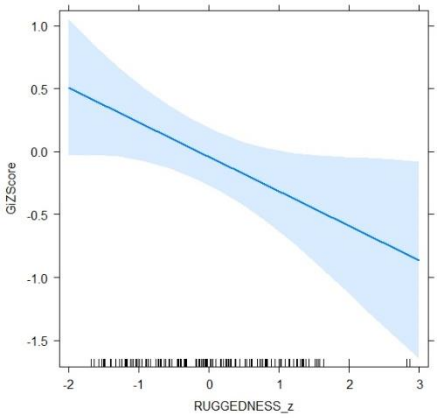

Figure 6.3c: Effect plot of GLM depicting decrease in probability of predation of wild ungulates with increase in ruggedness

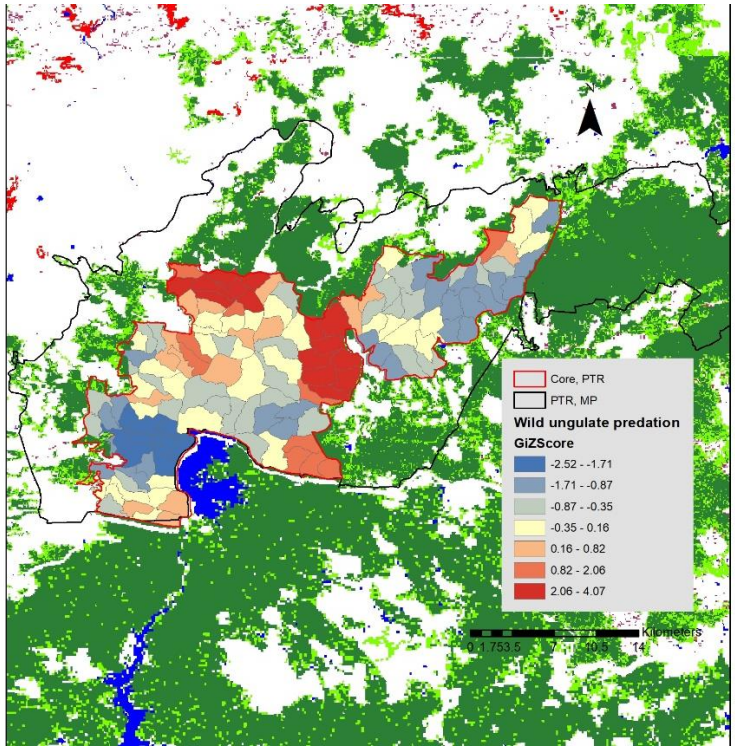

Figure 6.1: Depiction of spatial clustering of wild ungulate predation event hotspots where red cells represent higher probability of predation and blue cells represent lower probability of the same

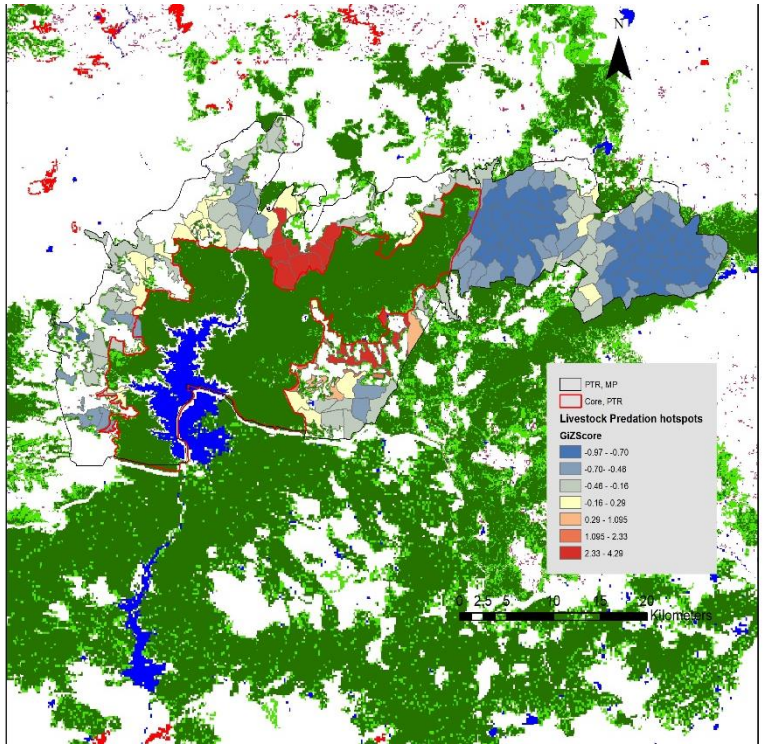

Figure 6.2: Depiction of spatial clustering of domestic livestock depredation event hotspots where red cells represent higher probability of predation and blue cells represent lower probability of the same

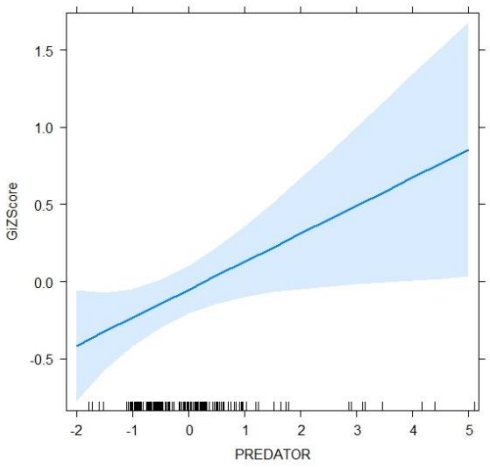

Figure 6.4a: Effect plot of GLM depicting increase in probability of depredation of domestic livestock with increase in predator density

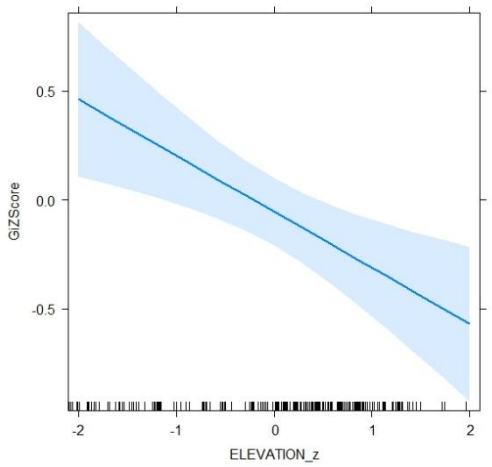

Figure 6.4b: Effect plot of GLM depicting decrease in probability of depredation of domestic livestock with increase in elevation

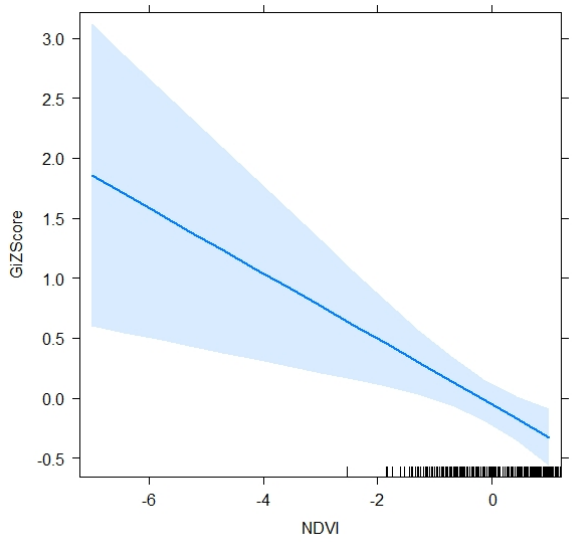

Figure 6.4c: Effect plot of GLM depicting decrease in probability of depredation of domestic livestock with increase in cover density (NDVI)

6.4. Discussion

The spatial distribution as well as social organisation of large carnivores is widely associated with the availability of food (Macdonald, 1983; Sandell 1989). Large carnivores persist in low densities in nature as they are at the top-most trophic level of the food chain (Linnell *et al.,* 2001) and wild-prey density has been identified as a pivotal factor in maintaining their density to a significant level (Carbone and Gittleman, 2002; Karanth *et al.,* 2004). Impact of decline in wild ungulate populations is clearly seen in terms of increased depredation of domestic livestock by snow leopards (Madhusudan and Mishra, 2003; Suryawanshi *et al.,* 2013). This ultimately increases the negative interactions between people and wildlife, creating a major obstacle in conserving the carnivores (Treves and Karanth, 2003; Woodroffe *et al*., 2005; Bagchi and Mishra, 2006; Inskip and Zimmermann, 2009; Miller, 2015). Tigers and leopards are no exception to this phenomenon (Bagchi, Goyal and Sankar 2003; Athreya *et al*., 2013; Dhanwatey *et al*., 2013). Biased understanding of livestock contribution to carnivore diet can hinder the effort of saving these rapidly declining carnivores and effective planning of conflict mitigation strategies (Bagchi and Mishra, 2006).

Livestock grazing is practiced in almost 70% of Indian wildlife reserves (Kothari *et al*., 1989; Madhusudan, 2003). Although the core zone of PTR, MP is devoid of any anthropogenic disturbance, the buffer zone harbours 61000 people with a livestock holding of 36000 (Sankar *et al.,* 2017). Most important predictors of domestic livestock depredation were density of carnivores and domestic livestock (Miller, 2015). The limiting boundary of the core zone does not put any physical barrier for

tigers and leopards to venture outside and very often they come into contact with anthropogenic presence.

The existing nonlethal tools for reducing carnivore attacks on domestic livestock are logistically challenging to implement and difficult to put into operation in big landscapes in spite of being cost-effective (Shivik, 2006; Lichtenfeld *et al*., 2015; McManus *et al*., 2015). As a result, pastoralists sometimes take up fatal means to control the losses imposed by carnivores resulting in further decline of these already threatened populations (Ogada *et al*., 2003; Inskip *et al*., 2013). As carnivores play a crucial role in maintaining ecosystem structure, these speedy declines result in loss of ecosystem services essential for human survival (Ripple *et al*., 2014). Hence pinpointing areas with high probability of depredation of domestic livestock is fundamental.

A spatial statistical approach known as predation risk modelling can effectively predict areas of high conflict probability. These models have been especially beneficial in quantifying prey-predator interactions and predict future hotspots of predation events. They use spatial dataset of past interactions and plot these interactions over a Geographic Information System (GIS) platform to visualize the predation pattern (Hebblewhite *et al*., 2005; Miller, 2015). The theory of these kinds of spatial risk modelling originates from spatial ecology, prey-predator interactions and optimal foraging theory. Similar to wild prey the nature of interactions between large carnivores and domestic livestock are also governed by predator hunting methods, prey foraging strategies and predator avoidance mechanisms (Sih, 1984; Kluever *et al*., 2009; Laporte *et al*., 2010; Miller *et al*., 2015). In case of ambush predators like tigers

and leopards, they try to look for prey in areas with high prey density with adequate cover as the process of searching for prey as well as handling the prey is extremely energy exhaustive (Holt, 1977; Hopcraft *et al*., 2005; Balme *et al*., 2007; Atwood *et al*., 2009). As prey-predator interactions are spatial in nature, habitat heterogeneity plays an important role and the pattern varies with variation of the habitat features (Wydeven *et al*., 2004; Gorini *et al*., 2012). This in turn gives rise to spatial variation of predation risk across the landscape and can be used to identify areas where prey has 'refugia' and a predator can successfully capture a prey (Brown, 1999; Laundre´ *et al*., 2010, Miller *et al*., 2015).

My results indicated that the probability of predation of wild ungulates increase with increase in chital density and cover density. The results also showed that predation probability decrease with increase in ruggedness. Chital has been identified as one of the major ungulate prey of both tigers and leopards in the study area (Biswas and Sankar, 2002; Majumder *et al*., 2012) and ungulate biomass has been known to influence the density of carnivores (Carbone and Gittleman, 2002). Hence, they are also more likely to consume prey in areas where they are most abundant. The fact that probability of predation of wild ungulates increases with increase in density of chital reinforces the point.

Both these sympatric felids are ambush predators which mean that they need suitable cover for successful hunting attempts. Denser canopy coverage provides a better cover which might be the reason for the increased kill rate of wild prey in such areas and declining rate in open areas. Additionally, open areas provide better visibility for the wild ungulates aiding in detection of predators and they can escape easily from

a predator. On the other hand, both tigers and leopards prefer trails and occupy rugged areas to a lesser extent (Chapter 3). The central zone of the study area has a submergence area of 65 sq. km. because of the *Totaldoh* reservoir. This area has produced a very productive grassland and bordering woodlands which also harbour abundant chital (Chapter 4). Hence majority of the predation events occurred in this area (Figure 6.1) and probability of predation was significantly lower in rugged areas. However, one point to note here that I have used secondary information from the forest department on predation events from their daily patrol logs. So, it is possible that some compartments are patrolled more than others which might introduce a bias in the results.

The model on depredation of domestic livestock show that probability of predation increased with predator density and decreased with increase in elevation and NDVI (cover density). As stated before, the core zone of PTR is devoid of any grazing pressure and density of predators is an important predictor of domestic livestock depredation (Miller, 2015). Hence, in areas of high predator density predation of domestic livestock is higher. I had followed herds of livestock to study their vigilance pattern and found no evidence of any discernible behavioural mechanism to avoid predator attacks. However, a trend was seen where domestic livestock spends less time in denser areas (Chapter 4). Dense forest provides more cover for ambush predators and the lack of ability to detect the presence of a predator by domestic livestock makes them an ‘easy prey’. As outside the core zone, abundance of wild ungulates showed a declining trend in comparison to the core zone and they are more adept at detection of the threat, domestic livestock becomes more susceptible to predation. As a smaller

number of domestic livestock is present in those areas, depredation is also less. Additionally, livestock is rarely grazed in high elevated areas. Tigers and leopards also occur less in high elevated which equates to less chances of predation as reflected in the results.

For my study, I have extensively used secondary information on predation events available from regular monitoring exercises. The identified predation hotspots once again prove the efficacy of remotely sensed data to answer such fundamental question of large carnivore ecology. Patrolling is a regular monitoring exercise in all the protected areas and systematically collected information from the field in addition to remotely sensed data can successfully identify such ecologically important hotspots. This not only helps in getting insights into the predation ecology of large carnivores but can also aid in formulating and strengthening management strategies for their conservation and reducing human-carnivore conflict. If livestock grazing is avoided in areas where probability of depredation is higher, probability of such negative interactions will also decline significantly.

Spatial risk modelling approach identifies habitat features associated with the kill site and can help predict the probability of a prey getting killed in similar habitat features. In spite of that it is impossible to identify habitat features associated with unsuccessful kill attempts or no attempts from this kind of dataset. Hence these spatial risk models reveal only a portion of the overall predation risk. Thus, it can be said that the magnitude of 'realized predation risk' is quantified from the kill sites and their associated landscape feature and the extent and features of 'fundamental predation risk' remains unmapped as it is not possible to decipher the habitat features where

unsuccessful hunting attempts may happen and come up with future predictions accordingly (Lima and Dill, 1990; Schmitz *et al*., 1997; Hebblewhite *et al*., 2005, Miller *et al*., 2015). Radio-tagged individuals and continuous monitoring of such individuals can help enumerate the 'fundamental predation risk' from unsuccessful attempts of predator and flight success of prey (Gorini *et al*., 2012). Additionally future studies can also look into the impact of presence of shepherd/herdsman on predation of domestic livestock. Presence of humans should act as a deterrent for the large predators from pouncing on the livestock which needs to be further investigated by systematic studies.

CHAPTER 7 – HUMAN DIMENSIONS OF WILDLIFE CONSERVATION: ECONOMICS OF STAYING NEAR PROTECTED AREAS AND ATTITUDE AND PERCEPTION OF LOCAL PEOPLE

7.1. Introduction

The great paradox that is human-wildlife conflict is that large carnivores in spite of being one of the most cherished animals; are the most threatened fauna owing to anthropogenic interventions (Karanth and Chellam, 2009; Dickman *et al*., 2011; Ripple *et al*., 2014). Many carnivores such as bears, wolves have been treated as teachers, helpers and are respected for their skill, cunning and strength (Lopez, 1979; Clark and Casey, 1994; Gittleman, 2001). In spite of that, these same qualities have made them inevitable competitors with and even enemies of humans (Clark *et al.,* 1999). They have also been personified as evils and 'beast of destructions' (Gittleman, 2001). "Human-wildlife conflict occurs when the needs and behavior of wildlife impact negatively on the goals of humans or when the goals of humans negatively impact the needs of wildlife. These conflicts may result when wildlife damage crops, injure or kill domestic animals, threaten or kill people" (IUCN, 2004). However, this definition of conflict poses a problem as it points to "wildlife as conscious human antagonists" (Peterson *et al*., 2010) and overlooks the human dimensions involved in it (Redpath *et al*., 2015). The definition given by Conover (2001) characterizes such interactions as adverse impacts on wildlife by humans and vice-versa.

Interactions between carnivores and people are influenced by species' allometric characteristics, energy requirements, population dynamics, hunting capability and social structure (Carbone *et al*., 1999; Cardillo *et al*., 2004). The fusion of low population density, high metabolic need and large spatial requirement,

frequently bring them into conflict with people. Such negative interactions between carnivores and people commonly result in loss of human property even lives, more often than not resulting in persecution of the 'problem animals'. Animals involved mostly lack the ability to respond rapidly to such harrying forces, leading to them becoming vulnerable and on the edge of extinction (Ripple *et al*., 2014). This anthropogenic persecution hampers their survival by disrupting their social structure, thereby disrupting the whole ecosystem equilibrium (Wallach *et al*., 2010). Absence of the dominant predators can result in an imbalanced system as the number of the smaller predators increase in this situation ['mesopredator release' (Crooks and Soulé, 1999; Ritchie and Johnson, 2009)], often resulting in decline of small carnivores as well as vulnerable and rare prey species (Prugh *et al*., 2009; Ripple *et al*., 2014). Hence conservation of large carnivores requires special attention because of the conflation of their importance in structuring the ecosystem, maintaining equilibrium and naturally prone towards extinction (Ripple *et al*., 2014).

Most of the carnivores differ in their ability to adapt to human modification of the landscape (Holmern *et al.,* 2007). Studies have shown that 75% of the extant felids are affected by conflict and the extent of the same increases with increase in the body size. The severity of this negative interaction is of great concern for the conservation of nine felid species - Caracal, Cheetah, Eurasian lynx, Jaguar, Leopard, Lion, Puma, Snow leopard and Tiger (Sillero-Zubiri and Laurenson, 2001; Karanth and Gopal, 2005; Inskip and Zimmermann, 2009). Intensification of human encroachment in terms of resource utilisation on wilderness has enhanced the human wildlife interface, leading to an admixture of co-existence and conflict. This negative interaction between

human and felids is typified by the wild animals preying on livestock or game and as a consequence persecution of the felids in retaliation or prevention (Inskip and Zimmermann, 2009).

Although both livestock depredation and attacks on human life spur human-wildlife conflict, the incidence of the former is much more frequent with sheep, cattle and goats being the majority of the attack targets. Leopards, lions and tigers are largely responsible for these attacks (Beier, 1991; Perovic and Herra´n, 1998; Quigley and Herrero, 2005; Altrichter, 2006). A 50% mortality of tigers (Miquelle *et al.,* 2005), 47% mortality of the cheetah (Marker *et al.,* 2003) and 46% mortality of the Eurasian lynx (Andre´n *et al.*, 2006) is due to retaliatory killings. Owing to their large ranging patterns, large carnivores often venture outside the protected area borders and enter human-dominated landscape. As a result, these edges become particularly severe in the conflict scenario (Woodroffe and Ginsberg, 1998).

The dynamic relationship between people and wildlife has become more susceptible to conflict since the day humans have succeeded in their role as an apex predator. In India, many of these carnivores are forced to share resources with one of the highest human densities as well as livestock population in the world (Jhala and Giles, 1991; Athreya *et al.,* 2011; Banerjee *et al.,* 2013). Carnivores preying on livestock result in major economic losses (Meriggi and Lovari, 1996; Biswas and Sankar, 2002; Mazzolli *et al.,* 2002; Bagchi *et al.*, 2004; Patterson *et al.,* 2004). India harbours the largest population of livestock with a number of 535.78 million animals, and it has gone through a 4.6% rise after the 2012 census (*20th Livestock Census*, 2018), in spite of a steady decline in the permanent pasturelands (FAO, 2004;

Madhusudan, 2004). The impact of such burgeoning population of domestic livestock is not confined to the adversities posed for carnivores. With each passing day, the wild herbivores become more and more restrained in the protected area which covers less than 5% of the total permanent land of India (Madhusudan and Karanth, 2002; Madhusudan, 2004). Three fourth of our country's protected areas are grazed by the resident livestock population (Kothari *et al.,* 1989), providing source of livelihood (Mishra *et al*., 2003). These extensive levels of grazing not only limit the resources for wild herbivores but also account for low wild herbivore density and even exclusion in those livestock grazed areas. This implies significant decline in suitable habitat for wild herbivores and an increased vulnerability to stochastic extinctions. The wild herbivores which are particularly more similar to livestock in body size and feeding ecology are even more prone to limitation of resources by livestock (Madhusudan, 2004; Dave and Jhala, 2011).

The pressing challenge of human-wildlife conflict is not only restricted to these animals, but extends much beyond, even to the grain eating rodents (Pimentel *et al*., 2005; Barlow, 2009; Dickman, 2010). Crop raiding by wild herbivores poses a significant threat for conservation of these species as it instigates a huge economic loss on the local people who live with these animals in their backyards (Naughton-Treves *et al*., 1998; Pimentel *et al.,* 2005; Perez and Pacheco, 2006; Dickman, 2010). Most of the protected areas in South Asia are situated in a matrix of human modified landscape with long "edges". The interaction between people and animals reaches its highest level at these edges owing to the animals' feeding and behavioural ecology (Madhusudan and Karanth, 2002). Damage of crops by wildlife is the most widespread

cause resulting in conflict in the tropics (Blair and Noor, 1981). The cost of these lost and damaged crops is significantly higher in developing countries because majority of the people live below the poverty level, and also because mostly people live in an agrarian society and the compensation for crop loss when practiced is negligible (Sekhar, 1998; Rao *et al.*, 2002). Agricultural crops have been well renowned to attract elephants and cause significant damage to human property and sometimes even human lives (Madhusudan and Karanth, 2002; Madhusudan, 2004). Wild pigs (*Sus scrofa*) are equally notorious for causing significant damage to agricultural crops worldwide, owing to their feeding ecology and life history traits (Kristiansson, 1985; Herreo *et al.*, 2006; Linkie *et al.*, 2007). Asia faces a bigger challenge in terms of expanding rural population and their dependencies on forested lands for agricultural uses than Africa (Achard *et al.*, 2002). Hence this increases the frequency of crop damage by these wild herbivores (Linkie *et al.*, 2007). These damages do not only include loss of crops, but also trampling, rooting and other losses to human properties (Madhusudan and Karanth, 2002; Dave and Jhala, 2011).

However, the relationships of humans with forest are not limited to conflict with wildlife only. A wide variety of ecosystem services are readily availed by the significant populations living nearby. Ecosystem services span over a long range and are of fundamental importance to human well-being, health, livelihoods, and survival (Costanza *et al.*, 1997; 2014; Millennium Ecosystem Assessment (MEA), 2005; TEEB, 2010). They are the conditions and processes within a natural ecosystem on which humans depend profusely for their survival. Their structural goal is to maintain biodiversity of the system and in turn provide ecosystem goods viz. food, fuel, timber,

pharmaceutical products to people. Harvesting and trading of these goods belong to the key components of sustaining human economy. Ecosystem services not only provide goods but also perform an assemblage of functions like water and air purification, weather control, natural waste management, agriculture as well as climate control, pivotal to survival of life and creating a platform for diverse human culture and aesthetics (Daily, 1997). Additionally, tourism can also add to these services by providing employment opportunities which in turn benefits the locals residing near forested areas. A recent study has showed that coexistence between large carnivores and the local community is feasible if a trade-off between the cost and benefits of staying near protected areas can be established. If benefits reaped from the ecosystem services compensate for the losses incurred adequately, harmonious co-occurrence between human and wild animals becomes feasible (Banerjee *et al.,* 2013).

Hence it is most pertinent to recognize this rapid change in the land use pattern and livelihoods as well as realizing the benefits and losses of local resident communities around theses protected areas to facilitate positive outcomes for sustainable conservation and development strategies in the developing countries (Terborgh and Peres, 2002; Naughton-Treves *et al.,* 2005; Shahabuddin and Rangarajan, 2007; Bruyere *et al.,* 2009; Karanth and DeFries, 2010). So, understanding the costs and benefits of people living in and around protected areas bears a great significance to achieve the goal to balance conservation aims and need of local people (Terborg and Peres, 2002; Naugton-Treves *et al.,* 2005; Shahabuddin and Rangrajan, 2007; Bruyere *et al.,* 2009; Karanth and Defries, 2010; Karanth and Nepal, 2011).

The response of the local communities to human-wildlife interaction is not only governed by the aforementioned trade-off between the cost and benefit, but also differ based on their religious reverence, customs, cultural values, actual and perceived level of these costs and the protection status of these wildlife involved (Goldman *et al.*, 2010). The outcomes of this interaction vary from local extirpation of the problem animal (Mech and Brakefield, 1991), removal to endurance (Karanth and Gopal, 2005; Athreya *et al.*, 2011) and existing in harmony (Raval, 1991; Banerjee *et al.*, 2013). Co-existence of wildlife with the resident communities is essential in present scenario, because with this ever-increasing human population and the simultaneous escalation in the demand of the resources shared with wildlife, it is becoming rather impossible to have protected areas which are free of human disturbance and large enough to hold a viable population for long-term persistence of large carnivores (Treves and Karanth, 2003; Inskip and Zimermann, 2009; Banerjee *et al.*, 2013).

For effective conservation and management planning to facilitate co-existence between wildlife and local people, their opinion about wildlife and conservation needs to be accounted for (Banerjee, 2012). There is every possibility that damages to human property, both in terms of crop and livestock and threat (actual and perceived) to humans will escalate the hostility of people towards wildlife (Treves and Karanth, 2003; Sillero-Zuberi *et al.*, 2007). The extent of local resentment gets amplified by conservation regulations that hinder the residents' capability to offset losses due to wildlife (Dickman, 2010). This augments the generation of negative attitude of people towards wildlife and conservation (Karanth *et al.*, 2013). To resolve conflicts, it is necessary to come up with a proper strategy. This requires evaluation of actual level and pattern of conflict along with the factors associated with tolerance for wildlife

(Karanth and Madhusudan, 2002; Karanth *et al.*, 2013). Even if tolerance of wildlife by local residents exists, they may undergo "food insecurity, opportunity costs and even diminished psychological well-being due to human-wildlife conflict" (Barua *et al.*, 2013), which may negatively affect their attitude towards wildlife.

Identification of causal factors of human-wildlife conflict has long been at the centre of several research initiatives. Abundance of prey, types of pastoral practices, distance from forest have been recognised as some of the major factors (Mech *et al.*, 2000; Kolowski and Holekamp, 2006; Bagchi and Mishra, 2006). Local peoples' attitude varies towards wildlife based on their dependence of the property lost as well (Bagchi and Mishra, 2006). Attitude has shifted towards positive when the residents' distance to the forest increased, because of the lack of direct negative impact (Karlsson and Sjöström, 2007). It may also vary depending upon their attitude and perception about forest and wildlife even if they are staying close to the protected area (Badola, 1998; Mehta and Kellert, 1998; Mehta and Heinen, 2001; Spiteri and Nepal, 2008a; b). So, for long term viability of these forested areas and the wild inhabitants, it is crucial to balance the trade-offs and analyse the factors which can facilitate positive attitude of people towards them (Newmark *et al.*, 2000).

In this chapter I aimed to understand the perception of people about wildlife and conservation in terms of actual loss due to human-wildlife interface and the ethics of conservation. I hypothesised that the cost: benefit ratio of the losses faced by people and benefits gained from the reserve, increases with increasing distance from the core zone. Human settlements near the core zone will suffer more losses than the settlements further away from the core as animal abundance is likely to be higher in

the core zone because of stricter management regime. However, the benefits gained in terms of employment opportunities, access to natural resources and compensation received for livestock depredation will also be more for them, than the people staying further away. I also hypothesised that the knowledge of local people about wild animals will be impacted by their duration of stay in the area, their level of education and extent of interaction with the animals. As the cost incurred by local people because of these negative interactions increases, they will tend to be more negative towards management strategies and conservation of wildlife.

7.2. Methods

7.2.1. Field methods

Pench Tiger Reserve is surrounded by dense human population and the population resides in 98 villages surrounding the protected area (Figure 7.1). Initially a pilot survey was carried out in 10 different villages; chosen from a gradient of distance from the core zone of the reserve to get acquainted with the existing farming and pastoral practices of the study area. Based on their responses, a close-ended questionnaire (Lavrakas, 2008) was created. The survey was conducted in 15 villages keeping the distance from the core zone in mind. A total of 213 respondents were interviewed from these 15 villages. Number of respondents from each village was selected on the basis of the total residents of the village. I tried to gather responses from both gender and all age classes to get a representative sample.

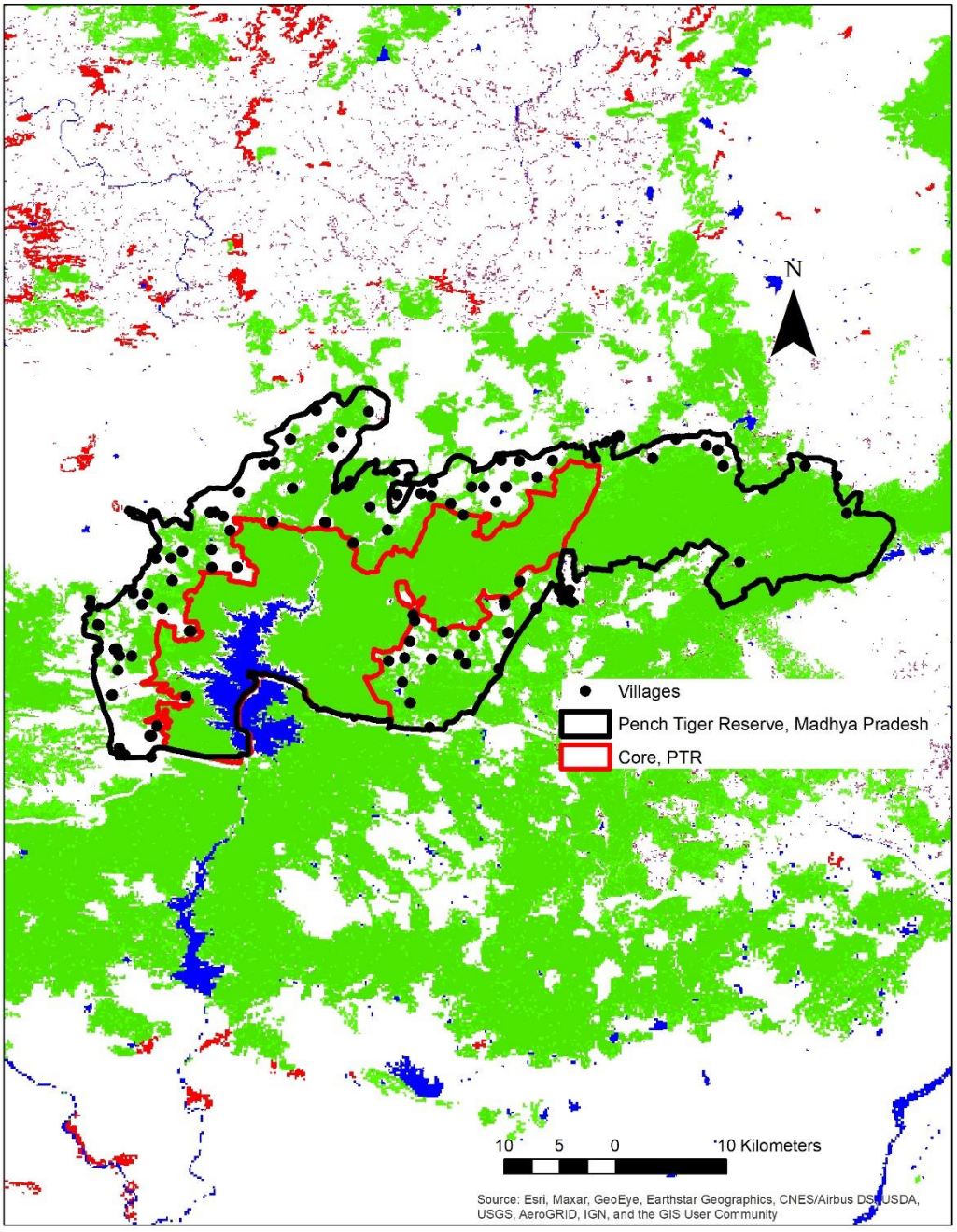

Figure 7.1: Distribution of 98 Villages surrounding the core area of Pench Tiger Reserve, Madhya Pradesh

i. *Economics of staying near protected areas*

These surveys were carried out to get an initial estimate the loss incurred and crop loss due to crop raiding ungulates, to evaluate the losses incurred by the farmers.

I asked them if they ever lost an animal(s) to any predator in the last 5 years and the market price of such lost animal(s). I also asked if they were aware of the compensation scheme of the forest department for animals lost to depredation in and around the village. If yes, they were enquired on the amount received. They were also questioned on quantity of total and productive agricultural lands, type of crops grown and expected yield of the crop to compare with the amount they said they got in hand after harvesting. Benefits were assigned depending on the income opportunities availed from the department, cost of fuel wood and fodder gathered from the forest and the amount of compensation received**.**

This data was cross-validated by using information on depredated livestock from the forest department from people who have applied for compensation. The economic value of the predated livestock was assigned in accordance with average prevalent market rate. After tallying it with the current compensation scheme provided by the Madhya Pradesh State Forest Department and the proportion of predation events claimed for compensation from the Government, I estimated the loss incurred by the local residents due to livestock depredation. Information was collected on the market price of the crop to estimate the monetary value of crop loss. Market prices were also gathered on values of fuel wood and fodder to estimate the monetary value of benefits received from the natural resources by locals.

ii. ***Attitude and perception of local people***

These survey responses were also used to look into the extent of tolerance of local people towards wildlife and their perception about co-existence, human-wildlife interaction and conservation. This survey aimed at understanding their knowledge on wild animals by using several pictures of these animals and their identification skills.

The respondents were also asked to rank existing management and conservation practices and their daily challenges. All the responses were recorded in a quantitative manner. They were shown a series of 6 hand-drawn images to gauge their perception on co-existing with wildlife in their backyards. These pictures included scenarios including only agricultural field, agricultural field with domestic livestock, access to fuel wood in addition to having agricultural fields and domestic livestock, presence of wild ungulates in the backyards along with agricultural fields, presence of carnivores in the neighbourhood along with domestic livestock in their agricultural field and all of these scenarios put together in a single frame. They were asked to rank these photographs on where they would prefer to stay to quantify their willingness to co-exist with wildlife.

7.2.2. Analytical methods

i. Economics of staying near protected areas

I looked at the monetary value of both cost and benefit to calculate the same. The actual value of cost incurred by the locales was calculated by taking into account the price of the lost livestock and/or crops as per the present market values. It was then compared with the perceived loss by the respondent by corresponding with the said value of the lost property. Similarly, the value of benefits obtained from the ecosystem was estimated using the present market value of fuel wood, fodder and NTFPs and cross-validated with the interviewees' responses. For cross-validation, I used the market prices and the responses received from each interviewee. The validation factor was calculated by dividing the market price by the respondents said value. I multiplied the responses by this validation factor to scale the responses. After that I calculated the net loss by subtracting the monetary value of benefit from that of the cost received. Then the ratio between cost and benefit was calculated.

I also examined if any of these responses changed with change in the respondent's distance from the core area changed. For this I divided the responses into five classes based on their distance from the boundary of the core zone. Then I plotted the responses against these categories to examine the changes. Kruskal-Walis test statistics (Kruskal and Walis, 1952) were used to compare to assess the effects of predictor variables on cost, benefit, net gain and cost: benefit ratio. Next, I used a combination of both categorical (e.g., economic status, educational status, social standing) and continuous variables (e.g., Distance form core) in a generalized linear models (GLM) framework with a Gaussian error distribution to model the responses *i.e.* cost incurred, benefit received, net gain and cost: benefit ratio. Best models were selected based on the lowest AIC values (Burnham and Anderson, 2002). All the analyses were carried out using Rcommander (Rcmdr) and ggplot2 packages in R version 4.3.1 (R development core team 2015).

ii. Attitude and perception of local people

To get an understanding of the attitude and perception of local people towards wildlife, existing management practices and conservation status, all the responses were transformed into likert-scale where 1 represents strongly disagree and 5 represents strongly agree. The value of the response on the scale corresponded with higher inclination of the response. Next, the positive responses (agree and agree strongly) as well as the negative responses (disagree and disagree strongly) were clubbed together for ease of analysis. I further grouped these statements in 4 categories – Knowledge, Perception, Attitude towards wildlife and conservation and attitude towards management strategies. Identification of animals was in knowledge category and what

needs to be done for animals were in perception category. Details of same are given in the Annexure.

I wanted to check the impact of different socio-economic variables (e.g., Age, Gender, Educational status, Caste, Economic Status, Land holding) on their knowledge and perception of wildlife as well as their attitude towards conservation and management strategies. I categorized continuous variables like distance from the core to use Kruskal-Walis test statistics (Kruskal and Walis, 1952) to discern these impacts. Significant predictors were then used to model the dependence of the ordinal response variables (perception and attitude) using an ordinal regression framework (Agresti, 2003). All analyses were carried out in MASS package in software R.

7.3. Results

7.3.1. Economics of staying near protected areas

Average annual cost incurred varied from INR 33665.78 (±SE 6809.96) in the farthest distance class (villages more than 10 km away from the boundary of the core zone of PTR) to INR 65852.89 (± SE 17094.82) in the 4th distance class (5 – 10 kms away from the boundary of the core zone (Table 7.1, Figure 7.2). Average annual benefit ranged from INR 17265.51 (± SE 4115.4) in the 4th distance class to INR 36253.15 (± SE 2922.81) in the farthest distance class (Table 7.1, Figure 7.3). Net loss decreased in the 2nd distance class in comparison with the 1st distance class and then increased in the 3rd and 4th distance class. Benefit received as more than the cost incurred only in the 5th distance class (Table 7.1, Figure 7.4). Cost: Benefit ratio as highest in the 4th distance class (5.4 ± SE 3.01) and lowest in the 5th distance class (1.17 ± SE 0.24) (Table 7.1, Figure 7.5). Cost: Benefit ratio also did not show any significant change with change in distance from the boundary of the core zone.

Distance class	Average annual cost	SE - annual cost (±)	Average annual benefit	SE - annual benefit (±)	Average Net Loss	SE - Net loss (±)	Average Cost: Benefit	SE Cost : Benefit (±)
1	51890.76	9411.05	24988.22	3359.35	26339.14	10000.74	3.29	0.95
2	39313.00	7187.11	27438.63	3365.05	10933.58	8197.513	3.95	1.24
3	68515.55	11020.34	35086.73	5473.85	31479.39	12181.18	3.01	0.64
4	65852.89	17094.82	17265.51	4115.40	48438.61	16798.4	5.40	3.01
5	33665.78	6809.96	36253.15	2922.81	-3136.28	7368.272	1.17	0.24

Table 7.1: Average annual cost incurred, benefit received, net loss and cost: benefit ratio in each distance class around the core zone of PTR, MP. Distance classes are based on distance from the boundary of the core zone (Class 1: 0-1 km from the core, Class 2: 1-2 kms from the core, Class 3: 2-5 kms from the core, Class 4: 5-10 kms from the core, Class 5: more than 10 kms from the core).

Benefit received varied with variation in proportion of productive land (productive land: total land) (Kruskal-Wallis chi-squared = 27.632, df = 17, p-value = 0.049), number of earning members in a family (Kruskal-Wallis chi-squared = 20.783, df = 6, p-value = 0.002) and distance class (Kruskal-Wallis chi-squared = 22.898, df = 4, p-value = 0.0001). Variation in net loss changed significantly in different distance class (Kruskal-Wallis chi-squared = 27.796, df = 17, p-value = 0.047). Cost: benefit ratio varied significantly as per changes in economic status (Kruskal-Wallis chi-squared = 27.796, df = 17, p-value = 0.04737). Mean annual cost did not show any significant change with changes in predictor variable ($p>0.05$).

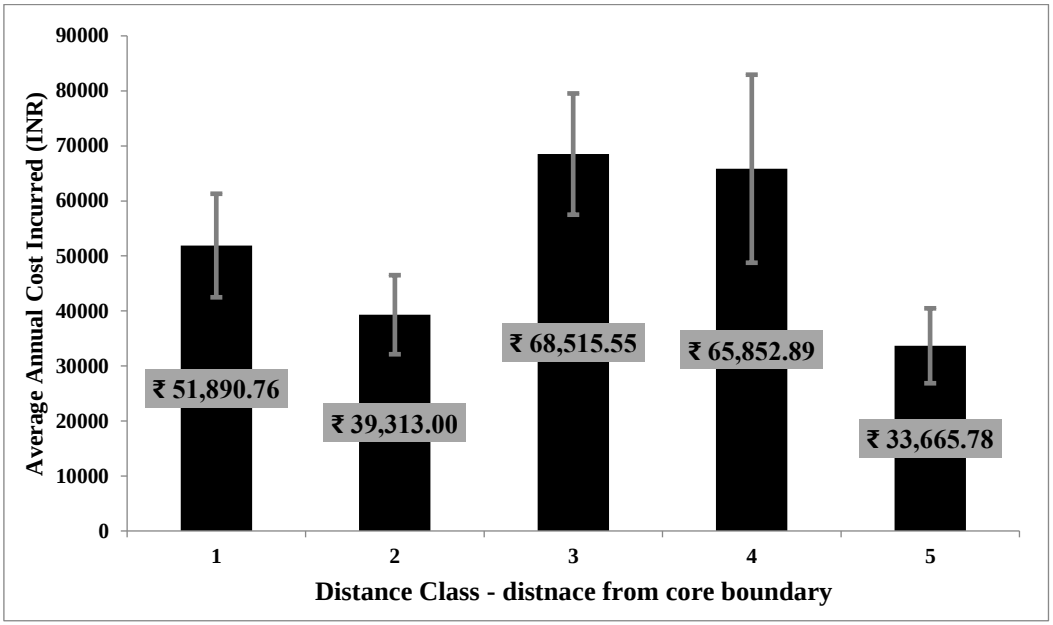

Figure 7.2: Changes in average annual cost incurred (INR) along the gradient of distance from the boundary of the core zone of the study area in 2016

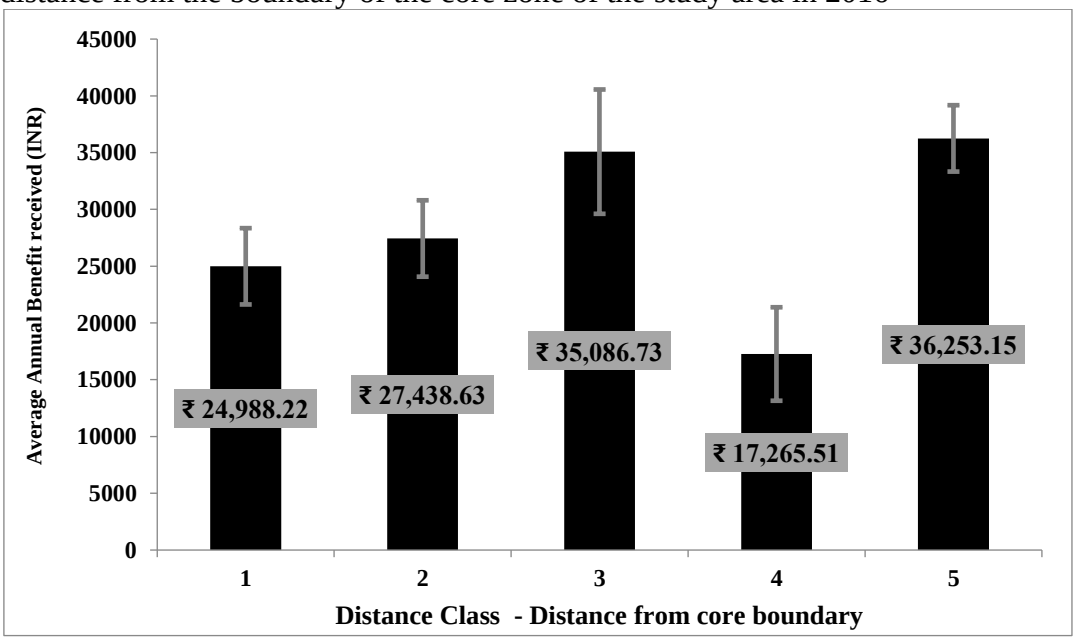

Figure 7.3: Changes in average annual benefit received (INR) along the gradient of distance from the boundary of the core zone of the study area in 2016

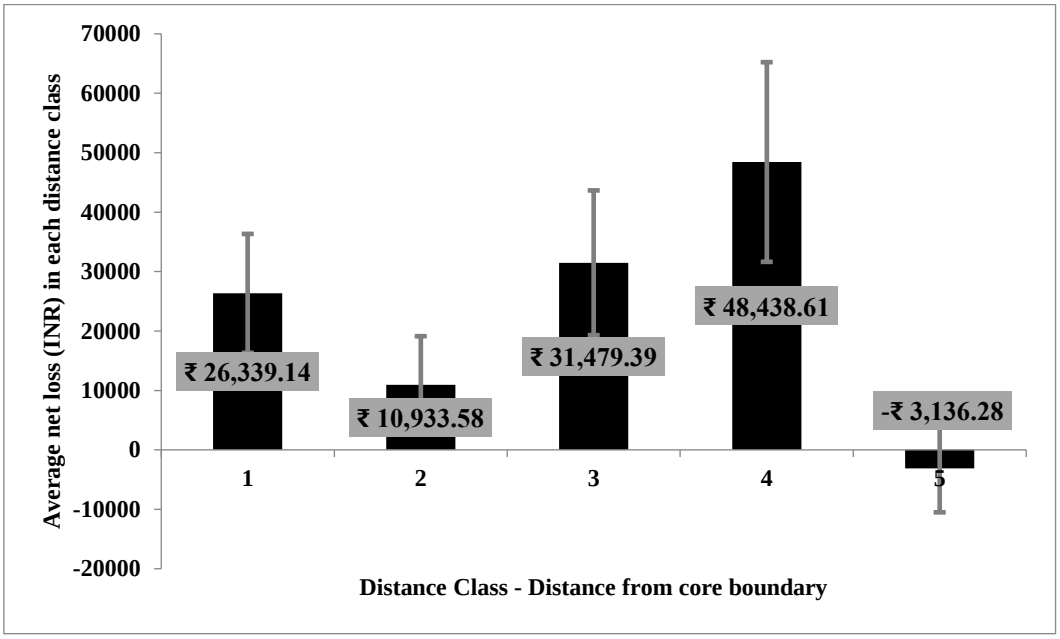

Figure 7.4: Changes in average annual net loss (INR) along the gradient of distance from the boundary of the core zone of the study area in 2016

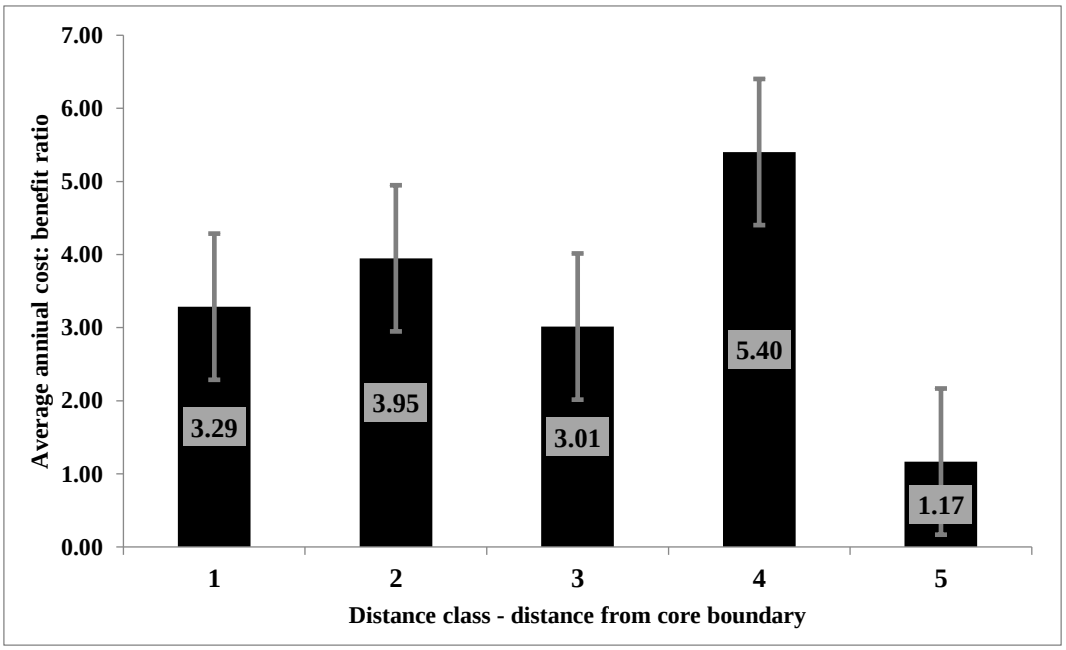

Figure 7.5: Changes in average annual cost: benefit ratio along the gradient of distance from the boundary of the core zone of the study area in 2016

None of the predictor variables had any significant impact on the cost incurred by people. The generalised linear model showed that the predicted values of mean annual benefit increased significantly if the respondent as dependent of NTFPs and increase in productive land. Being a member of the local governing body (*panchayat*) resulted in significant decline in the value of benefit (Table 7.2, Figure 7.6 a, b, c).

Parameters	Estimate	Standard Error	t value	Pr(>|t|)
Intercept	18076.1	7339.0	2.463	0.0146*
NTFP collector	9110.0	4044.8	2.252	0.0254*
Panchayat Member	-9702.8	4915.5	-1.974	0.0497*
Productive Land	1862.9	850.4	2.191	0.0296*
Distance Class	2666.9	1406.4	1.896	0.0593
Amount of land	-2709.5	3830.5	-0.707	0.48
Occupation – agriculture	-387.3	6716.9	-0.058	0.95

Table 7.2: Variables influencing annual benefit received from the forest by local people are collection of NTFP, amount of productive land and being a member of the local governing body (Panchayat). Distance class also had a comparatively significant effect on the same.

The best GLM model for net loss increased slightly with an increase in forest cover values (Table 7.3, Figure 7.7). No other variable had any effect on the net loss. The same for cost: benefit ratio demonstrated that increase in duration of stay decreased the cost: benefit ratio significantly (Table 7.4, Figure 7.8).

Parameters	Estimate	Standard Error	t value	Pr(>|t|)
(Intercept)	24817	7000	3.54	0.0005***
Forest Cover	4564	2548	1.791	0.075·
Distance	-1348	1201	-1.123	0.263

Table 7.3: Variables influencing net loss incurred by people staying near the study area is forest cover to some extent

Parameters	**Estimate**	**Standard Error**	**t-value**	**Pr(>|t|)**
(Intercept)	8.1088	2.9829	2.718	0.007
Stay duration	-1.818	0.9205	-1.975	0.05
Distance Class	-0.4659	0.3612	-1.29	0.20
Forest Cover	0.3295	0.2545	1.295	0.20
Panchayat Member	-2.0119	1.2438	-1.618	0.11

Table 7.4: Variable influencing cost: benefit ratio of staying near protected area of local people is duration of stay in the areas.

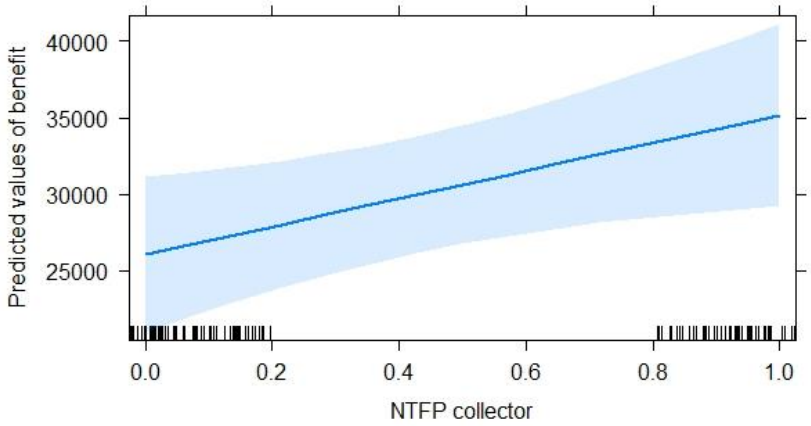

Figure 7.6a: Effect plot of GLM to illustrate increase in average annual benefit with increase in NTFP collecting occupation

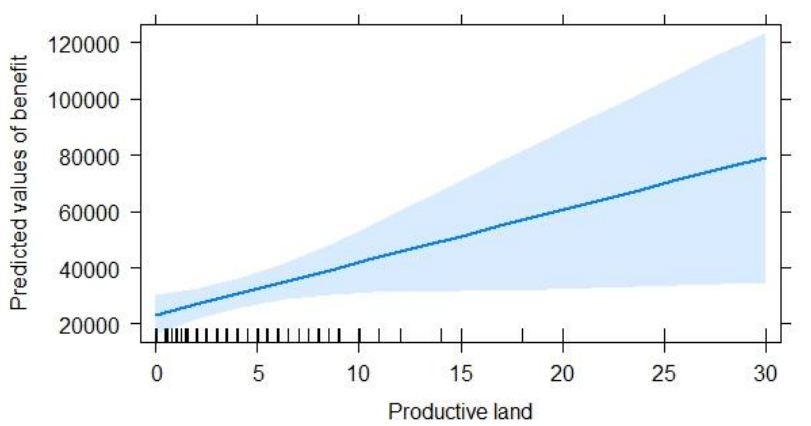

Figure 7.6b: Effect plot of GLM to illustrate increase in average annual benefit with increase in productive land

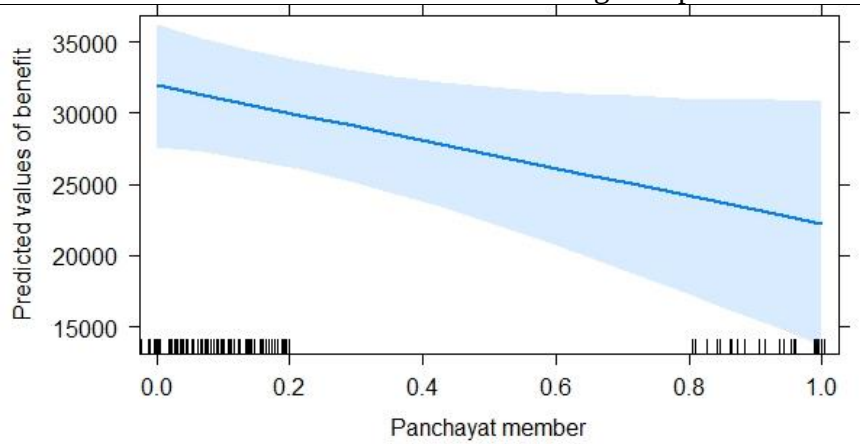

Figure 7.6c: Effect plot of GLM to illustrate decrease in average annual benefit ith being a member of the local governing body

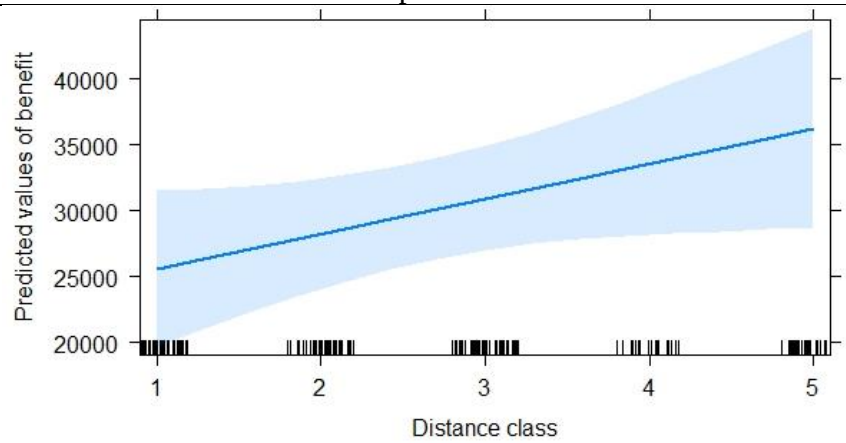

Figure 7.6d: Effect plot of GLM to illustarte increase in average annual benefit ith increase from distance from the core boundary

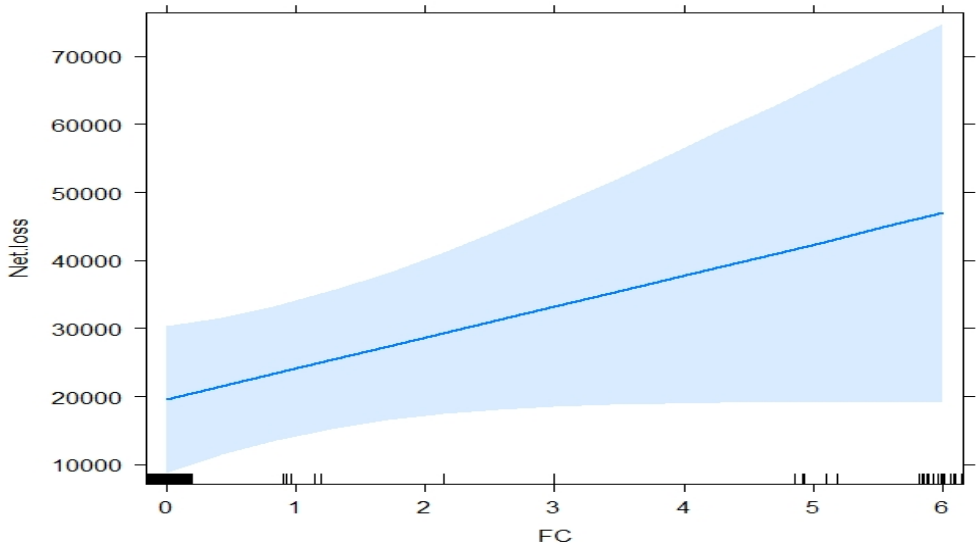

Figure 7.7: Effect plot of GLM to illustrate increase in net loss with increase in forest cover

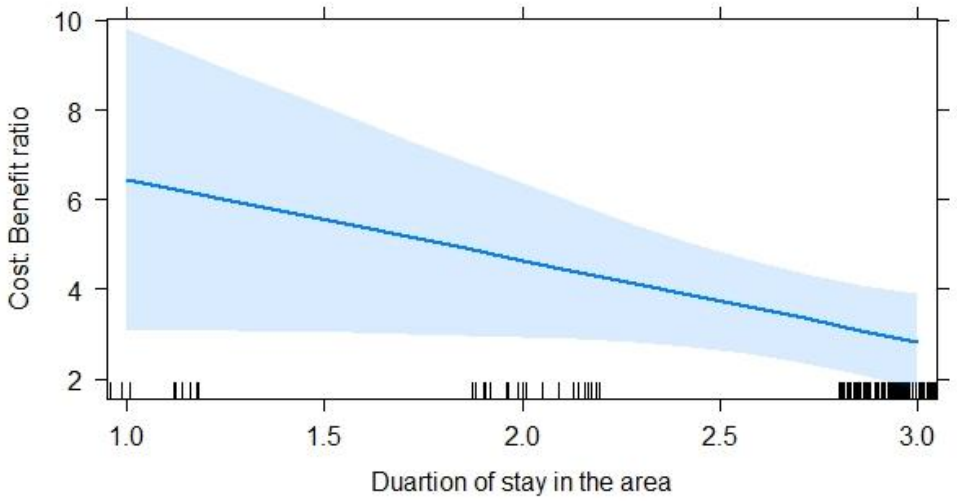

Figure 7.8: Effect plot of GLM to illustrate decrease in cost: benefit ratio with increase in duration of stay in the area

7.3.2. Knowledge, attitude and perception of local people

i. Knowledge of the respondents

Ninety six percent of the local residents could successfully identify tigers followed by more than 80% positive identification of sloth bears, wild dogs and leopards. The rate of positive response was also high for ruddy mongoose and grey mongooses. However, the same declined for smaller carnivores namely jungle cat, jackal and grey Indian wolves which are of common occurrence in the study area. No respondent could positively identify caracal and more than 95% of the respondents identified them as hare (Figure 7.9).

More than 95% of the respondents positively identified common langur, rhesus macaque and gaur. The rate of identification was more than 75% for chital and wild pigs. Yet, the same declined for other ungulates where they got confused between sambar and barasingha. Positive identification of antelopes was also near about 10% (Figure 7.10). More than 80% of the respondents answered about the prey preference of large carnivores and habitat correctly (Figure 7.11). Approximately 80% of the respondents agreed that carnivores and other wildlife are an important part of the forest and their presence designate a healthy environment (Figure 7.12). None of the predictor variables (e.g., age, gender, caste, economic status, education) had an impact on the knowledge of the respondents (Kruskal-Walis statistic, $p>0.05$).

ii. Perception of the respondents

When the respondents were asked to rate their attitude towards several carnivores and wildlife as a whole the average response was positive for most of the carnivores except for wolves. Almost 70% of the respondents mentioned that they dislike wolves (Figure 7.13). Seventy three percent respondents agreed that carnivores

attack livestock without any prior intention and almost 48% said that they prefer feeding on livestock even when ample wild prey is available because of their lack of vigilance behavioural mechanism (Figure 7.14). Almost half of them disagreed that wild ungulates raid crops owing to unavailability of feeding materials inside the forest. I got equal responses when asked whether human-wildlife interactions can only be negative (Figure 7.14).

Eighty one percent of the respondents said that both number of ungulates and crop raiding by them has increased significantly over the years. Sixty eight percentage perceive that the number of carnivores has also gone up over the same time period (Figure 7.15, 7.16). More than 50% of the respondents observed that such increase is because hunting has been prohibited and the animals are well protected inside the reserve. Approximately 40% of the respondents think that livestock depredation has also seen a steady upraise in the last 5 years (Figure 7.15).

Perception varied significantly if the respondent as a member of the local governance i.e., *panchayat* (Kruskal-Wallis chi-squared = 4.3249, df = 1, p-value = 0.038) and with variation in the number of earning members in a family (Kruskal-Wallis chi-squared = 11.139, df = 4, p-value = 0.025). Land owners too tended to perceive these statements differently than people who had no land of their own (Kruskal-Wallis chi-squared = 3.8075, df = 1, p-value = 0.051).

iii. *Attitude towards wildlife and conservation*

Almost 70% of the respondents agreed that all wild animals should be protected, though 20% of the respondents also think that authorities should grant them the permission to hunt wild ungulates without any limitation. Similar proportion of respondents also think that these 'problem animals' should be translocated

elsewhere (Figure 7.17). Seventy two percent of the respondents perceived that putting up fencing can reduce the extent of livestock depredation as well crop raiding. Proper compensation for both crops and livestock were also suggested as a way to offset their losses. Thirty one percent of the respondents chose only field and a house as a preferred place to stay followed by a scenario here house, livestock, field and access to fuel wood is seen. None of the respondents chose the scenario here wild ungulates were present in their backyard as a preferred place to stay (Figure 7.18).

The caste of the respondent had an impact on their respective attitude towards wildlife and conservation (Kruskal-Wallis chi-squared = 6.4838, df = 2, p-value = 0.039). No other predictor variable like age, education, duration of staying in the area, economic status had any significant impact on the attitude of the respondents regarding wildlife and their conservation. However, the educational status of the respondent and the cost incurred by them significantly influenced their choice of the preferred place to stay (Kruskal-Wallis chi-squared = 16.993, df = 4, p-value = 0.002(education) and Kruskal-Wallis chi-squared = 12.103, df = 5, p-value = 0.0334 (cost)).

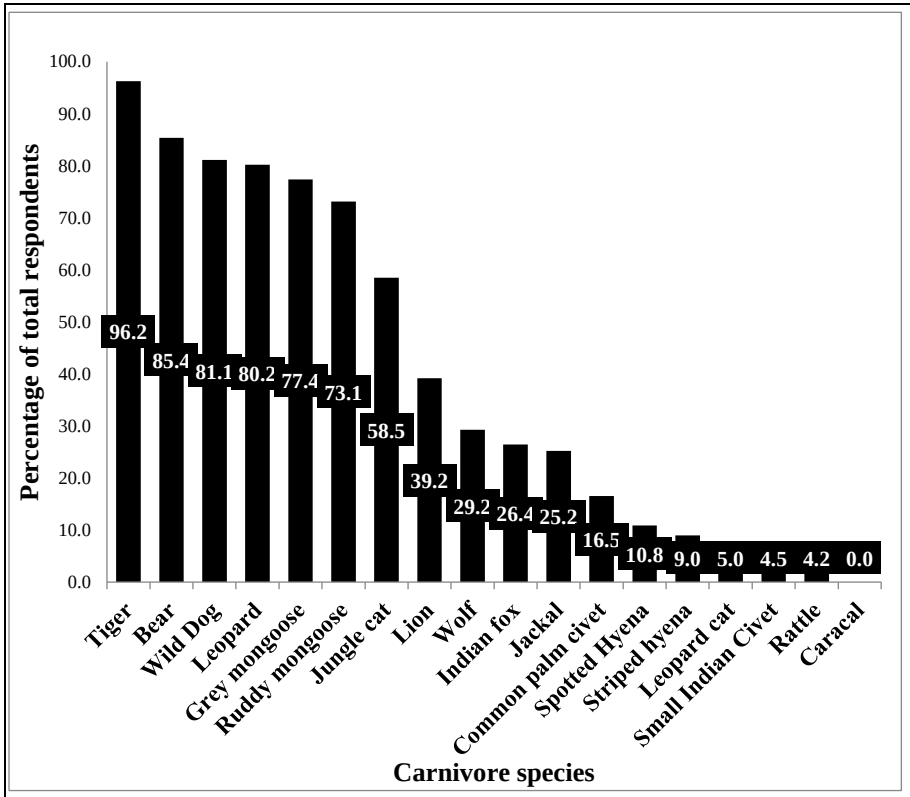

Figure 7.9: Diagrammatic representation of positive identification of pictures of carnivores by the respondents

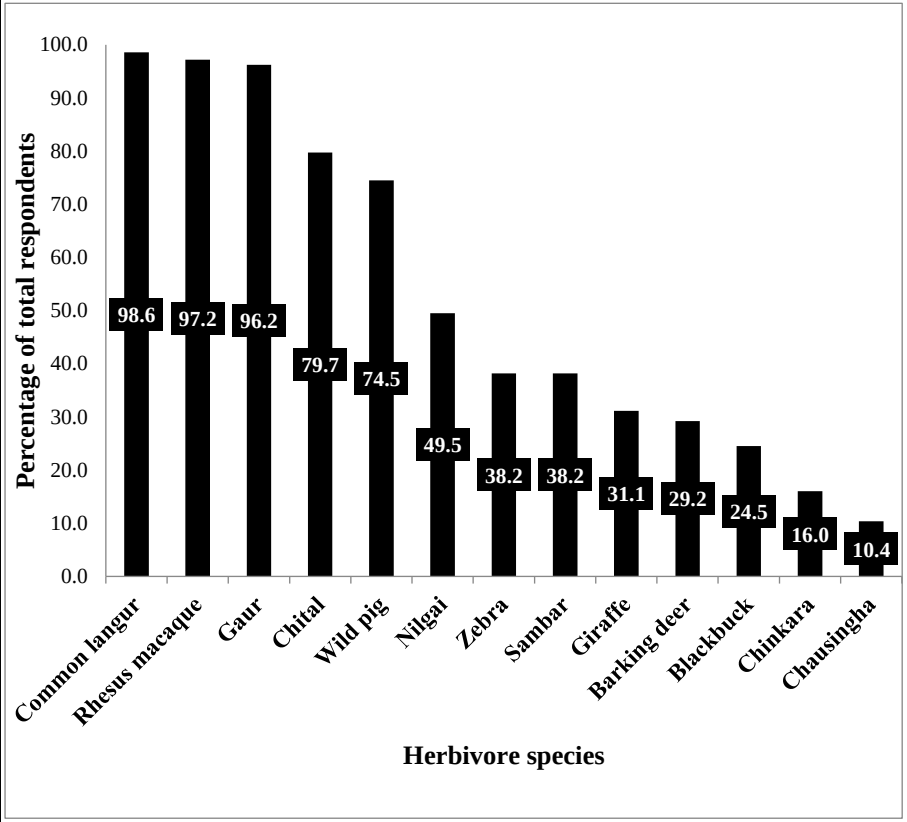

Figure 7.10: Diagrammatic representation of positive identification of pictures of herbivores by the respondents

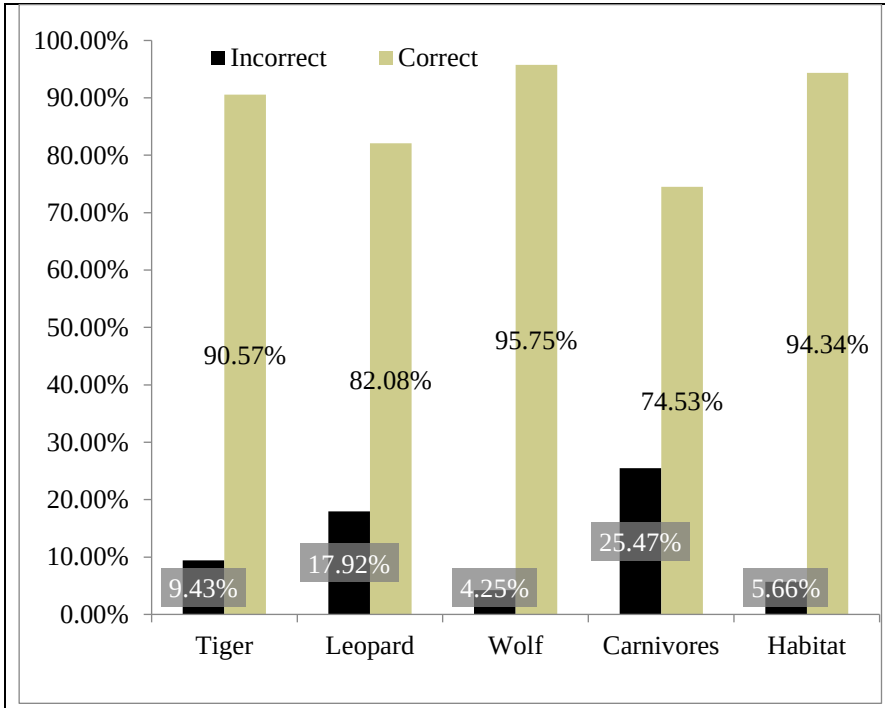

Figure 7.11: Diagrammatic representation of knowledge on the prey choice and habitat selection by large carnivores of the respondents

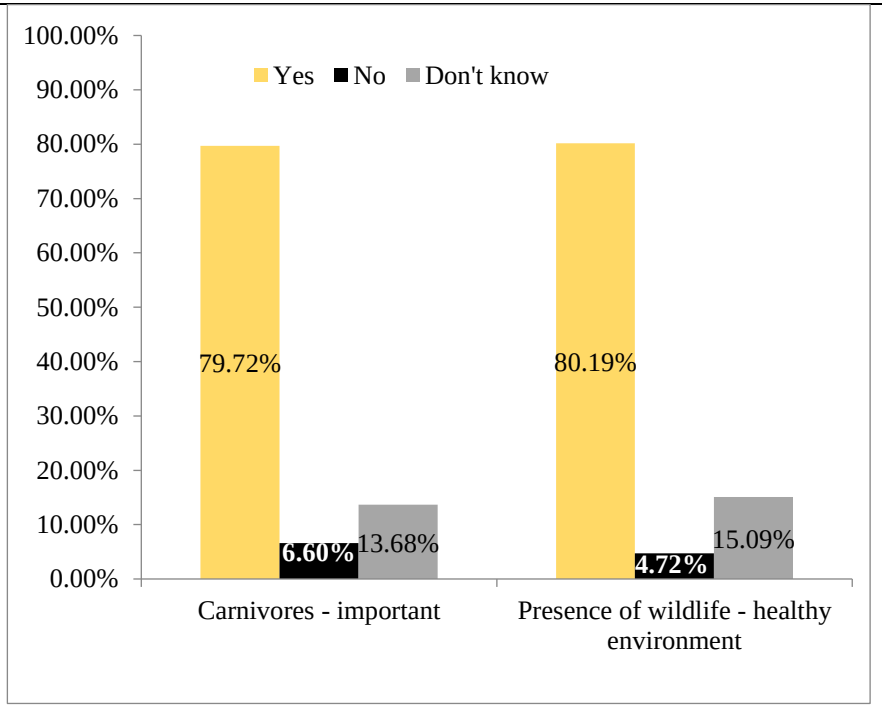

Figure 7.12: Diagrammatic representation of respondents knowledge on importance of wildlife around the study area

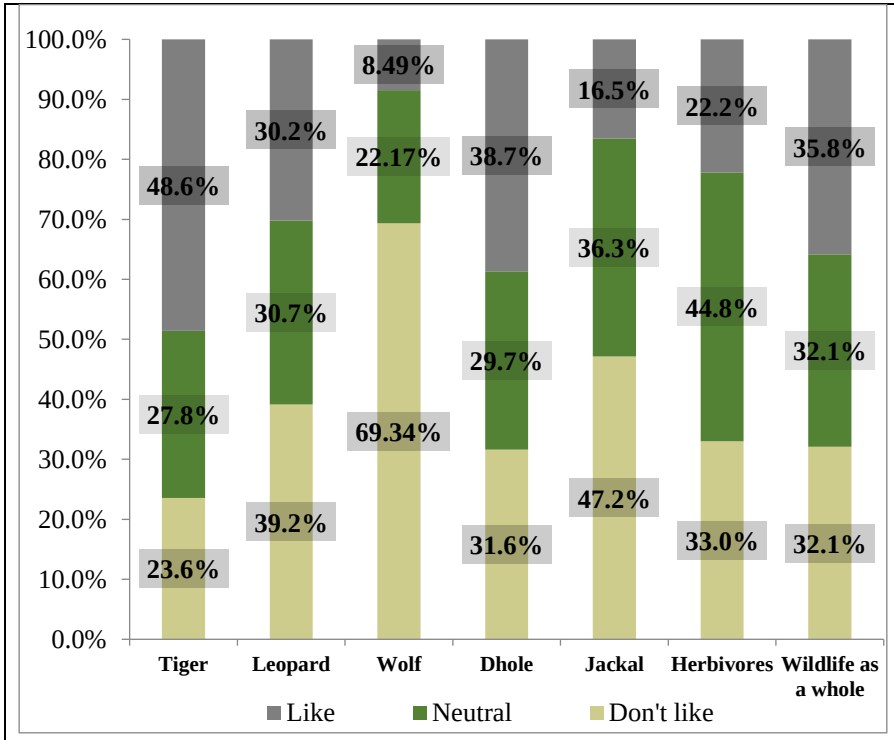

Figure 7.13: Perception of the respondents towards different animals around the study area

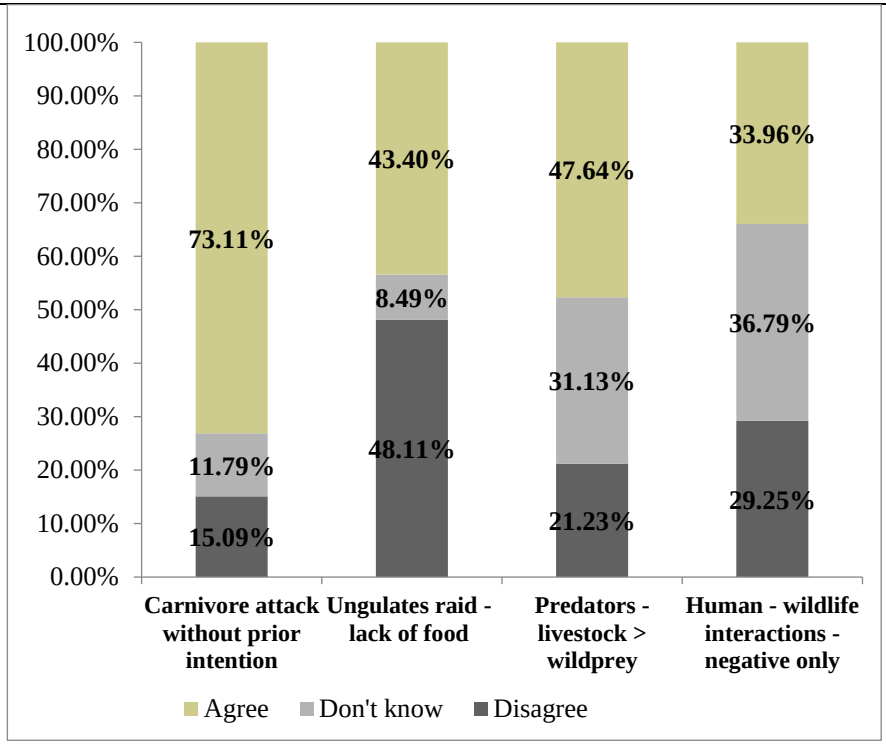

Figure 7.14: Perception of local residents about wildlife and their habits in the study area

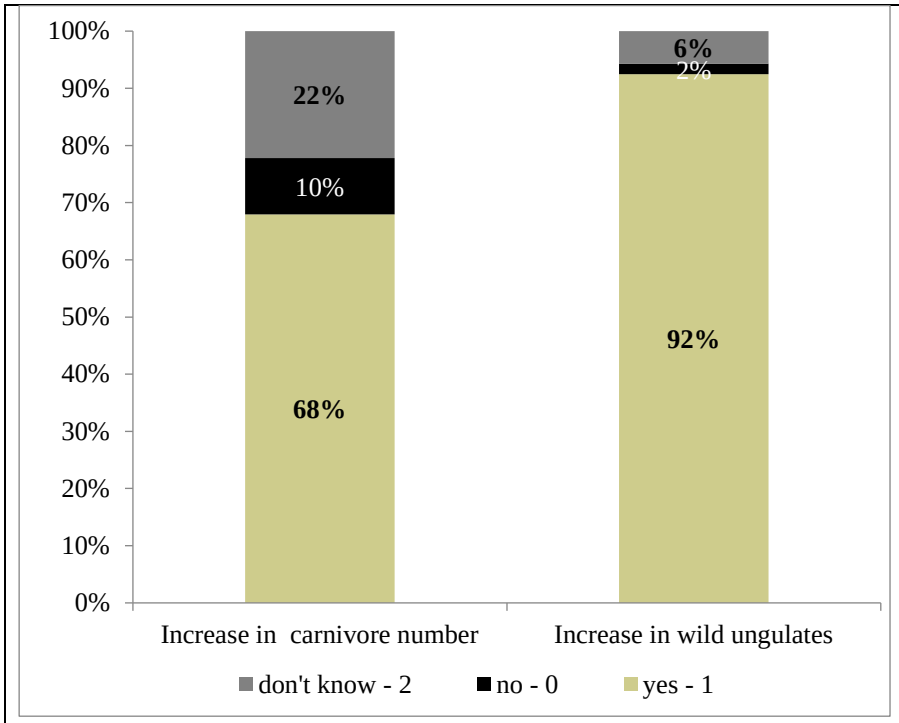

Figure 7.15: Diagrammatic representation of the respondents perception about change in the number of carnivores and wild ungulates in the reserve

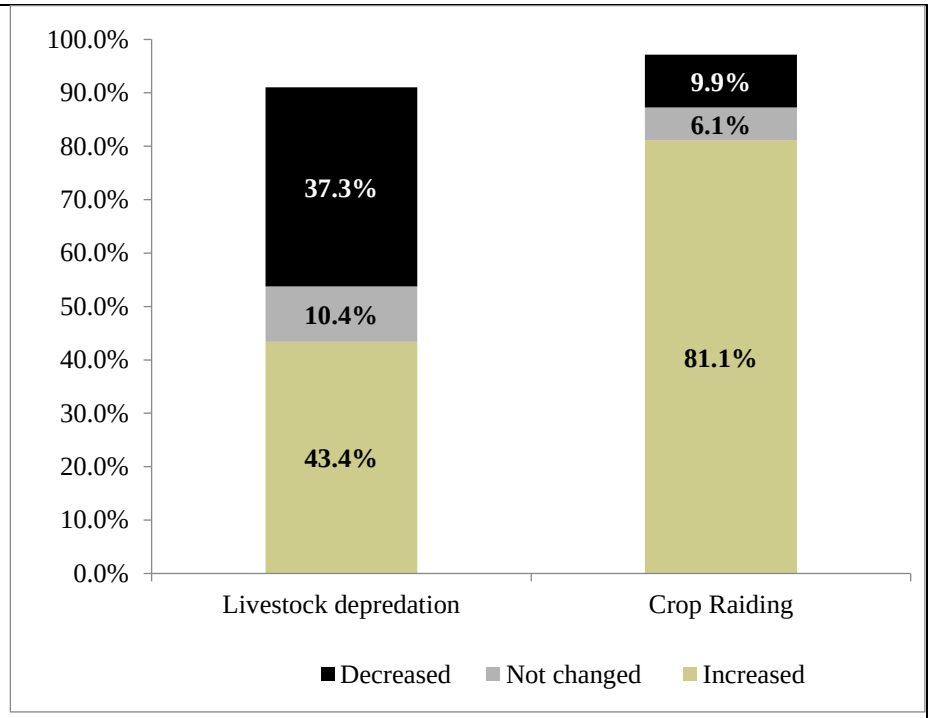

Figure 7.16: Diagrammatic representation of the perception of respondents on change in livestock depredation by wild carnivores and crop raiding by wild ungulates around PTR, MP

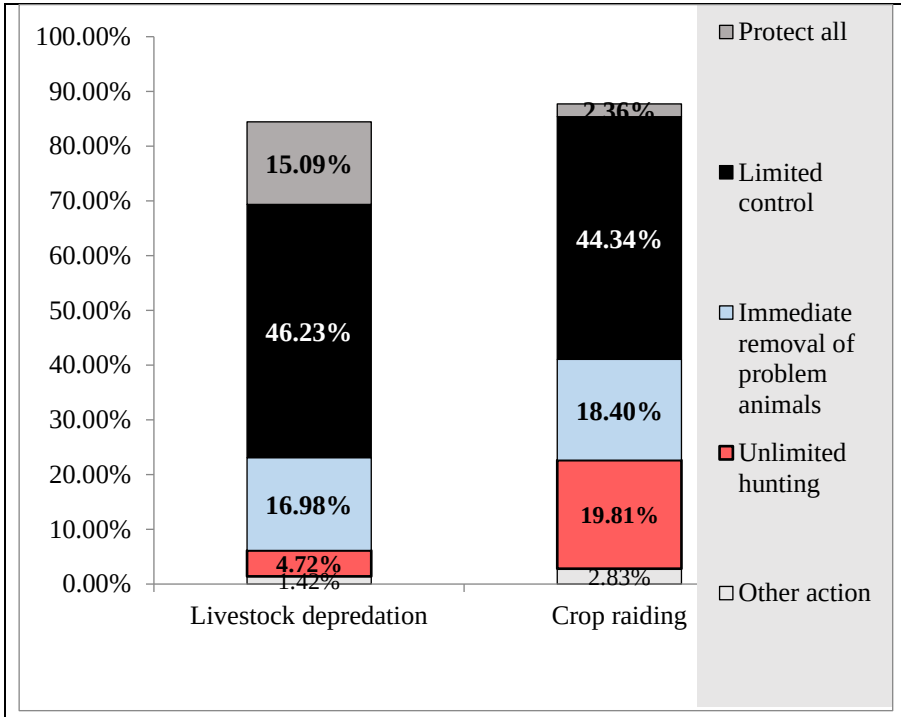

Figure 7.17: Graphical representation of peoples attitude on best action against 'problem animals' (both large carnivores and wild ungulates) around PTR, MP

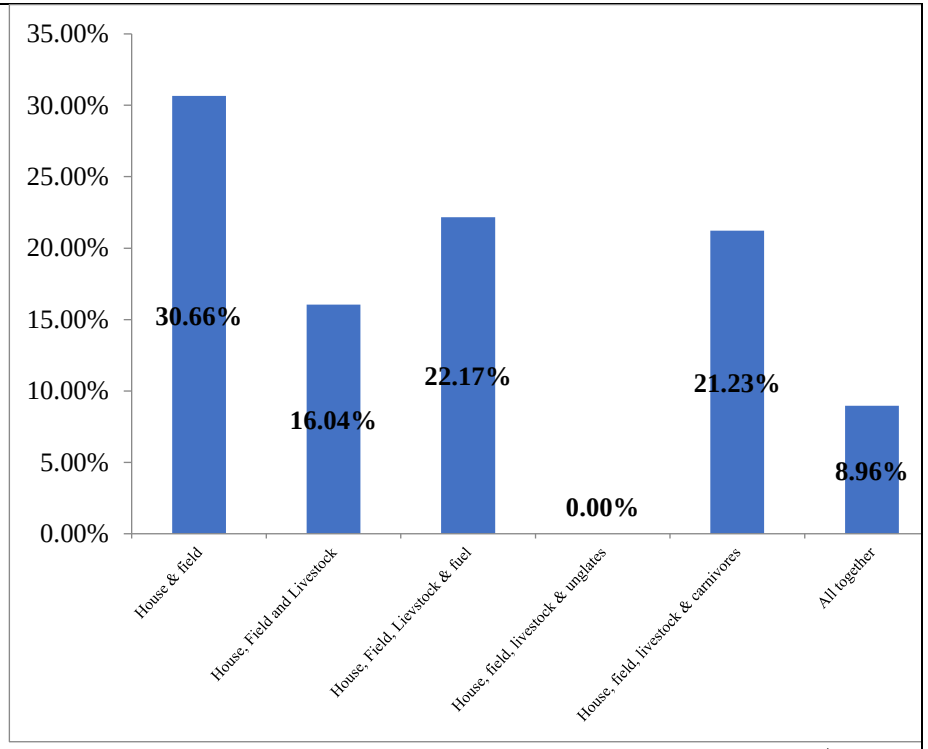

Figure 7.18: Graphical representation of a preferred scenario (1st choice) selected by the respondents around PTR, MP

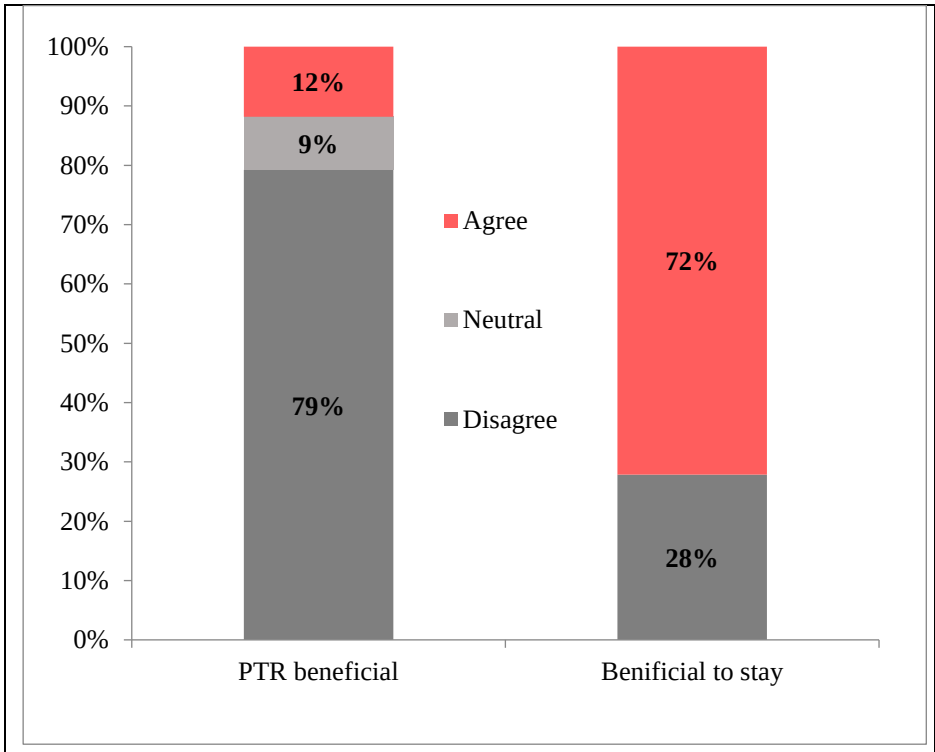

Figure 7.19: Diagrammatic representation of the respondents' attitude towards management strategies around PTR, MP

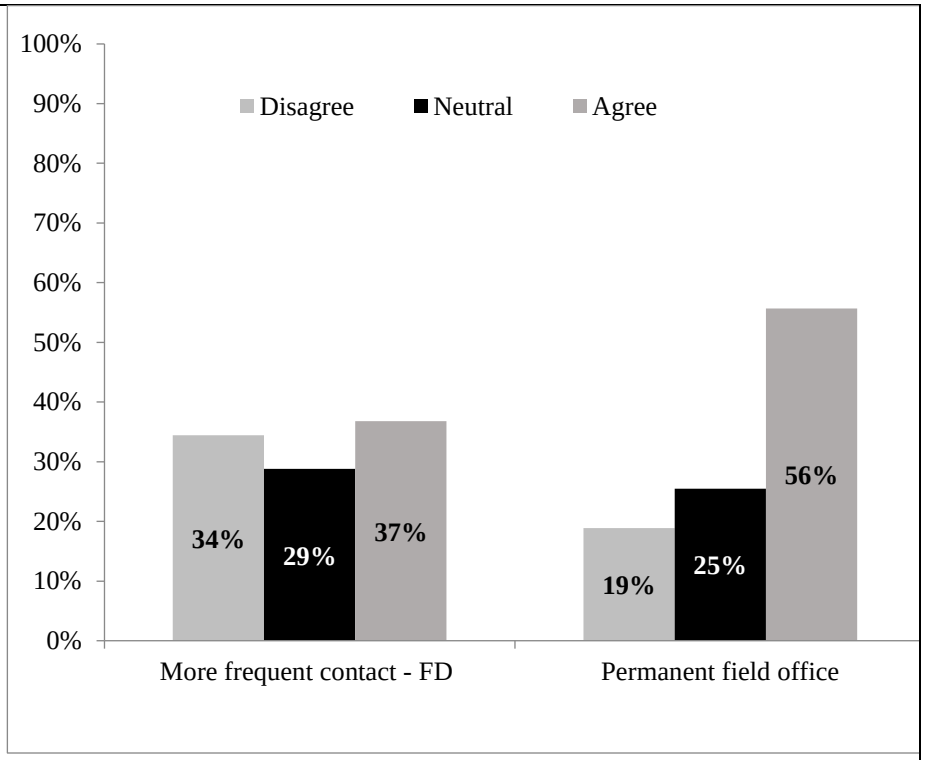

Figure 7.20: Diagrammatic representation of peoples attitude towards more frequent contact with the local forest department around PTR, MP

iv. *Attitude towards management strategies*

Most of the local residents (79%) also said the formation of protected area was not at all beneficial for them. Some respondents said that they received some employment opportunities and loss incurred has reduced and other facilities like bio-cooking fuel, infrastructure, and drinking water have been provided. Mostly people said that they receive no benefit and their right to the forest has been curbed additionally. Still, 73% of the interviewees responded that it is beneficial for them to stay near PTR in spite of all the troubles faced (Figure 7.19). People who think that it is beneficial for them to stay near the reserve think so mostly because it is their ancestral place and over the years they have established here. On the other hand, of the respondents with the opposite school of thought; 75% said they will shift if similar quality of agricultural field becomes available as the losses incurred are extensive. They also said they will be willing to be translocated provided proper compensation becomes available. More than half of the respondents thought a permanent field office in the area might be a good thing as it might help them pursue their paperwork to receive the compensation easier. On the other hand, same enthusiasm was absent when asked if more frequent contact with the staff of the local forest department would be warranted (Figure 7.20). Of all the predictor variables, being a member of the local eco-development committee (EDC) had an impact on their attitude towards the management strategies (Kruskal-Wallis chi-squared = 4.5751, df = 1, p-value = 0.032). Economic status also had a slight impact on the same (Kruskal-Wallis chi-squared = 5.9413, df = 2, p-value = 0.051).

7.4. Discussion

Human-wildlife conflict is very a common phenomenon globally and the involvement of large charismatic species is also frequent (Peterson *et al*., 2010; Redpath *et al*., 2015). Detailed knowledge on such types of interactions is essential to come up with an effective solution for animals and people to co-exist harmoniously (Linell *et al*., 2010; Redpath *et al*., 2013; 2015). I have tried to examine the nature of such interactions around Pench Tiger Reserve where tigers, leopards and wild ungulates are abundant. The human population surrounding the reserve is also dense which set the perfect stage for conducting this study.

Importance of protected areas (PAs) in saving threatened populations of wild animals has been well established. However, large-bodied animals are mostly wide-ranging and often venture beyond the boundaries of these PAs. This in turn leads to loss of human property and lives. Hence, in spite of being a cornerstone for conservation (Woodroffe and Ginsburg, 1998; Terborgh *et al*., 2002), these PAs have been heavily criticised for their "undemocratic imposition of a societal goal on local people" (Treves, 2008). In a lot of cases, local people have turned hostile towards these animals and end up retaliating. Addressing these hostilities is of paramount importance as retaliation can severely endanger the goal of conservation by reducing the target population critically. Even if regulations are enforced to stop such actions, it often results in people resenting the animals they are forced to coexist with (Madden, 2004; Woodroffe *et al*., 2005; Bhatia *et al*., 2020). Usually, such negative interactions between people and wild animals are categorised as human-wildlife conflict. Although, this can create a damaging effect on people's perception of risk from the animals they co-exist with (Gore and Kahler, 2012, Bhatia *et al*., 2020). In order to

ameliorate and mitigate the effects of such interactions which impact both wildlife and humans, detailed knowledge on local as well as broad geographical scale is necessary.

7.4.1. Economics of staying near protected areas

I observed that mean annual monetary value of cost incurred by the people living around PTR is above INR 30,000 and can go up to INR 70,000. Majority of the locals staying around the study area hail from 'Gond' tribe and more than 20% of the respondents had no to little land. The quantity of land was mostly 1-3 acre for approximately 70% of the respondents of agricultural land owners. The monetary value of benefits received from the natural resources of the forested areas in term of fuel wood, fodder and other NTFPs could seldom establish a trade-off. Except for the settlements which were more than 10 km away from the boundary of the core zone, the cost incurred was higher than the benefits received.

I did not find any significant relationship between any of the predictor variables and the cost incurred. The central Indian tiger landscape is highly fragmented and patches of sparse forest are abundant all over. PTR is a part of the Kanha-Achanakmar-Pench metapopulation (Jhala *et al*., 2020) and functional connectivity exists among these reserves. Hence, movement of large carnivores through these patches is common and they also harbour sustainable prey population to maintain the functionality. So, even though people are not adjacent to the core zone of PTR, presence of animals in their surrounding patches is regular. Even if tigers are not abundant in such patches, leopards are seen to thrive well near to human habitation in the study area (Chapter – 3). Opportunistic sighting, local people as well the latest camera trap images (Jhala *et al*., 2020) confirmed presence of wolves in these areas. Both of these predators have been known to predate on domestic livestock for their survival. Consequently, the

losses incurred because of wildlife do not decline as we move away from the core zone of PTR.

Additionally, the forest of central India is patchy in most areas and wild ungulates like wild pigs, nilgai even chital are widespread throughout this area and frequent crop fields for food. In fact, the cost sustained because of crop raiding is significantly higher than that because of lost domestic livestock. As per the existing policy, if an animal is preyed upon by carnivores (tigers and leopards), the owner gets compensated by the forest department. On the other hand, crop losses due to wild ungulates are mostly not paid for. Existing policies of the local administration does not specify which department should pay for the loss of crop. On top of that, the extent of crop loss should be at least 25% of the total yield owing to wild ungulates to avail such compensation. None of the interviewees has ever received any such compensation for crops. Approximately 50% of the respondents mentioned that they have stopped cultivating wheat from the fear of the extensive loss because of wild ungulates. This response was frequent in all the distance categories.

My model for predicted values of benefit also showed that collection of NTFPs and quantity of productive land increased it significantly. Dependence on natural resources for fuel and fodder does offset the cost sustained by the local people. NTFPs like tendu (*Diospyros melanoxylon*) leaves, mahua (*Madhuca indica*) flowers help them earn livelihood. Increase in fertile land also increases the yield of the crop which can be beneficial. However, being a member of the local governing body can reduce their natural resource dependence which might be the reason for the decline in benefits. The model also showed a slender relationship with increase in distance from the core

boundary. Although crop loss due to wild ungulates is similar across all distance categories, loss of domestic livestock is less. This probably gets reflected in the predicted values of benefits availed.

I also calculated the net loss suffered by each respondent in the study area. The best model illustrates that increase in forest cover result in the increase of losses incurred. If an area has more forested patches than other, abundance of animals will also be higher. Presence of animals in turn results in more loss from both livestock and crop which is reflected in the results.

The best model for calculated cost: benefit ratio shows that was lower for people who stayed in the area for generations. As one stays in an area for a long time, they become more familiar with the surrounding and adapt to the situation. Some people have changed their cropping pattern e.g., not cultivating wheat/paddy any longer, some have learnt the best way to deter an animal from entering the crop field. People who have stayed there for generations also know the best areas to graze their livestock in areas where risk of predation might be lower. Some have also shifted to only stall feeding the livestock and the fodder can be collected from either their own crop fields and/or the buffer zone. The combined effect of all these factors is the probable reason for observing such patterns.

7.4.2. Knowledge, attitude and perception of local people

Knowledge of the local residents was high for both identifying wild fauna and about their habitat. The low positive identification of wolves is noteworthy here. A major proportion of the interviewees said that they suffer from loss of livestock because of wolves and the lack of compensation makes them hostile. However, the

question remains that if one cannot identify an animal properly, how can they be convinced that the animals were killed by wolves. It also might be because of the age-old misunderstanding of the animal where they have been child-lifters and personified as evil.

I did not find any significant relationship between distance from the core zone, age, gender and education and the extent of knowledge on wild animals. Even respondents who work with the local forest department did not score higher on the knowledge section. I had expected regular interactions with animals to increase their knowledge. However, my results did not show any such trend.

Education has the power to shape people's attitude by using cognitive learning (Eagly and Chaiken, 1993; Kellert *et al*., 1996). Studies have observed that higher knowledge has been able to induce positive attitude towards a species (Kellert *et al*., 1985; Bath and Buchanan, 1989; Ericsson and Heberlein, 2003; Balčiauskas *et al*., 2010). In light of conservation of a species such positive relationships are important. Initial knowledge very often leads to further digging which in turn helps deal with age-old myths and misconceptions. However, our education system rarely emphasises on practical knowledge and most curriculums ignore environmental studies. As learning from our surroundings has never been imbibed by our teachers who have the principal role in shaping a child's mind, it goes unnoticed. Even living with these animals in their backyards does not automatically entail interest in them. Lack of interest ultimately leads to ignorance and less idea about their ecology. Targeted awareness and sensitisation programmes to educate the local can be pivotal for a better understanding of their relationship with wildlife.

The fact that lack of proper knowledge can lead to misleading perception of an animal can be seen in my data. Seventy percent of the respondents said that they dislike wolves with or without ever coming face to face with the animal. Rural societies are pretty close-knit and news travels from one place to another. A number of respondents said that they have heard about wolves, civets lifting livestock from their pens in some other village and the owner was never compensated. In spite of not facing any direct loss, the perceived loss makes them hostile towards an animal. Approximately half of the respondents perceive human-wildlife interactions to be only negative. Lack of awareness, knowledge and exposure might lead to such attitude in these people. Additionally, people who live in these rural societies stay in close proximity of these animals. Urban people who usually romanticise and marvel at their aesthetics, rarely deal with them in their backyards. Hence being safe in their respective places without facing any kind of loss allows them the privilege to worry about saving wildlife. Locals who struggle to survive and get their livelihood impact majorly owing to these incidents can rarely afford to glorify their coexistence.

Change in perception of wildlife of people from different economic background as seen in my data as well. Families whose income were higher because of a greater number of bread-earners and had their own lands, perceived conservation of wildlife differently than the economically weaker families. Land owners suffer extensive loss because of the wild ungulates which in turn makes them hostile towards them. Whereas landless people depend on other sources for their livelihood and the extent of loss is much less which probably makes them more tolerant. Similarly, a greater number of earning members in a family implies diversity in their livelihood options and less

dependence on agriculture and natural resource extraction. Additionally, the income generated for the whole family is also higher. If mean income increases, the ability to cope with loss of property also increases; this ultimately leads to a more positive perception of wild animals.

Even though change in perception is individualistic, attitude towards an issue is usually formed by the collective beliefs in the rural close-knit communities. Dependence on natural resource for livelihood is common in many forests and protected areas across India. Although in an ideal situation, proper zones should exist for wildlife conservation which is devoid of human presence (Linell *et al*., 2012), it is difficult to have such areas in a densely populated country like ours. Hence coexistence between wildlife and people becomes an integral part of conservation in such cases (Woodroffe *et al*., 2005; 2014; Jhala *et al*., 2020). Coexistence of 500 Asiatic lions and people in a human dominated landscape matrix has proved that such scenarios can become feasible with proper incentives (Banerjee *et al*., 2013; Jhala *et al*., 2019). However, historically formation of protected areas in India has either been synonymous with forceful eviction with minimal compensation and/or similar alternative livelihood options or sudden enforcement of strict policies (Wani and Kothari, 2007). They have rarely been involved in the decision-making process which further alienated them from the process of conservation. The extensive loss of property, lack of proper compensation and grievances towards the local authorities drove their attitude towards wild animals and their conservation to a negative side. Submission of hunting rifles and ripping them of their right to the forest for daily needs made them further estranged from the whole process. This is seen in the responses

when they answered that the increase in abundance of the wild ungulates is because of the prohibition of hunting. However, these misgivings have not forced them to retaliate by killing such 'problem animals' extensively. Even though they suffer economically, they do not want these animals to stop existing. Most of the respondents think that all animals should be protected irrespective of the damage they may cause. They just want these animals to not enter their field and eat their livestock. Even a compensation for both livestock and crops in accordance with the market price can tilt their attitude to a more positive angle.

Such attitude is majorly influenced by their cultural and religious beliefs. This is also reflected in the results as caste of the respondent was a predictor of their attitude towards wild animals. Majority of the deities worshipped by the locals are rooted in nature and her animals. One of their major festivals is around a deity based on tigers. They also depend on natural resources like branches, logs and leaves of *Syzigium* spp., *Terminalia elliptica, Boswellia serrata, Trigonostemon rufescens* for both religious and social celebrations. Ancient civilizations and their gods have extensively been interlinked with nature and this further illustrated the bond these people share with nature. Sharing their living space with wild animals has been their age-old tradition. So, the hostility towards conservation is directed more towards the authorities than the animals itself. This is further illustrated in the section which was focussed at understanding their attitude towards the existing management strategies.

Majority of the locals perceived the formation of PA as detrimental to their wellbeing. The benefits received in terms of employment opportunities, cooking fuel and infrastructure reached an insignificant proportion of the total population. Nearly everyone said that their loss of crop has gone up in the last five years and formation of

the PA as principally responsible for the same. They mentioned that the PA has protected the animals by enforcing the policies. A number of respondents thought that the increase in the abundance of the wild animals is because of animals being translocated from other forested areas to PTR. Huge economic loss and lack of proper incentives is mainly responsible for their negative attitude towards the existing policies. People who got the compensation for their lost livestock complained the amount to be much less than the market price. They also said even if the sanctioned amount is much higher, existing corruption resulted in them getting a miniscule amount. Even though the majority said that they preferred to live in the area as it is their ancestral home, when faced with the coexistence question, very few chose the picture representing the present situation where they live with large carnivores and wild ungulates. The handful of respondents who wanted to move out of the area wanted incentivized relocation with access to better resources like schools and hospitals. Use of modern technology to dispense the compensation directly to the affected party, inclusion of the locals in the decision-making process and sharing of revenue can ameliorate such negative attitude and ultimately aid in conservation.

CHAPTER – 8: CONCLUSIONS

Ecosystem structure is significantly influenced by mammalian carnivores and has long piqued the interest of ecologists. Inferences can be made about the health and conservation status of the ecosystem by monitoring the demography and the distribution of the predator guild as they act as flagship species in majority of the terrestrial ecosystems (Linnell and Strand, 2000; Durant *et al*., 2010; Harihar *et al*., 2011; Kumar *et al*., 2019). Being at the topmost level of a trophic chain, large carnivores can mediate the structuring of the ecosystem by resource exploitation and top-down effects (Terborgh and Estes, 2010; Ripple *et al*., 2014; Hoeks *et al*., 2020). In case of a multi-predator system, it is also necessary to investigate the effects of competitive interaction between two sympatric predators to get a holistic idea. Interspecific interactions not only impact the overall fitness of the species involved but also determine the function and structure of ecological communities and manoeuvre fundamental evolutionary processes (MCreel, 2001; Caro and Stoner, 2003; Durant *et al.*, 2010; Miller *et al.*, 2018). Present situation of large scale of decline of large carnivores warrants detailed understanding of such interactions across their geographical range to formulate effective conservation strategies (Cardillo *et al*., 2004; Estes *et al*., 2011; Ripple *et al*., 2014; Wilman *et al*., 2014, Di Minin *et al*., 2016).

Interactions between tigers and leopards are perfectly suited to study such patterns as leopards are sympatric with tigers across their range of occurrence in Asia and their mechanism of co-occurrence vary from differential prey selection (Karanth and Sunquist, 1995; 2000; Harihar *et al*., 2011, Ramesh *et al*., 2012), spatial segregation (Odden *et al*., 2010; Harihar *et al*., 2011, Rayan and Linkie, 2016) to temporal segregation (Ramesh *et al*., 2012, Carter *et al*., 2015, Yang *et al*., 2018) and

utilising areas of low tiger occurrence to increase their chances of survival (Kumar *et al*., 2019). Tiger-leopard interactions in the study area is ideal to understand such mechanisms as it is part of one the largest (Jhala *et al*., 2020; 2021) and most genetically diverse (Dutta *et al*., 2013; Kolipakam *et al*., 2019; Jhala *et al*., 2020) populations in India. Additionally, the diet overlap of these two sympatric predators in PTR is approximately 90% with chital as the principal prey species (Majumder *et al*., 2012) which makes the probability of exploitative interference competition in the predator guild even more likely (Creel and Creel, 1996; Hayward *et al*., 2006).

My results showed that the estimated spatially explicit densities of tigers and leopards remained stable over the years. This lack of variation over the years indicates stability in the population (Odden *et al*., 2010; Mitchell *et al*., 2012, Carter *et al*., 2015). I used the equation developed by Jhala *et al*. (2020) to estimate carrying capacity of tigers based on prey density and found that the carrying capacity of PTR varies between 6.96 and 8.86 tigers per 100 sq. km. My findings and the latest estimates of tiger and leopard densities in the area point towards the large carnivores attaining carrying capacity here. I also observed clear spatial segregation between these two predators. Photographic captures of leopards were higher near the peripheral edges where captures of tigers were lower. This realized capture pattern showcases the intensive usage of areas by leopards which are less frequented by tigers. Both Odden *et al*. (2010) and Harihar *et al*. (2011) report similar findings from Bardia National Park, Nepal and Rajaji National Park, India respectively where leopards are pushed towards the edges as a result of interference interaction with tigers. The relative avoidance of human-dominated areas by tigers probably created a 'competition refuge'

(Odden *et al*., 2010) for leopards near the peripheral areas. Even inside the park they use areas within the tiger ranges which are less frequented by tigers to avoid them spatially. Such type of avoidance mechanism allows leopard to coexist with tigers with overlapping diet (Majumder *et al*., 2012) in spite of having 1/4th body weight of a tiger. My results proved that leopards choose to be adaptive in presence of tigers. PTR has one of the highest prey densities in India. Such high prey densities also contribute to their coexistence.

In addition to spatial and prey partitioning, sympatric predators also adapt temporal partitioning to coexist (Steinmetz *et al*., 2013; Sunarto *et al*., 2015; Yang *et al*., 2018). Tigers and leopards do not segregate on the temporal niche in PTR. Their activity pattern coincides with that of their principal prey species. Energy availability of predators depends maximally on the prey density, spatial and temporal distribution (Sunquist and Sunquist, 1989). As leopards are already restricted to sub-optimal habitats to avoid tigers, they need to utilise the available resource to ensure survival as predator density is influenced by prey biomass to a great extent (Carbone and Gittleman, 2002).

Besides prey density, cover density; elevation and ruggedness were seen to be the determining factors of predation hotspots. Being ambush predators, cover is needed for hunting opportunities for both tigers and leopards. That is the same reason domestic livestock might be avoiding dense forested areas as it is a surrogate of presence of these predators. The low rate of depredation of domestic livestock in comparison to other areas might be because of such high abundance of wild ungulates. If the livestock grazers use the areas less frequented by tigers and leopards and the identified predation

hotspots of domestic livestock, rate of depredation will remain on the lower side and the cost incurred because of such losses will also be less.

Leopards, lions and tigers have been known to attack cattle worldwide which results in huge economic losses (Beier, 1991; Perovic and Herra´n, 1998; Quigley and Herrero, 2005; Altrichter, 2006). These kind of negative interactions between carnivores and people sometimes result in persecution of the 'problem animals' (Marker *et al*., 2003, Miquelle *et al*., 2005, Andre´n *et al*., 2006). Negative interactions between people and wildlife are not restricted to carnivores only in PTR. Crop raiding by wild ungulates very often results in huge economic losses. In fact, the cost incurred from lost crop is significantly higher than that of loss of livestock. Lack of availability of compensation for crop loss contributes to that greatly. People who have stayed in the area for longer duration, adapted to it by stopping cultivation of crops which attract more wild ungulates. This extensive economic loss has made them hostile towards the ungulates and the local authorities. Almost 20% of the respondents wanted unlimited hunting opportunities of ungulates to curb crop loss. Restriction of their access to natural resources has aggravated their hostility even further. Such antagonism has ultimately resulted in them resenting the conservation initiatives. Involvement of local people in decision-making process along with profit-sharing mechanism can help attain a harmonious co-existence between people and wildlife. Education can shape one's attitude and perception to a great extent. So, targeted awareness and outreach program can also help in obliterating the misleading ideas of different species which will in turn be beneficial for the goal of conservation.

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ANNEXURE

S.No.	Statement	Group
1	Attitude towards animals in pictures	Attitude towards wildlife and conservation
2	All wild animals should be protected	
3	Action against "problem livestock predators"	
4	Action against crop Raiders	
5	Actions to be taken against problem animals (both livestock and crop raiders)	
6	Folklore on wildlife	
7	Use of forest produce for cultural/religious/social purposes	
8	Pench Tiger Reserve is beneficial for community	Attitude towards management strategies
9	Types of benefits received from PTR	
10	Beneficial to stay near in spite of all the problems	
11	More frequent contact with the wildlife staff would be desirable	
12	A permanent wildlife field office in the park would be a good thing	
13	Usual meetings with the forest department staff	
14	Do you think the compensation provided the forest department is satisfactory	
15	Suggestions for solving issues	
16	Co-existence	Co-existence
17	Identification of carnivores	Knowledge
18	Identification of herbivores	
19	Carnivores and wild animals are an important part of the forest	
20	Presence of carnivores and other wild animals designate a healthy environment	
21.	Carnivores attack people and their property without any prior intention	Perception
22	Ungulated raid crops because of the lack of availability of food inside	
23	The predators prefer feeding on livestock even when ample wild prey is available	
24	The term human-wildlife interaction only implies negative expression	
25	Change in the number of livestock predators in the last 5 years	
26	Change in the amount of crop raiding over the last 5 years	
27	Number of carnivores increased in past 5 years	
28	Number of ungulates increased in past 5 years	

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Acceptance Letter

Manuscript No.: 29182
Authors: Anindita Bidisha Chatterjee, Kalyansudaram Sankar and Qamar Qureshi
Title: Density and Distribution of Principal Prey Species of Tigers and Leopards in Pench Tiger Reserve, Madhya Pradesh

Dear Anindita Bidisha Chatterjee, Kalyansudaram Sankar and Qamar Qureshi,

The Editorial Team of **Journal of Ecophysiology and Occupational Health (JEOH)** is pleased to inform you that your manuscript **"Density and Distribution of Principal Prey Species of Tigers and Leopards in Pench Tiger Reserve, Madhya Pradesh."** has been accepted. The article is scheduled to be published in upcoming issue 2022.

Thank you for your submission.

Best Regards,

Editorial Team

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Density and Distribution of Principal Prey Species of Tigers and Leopards in Pench Tiger Reserve, Madhya Pradesh

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Abstract

Conservation of large carnivores is dependent on a viable population of their principal prey species. Line transect based density estimation has been established as a robust method for monitoring prey population trend. Chital (*Axis axis*) and sambar (*Rusa unicolor*) are the major ungulates in Pench tiger reserve, Madhya Pradesh that are principal tiger and leopard prey. Estimated densities using line transect surveys were highest for chital in the study area with a range of 44–52 individuals per sq. km. from 2013–16. Sambar density remained stable ranging from 5–8 individuals per sq. km. over the three years (2013–16). Camera trap-based encounter rate was used to calculate the relative abundance index of the principal prey species of tigers and leopards in the study area. Spatial distribution pattern using the relative abundance index showed that 47.16% chital captures were congregated near the submergence area whereas 38.53% sambar captures were near rugged areas. Abundant resources and lack of competition from domestic livestock in the core zone contribute to such high estimates of prey population in the study area.

Keywords: Camera Trap Based Encounter Rate, Chital, Line-transect Based Density, Relative Abundance Index, Sambar

1. Introduction

The importance of large herbivores comprising of primates and ungulates with a body weight of more than or equal to 5 kilograms has been well documented in ecological studies. They can influence forest structure, composition, productivity of the ecosystem, soil composition and succession in a tropical ecosystem to a significant extent[1,2]. More importantly they form majority of the prey base of large carnivore diet worldwide[3–6]. Hence, in the face of the global challenge of declining large carnivore populations, understanding population dynamics of major prey species is pivotal. Robust scientific estimates of population, abundance and distribution are fundamental for such monitoring exercises.

Line transect based density estimation has been extensively used in such monitoring exercises because of its robustness[4,5,7]. This method overcomes the shortcomings of previously used techniques by incorporating detection probability in the sampled area along with modelling the width of the line depending on the detectability[8]. Line transects are placed in the study area random to the distribution of target species. The probability of detecting an individual declines with increasing distance from the line due to factors like habitat features, terrain and inherent animal heterogeneity. Using this information and modelling detection probability, the proportion of animals detected on the line are calculated which is in turn used to calculate the abundance and density of the target species in the entire study area[9,10].

In addition to abundance and density of major ungulate species, estimating their distribution pattern bears equal significance. Investigating spatial distribution of animals is fundamental in understanding their ecology as well as an integral part of their monitoring[11]. Detailed understanding of distribution pattern can explain species-habitat relationships. Additionally, predator movements are also likely to be governed by their preferred prey which makes monitoring distribution pattern even more useful for management practices[12]. Counts from camera-trap surveys have been widely used to study various matrices of population recently[7,11,12]. Photographic rate through camera traps have been used to estimate different

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indices of both individually identifiable and non-identifiable species[13,14].

Camera trap-based surveys are routinely conducted in Pench Tiger Reserve, Madhya Pradesh to estimate population parameters like density, distribution, survival probability of tigers since 2008[15,16]. As a result, enough amount of information is generated on the principal prey species of both tigers and leopards in the study area. Previous studies have established chital (*Axis axis*) and sambar (*Rusa unicolor*) as major ungulate prey in Pench Tiger Reserve for endangered carnivores like tiger (*Panthera tigris tigris*), leopard (*Panthera pardus fusca*) and dhole (*Cuon alpinus*) in the study area[5,17]. Chital is an endemic ungulate species of South Asia mainly occurring in India, Nepal, Bangladesh and Sri Lanka[18]. They are habitat generalist, residing in a variety of habitats starting from moist, dry deciduous forest to scrublands[15,16]. Sambar is a large deer native to South-east Asia namely India, Sri Lanka, Pakistan, Nepal, Myanmar, Thailand, Cambodia and the Malay Peninsula[18]. Their habitat generalist nature arises from broad spectrum of its diet and ability to both graze and browse depending on available resource[18,19]. Although, a number of studies[20–22] have demonstrated the importance of maintaining a healthy herbivore population to sustain viable large carnivore populations, there is a paucity of information on long-term population trends of the target species. Such long-term studies not only help understand the prey population dynamics over the years but also help formulate effective management strategies for conservation of both large carnivores and their prey. So, in this study we focus on the density and distribution pattern of chital and sambar over three years (2013–16) of study period.

2. Materials and Methods

2.1 Study Area

The core zone of Pench Tiger Reserve (hereafter PTR) in the state of Madhya Pradesh (MP) (78° 55' E to 79° 35' E and 21° 40' N to 21° 57' N) is comprised of Indira Priyadarshini Pench National Park and Pench Mowgli Sanctuary. It is part of one of the major 11 tiger conservation units (TCU) of India[23]. The buffer zone is comprised of six ranges. Biogeographically PTR falls within the Deccan Peninsula Central highlands. Major forest types vary from slightly moist teak forest to dry teak forest and Southern dry mixed deciduous forest. Other dominant vegetation types include southern moist mixed deciduous forest and *Boswellia* forest. The *Totladoh* reservoir has created a very unique and productive submergence area of 65 sq. km. in PTR. Wild ungulates found in the study area are chital (*Axis axis*), sambar (*Rusa unicolor*), gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*), barking deer (*Muntiacus muntjac*), chowsingha (*Tetraceros quadricornis*), chinkara (*Gazella bennetti*) and blackbuck (*Antelope cervicapra*). Although there are no villages inside the core zone, substantial human population resides in the surrounding buffer zone in 99 villages[15].

2.2 Density of Wild Ungulates

In the core zone, 44 transects were distributed in systematic random manner (Figure 1). Each transect was sampled at least twice during winter season over the entire study period (2013–16). Total effort invested in this exercise was 528 kilometres. We used animal clusters as the analytical unit since individual data tends to underestimate true variance[24]. For each detection, we recorded the GPS co-ordinates, the exact time, species, group size, group composition (age classes and sex, whenever possible) sighting angle and the sighting (radial) distance from the transect line.

We estimated density of each species separately for each session (2013–16). We examined distribution of the data by assigning very small cut-off points to the distance intervals during the curve fitting, to detect evidences of evasive movements by the animals or heaping of data. Data was truncated at suitable distances from the line. Most parsimonious model was selected after applying different set of parameters. The best model was selected based on their AIC values[25] and by visually judging the fit of the proposed model to the observed distance data close to the transect line. Average probability of detection (p), group density (Dg), group size (Sg), animal density (Dind) and effective strip width (ESW) were estimated. The population densities and other parameters of interest were calculated with respect to this effective strip width[9]. All analyses were conducted in DISTANCE software ver. 6.0[9].

2.3 Distribution Pattern of Wild Ungulates

Camera trap based encounter rate[13] was used to estimate the distribution pattern of chital, sambar and wild pigs in PTR. Two-sided camera traps were deployed at 82 locations over the entire core zone and same locations were sampled across three years (Figure 1). Cameras were operational for a period of 50-55 days in each session.

We prepared a temporal capture history of all the study species. Only the photographs which were at least 15 minutes apart from each other were taken for this analysis to maintain the independence of the events occurred at the same camera location. This information was then transformed into per 100 trap night encounter rate of chital and sambar to calculate the Relative Abundance Index (RAI) at each camera location[13]. We then used this abundance index to estimate the spatial

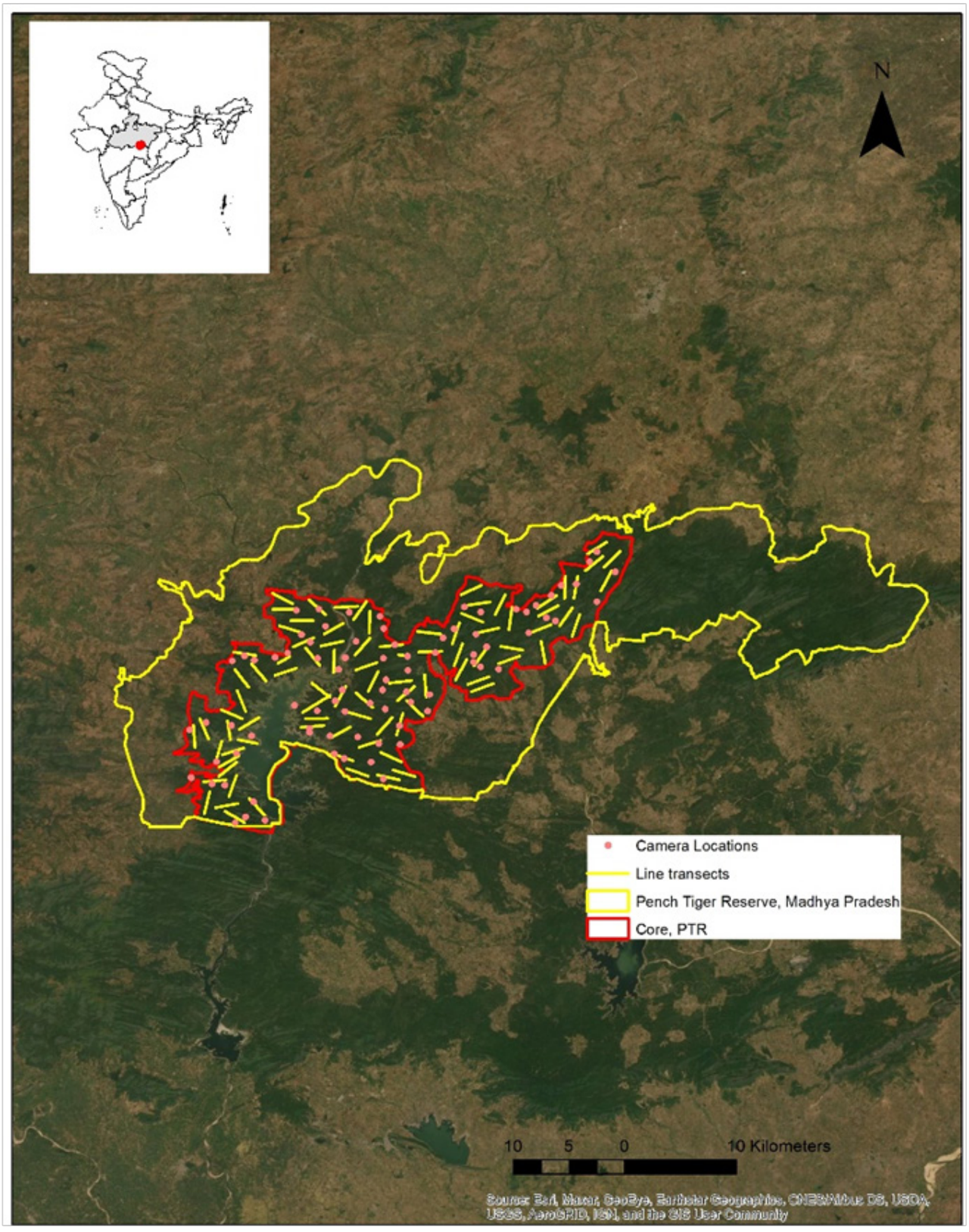

Figure 1. Locations of 44 line transects and 82 camera trapping stations in the core zone of Pench Tiger Reserve (2013-16). The inset map is geographical representation of the study area in India.

Table 1 Year-wise and pooled individual density, group density, cluster size and Effective Strip Width (ESW) for chital and sambar throughout the entire study period (2013–16)

Species	Year	Total no. of observations	Selected models	Chi-p	Density per/ sq. km. (SE)	Group Density/ sq. km. (SE)	ESW in metres (SE)	Cluster Size (SE)
Chital	2013-14	264	Half-Normal Cosine	0.705	54.12 (12.27)	7.9 (1.66)	63.98 (4.22)	6.85 (0.57)
Chital	2014-15	192	Half-Normal Cosine	0.986	52.75 (7.57)	9.94 (1.42)	50.88 (3.18)	5.48 (0.1.)
Chital	2015-16	121	Half-Normal Cosine	0.956	44.56 (9.82)	8.71 (1.65)	31.44 (2.93)	6.29 (0.65)
Chital	Pooled	577	Half-Normal Cosine	0.948	51.4 (9.5)	10.97 (2.03)	48.23 (3.0)	4.68 (0.00)
Sambar	2013-14	79	Uniform Cosine	0.97	7.68 (1.58)	2.73 (0.51)	53.65 (4.57)	1.76 (0.31)
Sambar	2014-15	51	Uniform Cosine	0.95	4.64 (1.01)	2.37 (0.49)	59.64 (6.62)	2.16 (0.23)
Sambar	2015-16	48	Uniform Cosine	0.95	6.75 (1.57)	3.59 (0.78)	38.94 (4.76)	1.88 (0.15)
Sambar	Pooled	178	Uniform Cosine	0.98	6.64 (1.11)	2.90 (0.48)	53.36 (4.67)	1.75 (0.00)

distribution pattern of the target species using Kriging in ArcMap ver. 10.5.1. Kriging is a spatial interpolation tool which uses known values to predict values for points whose values are not known[26].

3. Results

3.1 Density of Wild Ungulates

Of all three study species, chital had the highest abundance. Individual density of chital varied from 44.52 (SE 9.82) per sq. km. to 54.12 (SE 12.27) per sq. km (Table 1) but the population remained stable over the years as demonstrated by overlapping confidence intervals (Figure 2). Individual density of sambar ranged from 4.64 (SE 1.01) to 7.68 (SE 1.58) per sq. km. (Table 1) which also didn't vary over the years (Figure 3).

3.2 Distribution Pattern of Wild Ungulates

3693 independent photocaptures of chital and 1073 independent photocaptures of sambar were used to calculate their relative abundance index (RAI) in the study area. Estimated average RAI of chital and sambar were 70.08 (SE 12.91) and 10.88 (SE 2.00) respectively. Chital congregations were seen near the submergence area and the bordering woodlands in the central zone of the core area. 47.16% of total photocaptures of chital were from cameras deployed in this region (Figure 4). Sambars were found more near the undulating terrain with miscellaneous dry deciduous forest as 38.53% of total photocaptures from deployed camera traps were seen in this area (Figure 5).

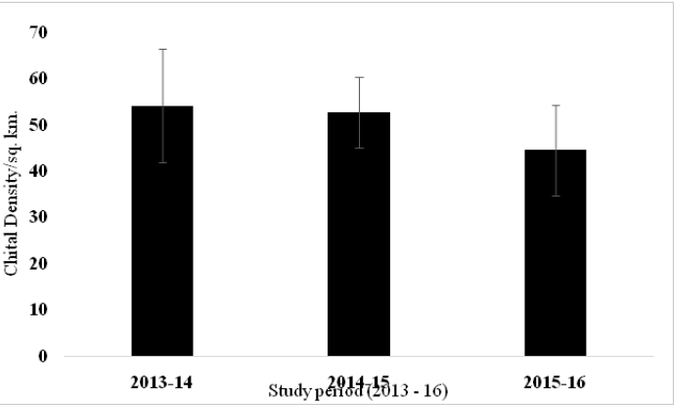

Figure 2. Comparison of individual density estimates of chital in Pench Tiger Reserve, Madhya Pradesh over the study period (2013–16).

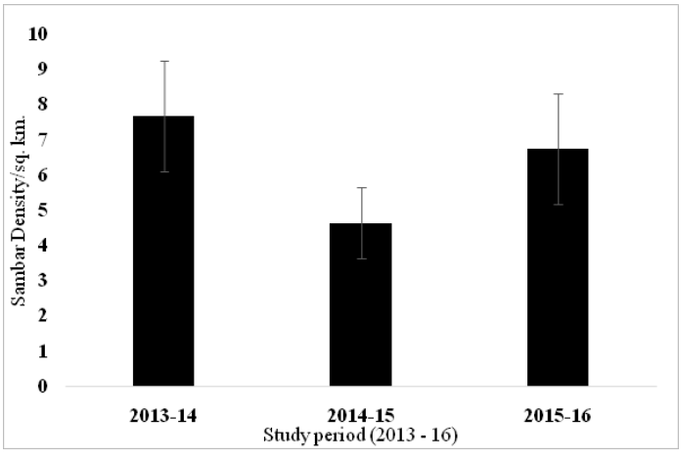

Figure 3. Comparison of individual density estimates of sambar in Pench Tiger Reserve, Madhya Pradesh over the study period (2013–16).

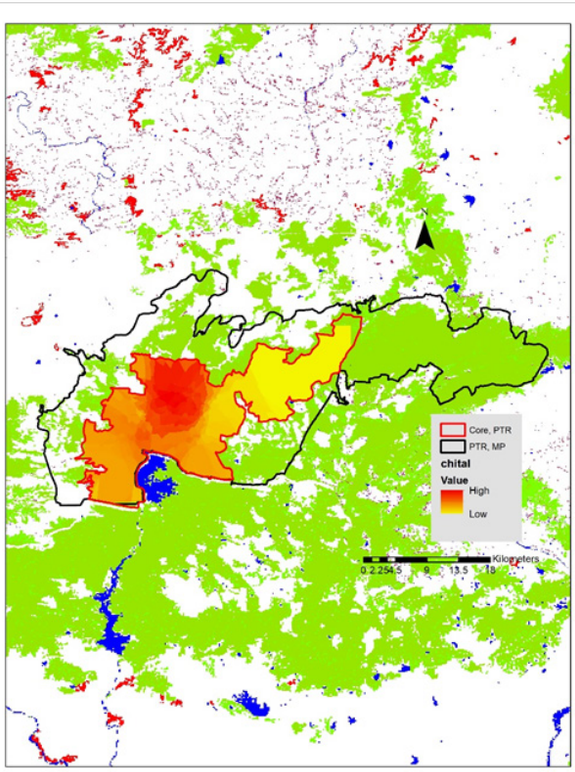

Figure 4. Estimated spatial distribution patternof chital using camera trap-based encounter rate in Pench Tiger Reserve, Madhya Pradesh.

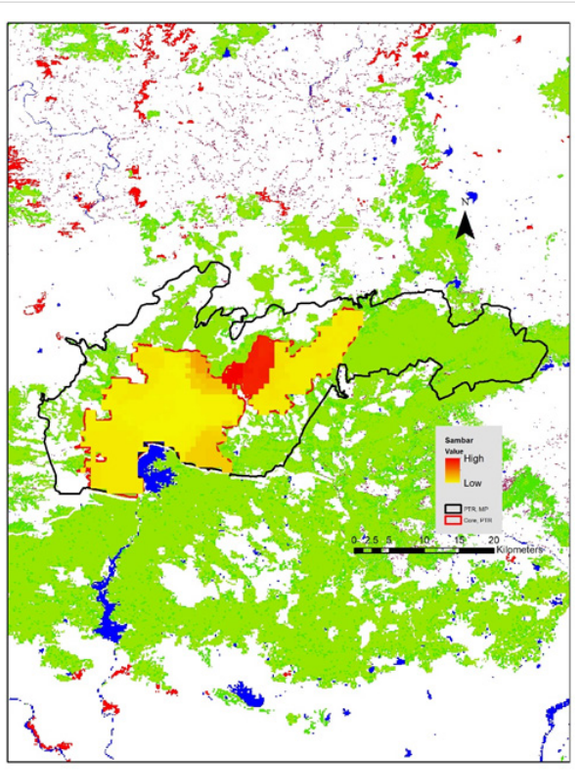

Figure 5. Estimated spatial distribution pattern of sambar using camera trap-based encounter rate in Pench Tiger Reserve, Madhya Pradesh.

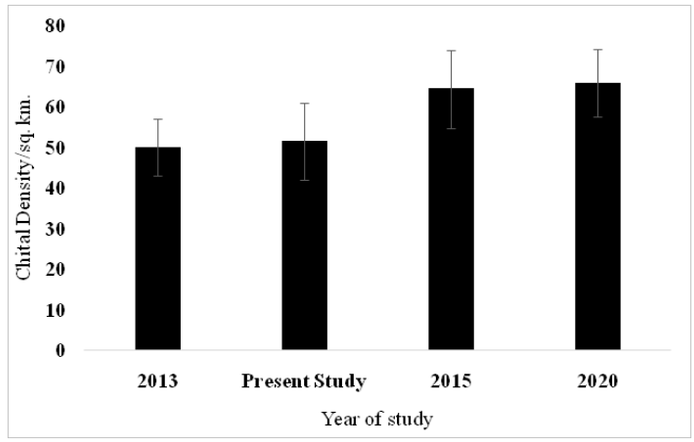

Figure 6. Comparison of individual density estimates of chita l7,15,24 in Pench Tiger Reserve over the years.

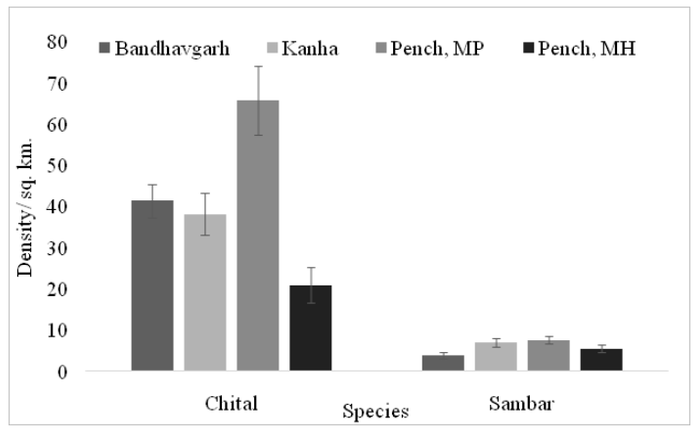

Figure 7. Comparison of density estimates of Chital and Sambar of PTR, MP with that of Kanha TR*, Bandhavgarh TR and Pench TR, Maharashtra (MH)(TR = Tiger Reserve).

4. Discussion

Use of line transect based distance sampling have been well established for prey population estimation of tigers as well as other large carnivores[5,15,27]. Data didn't show any sign of heaping of heaping or evasive movements[9]. Major variation in the data was from encounter rate of individuals on line transects. The encounter rate of animals on a line transect was hugely dependent on different habitat features like visibility, terrain and presence of *Lantana* spp.

Chital was found to be the most abundant ungulate in the study area. Sambar is primarily a dense forest dwelling species and its congregation was seen near the rugged areas. Distribution of chital in the study area were mostly governed by the surrounding habitat features. The submergence of *Totladoh* reservoir has created a unique productive habitat of grassland and bordering woodlands which results in such high numbers of chital in this area. Camera trap based RAI revealed that

larger groups of chital were also seen in these areas. RAI for sambar showed higher occurrence of captures were in dense forested areas. PTR being a part of Satpura-Maikal landscape offers heterogeneity in habitat. This diversity from grassland to moist deciduous forest is very well suited for the survival of both grazers and browsers[15,29] which has resulted in such high concentration of ungulates in this area.

We compared the results of the present study with the available literature[7,15,30] from the study area. The findings show that population of chital in PTR has remained stable over the years (Figure 6)

We also compared our results with other tiger reserves with similar habitat features in the landscape. As per the latest available estimates[7], PTR has one of the highest estimated densities of wild ungulates across India. Both chital and sambar has higher density estimates in the study area when compared with areas with similar habitat types like Bandhavgarh Tiger Reserve, Kanha Tiger Reserve and the bordering Pench Tiger Reserve, Maharashtra (Figure 7). Not only that, no livestock is permitted to graze inside the core zone which translates to undisturbed food resources for the wild ungulates. This might be another reason for observing such high numbers of them in the study area[17].

As PTR is part of the one of the major level – 1 TCUs[23], tigers have the highest probability of survival here. The positive relationship between prey biomass and carnivore density has been well established[31,32]. The carrying capacity of predators in any area is dependent on the prey density[7]. Hence these kinds of long-term estimates can help decide the viability of large carnivore population of those area. Additionally, the congregation of prey is also likely to result in higher occurrence of predator. So, investigating the distribution pattern of prey can help prioritise areas for conservation. Hence, it can be said that to protect the large carnivore population in PTR, it is crucial to monitor the prey population on a regular basis to observe their population trends.

5. Acknowledgement

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6. Statements

6.1 Statements about Contributorship

All the authors have contributed in this study.

6.2 Study Design

Kalyansundaram Sankar and Qamar Qureshi designed this study.

6.3 Data Analysis and Manuscript Writing

Anindita Bidisha Chatterjee wrote the manuscript. The final draft was edited and approved by all the authors.

6.4 Statements for Competing Interest

There is no competing interest among the authors.

6.5 Statement for Data Sharing

All relevant data has been given in the manuscript.

6.6 Statement of Ethical Approval

This study was conducted after receiving proper permissions from Madhya Pradesh Forest Department and all rules were adhered by diligently.

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To Whom it May Concern

This is to certify that Ms. Anindita Bidisha Chatterjee, has presented a talk on "Population Dynamics of Tigers (Panthera tigris tigris) in Pench Tiger Reserve, Madhya Pradesh" in the Annual Research Seminar of Wildlife Institute of India in the year 2015.

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Certificate of Presentation

We confirm that **Anindita Bidisha Chatterjee** presented an oral presentation entitled:

How much it costs? Economics of staying near protected area of people around Pench Tiger Reserve, Madhya Pradesh, Central India

the 29th International Congress for Conservation Biology

"Conservation Beyond Boundaries: Connecting Biodiversity with Communities, Government and Stakeholders"

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