RESOURCE PARTITIONING OF NON-PANTHERINE CARNIVORE COMMUNITY IN KANHA TIGER RESERVE, M.P., 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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June – 2022

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I also certify that the research work was appreciated by all who were present, and the comments made by the faculty and researchers have been appropriately included in the thesis.

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Acknowledgment

Undertaking this PhD has been a truly life-changing experience for me, and it would not have been possible to do without the support and guidance that I received from many people.

First and foremost, I am extremely grateful to my supervisors, Dr. Y.V. Jhala and Prof. Qamar Qureshi at Wildlife Institute of India, for their invaluable advice, stimulating suggestions, continuous support, and patience at each footstep of research and writing of the thesis. Their immense knowledge and plentiful experience have encouraged me throughout my academic research and daily life. Without their guidance and constant feedback, this PhD would not have been achievable.

Apart from my supervisor, I won't forget to express my gratitude to Director, Dean, and Research Coordinator, Wildlife Institute of India, for giving me the opportunity to pursue a Ph.D. from this institute and carry out the research work in the field site. I am sincerely grateful to Dr. V.P. Uniyal (Nodal Officer, External Affiliation) for his patience, cooperation, and valuable support in submitting my thesis at the very last minute.

I wish to thank the administrative and library staff of Wildlife Institute of India for their warm co-operation. I also thank Gyanesh Ji for their support and help in the last-minute thesis submission. I would also like to thank Vinay Ji, Devendra Bhaiya, and Shambhu Bhaiya for their support during the Ph.D. journey. I would also like to thank Mr. Prabir De, SCIENCE, for providing their support in data processing for my Ph.D. work.

I am very grateful to Dr. Ninad Mungi, Dr. Ujjwal Kumar, Dr. Nishant Kumar, and Neeraj Mahar, who supported me in numerous ways throughout the entire research program of my Ph.D. without whom it would not have been easy to complete this Ph.D. thesis.

I cannot stand aside without thanking the Forest Department of Madhya Pradesh and the National Tiger Conservation Authority for providing the necessary permissions and funds to carry out my research at Kanha Tiger Reserve. I am thankful to the Field directors, deputy directors, range offices, and frontline workers of Kanha Tiger Reserve for their help at various stages of my research work. I would certainly be remiss in not thanking Dr. Rakesh Shukla, Research Officer, Kanha Tiger Reserve, for his support in the field as well as for his strong comments and regular concern for this work.

The work involved in this thesis far exceeded what possibly had I done alone. If some persons are instrumental in my completion of the fieldwork, then I am thankful to my field assistant and driver, Nirottam, Kanhaiya, Dinu, Raju, Satish, Digambar, Ravi, Santosh, Gaurav and Suraj, who tirelessly assisted me with data collecting without whom fieldwork would not have been easier.

I would always remember my colleague and fellow teammates from NTCA-WII Tiger Cell and MSTrIPES for the fun time we spent together, the sleepless nights that gave us the courage to complete tasks before deadlines, and for stimulating the discussions. My seniors Dr. Kausik Banerjee, Dr. I.P. Boppana, Dr. Anupam Srivastav, my colleagues Neha Awasthi, Madhura Davate, Ashok Kumar, Ashish Prasad, Deb Ranjan Laha, Jayant Kumar Bora, Shravana Goswami, Rahul Rana, Sanjay Xaxa and interns/volunteers at Kanha tiger reserve Alex, Jain PK, Soham Patekar, Udita Bansal deserve my hearty thanks for their arguments, discussion and cooperation, which resulted into many good fortunes of corrections and modifications in my Ph.D. research work.

I would also like to thank my teammates Nanka Lakra, Ravi Kumar Sharma, Chiranjivi Sinha, Adarsh Kulkarni, Moulik Sarkar and Supragya Dimri, the form All India Tiger Estimation 2018-19 project, who helped with the data entry and data segregation for my Ph.D. work.

Last but not least, I am grateful to my parents, who gave me enough moral support, encouragement, and motivation to accomplish my personal goal. It goes without saying that completing my research work would have been impossible without the moral support and inspiration provided to me by my wife, Mitali, who has been the motivating factor behind my efforts. I appreciate her understanding, encouragement, and constant support keeping me motivated. I owe her a huge debt of gratitude. I express a very special thanks to my son Rohit for supporting me without any disturbance.

Apart from this, many more people have been a source of continual emotional support or a part of the technical effort in some way, so I owe my gratitude to everyone who has been a part of my venture.

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Executive Summary

Carnivores of all groups have unequivocal role in structuring and functioning of their ecosystems. Hence their existence need to be secured to maintain functional ecosystems. In the current scenario of rapid industrial growth and economic development, pressure on natural resources is escalating, which in turn has jeopardized the survival of important species. Hence, to maintain harmony between economic growth and ecological balance, an effective wildlife conservation and management plan should be a priority. The Kanha Tiger Reserve (KTR), spreading over an area of around 2100 km2 located in the central Indian highlands, has immense ecological significance as it supports a wide variety of flora and fauna. The tiger reserve is home to carnivores, including tiger, leopard, dhole, sloth bear, and many small cats. However, there are several conservation challenges exists for the persistence of this ecosystem. A thorough understanding of the ecosystem and its inclusive components is a prerequisite for developing and implementing an effective wildlife conservation plan. And in the case of KTR, despite several pioneer studies, the existing research gap on the ecology of small and meso-carnivores undermines the understanding of the complete ecological functioning.

To fill this research gap, I undertook this study focusing on distribution, habitat use and preference of small and meso-carnivores in KTR. I aimed to study the distribution pattern and abundance of non-pantherine carnivores (Sloth Bear, Wild Dog, Jackal and jungle cat) and their niche separation by developing a species distribution and habitat suitability map. I performed camera trapping exercises during three successive seasons in 2014, 2015, and 2016 successively in all the available habitat types to obtain

information on the abundance and distribution pattern of the targeted species. The camera traps were placed in a two sq km grid-based manner. I used data from transect surveys, remote sensing techniques and published literature to obtain other ecological variables. I used presence software to run the occupancy model for each focal species separately, considering relevant environmental variables. Similarly, I used the Maxent software to prepare the habitat suitability map for each species individually. I used the kernel density approach in R software to analyze the activity overlaps between these studied species.

As a result of occupancy analysis, tiger, leopard, sloth bear, and jungle cats were observed to be inhabited in the cores area of the tiger reserve and associated with dense forest cover, grasslands, and prey abundance. However, dholes preferred the fringe area of the forest, associated negatively with densities of tigers, leopard, and their preferred area, i.e., the core of the forest and positively with the grasslands. In addition, variables such as distance from human settlements, terrain ruggedness, and NDVI also affected the occupancy of these study species in the KTR. Jackal did not follow any particular pattern rather it observed throughout the forest area. Aligning with the occupancy result, the habitat suitability maps prepared by the Maxent model strengthened the observation of the spatial ecology of these carnivore groups in the KTR. The Maxent model showed that the large carnivores at the ecosystem's apex position preferred to live in the core area of the forest with abundant prey and least human interference. However, second and third order carnivores such as dholes, preferred to live outside the core to avoid possible strife with the dominant tiger and leopard. The habitat selection by these meso carnivores also indicates the dominancy of the large carnivores in occupying the central position and their influence in the placement of the subordinate group of carnivores in a common ecosystem. We did not observe any effect of tiger and leopard on the habitat preference of sloth bear and jungle cat which indicated the difference in the dietary pattern also play significant role in occurrence of these sympatric carnivores in a multi-predator ecosystem.

Tigers and leopards were primarily crepuscular and nocturnal. Despite high activity overlap, their activity peaks were different from each other. Dholes and jackals were active during the day, whereas Sloth bears and jungle cats were nocturnal. The results of temporal interaction among these carnivores were not completely diverged from the pattern of spatial interactions observed earlier. Instead, these results strengthen the findings of the spatial interaction among these carnivores in the KTR. As observed earlier, dholes and jackals shift their activity to avoid possible conflict and become diurnal. In contrast, the activity pattern of tigers and leopards did not influence the activity pattern of sloth bears and jungle cats.

The study provides information on the spatiotemporal interactions of a carnivore community in a multi-predator ecosystem in central India. The findings strengthen the earlier understanding of the ecology of large-bodied carnivores such as tigers and leopards. At the same time, it enhances the knowledge of their counterpart i.e. the lesser studies small and meso- carnivores of KTR. Large-bodied carnivores occupied the central and apex position of the ecosystem and regulated the distribution pattern of the meso-carnivores present in their ecosystem. However, species with a different ecological niche were less influenced by these apex predators.

Species diversity of the ecosystem has a direct link with its stability. Hence, to maintain the stability and balance of the ecosystem, we should focus on the conservation of all the species present in the ecosystem equally. The study utilizes information that is collected while studying charismatic carnivores like tiger and leopard to provide insights into carnivore guild of an ecosystem. Hence, I recommend further monitoring of their distribution pattern along with their population status will be helpful in providing ways for the management.

CHAPTER 1: INTRODUCTION

1.1. Introduction

Large predators can potentially help shape the structure and functioning of terrestrial ecosystems and exert important ‘‘top-down” controls on wild ungulates and plant communities through trophic cascades (Beschta & Ripple, 2009; Ford & Goheen, 2015). However, most large predators have experienced substantial population declines and range contractions throughout the past two centuries (Ripple et al. 2014). The extinction of large predators coupled with medium and small predators poses massive challenges and is a worldwide issue in the twenty-first century. Owing to their dwindling status, India remains to maintain an appreciable diversity of large and smaller animals; however, it cannot be denied that wildlife is the country's one of the fastest diminishing resources. In India, there is a dearth of knowledge about the biology of large and medium carnivores like Sloth bears, Melursus ursinus (Murthy and Shankar 1995, H.S. Bargali, Naim Akhtar and N.P.S. Chauhan, 2004), Wild dog, Cuon alpinus, (Chourasia et al. 2012, Johnsingh 1983, Karanth 1993, Venkatraman et al. 1995, Acharya et al. 2007), Golden jackal, Canis aureus, (Sankar, 1988, Aiyadurai, and Jhala, 2006) and Jungle cat Felis chaus (Schaller, G. B. 1967, Mukherjee et al. 2004). Kanha Tiger Reserve, which lies in the Central Indian landscape, provides a home to the carnivore population of Tiger, leopard, Wild dog and Jackal. The ecology of the tiger and leopard are well studied in Kanha (Schaller 1969 and ongoing study by Jhala et al. 2005-2013). However, little information exists about the other two large carnivores, i.e. Sloth Bear and Wild Dog and meso-carnivores such as Jackal and Jungle Cat. These Non-Pantherine

Carnivores (NPC) are essential for the ecosystem. Along with Pantherine carnivores, they constitute the carnivore community in Kanha Tiger Reserve.

Even though there is a universal consensus on the importance of preservation and maintenance of natural areas and their associated flora and fauna, in developing countries, the area assigned with the protected status is usually limited, and the fund provided for its management is often inadequate (Jha & Chaudhry, 2018). Establishing and maintaining Protected Areas (PA) requires both political and financial commitment in the long term (Bruner et al. 2004), as sometimes the benefits to society from PAs are often overestimated, and the immediate costs of protection appear to be large in comparison. Some researchers have tried to estimate such intangible benefits to the community from PAs. For example, the economic valuation of tiger reserves may provide the economic rationale for such resources and support biodiversity conservation. Human well-being through the villagers displaced due to the development of PAs has to bear the brunt of social costs incurred in the process (Menon & Rai, 2017).

The wild cat, a common carnivore species in India, inhabits various habitats. The hyena and the jackal, the other two carnivores of African origin, are high scavengers who feed on the slain remains of tigers and leopards. The golden jackal listed in Schedule III of the Indian Wildlife Protection Act (1972) is quite common in India and inhabits a wide variety of habitats, including open areas around human habitation. In India, the Ratel (Mellivora capensis) lives in deserts and dry and moist deciduous areas but avoids areas with heavy rainfall. They mainly prefer a mountainous area where shelter is easy to find (Prater, 1980). They are placed in Schedule I of the Wildlife Protection Act of India (1972). Scientifically based monitoring programs should be undertaken to assess wildlife population trends. Direct observation of the animals is not possible for nocturnal and shy species, which occur in very low densities. In addition, monitoring cryptic wildlife species such as top carnivores is often difficult or impossible. The basic ecology of lesser carnivores makes their populations inherently difficult to observe (Mukherjee, 1998). It is even more difficult to monitor some small carnivores' population trends effectively.

A new generation of camera traps and well-developed capture-recapture models have increased remote survey and monitoring methods for terrestrial species (Karanth, 1995; Jhala et al. 2008). As a result, population estimates can now be made for individually identifiable species, and relative abundance indices can be calculated for other species. The camera traps have also made possible more accurate estimates of species richness, species diversity, total mammalian biomass, spatial variation, and population size of some mammals. With prolonged use, the camera trap allows for the monitoring of population changes over time. An earlier study focused on human use and habitat ungulate density (Awasthi et al. 2016) on large carnivores in Kanha.

The present research conducted in Kanha Tiger Reserve (KTR), Madhya Pradesh, central India, from October 2014 to July 2016, aimed to study the population in terms of abundance using camera traps and tracings for medium and small carnivores such as the sloth bear (Melurus Ursinus), Dhole (Cuon alpinus), jackal (Canis aureus) and jungle cat (Felis chaus), ratel (Mellivora capensis), palm civet (Paradoxurus Hermaphroditus), small Indian civet (Viverricula indica), common Indian grey mongoose (Herpestes edwardsii), and ruddy mongoose (Herpestes smithii) and evaluation of habitat suitability for each study species in KTR. Scarce studies were conducted on medium and small-sized carnivores in the Indian sub-continent covering aspects such as food habits, habitat use and ranging patterns (Riley, 1913; Nuryatdinov and Reimov, 1972; Acharjyo and Mohapatra, 1976; Kruuk, 1972, 1976, 1986; Mukherjee, 1989; Karanth, 1987; Gupta et al. 2009; Singh, 2008; Harihar et al. 2010; Gupta et al. 2010; Ogurlu et al. 2010). Very few studies on medium and small-sized carnivores are available from South East Asia: (Pocock, 1939, 1941; Hutton, 1949; Glanz, 1977; Finn, 1980; Jerdon, 1984; Tehsin and Tehsin, 1988; Schreiber et al. 1989; Duckworth et al. 1994; Van Rompaey, 1995; Gannon and Foster, 1996; Tehsin, 1996; Duckworth, 1997; Loveridge and Mac Donald, 2002; Parameter et al. 2003; Wagner, 2006; Grassman et al. 2006; Holden, 2006; Long and Hoang, 2006; Wagner et al. 2008 and Chen et al. 2009).

So far, the ecology of the meso-carnivore community has received little attention in India. How do they cooperate and coexist? Our knowledge of this phenomenon has been far from detailed (Sunquist and Sunquist 1989), and many more investigations are strongly recommended for threatened species such as the golden jackal (Canis aureus) and Dhole (Cuon alpinus), and the jungle cat (Felis chaus). Observing predators' prey selection, competition, and cohabitation in unfragmented and affected ecosystems would help recognise the flexibility in predators' capacity to exploit available resources in a wide range of human-modified ecosystems. Individuals' fecundity, growth, or energy storage may be reduced due to competition from these four species, as may their population density and age structure (Korpimaki 1987; Petren and Case 1996). As a result, knowledge of their ecological separation would be precious in developing better management methods and contributing to an understanding of carnivore ecology in India's patchwork of savannah and tropical forest.

1.2. Study species

Tiger

The tiger is a top predator in the food chain and an umbrella species for landscape-scale biodiversity conservation (Albert, Luque, and tour champ, 2018). Asia's largest terrestrial animal species (Seidensticker et al. 1999). Tigers were distributed from the Caucasus Sea to the Caspian Sea in Siberia, Bali-Indonesia, the Philippines, and Palawan (Tilson and Seal, 1988). Tiger distribution has declined in India, Southeast Asia, China, and some eastern Russian regions. Parts of India, Bangladesh, Nepal, and Bhutan are home to the Bengal tiger (Panthera tigris tigris). By 2020, the total tiger occupancy in India was 88,985 km^2 (Jhala et al. 2020).

Despite having a burgeoning human population of over a billion, The Royal Bengal tiger (Panthera tigris) over 75% of the world's wild tigers live in India. The tiger is currently found in 20 Indian states (Jhala et al. 2020). The tigers are hunted for illegal trade for items such as skin, fangs, claws, bones, meat, and tonics. Poaching is one of the severe threats for tigres throughout their range.

Species description & Life history traits:

The tiger's body has a distinct stripe pattern that allows them to be recognized individually. It is the largest species in the cat family and is an apex predator. The average body weight of a tiger ranges between 180 and 230 kg, with females weighing less than 185 kg (Prater, 2005). The tiger's body length is nearly 3 metres from the nose tip to the tail end. Male tigers frequently mate with a large number of females. A tiger's lifespan has been estimated to be approximately 20 years (Prater, 2005).

Ecology & Behaviour:

Even though the tiger prefers to feed on large ungulates, it may also subsist on lesser prey such as chital, langur, porcupines, wild pigs, or even fish in the Sundarban mangroves. Each year, the tiger requires 50-60 large prey to kill (Karanth et al. 2004, Miller et al. 2013). Tigers can sometimes take considerably larger prey than their body sizes, such as Indian gaur, water buffalo, elephants, and rhinoceros (Nowel and Jackson, 1996).

Prey density influences carnivore territory size in terms of optimal energy expenditure, the density of breeding females, number of transients, reproduction, and cub & juvenile survival (Carbone, Teacher, & Rowcliffe, 2007).

Conservation status:

The tiger is presently categorized as threatened with extinction on the 2015 IUCN Red List of Threatened Species and is given a protected status (as a Schedule I species) by the Indian Wildlife (Protection) Act of 1972.

Leopard

Once found throughout northern Africa (except for Sub-Saharan Africa), Central Asia, India, Sri Lanka, Southeast Asia, China, Tibet, and the Russian Far East (Smithers 1983, Stuart 1981, Harrison and Bates 1991, Kingdon 1977, Corbett and Hill 1992), Leopard's geographical range have decreased in recent years. Leopards are found in woodlands, Acacia savannas, scrub forests, pine plantations, rocky slopes, and elevations ranging from sea level to 5000m (Harrison and Bates 1991). However, leopard populations fall across the human-dominated areas due to functional plasticity, whereas the other large panther species, i.e. tiger and lion, are eliminated (Athreya et al. 2014).

Except for deserts, Sunderbans mangroves, and islands, the leopard may be found throughout the Indian subcontinent (Khan, 1986; Johnsingh et al. 1991). For 2020, the total predicted leopard occupancy in India was 1,45,184 (Jhala et al. 2020).

Species description & Life history traits:

The leopard's body is yellow with black patches. The black patches seem like a flower pattern known as the rosette. A leopard's coat colour ranges from pale yellow to deep gold or tawny. If it lacks a rosette pattern (melanistic), it is the Black Panther, which lives primarily in wet forests (Kingdon, 1977; Danid, 1966). Leopards collared in human-dominated settings and had home range sizes ranging from 8 to 15 km^2 (Odden et al. 2014). The typical leopard male body weight ranges between 58 and 37.5 kg (Bailey 1993), with two individuals from Madhya Pradesh and Chhattisgarh weighing between 50 and 70 kilograms

(Nowel & Jackson 1996). Leopard size varies in different regions of India (Prater 1980). The leopard's body length can reach up to 8 feet from nose to tail (Daniel 1996).

Ecology & Behaviour:

Leopards are primarily active at dawn and dusk when they hunt more prey (Hamilton, 1976). Leopards are robust and capable of carrying prey weighing about three times heavier than their weight. The leopard has been seen regularly in India's deciduous and evergreen forests, scrub forests, grassland, rocky terrain, and human settlement margins. When moderate-sized ungulates (10-40 kg) are available, leopards prefer to hunt and feed on them (Hayward et al. 2006).

Conservation status:

As mentioned in the IUCN Red List of Threatened Species and CITES Appendix-1, the leopard is labelled as Vulnerable. The Indian Wildlife Protection Act of 1972 provides extensive protection (as a Schedule I species).

Dhole

Dholes are the most common canids in the Oriental Region’s Indian, Indo-Malayan, and Indo-Chinese sub-region. Dhole has historically been found in South, East, and Southeast Asia, including former Soviet Union countries. Currently, its geographical range spans countries of Afghanistan, Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Kazakhstan, the Korean peninsula, Kyrgyzstan, Laos, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Russia, Tajikistan, and Thailand (Fox 1984, Johnsingh 1985, Kamler et al. 2015).

Dhole's population distribution in India has been observed in the Indo-Gangetic plains, Terai region, Central Highlands of India, Western and Eastern Ghats in southern India, and some north-eastern states (Assam, Meghalaya, and West Bengal) (Johnsingh 1985, Durbin et al.2004). However, dholes have recently been discovered in the high altitudes of Sikkim, Ladakh, the western Himalayas, and Kashmir (Bashir et al. 2013, Pal et al. 2020).

Prey base depletion, habitat change and loss, pup persecution via poisoning, trapping, and killing, competition for prey, and danger of disease and infections from feral dogs (Fox 1984, Durbin et al. 2004), canine distemper and rabies are significant causes of dhole's mortality (Morris 1942, Davidar 1975).

Species description and Life history

Unlike Jackals, Dholes are huge canids (usually 12-20 kg) with shorter legs, a bushier tail, and a shorter, thicker nose. They have a minimum gestation period of 63 days (Durbin et al. 2004). The total body length is approximately 130cm, including the 40-45 cm long tail (Acharya et al.2008). Females are a tad smaller than males (Prater 1980). The dorsal and lateral pelage of the dhole is red to brown, with white to cream fur on the undersides, breast, inner legs, and lips (Ognev 1931). Puppies are born sooty brown and turn russet after around three months (Macdonald et al. 2001).

Ecology and behaviour

Dhole is found in dry deciduous, moist deciduous, and tropical dry forests in India, which enjoys a status of protected wildlife reserves with little human disturbance (Srivatsha et al. 2014).

Dhole's prey varies from location to location within the former's distributional range. Brander (1923) claimed that practically every type of forest animal within the dholes' range had served as prey at some point. Dholes' primary prey in the Indian subcontinent has been medium to large-sized ungulates (Davidar 1974, Fox and Johnsingh 1975, Johnsingh 1983, Venkataraman et al. 1995, Karanth and Sunquist 1995, 2000, Acharya 2008, Wang and Macdonlad 2009, Gopi et al. 2010, Selvan et al. 2013, Hayward et al. 2014, Srivastha et al. 2020).

Dholes are gregarious animals that live in groups of 5–10 individuals. However, groups of 18 (Alas Purwo, Java, Indonesia), 24 (Kanha, India), and 25 (Mudumalai Sanctuary, India) have also been observed (Durbin et al. 2004). Dholes exist in smaller groups and have smaller litters in Southeast Asia's tropical evergreen forests, most likely due to the low prey biomass and small size of ungulate prey in these settings (Kawanishi and Sunquist 2008).

Dholes' home range changes according to habitat conditions, prey population, and pack size (Srivathsa et al. 2017). Mudumalai had a home range size of 85 km2 (Venkataraman et al. 1995), Bandipur had a home range size of 40 km2 (Johnsingh and Acharya 2013), and Pench Tiger Reserve in Madhya Pradesh had a home range size ranging from 66 to 203 km2 (Acharya 2008). The species is primarily diurnal, with hunting activity peaking in the early morning and late evening (Johnsingh 1983, Kamler et al. 2012, Ramesh et al. 2012).

Conservation status:

Although there has been a considerable drop in cases of hunting in several reserves throughout India, the trend has not stopped completely. The IWPA 1972 (Schedule II) classifies dholes as 'endangered (EN)' while the IUCN classifies them as 'vulnerable' (Appendix II of CITES).

Sloth Bear

The sloth bear is found in the Indian subcontinental regions. Around 90% of the species' present distribution is in India, with a total occupied area ranging from 200,000 km^2 (Johnsingh 2003, Akhtar et al. 2004, Chauhan 2006) to 400,000 km2 (Sathyakumar et al. 2012) and an estimated population of 7,000-13,000 individuals (Jaffeson 1975, Yoganand et al. 1999). In India, it has five separate distributional areas: northern, north-eastern, central, south-eastern, and south-western (Johnsingh 2003, Yoganand et al. 2006, Sathyakumar et al. 2012). The north consists of Uttar Pradesh, Uttarakhand, Bihar, and a transboundary population with Nepal. This population is assumed to be geographically separated from other populations in India due to large-scale forest fragmentation caused by agricultural development, urbanisation, and industrialization (Bargali et al. 2012). Though the species is known from Manipur, Meghalaya, Mizoram, and Arunachal Pradesh (Yoganand et al. 1999, Dharaiya et al. 2020), Assam has the majority of the sloth bear population in the north-eastern region (Choudhury 2011), and their distribution coincides with Asian black bears and Malayan sun bears. The states of Madhya Pradesh and Chhattisgarh account for the majority of the distribution in the central area. At the same time, it also includes Odisha, Andhra Pradesh, Maharashtra, Telangana, Bihar, Jharkhand, and West Bengal. The south-eastern population of sloth bears is concentrated along the Eastern Ghats in southern Andhra Pradesh. The Western Ghats form the region's western boundary, encompassing Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu. Sloth bears have been spotted at up to 2,000 metres in the Western Ghats (Garshelis et al. 1999a). It eventually extends north-westward into Gujarat and Rajasthan, with deserts limiting their westernmost spread (Yoganand et al. 2013).

In addition to habitat degradation (Garshelis et al. 1999a), factors such as hunting for bile products, claws, meat, and skin (Yoganand 2005, Bargali et al. 2012), conflict with humans, and retaliatory killing (Rajpurohit and Krausman 2000, Bargali et al. 2005, Dharaiya and Ratnayeke 2009, Mardaraj 2014) pose a substantial risk to the sloth bear's population.

Species description & Life history traits:

The sloth bear has a shaggy black coat, a distinctive “V - U” shaped whitish or buff-coloured patch on the breast, a nose covered with thin and short greyish white hairs, and ivory-coloured claws. A rare brown variant was also discovered in peninsular India (Pocock 1933, Prater 1971, Brander 1982). The entire neck region is covered in dense and longer hair, from behind the ears to the shoulder (up to 30cm). The species is an adept insectivore due to its longer snout, unusually extensible lips and tongue, long claws, presence of rhinarium (furless skin that helps keep the nostrils closed when feeding), and lack of front two incisors (Pocock 1933). The overall body length is around 140-190 cm, including the 8-17 cm tail (Menon 2014), with adult males weighing 80-150 kg and adult females weighing 60-100 kg (Prater 1971, Garshelis et al. 1999a). In captivity, a sloth bear has a minimum lifetime of 40 years and a gestation period of 95-97 days (Hunter 2011, Joshi et al. 1999).

Ecology & Behaviour:

The sloth bear can be found in various environments across the Indian subcontinent. Moist deciduous woods are this species' most densely populated habitats, followed by dry deciduous forests, scrublands, and evergreen forests (Yoganand et al. 1999). The sloth bear enjoys dense forest cover, escarpment locations, and dense Lantana patches for resting and feeding throughout the day (Yoganand 2005). In the Terai Arc terrain, sloth bears prefer fertile alluvial grasslands as in dry and highland Sal forests in the rainy season, probably to aid termite eating. Despite having preferential food availability, sloth bears typically avoid human presence, as evident by the low concentration or complete absence in places with high anthropogenic activity (Garshelis et al. 1999b).

The only myrmecophagous ursid is the sloth bear. Their diet is primarily composed of social insects like ground-living ants and termites, common and found in enormous colonies. Fruits with high sugar content also appeal to sloth bears (Laurie and Seidenticker 1977, Yoganand 2005).

Although sloth bears live solitary, no territoriality was recorded (Joshi et al. 1999, Laurie and Seidenticker 1977). Joshi et al. (1995) observed home ranges of 9.4 km^2 for females and home ranges of 14.4 km^2 for males in Chitwan National Park, Nepal. Yoganand (2005) found sloth bears with substantially larger home ranges (25-100 km^2) in Panna. According to several studies, the sloth bear is active throughout the daytime but is most active at night hours (Sunquist 1982). These sloth bears also have a crepuscular activity pattern (Yoganand 2005).

Conservation status:

The IUCN Red List has classified these sloth bears as "vulnerable (VU)" and safeguarded by the IWPA of 1972, Schedule I.

Jackal

The Indian subcontinent is home to the Golden Jackal (Canis aureus). This is the jackal's northernmost distribution (Sheldon, 1992). It is a medium-sized canid with a wide range of north-eastern Africa, south-eastern Europe, the Mideast, and central, southern, and Southeast Asia down to Sri Lanka and Thailand. (Jhala YV, Moehlman PD 2008). Jackals are typically found in the most protected areas of India. The golden jackal can be found from East Africa through the Middle East to South Asia. In India, golden jackal populations abound in pastoral areas like Kutch, Maharashtra, Haryana, and Rajasthan. Jackals have been spotted at heights of 3,800 metres in Ethiopia's Bale Mountain ranges (Sillero-Zubiri 1996) and commonly in India near a 2,000-meter-high hill station (Prater 1980).

Except for protected regions, the jackal population have been quickly dropping across its range (MacDonald and Zubiri, 2004). This is because the traditional land-use practices are being replaced by intensive agriculture while wilderness areas and rural landscapes are increasingly becoming urbanised. The jackal population can adjust to this alteration and survive for a while, but it will eventually disappear from these locations. An estimated 80,000 jackals have been reported in the Indian subcontinent, but no population data from Africa has come to light (Jhala and Moehlman, 2004).

Species description & Life history traits:

The jackal is a medium-sized canid with golden as its primary coat colour. However, it fluctuates seasonally from delicate creamy yellow to dark tawny (Sillero-Zubiri et al. 2004). The underside of the eyes, lips, and throat are all white. A jackal's tail is bushy, medium-sized, and blacktip, similar to a wolf or a common peninsular fox. In comparison, it is one-half the size of an Indian fox and somewhat more prominent than a wolf. Male jackals are more considerable than female jackals. The dorsal section of the Golden Jackal is virtually black, mottled with white, while the legs are rusty in colour. Golden jackals are monstrous, with a 63-day gestation period. The litter size is 1-4 puppies.

Ecology & Behaviour:

Except for the high Himalayas, the jackal is usually found in forests, grasslands, mangroves, and urban and semi-urban regions throughout India. By adjusting to changing conditions, the gold jackal may survive in various environments. As a result, some aspects of jackal ecology remain unknown (Patil and Jhala, 2008).
In the presence of massive carnivores such as tigers, hyenas, and wolves, the golden jackal alarm sound differs significantly from the typical howling

repertory (Jerdon 1874). Howling is most common between December and April, primarily in India.

Golden jackals are omnivores and opportunistic feeders, and their food availability varies seasonally and locally. They graze mainly upon the fruit of Ziziphus sp., Carissa Carvnada, Syzygium cumini, Phoenix sylvestris, Prosopis juliflora, and Cassia fistula pods in the Indian ripening period (Kotwal et al. 1991; Y. Jhala pers. obs.). The jackal successfully hunts tiny prey such as hares, wild birds, rodents, and juvenile ungulates.

Golden jackals destroy watermelon, grape, peanut, coffee, maize, and sugarcane crops; they also kill goats, children, sick cattle, lambs, and domestic fowls (Jerdon 1874; Kingdon 1977; Prater 1980; Poche et al. 1987).

Conservation status:

It is grouped as Schedule III (Anonymous) by the IUCN Red List and the Indian Wildlife (Protection) Act of 1972. (1972).

Jungle Cat

The jungle cat's distribution ranges from Egypt, Israel, Jordan, northern Saudi Arabia, Syria, Iraq, and Iran, to the Caspian Sea and Volga River Delta, east through Turkmenistan, Uzbekistan, Tadzhikistan, Kazakhstan and western Xingjian, in Afghanistan. Pakistan, Nepal, India, Sri Lanka, Myanmar, Laos, Thailand, Cambodia, Vietnam and south-western China (Sunquist and Sunquist 2002, Mukherjee 2013). It is the most common cat in India. The most severe threat to the jungle cat is habitat fragmentation caused by urbanisation and industrialization of low-intensity agricultural landscapes and scrublands (Gray et al. 2016). Also, farmers frequently chase and poison jungle cats for attacking and killing their poultry birds. Road fatalities for jungle cats have also been reported in Iran, India, Nepal, and Sri Lanka (Sanei et al. 2016, Joshi et al. 2018).

Species description & Life history traits:

The jungle cat is related to the domestic cat. In India, the jungle cat is the most abundant of all wild cats. It has a sandy brown, reddish, or grey coat with no pattern except noticeable stripes on the legs and, less frequently, on the throat. The fur is black at the tips, the face is slender, and the muzzle has some white on it (Menon 2014). The ears are reddish on the back and topped with tiny black tufts up to 15 mm long (Prater 1971). Its tail is one-third of the cat's body and head, with black rings near the posterior end and a black tip at the end; it is brownish-grey on the upper and yellowish-brown on the lower sides. The jungle cat weighs between 2.5 and 12 kg (Mukherjee). 2013 Melanistic people have also been observed in western India (Sahu et al. 2017).

Ecology& Behaviour:

Although the distribution of the jungle cat has been reported up to 4,178 m elevation across its geographical range (Gray et al. 2016), it occurs at elevations as high as 3,300 m in the Himalayas (Shrestha et al. 2020). However, it is more prevalent in the lowlands (Mukherjee 2013). It favours dense vegetative cover near water and can be found in several environments, including deserts, meadows, shrubby woods, dry deciduous forests, and cleared areas in wet forests (Prater 1971, Nowell and Jackson 1996, Baker et al. 2003, Chatterjee et al. 2020a). It can be found in tall grass, dense scrub, riverfront wetlands, and reed beds. Also, it adapts to cultivated soil and may be found in a wide variety of semi-urban settings, including farms, communities, and forest plantations (Tikader 1983, Sunquist and Sunquist 2002, Ogurlu et al. 2010, Menon 2014).

The jungle cat hunts animals larger than itself, such as chital fawns or porcupines (Prater 1971, Mukherjee 2008), and primarily preys on species less than 1 kg. It regularly consumes rodents, lizards, snakes, frogs, birds, hares, fish, insects, livestock, and even fruit during the winter (Baker et al. 2003, Duckworth et al. 2008, Majumder et al. 2011). Rodents are its primary food source, accounting for up to 70% of its daily energy intake (Mukherjee et al. 2004).

The species is not sociable and lives alone (Hunter 2015), with home ranges ranging from 45 to 180 km^2 (Sunquist and Sunquist 2002, Ogurlu et al. 2010). Jungle cats' activity habits range from crepuscular (Prater 1971) to nocturnal (Majumder et al. 2011).

Conservation status:

The jungle cat is classified as a species of common concern. It has limited protection (classified as a Schedule II species) under the Indian Wildlife (Protection) Act of 1972.

1.3. Questions and Objectives:

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

A detailed long-term study on prey selection, food habits, population status, and distribution of four sympatric large and meso carnivores have not been documented earlier in the central Indian landscape. Even though large carnivores' prey selection and food habits have been studied, it was either for the small-time frame (Sujai 2004) or species-specific (Schaller 1967; Biswas and Sankar 2002; Acharya et al. 2007; Edgaonkar 2008). In many of India's well-Protected Areas (PAs), up-to-date scientific information on this aspect remains negligible. To supplement the current basic information, studied will be in Kanha Tiger Reserve. I have tried to answer the following questions

1) What is the status of NPC (Sloth Bear, Wild Dog, Jackal and jungle cat) in Kanha Landscape?

2) What influence does Pantherine predator abundance have on the distribution and abundance of NPCs?

3) What are the spatiotemporal interactions between NPC?

The proposed study will be carried out with the following specific objectives

1. To estimate the distribution and abundance of Non-Pantherine Carnivores (Sloth Bear, Wild Dog, Jackal and Jungle cat) in Kanha Tiger Reserve.

A. Distribution pattern of Non-Pantherine Carnivores (NPCs)

B. To determine the occupancy and abundance of NPCs

C. To assess the response of NPCs at varied Pantherine density

2. To gain an understanding of niche separation between Non-Pantherine Carnivores.

A. To develop the habitat suitability map of NPCs

CHAPTER 2: STUDY AREA

The Kanha Tiger reserve represents the high potential tiger habitat of the central Indian landscape. These highlands, constituted by the Vindhyas in the north and the Satpura in the south with mighty Narmada meandering through them, extend from east to west some 500 km across the state of Madhya Pradesh. The reserve is between N 22^0 70’ North and 22^0 27’ latitudes and 80^0 26’East and 81^0 30 East longitudes.

It falls in two districts of Madhya Pradesh, occupying the southern part of the Mandla district and the north-eastern part of the Balaghat district. Roughly described, its eastern boundary is constituted by the inter-district border between Balaghat and Kawardha (in Chhattisgarh State) districts and later by that between Mandla and Kawardha districts. In the north, it is bound by the reserve forest boundaries of north Phen, Raigarh, Bhaisanghat and Malidadar blocks. In contrast, reserve forest boundaries make its western and southern boundaries of Banjar Valleys and Bhaisanghat blocks.

The Tiger Reserve, with an expanse of 2074 km^2, is divided into two independent management strata: the core and the buffer zone, which cover an area of 940 km^2 and 1134 $km^{2,}$ respectively. The core area or the critical tiger habitat is dedicated to biodiversity protection and hence is free from human settlements. At the same time, the buffer zone is a multi-use region that permits human activities such as tourism-based resorts, hotels, small-scale industries, agricultural practices and infrastructure development for village people.

The catchment area of rivers Banjar and Halon are responsible for forming Kanha National Park (core area). The Kanha National Park (henceforth KNP) became a part of the Project Tiger in 1974. This National Park is a part of the Indo-Malayan Realm "floristically and a member of oriental region" zoo geographically. The reserve is located in biogeographic zone 6E, which includes the Deccan Peninsula and the Central Indian region. (Rodgers & Panwar, 1988). The shape of the park form is east to west (Figure 2.1).

Several spurs branch off to the north from the main Maikal and the Bhaisanghat ridges and divide the Halon headwaters into several tributaries, the chief of which are the Phen, Gourdhuni, Kashmiri and the Gondla. Near Bamhnidadar, the Bhaisanghat ridge bifurcates, and the main spur runs north, while the branch running west sub-divides the Banjar catchments between the Banjar itself and its tributary the Sulkum, also called the Surpan in the lower reaches. Features on the main ridge vary in elevation from 800 meters to 900 meters or more above MSL. In 1976, a five-square-kilometre forest area was added to the existing sanctuary, and its status was increased to that of a KNP, with some minor changes. The buffer area of 487 sq. km was established in the year 1974. It was augmented in the year (1976, 1977& 1995, and thus, the buffer area was enlarged to 1009 sq. km, and its regime was transmitted to the authority concerned with the park management (Rajesh Gopal & Shukla, 2001). As a result, the Kanha Tiger Reserve (KTR) now has a core area of 940 sq. km and a buffer area/zone of 1134 sq. km. Under the Wildlife (Protection) Act of 1972, the core area has the legal status of a National Park. The buffer zone consists of 40% local forests under the Indian Forest Act of 1927 and 60% revenue land. The buffer area serves as a conservation area. It comprises around 145 settlements, 64,000 people, and 50,000 animals and is of great utility to the people residing in this area (Kotwal & Parihar, 1989).

Since historical times, several tribal communities, with Gonds and Baigas forming a majority, have resided in the KTR. These tribal people have always depended on the nearby forests for their needs and demands of grass, fuelwood, timber, and a wide range of minor forest produces, which resulted in considerable biotic pressure on the forests and wildlife of the area. As KNP was conferred with the status of Tiger Reserve, from 1974 onwards, the tribal communities were prohibited from collecting non-timber forest produce (NTFP), grazing cattle in the forest area and exploiting wildlife and forest resources. As a result, the area's local people lost their jobs and potential sources to earn money. They were already battling with the recurring issue of human-wild animal conflict, which often resulted in human injury, sometimes death, and depredation of crops by the villagers. They were ready to be re-established outside the Park. From 1974 to 1978, twenty-six settlements totalling 64.3 square kilometres, containing twelve hundred five families total of 4,980 and 8,232 around 4900 people & 8230 animals, were relocated from the centre of the park (Jain 2001). Village relocation has proven as an important step toward the conservation of wildlife, especially barasingha in Kanha, which suffered the most due to human activities (Panwar, 1973; Gopal & Shukla, 2001; Gopal, 2012). Between 1969 and 2018, the Park Management successfully relocated 35 forest villages outside the National Park. The relocation has assisted Park Management in reclaiming over 10,000 hectares of wildlife habitat. KTR is a part and member of the Oriental Region. The dominant forest type of KTR is tropical moist deciduous forest mixed with artificial grasslands that have been held back in succession by yearly burning and wooded plant clearance (Kanoje.,1999). Due to the undulating topography and altitude (450-950 m above sea level), various floral diversity (Champion and Seth1968). The reserve comprises four habitat types: pure sal forest, miscellaneous-woodland, grassland and mixed bamboo forest. The sites with greater elevations are adorned with plateau-capped hills which support dispersed, scant or little tree growth of heterogeneous woodland and are essentially considered grasslands.

KTR has three unique seasons (Gopal & Shukla, 2001): summer, monsoon and winter. The **summer** season lasts from March through mid-June (the hottest period extends from late April to the first week of June). **Monsoon** is the rainy season from the middle of June to the end of September (maximum rainfall in July and August, and the average annual rain is around 1200 mm). **Winter** lasts from November to February (with night temperature dropping to -20C during December and January).

The weather is rainy season-like, with significant seasonal changes in temperature and rainfall. The average yearly rainfall is around 1623 mm, most of which falls during the monsoon season (Negi and Shukla 2011).

2.1. Flora

The vegetation of the park has initially been categorized into three broad types. These are sal forest, mixed forest and grasslands (Parihar & Kotwal, 1989). According to the (Champion & Seth, 1968), vegetation is classified in KTR: Moist Sal Forests (3C/C2), with subgroups High and low-level of Sal (3C/C2 ci); and Miscellaneous Forests (3A/C2), with subgroups Southern Tropical Dry Mixed Deciduous Forest, Southern Tropical Moist Deciduous Forest, and Grassland. The floral diversity includes over 850 species of angiosperms, 22 species of Pteridophytes, and two species of Gymnosperms (Pandey & Namdeo, 2009). The protected area's flora also comprises approximately 18 kinds of rare plants and 50 species of aquatic plants. Poaceae, with 109 species, is the dominant family in the National Park. The woody species (Butea monosperma, Lagerstoemia parviflora, Diospyros melonoxylon, Shorea robusta, Lagerstroemia parviflora, Anogeissus latifolia, Pterocarpus marsupium) are seen on various stages of growth in the grasslands. Besides, several species of aquatic plants are found in the National Park's various waterbodies (Parihar & Kotwal, 1989). There are many species of weeds, shrubs, grasses and climbers.

Wild Fauna, Habitats & Trophic Niches

Geography, topography, environment, and precipitation add to choosing the kinds of vegetation and natural surroundings of wild creatures in an untamed life biological system. The Tiger Reserve harbours level peaks and shifting inclines, providing unique settings and ecotones for creating various forms of untamed living natural environments, moulding appropriate specialities for various plants and animals. There are over 300 bird species and 43 mammal species. Insect, reptile, termite, and arthropod species can also be found in the Reserve. (Gopal & Shukla, 2001).

In Kanha Tiger reserve, mostly herbivores to be found are Chital (Axis axis), Sambar (Cervus unicolor), Barasingha (Cervus duvauceli branderi), blackbuck (Antelope cervicapra), Chousingha (Tetracerus qadricornis), Barking deer (Muntiacus muntjak), Gaur (Bos gaurus), Langur (Presbytis entellus), Wild pig (Sus scrofa). Among the main **predators** are the (Panthera tigris, Panthera pardus, Cuon alpinus, Canis aureus, Felis chaus, & Prionailurus rubiginosus). Whereas the Sloth bear (Melursus ursinus) is an omnivore. The habitat of Kanha National Park offers an ideal place for a variety of avifauna, reptiles and insects.

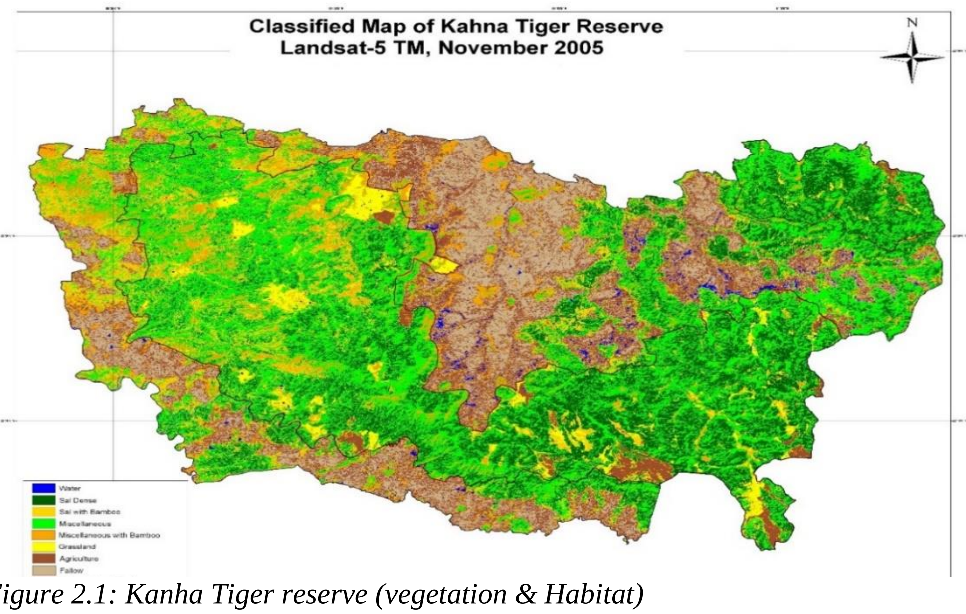


Figure 2.1: Kanha Tiger reserve (vegetation & Habitat)

Kanha Tiger reserve (vegetation & Habitat)

The Kanha-Pench corridor is important in facilitating tiger movement between the Kanha and Pench Tiger Reserves. The corridors encompass approximately 16,000 km2 of area, and this corridor serves as a refugee region. It is home to various animals, including leopard, wild dog, sloth bear, hyena, wolf, Indian gaur, sambar, and spotted deer. The Mandla forest division is an important component of the Kanha-Pench corridor. This division protects the Kanha Tiger Reserve. As a result, this area plays an important role in tiger or leopard distribution. The Balaghat forest division is also significant for the Kanha-Pench corridor as it serves as a haven for prey and dispersion tigers.

Another corridor, the Kanha-Achanakmar Corridor, connects the Kanha and Achanakmar tiger reserves via a wildlife sanctuary. This corridor is especially important for tiger or leopard distribution. It acts as a tiger breeding ground between two reserves, and many animals can be spotted here.

CHAPTER 3: OCCUPANCY AND INTERACTIONS OF CARNIVORE MAMMALS GUILD IN KANHA TIGER RESERVE

3.1. Introduction

Carnivores predominantly positioned at the top of the ecological hierarchy have wide-reaching influences on ecological structure and processes. Carnivores both directly or indirectly check and balance the population and behaviour of the lower order organisms vital to maintaining a balance of the ecosystem (Roemer, G.W., Gompper, M.E. and Van Valkenburgh, B., 2009). In addition, carnivores, with their majestic nature and fascinating appearance, have always been in the limelight; hence, their significance can be reflected in the history of our art, culture, mythology, and scientific research. However, the recent increase in the resource demand followed by human developmental activities has exaggerated significant negative consequences to these groups of animals. It has also been noticed that due to certain biological characteristics, this group of mammals has been extensively threatened by these developmental activities. In these contexts, a few recent studies have revealed that around 60% of the world's carnivores are on the verge of extinction, where conservation intervention is paramount for their future persistence (Ripple et al. 2014; Carter et al. 2015). Hence, concerns are growing across their distributional ranges to maintain their population with effective management planning and interventions implemented. Carnivore conservation generally focuses on the protection or rehabilitation of its native populations, and the achievement is frequently measured in terms of the sustainability of the preserved or restored population (Hayward et al. 2007).

Protected areas have always played a pivotal role or acted as a cornerstone in the conservation science field, particularly in the era of escalating human footprints on ecosystems and biodiversity (Nelson and Chomitz, 2011). Conservation organizations and governments frequently utilize information on the number of protected areas, the area under protection, and conservation spending to demonstrate their dedication to conservation programs. Given the extensive space requirements, conserving large carnivores requires protected areas and multiple-use zones within the human-dominated matrices to facilitate dispersal (Wikramanayake et al. 2011). Nevertheless, the protected area is regarded as an indicator of conservation inputs, but it does not provide an evaluation of conservation efficacy in terms of habitat protection and biodiversity preservation (Nelson and Chomitz, 2011). On the other hand, area-specific assessments of large carnivore communities have a far-reaching influence on spatial partitioning between apex and mesocarnivores (Ritchie & Johnson 2009; Brook et al. 2012; Davis et al. 2018), temporal or spatial partitioning between predators and their prey (Miller et al. 2012; Davis et al. 2018) or between potentially competing carnivores' interactions. Thus, understanding interactions among species and competition for resources are essential for systematic planning and proper biodiversity conservation.

The presence of apex predators in an ecosystem may harm other carnivores and subsequent trophic levels. Therefore, monitoring these species of such great ecological significance is paramount to assessing their population trends and distribution pattern. Tigers (Panthera tigris) and leopards (Panthera pardus) are cryptic felids whose elusive nature and low densities barely enable us to count them (Bailey, 1993; Karanth and Nichols, 1998; Barlow et al. 2009). However, the advent of modern tools and technologies has made the task possible. The arrival of camera traps can easily estimate the population of the marked species. However, as other carnivores like sloth bear and dhole do not have the unique mark on their body, it is not easy to estimate their population size. In these cases, the occupancy method can be applied to gain information sufficient to understand the carnivore community in a particular ecosystem. In addition, multi-season occupancy models can also be of great significance for understanding the long-term dynamics of the carnivore guild.

In this study, we employed extensive camera trapping data for two years, 2014 and 2016, to study the dynamics of the dispersion and interspecific interactions of large and mesocarnivores in Kanha tiger reserve, central India. It is anticipated that the findings will aid in the conservation and management planning of species in this protected area.

3.2. Materials and methods

Camera trapping

Camera trap data were collected during three successive seasons (December 2014- April 2015 and January- May 2016) in all the available habitat types in the KTR (Kanha Tiger Reserve). Due to logistical constraints, the survey was undertaken during the winter of 2015 (after this survey II) only covered the core division and did not sample the buffer division. Forest (KTR) in the buffer zone, although the winter 2016 survey (after this survey III) encompassed the entire core and buffer division (Figure 3.1 CAMERA TRAP LAYOUT), due to the limited availability of camera percentages, camera trapping was done in phase-wise (block-by-block) manner. I used three digital camera models in this research (Moultrie, Cuddeback ambush/C, and Reconyx). Moultrie (Moultrie GS D40, MOULTRIE), Cuddeback (ambush/C), and Reconyx H500 are infrared light cameras that operate freely and use heat and motion sensors to monitor movement and temperature in a specific region. Whenever an animal crosses in front of any camera, the sensor detects movement and temperature changes and triggers the camera to snap an image. The trap stations were, spaced 500 m to 1 km apart. The camera traps were placed approximately 40-45 cm from the ground, and the distance between the two cameras was maintained at 3-6 meters. The camera trap was set to work 24 h/day. The cameras were placed in KTR on forest trails, dry nullahs, near water holes, jungle roads, stream beds, ridge tops, animal trails, termite mounds and fruiting trees etc., to maximise the probability of animal detection. The cameras were reviewed every one to three days to ensure proper operation and battery life and to capture the existence of animal footprints. The photographs provided spatial and temporal information such as locations and the date and time stamp information. In each habitat, a camera trap was sampled for 35 days. The camera trap intensity is provided in table 3.1.

Table 3.1 Details of camera traps sampling in all available habitats of the Kanha Tiger Reserve

Year	#of CT Points	#of Occasion	Trap night
2014	**752**	**35**	**26,320**
2015	**384**	**35**	**13,440**
2016	**779**	**35**	**27,265**

As sloth bears are known to feed on termites, the present study recorded the termite availability at every camera trap station. At each camera trap station, the present study measured the number of active termite mounds in the proximity (50 m radius) and the subterranean termite colonies in the 10 m radius plot.

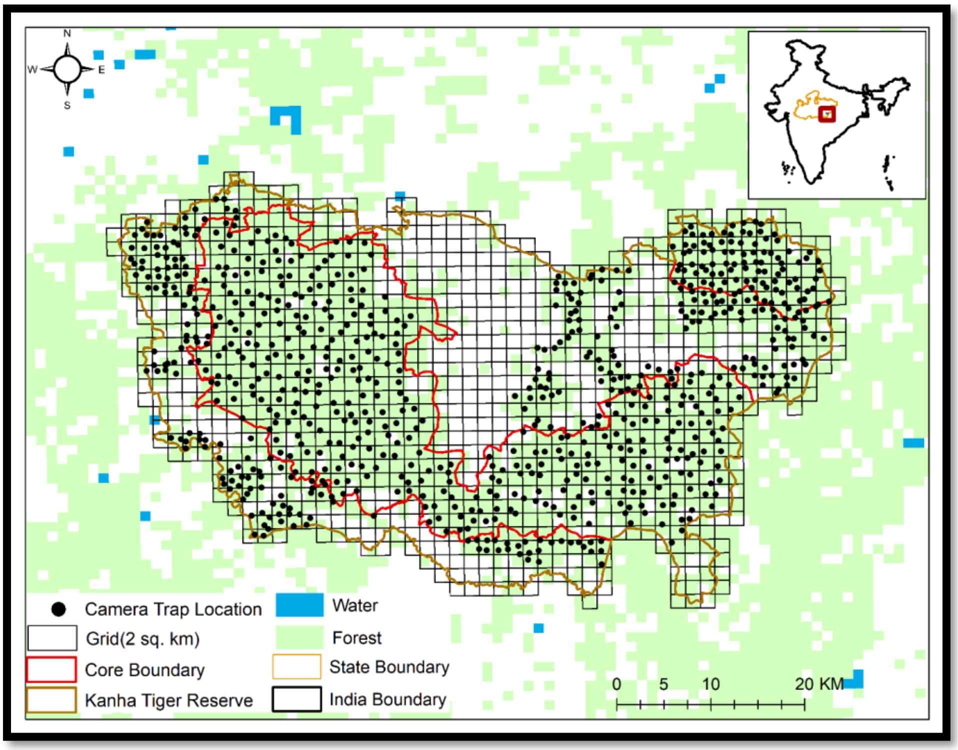


Figure 3.1: Camera trap deployment Location

Sampling habitat:

A transect survey is a popular method for studying animal populations. In its broadest meaning, a transect is a present line, which might be an undisturbed road, path, river, or a line chosen for whatever purpose. A transect survey entails travelling along this line and making qualitative or quantitative observations, depending on the study's objectives (Mathai, 2013). A transect is a line that runs through habitat or a portion of an ecosystem. It might be as basic as a thread or rope strung across the ground. At regular intervals, the number of creatures of each species along a transect may be examined and recorded. Line transect survey techniques have been employed in tropical forests to assess population density for a range of mammal species. Because of the low visibility in these woods, indirect techniques of assessing animal signals, such as counts of faeces or nests, have been utilised in several situations. The estimations of the generation and decomposition rates of these signs each have associated mistakes; however, for the vast majority of published research, these errors have not been included in the calculation of the standard errors or the density estimate's confidence bounds.

I was monitoring mammal populations with line transect techniques in African forests. Vegetation sampling was done on the same transect line by laying three concentric circular plots at every 400m interval on the transect line. The following parameters were collected in the datasheet (Daubenmire and Daubenmire 1968; Jhala et al. 2006 and 2010). In a 15 m circular radius plot, all dominant tree species were counted. The data on human impacts and number of trees cut, number of trees lopped, grass or bamboo cutting, termite mount count, presence of humans or livestock trail was noted.

In a 5 m radius plot, all shrub species were noted with their abundance. The shrub cover inside the plot was visually estimated by assuming the bare ground percentage visible.

In a 1m radius plot, we recorded the proportion of ground covered by herbs, grasses (green and dry), weeds and bare ground; three dominant herb species and their dominance in order were also noted.

Sampling ungulate occurrence:

At every 400m along the transect (line of walk), we sampled an area of 2X20 m perpendicular to the transect for quantifying ungulate pellets. Total pellets on each plot were identified based on external features to assign species. The plot was placed alternately to the right and left of the transect at every 400m. The topography and forest type were recorded for each plot, even if pellets were not seen.

Transects were walked for three successive years, covering the winter and summer seasons (December 2014- April 2015 and January- May 2016) in all the available habitat types in the KTR (Kanha Tiger Reserve). A total of 222 transects were covered each season with an effort of 1332 km for sampling habitat and pellet plots. A total of 1332 habitat and pellet plots were sampled with an average of 6 plots per beat.

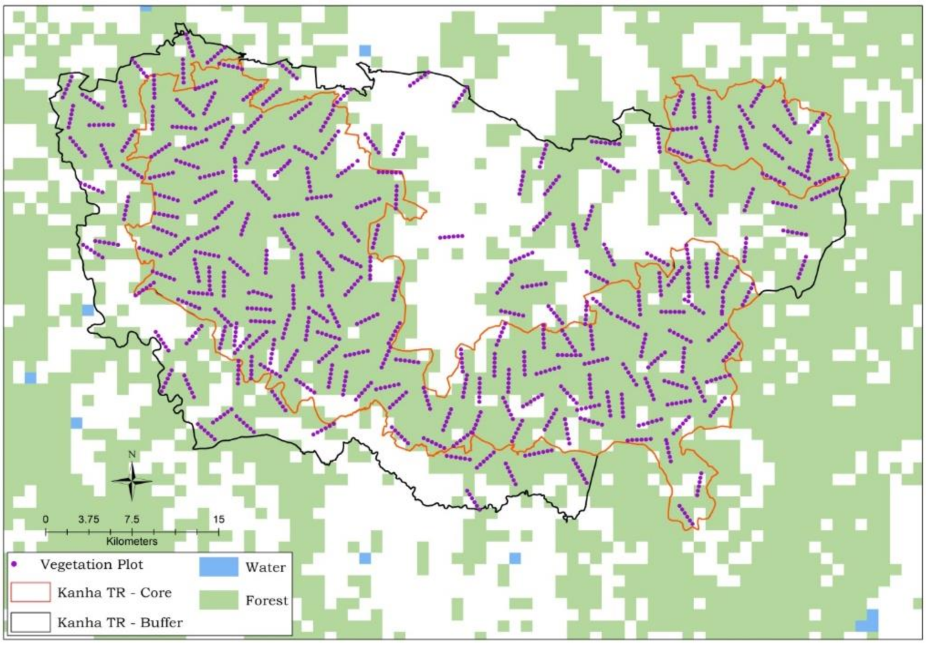


Figure 3.2: Transect and plot map

Environmental variables:

Grassland: In grasslands, it is easy for the carnivores to capture the prey because of the long and clear visibility; hence, usually preferred by the large carnivores. Grasslands make a good habitat for Jackals when it comes to den site selection (Atkinson, R. P. D., et al. 2002). Jungle cats are commonly found in grassland because of prey like rodents, lizards, and ground-nesting birds (Mukherjee, S., et al. 2010). Sloth bear prefers grasslands in the dry season and moves to upland Sal forests during the wet season, possibly to facilitate feeding on termites (Ratnayeke, S., et al. 2007). In general, grasslands are proxies for the abundance of rich food resources to most carnivores; hence, proximity to grasslands would be an important covariate.

Protected area (core): In the core area, the disturbance is less, the condition of the habitat is good, and the density of the prey is high (Awasthi et al. 2016). If the distance increases from the core area, the density of prey is reduced, and the disturbance increases. Sloth bear prefers a mosaic of heterogeneous vegetation cover, which is available more in the core. The leopard has been frequently encountered in the core area because the diversity and encounter rate of prey is high with less disturbance in a good habitat condition. Prey density plays an important role in maintaining tiger density. (Karanth, K. U., & Sunquist, M. E. 1995). Hence, as the distance from the core increases, the umbrella effect of protection on the occurrence of carnivores can be expected to reduce.

Human settlement: The wild carnivores often prefer to stay near human habitation because of the easy availability of food in the form of livestock or feral dogs. Also, in the case of the multi-predator ecosystem, where the landscape of fear occurs from the top ordered predators, the sub-ordinates are often found to avoid the core area occupied by the top order carnivores and prefer to occupy the fringe area of the forest near human settlements with subsidiary resources available for them. Hence, human settlements are considered significant environmental variables while assessing the ecological study of wildlife.

Tiger density: As an apex predator, the primary hunter for all other species. It also exerts the landscape of fear which contribute significantly to the alteration of the behaviour and activities of the lesser-sized animals. High tiger density also contributes to increased competition among the other sympatric species for the available resources. Hence, it is considered one of the important parameters.

All prey: Prey species are the most important covariates for carnivores which include small ungulates (<30kg), medium (30-175 kg), and large-sized ungulates (>176 kg) (Karanth., 2013). Small ungulates consist of animals like Chowsingha (15-25 kg), barking deer (20-28 kg) and mouse deer (2-4 kg). Medium ungulates include chital, weighing around 85 kg (Prater 1971). Large-sized ungulates comprise Sambar (males 225 to 320 kg, females are smaller and weigh about 135 to 225 kg), Nilgai 200 kg (Sankar 1994, Walker 1964), Barasingha whose females weigh around 140-145 kg female and males weigh around 170-200 kg and wild pig 45-320 kg.

Carnivore density: If tiger density is high, the jackal distribution is high. The effect of jackal distribution depends on the carnivore density. Predators like tigers and leopards may pose a threat to the cubs. Rather than sending their cubs up trees, sloth bear moms take babies up trees as their major defence against predator assaults. Tigers target sloth bears by hiding nearby termite mounds (Garshelis, D. L., et al. 1999).

Habitat cover: Habitat cover was taken as the important variable. It has a close association with the animals present in it. Jackal would likely prefer denser vegetation indicated by a higher Normalized Differential Vegetation Index (NDVI) (Aiyadurai, & Jhala, Y. V. 2006). It was found that jungle cats largely use high canopy cover (indicated by high NDVI values). In general, it provides food, shelter, and protection to the animals necessary for survival.

Another prevalent pattern was with the food resources (for tiger: Chital, sambar, barasingha, gaur; for leopard: chital, sambar, barasingha, gaur, barking deer, langur, chowsingha; for dhole: chital, sambar, barasingha, barking deer, chowsingha; for sloth bear: Euclidean distance from termite mounds and fruiting trees; for jackal: Euclidean distance from fruiting trees and agriculture; for jungle cat: Euclidean distance from agriculture as it is an important source of rodents), where carnivores were in high abundance when the food resources were high or in its proximity. Thus, these four categories of site characteristics were used to model species occupancy.

Relationship in carnivore occurrence and habitat information:

Using the camera trap photographs of the study species obtained during every sampling season, the average relative abundance index (RAI) of every species across the tiger reserve was calculated. For doing so, first, the independent species captures were obtained by thinning the camera trap photographs by 30 minutes to remove all images of the same individual who spent more time in front of the camera. After this, the following formula was used to derive the RAI:

$$\boldsymbol{RAI} = \frac{(\boldsymbol{Total\ independent\ captures})\ \boldsymbol{x}\ \mathbf{100}}{(\boldsymbol{Total\ camera\ trap\ nights})}$$

This provided RAI values of every species for every camera trap at every season. Subsequently, a 2 sq. km grid was created in GIS for the tiger reserve and spatially, the RAI values of all camera traps in every grid cell were averaged across the seasons. Thus, the product revealed the average occurrence of species under study across the tiger reserve during the sampling season.

Further, the aforementioned environmental layers for every grid cell were averaged to indicate the site characteristics. These site characteristics, if indicative of the habitat selectivity of the species, would follow a pattern where the species RAI would be higher in the preferred habitat and lesser in the less preferred habitat. To check this pattern, an exploratory analysis was done using a box and whisker plot, where the author divided RAI values for every species into 5 abundance categories based (0 = absent, 1-25% = Low, 25-50% = Moderate, 50-75% = High, 75-100% = Very high) and plotted against the environmental covariates. The most significant patterns, which could be ecologically explained, are shown in Figure 3.3.

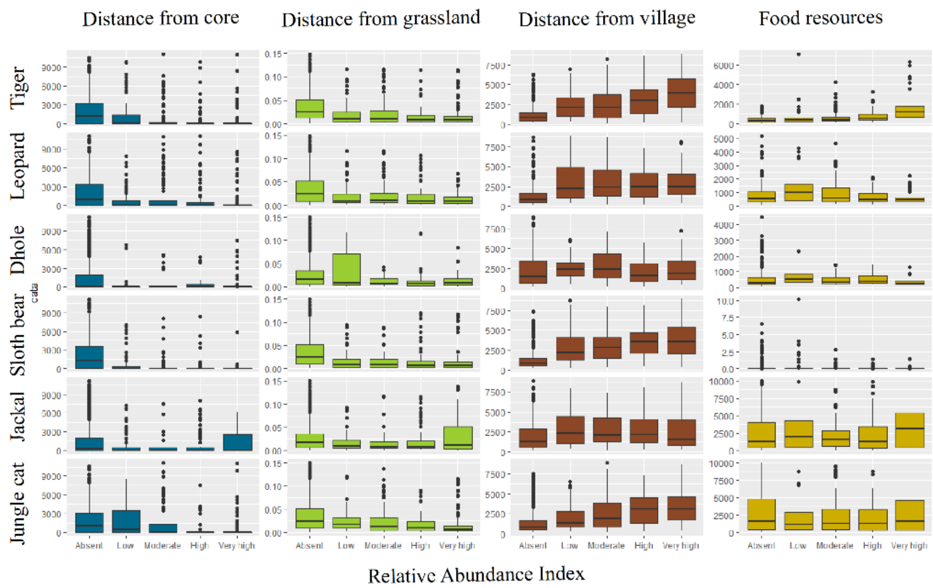


Figure 1.3 The relationship between the relative abundance of carnivores and environmental variables

Modelling approach Multiseason

A carnivore detection history was prepared (e.g., 010010) for every camera station, consisting of binary values with “1’’ indicating species present during the sampling occasion and “0” indicating absence (Otis et al. 1978). The survey period is 35 days. A 1.41 x 1.41km grid was set up for carnivores in Kanha Tiger Reserve. Detection records were combined for two years at this study location and inputted as multi-season models in PRESENCE v.13.10 (Proteus Wildlife Research Consultants, New Zealand; http://www.proteus.co.nz).

Several models incorporating covariates were used based on the primary hypothesis and correct for the imperfect detection of the occupied area. The theory proposed that carnivore occupancy and colonisation might be highly associated with the availability of prey, the quantity and quality of habitat and its quality in night lights, protected areas, human impacts, fruiting trees, and termite mounds documented all through ground surveys and that it would be inversely related with occupancy and colonisation and highly associated with patch extinction (Jhala et al. 2020). The covariates are occupancy intercepts and big prey, colonization intercepts and big prey, extinction intercepts and distance from core and detection year 1 and year 2. Along with the Distance from the moist forest, Distance from Grassland, Distance from Agriculture, Tiger density, leopard density, Ruggedness, Distance from the core, and Distance from Human settlement, these covariates were linearly transformed and normalized (Z-scores). To account for model uncertainty, models are assessed using the Akaike Information Criteria (AIC). Parameters are estimated from possible alternatives, which differ by 5 AICs and were averaged based on model weights (Akaike 2011). In addition to multi-season occupancy, colonisation and extinction levels, occupancy and detection probability, as defined by MacKenzie et al. (2018), were approximated together with covariates that can provide ecological perspectives on such important environmental methods and site characteristics to guide planning and management.

3.3. Results:

Tiger: Amongst the competing multi-season occupancy models (table 3.2), the best model explaining occupancy dynamics of tigers (table 3.3) revealed an ecologically known relationship with the site characteristics. The initial occupancy (the year 2014) had a positive relationship to big prey species availability in the year 2014; colonization from 2014 to 2016 was positively related to big prey availability in the year 2016; extinctions (i.e., reduced habitat uses) were positively related to least forested areas (negative NDVI) away from the core region. Though tiger occupancy increased from 2014 to 2016 (Figure 3.4), the difference was not significant after considering the confidence intervals for both years.

Table 3.2: Models under consideration for predicting the variables of tiger occupancy (Ψ), colonization (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve. The model with the lowest AIC was chosen as the best model for describing the species' occupancy

Model	**AIC**	**Delta AIC**	**no. Par.**
Ψ(BP14), γ(BP16), ε (DC, F), P (1, year)	15669.47	0	9
Ψ(BP14), γ (BP16), ε (DG, DC), P (1, year)	15848.47	179	9
Ψ(BP14), γ (BP16), ε (DG, DH), P (1, year)	15856.13	186.66	9
Ψ(BP_{14}+DG), γ (BP_{16}+DC), ε (DH), P (1, year)	15858.79	189.32	10
Ψ, (1)γ (1), ε (1), P (1)	15878.89	209.42	4
Ψ(BP14+DH), γ(BP16+DG), ε (DC), P (1, year)	15884.42	214.95	10
Ψ(BP14+DC+DG), γ(BP16), ε (1), P (1, year)	15893.99	224.52	9
Ψ(BP14), γ(BP16), ε (1), P (1, year)	15899.39	229.92	7
Ψ(BP14+DC+DH), γ (1), ε (1), P (1, year)	15901.14	231.67	8
Ψ(BP14), γ(BP16), ε (DG), P (1, year)	15901.39	231.92	8
Ψ(BP14+DC+DH+DG), γ (1), ε (1), P (1, year)	15901.83	232.36	9
Ψ(BP14), γ (BP16), ε (DG, F), P (1, year)	15903.39	233.92	9
Ψ(BP14+DC), γ (1), ε (1), P(year)	15911.48	242.01	7
Ψ, (1)γ (1), ε (1), P (1year)	16048.84	379.37	5

(DG: distance from grasslands, DH: distance from human settlement, DC: distance from the core, F: NDVI, BP: Big prey)

Table 3.3 Statistics for the best model explaining tiger occupancy (Ψ), colonisation (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve

Parameter	**Covariates**	**Estimate**	**SE**
Ψ	Intercept	0.519187	0.138573
Ψ	Big prey14	1.939664	0.323594
γ	Intercept	0.251075	0.246938
γ	Big prey16	1.815205	0.511762
ε	Intercept	-0.95357	0.173194
ε	Distance from core	1.296098	0.210592
ε	NDVI	-0.36866	0.184138
P	Year 1	-2.18491	0.036521
P	Year 2	-2.24057	0.031902

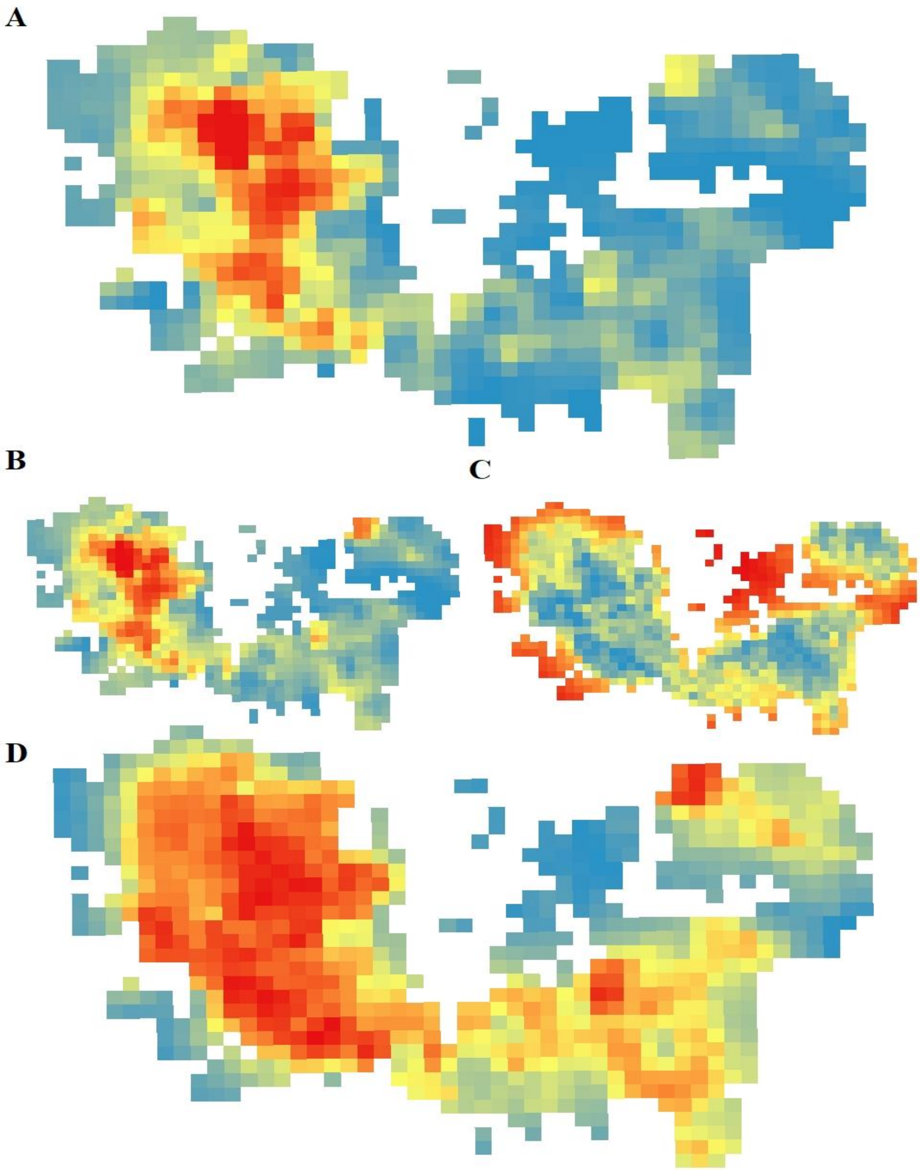


Figure 3.4: Occupancy of Tiger in Kanha Tiger Reserve for the years 2014 (A) and 2016 (D) and colonization (B) and extinction (C) during these years. Here the occupancy represents habitat use

Leopard: The best model amongst the competing multi-season occupancy models (table 3.4) explains that the occupancy dynamics of leopards were positively correlated with terrain ruggedness as tigers less use it (table 3.5). The result also showed that leopard occupancy had a positive relationship with distance from the core as the tiger occupancy increased from 2014 to 2016 (Figure 3.5) in the core region of KTR.

Colonization from 2014 to 2016 was negatively related to distance from the core and positive with the tiger density in 2016; extinctions (i.e. reduced habitat use) were negatively related to most minor forested areas (positive tiger density) away from the human settlement region. Though leopard occupancy increased from 2014 to 2016 (Figure 3.5), the difference was insignificant after considering the confidence intervals for both years.

Table 3.3: Models under consideration for predicting the variables of leopard occupancy (Ψ), colonization (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve. The model with the lowest AIC was chosen as the best model for describing the species' occupancy

Model	**AIC**	**Delta AIC**	**No.Par.**
Ψ (R, DC), γ (TD16, DC), ε (DH), P (1, year)	12940.51	0	10
Ψ(TD16 ,R), γ (DC), ε (DH),P (1,year)	12941.22	0.71	9
Ψ(R,DH,DC), γ (TD16 , DC), ε (DH),P (1,year)	12942.09	1.58	11
Ψ(TD16 ,DG_R), γ (DC), ε (DH),P (1,year)	12943.05	2.54	10
Ψ(R_TD14), γ (TD16 , DC), ε (DH),P (1,year)	12943.7	3.19	10
Ψ(R), γ (TD16, DC), ε (DH),P (1,year)	12943.81	3.3	9
Ψ(R_TD14 ,DG), γ (TD16 , DC), ε (DH),P (1,year)	12945.54	5.03	11
Ψ(TD16 ,DG,AP14), γ (DC), ε (DH),P (1,year)	12950.97	10.46	10
Ψ(TD16 ,DG), γ (DC), ε (DH),P (1,year)	12952.62	12.11	9
Ψ(DG,DH,DC,TD14), γ (TD16 , DC), ε (DH),P (1,year)	12957.18	16.67	12
Ψ(R,DC), γ (TD16), ε (DH),P (1,year)	12962.02	21.51	9
Ψ(TD16 ,DC), γ (DG), ε (DG,F),P (1,year)	12965.67	25.16	9
Ψ(TD16), γ (DH), ε (DG,F),P (1,year)	12972.52	32.01	9
Ψ(TD16 ,DC), γ (1), ε (1),P (1,year)	12985.5	44.99	7

Ψ(1), γ (1), ε (1),P (1,year)	12985.66	45.15	5
Ψ(TD16 ,DG,DH), γ (1), ε (1),P (1,year)	12986.82	46.31	8
Ψ(R,DC), γ (TD16 ,Prey), ε (DH),P (1,year)	12986.95	46.44	10
Ψ(DG,DH,DC,TD14), γ (TD16 , DC), ε (TD16,DH),P (1,year)	13143.33	202.82	13

(DG: distance from grasslands, DH: distance from human settlement, DC: distance from the core, F: NDVI, BP: Big prey, AP: All prey, R: Ruggedness, TD: Tiger density, LD: Leopard density)

Table 3.4: Statistics for the best model explaining leopard occupancy (Ψ), colonisation (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve

Parameter	**Covariate**	**Estimate**	**SE**
Ψ	Intercept	0.521587	0.115778
Ψ	Ruggedness	0.431141	0.111962
Ψ	Distance from core	0.263398	0.124029
γ	Intercept	-0.75267	0.545091
γ	Distance from core	-2.11475	0.967552
γ	Tiger density	0.087078	0.137755
E	Intercept	-1.17426	0.16646
E	Distance from Human settlement	-0.39731	0.215986
P	Year 1	-2.5418	0.04809
P	Year 2	-2.59628	0.03807

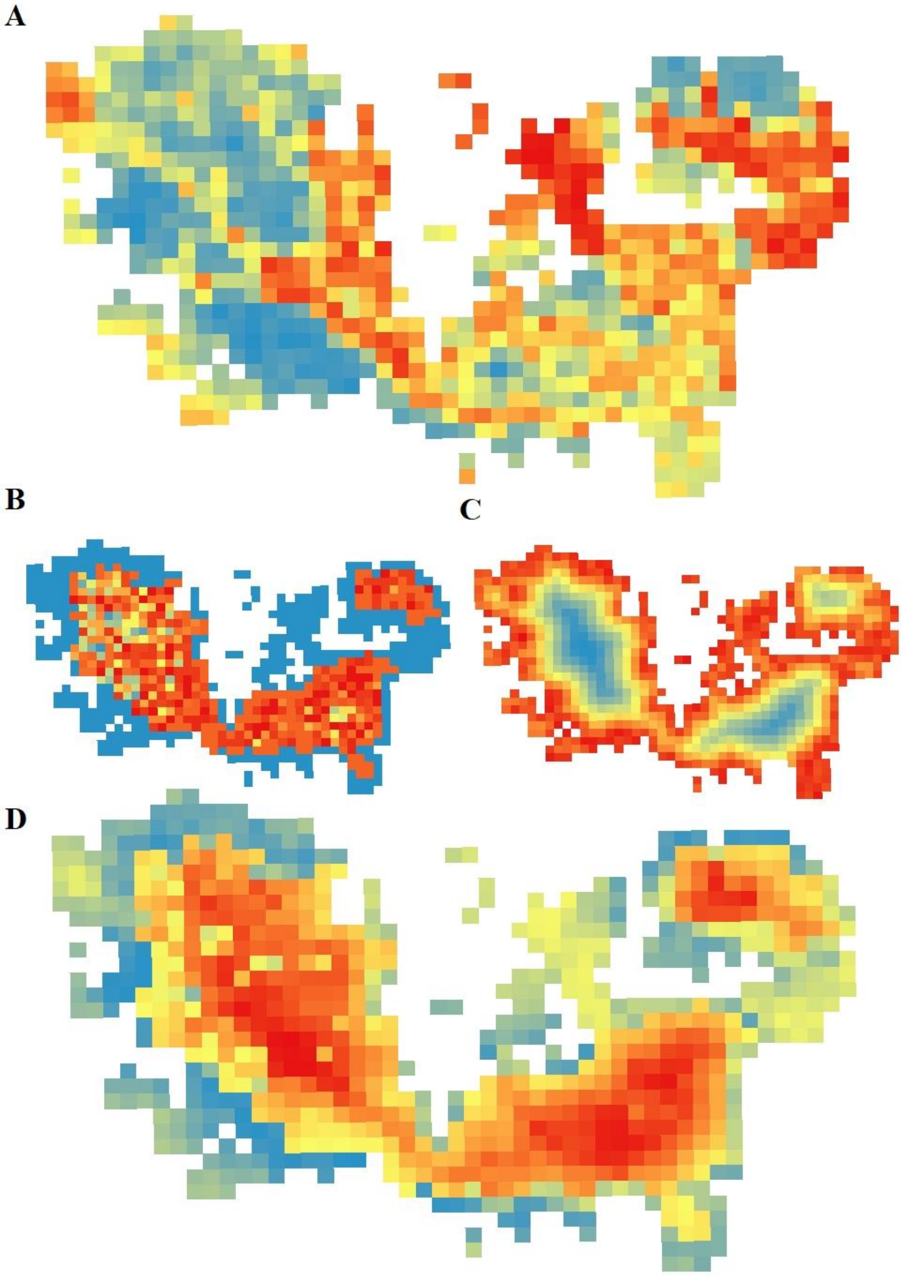


Figure3.5: Occupancy of Leopard in Kanha Tiger Reserve for the years 2014 (A) and 2016 (D) and colonization (B) and extinction (C) during these years. Here the occupancy represents habitat use

Dhole: Apparent the competing multi-season occupancy models (table 3.6), the top model explaining occupancy dynamics of dhole (table 3.7) was ecologically recognized with the site characteristics. The initial occupancy (the year 2014) had an antagonistic relationship between distance from grassland, distance from the core, and distance from a human settlement in 2014 and also negatively related to tiger density colonization from 2014 to 2016. In 2016 dhole occupancy was negatively related to distance from human settlement, grassland and core area of the forest; however, the extinction positively correlates with leopard density. Through dhole, occupancy was high in 2014 compared with 2016(Figure 3.6), but the differences were not significant after considering CI for both years.

Table 3.5: Models under consideration for predicting the variables of Dhole occupancy (Ψ), colonization (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve. The model with the lowest AIC was chosen as the best model for describing the species' occupancy

Model	**AIC**	**Delta AIC**	**no. P ar.**
Ψ (DG, DC, DH, TD14), γ (DH, DG, DC), ε (LD16), P (year)	1905.42	0	13
Ψ (DG, DC, DH, TD14), γ (DH, DG, DC), ε (TD16), P (year)	1906.35	0.93	13
Ψ (DG, DC, DH, TD14), γ (DH, DG, DC), ε (TD16, LD16), P (year)	1907.3	1.88	14
Ψ (SP, DC, DH, TD14, γ (DH, DG, DC), ε (TD16), P (year)	1908.5	3.08	13
Ψ (DG, DC, DH, TD14, γ (DH, DG, DC, SP16), ε (TD16, LD16), P (year)	1909.07	3.65	15
Ψ (DG, DC, DH, TD14, γ (DH, DG, DC, SP16), ε (TD16, LD16), P (year)	1909.07	3.65	15
Ψ (DG, DC, DH, TA14, γ (DH, DG, DC, SP16), ε (TG, LG), P (year)	1913.12	7.7	15
Ψ (DG, DC, DH, TD14, γ (DH, DG, DC), ε (LD16), P (year)	1914.67	9.25	13

Ψ (SP, DC, DH, TD14, γ (DH, DG), ε (TD16), P (year)	1918.11	12.69	12
Ψ (SP, DC, DH, TD14, γ (TD16, DG), ε (TG), P (year)	1921.61	16.19	12
Ψ (SP, DC, DH, TD14, γ (SP16, DG), ε (TD16), P (year)	1921.79	16.37	12
Ψ(SP,DC,DH,TA14, γ (1), ε (1), P (year)	1923.24	17.82	9
Ψ(SP,DC,DH,TA14, γ (TA16), ε (1), P (year)	1925.08	19.66	10
Ψ(SP,DC,DH,TA14, γ (TA16), ε (TG), P (year)	1926.84	21.42	11
Ψ(1,SP, TD14), γ (1,SP16,DC), ε (1,DH), P (1,year)	1943.79	38.37	10
Ψ(1), γ (1), ε (1), P (1,year)	1956.81	51.39	5
Ψ(1,SP, TD14 ,DC), γ (1,SP16,TD16), ε (1,DH), P (1,year)	1957.05	51.63	11
Ψ(1,SP, TA14,DC), γ (1,TG), ε (1,DH), P (1,year)	1961.37	55.95	10
Ψ(1,SP, TA14,DC), γ (1,SP16,TA16), ε (1,DH), P (1,year)	1964.68	59.26	11
Ψ(1,SP+DC), γ (1,SP16), ε (1), P (1,year)	1976.35	70.93	7
Ψ(1,SP), γ (1,SP16), ε (1), P (1,year)	1978.79	73.37	7

(DG: distance from grasslands, DH: distance from human settlement, DC: distance from the core, TR: Tiger RAI, TG: tiger growth, SP: small prey, TD: Tiger density, LD: Leopard density)

Table 3.6: Statistics for the best model explaining Dhole occupancy (Ψ), colonisation (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve

Parameter	**Covariate**	**Estimate**	**SE**
Ψ	Intercept	-0.65782	0.29558
Ψ	Distance from Grassland	-0.33059	0.224961
Ψ	Distance from core	-0.1807	0.208533
Ψ	Distance from Human settlement	-0.75368	0.2223
Ψ	Tiger density	-0.57711	0.248619
Γ	Intercept	-8.99755	3.825866
Γ	Distance from Human settlement	-3.47482	1.117668
Γ	Distance from Grassland	-1.95162	1.186708
Γ	Distance from core	-11.872	6.41076
E	Intercept	1.219138	0.379829
E	Leopard density	0.431339	0.441595
P	Year 1	-3.93511	0.210171
P	Year 2	-3.49905	0.171005

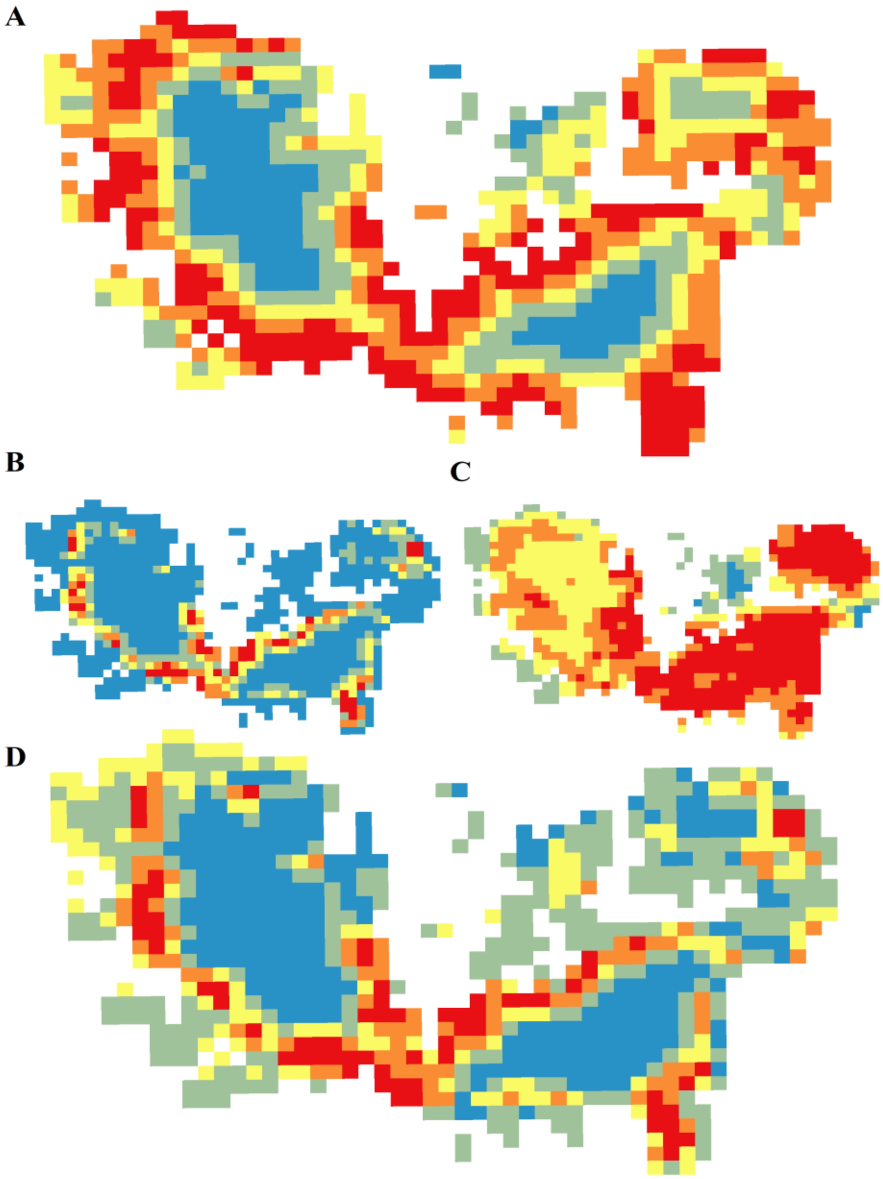


Figure 3.6: Occupancy of Dhole in Kanha Tiger Reserve for the years 2014 (A) and 2016 (D) and colonization (B) and extinction (C) during these years. Here the occupancy represents habitat use

Sloth Bear: Occupancy modelling result (table 3.8 & 3.9) explains variables such as distance from human and tiger density have a positive effect, and on the other side, variables such as distance from the core, distance from termites, and NDVI were negatively associated with the sloth bear occupancy in KTR. The initial occupancy

(2014) had a negative relationship with (reduced habitat) NDVI 2014. Colonization from 2014 was also negatively related to distance from the core and to tiger density; extinction was negatively related to human presence as it is located in low densities. The sloth bear occupancy in KTR from 2014 to 2016 is similar.

Table 3.7: Models under consideration for predicting the variables of Sloth bear occupancy (Ψ), colonization (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve. The model with the lowest AIC was chosen as the best model for describing the species' occupancy dynamics

Model	**AIC**	**Delta AIC**	**no. Par.**
Ψ (1,F+DT+DH),γ (DC+TD16),ε (HM),P (1,YEAR)	13186.57	0	11
Ψ (1,F+DT+DH),γ (DC+LD16 +TD16),ε (HM),P (1,YEAR)	13188.56	1.99	12
Ψ (1,F+DH+DC),γ (TD16),ε (LD16), P (1,YEAR)	13237.07	50.5	10
Ψ (1, F+DT), γ (DC), ε (DH), P (1,YEAR)	13273.57	87	9
Ψ (1,F),γ (DC),ε (DH), P (1,YEAR)	13274.62	88.05	8
Ψ (1,F+DC+DH),γ (TD16),ε (LD16), P (1,YEAR)	13302.74	116.17	10
Ψ (1,F+DC+DH),γ (LD16),ε (HM), P (1,YEAR)	13311.58	125.01	10
Ψ (1,F+DT+DC),γ (TD16),ε (DH), P (1,YEAR)	13312.81	126.24	10
Ψ (1,F+DC+DH),γ (TD14),ε (LD14), P (1,YEAR)	13314.88	128.31	10
Ψ (1,F+DC+DH),γ (DT),ε (HM), P (1,YEAR)	13322.16	135.59	10
Ψ (1),γ (1),ε (1), P (1,YEAR)	13387.48	200.91	5

(DH/HM: distance from human settlement, DC: distance from the core, DT: distance from termite, F: NDVI, TD: Tiger density, LD: Leopard density)

Table 3.8 Statistics for the best model explaining Sloth bear occupancy (Ψ), colonisation (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve

Parameter	**Covariate**	**Estimate**	**SE**
Ψ	Intercept	0.096178	0.105336
Ψ	NDVI	-0.1934	0.109978
Ψ	Distance from human	1.025269	0.132264
Ψ	Distance from Termite	-0.03347	0.092737
γ	Intercept	-1.49616	0.404946
γ	Distance from core	-3.19978	0.759767
γ	Tiger density16	0.303038	0.201416
ε	Intercept	-0.95358	0.175503
ε	Distance from human	-0.84447	0.246942
P	Year 1	-2.3555	0.039704
P	Year 2	-2.52331	0.038808

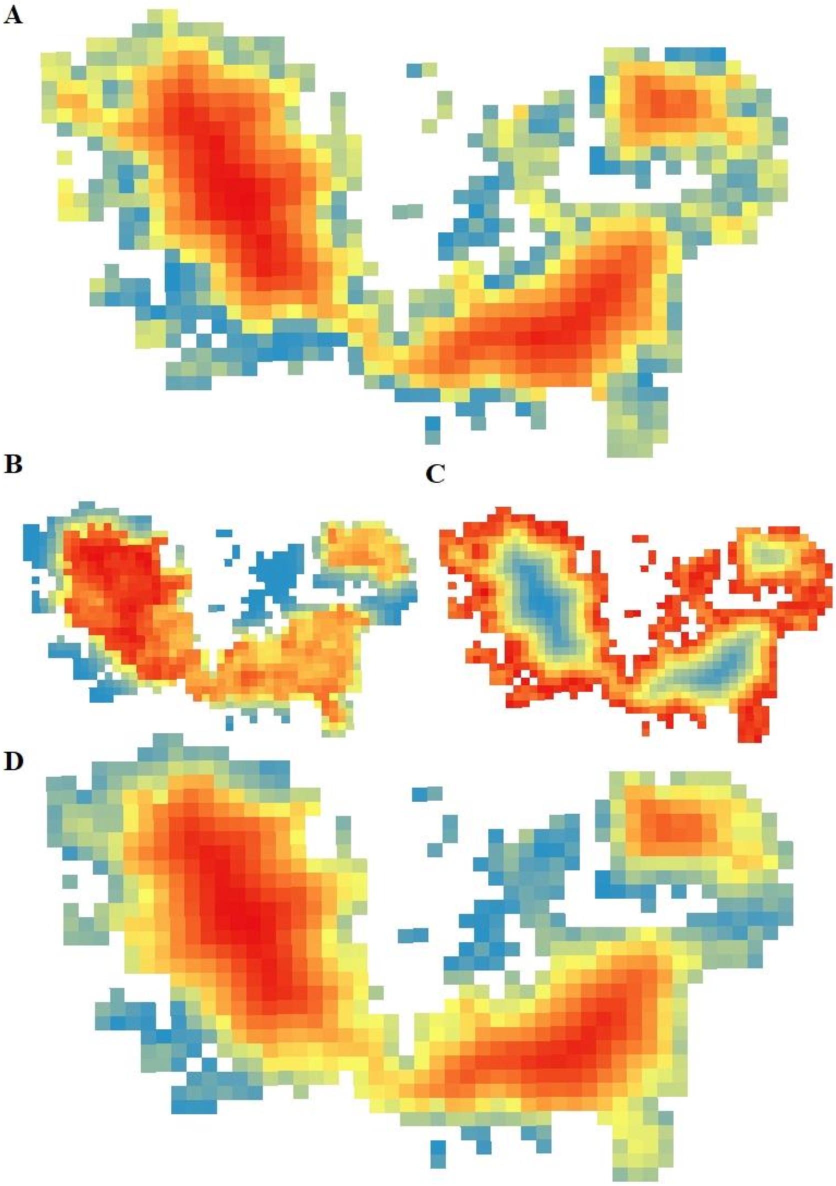


Figure 3.7: Occupancy of Sloth bear in Kanha Tiger Reserve for the years 2014 (A) and 2016 (D) and colonization (B) and extinction (C) during these years. Here the occupancy represents habitat use

Jackal: The occupancy model explaining the jackal occurrence in the KTR in 2014 had a negative relationship to moistness but positively related to distance from grassland and agriculture because the tolerance of jackal would likely prefer open vegetation. From 2014 to 2016, colonization was positively related to tiger density and leopard density; extinction (i.e., reduced small prey) was a negative relationship. Compared to 2014 and 2016, the jackal's occupancy was higher during 2016 (Table 3.10 & 11).

Table 3.9: Models under consideration for predicting the variables of Jackal occupancy (Ψ), colonization (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve. The model with the lowest AIC was chosen as the best model for describing the species' occupancy dynamics

Model	**AIC**	**Delta AIC**	**no. Par.**
Ψ (M+DG+DA), γ (TD16, LD16), ε (1, SP), P (1, YEAR)	10173.77	0	11
Ψ (M+DG+DA), γ (LD16), ε (1, SP), P (1, YEAR)	10174.36	0.59	10
Ψ (M+DG+DA), γ (TD16), ε (1, SP), P (1, YEAR)	10174.96	1.19	10
Ψ (M+DG+DA),γ (TD14),ε (1,SP),P (1,YEAR)	10176.25	2.48	10
Ψ (M+DG+DA),γ (TD14,ε (1,SP),P (1,YEAR)	10176.25	2.48	10
Ψ (M+DG+DA),γ (TD14),ε (1),P (1,YEAR)	10182.06	8.29	9
Ψ (DC+DG+DA+M),γ (TD16),ε (DH),P (YEAR)	10182.42	8.65	11
Ψ (M+DG+DA),γ (TD16),ε (1,DA),P (1,YEAR)	10182.6	8.83	10
Ψ (TA+DG+DA+M),γ (),ε (),P (YEAR)	10182.6	8.83	9
Ψ (DC+DG+M),γ (TD16+DG),ε (DA+SP),P (YEAR)	10182.71	8.94	12
Ψ (DC+DG+M+R),γ (TD16+DG),ε (DA),P (YEAR)	10184.65	10.88	12

Ψ (DC+DG+M+LD14),γ (TD14+DG),ε (DA),P (YEAR)	10184.92	11.15	12
Ψ (DC+DG+M),γ (TD16+DG),ε (DA),P (YEAR)	10185.36	11.59	11
Ψ (DC+DA+M),γ (TG+DG),ε (DH),P (YEAR)	10185.56	11.79	11
Ψ (DC+DG+M+R_TD14_LD14),γ (TD16+DG),ε (DA),P (YEAR)	10186.03	12.26	14
Ψ (DC+DM+DG+M),γ (TD16+DG),ε (DH),P (YEAR)	10186.25	12.48	12
Ψ (DC+DG+M+TD14),γ (TD16+DG),ε (DA),P (YEAR)	10187.33	13.56	12
Ψ (1),γ (1),ε (1),P (1,YEAR)	10196.87	23.1	5

(DG: distance from grasslands, DH/HM: distance from human settlement, DA: distance from agriculture, DC: distance from the core, SP: Small prey, TG: Tiger growth, R: Ruggedness, M: Moist, TD: Tiger density, LD: Leopard density, TA: Tiger RAI, DM/E: DEM)

Table 3.10 Statistics for the best model explaining jackal occupancy (Ψ), colonisation (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve

Parameter	**Covariate**	**Estimate**	**SE**
Ψ	Intercept	-1.13964	0.101413
Ψ	Distance from moist	-0.21154	0.104114
Ψ	Distance from Grassland	0.371819	0.106519
Ψ	Distance from Agriculture	0.249598	0.106989
γ	Intercept	-0.97688	0.107788

γ	Tiger density16	0.147342	0.090128
γ	Leopard density16	-0.18678	0.109087
ε	Intercept	-0.50097	0.183616
ε	Small Prery16	-0.55377	0.255293
P	Year 1	-1.74425	0.048122
P	Year 2	-1.93759	0.035391

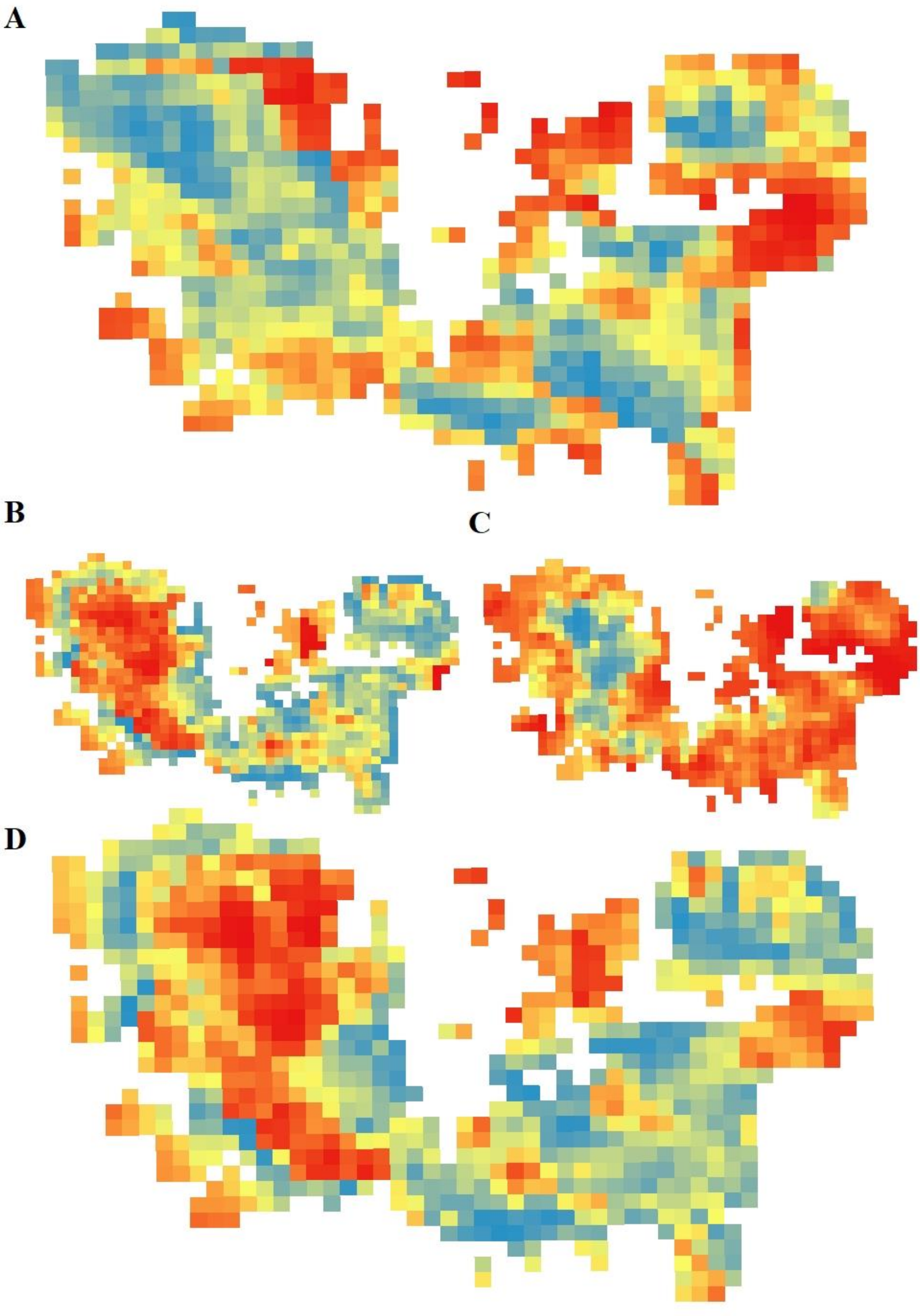


Figure 3.8: Occupancy of Jackal in Kanha Tiger Reserve for the years 2014 (A) and 2016 (D) and colonization (B) and extinction (C) during these years. Here the occupancy represents habitat use

Jungle Cat: In the case of jungle cat occupancy, the top model explaining occupancy dynamics (Table 3.12 & 3.13) was ecologically linked with the site characteristics. The initial occupancy (2014) had a positive relationship with DEM in 2014; Colonization from 2014 to 2016 was positively related to tiger density in 2016; extinctions were positively related to the forested areas. Jungle cat occupancy increased from 2014 to 2016 (Figure 3.9); the difference was less significant after considering the confidence interval for both years.

Table 3.11: l Models under consideration for predicting the variables of Jungle cat occupancy (Ψ), colonization (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve. The model with the lowest AIC was chosen as the best model for describing the species' occupancy dynamics

Model	**AIC**	**Dela AIC**	**no. Par.**
Ψ, (1+E+M+DA+TD_14), γ (1, TD_16), ε (1, DC), p (1, YEAR)	19759.17	0	11
Ψ, (1+E+M), γ (1, TD_16), ε (1, DC), p (1, YEAR)	19760.23	1.06	9
Ψ, (1+E+M), γ (1, TD_16), ε (1, DC), p (1, YEAR)	19760.23	1.06	9
Ψ, (1+E+M+DA), γ (1, TD_14), ε (1, DC), p (1, YEAR)	19760.9	1.73	10
Ψ ,(1+E+M+DA+TD_14), γ (1,LD_16,TD_16),ε (1,DC),p(1,YEAR)	19761.07	1.9	12
Ψ,(1+DC+M+F),γ (1,TD_16),ε (1,DH),p(1,YEAR)	19762.39	3.22	10
Ψ,(1+E+M+DA+TD_14),γ(1,LD_16),ε (1,DC),p(1,YEAR)	19762.53	3.36	11
Ψ,(1+E+M+DA+TD_14),γ(1,TD_14),ε (1,DC),p(1,YEAR)	19762.54	3.37	11
Ψ,(1+E+M+DA),γ(1,LD_14+DG),ε (1,DC),p(1,YEAR)	19762.9	3.73	11

Ψ,(1+E+M+DA+LD_14),γ(1,LD_16),ε (1,DC),p(1,YEAR)2	19763.06	3.89	11
Ψ,(1+E+M+DA+TD_14), γ (1,TD_16,LD_16,DG),ε (1,DC),p(1,YEAR)	19763.06	3.89	13
Ψ ,(1+E+M), γ (1,TD_14),ε (1,DC),p(1,YEAR)	19763.66	4.49	9
Ψ ,(1+E+M), γ (1,DG),ε (1,DC),p(1,YEAR)	19763.66	4.49	9
Ψ ,(1+E+M+DA+LD_14), γ (1,LD_16,TD_14),ε (1,DC),p(1,YEAR)	19763.68	4.51	11
Ψ ,(1+E+M+DA+LD_14+TD_14), γ (1,LD_16),ε (1,DC),p(1,YEAR)2	19763.92	4.75	12
Ψ ,(1+E+M+F), γ (1,TD_14),ε (1,DC),p(1,YEAR)	19765.27	6.1	10
Ψ,(1+E+M+DA),γ(1,TD_14),ε (1,DH),p(1,YEAR)	19766.08	6.91	10
Ψ ,(1), γ (1),ε (1),p(1,YEAR)	19776.21	17.04	5

(DG: distance from grasslands, DH/HM: distance from human settlement, DA: distance from agriculture, DC: distance from core, TD: Tiger density, LD: Leopard density, F: NDVI, M: Moist, E: DEM)

Table 3.12: Statistics for the best model explaining Jungle cat occupancy (Ψ), colonisation (γ), extinction (ε), and detection (P) in Kanha Tiger Reserve

Parameter	**Covariate**	**Estimate**	**SE**
Ψ	Intercept	0.825881	0.103962
Ψ	DEM	0.333408	0.118046
Ψ	Moist	-0.09824	0.112118
Ψ	Distance from Agriculture	-0.22761	0.115358
Ψ	Tiger density_14	0.087437	0.096705
γ	Intercept	-0.10688	0.168594
γ	Tiger density_16	0.464812	0.275408
ε	Intercept	-1.26819	0.132772
ε	Distance from core	0.478265	0.12382
P	Year 1	-2.15497	0.033591
P	Year 2	-1.9522	0.02571

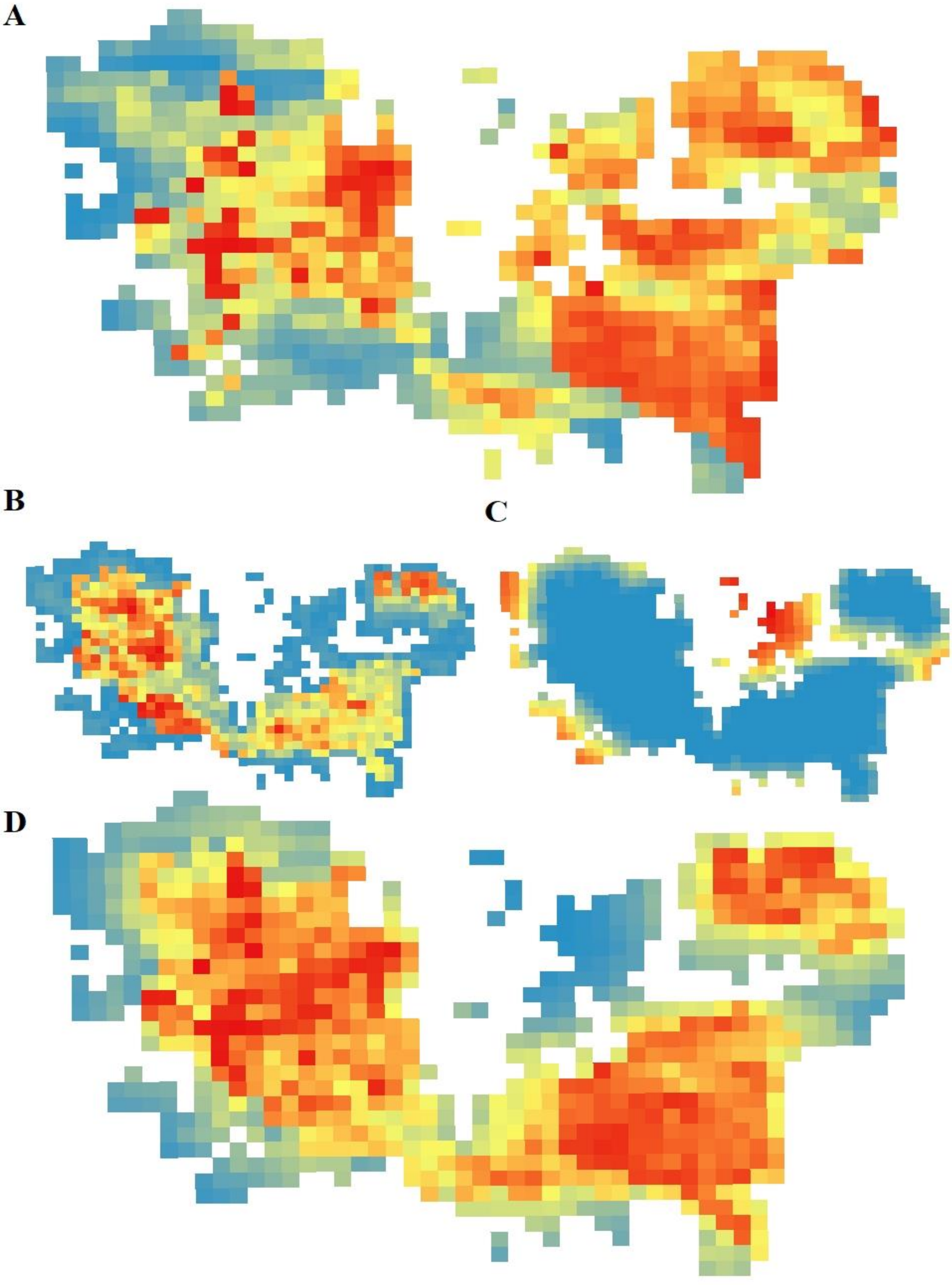


Figure 3.9: Occupancy of Jungle Cat in Kanha Tiger Reserve for the years 2014 (A) and 2016 (D) and colonization (B) and extinction (C) during these years. Here the occupancy represents habitat use

3.4. Discussions

This study identified the distribution pattern and occupancy of sympatric species of a carnivore guild in central India. Visual confirmations along with spatial information on the species were obtained from the camera traps to confirm the presence and absence of species within a particular area of the ecosystem. In addition, the long-term data sets of camera traps also allowed us to model the shift in the habitat use by these carnivore species in this multi-predator ecosystem over two years.

Tiger occupancy in KTR was associated positively with the big prey species availability, the core area of the forest. Being a large-sized carnivore, the tiger prefers large-sized prey as its food (McDougal, 1977; Sunquist, 1981; Johnsingh, 1983; Karanth & Sunquist, 1995; Stoen & Wegge, 1996; Biswas & Sankar, 2002; Bagchi et al. 2003). Hence, our result of tiger space use in the KTR is not surprising to the biology of tigers. Rather it replicates the known facts of tiger ecology revealed much before by the ecologist. Similarly, the tiger's preference for the core area and avoiding the fringe area near human settlements align with the earlier results of Karanth et al. (2011) and Jhala et al. (2008; 2015). It could be linked to the less human disturbance inside the core area overlapping with high prey density, which supports tiger distribution in the core of KTR as these factors have already been identified as the key factors for supporting tiger populations in their habitats (Karanth et al. 2011; Jhala et al. 2008, 2015). The result also showed colonization of tigers in the eastern part of the tiger reserve (Banjar catchment) between the initial and final years of the study periods. Interlinking this context to Kumar et al. (2019), the result could be due to the availability of high prey density and increasing conservation investment in this area.

Occupancy of leopards in the KTR was positively associated with the terrain's ruggedness and distance to the human settlements and negatively with the distance from the core area. In a multi-predator ecosystem where both tiger and leopard coexist, the leopard, the subordinate predator in general, modifies its activity or space use pattern to avoid a possible encounter with the tiger (Carter et al. 2015). However, exceptions have also been observed where the habitat is enriched with multiple species and a high density of prey potential supporting both species (Karanth & Sunquist, 1995). In KTR, the leopard's distribution associated with the ruggedness could be that tigers in KTR avoided rugged terrain. However, the resulted occupancy maps of leopards do not show complete avoidance of leopard to tiger presence in this KTR, which could be the consequence of the high diversity and density of prey species facilitating the occurrence of both these carnivores in a common ecosystem without coercing them to alter their behaviour. Comparing the occupancy of leopards from 2014 to 2016, remarkable colonization happened on the southern side of the Halon catchment area, which was seen as less preferred by the tigers. Colonization also happened in the Banjar catchment, which is known for its rich and diverse prey supplements and is less disturbed due to management interventions. In KTR, we observed both the scenario of multiple predator co-existence, i.e. with adequate resources availability in the Banjar catchment area, the tigers and the leopard co-exist without altering their behaviour significantly and in the second case in the Halon catchment leopard colonised remarkably in the absence of the dominant predator the tiger.

Unlike the leopards, dhole occupancy in the KTR was observed in the fringe area of the forest and associated positively with the distance from the core and distance from the grasslands. Dhole is one of the large carnivores that share habitats with tigers and leopards. In such a case, inter-specific competition between these species has been well documented. For instance, the hiding of kills by both tigers and leopards was documented to avoid competition with dhole packs. In addition, the killing of dhole by both the tigers and leopards was also observed intermittently. In KTR, the dhole is completely avoiding the tigers and leopards that occupy the core area of the forest and prefer to settle in the fringe area could be to avoid possible competition with these sympatric species. Factors such as prey availability and forest structure may facilitate these sympatric species in a common ground. However, spatial separation between these species also plays a significant role in facilitating co-existence. We did not find significant changes in the distribution pattern, such as the colonisation of dhole between 2014 and 2016. As we have observed the increasing colonization of both tigers and leopards in different sites of the core area of the tiger reserve, that might not be allowed the dholes to thrive inside the core area. Similar to dhole, no significant changes in the sloth bear's occurrence from KTR were observed from 2014 to 2016. Sloth bear occurrence was primarily governed by the distance from the core, distance from termites, and NDVI, which means its occurrence overlapped with the tiger and leopards but outspread with the dholes. Forest cover, shrub cover, water bodies, fruit-bearing trees, the presence of termite mounds, and the terrain factors are the major drivers influencing sloth bear distribution (Puri et al. 2015; Das et al. 2014; Ramesh et al. 2012). The KTR in its core area is characterized by dense forest, grasslands, bamboo forest, water bodies, and elevated hills, which have been identified as the optimum predictors to support the sloth bear distribution despite the habitat overlap with tigers and leopards. I also believe the omnivorous dietary pattern of the sloth bear might also influence reducing competition with these carnivores and facilitate co-existence. In the occupancy of golden jackal, a little change in the distribution pattern has been observed between 2014 to 2016. Jackals that abundantly occurred in the Halon catchment area in 2014 were also found in the Banjar catchment area in 2016. Distance from the agricultural land distance from grassland and tiger density was positively associated with the jackal distribution, whereas leopard density was negatively affected. The occupancy map of this species indicates the species' occurrence throughout the tiger reserve area irrespective of these model variables. Jackal, a scavenger of the ecosystem, depends primarily on the carcasses for their diet. Hence, competition between jackals and these large carnivores is almost absent, which might have facilitated the co-existence of this meso-carnivore in this carnivore guild. In addition, jackals are often found killing rodents, birds, and poultries which might be the reason for the jackal occurrence in the fringe area of the KTR near the human settlements.

Jungle cat A slight change in the distribution pattern of the golden jungle cat was observed between 2014 and 2016. We found that jungle cats preferred woodland, scrubland, grassland, areas high in canopy cover (determined by moist and DEM values), and areas close to roads. Six variables were retained in the analysis to develop a better model fit and conclusions. Despite these model variables, the occupancy map for this species indicates a presence across the tiger reserve. The most commonly eaten prey species of jungle cats were rodents and hares, while the remaining cattle and chital may be processed from large carnivores' kills. Competitions of a jungle cat with that of either large felids or canids are insignificant as their food choices are different; however, interactions with jackals have been reported (Selvan et al. 2019). The result also recognized the interaction between jungle cat and jackal while considering the occupancy maps generated for both species. Though jungle cats occurred throughout the forest, a spatial difference in occupancy with jackals has been observed.

Coming to the relative abundance index of prey species, as indicated by the boxplots, RAI for all species was highest when the distance from the core was least, meaning the species preferred areas inside and in close proximity to the core region and the site with species absence were present away from the core region. Jackal was the only species whose abundance was higher even in moderate proximity to the core region. It could be understood based on its natural history of using agro-pastoral land use that is prevalent away from the core. Distance from grasslands showed another important and common pattern, where higher RAI for all species was observed when the distance was least (i.e., inside grasslands) or in its proximity. It indicates carnivores utilizing grasslands' open habitats with more abundant prey resources. A difference in this pattern was observed for jackals, mostly due to their preference for agro-pastoral land uses away from the grasslands. Distance from the village provided an ecologically important pattern, where high RAI for tigers, leopards, sloth bears, and jungle cats was observed away from the village. These conflict-prone animals need undisturbed habitats with the least human disturbance. While the RAI for dhole and jackal was high even in proximity to the village. For jackal, it is mostly due to preference for agro-pastoral land uses, while for dholes, it could be due to the refugee that villages provided from top predators like the tiger and the leopard. The pattern only validated the field observations, where dholes mostly occurred in areas in the buffer region, but near grasslands in the core region, which provides proximity to abundant prey species and segregation from high densities of top predators in the area.

3.5 Conclusion:

Modelling results were congruent with our understanding of carnivore natural history and habitat preferences. Distance from the core, Distance from Human settlement, and Habitat heterogeneity are driven by the east-west climatic gradient that shapes carnivores' spatial distribution and conservation implications for species sensitivity. The species was found predominantly in the buffer region, mostly to avoid competition with top predators while still being in proximity to the dense prey population. Habitat requirements elucidated the need to conserve the mosaic of forest and grasslands outside the protected areas that could also support lower prey densities. Their colonization of new areas depends on the connectivity and interaction with humans in multi-use areas. Hence, while outlining the conservation plan for outside protected areas, it is important to consider the occupancy of dholes to arrest habitat and prey loss.

CHAPTER 4: HABITAT SUITABILITY OF SOME IMPORTANT CARNIVORES IN KANHA TIGER RESERVE

4.1. Introduction:

Understanding the link between animal distribution and environmental characteristics is critical for the conservation and management of species. Based on species habitat relationships, predictive habitat modelling and mapping provide an analytical foundation for informed conservation planning, mapping patterns of biodiversity, detecting distributional changes from monitoring data, and quantifying how variation in species performance is related to one or more controlling factors (Phillips et al. 2006). At the macro geographic scale, habitat models allow for the development of hypotheses regarding characteristics that influence species distribution (Manel et al. 2000). At a regional scale, habitat suitability maps, which provide baseline information on the spatial arrangement of potentially appropriate habitat for a species, are used to aid the protection and restoration of essential habitats and hence have extensive applicability in conservation biology and wildlife management (Manel et al. 2000).

Predictive species mapping is based on ecological niche theory and predictor analysis of the geographical distribution of factors that correlate with the presence of species. Remote sensing and geographical information systems (GIS) are widely used to establish this link and infer species' habitat suitability. Several statistical approaches can offer estimates on the likelihood of occurrence of a specific species by analyzing environmental information and presence/absence data (Guisan and Zimmermann 2000). Distribution models should consider sample size, predictability, and nonlinearity of relationships with covariates. Several advances in ecological niche modelling (ENM) have created new methods for estimating species ranges and identifying appropriate environments (Gaubert et al. n.d., Papeş & Gaubert, 2007. Thorn et al. 2009). Amongst them, "MaxEnt calculates the largest spread-out probability distribution for a species occurrence given the restrictions determined from available data" (Phillips et al. 2006) and is hence considered best to model the habitat suitability of species at multiple scales. For selecting covariates, most species have biological information available to guide judgments on which variables to include in habitat models. Environmental, bioclimatic, topography and disturbance indicators are the most important classes amongst which covariates are required at optimal scale.

Rare and secretive animals adapt to their surroundings for several reasons, some of which are difficult to justify or comprehend. Habitat suitability models have highlighted the ecological underpinnings of their habitat selection and subsequent conservation actions. For example, status reports, synoptic studies, and behavioral observations on small carnivores in the Western Ghats have provided information on their habitat usage (Prater 1971, Mudappa & Chellam, 2001). Recently, niche-based modelling of possible distributions has been used to investigate the distribution and habitat correlation of important wild mammals in India at a macroscale (Jhala et al. 2021). It is critical to examine how small carnivores respond to or relate to micro-scale factors in a Protected Area context. This can guide local-level conservation actions to maximize biodiversity by managing habitats and protected areas.

We used the camera trapping information from Chapter 3 to develop habitat suitability models for six study species (tiger, leopard, dhole, sloth bear, jackal, and jungle cat) in Kanha Tiger Reserve, using ground sampled and remotely sensed covariates on habitat parameters. The model output provides precise site scale information on the occurrence of individual species, their likely effects on other species, and their habitat requirements. This information is crucial for the tiger reserve as it aims to maximize the conservation of these rare species.

4.2. Materials and methods

Species presence:

I used presence-only data for this analysis. Camera trap data from all sampling years were used, and only one presence record was retained if multiple presence locations were recorded in a 1 km2 pixel. This was done to address the auto-correlation amongst the presence locations. The details of camera trapping are provided in chapter 3.

Environmental variables:

We used covariates on food resources, forest characteristics, competition from other species, human disturbance, and protection to assess the habitat suitability of all species. The details of all covariates are provided in table 4.1. All covariates were rescaled to a 1 km scale, and their correlation was assessed using Pearson’s correlation. All GIS analysis is done in ArcGIS 10.5.

Table 4.1: Lists the variables and information on its source and scale used for MaxEnt modelling

Variables	Source and rationale
Distance from core	This represents the effect of protection on species occurrence. Euclidean distance from protected area boundary obtained from MSTrIPES.in was used.
Distance from Human Settlement	This indicates the effect of human disturbance on species occurrence. Euclidean distance from villages digitized from Google Earth was used.
Distance from Grassland	This indicates the effect of habitats with high resources on species occurrence. Euclidean distance from grasslands digitized from Google Earth was used.
Distance from Agriculture	This indicates the effect of human subsidized food resources in the form of rodents for the jackal and jungle cat occurrence. Euclidean distance from agricultural fields and fallow lands digitized from Google Earth was used.
Distance from Termite	This indicates the effect of food resources on the occurrence of sloth bears. Field sampled during transect sampling and camera trap deployment. More details are in Chapter 3. Kernel density of termite mounds and termite encounters were used.
All prey	This indicates the effect of food resources in prey availability on predator occurrence. Encounter rate of pellets/dung of gaur, sambar, barasingha, chital, langur, chowsingha, barking deer, and wild pig were obtained from field sampled during the pellet plot. More details are in Chapter 3.
Large prey	This indicates the effect of food resources in prey availability on predator occurrence. Encounter rate of pellets/dung of gaur, sambar, barasingha, and chital were obtained from field sampled during pellet plot. More details are in Chapter 3.

Deciduousness	It indicates the deciduousness of the forest, which is the seasonal difference in habitat openness. The difference in the pre-monsoon NDVI (average for March, April, and May) and post-monsoon NDVI (average for October, November, and December) obtained from LANDSAT 8 satellite data for the year 2016 was used.
Ruggedness	It indicates the terrain complexity that provides cover for hiding and ambush for predators, derived from the SRTM digital elevation model using Relay et al. 1996.
Tiger density	It indicates the competition posed by a top predator on the occurrence of other carnivores and is used from data available by Kumar et al. 2019.
NDVI	It indicates the forest cover availability for species occurrence. LANDSAT 8, Red, and Near-infrared bands for the year 2016. Scale 30m

MaxEnt model:

The presence file was converted into CSV and covariates into ASCII format and fed into the MaxEnt 3.4.4. I then chose the jack-knife option in the software, which is critical for understanding the contribution of various environmental data layers (Phillips 2006). The linear, quadratic, and hinge functions fit non-linear relationships in species and covariates. Regularisation was set at 1, 10,000 background points were randomly selected from the entire area, and output was developed using the logistic relationship (Phillips et al. 2006) ;(Phillips & Dudík, 2008). We used the maximum test sensitivity plus specificity value as a threshold to classify the MaxEnt generated output into presence and absence. Area Under the receiver-operator Curve (AUC) was an accurate indicator. The response curves were used to interpret species' relationship with habitat characteristics.

4.3. Results

Jackal habitat modelling

A total of 1650 independent photo captures of Jackal were obtained from camera traps used for habitat suitability modelling with Maxent. Data and model parameters of Maxent are shown in Table 4.2 & 4.3, and modelled distribution map of jackal across KTR is given in Figure 4.3. As per the results obtained from Maxent analysis, distance from human settlement contributed the most (30.8%) to the Jackal habitat model revealing a favourable connection with the jackal’s presence (Table 4.3). Jackal’s habitat was also influenced by ruggedness (28.5%), showing the species prefers less rugged terrain. The next most important component was the distance from agriculture (16.7%), wherein the species preferred areas nearer to agriculture, showing both areas near and far from the settlements. The relationship with the tiger density (contribution 14.6%) was revealed to be incremental but was found to be negative with leopard density (contribution 4.9%). Lastly, Jackals declined with distance from grassland (model contribution 4.5%). The relationships of jackal distribution with the covariates are shown in Figure 4.2.

Table 4.2: Parameters used in MaxEnt setting for modeling the golden jackal habitat in Kanha Tiger Reserve

Model setting	**Values**
Model features	Linear, Quadratic
Output formats	Logistic
Specificity	44.04
The area under the ROC* Curve (AUC)	0.60

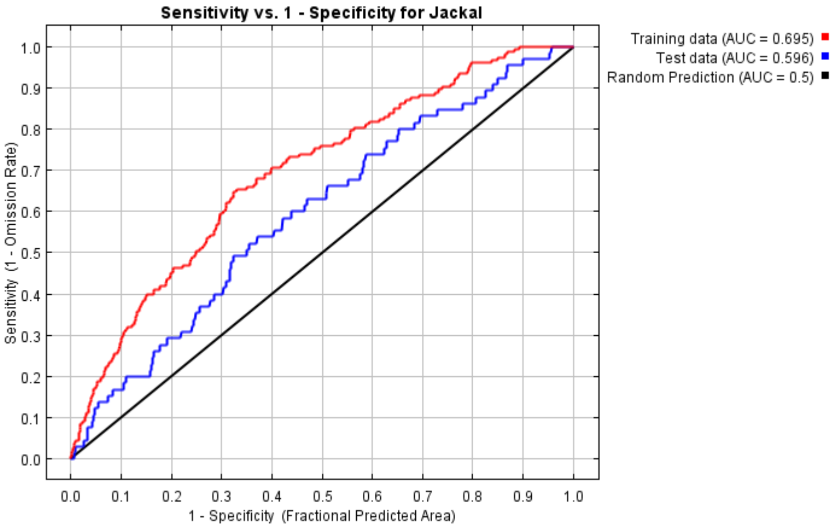


Figure 4.1: ROC curve of Sensitivity versus Specificity for the habitat model of Jackal

Table 4.3: Contribution percentage of every covariate (SD) to the best model explaining golden jackal distribution

Ruggedness	28.5
Distance from Grassland	4.5

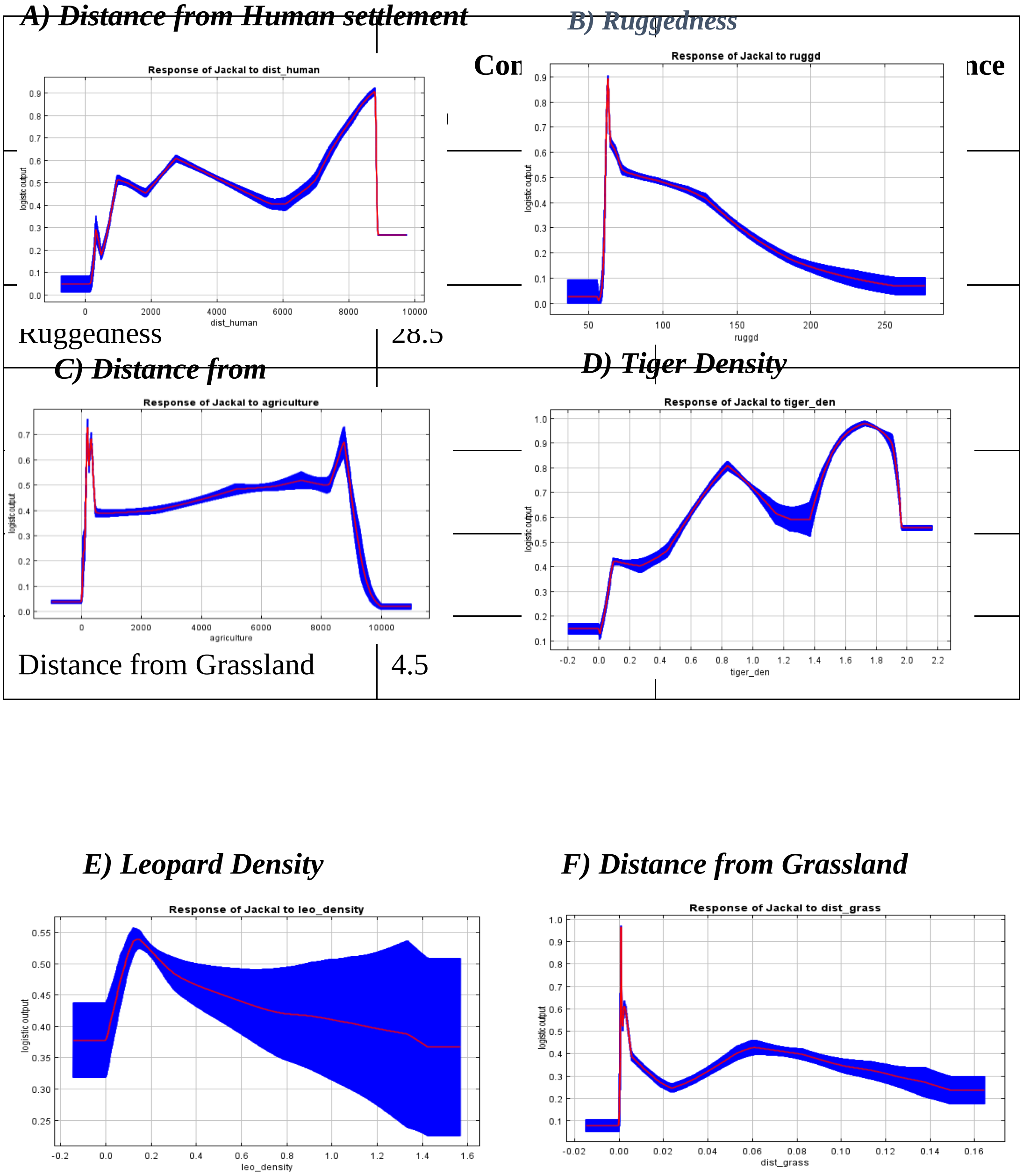


Figure 4.2: Relationship of golden jackal with environmental covariates: A) Distance from Human settlement, B) Ruggedness, C) Distance from Agriculture, D) Tiger Density, E) Leopard Density, and F) Distance from Grassland

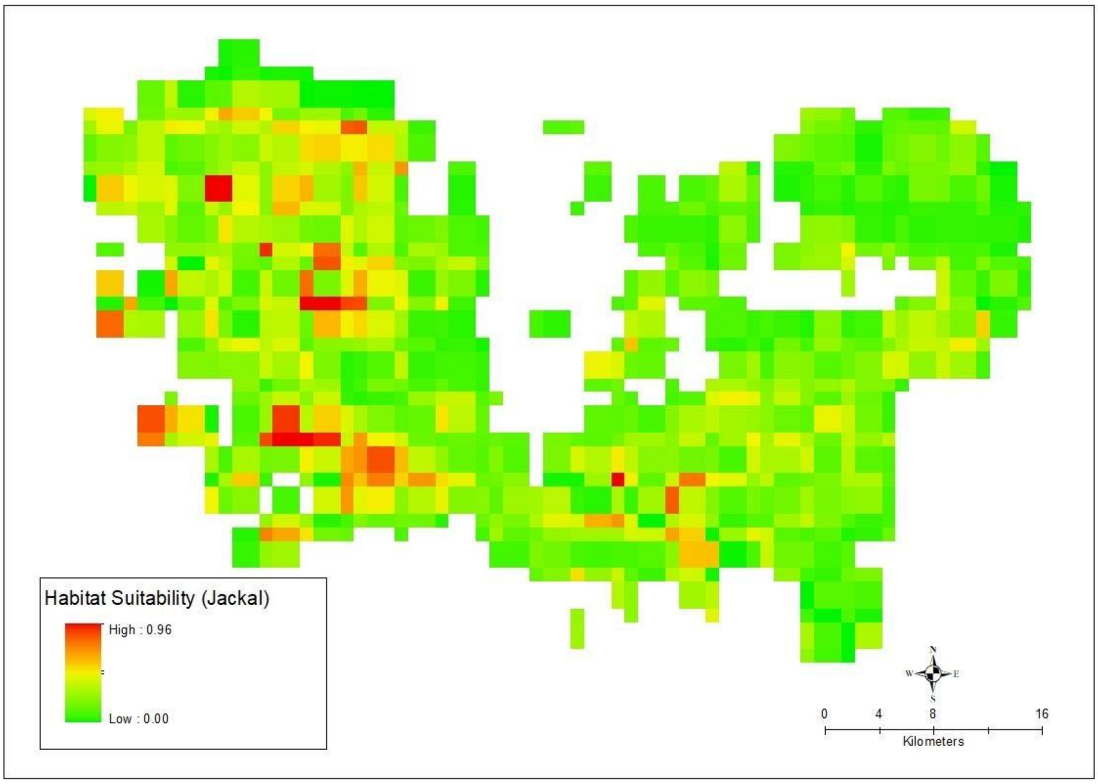


Figure 4.3: Distribution of golden jackals across Kanha Tiger Reserve developed from the presence obtained by camera trapping and environmental covariates

Jungle cat habitat modelling

Habitat suitability of jungle cat was modelled in Maxent based on the 2426 independent photo captures in camera traps. Table 4.4 & 4.5 shows the data and model parameters used for analysis, and Figure 4.3 – 4.6, shows the distribution of jungle cats in Kanha Tiger Reserve. The area under the curve of the AUC plot is 0.65 for training data and 0.56 for test data which is an indicator of good accuracy of the models (Figure 4.4). Among all the variables, the 'distance from core' moderates the jungle cat distribution the most by contributing 76.5% to the model. This indicates the species' preference for living inside the core area of the forest.

Similarly, tiger density contributes 7.3% to the Jungle cat habitat distribution, indicating a positive association between these two species. Jungle cats in KTR preferred to avoid agricultural land, as observed in the response curve of distance from agriculture (model contribution 6.5%). Besides, other variables such as deciduousness (3.9%), ruggedness (1.4%), and distance from grassland (1.2%) were also observed to have an impact on the jungle cat distribution. The relationships of jungle cat distribution with such variables are shown below

Table 4.4: Parameters used in MaxEnt setting for modelling jungle cat habitat in forested landscapes of Kanha Tiger Reserve

Model setting	**Values**
Model features	Linear, Quadratic
Output formats	Logistic
Specificity	23.70
The area under the ROC* Curve (AUC)	0.56

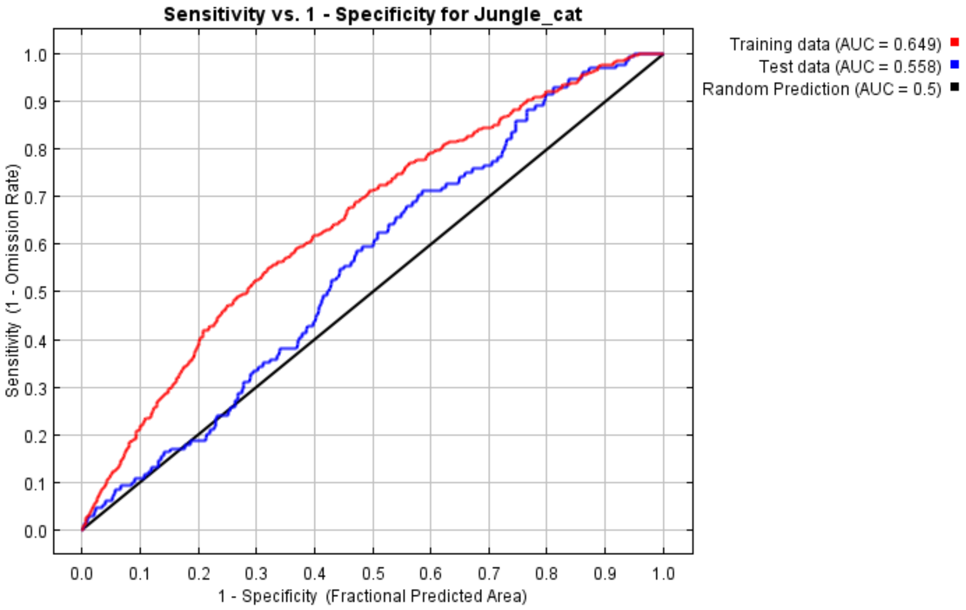
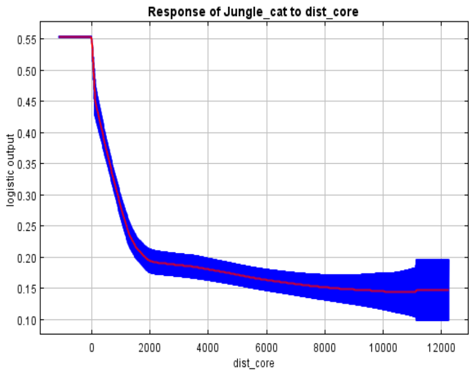


Figure 4.4: ROC curve of Sensitivity versus Specificity for the habitat model of a Jungle cat

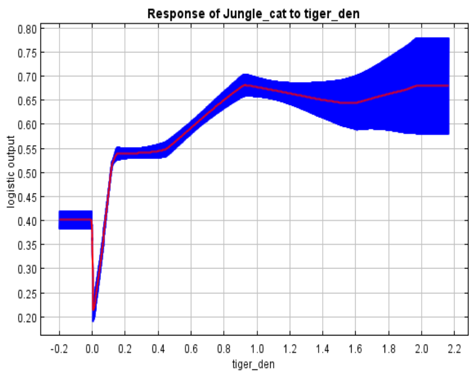
Table 13: Percentage contribution of every covariate (SD) to the best model explaining jungle cat distribution

Variable	**Model contribution (%)**	**Permutation importance (SD)**
Distance from core	76.5	50.3
Tiger Density	7.3	16.1
Distance from Agriculture	6.5	12.4
Moist	3.9	7
Leopard Density	3.2	7.1
Ruggedness	1.4	4.8
Distance from Grassland	1.2	2.2

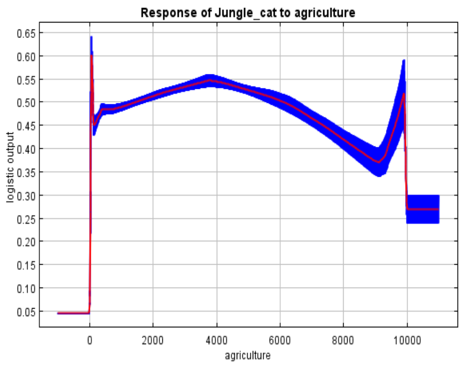
A) Distance from Core



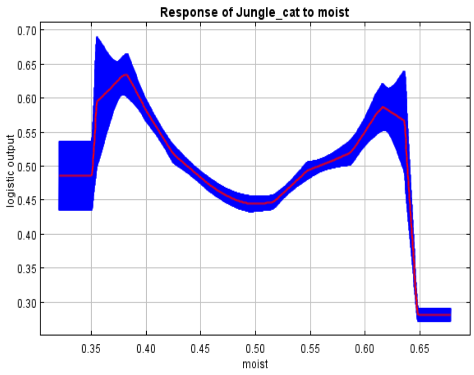
B) Tiger density



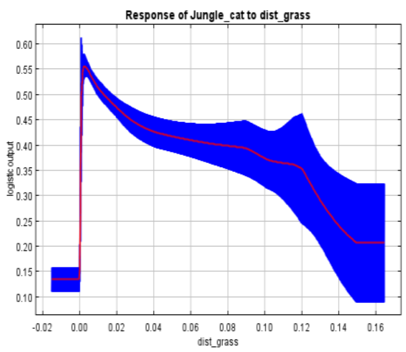
C) Distance from Agriculture



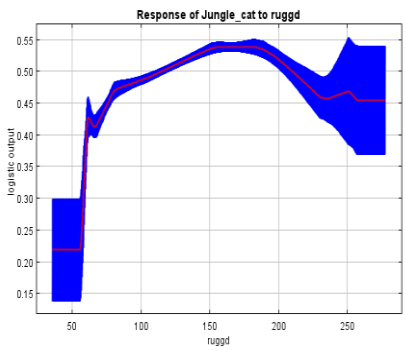
D) Moist



E) Distance from grassland



F) Ruggedness



G) Leopard Density

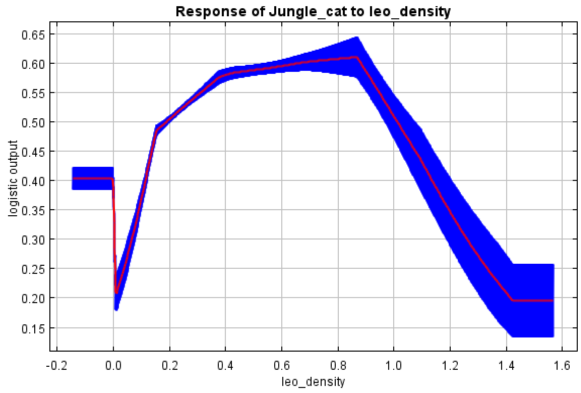


Figure 4.5: Relationship of jungle cat with A) Distance from core, B) Tiger Density, C) Distance from Agriculture, D) Moist E) Leopard Density, F) Ruggedness, and G) Distance from Grassland

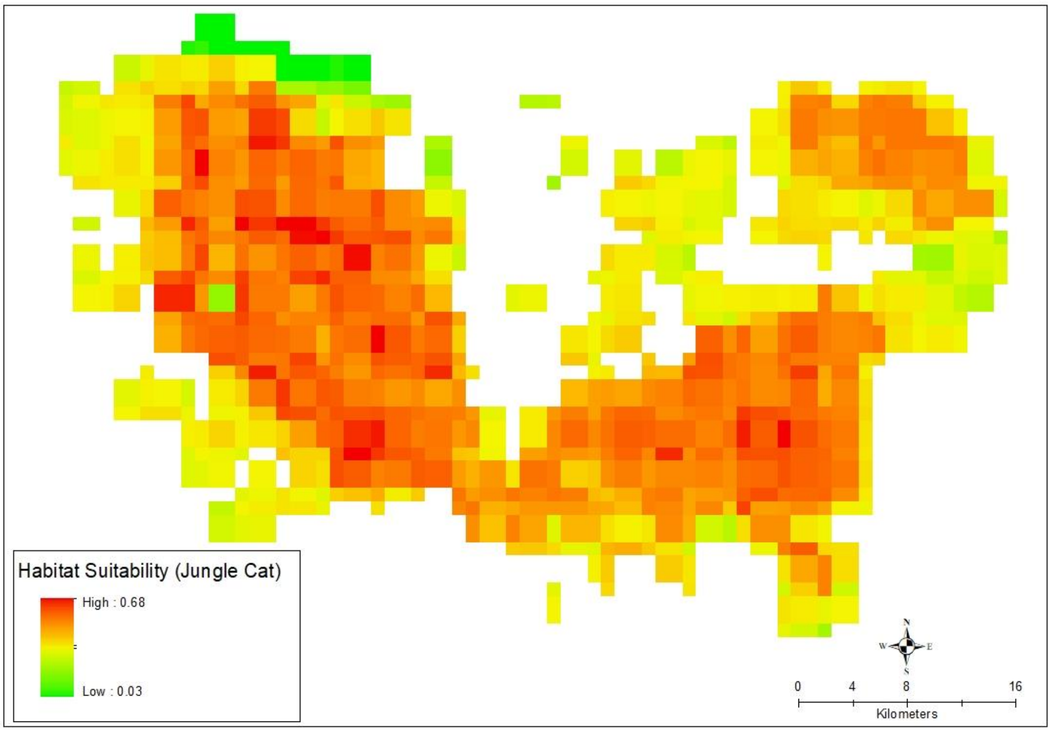


Figure 4.6: Distribution of jungle cats across Kanha Tiger Reserve developed from the presence obtained by camera trapping and environmental covariates

Dhole habitat modelling

A total of 408 photo-captures of dholes were obtained during the field sampling and are used for assessing habitat suitability based on different environmental parameters (shown in Table 4.6 & 4.7). The AUC value of training data is 0.59, which explains the goodness of the model fit. The predicted distribution of dhole across Kanha Tiger Reserve is shown in Figure 4.7 - 4.9. The distance from the grassland contributes 33.3 % to the dhole habitat distribution, indicating high chances of dhole occurrence in the grassland habitat. The result was also found to be supportive of the event that most of the dholes were photo captured in the grassland, open forest, or areas with moderate forest cover. The dhole habitat in Kanha tiger reserve can further be understood by considering the variable "Distance from the human settlement," which had the model contribution of 24.5%, indicating dholes using habitats proximity to human settlements and preferred likely to be in the periphery of the forest.

Prey species were also observed to be positively associated with the dhole distribution, which had a contribution of 20.5% to the habitat model. The other important variables influencing the dhole habitat distribution were a distance from the core (16.1%), leopard density (3.5%), and tiger density (2%). The variable distance from the core was positively associated with the dhole habitat indicating the species avoided the core area of the forest. Similarly, habitats with an increase in leopard and tiger density are also avoided by the dholes in the Kanha tiger reserve.

Table 14: Parameters used in MaxEnt setting for modelling the dhole distribution/habitat in the forested landscape of Kanha Tiger Reserve

Model setting	**Values**
Model features	Linear, Quadratic
Output formats	Logistic
Specificity	5.8
The area under the ROC* Curve (AUC)	0.59

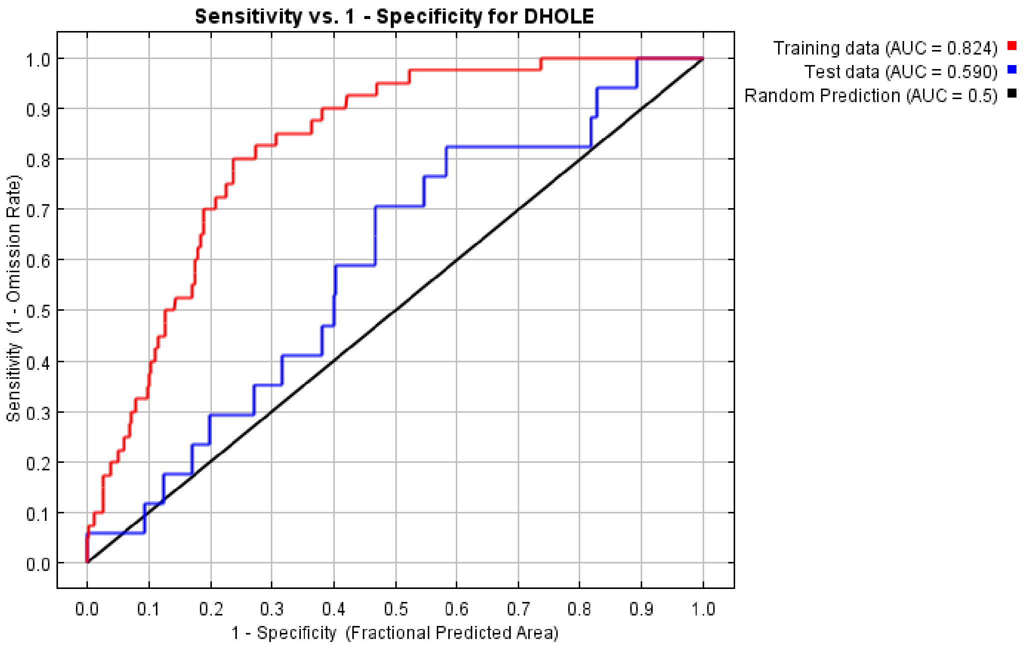
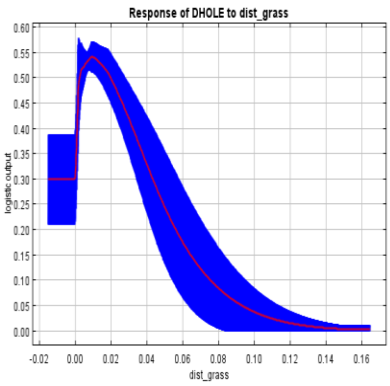


Figure 4.7: ROC curve of Sensitivity versus Specificity for the habitat model of Dhole

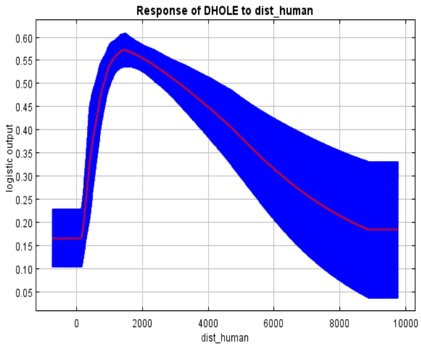
Table 15: Contribution %age of every covariate (SD) to the best model explaining the distribution of dhole

Variable	**% Contribution (SD)**	**Permutation importance (SD)**
Distance from Grassland	33.3	47.3
Distance from Human settlement	24.5	23.9
All Prey	20.5	12.6
Distance from core	16.1	9.3
Leopard Density	3.5	4
Tiger Density	2	2.9

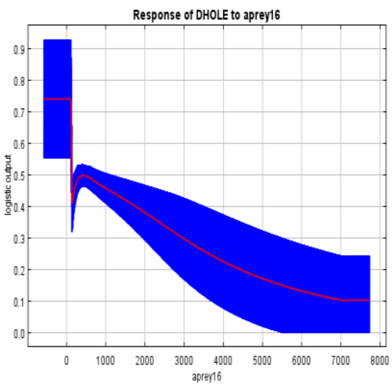
A) Distance from Grassland



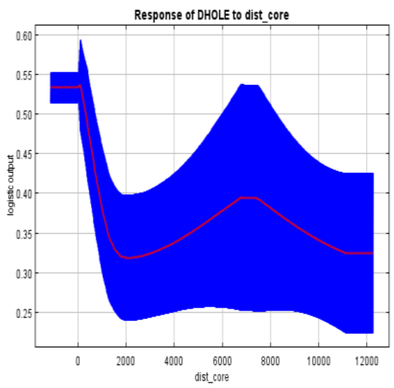
B) Distance from Human



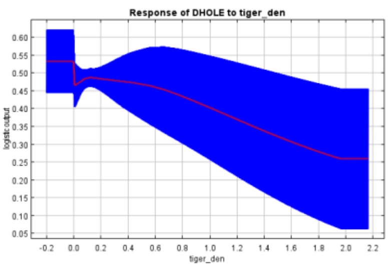
C) All Prey



D) Distance from core



E) Tiger Density



F) Leopard density

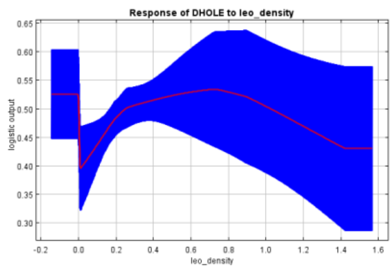


Figure 4.8: Relationship of Dhole with A) Distance from Grassland, B) Distance from Human settlement, C) All Prey, D) Distance from core, E) Tiger Density and F) Leopard density

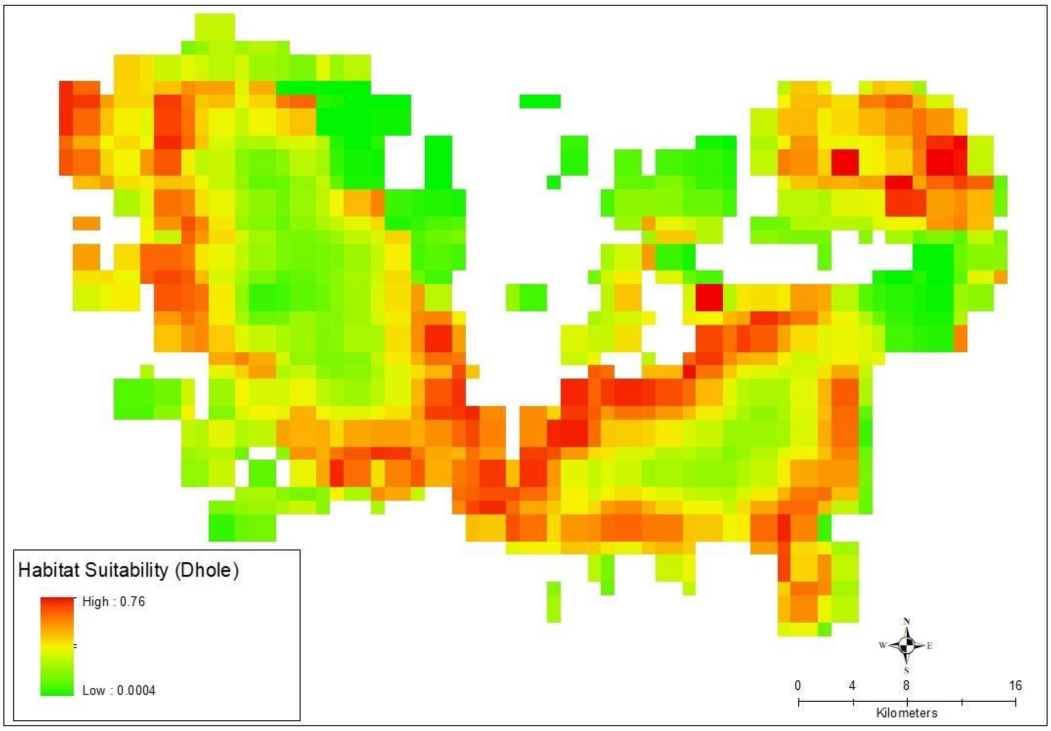


Figure 4.9: Distribution of dhole across the forested areas of Kanha Tiger Reserve developed from the presence obtained by camera trapping and environmental covariates

Sloth Bear habitat modelling

Maxent modelling with 1084 independent photo captures of sloth bear shows 0.75 AUC values meaning a fairly good fit of the models (model parameters are shown in Table 4.8 & 4.9). The response curve of distance from the core has the highest model contribution (71.7%), indicating a strong affinity of sloth bears to be in the reserve's core areas, which is also explained by the response curve of distance from human settlements (model contribution 14.5%). The response curve of NDVI (model contribution 4.4%) indicates the species' avoidance of open forests. Following that are tiger density (4.2 %) and ruggedness (model contribution 3.6 %), indicating that this species prefers rugged areas, and lastly, distance from termites (model contribution 1.5%), showing the independent relationship. The predicted distribution of sloth bear in KTR is shown in Figure 4.10 - 4.12.

Table 4.8: Parameters used in MaxEnt setting for modelling sloth bear distribution/habitat in the forested landscape of Kanha Tiger Reserve

Model setting	**Values**
Model features	Linear, Quadratic
Output formats	Logistic
Specificity	0.45
The area under the ROC* Curve (AUC)	0.74

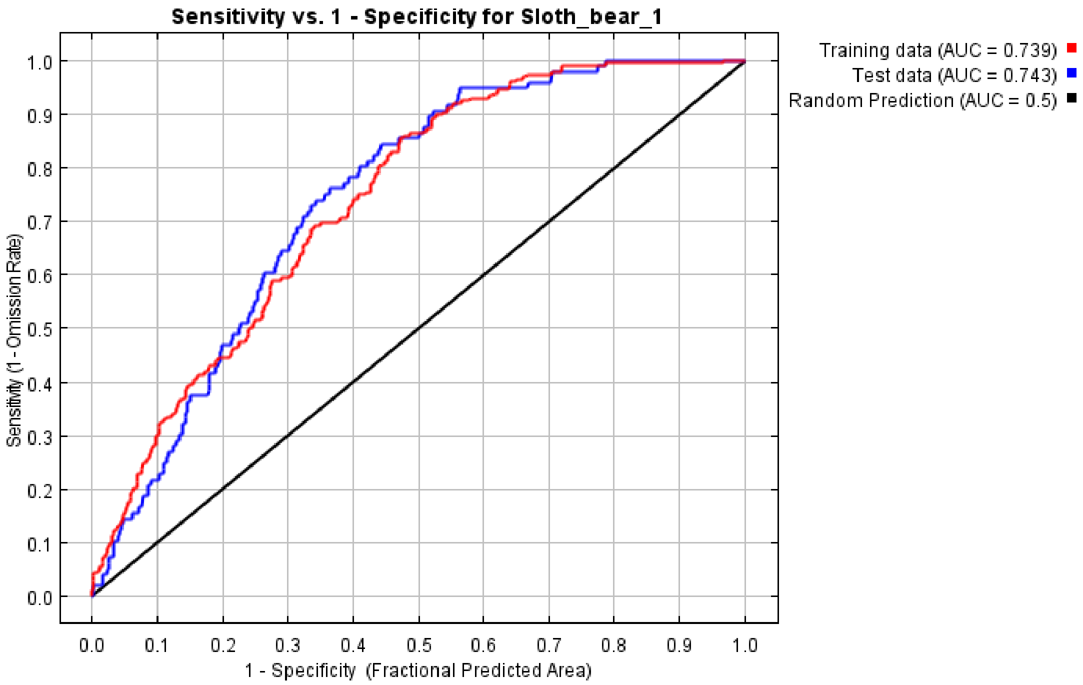
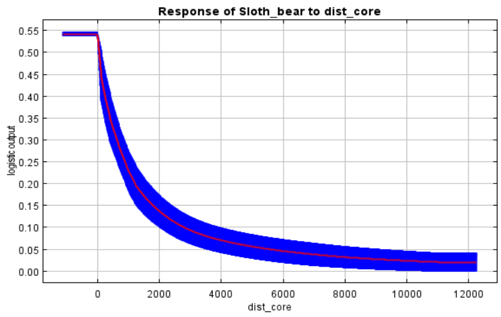


Figure 4.10: ROC curve of Sensitivity versus Specificity for the habitat model of Sloth bear

Table 4.169: Contribution percentage of every covariate (SD) to the best model explaining sloth bear distribution

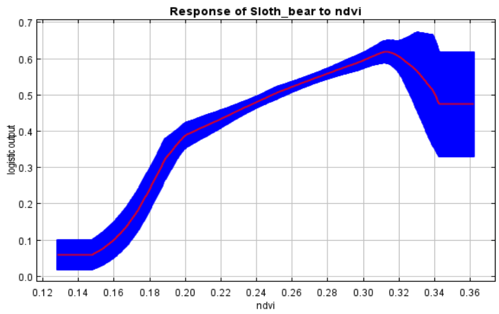
Variable	**% Contribution (SD)**	**Permutation importance (SD)**
Distance from core	71.7	47.4
Distance from Human settlement	14.5	27.8
NDVI	4.4	5.1
Tiger Density	4.2	3.9
Ruggedness	3.6	12
Distance from Termite	1.5	3.8

A) Distance from Core

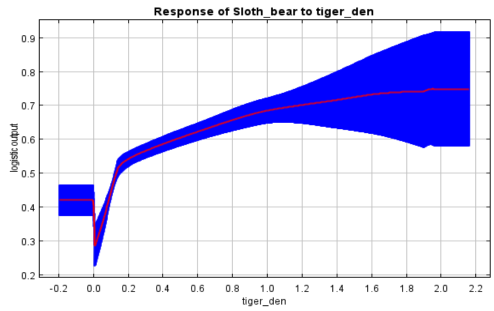


B) Distance from human settlement

C) NDVI



D) Tiger Density



E) Ruggedness

F) Distance from Termite

Figure 4.11: Relationship of sloth bear with A) Distance from core, B) Distance from Human settlement, C) NDVI, D) Tiger Density and E) Ruggedness and F) Distance from Termite

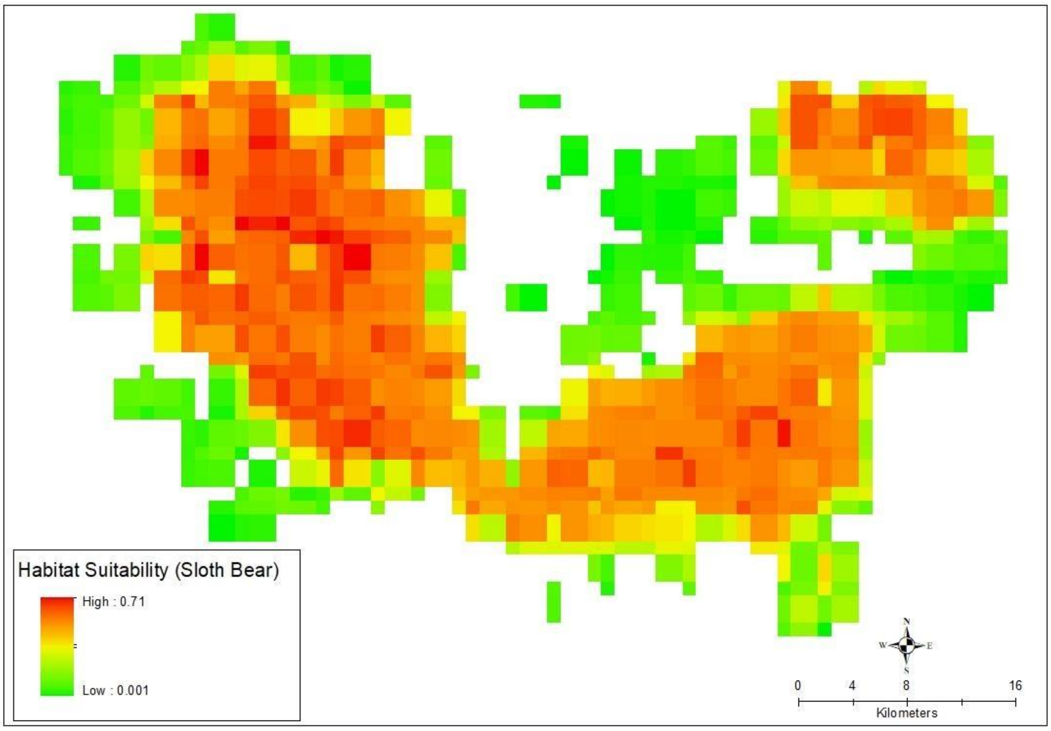


Figure 4.12 Distribution of sloth bear across the forested areas of Kanha Tiger Reserve developed from the presence obtained by camera trapping and environmental covariates

Leopard habitat modelling

To model the habitat distribution of leopards, a total of 1196 independent captured photos in-camera traps were used as the presence data frame in Maxent. Similar to the sloth bear leopard habitat was also influenced by distance from human settlements (40.8%) and distance from the core (31.1%), indicating the leopard preferred to use the core area of the forest and avoid the human settlements. In addition, NDVI (contributing 14.2%), prey density (8.9%), and terrain ruggedness (5%) were also found to be influencing leopard habitat in the Kanha tiger reserve. The response curve of leopard habitat with respect to NDVI shows leopard preferred habitat with less and moderate vegetation cover and avoiding very dense forest. Similarly, the response curve with all prey and ruggedness indicates the leopard avoids areas with higher prey density and rugged terrain ((Table 4.10 & 4.11 & Figure 4.13 – 4.15).

Table 4.10: Parameters used in MaxEnt setting for modelling Leopard distribution/habitat in the forested landscape of Kanha Tiger Reserve

Model setting	**Values**
Model features	Linear, Quadratic
Output formats	Logistic
Specificity	26.06
The area under the ROC* Curve (AUC)	0.70

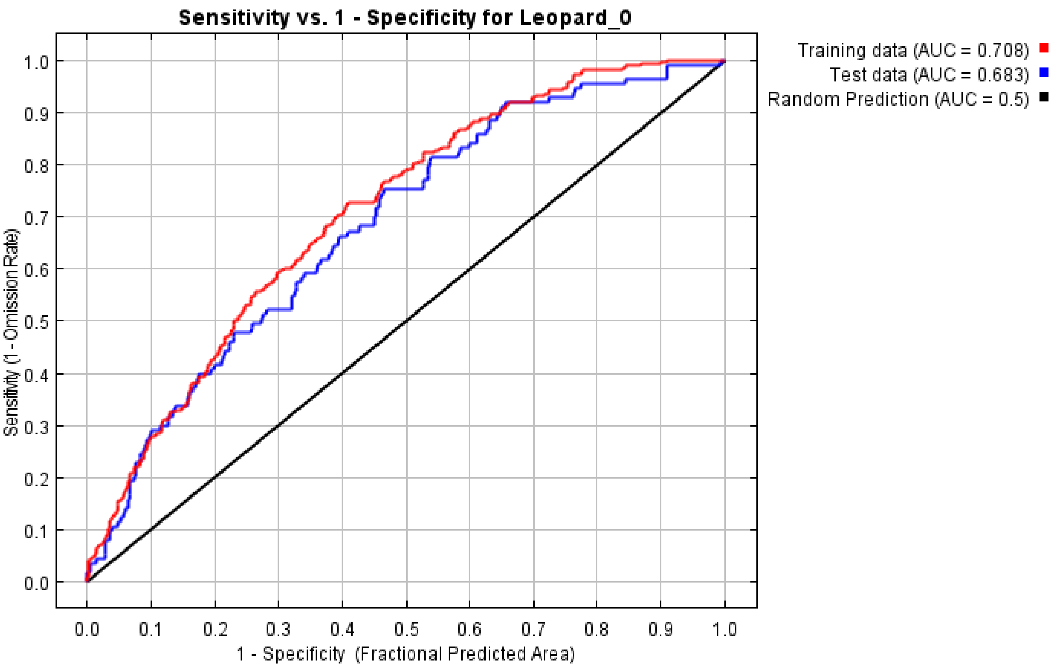


Figure 4.13: ROC curve of Sensitivity versus Specificity for the habitat model of Leopard

Table 4.11: Contribution percentage of every covariate (SD) to the best model explaining Leopard distribution

Variable	**% Contribution (SD)**	**Permutation importance (SD)**
Distance from Human settlement	40.8	42.2
Distance from core	31.1	16.4
NDVI	14.2	22.3
All Prey	8.9	12.5
Ruggedness	5	6.6

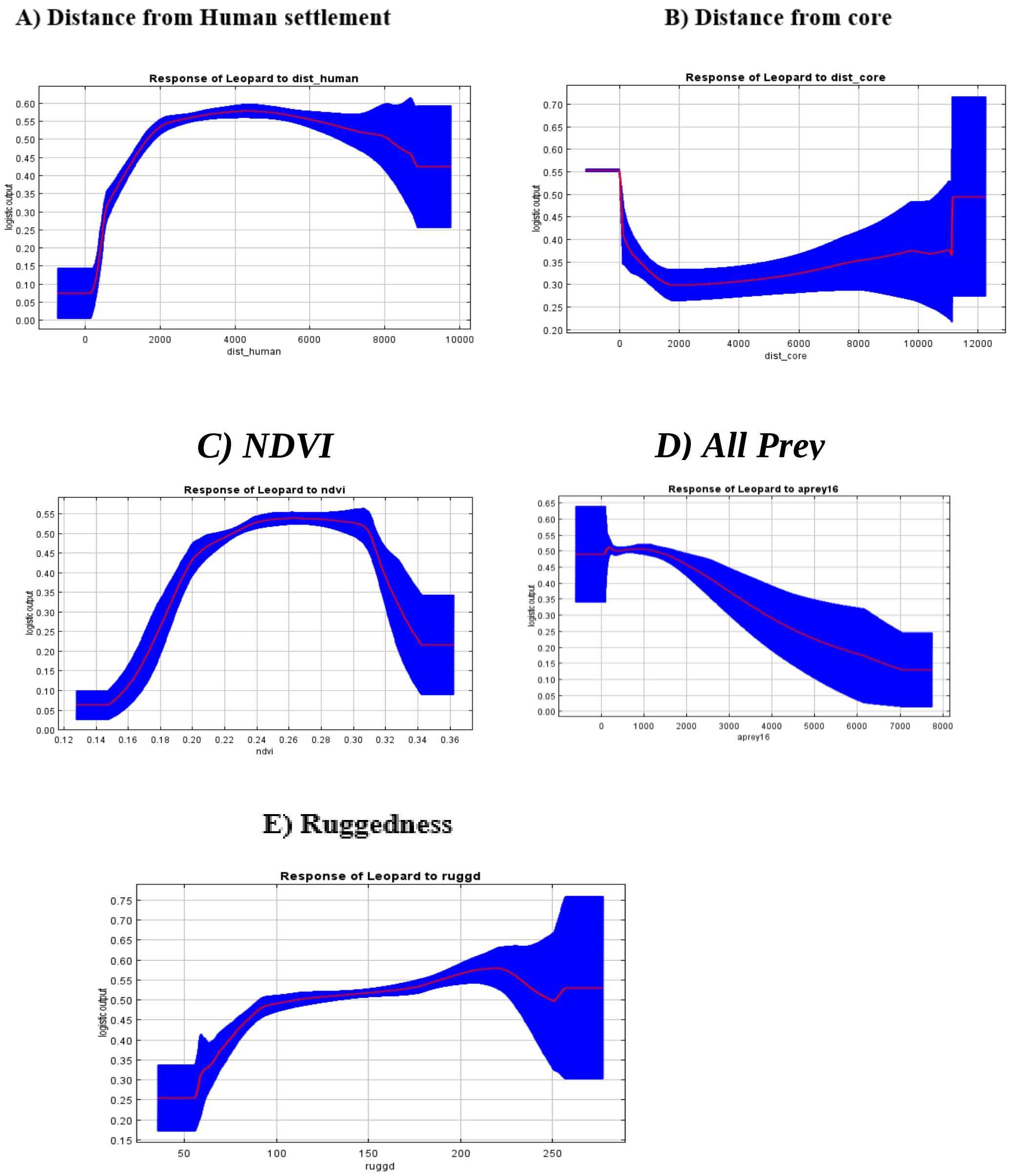


Figure 4.14: A) Relationship of Leopard with Distance from Human settlement, B) Distance from core, C) NDVI, D) All Prey, E) Ruggedness

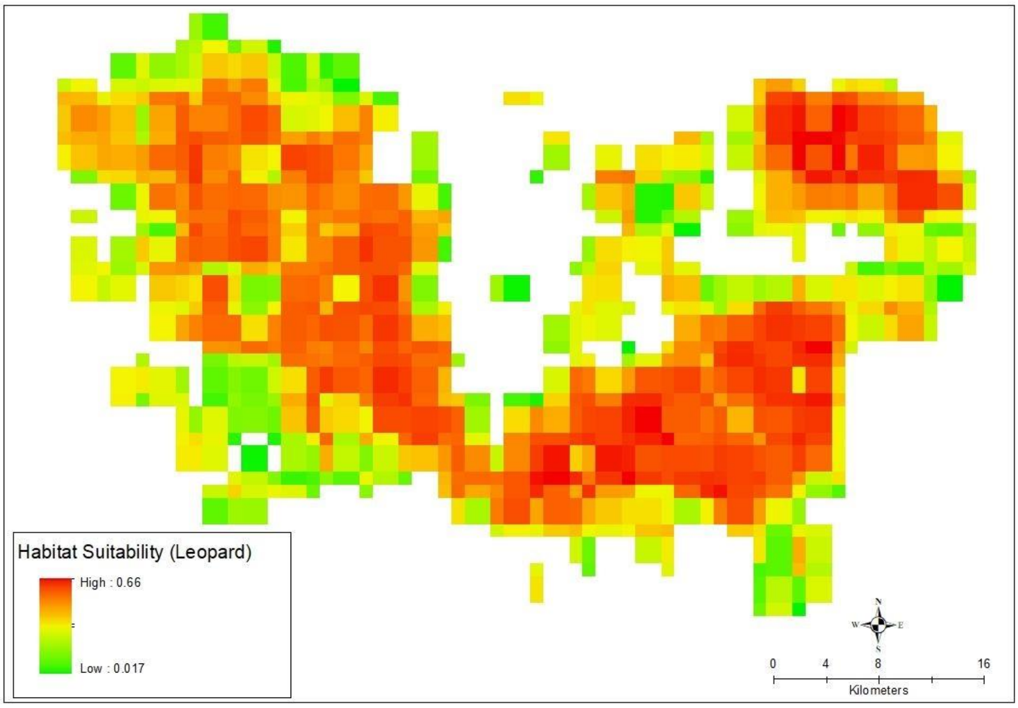


Figure 4.15: Distribution of Leopard across the forested areas of Kanha Tiger Reserve developed from the presence obtained by camera trapping and environmental covariates

Tiger habitat modelling

A total of 1530 camera-trapped photos of tigers were used in Maxent to analyse the tiger's habitat suitability. The probable distribution of the tiger's habitat and the important model parameters are provided in Figure 4.16- 4.18 and Table 4.12, and 4.13 respectively. Distance from the core was the most important variable contributing 52.5 % to the model, followed by distance from the human settlement (29.3%) and the presence of larger-sized prey (18.2%). Identical to leopard, sloth bear, and jungle cat, the tiger in the Kanha tiger reserve, was preferred to live in the core area of the forest along with a high density of large prey. Distance from human settlements was found to be positively associated with tiger habitat, which means habitat with an increase in the distance to human settlements had greater chances of tiger occurrence in Kanha tiger reserve.

Table 4.12: Parameters used in MaxEnt setting for modelling Tiger distribution/habitat in the forested landscape of Kanha Tiger Reserve

Model setting	**Values**
Model features	Linear, Quadratic
Output formats	Logistic
Specificity	21.33
The area under the ROC* Curve (AUC)	0.72

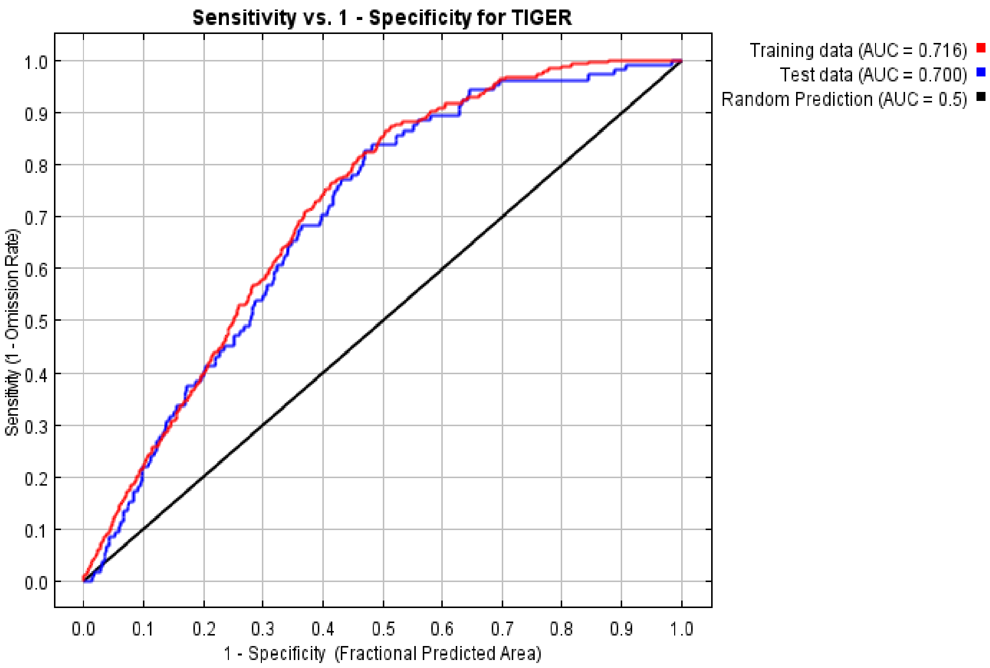
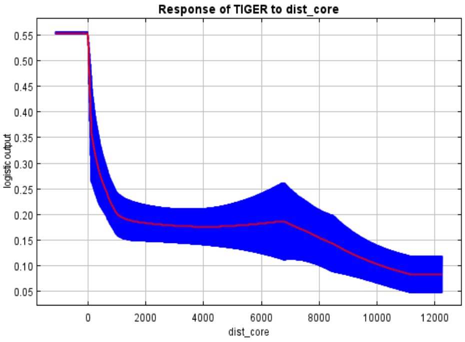


Figure 4.16: ROC curve of Sensitivity versus Specificity for the habitat model of Tiger

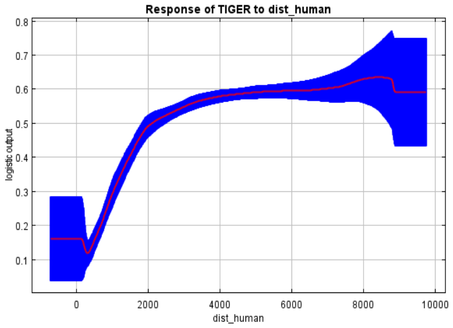
Table 4.173: Contribution Percentage of every covariate (SD) to the best model explaining Tiger distribution

Variable	Model contribution (SD)	Permutation importance (SD)
Distance from core	52.5	22.7
Distance from Human settlement	29.3	42.3
Big Prey	18.2	34.9

A) Distance from core



B) Distance from Human settlement



C) Big Prey

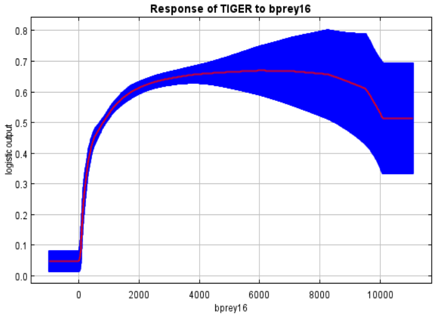


Figure 4.17: A) Relationship of Tiger with Distance from the core, B) Distance from Human settlement, C) Big Prey

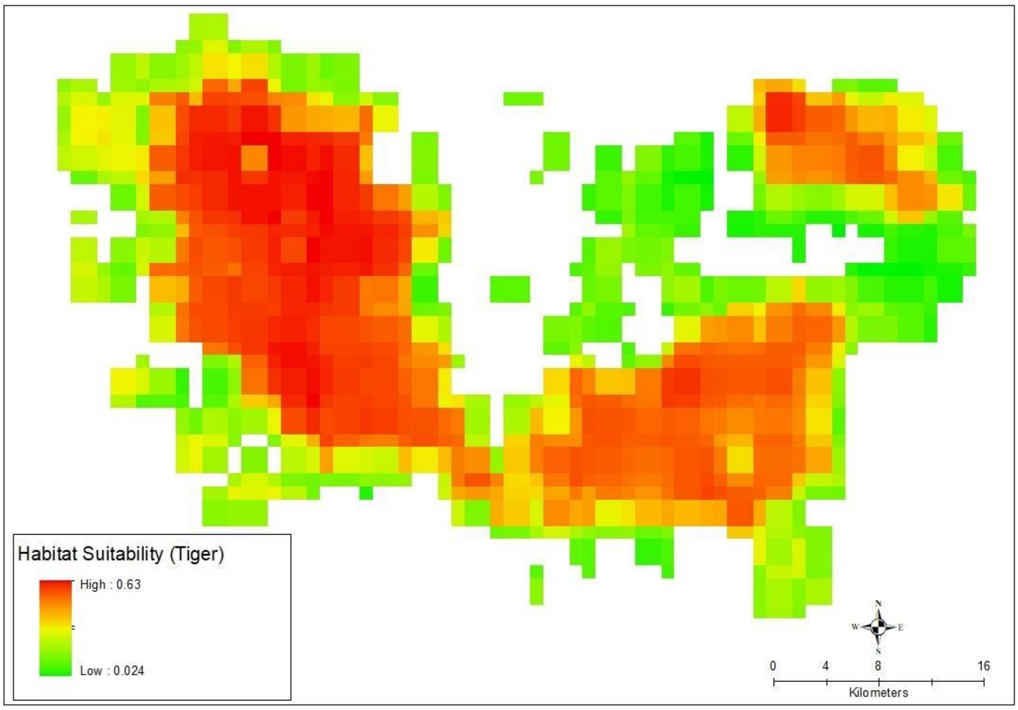


Figure 4.18: Distribution of Tiger across the forested areas of Kanha Tiger Reserve developed from the presence obtained by camera trapping and environmental covariates

4.4. Discussion

Information on the factors associated with the habitat selection of species in their ecosystem is essential to developing proper management and conservation strategy. In general, habitat selection of a species is generally governed by a combination of both intrinsic and extrinsic factors, including age, sex, fitness, availability of resources, intra and interspecific competition, anthropogenic disturbances, and geographic and environmental variables (Aryal et al. 2015; Lee et al. 2012; Mac Nally & Brown, 2001; Stuart et al. 2004). Hence, understanding such ecological processes needs thorough research with conventional scientific methods. In this study, I modeled the habitat suitability and investigated factors responsible for habitat selection of some important carnivore species in Kanha Tiger Reserve, central India, with the application of Maxent. I believe the findings will help a robust understanding of the community interactions and ecological processes, which can be utilized in conservation and management planning.

It demonstrates the extended usage of current-day data, which explains the vast dispersion of all kinds of animals (potential and realized). Its increasing data quality provides accurate and logical relevance and predictor variables available to understand information about species distribution.

The modelling results matched our understanding of carnivore natural history, particularly their habitat preferences in other parts of their distributional ranges. While models derived from coarse-grained landscape factors can accurately predict species distribution, finer-scaled habitat variables are difficult to be captured at this scale. Interestingly, each studied species had a distinct distribution pattern, limited, gradient, or random, showing the relevance of landscape heterogeneity and micro variables in shaping the distribution of sympatric carnivore communities. Identifying regions with high habitat appropriateness for all predators provides the groundwork for future study and conservation efforts.

In Kanha Tiger Reserve, jackals preferred the forest fringe area near the agricultural fields and human settlements. Also, their habitats were found to be overlapped with the preferred habitat of a tiger to an extent but outspread with the habitats of leopards and dholes. The habitat preference of golden jackals in the Kanha tiger reserve is similar to the earlier studies (Kamler et al. 2021; Šálek et al. 2014; Selimovic et al. 2021) conducted in the other part of their distributional range. Jackals are generally found in a wide range of habitats, from mountains to coastal regions (Ranc et al. 2018). Aside from that, they are adaptable to human-modified environments and utilize a wide variety of organic resources for their survival (Ćirović et al. 2016; Lanszki et al. 2018; Macdonald, 1979). However, a few variables, such as the availability of food, vegetative covers, shelters, and competition with sympatric species, sometimes disrupt their habitat selection (Jhala and Moehlman, 2004; Borkowski, Zalewski, & Manor, 2011). Here I believe the habitat selection of golden jackals reflects their general natural characteristics and might have been influenced by competition from other sympatric carnivores in this multiple predator landscape.

Unlike the golden jackal, the jungle cat in Kanha tiger reserve was found to prefer grassland and miscellaneous forest of the core area and avoid human settlements and agricultural fields. The findings have similarities and dissimilarities with (Chatterjee et al. 2020), where the species preferred to live in the open scrubland and avoid dense forest. However, the result can be supported by the findings of (Rather et al. 2020; Rostro-García et al. 2021). Furthermore, the result of tiger and leopard density affects the habitat suitability of jungle cats positively and negatively, respectively, which can be linked to their dietary pattern. A tiger, a specialist, might prefer to feed only on large-sized prey species and avoid smaller animals, whereas the leopard, being a generalist and opportunistic, may not avoid a jungle cat. Hence, to avoid predation, jungle cats might avoid leopards but not tigers in the KTR. The Jungle cat is a forest-dwelling species generally occurring in small isolated populations in South-East Asian forests. However, information on the ecological aspects of this species is limited. I believe my result on the habitat preference of this rare, elusive cat species will help understand the species deeply and provide necessary directions for planning appropriate conservation measures.

Dhole in my study area preferred grassland, a fringe forest area near human settlements, and habitat with high prey density. They were also observed avoiding the core area of the forest and habitats with a high density of tigers and leopards. In their other distributional range, Dhole primarily prefers to live in a variety of habitat types targeting a wide range of prey species and less competition (Aryal et al. 2015; Karanth & Sunquist, 2000; Namgyal & Thinley, 2017; Srivathsa et al. 2014). Dholes are generally observed in the multi-predator landscape, avoiding other large carnivores to reduce interspecific competition (Karanth et al. 2017; Steinmetz et al. 2013). Similar to the above findings, habitat selection of dholes in Kanha tiger reserve has mirrored their general ecological behaviour. The dhole preferring fringe area of the forest and avoiding the core area might be to avoid interactions with tigers and leopards, as the suitable habitat of tigers and leopards has been identified in the core area of KTR.

Unlike dhole and jackals, the Sloth bear habitat was predicted primarily deep inside the forest, overlapped with tiger and jungle cat. Sloth bears generally prefer various habitats with respect to the availability of resources such as fruit plants and colonies of insects (Yoganand et al. 1999). The result of sloth bears habitat preference in Kanha tiger reserve is found to be similar to Yoganand (2005) in Panna tiger reserve, central India, (Jain et al. 2021) in Sariska tiger reserve Rajasthan, (Ghimire & Thapa, 2015), and (Paudel et al. 2021) in Chitwan National Park Nepal, and Sukhadiya et al. 2013) in Jassore Wildlife Sanctuary, Gujarat where the sloth bear's habitat was found in the cores area of the forest with respect to the availability of fruit plants and termites. Furthermore, factors such as anthropogenic disturbances and other landscape features, including terrain ruggedness, affect their habitat preference. My result on sloth bear ecology in habitat selection seems to be a recurrence of the existing knowledge.

Based on the MaxEnt model, leopard habitats were predicted in the core area of the forest partially overlapped with the habitats of tiger, sloth bear, and jungle cat. Leopards here prefer habitats with less and moderate vegetation cover and avoid very dense forests. Also, leopard habitats were characterized by moderately dense prey and less ruggedness in KTR. Leopard is the most adaptive large cat species with evidence of living in a wide range of habitats, including human-dominated landscapes (Jhala et al. 2020). However, in the case of forested landscape, habitat selection of leopard has been influenced by the availability of prey species which further determine the competition among the different sympatric species. In addition, adequate forest covers also facilitate leopard habitat selection in the tiger habitat. In the case of a landscape with high density and diversity of prey species, a leopard can coexist with tigers whereas, in the opposite case, spatial avoidance of leopard to tigers and other sympatric carnivores' species has been observed (Johnsingh, 1992; Karanth &

Sunquist, 1995; Karanth & Nicolas, 1998; Odden et al. 2014). The preferred habitat of leopards in KTR was found to be partly outspread with the tiger habitat in the north-western part (Banjar catchment) but mostly overlapped in the south-east (Halon) regions. (Kumar et al. 2019) Their study in KTR observed an increasing trend of tiger population in the Banjar catchment area, whereas in the Halon region, they found it stable. Hence, I believe the habitat selection of leopards in KTR might be influenced by a combination of factors, including the prey abundance, their habitat selection with respect to different seasons (Awasthi et al. 2016), and the tiger population densities (Kumar et al. 2019) as observed earlier by (Carter et al. 2015) in Chitwan National Park, Nepal and (Odden & Wegge, 2009) in Bardia National Park in Nepal. Similarly, the leopard in KTR avoiding habitats with high prey density can be explained by considering the tiger's habitat preference. As the tigers occupied the high prey areas, the leopards, to reduce the chance of encountering tigers, might prefer to avoid such areas.

Tigers, the apex predator of the ecosystem, usually prefer a habitat with adequate prey abundance, availability of water, ample vegetation cover, and fewer anthropogenic disturbances (Jhala et al. 2008; 2011; 2015). In Kanha tiger reserve, the core area was identified as the most preferred habitat of the tigers. The core area of KTR is characterized by the high density of ungulate species (Awasthi et al. 2016) in comparison with the buffer zone. Similarly, the core area is also free from human disturbances and comprised of dense forest cover interspersed with grassland and bamboo mixed forest (Awasthi et al. 2016; Bora et al. 2020) and frequent water sources. The above characteristics are the optimum features necessary to support tigers in the ecosystem. Hence, I believe my result on tiger habitat selection in the KTR is not exceptional and match with earlier literature (Kafley et al. 2016; Kanagaraj et al. 2011; Smith et al. 1998; THAPA & KELLY, 2017; Jhala et al. 2015; 2020).

4.5. Conclusion

The modelling results matched our understanding of carnivore natural history, particularly their habitat preferences in other parts of their distributional ranges. In Kanha Tiger Reserve the habitat preference of jackals was observed throughout the forest but outspread with the habitats of leopards and dholes. Unlike the golden jackal, the jungle cat in Kanha tiger reserve was found to prefer grassland and miscellaneous forest of the core area and avoid human settlements and agricultural fields. Dhole preferred grassland, fringe area of forest near to human settlements, and habitat with high prey density. Sloth bear habitat was predicted primarily deep inside the forest overlapped with tiger, leopard and jungle cat. In addition to the inter and intra specific competition the habitat variables such as prey density, grasslands, NDVI, ruggedness and human settlements also played significant role in the habitat preference of the carnivore community in the KTR.

CHAPTER 5: SPATIO-TEMPORAL OVERLAP OF CARNIVORES IN KANHA TIGER RESERVE

5.1. Introduction

The proliferation of the anthropogenic pressure in the past few decades, resulting in loss, fragmentation, and degradation of wildlife habitats, has seriously undermined the conservation of wildlife, particularly the carnivores across the globe (Ripple et al. 2014; Bateman et al. 2012; Lamb et al. 2020). In such a scenario where the habitat loss to these large carnivores is rampant, protected areas play a significant role in upholding their conservation. Hence, in order to ensure the persistence of these top predators in the foreseeable future, effective conservation, and management planning of this protected area is of utmost importance, which further needs were accruing robust ecological knowledge (Weber and Rabinowitz 1996; Linnell et al. 2001; Wikramanayake et al. 2004; Lamichanne et al. 2019). The Kanha Tiger Reserve is a protected area in the central Indian region. It has immense significance for the conservation of carnivores as it is known to support the carnivore community comprised of tiger, leopard, dhole, sloth bear, jackal, fox, and other small cats, including jungle cat, rusty-spotted cat, etc. (Jhala et al. 2010).

Ecological knowledge in understanding Spatio-temporal interactions among the species has significant implications in conservation planning as it provides insight into the community structure and function (Karanth et al. 2017; Steinmetz et al. 2013). These interactions are also responsible for the distribution and behaviour of the species in their ecosystem. However, several factors, including the availability of the resources and their utilization by the species in different dimensions, are known to be the prominent factors governing the Spatio-temporal interactions among the species. In KTR, though many empirical studies have been conducted on various aspects of carnivore and herbivore ecology, no information is available on the interactions between the large meso and small carnivores in their ecosystems. Hence to fill such a research gap, I undertook this study. I sought to understand the spatial and temporal interactions among these carnivores and the major factors associated with these phenomena in the ecosystem of KTR through camera traps.

Camera trapping, a non-invasive method, has become an increasingly popular tool in wildlife research. It provides opportunities to undertake widespread and reliable species sampling in an ecosystem. The information generated from the camera trap sampling was most commonly used for population estimation in the earlier days. However, in recent times this information has a wide range of applications which has been extensively used to study the behaviour, activity, occupancy, etc. of the animal species

5.2. Methodology

In this study, the imprinted date and time stamp of photographs captured from 752 camera trap locations were used to analyze the activity pattern of three large meso and one small carnivore in the Kanha tiger reserve.

To analyse the activity pattern and overlap of different species, we followed the kernel density approach of Ridout and Linkie (2009). Linkie and Ridout (2011) in the overlap package in R. This package's functions quantify activity overlap with confidence intervals by using bootstraps function (Meredith, M., & Ridout, M., 2021).

Simultaneously active species The overlap coefficient is a similarity measurement that determines how much overlap exists between two different species. In the package 'overlap,' data are regarded as a random sample from the underlying distribution that describes the probability of a photograph being taken within any particular interval of the day. The probability density function of this distribution is then referred to as the activity pattern, which assumes that the animal is equally likely to be photographed at all times when it is active (Ridout & Linkie 2009). It is a two-step process. In the first step, kernel density estimation estimates each activity pattern non-parametrically. The kernel density estimates used a bandwidth parameter selected following the procedure developed by Taylor (2008). For the second step, a measure of overlap between the two estimated distributions was calculated. Ridout and Linkie (2009) reviewed several alternative measures of overlap between two probability distributions, favouring the coefficient of overlapping, Δ (Weitzman 1970), which ranges from 0 (no overlap, e.g., one species entirely diurnal, the other entirely nocturnal) to 1 (complete overlap). This is the area under the curve formed by taking the minimum of the two density functions at each time point. A useful interpretation of the overlapping coefficient is that for any period during the day, the proportion of activity that occurs during that period differs between the two distributions by <1- Δ. When the sample size became less than 50, Δ 1 performed best, while Δ 4 became better with a sample size of more than 75 (Ridout and Linkie 2009). Hence, we used Δ 4 for the coefficient of overlap in our study as we have got >100 capture of every species.

In my analysis, individuals captured more than once in the same location were counted as separate catches. To guarantee the independence of images of the same species and location, each shot was defined as a separate event if taken less than thirty minutes (Linkie and Ridout 2011). In the instance of individually identified animals (e.g., tiger, leopard). However, capture has been independent if subsequent images taken within thirty minutes are of such separate individuals. Independent photo-captures were translated to a per cent of images captured in 24hrs and then linked with some other individuals' activity to explore the temporal relationships in activity between species. Time evidence obtained from carnivore video traps was then carefully collected and analysed using the package ‘overlap’ in program R (version 4.0.3).

On the other side, space utilization measures whether and how the species utilize space. The utilization rate is determined by the species' frequency or capture rate and occupancy rate. Relative abundance indices of carnivores were extracted at 2 square kilometres spatial grid-scale using ArcGIS version 10.5. Using the RAI values, three-dimensional surface plots were generated in the program NCSS to estimate the relationship in spatial occurrence between each carnivore. To test the research hypothesis of sympatric competition, we looked at the overlap between apex carnivores (tiger &leopard) and meso and small carnivores (/ Sloth bear, dhole/ jackal/ jungle cat). In each surface plot, I kept the predictors (Tiger and Leopard the RAIs) on the X and Z axis and the response variable (RAIs of dhole, sloth bear, jackal & jungle cat on the Y-axis.

5.3. Results

Activity overlap:

In KTR, the activity pattern of both tiger and leopard was observed to be crepuscular and nocturnal and the activity overlapped between them was noted to be 87 percent (CI95 percent range 83-89). The peak activity period of the tiger was observed between 21:00 and 22:00 (Figure 5.1 (a)), whereas in the case of the leopard, it was between 18:30 and 19:30 (twilight).

Similarly, in the case of dhole, I found that they were most active in the morning between 7:00 and 8:00 (Figure 5.1 (b)) and remained active during the earlier hours of the day and the evening. The activity overlap between dhole and tiger was observed as 51 percent (CI95 percent range 46-60), and in the case, of leopard, it was 63 percent (CI95 percent range 54-71).

Sloth bear's activity in KTR was more or less similar to that of the tigers and leopards with overlap percentages of 92 (CI95 percent range 89-95) and 83 percent (CI95 percent range 81-87), respectively. Their peak activity hour was observed between 20:00 and 21:00.

The peak activity of jackal was observed between 5:30 and 6:30 AM (Figure 5.1 (d)), whereas the species was found to be cathemeral and remain active both during the day and night. The overlap of their activity with tigers and leopards was observed as 75 percent (CI95 percent range 72-80) and 86 percent (CI95 percent range 81-90), respectively.

The overlap in activity between a tiger and jungle cat was 83 percent (CI95 percent range 81-86), and between the leopard and jungle cat, it was 71 percent (CI95 percent range 69-77). The jungle cat's activity peak was between 10:00 and 11:00 PM (Figure 5.1 (e)), and the species was nocturnal in KTR.

Similarly, the activity overlap of dhole with sloth bear, jackal, and jungle cat was 51 percent (CI95 percent range 46-61), 70 percent (CI95 percent range 64-80), and 37 percent (CI95 percent range 33-49), respectively (Figure 5.1 (a, b, & c)) and in the case of a sloth bear with jackal and jungle cat it was 74 percent (CI95 percent range 72-79) and 81 percent (CI95 percent range 79-86) respectively, and in the case of jackal and jungle cat it was 62 percent (CI95 percent range 60-68) (Figure 5.4 (c)).

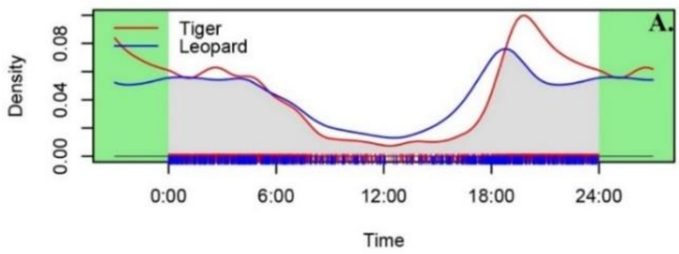


Figure 5.1: a) Temporal activity pattern and overlap between tigers and leopards in Kanha Tiger Reserve

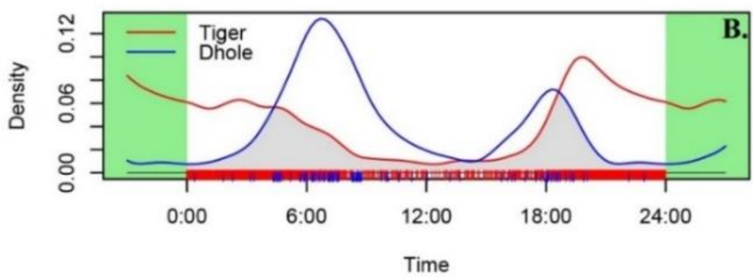


Figure 5.1: b) Temporal activity pattern and overlap between tiger and dholes in Kanha Tiger Reserve

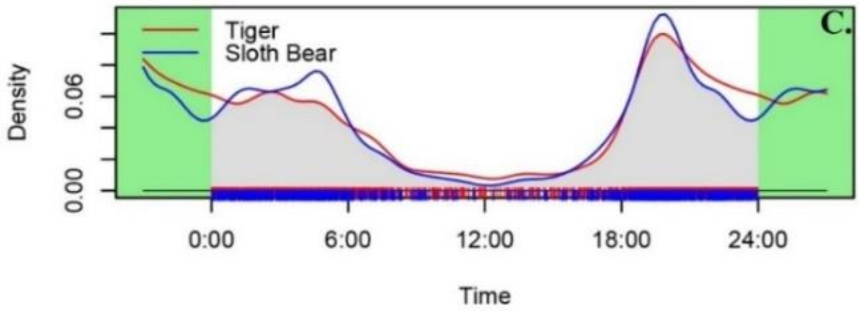


Figure 5.1: c) Temporal activity pattern and overlap between tigers and sloth bears in Kanha Tiger Reserve

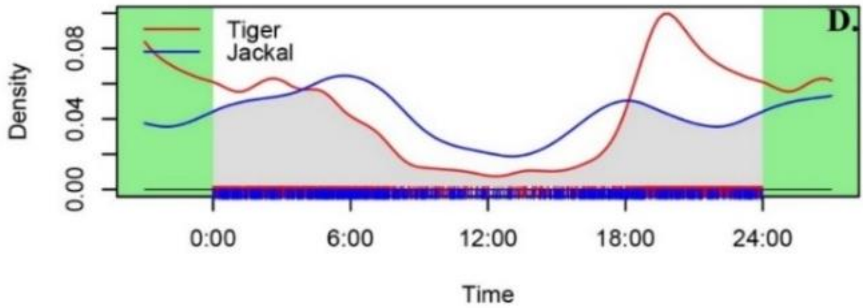


Figure 5.1: d) Temporal activity pattern and overlap between tigers and jackals in Kanha Tiger Reserve

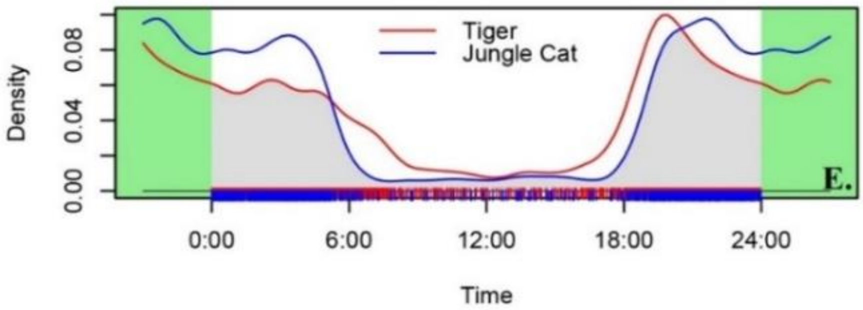


Figure 5.1: e) Temporal activity pattern and overlap between tigers and jungle cats in Kanha Tiger Reserve

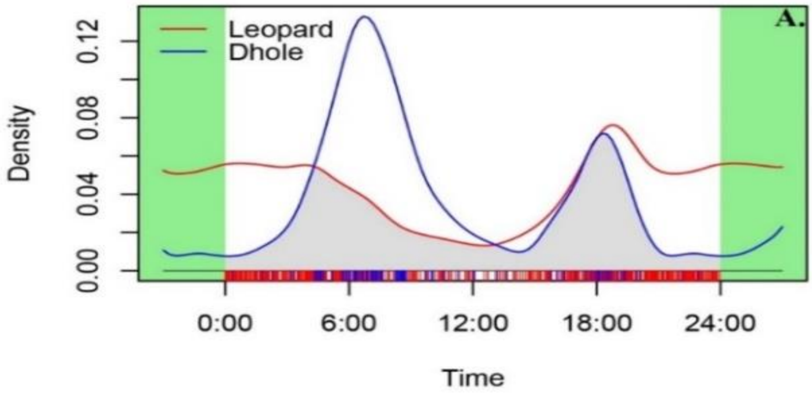


Figure 5.2: a) Temporal activity pattern and overlap between leopards and dholes in Kanha Tiger Reserve

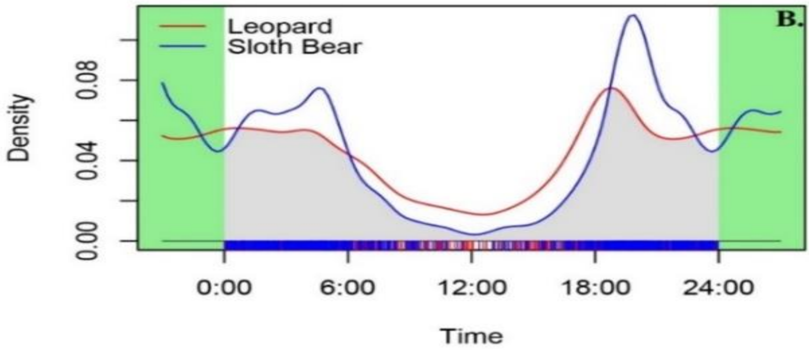


Figure 5.2: b) Temporal activity pattern and overlap between leopards and sloth bears in Kanha Tiger Reserve

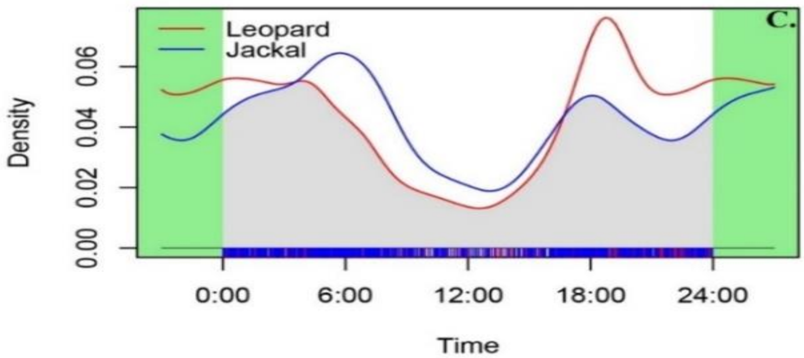


Figure 5.2: c) Temporal activity pattern and overlap between leopards and jackals in Kanha Tiger Reserve

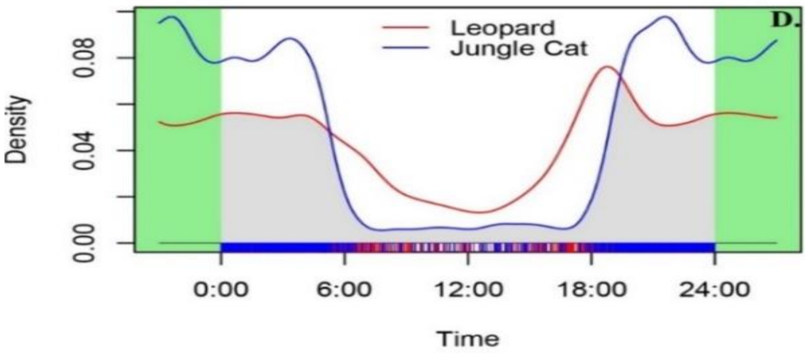


Figure 5.2: d) Temporal activity pattern and overlap between leopards and jungle cats in Kanha Tiger Reserve

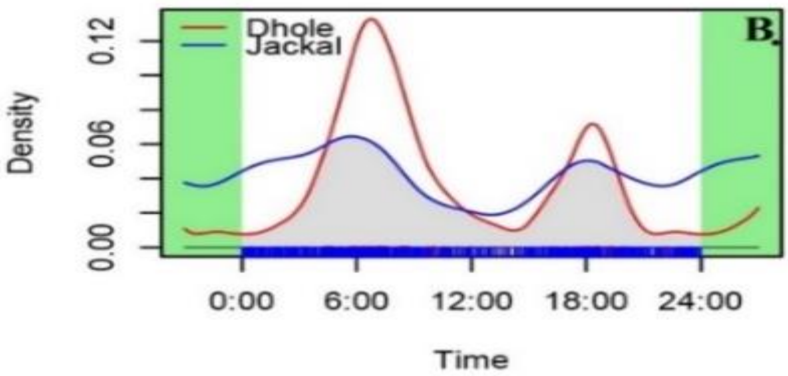


Figure 5.3: a) Temporal activity pattern and overlap between dholes and jackals in Kanha Tiger Reserve

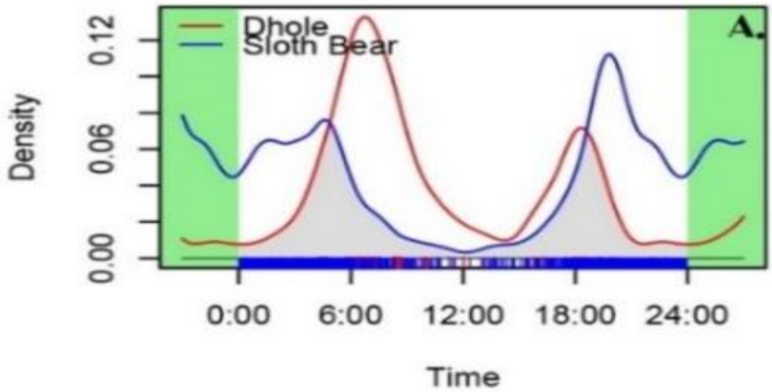


Figure 5.3: b) Temporal activity pattern and overlap between dholes and sloth bears in Kanha Tiger Reserve

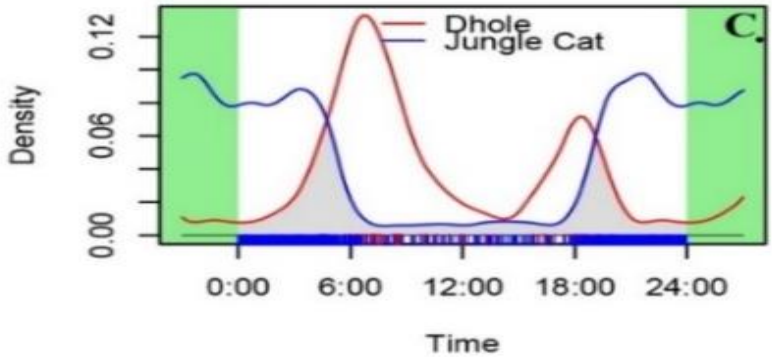


Figure 5.3:c) Temporal activity pattern and overlap between dholes and jungle cats in Kanha Tiger Reserve

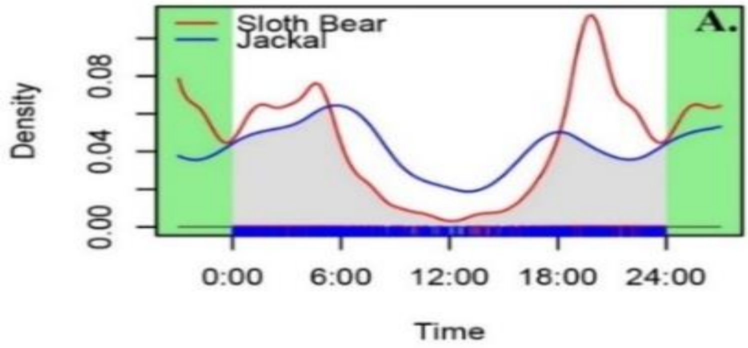


Figure 5.4: a) Temporal activity pattern and overlap between sloth bears and jackals in Kanha Tiger Reserve

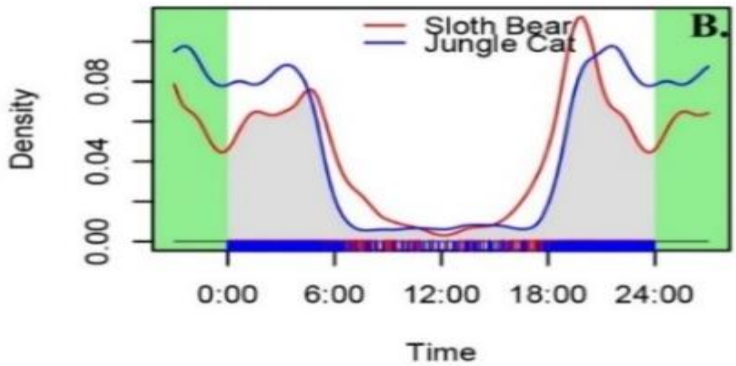


Figure 5.4: b) Temporal activity pattern and overlap between sloth bears and jungle cats in Kanha Tiger Reserve

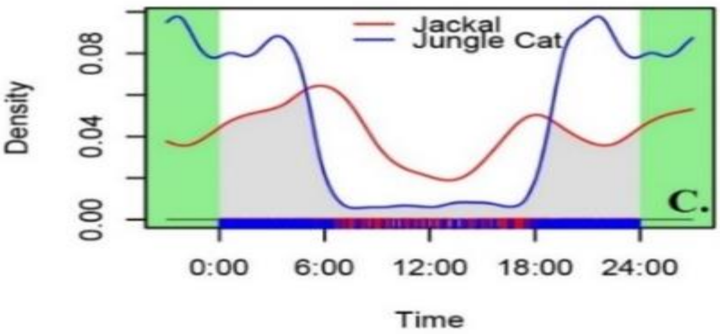


Figure 5.4: c) Temporal activity pattern and overlap between jackals and jungle cats in Kanha Tiger Reserve

Spatial overlap

The surface plot (Figure 5.5) shows that dholes are abundant (here RAI as an index of abundance), where tigers and leopards were infrequent. Similarly, Jackals are abundant, whereas tigers are abundant, while leopard abundance does not affect Jackals (Figure 5.6). Sloth bears are abundant in the area where tigers and leopards are both abundant (Figure 5.7). Jungle cats are abundant in those areas where tiger and leopard abundance is low (Figure 5.8). So when activity overlaps and spatial connections of three great predators (tiger, leopard, and dhole) were evaluated, a high activity overlap was identified between the tiger–dhole confidence interval, and moderate activity overlap was identified between the tiger and leopard confidence interval, but no spatial connection was detected. Leopard and dhole displayed varied activity overlap and a statistically insignificant positive relationship. Tiger’s trap rate against leopard and jackal is found to have a moderate relationship (Figure 5.6). The tiger’s trap rate against leopard and sloth bear was found to be significantly low, and the tiger’s trap against jungle cats is positively high. Overlap indicated species-specific spatial relationships and activity overlap. Tigers exhibited more activity overlap with leopards and sloth bears but less with dholes (Figure 5.1). The tiger's only major positive overlap has been with the jungle cat. Leopard had partial activity overlap with sloth bear, jackal, and jungle cat and less overlap with the dhole (Figure 5.2). Dhole had moderate activity overlap with jackal and lesser overlap with the jungle cat and jackal (Figure 5.4). It had a higher spatial association with tiger and leopard. While the Asiatic wild dog was temporally isolated from the tiger and leopard, it exhibited spatial overlap with both. Sloth bear had a high activity overlap with jungle cat and a moderate activity overlap with the jackal. Sloth bear had a moderate spatial overlap with leopard and tiger. Jackal and jungle cats had only a moderate activity overlap (Figure 5.4)

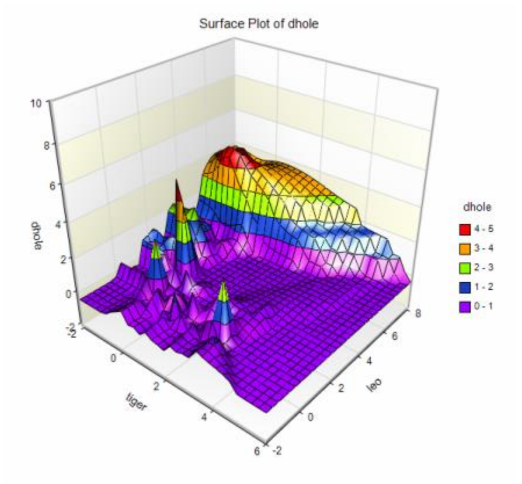


Figure 5.5: Response of Dhole trap rate to varying tiger and leopard density at 2 km2 grid spatial resolution

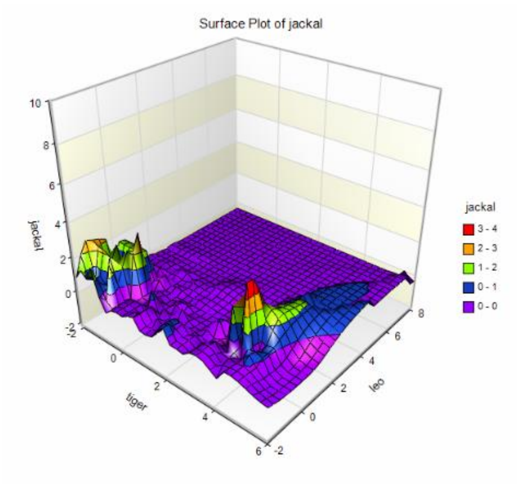


Figure 5.6: Response of Jackal trap rate to varying tiger and leopard density at 2 km2 grid spatial resolution

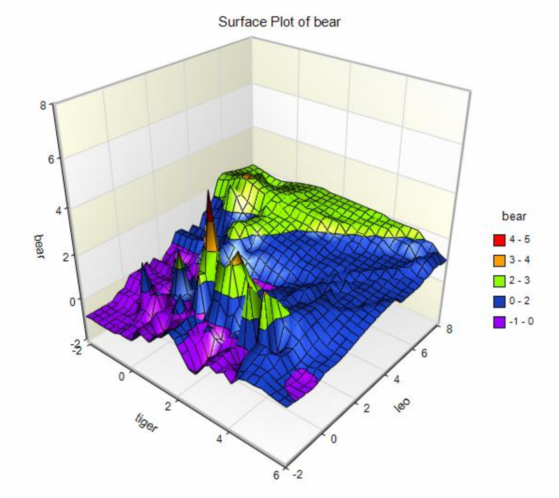


Figure 5.7: Response of sloth bear trap rate to varying tiger and leopard density at 2 km2 grid spatial resolution

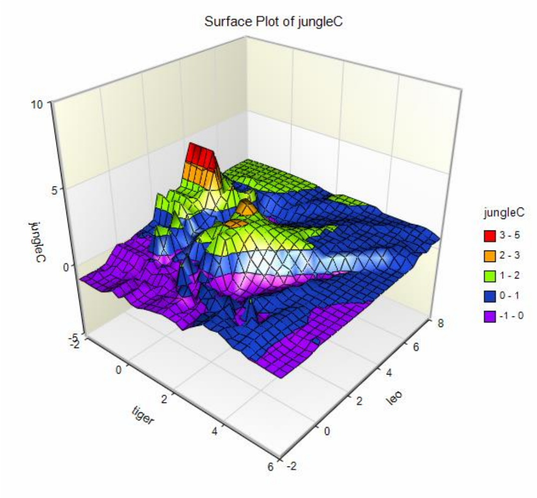


Figure 5.8: Response of Jungle cat trap rate to varying tiger and leopard density at 2 km2 grid spatial resolution

5.4. Discussion

A study on the Spatio-temporal interaction of large carnivores is crucial for understanding them ecologically. In this study, I used the camera trap information to understand the Spatio-temporal interactions of 4 large carnivores, i.e., tiger, leopard and dhole and sloth bear, one meso-carnivore jackal, and one small carnivore jungle cat, living sympatrically in Kanha tiger reserve. The activity pattern of both tiger and leopard was observed to be overlapped with each other where both the species were active during dawn and dusk and also during the night. However, spatial avoidance between these two species has been observed. At the same time, dhole avoided these two species temporally, but a partial spatial overlap has been observed. To avoid intraguild competition, sympatric species generally utilize the resources in different dimensions (spatial or temporal scale). Tiger being the most predators of the ecosystem, generally modify their activity pattern and spatial distribution corresponds to their prey species to maximize the chances of an encounter. However, the distribution and activity of the other sympatric species, such as leopard and dhole, can be influenced by both the prey species and the tiger distribution (Steinmetz et al. 2012; Kafley et al. 2018; Lamichhane et al. 2019). Carter et al. (2015), Lamichhane et al. (2019), and Kyaw et al. (2021) have also observed a similar pattern of results in such felid assemblage in other multi-predator ecosystems of south-east Asia. Hence, my result in KTR replicates an earlier understanding of these carnivores in multi-predator communities.

Sloth bear's temporal activity in KTR was highly overlapped with the tigers and leopards. However, it had a moderate spatial overlap with these apex predators. The occurrence of sloth bears in the tiger habitats of the Indian subcontinent has often been reported, except in the high-altitude regions of the Himalayas. Despite being a large carnivore, the resource used by this species in comparison with its other sympatric large carnivores is quite different. Tiger, leopard, and dholes are the typical hunters who depend on their lower trophic level animals for survival. However, despite being a large carnivore, the sloth bear often feeds on the fruits, roots and insects by avoiding direct competition with its sympatric predators. In addition, sloth bears were often killed by tigers and leopards, and frequent infighting between these species has also been reported (Yoganand 2005). Hence, I believe such a pattern of Spatio-temporal activity by the sloth bear might have been influenced by a combination of factors, including resource availability and fear of other large carnivores.

In the case of jackal and jungle cat, the former was cathemeral, whereas the latter was nocturnal. Though resource utilization by these meso and small predators was somewhat overlapped, we can also say there is partial separation between these sympatric species in their resource utilization pattern, which facilitates coexistence.

In KTR, my result on these carnivores' Spatio-temporal interaction allies with the niche theory of Hutchingtion (1957), where co-existence of sympatric species in a common habitat can only be possible when the realized niches of the species are different regardless of the common fundamental niche. Furthermore, it is also apparent that the distribution of the species and their activity in the ecosystem of KTR is primarily driven by the availability of resources along with the competition among the sympatric species.

The study provides an unambiguous understanding of the Spatio-temporal interaction of the carnivore community in a multi-predator landscape of central India. The findings also strengthen the knowledge of the intraguild interactions among the sympatric predator in their ecosystems. Where the similarity in the activity pattern was observed, spatial segregation in distribution occurs. In the case of spatial overlap in distribution, temporal separation in their activity was observed. This indicates these sympatric species' resource utilisation in different spatio-temporal scales to minimize the interspecific conflict in a common carnivore guild. The study also highlights the effect of the dominant predator over the subordinate one and how each species utilizes the resources in such a way to avoid clashes with each other that support the co-existence in a common ecosystem.

5.5. Conclusion

The study shed lights on the temporal interaction among the carnivore community in the Kanha Tiger Reserve of Central India. The tiger and leopard were active during dawn and dusk and in night. A highly similar pattern of activity was observed in the case of Sloth bear which active during night. However, Dhole avoided these three species temporally and active during day. In the case of jackal and jungle cat the former was cathemeral whereas the later was nocturnal. The study provides unambiguous understanding on the temporal interaction of the carnivore community in a multi-predator landscape of central India. This also indicates the resource utilization by these sympatric species in different Spatio-temporal scale to minimize the interspecific conflict in a common carnivore guild. The study also highlights the effect of dominant predator over the subordinate one and the resource utilisation of the different species in such a way so that the internal conflict can be avoided.

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ZBC-12

TEMPORAL OVERLAP IN CARNIVORE COMMUNITY OF KANHA TIGER RESERVE

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Ecology of tiger and leopard are well studied in Kanha (Schaller 1969, Pawar 1972 and ongoing study by Jhala *et.al*. 2005-2013), however very little information are available on other two large carnivore i.e., Sloth Bear and Wild Dog and meso carnivores like Jackal and Jungle Cat. These Non-pantherine carnivores (NPC) are important and constitute a viable carnivore community along with pantherine carnivores in Kanha Tiger reserve. We studied temporal interaction of carnivore community in Kanha Tiger Reserve. We deployed 1022 camera traps in Kanha tiger reserve during 2014. Camera traps were placed in 1 km^2 grid at the best possible locations such as animal trails, forest road and nallah where the chances of getting carnivore photo-capture were maximum. Each photograph was stamped with the date and time of photo-capture along with the location id and extracted for understanding temporal activity pattern. To ascertain independence in the activity data, we used 15 min interval between the previous photographs at the same location. We used overlap package in R programming environment to analyse the temporal activity pattern of overlap between the animals. We found that tiger, leopard, sloth bear and jungle cat were nocturnal while wild dog was diurnal in nature. We found that tiger and leopard had high overlap ($d_4 = 0.86$) in their time of activity, however tigers were highly active during night time while leopard activity was high during evening hours. The activity overlap between wild dog and tiger was minimal ($d_4 = 0.24$). This reflects the niche separation between tiger and wild dog. Activity overlap between jackal and tiger was moderate ($d_4 = 0.55$). Jackal are known to scavenge on the tiger kill and predate on chital fawn hence they were more active during morning. This study is important in relevance to conservation and management of Non Pantherine Carnivores as they hold trophic positions below tiger and leopard influences the community structure and resource sharing between species in Kanha.

ZBC-13

CAPTIVE RED JUNGLE FOWL (*Gallus gallus*) PREFERRED WILD HABITAT IN CAPTIVITY

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Rasikbeel Mini Zoo, Cooch behar, West Bengal received 4 Red Jungle Fowls (2 adult Male and 2 adult female birds) from Padmaja Naidu Himalayan Zoological Park

WILDCON 2020

International Conference

Organized By :

Wildlife Research & Training Centre, Gorewada Rescue Centre, Nagpur & Association of Indian Zoos & Wildlife Veterinarians, Bareilly

CERTIFICATE OF PARTICIPATION

This is to certify that

Anup Kumar Pradhan

has participated in Wildcon- 2020 (Online International Conference) on "***Insights into wildlife conflicts, rescue and rehabilitation: Challenges and opportunities for Conservation***" and 14th Annual Convention of Association of Indian Zoo and Wildlife Veterinarians organized by Wildlife Research & Training Centre, Gorewada Rescue centre, Nagpur & Association of Indian Zoos & Wildlife Veterinarians, held during 18th - 20th December, 2020 conducted from Nagpur.

PROF. B.M. ARORA
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DR. S.V. UPADHYE
Organizing Secretary
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MAFSU/WRTC/WEB-CONF/ 1549/2020 dated 20/12/2020

Effect of human use, season and habitat on ungulate density in Kanha Tiger Reserve, Madhya Pradesh, India

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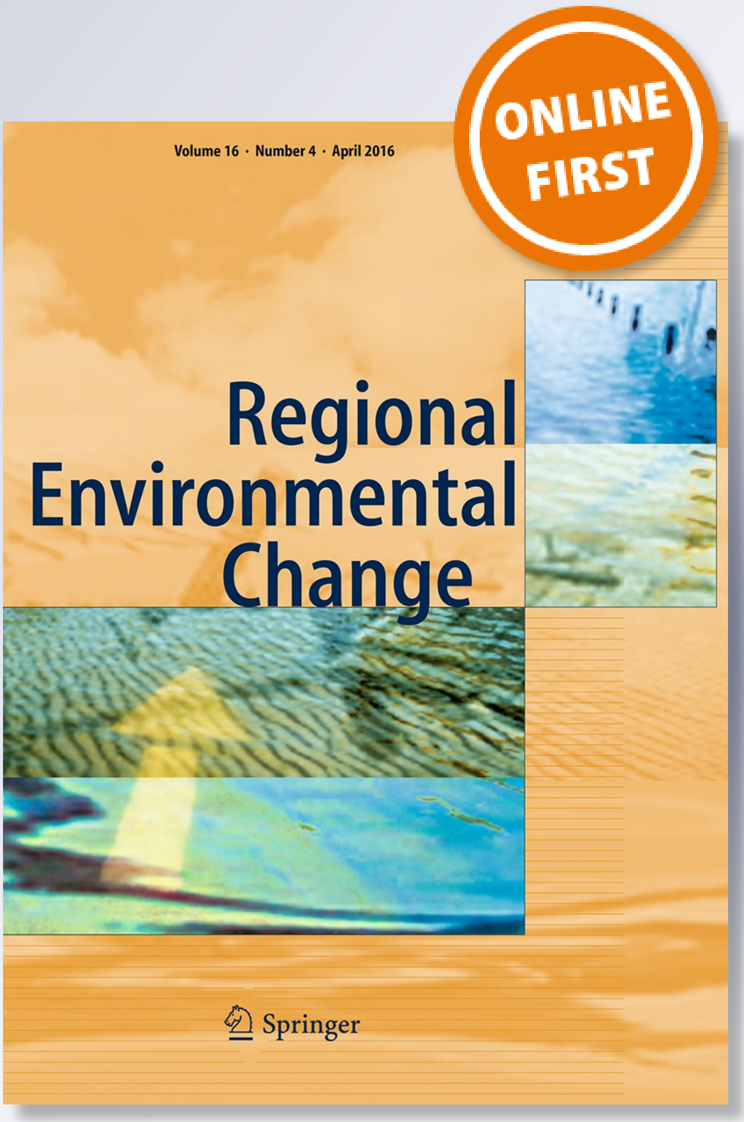
Regional Environmental Change

ISSN 1436-3798

Reg Environ Change
DOI 10.1007/s10113-016-0953-z



Reg Environ Change
DOI 10.1007/s10113-016-0953-z

ORIGINAL ARTICLE

Effect of human use, season and habitat on ungulate density in Kanha Tiger Reserve, Madhya Pradesh, India

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Received: 6 June 2015 / Accepted: 6 March 2016

Abstract Conservation practitioners require strata specific, seasonal species densities for habitat management. Herein, we use stratified distance sampling in Kanha Tiger Reserve (KTR) with 200 spatial transects and an effort of 1200 km walk in the year 2013. Analysis was done to access (a) impact of human use and (b) effect of habitat and season on ungulate densities in KTR. While a single detection function for each species was used for estimating density within human-restricted core and multiple use buffer of KTR, species-specific seasonal detections were modelled for each habitat. Ungulate biomass was 4.8 times higher in the core area compared with the buffer zone. The core supported a herbivore density and biomass of $50 \pm 4.80/km^2$ and $26{,}806 \pm 2573$ kg/km^2, respectively. Chital were found to be most abundant, having a density of $30.1 \pm 4.34/km^2$ and contributing 33 % of the biomass with a habitat preference for grasslands ($106 \pm 39/km^2$) in summer and winter. Sambar had highest density ($15.4 \pm 3.34/km^2$) in bamboo-mixed habitat, in both seasons. Gaur contributed 39 % of the ungulate biomass and showed a seasonal shift in density from sal forests ($9.65 \pm 3.55/km^2$) in summer to miscellaneous forests ($8.13 \pm 1.94/km^2$) in winter. Barasingha were restricted to grasslands with similar summer and winter densities of $1.56 \pm 0.76/km^2$. Chousingha were rare ($0.1 \pm 0.04/km^2$), found mostly in miscellaneous forests and plateau grasslands. Grassland and bamboo-mixed forests supported 58 % of the total ungulate biomass. Management for an optimal habitat mosaic that maintains ungulate diversity, addresses the specific needs of endangered species and maximizes ungulate biomass is recommended.

Keywords Distance sampling · Habitat management · Habitat mosaic · Protected areas · Tropical forest · Ungulate biomass

Introduction

Tropical deciduous forests are capable of supporting high density of ungulates due to their high productivity and nutrient availability (Field et al. 1998; Melillo et al. 1993). Subsequently, due to a high prey abundance, these forests are important refuges for conserving large carnivores. Land for conservation comes at a high premium in tropical countries with burgeoning human populations (Dinerstein et al. 2010). Severe biotic pressure such as bush meat consumption, use of non-timber forest products, and livestock grazing has likely resulted in an unprecedented reduction in ungulate abundance in these forests. Protected areas in the tropics are relatively small compared with other biomes (Schmitt et al. 2008). Often large carnivore populations in the tropics, such as those of tigers, are primarily restricted to protected areas (Jhala et al. 2015). Rarely does a single reserve harbour a tiger population of sufficient size required for its long-term persistence (Yumnam et al. 2014). Density of large carnivores is primarily dictated by the density of their prey (Hayward et al. 2007). Therefore, managing them optimally to serve both

Electronic supplementary material The online version of this article (doi:10.1007/s10113-016-0953-z) contains supplementary material, which is available to authorized users.

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Published online: 19 April 2016

the purpose of conserving biodiversity and harbouring viable large carnivore populations becomes crucial. The Tiger Reserves in India are legally mandated to delineate a core area where large investments by the Government are made to resettle human habitations from within the core area through an incentivised, voluntary, relocation scheme (Wild life (Protection) Amendment Act 2006). The core is subsequently declared 'inviolate' with extremely restricted human activity (Gopal et al. 2007). Scientific data that document the effectiveness of these investments in achieving the desired conservation objectives would encourage Governments to invest further in such schemes that benefit both the local communities through better livelihood options and biodiversity conservation (Secretariat of the Convention on Biological Diversity 2008).

Ungulates meet their food and cover needs from a wide range of resources and habitats. Food quality, plant productivity and water regime vary in availability with seasons (Prins and Loth 1988; Beever et al. 2000), which often force ungulates to expand their home ranges, or shift their use of habitats in a seasonally predictable fashion. Distance sampling (Buckland et al. 2001) has opened up the field of estimating forest dwelling ungulate abundance. However, current application of distance sampling has been done on random foot transects that typically traverse multiple habitat types. Although estimates from such studies are unbiased to the region of inference, they fail to provide information on how ungulate abundance responds to different habitats, a vital requirement for management. Precision of estimates from distance sampling on foot transects depends on variability of effective strip width (ESW), encounter rate and cluster size (Buckland et al. 2001). For a given sample size, habitat-specific distance sampling would provide more precise density estimates compared with the same number of transects that traverse habitat mosaics (Thomas et al. 2010). Estimating abundance by habitat stratification is a sensible approach to improve the precision of estimates and ensure proper coverage of habitats (Sutherland 2000).

Herein, we use stratified line transect sampling in Kanha Tiger Reserve, Madhya Pradesh, India, and analyse our data with conventional distance sampling to assess the effect of a) extractive anthropogenic use and b) habitat and season on ungulate densities. Our results showed that ungulate densities were significantly depressed in "multiple use" forests of the buffer zone compared with the "human-restricted" core area of KTR. Some ungulates of KTR showed significant seasonal shifts in their habitat-specific densities, while others seemed to be habitat specialists and maintained high habitat-specific densities in summer and winter. We attempt to interpret our results in the context of nutritional and cover requirements of ungulates and thereby provide management options for specific ungulate species and for the overall conservation objectives of KTR.

Materials and methods

Study Area

Kanha Tiger Reserve is located in the state of Madhya Pradesh (latitudes 22° 7′ N and 22°27′ N and longitudes 80° 26′ E and 81° 3′ E) in the Maikal chain of hills in the eastern Satpura mountains of the Central Indian Highlands. The Tiger Reserve comprises of two distinct management strata: the core which covers an area of 940 km^2, devoid of human settlements and has the prime objective of biodiversity conservation and a 1134 km^2 of buffer zone which is a multiple use area, having human settlements where tourism-based resorts and hotels, small-scale industries like rice mills, agriculture practices, and infrastructure development for village people are permitted although activities adverse to conservation such as mining and large polluting industries are not permitted in the buffer zone. The area of forest or wild ungulate habitat available within the buffer zone is 585 km^2, and thus, the conservation unit totals an area of 2074 km^2, and is designated as a Tiger Reserve.

Kanha is a tropical moist deciduous forest interspersed with grasslands of anthropogenic origin, arrested in succession by management activities of annual burning and woody plant removal (Kanoje 1999). The undulating terrain and variation in the altitude (450–950 m above mean sea level) has resulted in a diversified floral composition (Champion and Seth 1968). In general, four different habitat types, viz. grassland, pure sal forest, miscellaneous forest and bamboo-mixed forest, are present in the reserve. The higher elevation sites consist of extensive plateau-capped hills supporting sparse or little tree growth of miscellaneous forest and are primarily grasslands. The depressions, gorges and streams, just below these plateaux, support bamboo (*Dendrocalamus strictus*), while the low-altitude sites comprise valleys with grassy meadows interspersed with groves of sal (*Shorea robusta*) and the lower slopes carry dense stands of sal with bamboo which also occur in miscellaneous stands in the upper slope. The faunal assemblage consists of endangered carnivores like tiger (*Panthera tigris*), leopard (*Panthera pardus*), wild dog (*Cuon alpinus*) and sloth bear (*Melursus ursinus*), and nine species of ungulates such as hard ground barasingha (*Rucervus duvaucelii*), chital (*Axis axis*), sambar (*Rusa unicolor*), gaur (*Bos gaurus*), barking deer (*Muntiacus vaginalis*), wild pig (*Sus scrofa*), chousingha (*Tetracerus quadricornis*), nilgai (*Boselaphus tragocamelus*) and mouse deer (*Moschiola indica*). Among small carnivores, jungle cat (*Felis chaus*) and rusty spotted cat (*Prionailurus* *rubiginosus*) are present in the reserve. The climate is monsoon type with marked seasonal variations in temperature and rainfall. The mean annual rainfall is 1623 mm, most of it restricted to the monsoon months (Negi and Shukla 2011). Three seasons are observed in the area: namely winter (December–February), summer (March–May) and rainy seasons (June–September). October and November are a transition period from monsoon to winter.

Habitat mapping and validation

Extensive ground truthing was done by sampling 900 vegetation plots of 707 m^2 size in the field by trained personnel. Each vegetation plot was classified to its dominant vegetation community to record major habitat types (Fig. S7). Plots (1) with >70 % sal were considered as "pure sal"; (2) having <70 % sal and >30 % other tree species were considered as "miscellaneous forests"; (3) with miscellaneous forests having >20 % bamboo were considered as "bamboo-mixed forests"; and (4) having <10 % tree cover and ground vegetation dominated by grasses were defined as "grasslands". The other habitat categories were (5) agriculture/fallow fields, (6) barren areas and built-up human habitation area and (7) water bodies. We used 70 % of ground plots for modelling vegetation classification, while 30 % were used for model validation to assess the performance of our image classification. Unsupervised classification of LANDSAT-8 satellite imagery (pixel size = 30 metres; acquisition date; April and November 2013) was carried out. The results of the unsupervised classes were merged by supervised classification to adhere to field identifiable classes mentioned above. Digital image processing, geo-referencing and digital classification of remotely sensed data were done using ERDAS imagine 2010 (Earth Resources Data Analysis System, Leica Geosystems, Atlanta, Georgia, USA).

We built an error matrix that compared the habitat classes identified in the field for independent, randomly selected 450 vegetation plot locations against their corresponding classified pixels on the image using kappa coefficient (Cohen 1960). Kappa indicates to what extent classification accuracy is due to the true agreement of the field data with classified data (Lillesand et al. 2004). Its values generally range from 1 for perfect agreement to 0 for no agreement (Rosenfield and Fitzpatrick-Lins 1986). Habitat classification was assessed as accurate if kappa coefficient was greater than 0.6 (Landis and Koch 1977).

Sampling design and data collection

Ungulate density is likely to respond to regimes of protection as well as to vegetation types. Hence, we used a stratified design in the core area of the Tiger Reserve, where the number of transects in each habitat was approximately in proportion to the area of the habitat. Thus, grassland had 12 transects, sal forest had 36 transects, bamboo-mixed forest had 29 transects, and miscellaneous forest had 73 transects. Based on management zones, the core area had 150 transects, while the forest of buffer zone had 50 transects (Fig. 1). Line transects of 2 km were marked within each strata and walked during early morning (6:00 a.m. to 8:00 a.m.), for three consecutive mornings in summer and winter of 2013. In each season, sampling was completed within 30 days. The total transect survey effort comprised 1200 km of walk along 200 spatial replicates in both seasons. Radial distance, animal bearing and group size were recorded with encounter of each ungulate species. We surveyed the entire reserve with 20 observers who were well versed with field craft and species identification. We trained and tested each observer in the use of laser range finder (Bushnell RX 1000), see through compass (Suunto KB-20) and GPS (Garmin eTrex 10).

Data analysis

Ungulate abundance estimates were derived from 200 line transect samplers placed across 1945 km^2 of the study area using conventional distance sampling (CDS) approach (Buckland et al. 2001) in program Distance (version 6.2; Thomas et al. 2010). Densities of six major ungulates (chital, sambar, gaur, wild pig, barasingha and barking deer) were recorded for each management and habitat strata. Chousingha and nilgai were analysed only for management strata as the number of observations recorded for these species was insufficient to separately estimate detection functions and densities for each habitat type.

For the first analysis, we were interested in finding out whether density of specific species differed between two regimes of management, i.e. the core area, devoid of human settlement and the buffer zone, a multiple use area with extractive use by local communities. For this analysis, we developed detection functions for each species from all transects pooled across management zones and subsequently estimated density for each species for each management zone by post-stratification. Since habitat types between core and buffer areas were similar, we did not expect detection functions for each species to differ between the core and buffer zones. We tested this premise for species that had a large number of detections in both management strata (chital and barking deer), by comparing the effective strip width (ESW) and detection probability obtained from independent fitting of detection functions for core and buffer habitats. Since ESWs and detection probability did not differ between core and buffer, we pooled

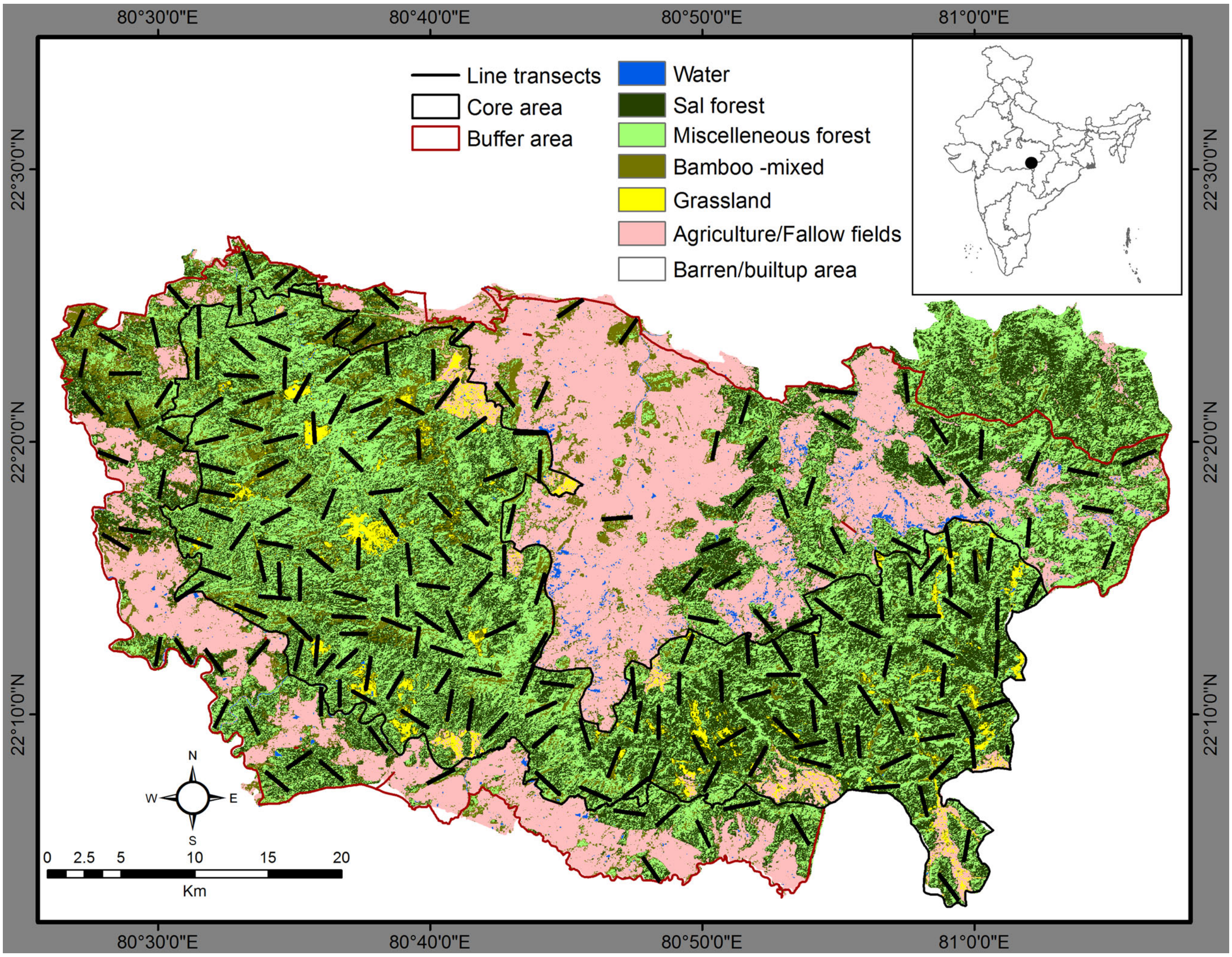

Fig. 1 Vegetation cover map of Kanha Tiger Reserve showing the spatial distribution of habitat-specific line transects

data separately for individual species between core and buffer zones to obtain a more robust and precise estimate of ESW for each species and estimated density separately for core and buffer using a common detection function (Figs. S1 and S2).

In our second analysis, we were interested in the effect of habitat type and season on ungulate densities. We restricted our analysis to the core of the Tiger Reserve since transects in the buffer area were not habitat specific. This was because habitat patches in the buffer were too small to lay a transect of reasonable length. Since there were few detections of sambar, gaur and wild pig in grassland for both seasons and few detections of gaur within sal forests and bamboo-mixed forests for winter season to permit the modelling of detection functions, we pooled individual species detection data for these species from our transect walks in these habitats for the years 2012 and 2013. A detection function was then modelled for each species for a particular habitat in a specific season by combining the 2-year data. This detection function was then used to obtain the species density for the year 2013 by post-stratification by years, for a particular habitat in a specific season. Shape criteria were examined for heaping and any outliers were right-hand truncated where necessary (Buckland et al. 2001). Three key functions (uniform, half-normal and hazard rate all with cosine series adjustment) were considered for each analysis. Model selection was evaluated using Akaike's information criteria (AIC), while Kolmogorov–Smirnov statistics were used to assess the goodness of fit of each model (Buckland et al. 2004).

Considering ungulate abundance in a habitat type to be the use by that species, we computed Ivlev index of electivity (1961). Ivlev index measures the utilization of habitat types (U) by species in relation to their availability (A) in the landscape (Dyke 2008). Ivlev index of selection is determined as U-A/U + A. It is an algorithm for identifying the strength of selection for habitats (Yeo and Peek 1992). The selection index will be zero whenever animals use the habitat in the same proportion as its availability. It will approach the value of one when use is proportionately much higher than availability suggesting the strong preference for that habitat. Alternatively, it will approach a value of negative one when use is less than availability (Dyke 2008). Ivlev index was only used for graphical representation (Fig. 2). Following Byers et al. (1984), we first tested for overall seasonal habitat preference by an ungulate species through a Chi-square test, and subsequently, we used simultaneous Bonferroni confidence intervals that control for an overall experiment wise error rate, to check for preference of each habitat type. We

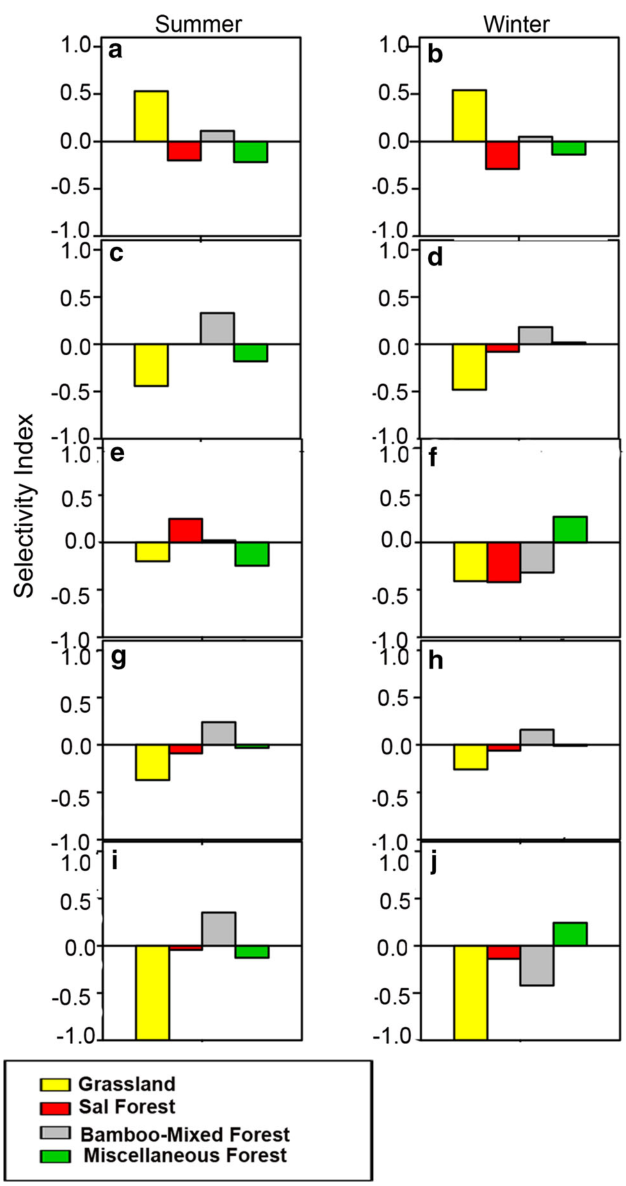

Fig. 2 Seasonal habitat selection by chital **a** summer **b** winter; sambar **c** summer **d** winter; gaur **e** summer **f** winter; wild pig **g** summer **h** winter and barking deer **i** summer **j** winter in Kanha Tiger Reserve depicted by Ivlev's selectivity index

computed ungulate biomass for each habitat in each season by multiplying species density with the 3/4th of the adult female body mass (Schaller 1972) (Table S1 and S2).

Results

A kappa statistics value of 0.8 ($p < 0.001$) suggested good agreement of validation plots with the vegetation map (Fig. S7). As per the habitat classification map prepared in this study, the area under (1) pure sal was 426 km^2, (2) miscellaneous forests was 648 km^2, (3) bamboo-mixed forests was 425 km^2, (4) grassland was 88 km^2, (5) agriculture/fallow fields were 268 km^2, (6) barren and built-up areas were 218 km^2, and (7) water bodies were 16 km^2. Chital was the most commonly sighted ungulate followed by sambar, barking deer, gaur and wild pig (Tables 1, 2 and 3).

Human use and ungulate density

Species densities differed between core and buffer zones (Table 1). The results showed that among all ungulates, chital was the most abundant with much higher density in the core area (30.1 ± 4.34) compared with the buffer zone (8.45 ± 2.37) of the Tiger Reserve. The next most abundant were sambar and gaur, with a consistent trend between core and buffer areas, in both summer and winter seasons. Only in the case of wild pig and barking deer, densities were comparable between both management strata and seasons. Only nilgai had higher densities in buffer zone compared with the core zone (Table 1) while barasingha and chousingha were not detected in the multiple use buffer zone. Group size of all ungulates except nilgai was larger in the core zone (Table 1). Detection probabilities and ESWs for chital and barking deer did not differ between core, buffer and combined analysis (Figs. S1 and S2).

Habitat-specific densities and preference by ungulates

All species of ungulates showed preference for certain habitats ($\chi^2 > 7.85$, $p < 0.05$). Chital was most abundant among all ungulates, across all four habitats and in both summer and winter seasons. Chital densities were highest in grassland followed by bamboo-mixed forest with little seasonal variation (Tables 2 and 3). Chital consistently showed a high preference for grassland in both summer and winter seasons (Figs. 2a and b; Tables S3 and S4). Sambar had the highest densities in the bamboo-mixed forest in summer followed by sal forest and miscellaneous forest. The seasonal densities of sambar show a little habitat shift from bamboo-mixed forest in summer season to

Table 1 Density of ungulates in the core and buffer area of Kanha Tiger Reserve in 2013

Species	season	Management site	Best model	Detection probability $\hat{P}$ (SE)	KS test *p* value	No of observation (n)	Mean Cluster size E(s) (SE)	Group density $\widehat{DS}$ (SE)	Density $\hat{D}$ (SE)
Chital	Summer	Core	HRC	0.25 (0.01)	0.892	357	9.62 (0.52)	3.14 (0.48)	30.3 (4.9)
		Buffer				51	5.8 (0.65)	1.35 (0.28)	7.9 (1.88)
	Winter	Core	HNC	0.18 (0.01)	0.823	326	8.35 (0.47)	3.59 (0.40)	29.9 (3.7)
		Buffer				55	5.93 (0.66)	1.51 (0.43)	9.0 (2.79)
Sambar	Summer	Core	HRC	0.29 (0.01)	0.727	250	2.86 (0.10)	2.76 (0.33)	7.90 (0.99)
		Buffer				15	2.58 (0.43)	0.49 (0.13)	1.29 (0.42)
	Winter	Core	HNC	0.13 (0.01)	0.721	258	2.33 (0.08)	3.58 (0.36)	8.38 (0.89)
		Buffer				18	2.24 (0.37)	0.54 (0.17)	1.22 (0.43)
Gaur	Summer	Core	HRC	0.21 (0.03)	0.712	102	5.25 (0.63)	0.92 (0.21)	4.83 (1.25)
		Buffer				10	2.75 (0.82)	0.30 (0.15)	0.83 (0.49)
	Winter	Core	HRC	0.28 (0.02)	0.810	98	3.59 (0.42)	1.18 (0.17)	4.27 (0.81)
		Buffer				8	4.9 (1.12)	0.29 (0.14)	1.44 (0.76)
Wild pig	Summer	Core	HRC	0.21 (0.01)	0.858	91	4.94 (0.53)	1.0 (0.15)	5.29 (0.95)
		Buffer				17	7.66 (2.92)	0.53 (0.14)	4.11 (1.92)
	Winter	Core	HRC	0.21 (0.02)	0.772	90	4.74 (0.55)	1.31 (0.22)	6.22 (1.27)
		Buffer				19	9.44 (4.07)	0.53 (0.14)	5.07 (2.58)
Barking deer	Summer	Core	HRC	0.20 (0.01)	0.821	124	1.22 (0.03)	1.36 (0.16)	1.66 (0.20)
		Buffer				51	1.25 (0.06)	1.68 (0.30)	2.11 (0.40)
	Winter	Core	HRC	0.23 (0.03)	0.897	127	1.12 (0.02)	1.99 (0.22)	2.23 (0.26)
		Buffer				56	1.31 (0.08)	1.80 (0.35)	2.37 (0.49)
Barasingha	Summer	Core	UC	0.3 (0.02)	0.810	32	15.9 (3.54)	0.10 (0.03)	1.59 (0.70)
		Buffer	–	–		–	–	–	–
	Winter	Core	UC	0.6 (0.08)	0.882	40	7.5 (1.42)	0.20 (0.10)	1.52 (0.81)
		Buffer	–	–		–	–	–	–
Chousingha	Summer	Core	HRC	0.25 (0.01)	0.892	8	1.39 (0.26)	0.06 (0.02)	0.09 (0.04)
		Buffer				–	–	–	–
	Winter	Core	HNC	0.18 (0.01)	0.823	10	1.37 (0.07)	0.08 (0.03)	0.11 (0.04)
		Buffer				–	–	–	–
Nilgai	Summer	Core	HRC	0.20 (0.01)	0.727	4	1.41 (0.45)	0.04 (0.03)	0.06 (0.05)
		Buffer				16	2.69 (0.45)	0.19 (0.10)	0.52 (0.28)
	Winter	Core	HNC	0.13 (0.01)	0.721	12	5.08 (1.13)	0.06 (0.03)	0.33 (0.20)
		Buffer				14	2.5 (0.38)	0.17 (0.05)	0.44 (0.16)

A single global detection function was modelled for each species by pooling data from the entire study area, while density for each management strata was estimated subsequently in program DISTANCE

SE standard error, *KS* Kolmogorov–Smirnov test. Best models are *UC* uniform cosine, *HNC* half-normal cosine, *HRC* hazard rate cosine

miscellaneous forest in winter (Tables 2 and 3). Sambar exhibited preference for bamboo-mixed habitat in both summer and winter seasons (Fig. 2c and d; Tables S3 and S4). Sambar clustered in similar size groups across habitats and seasons. Gaur densities were highest in sal forest in summer and miscellaneous in winter. Gaur showed a major seasonal shift in density from bamboo-mixed and sal forest in summer to miscellaneous forest in winter (Tables 2 and 3). They preferred sal in summer, whereas in winter, gaur showed preference for miscellaneous forests (Fig. 2e and f; Tables S3 and S4). Wild pig density was also found to be higher in bamboo-mixed habitat, and seasonal densities were similar across all habitats (Tables 2 and 3). Wild pig showed preference for bamboo-mixed habitat in both summer and winter (Fig. 2g and h; Tables S3 and S4). Barking deer had highest densities in bamboo-mixed and miscellaneous forests (Tables 2 and 3) and also showed preference for these habitat types (Fig. 2i and j; Tables S3 and S4). Barasingha being obligate to grassland were only detected in grassland habitat (Tables 2 and 3), while

Table 2 Habitat-specific summer densities and biomass of major ungulates in Kanha Tiger Reserve 2013

Habitat type	species	Best model	KS test *p* value	No of observations (n)	Effective strip width (ESW) [SE] m	Encounter rate(n/l)	Detection probability $\hat{P}$ (SE)	Group Density $\widehat{DS}$ (SE)	Mean Cluster size E(S) (SE)	Density $\hat{D}$ (SE)	Biomass Kg/km^2 (SE)
Grassland	Chital	UC	0.831	82	122.5(14.2)	1.13	0.56 (0.05)	4.64 (1.63)	23.7 (2.99)	110.09 (41.15)	5174 (1934)
	Sambar[a]	UC	0.869	36	86.08 (6.62)	0.20	0.55 (0.04)	1.21 (0.39)	2.93 (0.26)	3.55 (1.22)	483 (166)
	Gaur[a]	UC	0.869	21	86.08 (6.62)	0.11	0.55 (0.04)	0.57 (0.22)	7.5 (1.88)	3.88 (1.91)	2177 (1072)
	Wild pig[a]	UC	0.831	20	122.5 (14.2)	0.11	0.56 (0.05)	0.88 (0.37)	5.12 (1.35)	3.01 (1.52)	81 (41)
	Barasingha	UC	0.882	32	182 (24.4)	0.40	0.6 (0.08)	1.10 (0.35)	14.34 (2.19)	15.8 (5.59)	2512 (889)
	Barking deer	–	–	–	–	–	–	–	–	–	–
Sal forest	Chital	HRC	0.619	91	74.05 (8.56)	0.42	0.41 (0.04)	2.84 (0.75)	7.94 (0.61)	22.61 (6.24)	1063 (293)
	Sambar	HRC	0.963	56	41.32 (5.81)	0.25	0.40 (0.05)	3.13 (0.83)	2.86 (0.25)	9.0 (2.52)	1224 (343)
	Gaur	HNC	0.795	29	48.44 (9.56)	0.13	0.42 (0.08)	1.38 (0.45)	6.96 (1.11)	9.65 (3.55)	5414 (1992)
	Wild pig	HNC	0.623	21	43.8 (5.90)	0.09	0.47 (0.06)	1.10 (0.34)	4.88 (1.26)	5.42 (2.17)	146 (59)
	Barking deer	HNC	0.829	24	39.37 (6.74)	0.11	0.69 (0.11)	1.41 (0.39)	1.41 (0.09)	1.99 (0.57)	36 (10)
Bamboo-mixed forest	Chital	HNC	0.615	71	46.72 (6.67)	0.4	0.18 (0.02)	4.36 (1.08)	8.04 (1.00)	42.56 (12.3)	2000 (578)
	Sambar	HRC	0.916	90	39.8 (5.09)	0.5	0.40 (0.05)	6.49 (1.34)	2.76 (0.16)	17.9 (3.88)	2434 (528)
	Gaur	HNC	0.675	22	47.22 (13.03)	0.12	0.20 (0.05)	1.33 (0.53)	4.52 (0.99)	6.05 (2.76)	3394 (1548)
	Wild pig	HRC	0.685	23	48.3 (13.2)	0.13	0.29 (0.08)	1.36 (0.53)	7.78 (1.90)	10.64 (4.89)	287 (132)
	Barking deer	HRC	0.939	34	28.6 (4.67)	0.19	0.22 (0.03)	3.4 (0.85)	1.33 (0.07)	4.55 (1.16)	82 (21)
Miscellaneous forest	Chital	HRC	0.601	115	54.5 (8.2)	0.26	0.35 (0.05)	2.41 (0.6)	9.08 (0.88)	21.97 (6.04)	1033 (284)
	Sambar	HRC	0.871	89	46.9 (5.09)	0.20	0.38 (0.04)	2.17 (0.47)	2.87 (0.19)	6.25 (1.42)	850 (193)
	Gaur	HRC	0.923	32	48.1 (14.6)	0.07	0.29 (0.01)	0.76 (0.30)	4.61 (1.04)	3.51 (1.62)	1969 (909)
	Wild pig	HRC	0.629	50	46.6 (3.62)	0.11	0.57 (0.04)	1.23 (0.23)	4.93 (0.73)	6.07 (1.47)	164 (40)
	Barking deer	HRC	0.670	62	48 (5.78)	0.14	0.38 (0.04)	1.47 (0.28)	1.14 (0.04)	1.69 (0.33)	30 (6)

UC uniform cosine, *HNC* half-normal cosine, *HRC* hazard rate cosine, *KS test* Kolmogorov–Smirnov test, *SE* standard error

[a] Indicates that we used pooled detection data for 2012 and 2013 to fit a detection function but report density, group density, cluster size and biomass only of 2013

Table 3 Habitat-specific winter densities and biomass of major ungulates in Kanha Tiger Reserve

Habitat type	species	Best model	KS Test p value	No of observations(n)	Effective strip width (ESW) (SE) m	Encounter rate (n/l)	Detection probability $\hat{P}$ (SE)	Cluster size Density $\widehat{DS}$ (SE)	Mean Cluster size E(S) (SE)	Density $\hat{D}$ (SE)	Biomass (kg/km^2) (SE)
Grassland	Chital	UC	0.679	84	81.7 (6.74)	1.16	0.40 (0.03)	7.15 (2.36)	14.74 (2.02)	103.5 (36.9)	4865 (1734)
	Sambar[a]	UC	0.909	26	67.68 (10.31)	0.18	0.22 (0.03)	1.33 (0.43)	2.38 (0.28)	3.18 (1.10)	432 (150)
	Gaur[a]	HNC	0.909	20	88.8 (20.95)	0.06	0.75 (0.17)	0.39 (0.20)	5.0 (1.30)	1.95 (1.13)	1094 (634)
	Wild pig[a]	UC	0.679	23	81.73 (6.74)	0.12	0.39 (0.09)	0.49 (0.18)	9.55 (1.47)	4.7 (1.8)	127 (49)
	Barasingha	UC	0.932	40	115.4 (17.09)	0.51	0.71 (0.10)	2.22 (1.06)	7.97(1.37)	17.7 (9.0)	2814 (1431)
	Barking deer	–	–	–	–	–	–	–	–	–	–
Sal forest	Chital	HRC	0.708	60	53.04 (12.54)	0.27	0.38 (0.09)	2.61 (0.93)	6.58 (0.60)	17.23 (6.33)	810 (298)
	Sambar	HRC	0.711	62	42.5 (39.23)	0.28	0.26 (0.02)	3.71 (0.7)	2.08 (0.14)	7.73 (1.66)	1051 (226)
	Gaur[a]	HNC	0.711	22	44.99 (11.71)	0.05	0.34 (0.08)	0.56 (0.23)	3.36 (1.40)	1.90 (1.11)	1066 (623)
	Wild pig	HNC	0.624	21	33.2 (8.11)	0.09	0.18 (0.04)	1.46 (0.47)	4.64 (1.27)	6.78 (2.9)	183 (78)
	Barking deer	HNC	0.764	31	36.9 (4.05)	0.14	0.59 (0.06)	1.94 (0.44)	1.01 (0.05)	1.97 (0.46)	35 (8)
Bamboo-mixed forest	Chital	HNC	0.611	75	47.09 (7.20)	0.43	0.25 (0.03)	4.57 (1.09)	7.6 (0.57)	34.74 (8.74)	1633 (411)
	Sambar	HRC	0.620	72	42.6 (15.9)	0.41	0.26 (0.09)	5.8 (1.16)	2.22 (0.15)	12.97 (2.7)	1764 (367)
	Gaur[a]	HRC	0.620	34	37.46 (7.93)	0.08	0.22 (0.04)	1.07 (0.39)	2.26 (0.68)	2.43 (1.15)	1363 (645)
	Wild pig	HRC	0.712	21	26.3 (10.7)	0.11	0.24 (0.09)	2.18 (1.15)	4.82 (1.26)	10.53 (6.24)	284 (168)
	Barking deer	HRC	0.670	20	51.2 (13.26)	0.10	0.46 (0.12)	1.0 (0.3)	1.0 (0.05)	1.01 (0.40)	18 (7)
Miscellaneous forest	Chital	HRC	0.744	103	51.8 (3.77)	0.23	0.47 (0.03)	2.29 (0.44)	10.15 (0.91)	23.33 (4.98)	1095 (234)
	Sambar	HRC	0.722	110	34.2 (2.91)	0.25	0.43 (0.03)	3.72 (0.64)	2.49 (0.14)	9.29 (1.69)	1263 (230)
	Gaur	HRC	0.747	68	47.9 (6.11)	0.15	0.40 (0.05)	1.64 (0.32)	4.95 (0.65)	8.13 (1.94)	4561 (1088)
	Wild pig	HRC	0.685	40	36.07 (7.13)	0.09	0.55 (0.11)	1.28 (0.39)	5.82 (1.02)	7.47 (2.63)	202 (71)
	Barking deer	HRC	0.600	69	31.22 (2.77)	0.15	0.61 (0.05)	2.55 (0.38)	1.60 (0.04)	4.07 (0.50)	73 (9)

UC uniform cosine, *HNC* half-normal cosine, *HRC* hazard rate cosine, *KS test* Kolmogorov–Smirnov test, *SE* standard error

[a] Indicates that we used pooled detection data for 2012 and 2013 to fit a detection function but report density, group density, cluster size and biomass only of 2013

chousingha were detected on transects in miscellaneous forests and plateau grasslands. Detection probabilities were highest for grassland habitat and lowest for bamboo forests for all species in both seasons (Fig. S5).

Discussion

By sampling habitats in proportion to their availability, our sampling design permits the conventional global analysis as well as habitat-wise analysis. The precision of density estimates depends on the variability in effective strip width, encounter rates and the cluster size (Thomas et al. 2010; Ogutu et al. 2005). We believe that by laying habitat-specific transects and subsequently analysing the data separately for each habitat type, we can minimize the variability contributed by ESW. However, sample size and encounters obtained in each habitat strata were small in comparison with the global analysis. The stratified analysis provides more ecologically meaningful results. Unfortunately, homogenous habitat patches of sufficient size to mark independent transect line within each habitat patch were not available in the human dominated buffer zone. We, therefore, could not extend the habitat-specific analysis to the buffer zone.

Core and buffer densities

Our study unambiguously demonstrates the impact of even low human use on wild ungulate densities. The core area, where there were no human habitations and had minimal use by humans, had higher densities of all ungulates except wild pig, barking deer and nilgai. The core had 4.8 times higher wild ungulate biomass compared with the buffer zone. This higher biomass density in the core area was due to both increased encounter rate and larger cluster size. It is well known that larger cluster sizes are found in resource-rich areas (Pulliam and Caraco 1984), suggesting that habitat quality was better in the core area for most ungulates. More importantly, barasingha and chousingha were found only within the core area of the Tiger Reserve and were either absent or occurred in very low densities in the multiple use buffer zone forests, highlighting the importance of undisturbed areas for endangered and rare ungulates. The depression of wild ungulates in the forests of the buffer zone was likely due to competition with livestock (Loveridge et al. 2010), extraction of minor forest produce and biomass, and subsistence level poaching (Steinmetz et al. 2010). In countries like India, with high human densities and associated high demand for land, protected areas are small by global standards (Lopoukhine et al. 2012). Harbouring viable populations of apex carnivores such as tigers in such small reserves is a major conservation concern. Our study lends support to the conservation strategy of relocating human habitation by incentivised voluntary relocation from core areas of Tiger Reserves; as such, areas would then support a much higher density of prey and subsequently the carnivore community, including tigers.

Habitat-specific seasonal densities

Seasonal habitat selection by ungulates is influenced by metabolic and nutritional requirements for maintenance, growth, rut, gestation and lactation (OwenSmith 1994). These physiological needs combined with predation risks vary across habitat types (Kie 1999) and determine animal distribution. Tropical India is highly seasonal due to the effect of monsoon. Ungulate densities are likely to respond to varying seasonal nutrient availability in different habitats.

Grasses grow during monsoon (July–September), mature and flower in October and November, and become senescent in summer (March–June). However, due to high soil moisture and management practice of late winter burn, most grasses produce a fresh flush of new shoots during early summer. Thus, protein and nutrient availability are maximum in monsoon and in a month of early summer after the annual late winter burn (February–March) in grasslands. In forested habitats, new flush of leaves, flowers and fruits emerge prior to monsoon in the peak of the dry summer season (May and June). Bamboo (*Dendrocalamus strictus*) produces new shoots at the beginning of summer and growth declines by October and November (Liese and Kohl 2015). Patterns of ungulate distribution may change in different times of the year because of plant growth, and thus, food availability changes between the seasons.

In our study, chital used grassland habitat throughout the year and maintained large herd size and high densities over other habitat types. Due to smaller mouth parts, chital could possibly obtain the required nutrients by selective foraging (Schaller 1967) even when the nutrient quality of grasslands declined in summer. Chital fawns have a “lying out” stage wherein they remain hidden in tall grass clumps and bushes for the initial few weeks of their life in winter (Schaller 1967). Thus, the requirement of food and cover by chital could potentially be achieved by living within grassland and bamboo-mixed forests in both the seasons.

Maximum densities of sambar were recorded in bamboo-mixed habitat throughout the year, and sambar also showed a high preference for this habitat type. Sambar are primarily browsers and prefer undulating to steep terrain (Hofmann 1989). Bamboo-mixed forests provide the maximum diversity of browse species, and this habitat type occurs on hill slopes, explaining the high density and preference shown by sambar for this habitat mainly in summer. The cluster size of sambar was small and similar across habitats.

Gaur are known for their seasonal movements (Imam 1985). Unlike other ungulates, there was a distinct difference in their seasonal densities between different habitats. During the summer, their density, as well as preference, was higher for sal forest. Plants such as *Flamingia spp*. and *Mallotus philippensis* sprout in sal forest during this season and are a significant source of food for gaur. During winter season, gaur mainly shift to areas with more browse and having dense plant cover. Gaur herds were observed to be larger in summer compared with winter in all habitats. During summers, water becomes a limiting factor in the higher elevations and gaur descend to valley habitats where they calve and rut (Schaller 1967). This results in larger aggregations of gaur in summer.

Conclusion and management implications

Our study stresses the importance of inviolate core areas for achieving high wild ungulate densities and for maintaining populations of endangered and rare species. We show the relevance of different habitat types for differential seasonal use by ungulates and attempt to interpret these in the context of nutrition and cover needs by wild ungulates. Much of the Kanha forest was worked for enhancing timber production in the past, and the current stands of sal forests are a result of selective thinning of non-timber species (Blakesley1905). Now the thrust of management within protected areas is for the conservation of diversity, endangered species and ungulate biomass to sustain viable populations of large carnivores. Maximum diversity and ungulate biomass were supported by grassland followed by bamboo-mixed habitat. Furthermore, endangered species like barasingha and blackbuck were found only in the grassland habitat. Grasslands account for 9 % of the KTR core area, most of which originated due to the anthropogenic activity of agriculture and livestock grazing. Most grasslands of KTR are currently maintained by management of woody plant removal and fire in this arrested stage of succession. Enhancing this habitat along with its appropriate management would help maintain ungulate diversity, cater to the needs of the only surviving population of the endangered hard ground barasingha and increase ungulate biomass so as to sustain a source population of tigers in this landscape. In historic times, a dynamic habitat mosaic was maintained in the larger landscape by natural processes of fire, flood and anthropogenic activities (Hansen and DeFries 2007). However, now these forces no longer operate at such a scale and wildlife populations of most species have become insular within protected areas. Therefore, interventions that manage these habitat mosaics in optimal conditions would be in the interest of achieving the conservation objectives of the protected area.

Acknowledgments We thank Chief Wildlife Warden of Madhya Pradesh and management of Kanha Tiger Reserve for permissions and logistics for the study. We thank our field assistants Nirottam and Kanhaiya and the team of forest guards for their help in field data collection. We thank former deputy director Kanha, H.S. Mohanta and Research Officer Rakesh Shukla for logistic support and Swati Saini and Ninad Shastri for GIS inputs. This study was funded by National Tiger Conservation Authority, Ministry of Environment, Forest and Climate change, Government of India. QQ & YVJ conceived the study, NA, UK & AP conducted the field work, JSC, QQ and YVJ provided logistic support and supervised the study, and NA, UK, QQ and YVJ did the data analysis and wrote the paper.

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