ROLE OF TOP PREDATOR IN SHAPING CARNIVORE COMMUNITIES

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Dedicated to my family

Who made me believe in Myself

"Whenever we find rather similar animals living together in the wild, we do not think about competition by tooth and claw, we ask ourselves, instead, how competition is avoided"

Paul A. Colinvaux

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THE TOP DOWN CONTROL IN TERRESTRIAL ECOSYSTEM: A REVIEW TO UNDERSTAND DOMINANT PREDATOR EFFECT ON SUB-ORDINATE PREDATOR.

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ABSTRACT:

Majority of papers address the top down control of predator in aquatic environment and effect on prey and vegetation in terrestrial habitat. Understanding the regulation of sub-ordinate predator by dominant predator in terrestrial environment is important to manage the ecosystem. The interaction in carnivore community is difficult to document in natural environment yet is an important aspect of carnivore conservation and management. The monitoring and maintenance of a) top predator prevent trophic cascade and mesopredator release, b) prey and habitat according to carrying capacity of carnivore guild helps in co-existence of sympatric carnivore, as well as in mitigating human-carnivore conflict. However, the studies oriented to understand relationship of top predator with sub-ordinate predator is limited and dominantly addressed in one of the three axis of niche partitioning (the diet, diel and habitat usage). The effect on mesopredator in abundance or absence of top predator is found to be patchily studied for major predator species across the world.

KEYWORDS: *top-down control, carnivore, terrestrial habitat.*

INTRODUCTION :

The importance of apex predatorfor regulation of an ecosystem in wildlife conservation ambit, was discussed more than half century ago (Leopold 1943,1949, Ripple et al 2005). The top down hypothesis or the cascading trophic interaction drew much of scientific community attention through 1940 to 1990s and in the context of three trophic (producer-herbivore-predator), elaborately in controlled lotic and lentic ecosystem (Hairston et al 1960, Carpenter et al 1985, Power 1992, Strong 1992). A review to understand the role of top predator on terrestrial ecosystem was done during these time (Terborgh et al 1999).The role of terrestrial top predator as umbrella species and effect on prey, vegetation and other communities like avi-faunawas also researched from late 1990s (McLaren & Peterson 1994, Rogers and Caro 1998, Crooks & Soule 1999,Terborgh et al 2001, Berger et al 2001, Rooney et al 2003, Ripple and Beschta, 2003, 2008).

In a Predator Prey system both Mesopredator release and Intra-guild predation occur (Palomere et al 1995) as in Top predator (limited by competition), mesopredator (limited by predation and competition) and prey (limited by predation); though the indirect effect on vegetation by top predator is a debated question (Polis et al 1999, Schmitz et al 2000). Also, the Optimal foraging theorydoesn't link top predator with small sized prey, however the research development in top down control contradicted the theory (Palomere et al 1995,Courchamp et al 1999,Letnic 2009, Brashares et al

2010).

Since studies to understand trophic cascade due to elimination, decimation, reintroduction of top predator requires long-term data in natural eco-system, it is considered difficult logistically and being ethically challenging (Trewby 2007). However,due to elimination of top predator in natural ecosystem like wolf, dingoes and African lion provided such opportunity (Glen et al 2007, Berger et al 2008, Sinclair et al 2011, Ripple et al 2013).Experimentally certain studies prove individual behavioral shift in sympatric sub-ordinate predator due to top predator (Watt et al 2010).

The present literature review investigated the following question in a terrestrial top down control:

The effect on the lower carnivore community with Increase /Decrease in abundance and elimination/reintroduction of top terrestrial predator.

The web search was done with keywords "predator", "predation", "intra-guild predation", "carnivore", "ecological meltdown", "trophic cascade", "meso-predator release", "trophic interaction", "tiger", "leopard", "wolf", "leopard"," lion", "dingoes", "reintroduction", "extinction", "terrestrial".

RESULT:

The literature search for terrestrial carnivore top down control synthesized into 28 research. Multiple research from similar area especially oriented to fox, coyote was eliminated. Terrestrial predator effect on only herbivore and involving invertebrate predator was further eliminated from the synthesis. The top predator whose effect and regulation on lower trophic carnivore is observed in natural environment is tiger, wolf, lion, dingoes, lynx, coyotes, puma, badger and feral cats. Hypothesis of few of the individual studies on sympatric carnivore did not include to understand top down control and inter-specific competition. The studies which concluded niche overlap but no direct effect on subordinate predator by dominant predator was excluded from the following synthesis.

Table1: Effect of top terrestrial predator on lower carnivore community

S.No.	References	Top predator status	Effect of Top-down control/ trophic cascade	Process
1	Morse 1974	Tiger presence	Reduction in niche breadth of leopard	Interspecific competition
2	Major et al 1987	Presence of Coyotes	spatial avoidance by red fox	Interference competition
3	Litvaitis et al 1989	Increase in abundance of Coyote	reduction in Bobcat population	Exploitative competition
4	Palomere et al 1995	Abundance of Iberian lynx	limitation to mongoose, Rabbit increase	Intra-guild predation
5	Palomere et al 1996	Iberian lynx home range	Egyptian mongoose and genet avoided lynx habitat	Intra-guild predation
6	Courchamp et al 1999	Feral cats	limit exotic mesopredator rodents, Increase in kakapo	Intra-guild predation
7	Crooks and Soule 1999	Presence of coyotes	Suppression of mesopredator and increase in scrub breeding birds	Intraguild predation and mesopredator control
8	Kitchen et al 1999	Presence of Coyotes	temporal, spatial overlap. Segregation on basis of diet. High mortality of swift fox by coyote	intraguild predation
9	Mitchell et al 2005	Presence of wild dog	temporal avoidance/ localized habitat shifts by fox	Intraguild predation
10	Helldin et al 2006	Presence of Lynx	Partial decrease in red fox population	Intraguild predation
11	Glen et al 2007	Reduction in dingoes and feral dogs	Increase in fox population	Intraguild predation
12	Berger et al 2008	Presence of wolf	Limitation to presence and abundance of coyotes	Intraguild predation
13	Letnic et al 2008	Presence of Dingoes	reduction of red fox, increase in rodents	intraguild predation

14	Trewby et al 2008	culling Eurasian badgers	Increase in red fox	intraguild predation
15	Johnson et al 2009	Presence of Dingoes	Decrease in abundance of red fox	intraguild predation
16	Wang et al 2009	Tiger presence	leopard habitat usage did not overlap with tiger	Habitat preference
17	Hayward et al 2009	Lion and spotted hyena	temporal avoidance by wild dog and cheetah	Interference competition
18	Brashares et al 2010	Decimated lion and leopard	Primate mesopredator Olive baboon increase; reduction in ungulate population	Mesopredator release
19	Cupples et al 2011	Presence of dingoes	Suppression of fox population, increase in small prey	Intraguild predation and dietary competition
20	Harihar et al 2011	Increase in abundance of tiger	shift in habitat usage and diet in leopard	Intraguild predation
21	Viota et al 2012	Iberian lynx home range	shift in microhabitat use of Egyptian mongoose	Intra-guild predation avoidance
22	Mondol et al 2012	Reintroduction of tiger	Spatial and temporal avoidance by leopard	Intra-guild predation avoidance
23	Bhattarai et al 2012	Tiger presence	Leopard diet have more of small sized prey	resource partitioning
24	Swanson et al 2014	Increase in African lion population	local extinction of wild dog	Intraguild predation
25	Gordon et al 2015	Dingo presence	restriction to feral cats; abundance of rodents and its foraging efficiency	Intra-guild predation avoidance
26	Wang et al 2015	Puma occupancy	spatial and temporal segregation due to coyote activity which in turn by Puma activity	Intra-guild predation avoidance
27	Allen et al 2016	occurrence of Puma	subordinate fox uses dominant Puma scent to avoid Coyotes	behavioral cascade
28	Sugimoto et al 2016	Presence of Amur tiger	Leopard have wider niche breadth	Niche partitioning
29	Groom et al 2016	increase in Lion population	Reduction in pup to adult wild dog ratio, Shift in habitat usage	Intra-guild predation

DISCUSSION:

The literature synthesis established top down regulation by predator in terrestrial ecosystem. The diversity in predator level can affect the intensity of top-down effects by niche complementarity or intraguild predation and interference between predator species (Straub et al 2008, Stachowicz et al 2007). However, such intensity observation is difficult for terrestrial mammalian predator due to their cryptic behavior. The terrestrial mammalian community studies mainly focus on three axes to understand co-existence of sympatric carnivores; The diet partitioning, the diel partitioning and the habitat partitioning. The body size decides the social dominance amongst predator and hence the sub-ordinate carnivore avoid the dominant predator on one or more of the above-mentioned axes.Studying the overlap between sympatric carnivore on any one of the three axes fail to highlight the top down control due to body size by tiger (Wang 2009, Sevlan, 2013, Lovari 2015, Sugimoto et al 2016). Where top down control and biodiversity regulation is reported for wolf (Beschta and Ripple, 2007, Ripple and Beschta, 2008), Dingo (Letnic et al 2012, Dickman 2009), lion (Sinclair et al 2010), it was observed that such studies lacked for tiger. The avoidance of tiger by subordinate predator leopard and dhole is reported (Morse 1974,Harihar et al 2011, Mondol et al 2012). The co-existence amongst tiger, leopard and dhole is driven by principal prey (Ramesh et al 2012) or habitat heterogeneity (Karanth et al 2000), large size prey density (Seidensticker, 1976), contradictsthe theory of top-down control by tiger. The co-existence of sympatric carnivore is said to be facilitated by expulsion rate of subordinate predator by dominant predator (Seidensticker, 1976).

Apart from few, diversity of carnivore studies proffers that top down control regulates the carnivore communities. The mesocarnivore whose distribution may widely be affected not only by habitat, anthropogenic effects but also by carnivore community interaction cannot be monitored over large scale due to logistic constraints and elusive nature of the species. However, certain management intervention has been undertaken which had been positive as well as negative in long run e.g controlling exotic rodents by feral cats to conserve endangered kakapo (Courchamp et al. 1999), persecution of dholes was undertaken to save livestock but it resulted in increase in wild boar hence more crop raiding and loss of agricultural fields (Wangchuk 2004). The management of ecosystem can benefit from understanding carnivore community.

The social impact of loss of top predator has also resulted spread of diseases and change in living condition of people apart from change in attitude e.g. reduction of lion and leopard resulted in olive baboon release , more crop raiding and spread of diseases in humans and also the children had to leave school to guard the agricultural fields (Brashares et al 2010). The estimation and monitoring of carrying capacity of various trophic carnivore and their prey can involve timely managerial intervention. This would prevent dispersal of sub-ordinate carnivores to fringe areas of forest causing human wildlife conflict.

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Photographic records of the Asiatic Wildcat from two states of India

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Photographic records of the Asiatic Wildcat from two states of India

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The Asiatic Wildcat *Felis silvestris ornata* Gray, 1830 also known as the Indian Desert Cat is one of the five subspecies of the globally widespread Wildcat *Felis silvestris* Schreber, 1777 (Driscoll et al. 2007). It is legally protected under Schedule-I of the Wildlife Protection Act (1972) of India and also included in CITES Appendix II, but appears as Least Concern in the IUCN Red List database (Driscoll & Nowell 2010).

The Asiatic Wildcat inhabits dry steppes, savannahs, bush and semi-deserts kind of habitats across southwestern Asia (Nowell & Jackson 1996). Fairly distributed in western India (Menon 2003; Prater 2005), it has been reported from western and central Rajasthan (Sharma et al. 2003; Chhangani & Mohnot 2008) including the Thar Desert (Dookia 2007), Jaipur (Sharma 1998), Saurashtra (Singh 1998) and northern Gujarat (Gajera & Dharaiya 2011). Kankane (2000) reported the presence of the Asiatic Wildcat east of the Aravalli Hills near Jhalawar, Rajasthan. In Maharashtra, it is reported from drier areas such as Shirur, Baramati and Indapur talukas (Gogate 1997) and near Pune (Lamba 1967).

Apart from these sightings, the Asiatic Wildcat's presence has also been recorded from some protected areas in the past. Recently Gupta et al. (2009) reported the presence of the Asiatic Wildcat in Sariska Tiger Reserve, Rajasthan. Earlier it was reported from Pench Tiger Reserve (Gogate 1997; Mukherjee 1998) and Tadoba Tiger Reserve, Maharashtra (Gogate 1997). A road kill of the species was also found near Semadoh, Melghat Tiger Reserve, Maharashtra (Gogate 1997). Pardeshi et al. (2010) confirmed the presence of the species in the Narayan Sarovar Sanctuary located in the westernmost part of the Kachchh Desert, Gujarat. In Madhya Pradesh, Yoganand (1999) recorded this species from Panna National Park, while the easternmost sighting has been reported from Bagdara Wildlife Sanctuary (Shekhar Kolipaka 2011 pers. comm.). A dead specimen (Image 1b) was also confiscated from a group of Kal Bahelia hunters on the Nauradehi-Jabalpur Road, Madhya Pradesh (Shekhar Kolipaka 2011 pers. comm.). However, it is worth mentioning that only two of above sightings were photographic records and thus, the ones without photographs remain unauthenticated. Kankane (2000) photographed a young individual of the Asiatic Wildcat from Rajasthan while Gupta et al. (2009) reported a camera trap picture of the species from Sariska Tiger Reserve.

We report here the sight records with photographs of the Asiatic Wildcat from two different bio-geographic zones of India (Fig. 2a). The sightings were made during our field work for the "Re-introduction of Cheetah in India" project at Shahgarh landscape, Jaisalmer, Rajasthan and Nauradehi Wildlife Sanctuary, Madhya Pradesh.

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सत्यमेव जयते
जहाँ है हरियाली । वहाँ है खुशहाली ॥
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Shahgarh Landscape, Jaisalmer, Rajasthan: We sighted an individual near Murar (26^{0}37'6.46"N & 70^{0}01'7.5"E) on 08 August 2011 at 19.36hr (Fig. 2b). It appeared unperturbed by our presence giving us enough time to photograph it (Image 1a). The body was heavily spotted, dusky brown in color; the lower portion of the tail had dark black rings and was black-tipped. The ears were pointed and had pinkish insides. Two distinct black horizontal stripes on the inside of the forelimbs were also clearly visible. The terrain was slightly undulating with a number of shrubs of *Calligonum polygonoides* and a sparse distribution of *Capparis decidua.* Three more individuals were seen after the first sighting; one on the road from Murar to Dhanana (26^{0}42'20.4"N & 70^{0}11'50.8"E) on 15 August 2011, another between Dhanana and Lunar (26^{0}22'23.81"N & 70^{0}24'9.86"E) on 22 August 2011 and the last between Asutar (27^{0}12'58.43"N & 70^{0}07'48.2"E) and Mirtala (27^{0}03'20.63"N & 70^{0}10'40.4"E) on 25 August 2011. All the sightings happened in broad daylight between 08.00–16.00 hr. However, on all occasions the individuals

Image 1. A - Asiatic Wildcat in Nauradehi Wildlife Sanctuary, Madhya Pradesh; B - Asiatic Wildcat skin collected near Nauradehi-Jabalpur Road, Madhya Pradesh; C - Asiatic Wildcat at Shahgarh, Rajasthan.

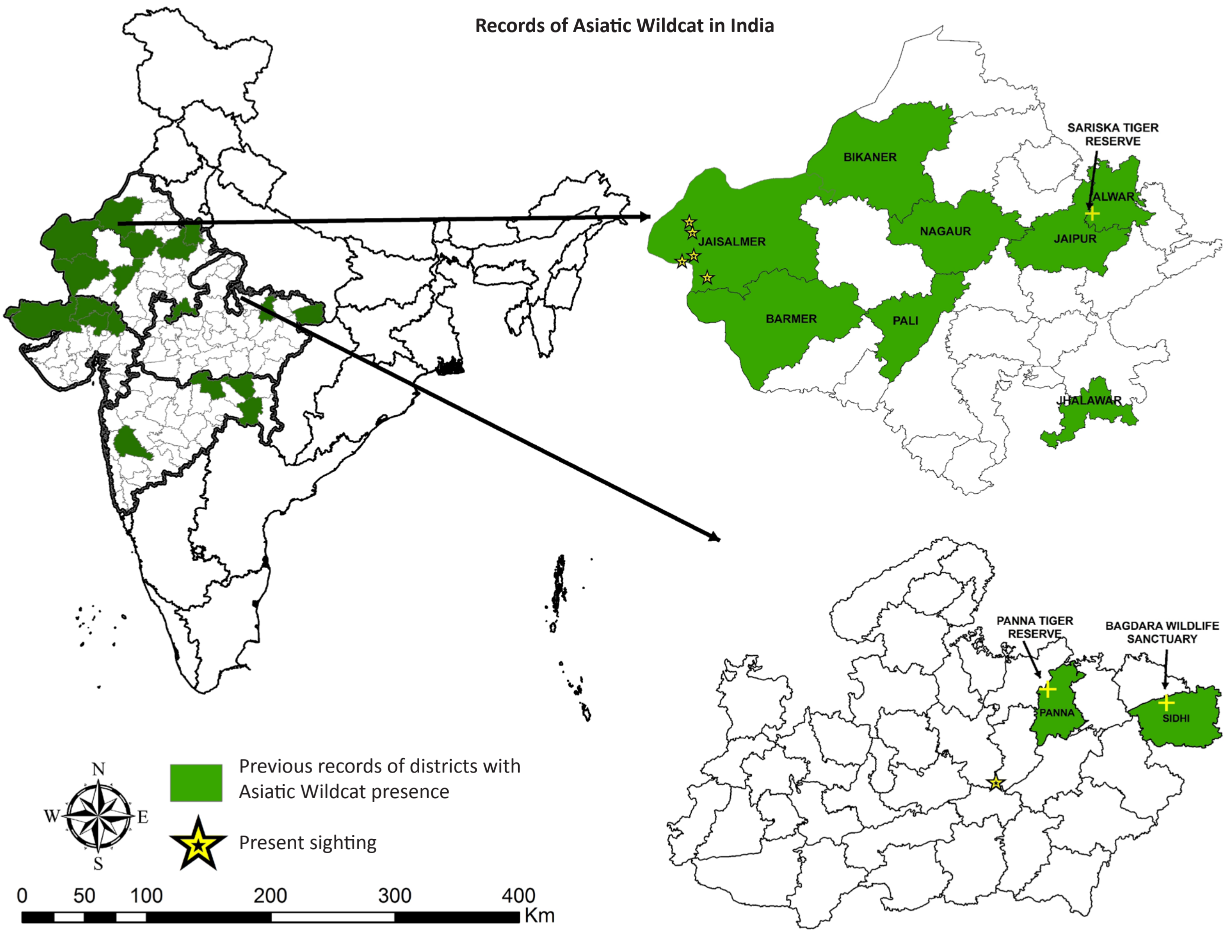

Figure 2a. District-wise distribution map of Asiatic Wildcat based on sight records.

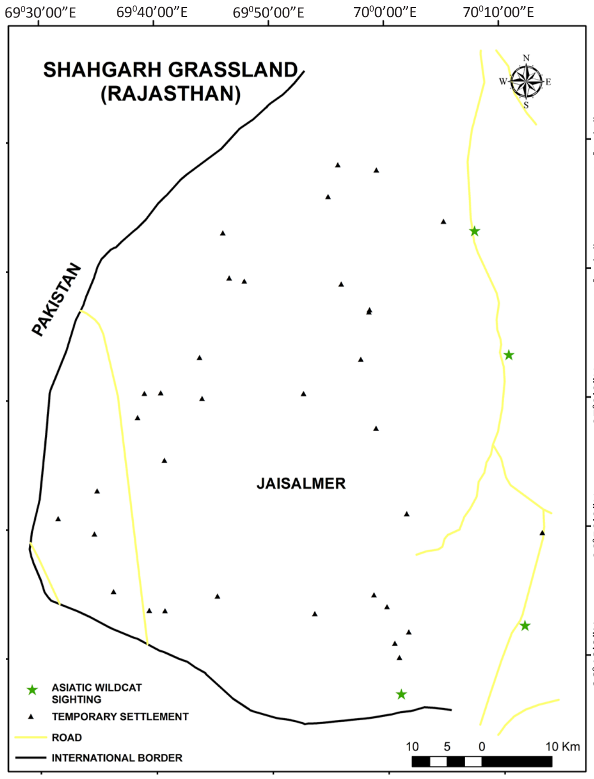

Figure 2b. Sighting locations in Shahgarh grasslands.

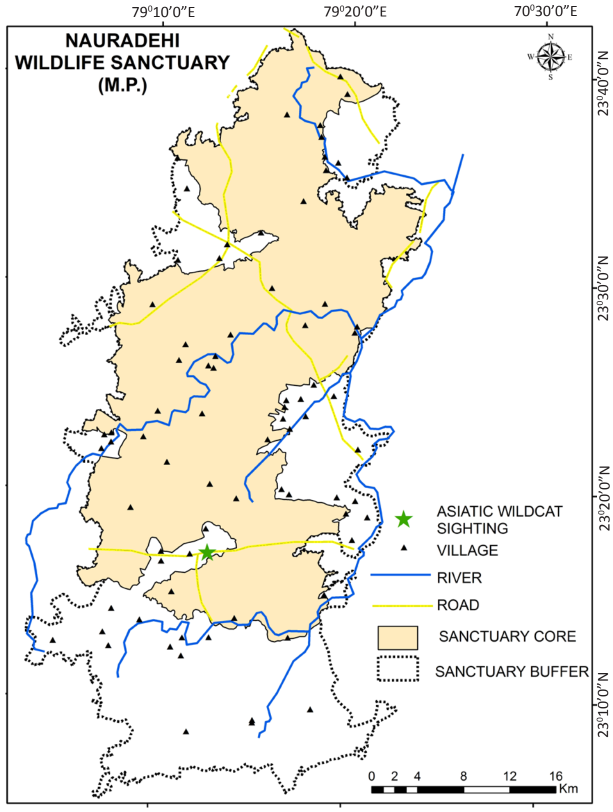

Figure 2c. Sighting location in Nauradehi Wildlife Sanctuary.

ran away quickly from the observers giving no chance to take a photograph.

The Shahgarh Grasslands (27^{0}18’–26^{0}47’N & 69^{0}37’–69^{0}29’E) are located in Jaisalmer District of western Rajasthan covering an area of over 4000km^2 (Ranjitsinh & Jhala 2010). These grasslands fall in the sand dune covered Desert-Thar (zone 3A) bio-geographic zone of India (Rodgers et al. 2002) and the vegetation of the area is classified as northern tropical thorn forest (6b) - subdivision desert thorn forest-type C1 (Champion & Seth 1968). The major vegetation of the area includes trees of *Capparis decidua*, *Prosopis cinereria* and *Salvadora persica*; shrubs like *Calligonum polygonoides*, *Leptadenia pyrotechnica* and grasses like *Lasiurus sindicus*, *Cenchrus catharticus* etc. The habitat also has a good number of prey species of the Asiatic Wildcat like the desert monitor, hare, doves, gerbils, geckos, scorpions and snakes (Anant Pande 2011 pers. obs.).

The area is located along the international border of India and Pakistan and much of the area is under the control of the Border Security Force (BSF) and the Indian army. Due to the harsh climatic conditions and restrictions imposed by the government, the area is sparsely populated by people. Oil and natural gas exploration activities are being carried out at a few locations here paving the way for infrastructurel development in this fragile ecosystem. Recently, huge reserves of gas were discovered at one of the sites which have accelerated the exploratory and other auxiliary activities in the region (Bhatia 2012, 2013). The Indira Gandhi canal flows along the eastern edge of the landscape and the ecology of the surrounding areas is transforming rapidly due to the invasion of mesic species (Prakash 2001; Idris et al. 2009).

Nauradehi Wildlife Sanctuary, Madhya Pradesh: An individual was seen crossing the road at 14.36hr on 19 December 2011 near Jhamara Village (at 23^{0}17’0.2”N & 79^{0}12’51.1”E) in Nauradehi range of the sanctuary (Fig. 2c). It crouched first and then started running when we approached it on foot. The body was greyish-brown in color and spotted. We were able to take a picture of only the back portion of the cat before it ran inside the bushes, mostly *Lantana camara*, thereby blocking a clear view. However, the photograph shows reddish underparts as well as black rings on the terminal portion of the tail based on which it was confirmed as the Asiatic Wildcat. The vegetation of the area was dominated by *Chloroxylon sweitenia* mixed with *Terminalia tometosa* and shrubs of *Helecteres isora.*

The Nauradehi WS ($23^0$05'–$23^0$43'N & $79^0$05'–$79^0$25'E) covers an area of 1197.04km^2 across three districts of Sagar, Damoh and Narsinghpur in Madhya Pradesh (Ranjitsinh & Jhala 2010). It lies in the Deccan peninsula (zone 6A) biogeographic zone (Rodgers et al. 2002). The sanctuary continues as a thin strip of forest towards the west into Bareli Tehsil in Raisen District and towards the east it is intermittently connected to the Rani Durgavathi Wildlife Sanctuary in Damoh District and extending up to the Bandhavgarh Tiger Reserve. The extent of this forested landscape is about 5500km^2 (Shukla 2007). The vegetation of the area is classified as southern tropical dry deciduous forest-type 5A (Champion & Seth 1968) represented by dominant tree species of *Tectona grandis*, *T. tomentosa, Lagerstroemia parviflora, Madhuca indica* and *Chloroxylon sweitenia*. Shrubs of *Zizyphus mauritiana*, *Helicteres isora, Holorhina antidysentrica* and grasses like *Themeda quadrivalvis* and *Heteropogon contortus* are abundant.

There are 74 villages inside the Nauradehi WS of which seven are forest villages and the rest are revenue villages. Livestock grazing, forest fire and illegal timber extraction are of serious concern to park management. Three important roads National Highway 12, Tendukheda-Deori and Sagar-Jabalpur via Mohli bisect the park. Road widening activities are being carried out/planned in some parts of the park to divert more vehicular traffic on these roads causing further disturbance.

Threats and conservation: In common with the other sub-species of wildcat, the Asiatic Wildcat faces considerable threats from habitat loss and poaching (Nowell & Jackson 1996; Driscoll & Nowell 2010) although there is a need for dedicated studies to ascertain the extent of these threats to Asiatic Wildcat populations in India. Reclaiming wastelands in the name of planned development has resulted in the destruction of the Asiatic Wildcat habitat and breeding areas in India (Sharma 1998). Although, presently little international trade persists in Asiatic Wildcats, they have been killed in large numbers for their fur in the past (Nowell & Jackson 1996). In 1979, traders in India declared stocks of 41,845 pelts for an export amnesty (Panwar & Gopal 1984). Asiatic Wildcat pelts formed a major portion of the small cats' skin seizures by Wildlife Preservation Society of India from Delhi, Srinagar and Puri (1982–1998) (Sanyal 1998). About 97 skins of the species were also recovered from a poacher in Barmer District, Rajasthan (Sharma 1998). Since the wildcat is the progenitor of the domesticated cat *F. s. catus*, there is a high probability of its cross-breeding with the abundant population of feral domestic cats in the vicinity of human settlements, the extent of which remains unclear, especially in the Indian subcontinent.

All the sightings described in the present communication happened during the daytime (except the first) supporting some earlier reports of the species being diurnal (Mukherjee 1998). Although these records may not represent a significant increase of the known geographical range of the Asiatic Wildcat in India, it contributes towards the understanding of its habitat and distribution. No detailed ecological studies exist on Asiatic Wildcats in India and the available information on their distribution and ecology seems to be based exclusively on available opportunistic and often unauthenticated observations. Because of the lack of surveys concentrating on the Asiatic Wildcat, especially in areas beyond their recorded geographical range in India, it is possible that their true occurrence and distribution has gone unnoticed. Their solitary nature and elusive behaviour has largely contributed to such paucity of information on them. Most of the sightings of the species being reported from cultivated landscapes highlight the immediate need of a proper study outside protected areas. Extensive surveys might throw up more light on their distribution, current population status, ecological requirements and the imminent threats they face.

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Understanding Landscape Vulnerability with Reference to *Panthera Pardus* (Common Leopard) in Peri-Urban Environments (Rajaji Tiger Reserve and Gurugram): A Revisit to Biodiversity Management in Smart City Concept.

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Global Tiger Forum ,an inter-governmental international organization for conservation of tiger across its global range.

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Abstract

The concept of smart city needs to be routed in green development. Biodiversity is not confined to the portals of a protected area or forest patch but extends beyond into a larger landscape. Thus, as subsets of a larger landscape with varied land uses, the dynamics of a forest or wildlife habitat are ordained by the ever-changing dynamics of its landscape owing to anthropogenic causes. While, the Man and Biosphere (MAB) approach visualized a "centripetal buffer" around biodiversity rich areas**,** the in-situ conservation of big cats warrant a "centrifugal approach" necessitating safeguards for corridor linkages to ensure gene porosity. The urban and semi-urban scape are great agents of change and transform the landscape by severing inherent wild gene pathways, with creation of induced cover. Such centripetal effect of urban/semi-urban foci foster "ecological dislocation" of wild fauna resulting in increased human-wildlife interface conflicts. The present situation around urban/semi-urban areas requires a landscape level portfolio of actions emanating from a master plan, for factoring concerns of wildlife, including leopardsamongst stakeholders whose goal is not biodiversity. The said approach based on remotely sensed macro-level data in the GIS domain, complemented by ground truthing would enable delineation of a landscape, and its vulnerability with prescriptions for urban, semi-urban and rural landscapes to prevent wild animals from earning a pest value on account of unwise land use based on expediency.

Keywords: Peri-urban forest, GIS, human-wildlife interface, biodiversity, smart city.

Introduction

Managing the ever-burgeoning urban population is undoubted a paragon issue to be attended to in present scenario of urbanization and development (UNFPA,2007). Urbanization has shown a steady increasing trend with 54% urban population globally and 34% urban population in India in 2017 which is resulting in dynamic land-use change and loss of forest cover (Lambin, et al., 2001 and Mather and Needle, 2000). When archaeologist V. Gordon Childe coined the term "urban revolution", he not only defined it as the development of cities but almost entirely a transformation of social institutions and practices (Smith, 2009). Urbanization leads to change in social set-up, change in occupation of land as well as the individuals constituting the society and can cause unidirectional transformation of rural land use to urban land use. (Bloom and Khanna, 2007). This can lead to un-necessary pressure on the natural habitat as well as loss of agricultural fields and biodiversity which were protected in rural and semi-urban landscape. With the encroachment of urban areas into multi-user rural, semi-urban and agricultural landscape, and increased fragmentation of natural environment, the urban green spaces are becoming an increasingly important refuge for native biodiversity (Benton, 2003 and Goddard *et al.,* 2009). The urban green space projects many ecosystem services in dictionary of urban planner but they mainly restrict to recreational, educational and having a positive impact in quality of life, human health and wellbeing,lowering temperature, awareness regarding nature conservation issues (Fuller *et al*., 2007., Gill *et al*., 2007., Mitchell and Popham, 2008., Bowler *et al*., 2010 and Mensah *et al.,* 2016). However, the importance of urban green space/urban commons/ forests in urban planning remain elusive to the conservation of a large predator co-existence.

The reducing forest and increasing urban cover have brought municipal management planners at loggerhead to arrest the inevitable wildlife conflict. The inability to plan landscape with a holistic approach to ecosystem and in tune with inclusive agenda for biodiversity, carnivores and forests often result in animal conflicts which garner negative perception of humans towards wildlife in general (Treves and Karanth, 2003., Chapron *et al*., 2014, Nyhus, 2016). The large carnivore needs a

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large green cover area and good wild prey population to survive and green space in urban conglomerate fail to provide either. Most of the Indian urban areas can sustain the mammalian synanthropes like mongoose, fox, jackal, ungulates but large carnivore tend to come in conflict with human easily due to threat to human and livestock. Leopard is one such large carnivore found across India which being very adaptable has been reported from many urban areas which had or is in vicinity of remnant forests (e.g. Mumbai, Gurugram, Dehradun, Shimla, Jaipur, Ooty, Pilibhit etc). Such hubs of human development are providing refuge in the form of a green cover which is substitute of forests. But such green cover does not provide protection to ungulates which have high mortality in an urban conglomerate. The threats to wildlife consist of poaching, roadkill, dog-kill, disease transmitted through domestic animals. The urban garbage is a lure to domestic, feral and wild animals residing or moving around such food source. The diet of leopard has a large diversity and hence with a small forest cover or agricultural mosaic, leopard is surviving in human dominated landscape. The reason for venturing into human habitat could be non-availability of water, prey, avoidance of a large carnivore, loss of forests and prey (Harihar *et al*., 2011, Mondal *et al*., 2013), yet each such interaction is causing cumulative loss to human and leopard.

Study Area

To understand the large carnivore existence in fast developing urban conglomerate two peri-urban sites were chosen for study (figure 1). Doon Valley in Shivalik and Gurugram in Aravalli has few things in common. Both the ranges have historical inclusivity of leopard and encompasses developmental urban agglomerates. Shivalik is witnessing tremendous pressure due to developmental and religious pressure in and around Dehradun, Hrishikesh and Haridwar. Dehradun city alone has shown two-fold increase in urban growth over a decade (Gupta,2013). Similarly,Aravalli'scontains fast developing cities like Delhi and Gurugram in its vicinity. Delhi has seen fastest rate of urbanization between 2001 and 2011 (approx. 4.1%- National census India 2011). A 16% increase in built-up area in Delhi is reported with major conversion of agriculture land, waste land, scrub-land, sandy areas and water bodies (Mohan *et al*., 2011). Both Doon Valley and Aravalli's were inception cases for Environment (Protection) Act (EPA) 1986, where Doon valley notification 1989 declared limestone quarrying illegal in valley, the Aravalli notification 1992 stopped farmhouse development and restricted mining (Kapoor *et al*., 2009).

However, the difference lies in the biogeographic zone (Shivalik being in Himalayan zone and Aravalli's in the Semi-Arid Zone) and the varying intensity of urban growth since historical time scale. Shivalik landscape witness other large mammal conflict like Tiger and Elephant but study area in Aravallis has no other large mammal besides leopard. NCR has limited areas under wildlife protection (Asola Bhati in Delhi and Sultanpur bird sanctuary in Gurgaon) and highly fragmented connectivity to Sariska Tiger Reserve, Doon valley has a tiger reserve (Rajaji Tiger Reserve) in its aegis with connectivity to Corbett Tiger Reserve.

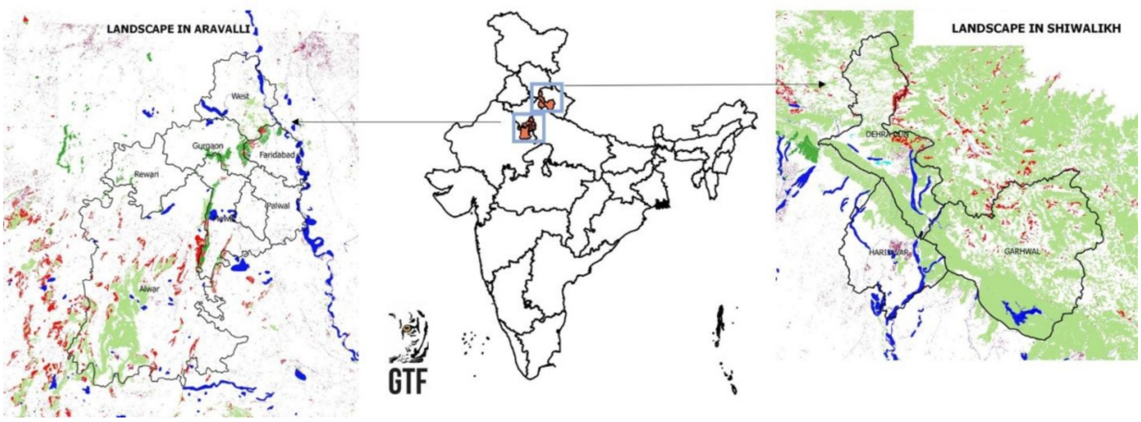

Figure 1. Study area: Shiwalik and Arravali.

Methodology

The utilization of open source information is increasing in various scientific analysis. A web search was done to collect human- leopard conflict reports from the study area. Keywords like “conflict”, “leopard”, “Gurugram”, “Delhi”, Dehradun”, “Haridwar”, “Hrishikesh”, “Rajaji Tiger Reserve”, “Uttarakhand” were used. The web search was done for past one decade. The village location was taken into consideration but road-kill with dubious location were discarded. The locations were plotted on Google Earth and then imported to QGIS domain (QGIS version 2.18.11). The conflict locations for Shivalik conglomerate was 17 (figure 2) and for Aravalli conglomerate was 12 (figure 3). Heatmap plugin with 8km radius was used to generate heatmap and zone (figure 4 and 5). Overlaying conflict cases on land-cover, human footprint, water and road network was done to develop vulnerability criterion.

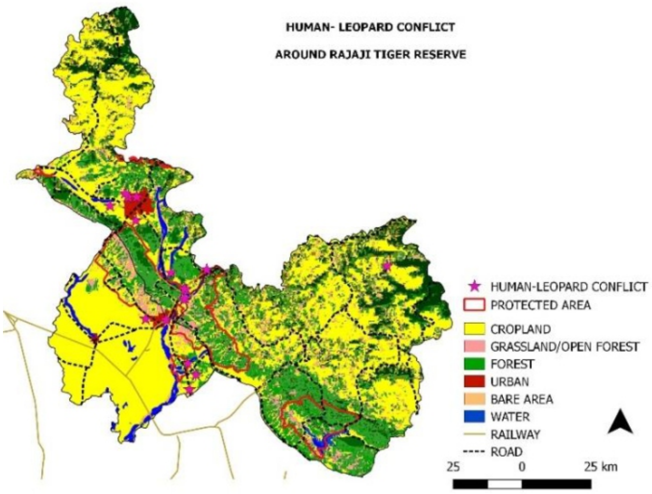

Figure 2. Conflict location in Shivaliks.

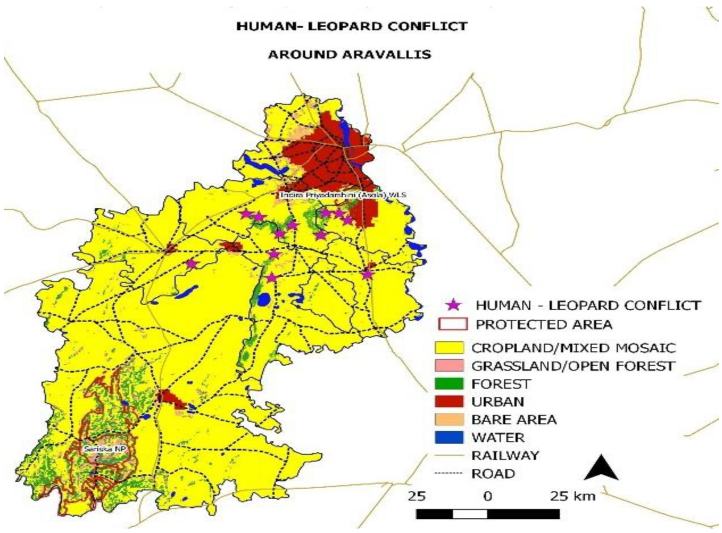

Figure 3 Conflict location in Arravalis.

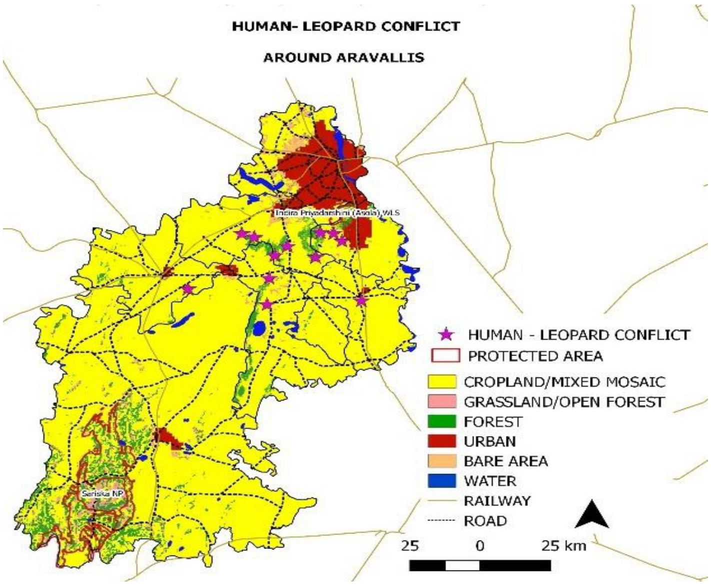

Figure 4. Conflict hotspot zone in Shiwalik.

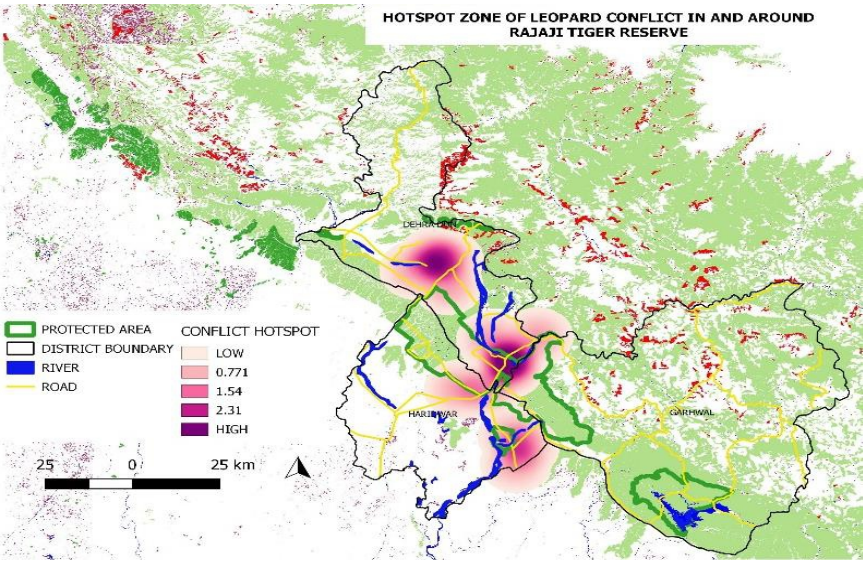

Figure 5. Human-Leopard conflict zones around Rajaji tiger reserve.

Results

The conflict locations in Shivalik landscape overlapped with forest edge and agricultural land and human settlements mosaic (figure 6) while in Aravalli landscape the conflict was observed in green cover and agricultural land mosaic (figure 7). The conflict locations overlapped with high human footprint in Shivalik study area (Figure 8) but is observed to overlap with low human footprint in Aravalli study area (figure 9). Both the study area high conflict hotspot showed overlap with road network.

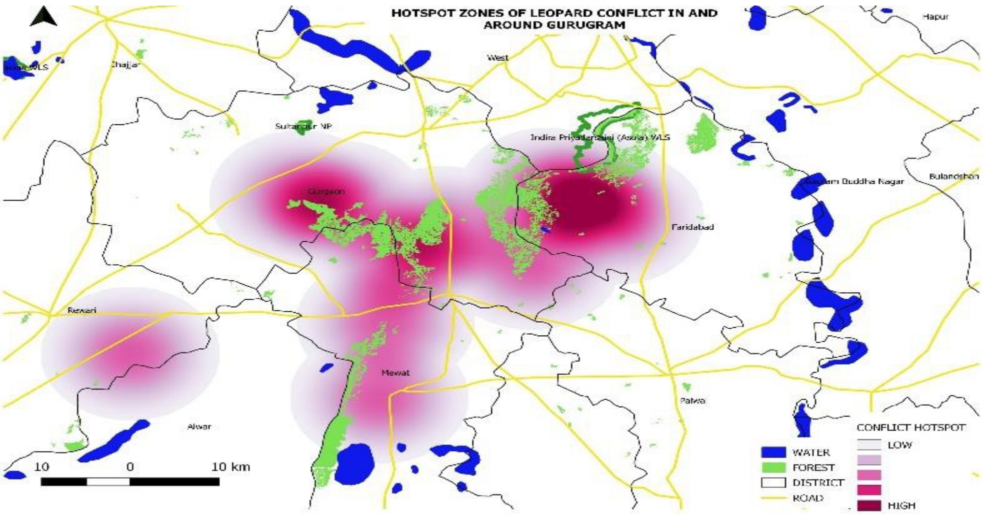

Figure 6. Hotspot zone of Leopard conflict in and around Gurugram.

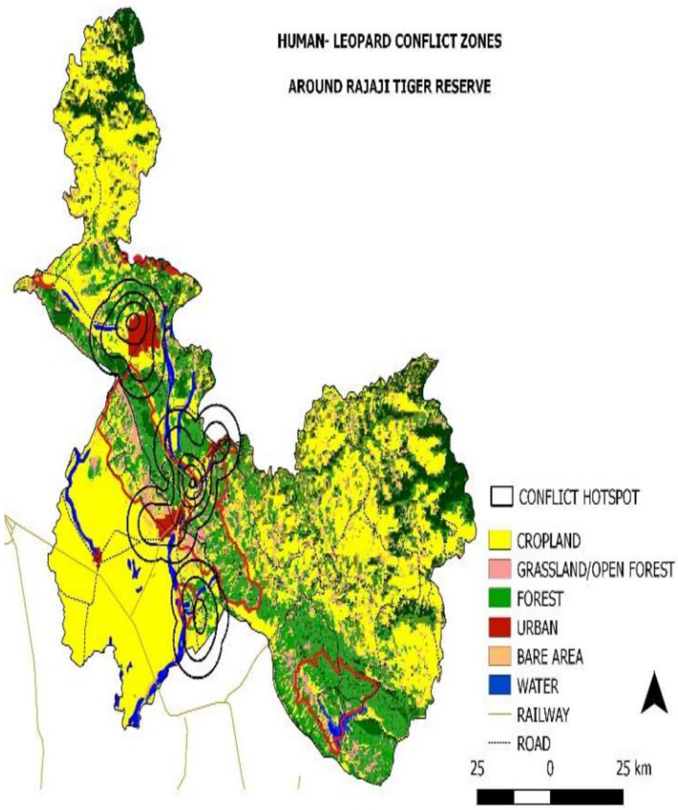

Figure 7. Human-Leopard conflict zone around Rajaji Tiger Reserve.

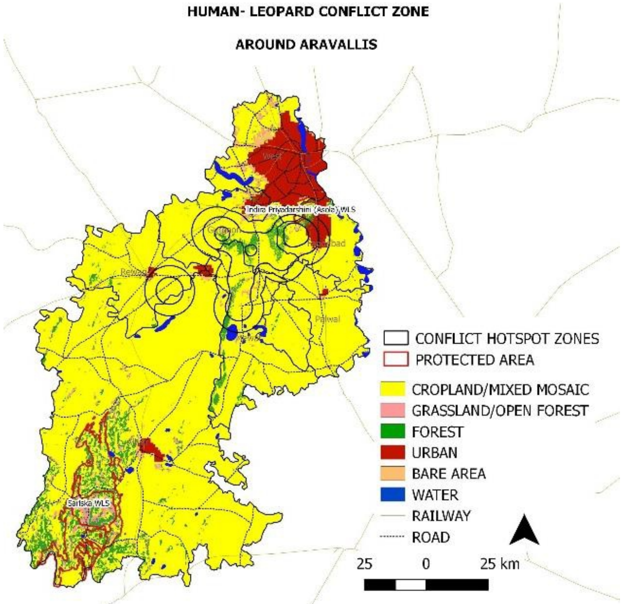

Figure 8. Human-Leopard conflict zone around Aravalis.

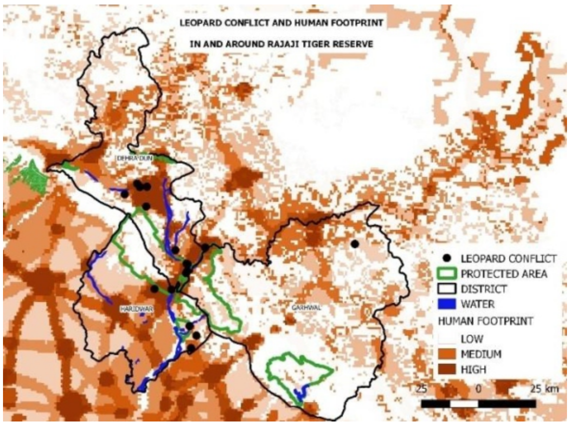

Figure 9a. Conflict overlap with human footprint (Shiwalik).

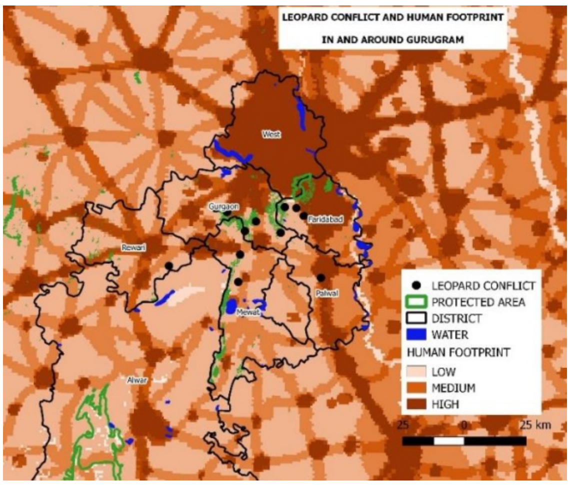

Figure 9b. Conflict overlap with human footprint (Arravalis).

Both the study area with land cover mosaic and leopard conflict cases concluded following vulnerability gradient according to land interface situations (Table1).

Table 1. Landcover mosaic categorized to leopard conflict vulnerability in Shivalik and Arravalis.

Interface Situation	Category
Only Forest Patch	Least Vulnerable
Forest Patch + Presence of Settlement/Practices + developmental/urban barrier	Vulnerable
Forest Patch + Presence of Settlement/Practices + No developmental/urban barrier (excluding road/pilgrim/visitation areas with food material accumulation/waste)	Most Vulnerable

Discussion

Protected urban green areas offer no guarantee for successful biodiversity conservation (Colding *et al*.,2006). Many nature reserves/ forests in vicinity of urban areas are unable to sustain their species over time (Drayton and Primack,1996., Woodroffe and Ginsberg.,1998). The surrounding landscape matrix needs to be taken into account for conservation of biodiversity and the sustenance of urban ecosystem services (Ricketts, 2001).We prescribe an eco-developmental approach for co-existence portfolio of a smart city which includes:

1.Safeguarding against Land-Use Changes

· Buffer/Eco Sensitive Zones(ESZ)/Transition Zone which act as connectivity and restoration areas should be developed for all protected area where sensitization towards wildlife should be actively undertaken. The centrifugal zoning model (figure 10) should be core concept of smart city development.

· Urban commons should be protected against concretization and privatization. The urban commons have been suggested to provide four purposes i.e., provisioning, regulatory, recreational and supporting ecosystem services. All four provision should be kept in mind while conserving the urban commons.

- Eco-sensitive zone around green space should be included.
- Prevention of sudden change in land-use and cropping pattern
- Protection of land from encroachment/poaching
- Protection of unique habitat in such zones

2. Payments for ecosystem services (PES), for Ecologically Sustainable Livelihood Options

3. River Pollution Abatement

- to maintain health of forest and wildlife water pollution should be prevented.
- Technology driven methods should be employed to manage water pollution.
- Awareness should be promoted against ill effects of polluted river entering the pristine forest areas.

4. Garbage/Waste Management should be managed to prevent habituation of wild animals and transfer of communicable diseases

5. Industrial Pollution Abatement

- Green portfolio under corporate environmental responsibility

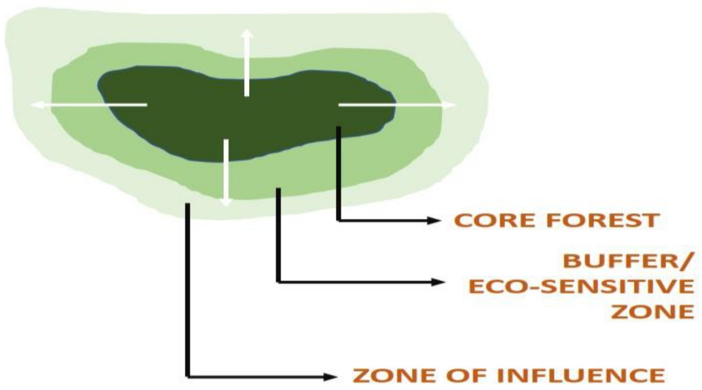

Figure 10. Centrifugal zoning model.

- Polluter pays principle

6. People Park Interface

- Rapid response team
- Agricultural/crop pattern monitoring
- Covering of wells /fencing of livestock barns

7. Safeguard against Invasive Species

8. Development of Green Fund: where various government and private agencies should contribute fund for the ecological development of the landscape**.** Other financial sources should be explored too, *viz.* Corporate Social Responsibility (CSR), capital market investments in forestry, payment for forest goods and services (Payment for Ecosystem services), Reducing emissions from deforestation and forest degradation (REDD/REDD+), Clean development Mechanism (CDM).

9. Stewardship Program: where local people should be made forerunner in the conservation and protection of the green space/forest. The locals should get benefit from the biodiversity and forest in form of livelihood option. The stewardship program should also have government and civil representative who should be responsible for periodic green audits which should emphasize green development through course corrections. The committee should be responsible for GIS based time series monitoring of land use changes. While taking care to safeguard ' no go areas '.

Conclusions

As was rightly put by Ban- ki-Moon Secretary General UN (2008) that "our rapidly urbanizing world cannot claim to be harmonious if the growth and expansion of urban areas come at the expense of natural environment". Most of the urban planning still ignore the sustainable conservation and harmonious inclusion of natural environment (Dale *et al*., 2000). As our urban areas continue to grow in both extent and magnitude, we need a better understanding of the potential consequences both positive and negative of different urban forms. The inherent fluidity of the agglomeration boundaries not only surfaces the management issues which have to be attended by the policymakers as well as resolving the conflicting goals and uses of the land by various stakeholders. Hence a ecosystem centric approach would help us to prevent ill effects of land use changes.

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“GTRP score”: A tool for Strategic Approach for tiger conservation planning in Tiger Range Countries

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ABSTRACT

The Global Tiger Forum, as the only intergovernmental, international organization for tiger is mandated to implement and monitor the Global Tiger Recovery Programme (GTRP). The said programme was launched under the aegis of the Global Tiger Initiative of the World Bank, with commitment from Tiger Range Countries for its implementation in 2010 at the St. Petersburg Summit, vis-à-vis the goal for doubling wild tiger numbers (Tx2) by 2022. The GTRP is a composite portfolio of actions at several levels viz. tiger source area, national and transnational, for strengthening and fostering wild tigers across its natural range in sovereign Tiger Range Countries. The status of wild tiger continues to remain endangered globally, with its population reaching sub-optimal levels in several areas. The Key Performance Indicators (KPI) of the GTRP have been scored, while qualitatively factoring the outcome from the score in the Population Habitat Viability Analysis (PHVA) for generating futuristic scenarios towards highlighting the extant vulnerability of tiger populations, along with broad suggestions for a future roadmap towards tiger recovery.

Introduction

The Tiger evolution in Asia goes back to the Pleistocene geological timescale (Brongersma, 1937, Mazák,2006) [around 1.8 million to 11,000 years ago], and gradually had a widespread distribution in the said continent, ranging from Caspian area to central China, Russia, and countries of Southern as well as South East Asia (Mazak, 1981). However, the present-day distribution is restricted to only 13 range countries, *viz.* Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Russian Federation, Thailand, and Vietnam (Luo et al 2004). The global population of wild tiger is around 3890 (GTF and WWF 2016).

Fig 1: Global Tiger Status (GTF and WWF 2016)

* Global Tiger Forum Secretariat

The wild tiger status continues to remain endangered across its range owing to several causatives (Goodrich et al 2015, Nowell et al 1996, Dinerstein et al 1997), which are overarching to all TRCs, *viz.* poaching for consumptive use of body parts and derivatives, loss of prey owing to habitat fragmentation, low density of prey base and tiger owing to anthropogenic causes, restricted tiger movement across its landscape owing to loss of corridor linkages, targeted killing owing to sensitive human tiger interface, mortality on account of surface/rail transport, lack of desired field actions owing to paucity of resources (funding and frontline) and priority for development, while viewing tiger as a drag on such initiatives.

The TRCs do have their sovereign tiger agenda with country level action plan. Over the years, collaboration with conservation partners is discernible in several TRCs on the tiger front. The Global Tiger Forum (GTF), as the only inter-governmental body of TRCs, since its formation in early 90s has been engaging with TRCs for handholding on several fronts, with more focus on capacity building. The said forum has also subsequently initiated the compilation of Tiger Action Plans of individual range countries.

The Global Tiger Initiative (GTI) was launched by the World Bank during 2008. The convening power and the presence of the bank facilitated the evolution of a Global Tiger Recovery Program (GTRP), which was endorsed by all TRCs in the St. Petersburg Summit during 2010, with a goal to double the wild tiger population (T X 2) by 2022. This has been subsequently ratified in several conclaves, including a ministerial meeting held in New Delhi in April 2016. With the phasing out of the GTI by the World Bank, and the subsequent creation of the Global Tiger Initiative Council (GTIC) in 2015, the GTF has been mandated as the implementing arm for the tiger agenda in the new dispensation. Thus, the GTF has been monitoring the GTRP performance by TRCs through several Key Performance Indicators (KPIs).

The GTRP is a composite portfolio involving actions at three levels, *viz.* field formations, national and international. A good GTRP performance results in more assured status for the wild tiger. The GTF missions have visited many TRCs in the South and South-East Asian region, which includes field visits and interaction with senior officials. Based on the same, it can be broadly stated that the global status of wild tiger categorized as optimal and suboptimal, the latter including most of TRCs from South-East Asia, including China. In the recent past, tigers are locally extinct in large portions of Cambodia, Lao PDR, Vietnam and China; the density status is very low in Myanmar along with paucity of wild prey (Lynam, 2010). Thailand and Indonesia have a comparatively better tiger status, followed by Malaysia. Hence, the need was felt for scoring the GTRP performance while factoring the same in the PHVA of select sites in several countries of the South-East Asian region for flagging the urgency towards immediate actions. Three scenario simulations have been attempted in the PHVA process: an optimal situation with satisfactory implementation of GTRP, along with two suboptimal situations of low GTRP performance and varied values of initial population and habitat carrying capacity.

Table 1: The GTRP matrix for scoring

S No.	KPI Criteria	Normative Standards
1	Enabling Law	Dedicated legislation
2	Enabling Policy for National Funding	Committed sovereign allocation and budgetary provision
3	Policy on Donor Support	Dedicated externally aided project for tiger/protection
4	National Resolution/Policy on Corridor/SGI	Identification of corridors and resolution on SGI
5	Resolution on inclusive agenda for people	Commitment for PES, livelihood options
6	Frontline staff	Staff deployment per unit area/and salary support
7	Action Plan	Approved National Action Plan
8	Tiger Monitoring	Use of modern protocol (camera traps and GIS based inference)
9	Tiger Management Plan	Exclusive tiger plan for the site in tune with action plan
10	Use of technology	Support for technological inputs
11	Smart Patrol and Monitoring	SOP and Protocols in place
12	Protection Infrastructure	Range Stations/barriers/communication network etc.
13	Antipoaching/tiger/other wildlife body parts trafficking prevention	Effective surveillance, intelligence-based enforcement, high prosecution and conviction rates
14	In-situ prey/predator build-up and securing inviolate space	Protocols and field action ongoing
15	Human-Wildlife Interface	SOP and Compensation regime defined
16	Assessment (MEE/CA|TS)	Protocols and directives in place
17	Transnational Actions	Ongoing bilateral engagement

GTRP scoring and PHVA computation

The GTRP status of 13 TRCs, based on a combination of management scenarios, ecological status and poaching has not been compiled earlier. In addition to overarching constraints which are common to TRCs, there are country, as well as site specific issues warranting a "differentiated" approach. The GTRP score for each indicator was done by the same team on a 0 to 1 scale, vis-à-vis normatives, based on updated information contained in Tiger Action Plans of individual TRCs and KPI of the GTRP, as provided to the GTF. In the context, information from China and Indonesia, was obtained from respective action plans, and earlier updates provided in the ministerial meeting (2016). Related information was also from literature review, poaching data and reports of Conservation Assured Tiger Standards (CA|TS).

Various ethological aspects of tiger and decimating factors (poaching, habitat degradation and the like) have been documented in the context of some TRCs (TRAFFIC 2016, EIA

2018, Duckworth1998, WWF 2017). An attempt has been done to incorporate such information into the PHVA process for long-term tiger sustainability in the region. The key priority sites of the TRCs were considered to compute the habitat carrying capacity for tiger, vis-à-vis the latest population figures (considered as founders for PHVA) (Simcharoen et al, 2007,2014, Kawanishi & Sunquist 2004, Lenkie 2005, Sukmasua et al 2001). The area of key priority sites in the region range from 2000 to 14000 sq km, *viz.* Kerinci Seblat: 13,791 sq km (Indonesia); HKK: 2,780 sq km (Thailand); Taman Negara: 4,343 sq km (Malaysia); Htamanthi: 2,150 sq km, and Hukaung Valley; 11,519 sq km (Myanmar). The computed carrying capacity ranged from 60 to 420 tigers, vis-à-vis initial populations ranging from 8 to 136 (Lenkie 2005, Simcharoen et al 2007). Large patches were not considered for computation for want of active corridor management along linkages between source sites within a landscape. (ex: Hukaung Valley - Htamanthi).

The 17 GTRP KPI foster in-situ protection resulting in conservation of the endangered tiger in source areas across its natural range. The global experience indicates that tiger responds quickly to protection [Project Tiger in India] (Jhala et al 2014, WWF 2017). In the context of tiger, “protection” has an umbrella connotation since a tiger population in its source area requires protection from several decimating factors: poaching, loss of habitat, paucity of prey base, poor habitat quality, rampant fire, forest resource dependency of people, interface problems and revenge killings.

Poaching is a serious threat for tiger conservation (Galster & Vand Elliot 1999, Check 2006, Jhala et al 2008, Wikramanayake et al 2011) and has been investigated for incorporating policy actions (Kenny et al 1999). Law enforcement, frontline training and capacity building, national enabling policies and transnational actions are important for long-term survival of tiger population. However, in a large number of researches, often the focus has been on habitat restoration, corridor connectivity and maintenance of prey density (Miquelle et al 2005), vis-à-vis tiger resilience and low rate of extinction. It is observed that in the event of paucity of tiger population data, selective harvesting (poaching/targeted killing) of tiger population, conflict and mortality of dispersing tiger in a fragmented habitat, negative effect due to cultural dependency on forest and ethical unrest are not given enough weightage to plan conservation policies. In such scenarios, often the data is substituted and quoted from another study site and conservation policies are brought into effect after generalization.

Anti-poaching was one of the indicators for assessing the TRCs based on their acquired GTRP Score. For obtaining tiger numbers, individualistic body parts from seizures were considered, viz.: full skeleton, skin, carcass, taxidermy mount, skull and live animal akin to procedure followed in TRAFFIC as indicated below:

Table 2: Tiger poaching across South East Asian TRC.

YEARS	THAILAND	MALAYSIA	INDONESIA	MYANMAR	LAOS	VIETNAM	CAMBODIA
1	10	12	4	1	3	5	7
2	6	7	26	1	5	18	1
3	50	26	10	1	3	7	
4	2	1	9		17	6	
5	12	1	34		11	3	
AVERAGE	**16**	**9.4**	**16.6**	**1**	**7.8**	**7.8**	**4**

(TRAFFIC's 2016 Report- Reduced to Skin and Bones, re-examined)

In view of local extinctions of Tiger in the South-East region, the survival probability assumes importance, vis-à-vis the GTRP score. Hence, priority sites of some TRCs within the region were considered for PHVA (Vortex 10 [Version 10.8.2.0] (Lacy et al 2017), which evaluates the likelihood of species persistence for a given period into the future. The simulation was done with inputs from well-known findings on tiger ecology, mating, reproduction, mortality, immigration and harvesting. The PHVA process projects the survival chances over a period of 100 years by describing the years to extinction. Based on empirical data, it has been found that a viable population of tiger 20 breeding tigresses requires an inviolate space of 800-1000 sq km, with a buffer of 1000-3000 sq km. Given the land tenure dynamics, source-sink interactions, internecine attributes and sex-ratio of tiger, the above dispensation would result in a tiger population of 85-90 individuals within an area of 3000 sq km (Guidelines of Tiger Conservation Plan, NTCA, 2006). Keeping in mind the PHVA process (Vortex analysis), three scenarios have been depicted in the context of GTRP, *viz.* scenario 1 presenting an optimal situation, scenario 2 and 3 depicting suboptimal situations with different values of initial populations and habitat carrying capacity for the tiger. The instant approach of factoring GTRP scores in a PHVA has been done for the first time for stepping up managerial efforts on a priority basis.

The life history data used for Vortex modelling was based on published literature (Mazak 1981, Sunquist & Sunquist 2002, Gopal 1992) as provided in table 2. The natural disasters have not been taken into account in the PHVA process.

Table 3: Inputs for PHVA (Vortex 10 [Version 10.8.2.0]

Vortex parameters	**Classical**	**GTRP approach**	
	Scenario 1	**Scenario 2**	**Scenario 3**
Age of first offspring female breeding	3	3	3
Age of first offspring male breeding	4	4	4
Maximum life span	15	15	15
Maximum number of brood/years	1	1	1
Maximum number of progeny/broods	3	3	3
Sex ratio at birth-in %males	50	50	50
Maximum age of male and female reproduction	15	15	15
% Adult female breeding	50*	40	50
%Male in breeding pool	50	60	50
%Mortality from age 0-1	50	50	50

%Mortality from age 1-2	30	30	30
%Mortality from age 2-3	5*	20	20
%Mortality after age 3	5*	20	20
First year of harvest	1	1	1
Last year of Harvest	100	100	100
Interval between harvest (poaching/targeted killing)	5	1	1
Number of females harvest after age 3	1	2	1
Number of males harvest after age 3	1	1	1
Supplementation of individual (number)	2	1	-
Supplementation year interval	5	5	-

Assumptions

For **scenario 1**, the habitat carrying capacity computation for tiger was based on an average from highly productive tiger source areas in India (large number of births and deaths, with the former exceeding the latter) like Kanha (area 2051 sq km), Tadoba (area 1728 sq km) and Corbett (area 1288 sq km). As stated earlier, based on empirical data, it has been found that a viable population of tiger 20 breeding tigresses requires an inviolate space of 800-1000 sq km, with a buffer of 1000-3000 sq km. Given the land tenure dynamics, source-sink interactions, internecine attributes and sex-ratio of tiger, the above dispensation would result in a tiger population of 85-90 individuals within an area of 3000 sq km (Guidelines of Tiger Conservation Plan, NTCA, 2006). Based on the same, the average carrying capacity for tiger, vis-à-vis area works out to 30, which has been considered as the initial population.

For Scenarios 2 and 3, which represent suboptimal conditions in the context of tiger status and GTRP implementation: Initial population of 136 (carrying capacity 420) and 8 (carrying capacity 60) were used in the PHVA process. In all, two key protected areas (Scenario 2 – Hua Kha Khaeng WLS, Thailand; Scenario 3 – Htamanthi WLS, Myanmar). from the South East Asian region were taken into consideration. In some sites within Malaysia, camera trapping has revealed an abnormal sex ratio (more of males and few females), which may result in local extinction. Perhaps, the pronounced site fidelity of females makes it more vulnerable for targeted killings.

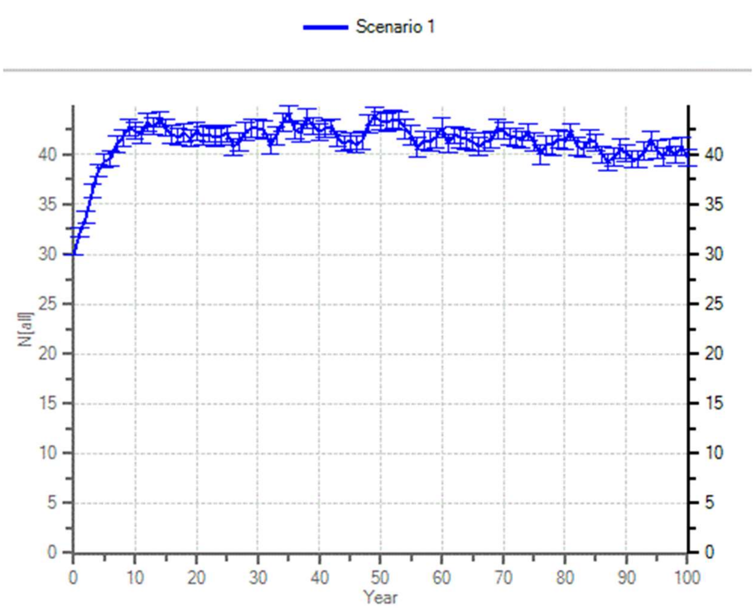
Results:

The GTRP score presented two categories of TRCs, viz. Category 1: optimal (GTRP score >=0.6), and Category 2: sub-optimal (GTRP score <0.60).

Category 1 includes TRCs, which more or less, have an optimal wild tiger status with a long-standing track record of in-situ conservation, including monitoring and country level estimations (Russia, India, Bhutan, Nepal, Bangladesh). The said countries also have source area specific tiger conservation plans, forming part of a national thought process, including macro-level mapping of habitat connectivity (corridor). Apart from such initiatives, transnational engagements with bordering TRCs are also ongoing for strengthening tiger monitoring.

Category 2 includes TRCs, with sub-optimal tiger status. However, several source areas in such countries have immense potential for harbouring viable tiger populations. Though corridor mapping and a landscape vision with initiatives for green infrastructure have been initiated in a few countries (with partial gene porosity at places) within the region, there is an urgent need for reviving several source areas with active management for protection and prey base buildup.

It is pertinent to add that countries falling within this category have not carried out a nation-wide assessment of tiger, co-predators and prey. Issues like paucity of sovereign funding, frontline staff and protection infrastructure have slowed down the GTRP implementation.



Scenario 1 Vortex result: The probability of extinction is nil for optimal TRCs as connectivity allows a minimum of 2 individual immigration at every 5-year interval, harvesting (poaching/targeted killing) of 2 individuals at every 5-year interval, no skewed sex ratio, population below carrying capacity.

Fig 2: Vortex scenario 1 output graph

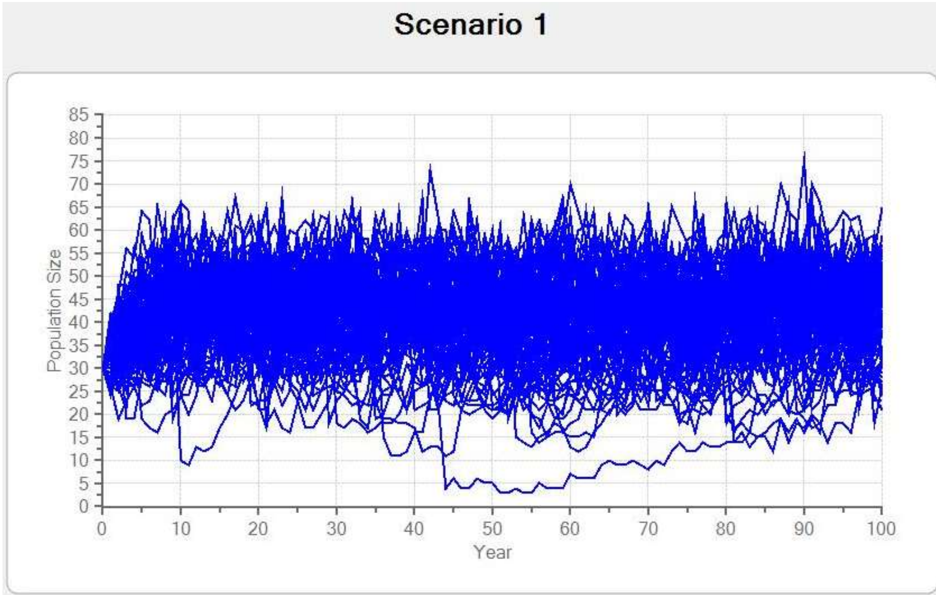


Fig 3: Vortex scenario 1 simulation

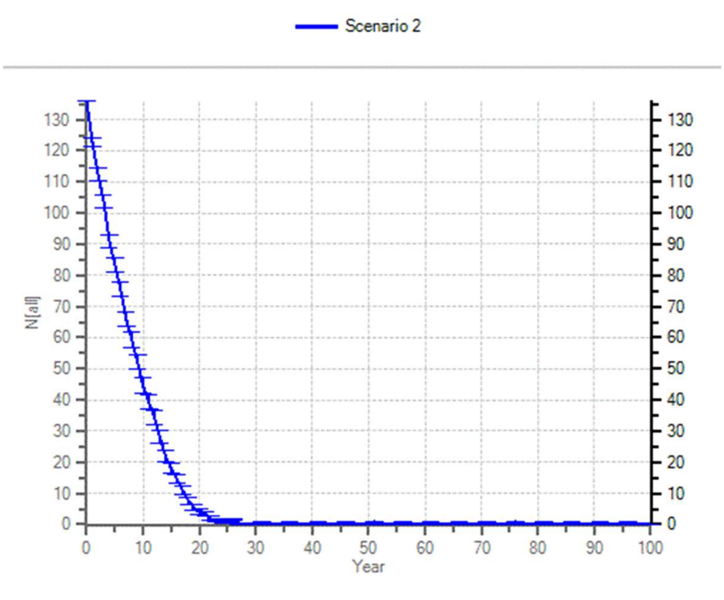


Fig 4: Vortex scenario 2 output graph

Scenario 2 Vortex result: Large forests with high initial tiger population. The probability of extinction is high (extinction in 26 years) for sub-optimal TRCs as partly functional connectivity was taken into consideration hence supplementation of 1 adult male (after 4 year of age) individual at 5-year interval. Harvesting (poaching/targeted killing) of 3 individuals (2 females and 1 male after age 3) at every 1-year interval, **skewed sex ratio** resulted in less breeding females in the population, and high mortality of dispersing tigers.

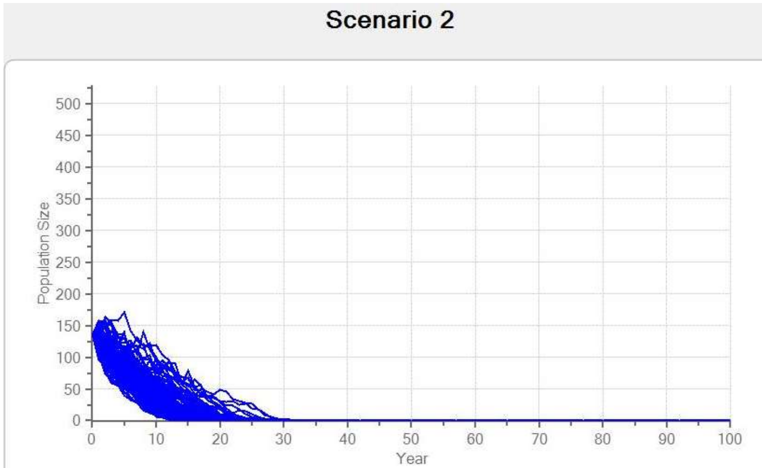
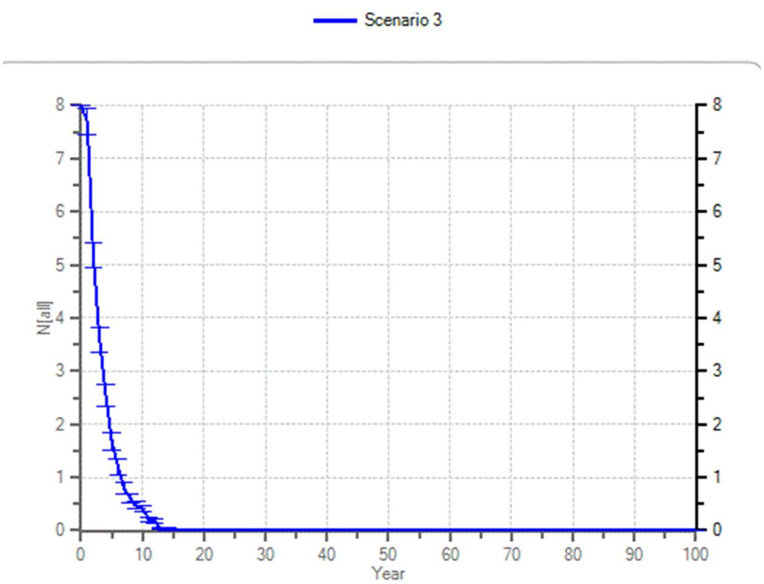


Fig 5: Vortex scenario 2 simulation



Scenario 3 Vortex result: Large forests with low initial tiger population. The probability of extinction is very high (extinction in 15 years) for sub-optimal TRCs as no connectivity was taken into consideration hence no supplementation. Harvesting of 2 individuals (1 female,1 male after age 3) at every 1-year interval, no skewed sex ratio (50% breeding female in the population), and high mortality of dispersing tigers.

Fig 6: Vortex scenario 3 output graph

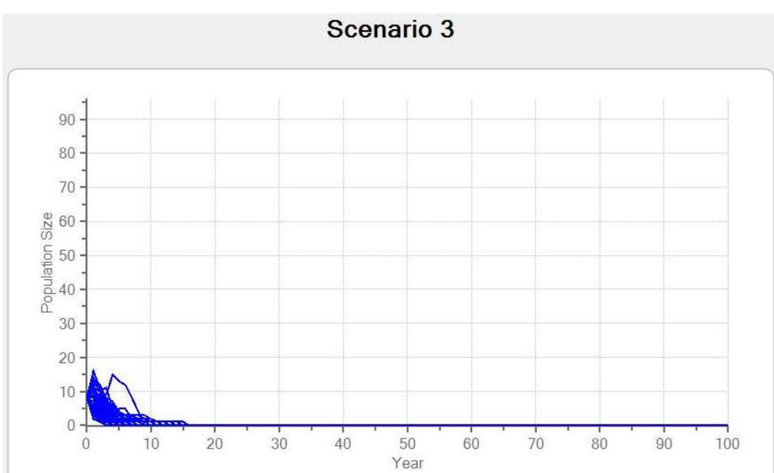


Fig 7: Vortex scenario 3 simulation

Discussion and Way Forward

The composite portfolio of GTRP involves action at several levels to strengthen the in-situ conservation of wild tiger populations across TRCs. For the first time, Key Performance Indicators of the GTRP have been scored and factored into the PHVA process of select priority sites. This becomes crucial at this juncture to garner the desired support towards resources and containing trafficking of body parts and derivatives of tiger.

The tiger source areas across TRCs falling in both categories are in varied status in the context of habitat quality, prey base and tiger density. A site which is depauperate even at the habitat level would warrant more time, effort and resources for tiger recovery. On the contrary, areas with only low tiger density for want of protection or prey revival may require less effort. Since, such conditions are resultant of a combination of factors ranging from transnational, national and site levels, a differentiated approach is much needed for concerted time bound tiger revival. However, tiger conservation efforts with landscape approach and prey recovery would not be enough for tiger survival if the mortality exceeds 15% of the adult female population (Chapron et al 2008), which reiterates the need for security planning and protection.

Containing trafficking of body parts and derivatives of big cats, including the tiger, is an over-arching threat for all TRCs. Though much conversation and local actions have happened on this front, more are required. The demand in the said context need to be eliminated, as local extinctions of an ecological umbrella species like the tiger would usher in dismantling of ecosystem service processes and carbon sequestration in tiger bearing forests.

Tiger agenda is fortunate to have considerable commitment of TRCs and hence, the situation is not unsurmountable. The TRCs are aware of the GTRP portfolio and need to garner resources for implementing their priority actions as responded by them in the KPI review. The broad roadmap for strengthening wild tigers would involve actions at three levels, viz. tiger site, national and transnational. The urgent site actions for large habitats with very low prey density needs to include smaller focal areas in the form of "micro-cores", facilitating concerted field actions related to protection infrastructure, communication, frontline deployment, active prey revival, followed by reintroduction of tiger. The normatives of GTRP are based on ground reality and may guide the process. Such actions need to form part of a National Tiger Action Plan complemented by an enabling policy regime. Several tiger source areas need to be fostered as a regional network merging into a national web of larger green space. This would entail a landscape approach for engaging with many owners (stakeholders) who operate in the larger landscape area but nevertheless impact the tiger source, directly or indirectly. The stakeholders bearing the brunt of direct impact (local people) need priority involvement in the tiger agenda to ensure the desired stability based on local support and ownership. An active engagement with donors and collaborators is called for at this juncture for mutually complementary actions based on regional, national and area specific projects forming part of the Tiger Action Plan.

The Global Tiger Forum is committed to assist tiger range countries in their efforts to save the endangered wild tiger.

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We confirm that **Ridhima Solanki** presented an oral presentation entitled:

Panthera pardus photo-identification through Hotspotter: challenges and lessons learnt in usage of pattern recognition softwares

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National Seminar

on

Climate Change, Biodiversity and Urban Environment: Current Trends and Challenges in the Conservation of Urban and Peri-urban Biodiversity (NSCCBUE-2019)

April 26th, 2019

NSCCBUE 2019

Organized by

UNIVERSITY SCHOOL OF ENVIRONMENT MANAGEMENT (USEM), GGS INDRAPRASTHA UNIVERSITY

CERTIFICATE OF PARTICIPATION

This is to certify that Prof./Dr./Mr./Ms. Ridhima Solanki has **~~participated~~/presented** in National Seminar organized by University School of Environment Management, Guru Gobind Singh Indraprastha University, Dwarka, New Delhi as **oral/~~poster~~** presentation entitled Understanding landscape vulnerability with therefeence to Panthera pardus (Common Leopard) in peri-urban environments (Rajaji NP and Gurugram): a revisit to biodiversity management in smart city concept

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Wildlife Institute of India

DECLARATION

I hereby declare that the thesis entitled "Role of Top Predators in shaping carnivore communities" submitted by me (Regd. # 12PHD240) to Forest Research Institute (Deemed) University, Dehradun, for the award of the degree of Doctor of Philosophy in Forestry (Wildlife Science), is a record of original research work carried out by me under the supervision of Prof. Qamar Qureshi and co-supervision of Dr. Y.V. Jhala, both Scientist-G at the Wildlife Institute of India, Dehradun. It has not formed the basis for the award of any other degree or diploma. I also declare that the thesis embodies my own work, observation and analysis; and in those respects, the investigation appears to advance knowledge in the subject.

Ridhima Solanki

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ROLE OF TOP PREDATOR IN SHAPING CARNIVORE COMMUNITIES

THESIS

SUBMITTED TO THE

FOREST RESEARCH INSTITUTE Deemed to be UNIVERSITY

DEHRADUN, UTTARAKHAND

For

THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY IN FORESTRY

(WILDLIFE SCIENCES)

By

Ridhima Solanki

Under the Supervision of

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The aim of the study was to explore sympatric carnivore in higher trophic interaction with lower trophic carnivore within the guild. The selection of site was based on this requirement. The core of well managed tiger reserve where impact of anthropogenic effect (encroachment, livestock, domestic dogs), if not prevented, were limited. The sampling design oriented for tiger initially was updated for other carnivore sampling. The small grid size (1x1) proved suitable for photo-capturing smaller carnivores. However, as observed in chapter II, it was concluded that 45 days camera-trap session suggested for tiger sampling was not optimal for leopard. It was observed through species – occasion curve that new leopard individual was added to population post 45 days too, especially in large protected area. Hence, a further investigation is suggested to decide a "optimal trap nights" for smaller carnivores.

However, ecological conclusion based on camera-trap studies are difficult as many species detection probabilities depend on various factors (Bauk et al 2014, Dechner, 2018). In this study an attempt was made to winnow the carnivore guild according to body size. The limitation was carnivore community composition differed within the same central Indian landscape. In Bor, major representation was by Jungle cat and limited photo capture of other meso-carnivores. Similarly, honey badger was detected largely in NSTR followed by Melghat. A uniform and grid based cameratrap cannot necessarily account for capture of all small carnivores due to habitat and terrain preferences. Although the single season occupancy analysis did not show significant relation with any habitat characteristics like terrain, human disturbance and forest cover but avoidance between trophics was observed at patch level. The composition of a patch is mostly not used to understand the occurrence of animals. In a protected area dominated by deciduous forest type presents substantially uniform landcover type.

In tiger absent area

According to relative abundance index, first trophic dominates and low abundance of meso-predator is concluded through camera-trap survey. However, overall density of first trophic (leopard) is calculated as low compared to other study sites. The probable low density of prey can be reason for the low density of leopard. A medium temporal overlap was observed between first trophic and meso predator suggesting slight avoidance between the two on temporal scale. In absence of top predator, the first trophic predator (leopard) act as dominant where its temporal activity majorly corresponds with the peak time of prey i.e., Sambar and with peak activity at dusk and dawn along with dormant temporal phase. A medium temporal overlap was observed between the two-dominant predator in first trophic suggesting activity of sub-ordinate (to tiger) predators is directed by prey segregation in low prey density site. The spatial avoidance was observed too between first trophic and meso-carnivores where SIF is less than 1. The meso-carnivore preferred mosaic of vegetation (50-70%) and grassland followed by mosaic of grassland (50-70%) and vegetation. The first trophic also showed affinity to mosaic of vegetation (50-70%) and grassland but less than meso-carnivore. The second preferred habitat for first trophic was cropland and also large water bodies. Large water bodies and cropland is preferred for domestic prey in human dominated and wild prey deficient site.

In such site sub-ordinate predator to tiger becomes dominant and hence interference competition is suggested between first trophic and meso-predator resulting in meso-predator avoidance at temporal and spatial scale.

In low tiger density area

The RAI analysis suggests first trophic dominates and is expressed more at camera trap in low tiger density sites. The meso-predator is suppressed by first trophic suggesting interference competition between the two (the meso-predator suggests limited activity and encounter rate at camera-trap) with exception of one site. The site with extremely low prey although show high RAI/100nights for first trophic but is low compared to other low tiger density sites. Hence in such area, the meso-predator shows no suppression by first trophic. **Comparing the Leopard density in all study sites, it was observed that it increases with decrease in tiger density areas** but the predator density is also resource driven. The leopard density is comparatively high in low tiger density sites with exception of site with very low prey density.

The temporal overlap is high between first trophic and meso-carnivore but medium between tiger and first trophic as well between tiger and meso-carnivore. The interaction between predators of first trophic i.e. dhole and leopard show segregation at fine scale. Dhole has smaller niche width with peak activity being in dawn while leopard has larger niche width with peak activity at dusk. In low tiger density area where prey density is scarce, the high temporal overlap between first trophic and meso-carnivore suggest overlap at macro-level due to segregation of resources but avoidance at finer scale. The spatial avoidance was observed by SIF < 1 between first trophic and meso-carnivores but cohesion in small protected area with human disturbance. The interference competition is not visible in small site with human disturbance. Spatial cohesion was observed between tiger and first trophic and between tiger and meso-carnivore.

The medium temporal overlap between tiger and first trophic but SIF> 1 suggest interference competition at temporal scale and not at spatial scale.

The interference competition between first trophic and meso-carnivore exists but at finer scale at temporal axis and evidently expressed at spatial axis.

In medium tiger density area

In medium tiger density area, the first trophic predator shows higher abundance compared to tiger according to camera-trap capture. The leopard density is highest in such sites compared to other tiger density areas. However, the meso-predator is expressed more despite of high RAI/100trapnight for first trophic and highest leopard density. This suggested high interference competition between first trophic and meso-carnivores. The lowest temporal overlap amongst **all sites** between first trophic and meso-carnivore suggest avoidance due to interference competition. Although high temporal overlap was observed between tiger and first trophic, the avoidance is observed at finer scale.

The interference competition is not expressed on spatial axis between first trophic and meso-carnivore but cohesion between tiger and first trophic is observed.

For tiger and first trophic, temporal and spatial avoidance is observed at fine scale only in medium tiger density area.

Interference competition is suggested between first trophic and meso-carnivore evidently at temporal scale but no interaction on spatial scale. However, preference of difference habitat is observed by first trophic and meso-carnivore.

In High tiger density area

The tiger RAI/ 100trapnight is higher than first trophic and first trophic is suppressed at majority of sites. The meso-predator are expressed more and activity/ abundance is concluded higher than first trophic in majority of site. It can be concluded that higher abundance of tiger suppresses first trophic which in turn cannot suppress meso-carnivore. Compared to low tiger density sites, density of leopard is lowest here. A high overlap between tiger and first trophic was observed yet at finer scale it was observed that while tiger peak activity which was post dusk was avoided by first trophic. The abundance of meso-carnivore suggests interference competition between first trophic and meso carnivore but a medium temporal overlap concludes avoidance at temporal scale.

The species interaction factor concludes that in high tiger density area, the predator interaction suggests co-occurrence of large predators (tiger and first trophic) due to prey occurrence and habitat usage. However, no effect between first trophic and meso-carnivore on spatial scale was observed. The habitat preferred by both first trophic and meso-carnivore is relatively similar.

In high density area, the interference competition between tiger and first trophic is expressed both at temporal and spatial scale only at fine scale.

The interference competition between first trophic and meso-carnivore is expressed at temporal scale but not at or in limited level at spatial scale.

Tiger conservation in India has proved successful with roadmap of Tx2 target. Tiger in India occupy various habitats with unique characteristics. The importance of large habitat and corridor connectivity due to large ranging animal is recognized and efforts are in place. The focus has been on the tiger habitat requirement and finding the gaps in the same which mostly result in human-tiger conflicts. The dispersal of tiger outside a protected area in human dominated landscape causes human wildlife conflict and negative impact on this flagship species (Karanth and Gopal, 2005, Loveridge et al 2010). However, this human wildlife conflict is attributed to direct involvement of tiger. The role of tiger as keystone species has not been explored for active management and mainly flagship status is highlighted which without doubt has brought positive conservation. Such impact has been studied in reintroduction/relocation plan where tiger effect on prey and sympatric carnivore has been researched. The tiger number is regularly monitored and assessed to understand the demography, dispersal for site specific population. Such research has proved to be successful in highlighting management intervention when the change is perceived and threat resulting from the same is accounted (Mapstone,1995, Gibbs et al 1998). The result for change in tiger population is anthropogenic, policy change, temporal variation, prey fluctuation or natural calamities (All India Tiger Monitoring 2010, 2014, 2018). However, for lower carnivore communities another factor that plays a role is "top predator" population fluctuation.

In various type of habitat where tiger exists in varying density, understanding the effect on other carnivore abundance and community structure is important to bring management interventions. It is observed that if the top predator is low or absent the human conflict due to lower trophic carnivore and larger prey would increase too. In the absence of tiger, the overabundance of large prey is observed whose overrepresentation disbalances the resource availability of other prey. The low density/ deficiency of medium and smaller sized prey on which maximum carnivore are dependent present a case of "artificial prey" in form of livestock resulting in increased human wildlife conflict (Nynus, 2016). An understanding of carnivore communities is required to analyze avoidance due to fear and movement, restriction and prey, habitat augmentation of the same. The diversity of carnivore community not only affect the wild prey dynamics in the park but also plant communities. Such understanding is important to develop management plan of the park adhering to requirement all carnivore species.

In tiger absent area, large prey like Gaur is present but there is severe scarcity of medium/small sized prey. In such site's leopard act as top carnivore whose preferred prey is medium sized prey. It is very likely to come in conflict with human due to scarcity of prey and habitat fragmentation. Reintroduction of tiger is important to limit the population of Gaur which is currently controlled by dhole. However, the park is managed according to the habitat requirement of dhole. In absence of top-down control of tiger, the interference competition between first trophic and meso-carnivore is visible both at temporal and spatial scale. The low abundance of meso-carnivores and less diversity of the same is also observed in site with absence of tiger.

In low tiger presence areas, where large prey like gaur is absent and large area is available, the large predators are dependent on medium and small sized prey. Since suitable common resources are in limited areas/segregated in such landscape hence tiger and first trophic show overlap in space but avoidance at temporal axis. However, the avoidance at spatial axis is observed here between first trophic and meso-carnivore and also at temporal scale. Due to availability of large habitat suitable for meso-carnivore, the abundance of this trophic is visible inspite of interference competition.

In medium tiger density areas, where prey availability is diverse and suitable, first trophic density is highest. The overlap between tiger and first trophic is lower than as observed in high tiger density sites. The niche separation between tiger and first trophic on prey availability prevent interference competition between them. The temporal and spatial overlap suggest co-existence with separation at "finer scale". Although the interference competition between first trophic and meso-carnivore is not expressed at spatial scale but avoidance at temporal axis confirm the interference competition. At medium tiger density compliments first trophic and meso-carnivore abundance but a threshold should be observed for prey availability. In such areas, regular monitoring and active management for prey must be done to avoid dispersal of predator and resulting human-wildlife conflict.

In high tiger density area, the resource partitioning between tiger and first trophic is not visible. Although high temporal and spatial overlap rules out interference competition (it does exist at fine scale), but low density of first trophic (leopard) suggest that a regular supplementation of prey and protection of habitat should be promoted for active management to maintain the diversity of carnivores. The high density of tiger would drive the first trophic to human interfering habitat in search of prey and possible conflicts.

Carnivore guild and their prey requirement should be regularly monitored to suggest active management and mitigate human wildlife conflict (present and probability).

INTRODUCTION: The mammalian carnivores are found to be the major determinants in structuring of the trophic levels (Terborgh et al 1999, 2001 Sinclair et al 2003, Palomere and Caro 1999), by their interaction of apex predator and mesopredator (Johnson 2010, Crooks and Soule 1999, Elmhagen 2007). By controlling meso-predators, which are generally generalist species and cause over-predation of prey, the apex predator indirectly protects biodiversity (Johnson 2010, Prugh et al 2009). The direct effect of top predator on meso-predator and prey has been well studied by the top-down regulation of school of thought. The exploitative ecosystem hypothesis by Oksanen & Oksanen (2000) studied the top down effect with the contribution of productivity in the mechanism. A study by Elmhagen et al (2007,2010) in support to this concluded that ecosystem productivity sets an upper limit on impact by declining top predator on the lower trophic. Though understanding the mechanism and dynamics to predict pattern in food web Network theory approach has been proffered to be the best approach (Ings *et al*.2009) as top predator affect its prey, meso-predator and their prey as well as competition among mesopredator (Johnson 2010).

Aldo Leopold in A Biotic View of Land (1949) mentions in case of "termination of Top predator, food chains are made shorter than longer". Though not used as a term per se, the top-down and bottom up approach as well as consequences of loss of top predator as trophic cascade was proffered by Aldo Leopold in his essay The Land Ethics (1949). His writings indicate the importance of top predators in an ecosystem (Thinking like a Mountain, 1949). He mentions the control by predator, deer irruptions and over-browsing and the adverse effects on vegetation in absence of top predator in A Sand County Almanac (1949) and thus consequences of loss of predator which we today call Trophic Cascade (Paine,1980).

Trophic cascade has been defined as "Reciprocal predator-prey effects that alter the abundance, biomass or productivity of a population, community or trophic level across more than one link in a food web (Pace, 1988)" and propagation of indirect mutualism between non-adjacent levels in a food chain (Persson,1999)" and has been considered as one of the fundamental way in which consequences of the loss of top-down regulation occur, other being Competitive exclusion (Holt,2000). Trophic cascade has mention in the tri-trophic Green World Hypothesis (Hairston, 1960) which was later modified in one to five trophic levels in Explotative Ecosystem Hypothesis (Fretwell,1987).

The Exploitative Ecosystem hypothesis (Oksanen & Oksanen 2000) studied the mechanism of top down control with productivity affecting the mechanism. Accordingly, herbivore population is too sparse in unproductive environment to support predators. Hence productivity increases the predator population but since herbivore population is constant resulting increase in plant biomass with increase in productivity which results in Green world of Hairston (Johnson 2010).

In terrestrial system cascading effects are focused interactions within subset of population (Schmitz et al. 2000).Community level interactions are difficult to study in terrestrial systems as the habitat are heterogeneous with fuzzy boundaries, there are variable prey population dynamics and the prey not being uniformly edible to single consumer, the system are reticulate and complex and interaction between species tend to be weak and diffuse (Polis, 2000)

Terrestrially, trophic cascades with top-down dominance are restricted to systems of low species diversity. Schmitz found out that the magnitude of effect of predator removal on plant damage was greater in systems with low herbivore diversity. A more recent term to describe such phenomenon is ecological meltdown (Terborgh, 2001); is a consequence of fundamental and dramatic changes to ecological communities in fragmented habitats driven by disruption of ecological interactions through the losses of species with higher trophic roles. The removal of higher trophic level result in increase in prey population or reduction in prey population if predator population is increased, mortality is largely or completely due to predation, indirect response at the plant trophic level resulting in predator number change.

The reduction or loss of apex predator from an ecosystem bring trophic cascade or ecological meltdown (Terborgh et al 2001), the consequences of which are seen as ecological imbalance, the loss or restructuring of ecosystem as well as economic (Myers et al 2007) and social harm

(Brashares et al 2010, Prugh et al 2009). Top predator has been proved to play crucial role in maintaining the community structure and composition (Rogers and Caro 1998, Crooks and Soulé 1999, Schmidt 2003). Top predator can limit meso-predator abundance directly (interference competition and predation) and indirectly (behavioral avoidance and displacement). The process of lower trophic regulation by top predator has mesopredator release and intraguild predation theories, the former being result of latter or can occur independently (Barton 2003). Both these theories (MPR & IGP) suggest trophic interaction to be indirect and non-linear. In a Predator Prey system both MPR and IGP occur (Palomere et al 1995) as in Top predator (limited by competition), mesopredator (limited by predation and competition) and prey (limited by predation); though the indirect effect on vegetation by top predator is a debated question (Paine 2000, Polis et al 2000, Schmitz et al 2000). The effects of trophic cascade through nutrient deficiency have been shown by Croll et al 2005 and willow plant release by wolf reintroduction shown by Ripple and Beschta 2003.

The removal of top predator has caused cascade in trophic as shown by deer irruptions (Leopold 1949, Rooney et al 2003), growth of balsum fir (McLaren & Peterson 1994), and suppression of woody plant recruitment (Terborgh et al 2001), restructure the plant diversity and pattern of forest regeneration (McLaren & Peterson 1994, Ripple and Beschta 2008), reduction in bird population (Crooks & Soule 1999, Rogers and Caro 1998, Berger et al 2001). Cascade by Dingo, a top predator, has found to affects the population of Feral cats and foxes negatively and terrestrial marsupials positively (Johnson et al 2006). Similarly, Coyote has found to affect the mammalian mesopredators negatively while birds and rodents positively (Roger and Caro 1998, Henke and Bryant 1999). By resource felicitation, reintroduction of wolves in Yellowstone National Park promoted scavenger population (Wilmer et al 2003, Sergio et al, 2008).Top predator act as biodiversity regulator such as wolf (Miller et al 2012, Ripple and Beschta, 2011, Beschta and Ripple, 2007) and Dingo (Lentic et al 2011, Dickman 2009) have been established. The loss of top predator leads to biodiversity loss (Terborgh et al 2001, Estes et al 2001. Ale et al 2008) as a study in Venezuelan lake concluded that extinction of predator led to 100-fold increase in herbivore density (Terborgh et al 2001, Sergio et al.2008). Also, it is worth mentioning that the species richness of predator assemblages is indicator of their prey richness (Begon et al 1990).

The carnivores being at the apex of their food chain have complex interactions with their habitat and other species including their prey; hence their distribution cannot be affected by one factor (Campbell, Kotler and Brown 1988). The many interacting factors affecting the dynamic structure of the community, function and respond at different scales making the study of community difficult (Booth et al 2002, Menge and Olsen 1990). Understanding of a community requires an “assembly rule” framework instead of reductionist approach (each component of community studied separately to scale up to understand community as a whole) or holistic approach (where community is treated as one entity); in both the latter cases, loss of information occurs (Booth et al 2002). The “community assembly rule” framework helps in understanding “how” community assemblage occurs from the species pool (Keddy and Weiner, 1999). The main structuring force identified for the species co-occurrence rules are argued by some as biotic components only (Diamond 1975, Wilson and Watkin 1994) while others point out that both biotic and abiotic components work behind these rules (Keddy 1989, Roughgarden 1989, Booth and Larson 1999).

The current study was undertaken with an **AIM** to understand the role of tiger in top down control of carnivore community across the gradient of tiger density. The study was undertaken in central Indian landscape which presents various scenario of tiger density. The role of dominant predator in the context of mesopredator release has been studied mainly in three chain ecosystems. However, in a four-chain ecosystem the top predator is found to facilitate the abundance of most sub-ordinate predator (Yiwei Wang, Levi and Wilmers 2012). In the central Indian landscape, the sympatric predators are Tiger, leopard, dhole, hyena, golden jackal, and small predator. In this study the predator is grouped on the basis of body size. The **top predator/ alpha predator** is considered for the **body size greater than 150 kg,** the sub-ordinate predator/ **beta predator** is considered for the body size between **20-150 kg** and the **meso-predator** is considered for body size **less than 20 kg** (Fig 1.).

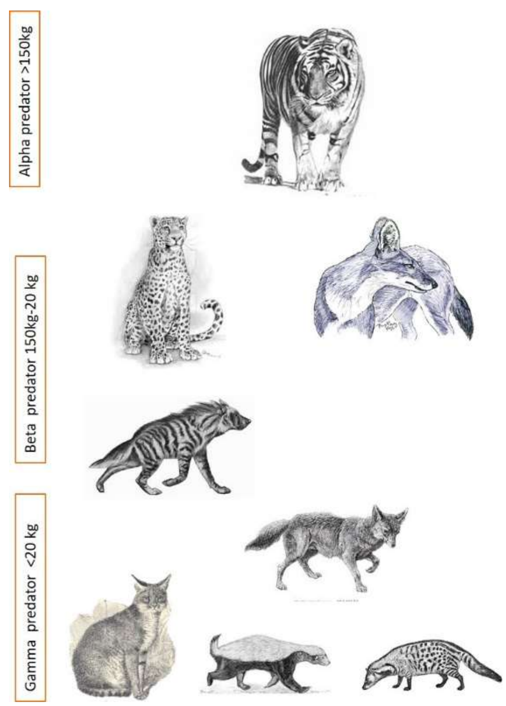


Figure 1.1 Categorization of study species according to body size

Table 1.1 The body weight of carnivores of central Indian landscape

	Body weight (averaging of min-max. Ref Vivek Menon)	
Species	**Male**	**Female**
Tiger	218	130
Leopard	61	38
Dhole	17.5	11.5
Hyaena	34	30
Sloth bear	57.5	72.5
jungle cat	4	
fishing cat	10.5	
rusty spotted cat	1.6	1.3
Jackal	8.7	7.15
Small Indian Mongoose	0.75	
Ruddy mongoose	2.5	
Grey Mongoose	1.4	
Fox	2.95	
Common Palm civet	3	
Small Indian civet	3	

Hypothesis: A greater segregation would be observed amongst the interfering species in important dimension of ecological niche (habitat, food and time).

The body size is considered to have an impact on the sympatric carnivores where the sub-ordinate carnivore would avoid the dominant one in any or all of the ecological niche i.e. habitat, food and time.

In the central Indian landscape, the tiger being the largest predator would suppress the activity of beta predator i.e. leopard and dhole which in turn would suppress activity of meso-predator. Hence Tiger abundance should facilitate the activity of meso-predator (Figure 1.2).

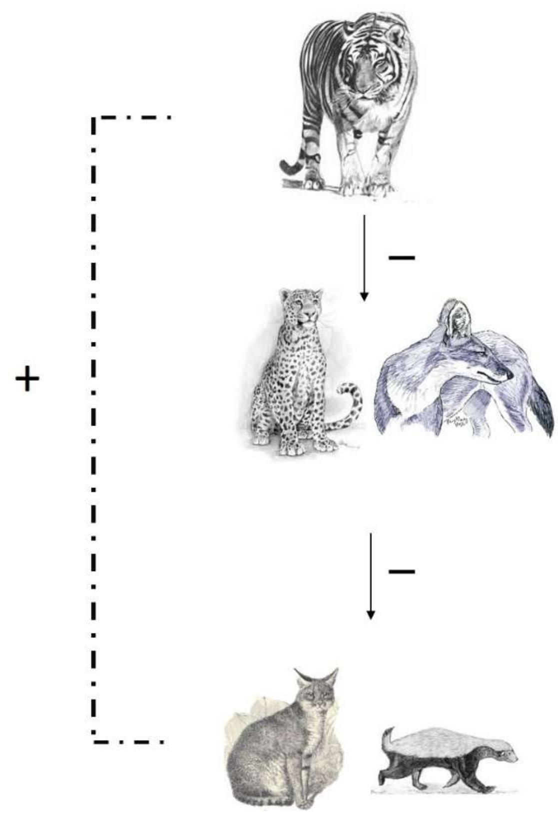


Figure 1.2. Graphical representation of Hypothesis

Objective:

The two objectives which were undertaken for the study:

1. To estimate the degree of inter-specific overlap in habitat use and activity pattern of carnivore across the three trophic.
2. To estimate spatial segregation in carnivore due to habitat heterogeneity

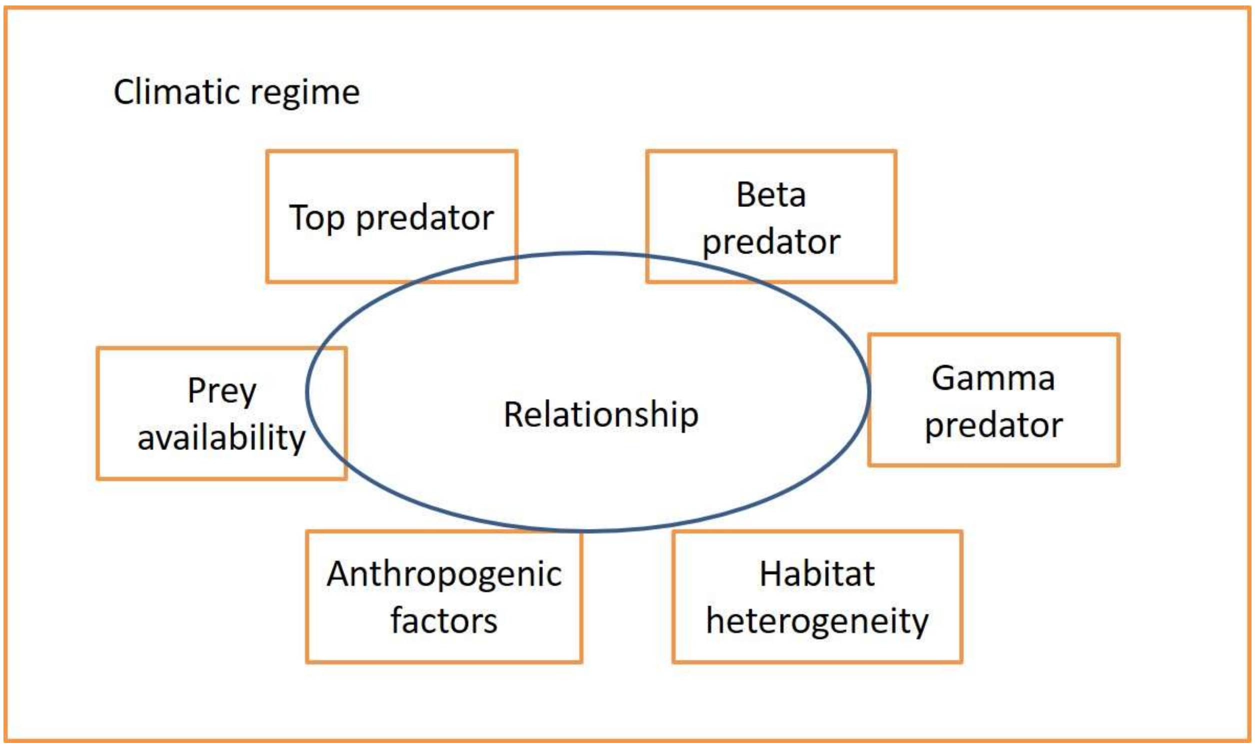


Figure 1.3. Graphical representation of Objective

The monitoring of carnivore community at local scale has been done worldwide but to conclude what factors actually affect the carnivore assemblage, both spatially and temporally monitoring will be appropriate. The large carnivore distribution has been reduced considerably by habitat fragmentation and human pressure (Sunquist and Sunquist 2001). The multitude interaction of carnivores enhances the importance of conservation of community of carnivores. The species-specific and ecosystem-specific conservation planning have gained much attention in conservation of carnivores but there is a dearth of community–specific information and research of the same. The ecosystem-based conservation planning help to understand the interactions between species affecting the single species viability. Similarly, species-based conservation planning helps to understand the species interaction with its surrounding though within its community is not addressed in particular. The mesocarnivore whose distribution may widely be affected not only by habitat, anthropogenic effects but also by carnivore community interaction cannot be monitored over large scale due to logistic constraints and elusive nature of the species.

Literature review/ Meta-analysis in support of the hypothesis

↓

Camera-trap protocol for data collection (All India Tiger Monitoring 2014)

↓

Relative Abundance Index for seven species in all study area

↓

OBJECTIVE 1: SPATIO-TEMPORAL ANALYSIS

Tiger and leopard Analysis for all study area

- Leopard identification for all study area through novel method (Hotspotter)
- Temporal analysis and overlap (Overlap package in R used)
- Species interaction through single-species and multiple species occupancy

- Temporal overlap amongst all three trophic in all study area (Overlap package in R used)
- Species interaction between trophic single-species and multiple species occupancy

OBJECTIVE 1: DIET PARTITIONING

Diet Analysis for first and second trophic for study area

LIMITATION OF DATA (LESS SCAT FOR TIGER GRADIENT STUDY AREA). Couldn't be undertaken

OBJECTIVE 1: SEGREGATION DUE TO HABITAT HETEROGENEITY

Habitat heterogeneity analysis for all trophic for tiger gradient study area and across landscape.

LITERATURE REVIEW

(Top down control in Ecosystem)

Top-down regulation: Top down means species occupying the higher trophic level exert a controlling influence on the species at the next lower trophic level (Holt, 2000). It includes predation and herbivory. Primary produces will be resource limited in chains that contain odd numbers of trophic levels and consumer limited in habitats that contain an even number of trophic levels. Oksanen et al. (1981) argued that effective top-down forces are only likely to occur in habitats with high primary productivity, since low productivity habitats do not have functional upper trophic levels.

Top-down regulation has been found to be controversial (Pace et al 1999) as bottom up effect contributed by land transformation as well as ecological communities' dependency on ecosystem productivity has not been taken into account to study the top-down regulation by top predators (Litvaitis & Villafurte 1996, Oksanene & Oksanen 2000).

Bottom-up regulation (donor control) (*Power 1992*, *Strong 1992*): Organisms at each trophic level are limited by resources from trophic level below and hence plants have primacy in biotic systems because if no primary resource then trophic structure cannot be formed. Bottom up regulation is driven by energy moving from plants to herbivore to carnivore up the food chain (*Holt, 2000*).

Density dependent mortality is caused by lack of food, density dependent reduction in the instantaneous rate of increase in absence of predation, little or no response in the prey population because the latter is regulated from below.

Though according to Brian Miller and David Brower, both top down and bottom up operates simultaneously, especially in terrestrial ecosystem, where there is no clear pattern for which of the bottom up or top down trophic cascades operates. *Gripenberg and Roslin (2007)* consider it scale-dependent.

Diversity in the prey trophic level can at times moderate top-down control (Leibold 1997, Stachowicz,2007). Diversity in predator level can either increase top-down effects, niche complementarity, (Straub & Snyder 2008) or weaken them , intraguild predation and interference between predator species is strong, (Stachowicz et al 2007).Interference competition (Intraguild predation, Kleptoparasitism at carcasses) has been observed to have a greater affect than exploitative competition (Linnel and Strand,2000, Palomere and Caro 1999,, Seleni ,2007).

The consequences of mesopredator release and importance of top predator has been realized for conservation purposes and the appropriate management interference have been undertaken which had been positive as well as negative in long run e.g controlling exotic rodents by feral cats to conserve endangered kakapo (*Strigops habroptilus)* (Courchamp et al. 1999),to protect sea egg turtles, control of raccoon*(Procyon lotor*) was undertaken which resulted in release of another predator ghost crab *(Ocypode quadrata*). These management induced steps have resulted in economic losses also as in case of Bhutan, persecution of dholes was undertaken to save livestock but it resulted in increase in wild boar hence more crop raiding and loss of agricultural fields (Wangchuk 2004). Similarly, game hunting is also affected by reduction or increase of apex predator e.g. in North America drop in coyotes has a positive attitude for antelope hunters and sheep ranchers and return of wolves has negative attitude with elk hunters and cattle ranchers. The reduction in great shark led to ultimate reduction in bay scallop to the limit that the scallop industry need to be closed resulting in big blow to livelihood as well as economic loss of nation (Myers 2007).The social impact of loss of top predator has also resulted spread of diseases and change in living condition of people apart from change in attitude e.g. reduction of lion and leopard resulted in olive baboon release which is comparatively more human interacting species and hence more crop raiding and spread of diseases in humans and also the children had to leave school to guard the agricultural fields (Brashares et al 2010). The invasion by exotic species is also one of the major concerns of biodiversity conservation e.g. on Finnish island loss of white-tailed sea eagle resulted in invasion by American mink.

Top carnivore and human dimension

The impact of loss of top predator is not only visible on the ecosystem of which they are integral part of but direct and indirect vagaries of human environment. The mesopredator release often results in abundance of meso-carnivores which are much harmful to humans because of their niche proximity to human habitation. Apart from economical loss (direct effect by crop raiding) sociological loss has been observed (indirect effects like spread of diseases, reduction in education status of the community). The closing of cottage industries (e.g. bay scallop industry) not only give a blow to economy of nation but also in paucity of alternate livelihood option brings other unforeseen effects of unemployment. Since the top down effect of top carnivore which presents them in foreground as biodiversity regulator, many forest dependent options of livelihood are also affected. The irruption in ungulate population affects regeneration adversely. Many industries based on forest products supporting the economy as well as livelihood option is wrongly affected can be called as one of the consequences of loss of top predator.

The biodiversity conservation and monitoring department across the world is regularly updating the protocols and interventions but at the same time invasion by exotic species in the event of loss of native top predator requires new management protocols which are time and money consuming. It has been posited by many researchers that the loss of apex predator result in mesopredator releases and the costs of management intervention to control the economically threatening (Berger 2006, Baker et al 2008) mesopredator is higher than compared to the introduction of apex predator (Prugh 2009). The loss of apex predator causes trophic cascade due to disruption in predation and hence reintroduction of predator is very crucial in conserving biodiversity as well as restoration of habitat (Estes et al 2011).

Table2.1: The examples of trophic cascade through apex predator in various ecosystems, top down regulation and through resource regulation by bottom up regulation:

S.No.	**References**	**Top predator status**	**Effect of trophic cascade**	**Process**	**Mechanism**	**Additional process**	**system**
1	Leopold 1943	Eradication of wolf	Irruption of kaibab deer	Predation	Top down regulation		Natural
2	Hall et al 1970	Increase in nutrients	Fish population increases	Resource driven	bottom up and top down		Natural experiment
3	Hurd et al 1971	Fertilizer increased	Stability of herbivore and carnivore increases		Bottom up and top down	Effect seen at higher trophic level	Experiment
4	Morse 1974	Tiger presence	Reduction in niche breadth of leopard	Interspecific competition			
5	Kajak 1981	Reduction on primary productivity	Increase in spider biomass	-	Predation on detrivorus and fungivores reduces primary		experiment

					productiv ity		
6	Davidson and Potter 1985	Fertilization of fescue turf	Staphylinid beetle increase but none of another major predator		Effect not seen on higher trophic predator universally	Bottom up	Experiment
7	Major et al 1987	Presence of Coyotes	spatial avoidance by red fox	Interference competition			
8	Litvaitis et al 1989	Increase in abundance of Coyote	reduction in Bobcat population	Exploitative competition			
9	Marquis & Whelan 1994	Presence of passerine birds	Limiting arthropod herbivore; decrease in leaf loss and hence increase in leaf biomass of oak forest	Predation	Top down regulation		Experimental

10	Palomere et al 1995	Abundance of Iberian lynx	limitation to mongoose, Rabbit increase	Intra-guild predation			
11	Palomere et al 1996	Iberian lynx home range	Egyptian mongoose and genet avoided lynx habitat	Intra-guild predation			
12	Schmitz et al 1997	Presence of spider	Grasshopper change in habitat use and foraging activity	Trait-mediated response of prey (predation)	Top down regulation		Experimental
13	Estes et al 1998	Scarcity of prey in marine system	Killer whale prey on another predator sea otters	Differential predation		Natural	
14	Dyer and Latourneau 1999	Addition of *Tarosbaenus letourneauae(beetle)*	Reduction in *Pheidole bicornis (Ant)* increase in herbivory by *Piper cenocladum* and hence reduction in	Predation	Top down control		experimental

			leaf area of Piper.				
15	Wise and Chen 1999	Increase in detrital inputs; increases collembolan and fungivores	Spider density increases	Resource driven	bottom up		Natural experiment
16	Courchamp et al 1999	Feral cats	limit exotic mesopredator rodents, Increase in kakapo	Intra-guild predation			
17	Crooks and Soule 1999	Presence of coyotes	Suppression of mesopredator and increase in scrub breeding birds	Intraguild predation and mesopredator control			
18	Kitchen et al 1999	Presence of Coyotes	temporal, spatial overlap. Segregation on basis of	intraguild predation			

			diet. High mortality of swift fox by coyote				
19	Berger et al 2001	introduction of wolf	Decline in moose; recruitment of riparian vegetation; increase in riparian birds	Predation	Top down regulation	Trophic cascade at different levels	Natural
20	Terborgh et al 2001	Absence of top predator	Invertebrates, seed predators, herbivores 100 times more from predator present island; seedling and sapling reduced considerably	No predation	Absence of Top-down regulation		Natural experiment
21	Ripple & Beschta 2003	Extermination of wolf	Increase in elk population, decrease in	No predation	Absence of top down	Trophic cascade at	Natural

			willow recruitment		regulation	herbivore level	
22	Wilmer et al 2003	Reintroduction of wolf	Increase in scavenger population	Resource facilitation; carrion availability	Top-down regulation		Natural
23	Gruner D.S. 2004	Exclusion of bird	Increase in spider number	Predator control;	Top down regulation in higher trophic	Bottom-up regulate the forest	Experiment
24				Meso-predator release			
25	Croll et al 2005	Introduction of arctic fox	Decrease in seabird (guano decrease); grassland to shrub vegetation conversion	Predation	Top-down regulation	Nutrient transport major source of change	Natural
26							Experiment
27	Mitchell et al 2005	Presence of wild dog	temporal avoidance/ localized habitat shifts by fox	Intraguild predation	Top down regulation		

28	Helldin et al 2006	Presence of Lynx	Partial decrease in red fox population	Intraguild predation	Top down regulation		
29	Glen et al 2007	Reduction in dingoes and feral dogs	Increase in fox population	Intraguild predation	Top down regulation		
30	Berger et al 2007	Presence of wolf	Limitation to presence and abundance of coyotes	Intraguild predation	Top down regulation		
31	Figueredo et al 2007	Tilapia fish increases the nutrients through excretion	Phytoplankton biomass increases		Bottom up regulation because of nutrient driven; selective foraging by fish affect the plant community hence	Bottom up and top down	experiment

					top down also		
32	Letnic et al 2008	Presence of Dingoes	reduction of red fox, increase in rodents	intraguild predation			
33	Trewby et al 2008	culling Eurasian badgers	Increase in red fox	intraguild predation	Top down regulatio n		
34	Johnson et al 2009	Presence of Dingoes	Decrease in abundance of red fox	intraguild predation	Top down regulatio n		
35	Wang et al 2009	Tiger presence	leopard habitat usage did not overlap with tiger	Habitat preference	Top down regulatio n		
36	Hayward et al 2009	Lion and spotted hyena	temporal avoidance by wild dog and cheetah	Interferenc e competitio n	Top down regulatio n		
37	Brashare s et al 2010	Decimated lion and leopard	Primate meso-predator Olive baboon	Meso-predator release	Top down regulatio n		

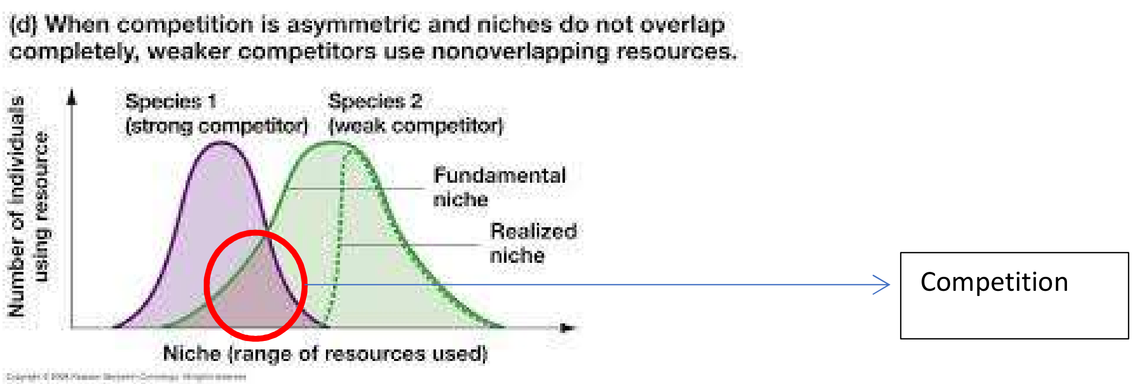
			increase; reduction in ungulate population				
38	Cupples et al 2011	Presence of dingoes	Suppression of fox population, increase in small prey	Intraguild predation and dietary competitio n	Top down regulatio n		
39	Harihar et al 2011	Increase in abundance of tiger	shift in habitat usage and diet in leopard	Intraguild predation	Top down regulatio n		
40	Viota et al 2012	Iberian lynx home range	shift in microhabita t use of Egyptian mongoose	Intra-guild predation avoidance	Top down regulatio n		
41	Mondol et al 2012	Reintroduction of tiger	Spatial and temporal avoidance by leopard	Intra-guild predation avoidance	Top down regulatio n		
42	Bhattara i et al 2012	Tiger presence	Leopard diet have more of small sized prey	resource partitionin g	Top down regulatio n		

43	Swanson et al 2014	Increase in African lion population	local extinction of wild dog	Intraguild predation	Top down regulation		
44	Gordon et al 2015	Dingo presence	restriction to feral cats; abundance of rodents and its foraging efficiency	Intra-guild predation avoidance	Top down regulation		
45	Wang et al 2015	Puma occupancy	spatial and temporal segregation due to coyote activity which in turn by Puma activity	Intra-guild predation avoidance	Top down regulation		
46	Allen et al 2016	occurrence of Puma	subordinate fox uses dominant Puma scent to avoid Coyotes	behavioral cascade	Top down regulation		

47	Sugimoto et al 2016	Presence of Amur tiger	Leopard have wider niche breadth	Niche partitioning	Top down regulation		
48	Groom et al 2016	increase in Lion population	Reduction in pup to adult wild dog ratio, Shift in habitat usage	Intra-guild predation	Top down regulation		

Competition due to body size

Co-existence of species has been well studied (Holt, 2001, Hutchinson 1959). The constraints of co-existence were presented by competitive exclusion principle assumption being species are affected by single limiting factor and interact in closed habitat. Competitive exclusion principle states that two competing species coexist in a stable environment by niche differentiation, in absence of which one competing species will eliminate or exclude the other (Begon et. al. 1996).

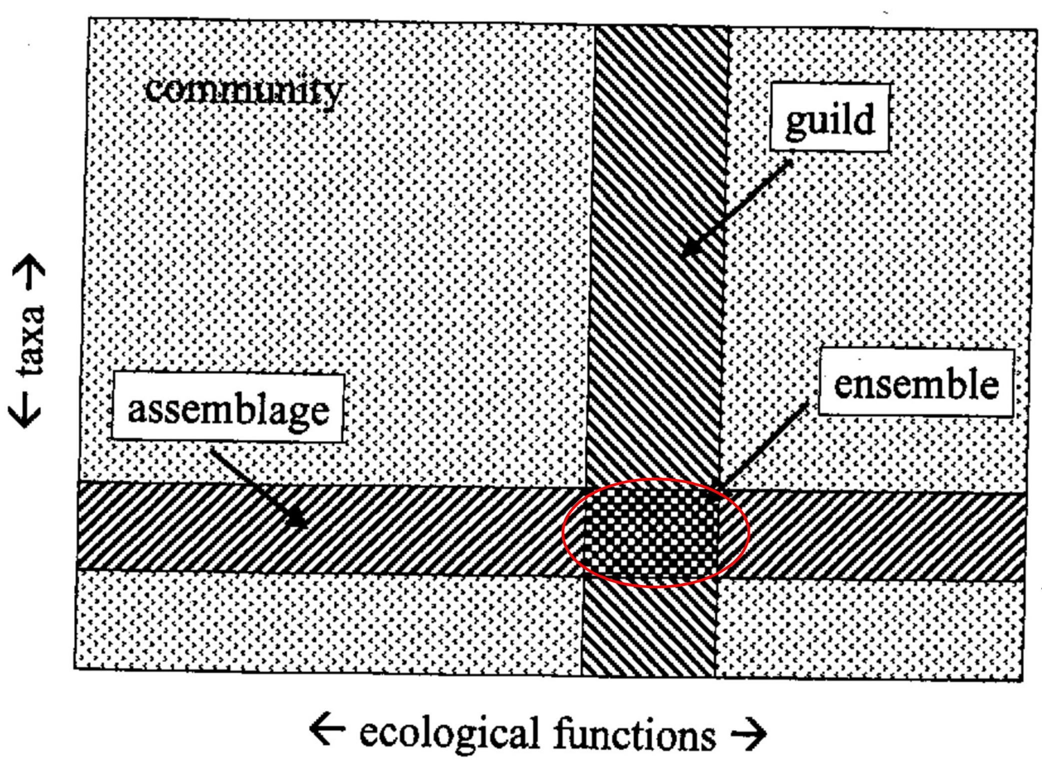


Species to co-exist, they must have different ecologies. The co-existence is unlikely with ecologically similar species.

According to Volterra Gausse Principle, **(natural selection + isolation) + mutual invasion of ranges = evolution of sympatric species**

Now in a space the sympatric species co-exist by avoiding competition. The many factors playing role in co-existence of species (in a way avoidance of competition), mainly falls under heading

1. Evolutionary (Body size, developed sensory organs, evolved beak)
   Difference in beak size of Galapagos finches directly translates to difference in diet; hence they survive in the island as their limiting factor (resource) was different (Peter Grant, 1986).
2. Spatial separation
3. Temporal separation
4. Resource separation
5. Adaptation (foraging tactics)
6. Environmental effects



Conceptual partitions of an ecological community (after Fauth et al 1996)

Does this mean that species cannot co-exist having same taxonomic position and having same ecological function?

Terrestrial carnivores play a crucial role in top down regulation. They exist at the same local scale. Body size as proposed by Hutchinson may be an important aspect in these carnivores' dynamics.

Hutchinson seminal paper "Homage to Santa Rosalia or Why are there so many kinds of animals?"

Hutchinson 1959: *size ratio of co-existing species is 1.3 which is "an indication of the kind of difference necessary to permit two species to co-occur in different niches but at the same level of a food-web".*

Hutchinson & MacArthur 1959 *: a size ratio of 1.3 between sympatric forms " would ordinarily prevent complete competition between species"*

According to Hutchinson, different size forms available to avoid competition.

Schoener 1965,70,74): In scarcity of food species size must be more different, the contiguous size ratio increasing while going up in size scale.

MacArthur 1972: *large species will be more widely separated from their neighbors on a size sequence than small species on a logarithmic scale the species will be evenly spaced.*

Diamond 1975: *developed an approach competitively driven constraints on size spacing only combination of species occur in "minimal spacing".*

Pulliam 1975*: Constant average bill size ratio can predict the bill size ratio of a bird which can co-exist with them.*

Simberloff & Boecklen 1981: *criticized Hutchinson ratio for not supporting the data with statistical proof for his claim of minimum size ratio amongst the co-existing species and also size ratio to be constant amongst the co-existing species pairs. It was a deductive analysis stating that the size difference occur to avoid competition. Even variable tested is different for different species* *like for birds Diamond (1972) gave weight ratio, Hutchinson (1959) culmen length ratio and Grant (1968) bill length and wing length.*

Thus even if we ignore the criticism faced by "Hutchinson Rule", there is no denying that *species size differ by minimum amount because of competition*. As is observed in ecosystem, the process which operates in the co-existence of species has two basic approach: interference (behavioural interaction like predation, also subordinate species change their habitat usage) and exploitative (indirectly through consumption of shared resource). Interference competition is detected in the nature but exploitative is the underlying slow process which leads to extinction and evolutionary divergence (Krebs 1994). It was observed by Palomere and Caro 1999 competition, especially interference, can change community structure and can cause extinction (Linnell and Strand 2000).

The carnivores are generalist as well as specialized with respect to niche. Direct interference (Intra guild predation) has been reported in the genera. Tiger predation on leopard in Chitwan NP (Seindensticker, 1976), Bandipur TR(Johnsingh, 1979,1992). Tiger predation on dhole is reported from Nagarahole National Park (Karanth & Sunquist 2000). As Odden et al. (2010) puts it "Low abundance of large ungulate prey decreases foraging efficiency of tigers, leading to increased energetic stress and aggression towards leopards; and increased diet overlap due to scarcity of large prey leads to increased encounter rates and increased levels of interference competition."But fight between dhole and tiger for resource has also been reported (Tiger wounded and left chital kill because of dhole pack, H. Khajuria,Lt Col R.W.Burton). Leopard predation on dhole reported from Bandipur (Johnsingh 1983, 1992) and Nagarahole (Karanth & Sunquist 1995).

The different ecologies of various carnivore support co-existence as in case of wolf and dhole. Wolf is adapted to arid open environs whereas dholes prefer closed forest type, dholes largely diurnal whereas wolves nocturnal, Dholes thrive on wild prey while wolves on domestic livestock and wolves in and around inhabitation whereas dholes on less inhabitation (Johnsingh et al , 2000).

Small Indian mongoose prefers the human habitation? (as threat to be killed by domestic dogs are much more in these areas) or simply avoid the habitat of ruddy mongoose and grey mongoose? With grey mongoose it is not large difference in body size so interference will be more or exploitative competition? Identifying a niche is a **preference** or a **consequence of competition avoidance** for a species is required.

The animal which does not differ in body size has no competition? Small indian civet and common palm civet. Or is it plenty resource available and less food requirement does not allow the exploitative competition to be visible?

Hutchinson ratio are not applicable to many exceptions like civets and pack animals (dhole).

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The top down control in terrestrial ecosystem: a review to understand dominant predator effect on sub-ordinate predator.

Introduction:

Majority of papers address the top down control of predator in aquatic environment and effect on prey and vegetation in terrestrial habitat. Understanding the regulation of sub-ordinate predator by dominant predator in terrestrial environment is important to manage the ecosystem. The interaction in carnivore community is difficult to document in natural environment yet is an important aspect of carnivore conservation and management. The monitoring and maintenance of a) top predator prevent trophic cascade and mesopredator release, b) prey and habitat according to carrying capacity of carnivore guild helps in co-existence of sympatric carnivore, as well as in mitigating human-carnivore conflict. However, the studies oriented to understand relationship of top predator with sub-ordinate predator is limited and dominantly addressed in one of the three axis of niche partitioning (the diet, diel and habitat usage). The effect on mesopredator in abundance or absence of top predator is found to be patchily studied for major predator species across the world.

The importance of apex predator for regulation of an ecosystem in wildlife conservation ambit, was discussed more than half century ago (Leopold 1943,1949, Ripple et al 2005). The top down hypothesis or the cascading trophic interaction drew much of scientific community attention through 1940 to 1990s and in the context of three trophic (producer-herbivore-predator), elaborately in controlled lotic and lentic ecosystem (Hairston et al 1960, Carpenter et al 1985, Power 1992, Strong 1992). A review to understand the role of top predator on terrestrial ecosystem was done during these time (Terborgh et al 1999).The role of terrestrial top predator as umbrella species and effect on prey, vegetation and other communities like avi-fauna was also researched from late 1990s (McLaren & Peterson 1994, Rogers and Caro 1998, Crooks & Soule 1999, Terborgh et al 2001, Berger et al 2001, Rooney et al 2003, Ripple and Beschta, 2003, 2008).

In a Predator Prey system both Mesopredator release and Intra-guild predation occur (Palomere et al 1995) as in Top predator (limited by competition), mesopredator (limited by predation and competition) and prey (limited by predation); though the indirect effect on vegetation by top predator is a debated question (Polis et al 1999, Schmitz et al 2000). Also, the Optimal foraging theory doesn't link top predator with small sized prey, however the research development in top down control contradicted the theory (Palomere et al 1995, Courchamp et al 1999, Letnic 2009, Brashares et al 2010).

Since studies to understand trophic cascade due to elimination, decimation, reintroduction of top predator requires long-term data in natural eco-system, it is considered difficult logistically and being ethically challenging (Trewby 2007). However, due to elimination of top predator in natural ecosystem like wolf, dingoes and African lion provided such opportunity (Glen et al 2007, Berger et al 2008, Sinclair et al 2011, Ripple et al 2013). Experimentally certain studies prove individual behavioral shift in sympatric sub-ordinate predator due to top predator (Watt et al 2010).

The present literature review investigated the following question in a terrestrial top down control:

The effect on the lower carnivore community with Increase /Decrease in abundance and elimination/reintroduction of top terrestrial predator.

The web search was done with keywords “predator”, “predation”, “intra-guild predation”, “carnivore”, “ecological meltdown”, “trophic cascade”, “meso-predator release”, “trophic interaction”, “tiger”, ”leopard”, “wolf”, “leopard”,” lion”, “dingoes”, “reintroduction”, “extinction”, “terrestrial”.

Result:

The literature search for terrestrial carnivore top down control synthesized into 28 research. Multiple research from similar area especially oriented to fox, coyote was eliminated. Terrestrial predator effect on only herbivore and involving invertebrate predator was further eliminated from the synthesis. The top predator whose effect and regulation on lower trophic carnivore is observed in natural environment is tiger, wolf, lion, dingoes, lynx, coyotes, puma, badger and feral cats. Hypothesis of few of the individual studies on sympatric carnivore did not include to understand top down control and inter-specific competition. The studies which concluded niche overlap but no direct effect on subordinate predator by dominant predator was excluded from the following synthesis.

Table3.1: Effect of top terrestrial predator on lower carnivore community

S.No.	**References**	**Top predator status**	**Effect of Top-down control/ trophic cascade**	**Process**

1	Morse 1974	Tiger presence	Reduction in niche breadth of leopard	Interspecific competition
2	Major et al 1987	Presence of Coyotes	spatial avoidance by red fox	Interference competition
3	Litvaitis et al 1989	Increase in abundance of Coyote	reduction in Bobcat population	Exploitative competition
4	Palomere et al 1995	Abundance of Iberian lynx	limitation to mongoose, Rabbit increase	Intra-guild predation
5	Palomere et al 1996	Iberian lynx home range	Egyptian mongoose and genet avoided lynx habitat	Intra-guild predation
6	Courchamp et al 1999	Feral cats	limit exotic mesopredator rodents, Increase in kakapo	Intra-guild predation
7	Crooks and Soule 1999	Presence of coyotes	Suppression of mesopredator and increase in scrub breeding birds	Intraguild predation and mesopredator control
8	Kitchen et al 1999	Presence of Coyotes	temporal, spatial overlap. Segregation on basis of diet. High mortality of swift fox by coyote	intraguild predation

9	Mitchell et al 2005	Presence of wild dog	temporal avoidance/ localized habitat shifts by fox	Intraguild predation
10	Helldin et al 2006	Presence of Lynx	Partial decrease in red fox population	Intraguild predation
11	Glen et al 2007	Reduction in dingoes and feral dogs	Increase in fox population	Intraguild predation
12	Berger et al 2008	Presence of wolf	Limitation to presence and abundance of coyotes	Intraguild predation
13	Letnic et al 2008	Presence of Dingoes	reduction of red fox, increase in rodents	intraguild predation
14	Trewby et al 2008	culling Eurasian badgers	Increase in red fox	intraguild predation
15	Johnson et al 2009	Presence of Dingoes	Decrease in abundance of red fox	intraguild predation
16	Wang et al 2009	Tiger presence	leopard habitat usage did not overlap with tiger	Habitat preference
17	Hayward et al 2009	Lion and spotted hyena	temporal avoidance by wild dog and cheetah	Interference competition

18	Brashares et al 2010	Decimated lion and leopard	Primate mesopredator Olive baboon increase; reduction in ungulate population	Mesopredator release
19	Cupples et al 2011	Presence of dingoes	Suppression of fox population, increase in small prey	Intraguild predation and dietary competition
20	Harihar et al 2011	Increase in abundance of tiger	shift in habitat usage and diet in leopard	Intraguild predation
21	Viota et al 2012	Iberian lynx home range	shift in microhabitat use of Egyptian mongoose	Intra-guild predation avoidance
22	Mondol et al 2012	Reintroduction of tiger	Spatial and temporal avoidance by leopard	Intra-guild predation avoidance
23	Bhattarai et al 2012	Tiger presence	Leopard diet have more of small sized prey	resource partitioning

24	Swanson et al 2014	Increase in African lion population	local extinction of wild dog	Intraguild predation
25	Gordon et al 2015	Dingo presence	restriction to feral cats; abundance of rodents and its foraging efficiency	Intra-guild predation avoidance
26	Wang et al 2015	Puma occupancy	spatial and temporal segregation due to coyote activity which in turn by Puma activity	Intra-guild predation avoidance
27	Allen et al 2016	occurrence of Puma	subordinate fox uses dominant Puma scent to avoid Coyotes	behavioral cascade
28	Sugimoto et al 2016	Presence of Amur tiger	Leopard have wider niche breadth	Niche partitioning
29	Groom et al 2016	increase in Lion population	Reduction in pup to adult wild dog ratio, Shift in habitat usage	Intra-guild predation

Discussion:

The literature synthesis established top down regulation by predator in terrestrial ecosystem. The diversity in predator level can affect the intensity of top-down effects by niche complementarity or intraguild predation and interference between predator species (Straub et al 2008, Stachowicz et al 2007). However, such intensity observation is difficult for terrestrial mammalian predator due to their cryptic behavior. The terrestrial mammalian community studies mainly focus on three axes to understand co-existence of sympatric carnivores; The diet partitioning, the diel partitioning and the habitat partitioning. The body size decides the social dominance amongst predator and hence the sub-ordinate carnivore avoid the dominant predator on one or more of the above-mentioned axes. Studying the overlap between sympatric carnivore on any one of the three axes fail to highlight the top down control due to body size by tiger (Wang 2009, Sevlan, 2013, Lovari 2015, Sugimoto et al 2016). Where top down control and biodiversity regulation is reported for wolf (Beschta and Ripple, 2007, Ripple and Beschta, 2008), Dingo (Letnic et al 2012, Dickman 2009), lion (Sinclair et al 2010), it was observed that such studies lacked for tiger. The avoidance of tiger by subordinate predator leopard and dhole is reported (Morse 1974, Harihar et al 2011, Mondol et al 2012). The co-existence amongst tiger, leopard and dhole is driven by principal prey (Ramesh et al 2012) or habitat heterogeneity (Karanth et al 2000), large size prey density (Seidensticker, 1976), contradicts the theory of top-down control by tiger. The co-existence of sympatric carnivore is said to be facilitated by expulsion rate of subordinate predator by dominant predator (Seidensticker, 1976).

Apart from few, diversity of carnivore studies proffers that top down control regulates the carnivore communities. The mesocarnivore whose distribution may widely be affected not only by habitat, anthropogenic effects but also by carnivore community interaction cannot be monitored over large scale due to logistic constraints and elusive nature of the species. However, certain management intervention has been undertaken which had been positive as well as negative in long run e.g controlling exotic rodents by feral cats to conserve endangered kakapo (Courchamp et al.

1999), persecution of dholes was undertaken to save livestock but it resulted in increase in wild boar hence more crop raiding and loss of agricultural fields (Wangchuk 2004). The management of ecosystem can benefit from understanding carnivore community.

The social impact of loss of top predator has also resulted spread of diseases and change in living condition of people apart from change in attitude e.g. reduction of lion and leopard resulted in olive baboon release , more crop raiding and spread of diseases in humans and also the children had to leave school to guard the agricultural fields (Brashares et al 2010). The estimation and monitoring of carrying capacity of various trophic carnivore and their prey can involve timely managerial intervention. This would prevent dispersal of sub-ordinate carnivores to fringe areas of forest causing human wildlife conflict.

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Introduction of Central Indian Landscape:

The study sites are in Deccan peninsula biogeographic zone and 6A (Deccan Plateau South), 6B (Central Plateau) and 6E (Central Highlands) biotic Province (Rodger and Panwar 1988). The 6A Deccan Plateau have Central Eastern Ghats (NagarjunasagarSrisailam Tiger Reserve), 6B Central Plateau have protected areas of Maharashtra and Telangana (Kawal, Tadobaandheri, Nawegaon-Nagzira, Umred, Bor, Pench MH, Melghat) and 6E Central Highlands have Satpuda –Maikal(Satpuda TR) of the study area. The northern portion of the Deccan peninsula has a dominant Teak forests and also miscellaneous forests of series *Tectona-Terminalia-Anogeissus-Chloroxylon* (Nasulu et al 2000).

The study area is under category of Southern tropical dry deciduous forests (Champion & Seth, 1968). The forests can be teak bearing having association of *Anogeissuslatifolia* and Terminalia and Non-teak forests where dominant species is Anogeissus and Terminalia in association with Diospyros, Boswellia and Sterculia. The chief bamboo of the area is *Dendrocalamusstrictus*. The grasses are of medium height like *Heteropogon*, *themeda* and *Saccharamspontaenium*. The annual mean maximum temperature is 29°C -35°C and mean minimum is 18°C – 23°C.Typical annual rainfall is 1000-1300mm (the study sites precipitation table 4.1)

Table 4.1: Details of precipitation of study sites

District	**Study site**	**Precipitation (mm)**	**classification**	**Catchment**
Nagpur	Umred	1092	Aw	
	Pench MH			
Wardha	Bor	1018	Aw	
Gondiya	NNTR	1418	Aw	
Amravati	Melghat	808	Bsh	Tapti
Adilabad	Kawal	1101	Aw	Godavari
Kurnool	NSTR	659	Bsh	Krishna
Hoshangabad	Satpura	1214	Aw	Narmada

The river basin of study area as classified by Zoological survey of India is Godavari basin, Tapi basin, Narmada basin and Krishna basin; also subgroup of Ganga as Yamuna basin (Chandra et al 2010). The soil is sandy, lateritic and shallow clay. The catchment of major river like Tapti (Melghat TR) Narmada (Satpuda TR), Ken river (Panna TR), wainganga (Vidarbha), Pranahita (kawal TR), Krishna (NSTR) helps in irrigating the soil and vegetation of the area. The major river Godavari, Yamuna, Krishna, Narmada and Tapti face various ecological problems which in turn is faced by the forests too.

According to Dibadghao and Shankarnarayan 1973 classification of grassland, Central Indian plateau is*Sehima-Dichanthium* type of grassland. According to Wildlife Institute of India, only less than 1% of the grasslands come under Protected Area network (Singh et al 2006), understanding the other grassland carnivores is difficult for the study as camera-trapping was done in protected areas.

The history of human conflict with tiger and its habitat can be traced to initial issues of tiger conservation when in NSTR, 20 cases of tiger poisoning were reported and extensive forest fire in Melghat. The forests of central Indian landscape provide a major habitat for forests yet it is part of “schedule V area (primarily inhabited by tribals having little or no irrigation facilities” .The area is rich in mineral deposits but due to poverty driven society, it is highly prone to conflict with people (Narain et al 2005). During British era, the area was explored for vast timber wealth and was a major resource utilization centre (Forsyth 1871).

Kawal Tiger reserve in Adilabad still have patches of pristine teak forests. The landscape was rich in mammal biodiversity as Cheetah was found in the landscape till 1950's (Divyabhanusinh 1999). Wild buffalo used to cover whole of eastern part of central province, south of Narmada, plateau of Mandla and Godavari forests (Forsyth 1871). The wild buffalo is discovered in rock paintings of central India, and also many tribal and non-tribal worship "*bhainasur*" to protect their cattle from diseases (Tiwari 2000). The Asiatic lion was well distributed in central India (Nowell and Jackson, 1996) and further up to Bihar where last lion was killed in 1814 (Khoshoo, 1997).

The surviving species status is not good either. As Brander (1923) puts forth, Gaur or, "Bison appears to inhabit every part of India where he can find suitable condition". He wrote Gaur inhabits many parts of Vindhya Mountains and penetrates into hills of Chota Nagpur and Midnapur. But currently Gaur inhabits only certain protected area in central India. The habitat and connectivity degradation are making this large ranging mammal locally extinct from areas such as Bandhavgarh TR; where it was reintroduced (Jhala et al 2011).

However due to conversion of land historically for agricultural purpose (Brander 1923, Stebbing 1923, Champion 1934), as shifting cultivation by Gonds and Korku was quite common (Mukherjee 1984), it was predicted the higher extinction probability of grassland species like hyaena, wolf, chinkara, four horned antelope (Karanth et al 2010). The forests of deccan are under constant threat due to human disturbance (Rodger and Panwar 1988) (causes are natural gas exploration, iron and uranium deposits, hydroelectric projects etc). Due to strict laws and increased protected areas, the forest cover within Ministry remains conserved but outside forests are getting degraded (Agarwal et al 2016).

Panna tiger reserve has been since long affected by diamond and sandstone mines and the contamination affects Ken river. A part of Melghat Tiger reserve was de-reserved for dam construction and timber harvesting (Sampat 1998)

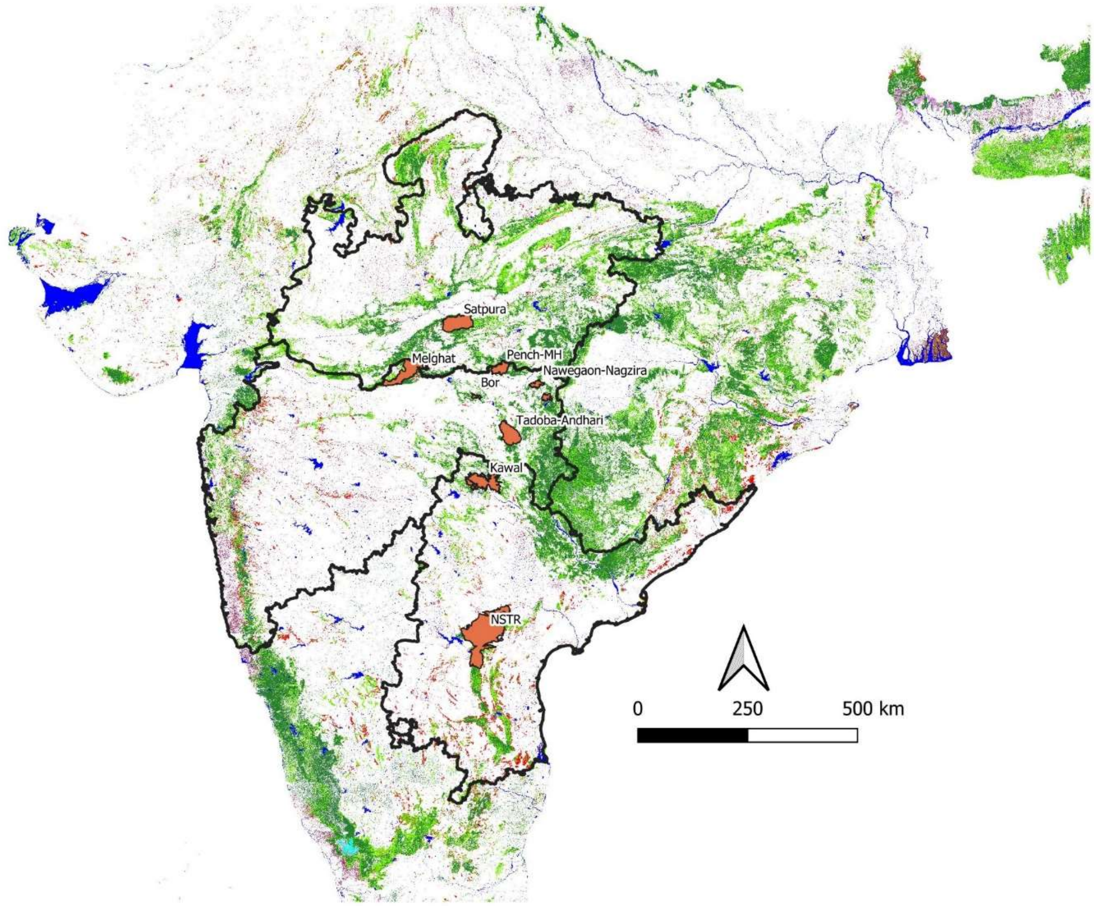

Figure 4.1. The study sites in Central Indian Landscape

4.1.Godavari basin and Eastern Ghats complex:

The study includes Nagarjunasagar-Srisailam Tiger Reserve in Andhra Pradesh and Kawal Tiger Reserve in Telangana from this complex. Kawal Tiger reserve is on the bank of Godavari and acts as sink for tigers of Tadoba-Andhari Tiger reserve, whereas NagarjunasagarSrisailamTiger Reserve is on the bank of river Krishna and is the largest tiger reserve of India. In the above-mentioned complex, four distinct tiger population were identified on the basis of connectivity (Jhala et al 2008); they are 1) Adilabad district 2) Karimnagar, Warangal and Khammam 3) East Godavari and Vishakhapatnam and 4) Nagarjunasagar-Srisailam.

4.1.1.Nagarjunasagar-Srisailam Tiger reserve

Administrative history: The NagarjunasagarSrisailam Sanctuary was notified in 1978 and has association with Project Tiger since 1983. It was remained as Rajiv Gandhi Wildlife Sanctuary in 1992. The history of this reserve is associated with the hunting ground of Princely state of Hyderabad (Management Plan, 1980). GundlaBrahmeswaram Wildlife Sanctuary as its extended core is one of the largest conservation landscape in the country with nearly 6000 sq.kms. In the memory of LateDr.Y.S. Rajasekhara Reddy former Chief Minister of Andhra Pradesh who died in the helicopter crash on 2nd September 2009 in the GundlaBrahmeswaram Wildlife Sanctuary (Nandyal Reserve Forest) (Management Plan ,1990, AP forest department report, ANNUAL ADMINISTRATION REPORTS FOR THE YEAR - 2010-11).

NagarjunaSagar-Srisailam Tiger Reserve (approximate area 4502.96 sq km) and Gundlabrahmeshwaram (GBM)(approximate area 1098.66 sq km) forms the Nagarjunasagar-Srisailam Tiger Reserve. The altitude of the reserve ranges from 500 to 850 m. The TR is traversed by several public roads and a state highway. The forest type in the TR is mainly southern tropical dry mixed deciduous forest (Champion and Seth 1968). The forest consists of miscellaneous timber species such as Nallamaddi (*Terminalia tomentosa*), Chirumanu (*Anogeissuslatifolia*), Bandaru (*Adinacordifolia*), Teak *(Tectonagrandis*), etc. Sandal wood (*Santalum album*) and a number of medicinal plants are also found and the TR has a variety of faunal diversity (Behera, 2010).
At the time of survey for the study, the Tiger reserve had 7 divisions i.e. Atmakur, Giddalur, Markapur, Nandyal, Achampet, Nalgonda, WL-sagar. The area sampled for current study was in Atmakur and Markapur division. However, forest department carried out camera-trapping in GBM which was analyzed separately for the study.

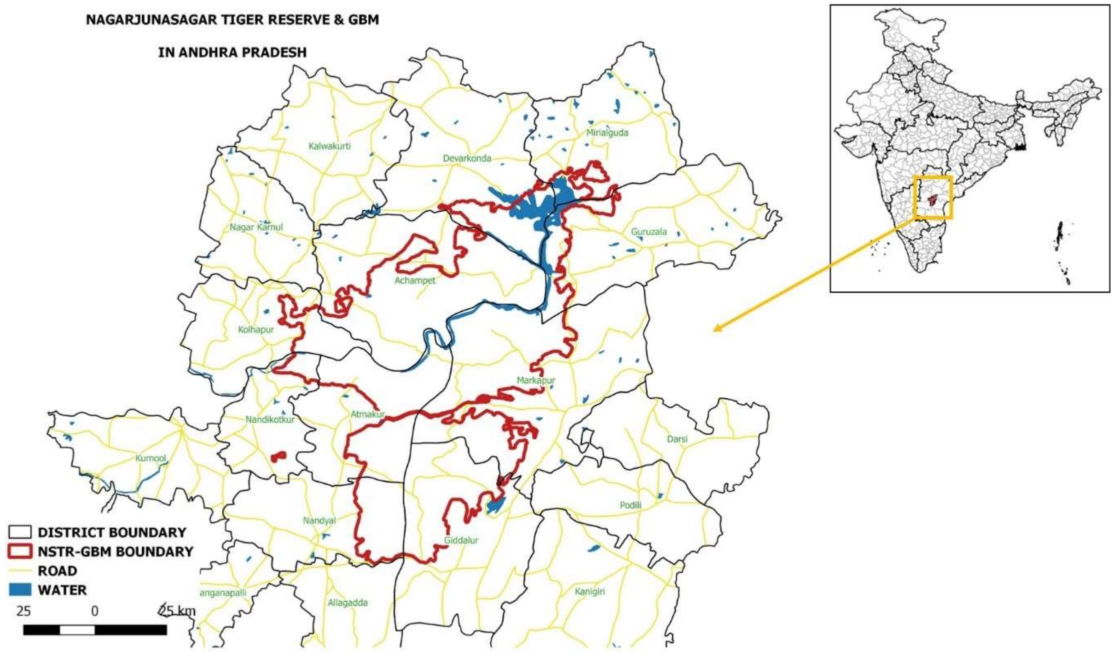

Figure 4.2.Location of NSTR-GBM

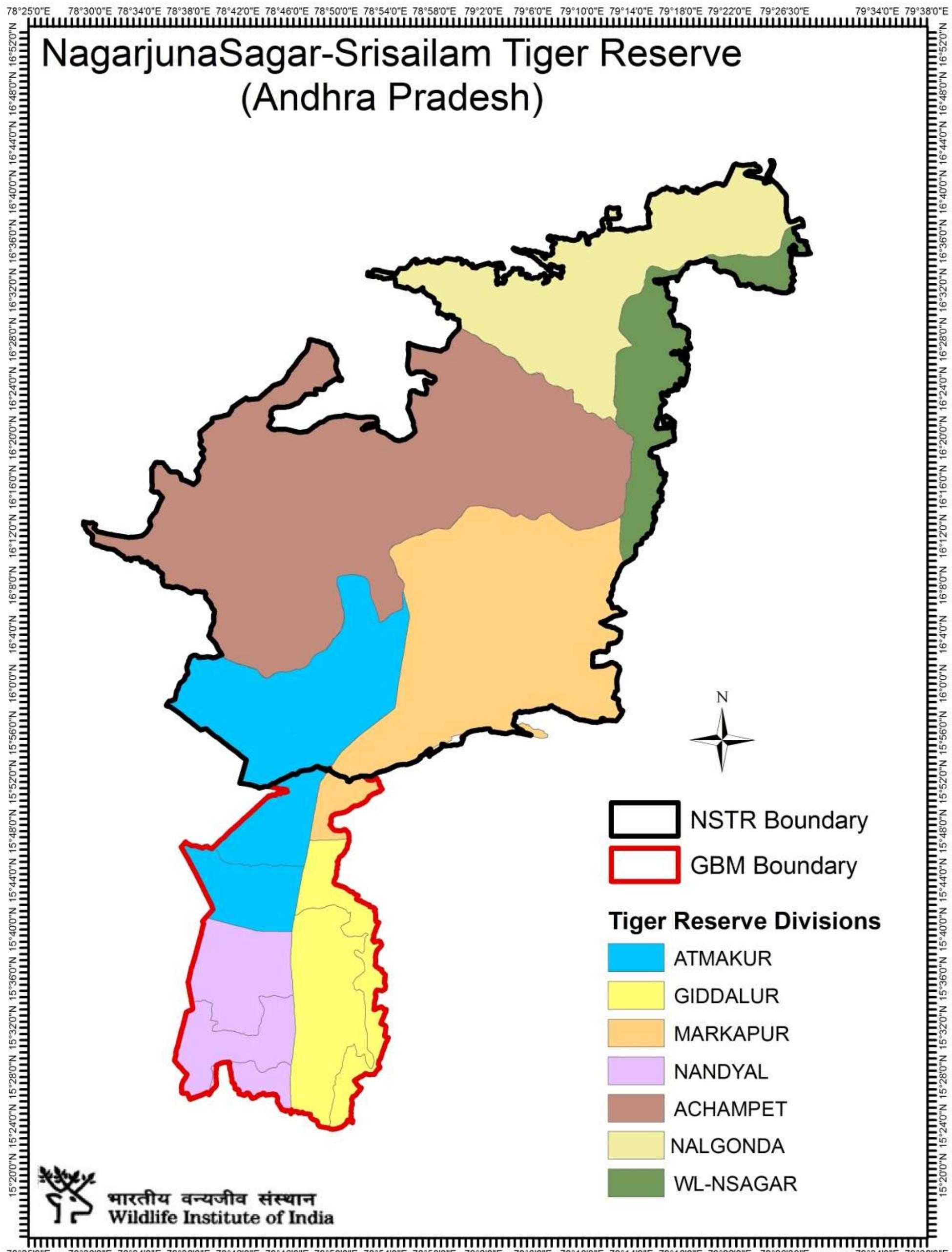

Figure 4.3 Details of divisions in NSTR& GBM

Biodiversity and tiger census: The eastern Ghats have been researched for flora mainly. However, most of the research started happening in 1990's. The first avifaunal survey was done by Salim Ali in state ornithological survey of Hyderabad (Ali 1933). The Krishna river landscape is said to be crucial tiger habitat of the country yet likely to support <50 tigers due to various human pressures, unless the anthropogenic pressure is reduced the landscape would not be able to sustain tigers in future (Johnsingh et al 2010). However, the All India Tiger Monitoring 2010 reported 60 tigers in 3159 sq km in 2010 and 58 In 2014. In 1989, NSTR reported to have 94 tigers but prone to poaching (Kenny et al 1995). In NSTR the mean prey size consumed was 56.3 kg. and it relied on smaller prey like chital and boar. The wild prey density in NSTR is low (Srinivasulu 2002) and livestock density is high. However total contribution of livestock in tiger diet is low (6.2%) same as Pench. The tiger is adapted for smaller prey and prey on livestock occasionally (Reddy, 2004).

The Nallamalla hills have rich tribal diversity. Amongst them chenchus are the obligate food-gatherer and hunters. They have inhabited the forests on either side of Krishna river but presently they are confined to Nallamalai hills (Hamendorf et al 1982).

Natural restraint in the TR: Most of the sanctuary has been since ages affected by periodic fire which damages the forest floor vegetation affecting ungulates. Also, it clears the visibility below the canopy for up to 150m. The soil is shallow and low in humus and frequent fire lower the fertility even further reducing the productivity of the entire ecosystem (Management Plan 1980).Old teak plantation started during British period dating 1903. Krishna river flows through a 130 km stretch inside the Reserve forest. The river causes erosion in the area and as such soil fertility is low. The terrain of high hills and deep valleys and gorges makes it a difficult area for census. Still numerous plateaus like Amrabad, Srisailam, Peddacheruvu, Sivapuram, Nekkanti, play a crucial role for the wildlife flourishing in monsoon. The wildlife is confined to valleys in summer as perennial water source is located in valleys (Belsare, 2011).

Dr Salim Ali 1931, in the fall of sparrow mentioned “TheMannanur locality stands out vividly in my memory for its wealth of wild animals, including a great number of tigers that I had ever experienced before”. Capt Russell in 1852 mentioned “Nallamalla forests were most uninviting tracts inhabited by chenchus and subjected to virulent annual fires.

Threats: *Pterocarpus santalinus* is endemic to these forests and are smuggled in large quantity. The Nallamalla forests are facing threat due to anthropogenic interference, livestock pressure and habitat destruction (Srinivasulu,2002). Chenchus the primitive nomadic tribe are basically food gatherer. However, the damage to certain valuable species is observed, as Teak is almost disappearing from Nallamallas. Gumtapping of *Sterculeaurens* is resulting in fast disappearance of same. Gum yielding species face danger *Gevotiacottleriformis, Gyrocarpusjaquini, Cochlospermumgossypium*etc. Thelambada’s clear fell forest for cultivation. In eastern parts of sanctuary, they have almost denuded forests growth.Also, the forests formed a major connection to the forests of Orissa and further down to western Ghats (Rawat, 1997) but due to habitat fragmentation, the connectivity is fast depleting The NSTR reports animal kill by vehicle on road. Large mammal like leopard and sloth bear has been reported to be killed on road (Behera et al 2010).

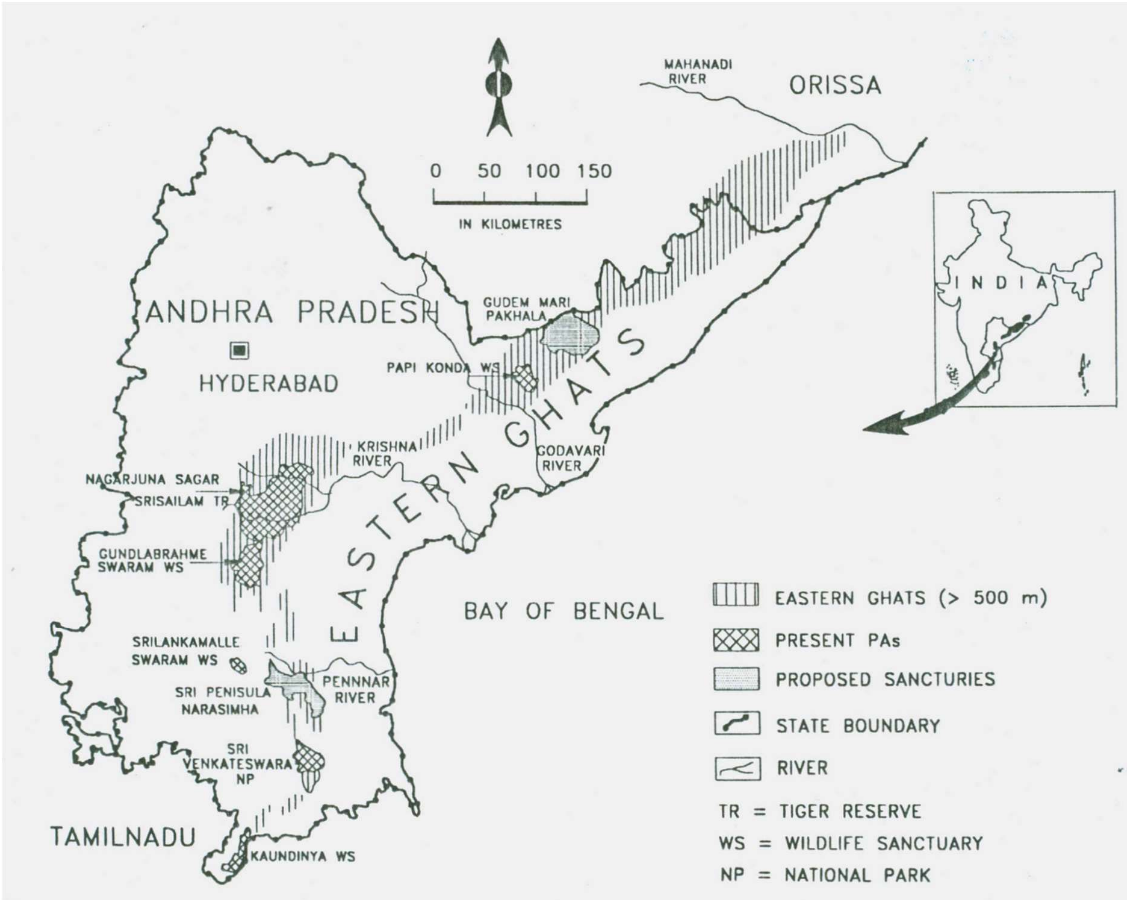

Figure 1 Map of Andhra Pradesh, India showing the location of the Eastern Ghats and adjoining protected areas.

4.4 Map of Eastern Ghats (Map courtesy G.S.Rawat 1997).

4.1.2.Kawal Tiger Reserve

Administrative history: It was established a sanctuary in 1965 at extreme end of the northern border of Andhra Pradesh to Maharashtra with 893 sq km (Negi,2002) and a Tiger Reserve in 2012. Godavari River flows in the south of the sanctuary, which combined with the urban settlement of Jannaramcuts off movement of animals in south. However, in north the sanctuary is connected to Maharashtra and Chattisgarh (Reddy et al 2011). The tiger movement from Tadoba-Andheri tiger reserve though sirpur forests of Adilabad to Kawalhas been observed. The state government declaration for the tiger reserve status of Kawal was"to protect, restore, manage and maintain representative biodiversity of the Deccan plateau of the Sahyadri Mountain Ranges along with ecological processes and conservation of wild gene pool with a focus on Tiger" as the park offered a sink for tigers of Tadoba and Indravati but not resident tigers to get approval for tiger reserve status.

Biodiversity and Tiger census: Kawal has been reported to be rich in tigers (Sankhala, 1969). Tigers were abundant in the forests of South India and were numerous in the forests of eastern and western circles of Hyderabad till 1935 (Jerdon, 1874). Red jungle fowl and grey jungle fowl were the common inhabitant of Kawal wildlife sanctuary .The research studies conducted were mostly recently are of additional records or range extension of diverse species in Kawal like vegetation quantification (Murthy, 2015), grasses (Poaceae) records (Chorghe et al, 2015), quantification of fungi (Nagaraju et al, 2014), enumeration of piscicidal plants used by Gond tribes (Murthy et al 2010). Most of these researches undertook post 2010.

Natural restraints in Tiger reserve: Being a novice Tiger reserve, the staffsare not very updated about monitoring protocols of tiger as well as animal identifications. The tiger reserve falls in two divisions, **Nirmal** and **Jannaram**. Since JannaramDFO's office is near the Tiger reserve and Jannarambeing a big settlement, tourism is being handled by the Jannaram division itself. Hence lack of teamwork in the two divisions was clearly visible. Also due to extremism history, many areas are still not regularly monitored. Due to dry deciduous teak forests, forest fires are common and the understaff tiger reserve as well as unapproachable areas pose difficulty in clearing the forest fire.Also, there are unrecognized settlements inside the park and forest staff is unable to keep track of the illegal activities because of this. The restraint is not much of natural causes but due to lack of proper training of the staff and administration updates. Lack of baseline data is also an issue for this tiger reserve. Most of the information are recent and through newspaper reports.

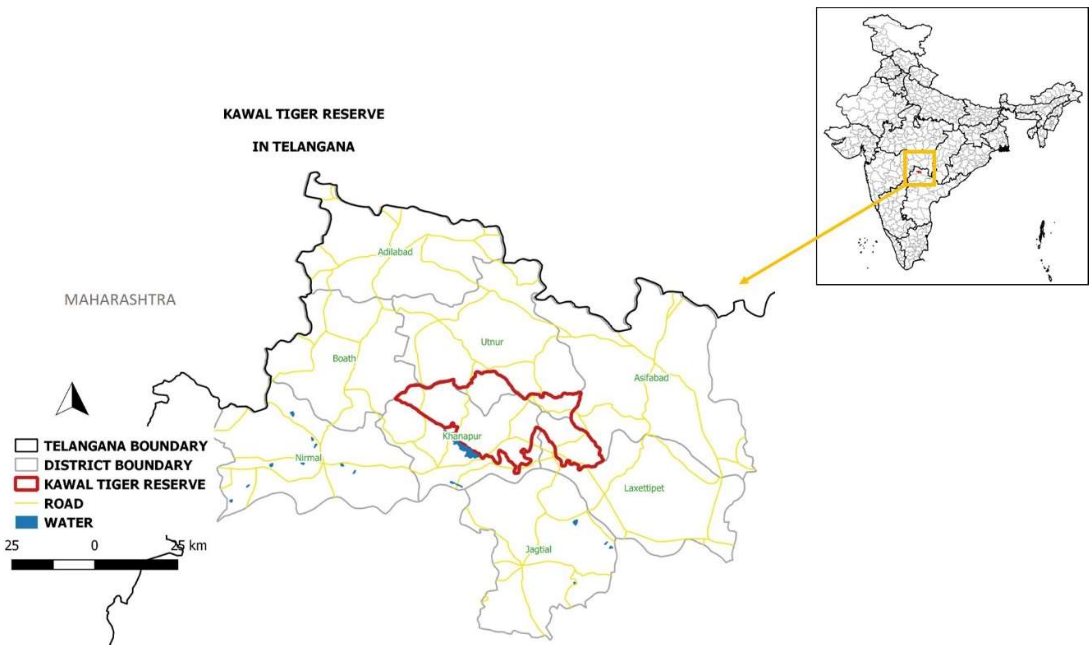

Figure 4.5. Location of Kawal Tiger Reserve

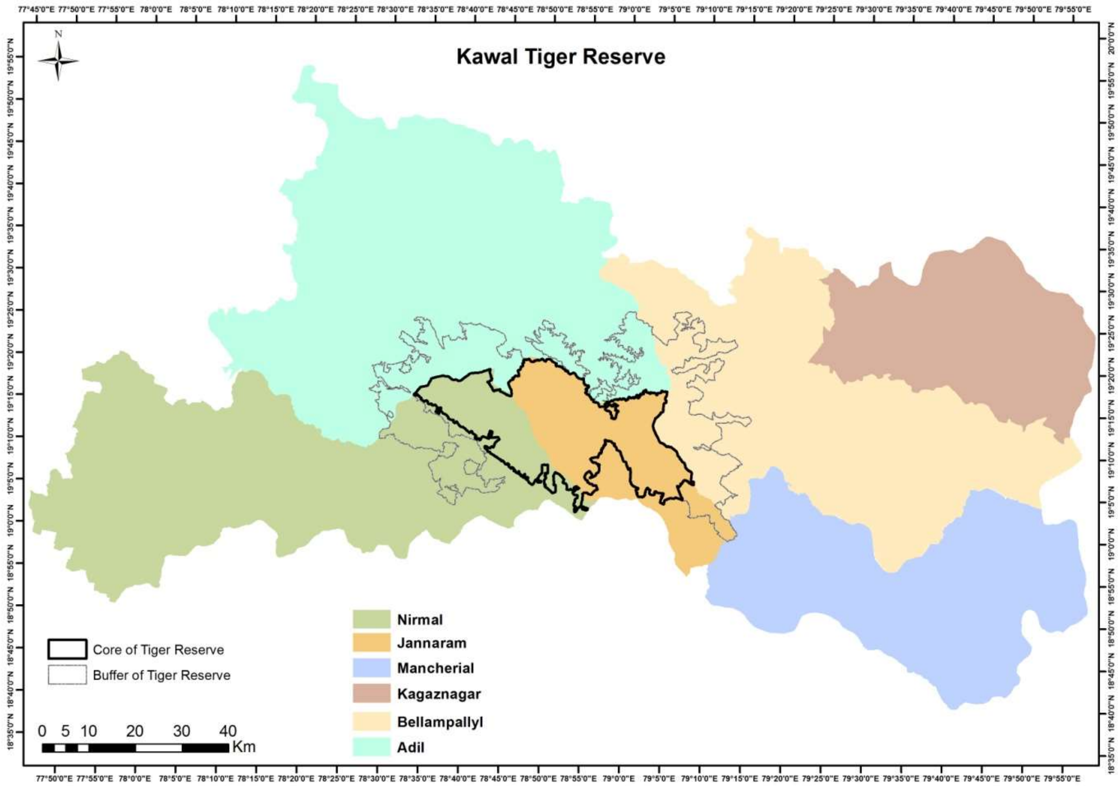

Figure 4.6. Details of Divisions in Kawal tiger Reserve

Threats: Rampant Tiger poaching has been reported from the sanctuary, also hunting of nilgai, wild boar, spotted deer, peafowl, jungle fowl are hunted for meat as well as retaliation for crop depredation.Forest Right Act had a negative effect on Kawal where thousands of trees were cut down and over 600 acres of prime habitat was ploughed in various locations (TIGERLINK, 2011).The tiger reserve has the pristine teak forests, the smuggling of which is a common threat. Due to past extremism history, smuggling and forest fires are quite common. Many tribes which includes hunter and agriculturalists are part of Kawal Tiger Reserve (STRIPES). The inhabitant has been observed to do hunting with their pet dogs (pers observation)**.**

4.2 Vidarbha region

4.2.1. BorTiger Reserve

Administrative History: Initially a game reserve, Bor was declared a sanctuary in 1970 and a Tiger reserve in 2014. Its small size interfered in its declaration as tiger reserve. However due to its crucial position and it acting as satellite core for Pench Tiger reserve, its protection was justified (Times of

India,12-03 2012). Bor forests act as stabilizing factor for the catchment of bor reservoir (Forest Survey of India,1985-87).

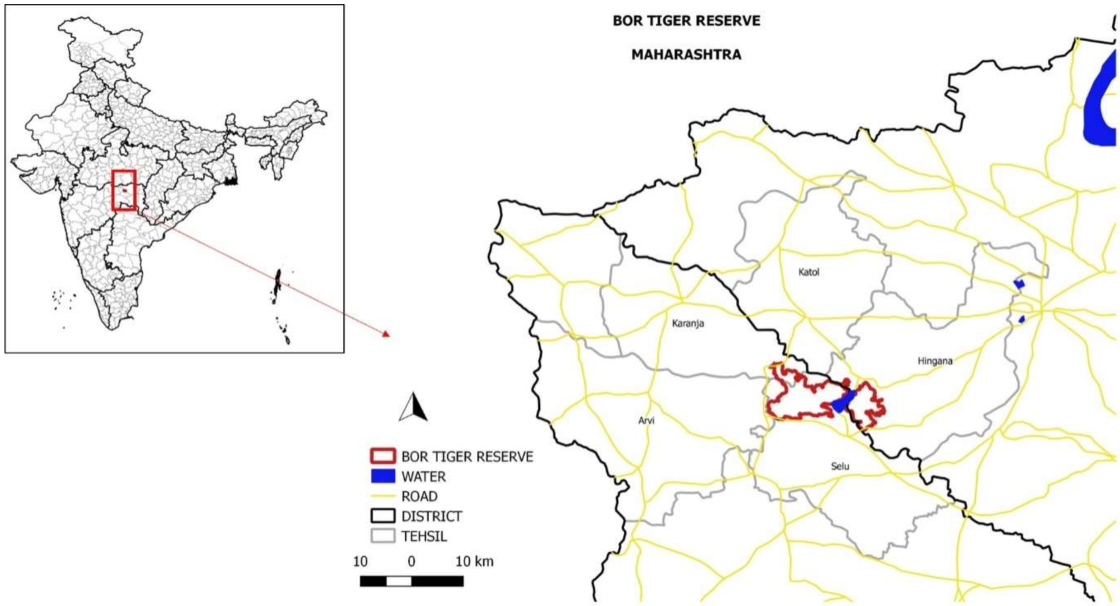

Figure 4.7 Location of Bor TR

Biodiversity and tiger census: tiger abundance calculated in 2010 for Bor was 12 and area occupied was 775 sq km.

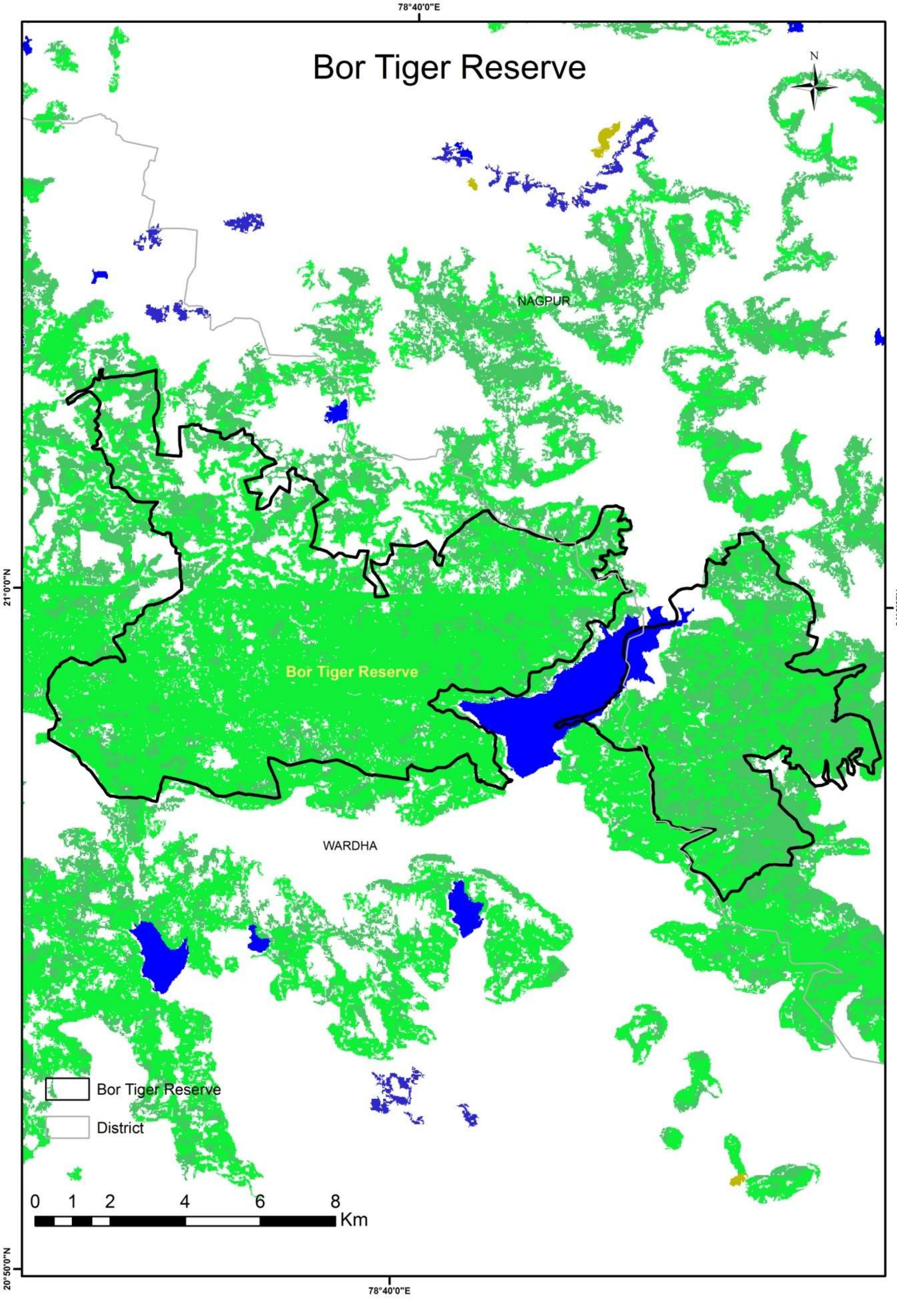

Figure 4.8Forest cover in Bor TR

4.2.2. Nawegaon –Nagriza Tiger reserve

Administrative History: Nawegaon and Nagzira are in Gondiya district of Maharashtra. Gondiya is famously called “rice fields” of Maharshtra.Nawegaon was declared a national park in 1975 and Nagzira was declared a sanctuary in 1969. The two protected area are connected by a fragmented strip of forests (Forest Survey of India,1985-87). Although the first working plan was made as early as 1897, its importance as a tiger reserve came not until 2013.NTCA notified Nawegaon-Nagzira as 46th tiger reserve of the country.Nawegaon gets its name from Nawegaon bandh which is a 11 sq km lake at the outskirts of Nawegaon. The lake is surrounded by 7 peaks of Nishaani hills (the seven sisters). The Dongarwar family was instrumental in constructing the lake in 13th century which was further taken up by government of India in 1951.

Nagzira is named after an idol of Nagdev and NagziraLake. It is famously called “green oasis” of Vidarbha and preserves the unique floristic composition in easternmost Maharashtra (Patil 2016).

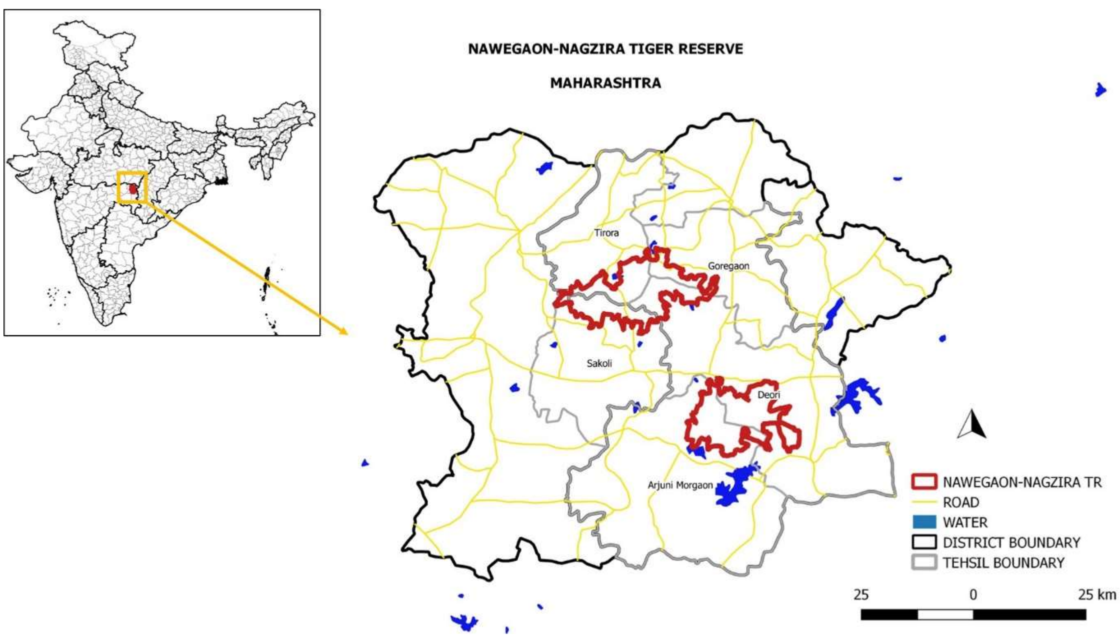

Figure 4.9 Location of NawregaonNagzira Tiger Reserve

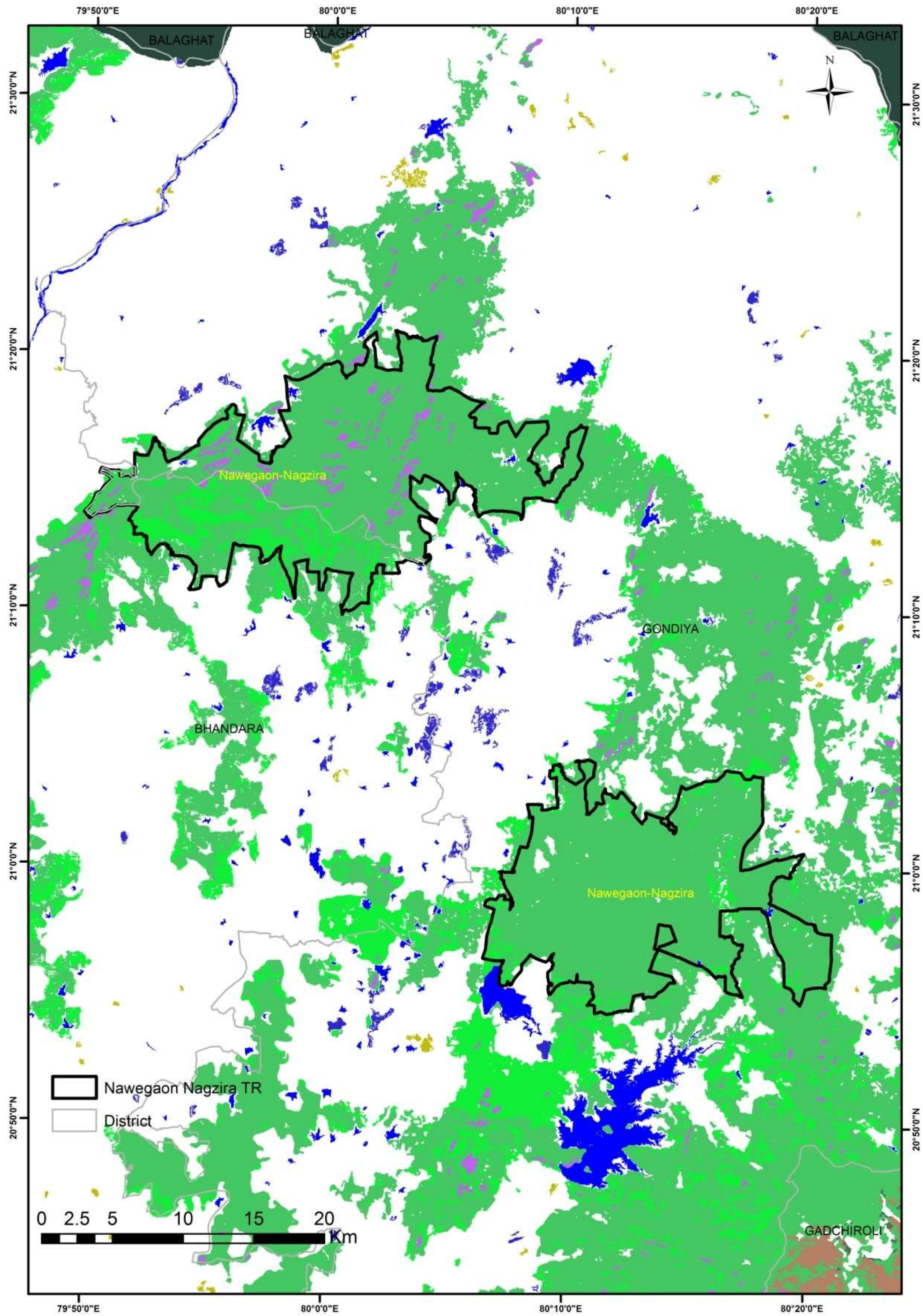

Figure 4.10 Forest cover in NawegaonNagzira

Biodiversity and Tiger census: It was a game reserve where ungulate hunting was stopped in 1961 and tiger in 1970 (Kondawar :Management plan 1995-1996 to 1999-2000). Being in the catchment of Chulband River, Nawegaon and Itiadoh lakes provide water for the animal survival. The forests provide refuge to unique aquatic and semi aquatic flora which are not found anywhere else in Western Ghats of Maharashtra (Govekar,2008). Nawegaon and Nagzira are notable for

Anogeissuslatifolia-Terminalia and *Anogeissuslatifolia-Terminalia- Cleistanthus* series which are fast degrading biomes. The area is also considered reservoir of medicinal plants especially Pteridophytes which were and are used for treatment of various ailments by tribals (Cherian, 2010). Hence being the last stronghold of such vegetation and also the rich floristic composition, the parks signify protection (Patil 2016). Since the Dongarwar family era, the natural history especially birds have special significance in the area. Dr Salim Ali visited the Nawegaon Bandh with Dongarwar family as the bandh is famous for migratory birds. A checklist of water birds highlights the ornithological importance (Dharankar, 1976).The Nawegaon bandh is a proposed Ramsar site.

Gaur is predominantly found in Nawegaon -Nagzira Tiger reserve.However, it is distributed in the other forests of Gondia. Wild dogs are found in Nagzira WLS (Choubey, 2013-2014).

Barking deer has not been reported from sanctuary since 1995 and Pangolin has not been reported since 1988 (Pande, 2005).The tigers of Nawegaon and Nagzira have been in news for their long-distance migration. In 2013, “Jai”tiger travelled from Nagzira Wildlife sanctuary to Paoni range of UmredKarhandla WLS 120-130 km away. In 2014, another tigress “Kaani”travelled 70km to reach Navegaon WLS from new Nagzira crossing busy NH6 (Times of India 2014).

Natural restraint in Tiger reserve: The tiger reserve importance is being the stepping stone to the migratory population of Tadoba-Kanha-Pench- Indravati. The corridors are more crucial for the movement of animals across various protected areas in central Indian landscape. The irrigational canals are affecting these corridors since long. Corridor between Nagzira-Nawegaon is disturbed by Itiadoh-Zasinagar-Nawegaon canal. The Ghodazari canal network has fragmented Tadoba-Nawegaon through Brahmapuri Forest division. A coal based thermal power plant is functional at the periphery of Nagzira which is affecting the wildlife by polluting air as well as increased vehicular traffic.Also, railway line expansion in corridor is a concern (SanctuaryAsia, August 2010).Nawegaon- Nagzirais crucial in connecting the population of Tadoba-Kanha-Pench in central Indian landscape; although the small size of Nawegaon is a restraint for animal movement (Dutta 2015).The construction of NH6 which bisects Nawegaon- Nagzira corridor will not only affect the movement of animal but also support the fragmentation of the small sized parks.

Threats: Infestation of Ipomoea spp. In Nawegaon lake is one of the major problems.TheGondia district is part of red corridor, hence major dependency of natural resources is affecting the forests. Grazing, Illegal felling, encroachment and developmental projects which are increasing the human-wildlife conflict in the region are major threats for the forests. It was observed through remote sensing studies, high amount of deforestation and loss of forest is occurring in between Nawegaon and Nagzira corridor (Yadav, 2012)

4.2.3.Satpura Tiger reserve

Administrative history: Satpura Tiger Reserve (STR), Hosangabad, Madhya Pradesh (22° 15'- 22° 45'N; 77° 50'- 78° 30'E) is in the Satpura range (Mahadeo Hills) and situated in Hoshangabad district of Madhya Pradesh

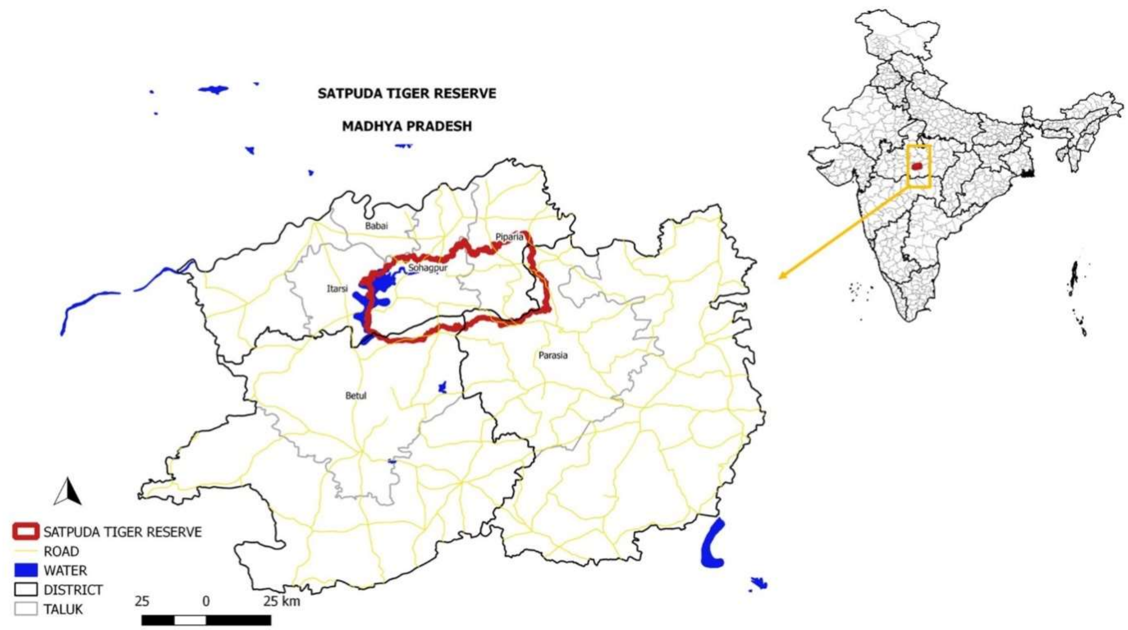

Figure 4.11. Location of Satpuda TR

Biodiversity and Tiger census:

The Satpura range is one of the oldest mountain ranges in the world and, together with the Vindhyachal range in the north and the Maikal range in the east, forms the catchments of the Narmada and the Tapti rivers and their tributaries (Sharma et al 2013, Krishnan 1982). The area represents the central Indian Highlands and the forests are economically amongst the most valuable of the dry deciduous types. The connectivity from Eastern Himalayas to western Ghats have been proposed to explain the dispersal of source species from the eastern Himalayas to the Western Ghats (Wagh, 2011). Vindhya-Satpuda range in central India is proposed as a corridor for dispersal of taxa from eastern Himalayas to western Ghats (Shrinivasan& Prashanth, 2006). Hora (1949) postulated that the wet zone species colonised southern India by way of a once continuous corridor of tropical evergreen forests from the eastern Himalayas across the Vindhya–Satpuda range to the Western Ghats of South India (Karanth, 2003).

Of great archaeological interest are more than 130 rock shelters with rock paintings depicting battles, hunts, animals, ceremonies and routine daily life of the people, found all over the park in the Pachmarhi plateau. Some of these are estimated to be over 10,000 years old.

The principal species of carnivores are tiger *Panthera tigris*, leopard *Panthera pardus*, wild dog *Cuonalpinus*, Hyena *Hyaenahyaena* and jackal *Canis aureus*. The sloth bear *Melursus ursinus,* the honey badger *Mellivoracapensis* and the wild pig *Sus scrofa* are the three important omnivores. Small carnivores include the jungle cat *Felischaus*, the palm civet *Paradoxurus hermaphroditus* and the small Indian civet Viverriculaindica.

Satpuda reported 39 tigers in All India tiger monitoring 2006 and increased to 43 in 2010 census.

Natural restraint in Tiger reserve: The terrain of the park is generally hilly with precipitous slopes, deep and narrow gorges, ravines, sheltered valleys and dense forests with many water falls.

4.2.4. Melghat Tiger reserve

Administrative history: The tiger reserve is situated in Satpuda hill ranges of Central India, where the core area of tiger lies in forests of Amravati, Akola and Buldhana Districts of Vidarbha region of Maharashtra, bordering Madhya Pradesh in the North and East. The area of the Critical Tiger Habitat is 1500.49 Sq.Km. falling in the heart of the Melghat. Out of this, 1150.03 Sq.Km. (Gugamal and Melghat Sanctuary) belongs to the initially declared Melghat Tiger Reserve which was declared on 22nd February 1974 and the remaining area of three Wildlife Sanctuaries namely Wan, Ambabarwa and Narnala, added to it on 27/12/2007 now comprise the core area of the Critical Tiger Habitat of the Melghat Tiger Reserve.Melghat Tiger Reserve is one of the earliest 9 Tiger Reserves established by the Government of India and is the First Tiger Reserve to be declared in the State of Maharashtra. It came into being on 22nd February, 1974. Administratively, the area of Gugamal National Park, Melghat Sanctuary and Wan Sanctuary falls in Dharni and Chikhaldara Tehsils of Amravati District, Ambabarwa Sanctuary falls in Sangrampur Tehsil of Buldhana District and Narnala Sanctuary is in Akot Tehsil of Akola District. For control and Management purpose, the area of the Critical Tiger Habitat is included in three Wildlife divisions, namely; Sipna Wildlife Division, Paratwada, Gugamal Wildlife Division, Paratwada and Akot Wildlife Division, Akot.

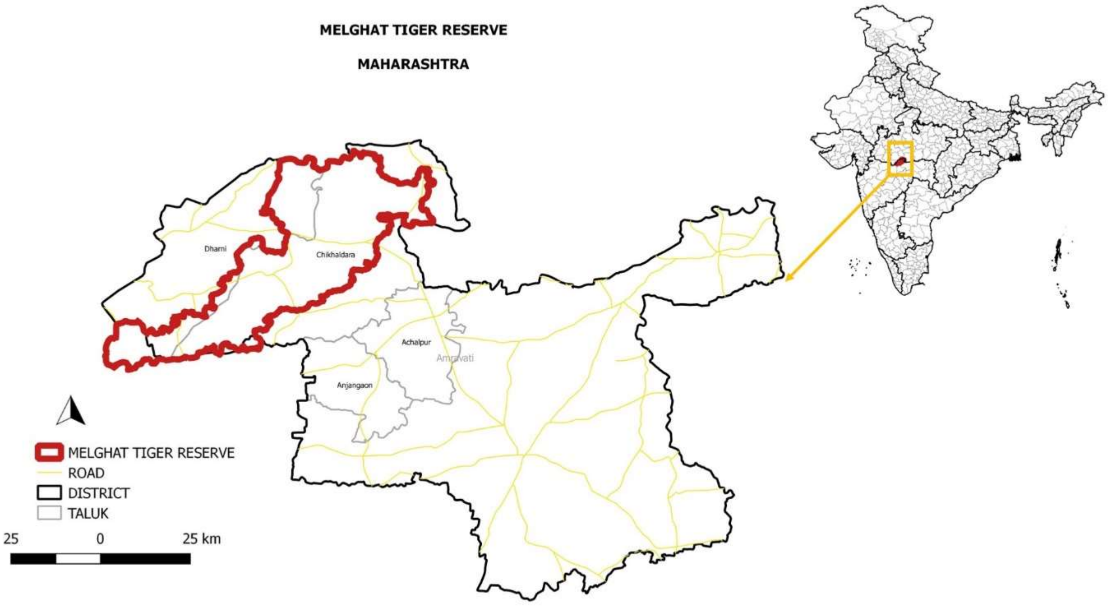

Figure 4.12. Location of Melghat TR

Biodiversity and Tiger census:

Prior to be declared as Tiger reserve, the park was used for commercial logging by the Indian state and the British Raj. The area is catchment to the five major rivers viz Khndu, Khapra, Sipna, Gadga and Dolar, all of which are tributaries of the river Tapi. The north-eastern boundary of the reserve is marked by river Tapi. It consists of metamorphic rocks along the northern border of district. It has a connectivity to Satpuda hills and hence a long-termcorridor connectivity to wildlife in the region. In the valleys of Melghat, the forest is thick and dense in the Semadoh - Kolkhasbelt. It is in this region, that Tiger and Leopards are well protected along with Deer, Bison, Sloth beer, etc. The area shows the dominant growth of teak population, followed by *Butea monosperma*. Among the monocots, specifically bamboo species like *Dendrocalamusstrictus* is well represented in the forest.

Melghat reported 30 tigers in All India tiger monitoring 2006 and increased to 35 in 2010 census.

Natural restraint in Tiger reserve: Melghat has a rugged topography with very few entry points. The Makhala,Chikhaldara, Chiladari, Patulda and Gugamal are the large plateau amidst rugged terrain (Kazi, 2012).

Threats: The Park has original inhabitant as Korku people who have been shifting cultivator historically. The land transformation has seen them as settled agriculturalists and labourers. The villagers in and around Melghat TR has resource dependency on the park.

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With the popularity of non-invasive method like camera trap, it is increasingly used to study and monitor wildlife (O'Connell et al, 2010). Statistically sound abundance estimate like spatially explicit capture recapture are popularly used for individually identified species using these camera trap data (Karanth and Nichols, 1998). Abundance estimates of non –identifiable species pose a problem and hence mostly one has to rely on indices to make inference about differences in abundance across time, space and species (O'Brien, 2011). Relative abundance indices (RAIs) have been used for photographic capture rates from camera trap surveys for a wide variety of medium- to large-bodied wildlife species. RAIs are less complex than other estimation methods and are commonly used when true abundance is difficult or costly to measure (Palmer et al 2018).

The initial understanding of camera-trap data (AITM 2014) involved calculation of relative abundance index. Since the carnivore presence varied in the study area, the common species tiger, leopard, dhole, badger, small Indian civet and Asian Palm civet were used for RAI. The sites taken for the study were Kawal, Nagarjunasagar (NSTR), Bor, Umred, Nawegaon -Nagzira (NNTR), Pench MH, Melghat, Satpuda, Gundel brahmeshwaram (GBM). In Kawal , Melghat, NNTR, Pench MH, Satpuda and NSTR has presence of Mongoose . NSTR has presence of rusty spotted cat in camera-trap. Jackal presence in camera-trap has been reported from Pench MH and Satpuda. However, fox was captured only in Satpuda amongst the study area.

A carnivore event was defined as any series of continuous photographs triggered by a "one" carnivore species. To determine the relative abundance of carnivores and their presence at each camera trap site was calculated. To reduce pseudo-replication when calculating relative abundance, we considered multiple photographs of a species within 30 min of a previous photograph to be the same event (Allen et al 2018).

To calculate relative abundance (RA) for each carnivore species as:

$$\textbf{RA = (D / TTN) x 100}$$

where D is the number of detections and TTN is the total number of trap nights at a camera, and overall relative abundance is the mean of all cameras. The carnivore captures were segregated into top carnivore i.e., tiger, first trophic as leopard and dhole and meso-carnivore as other small carnivores. The mean relative abundance of a trophic was correlated with the next level trophic using linear regression.

Limitation: *The design of camera-trap survey was oriented for large predator. Although the survey was designed for small grid size according to meso-predator, yet the site-specific locations, habitat requirements, duration of trap nights are not well documented for meso-predator.*

Table 5.1The animal capture in study sites

Sites	Tiger	Leopard	Dhole	Ratel	Jungle cat	Small Indian Civet	Asian Palm Civet
Kawal	0	27	39	17	26	24	82
NSTR	92	124	87	129		418	240
Bor	85	92	4		134		
Umred	55	93	4	9	36	8	44
NNTR	83	79	60		58	9	24
Pench MH	263	88	61	12	64	5	26
Melghat	114	192	42	64	134	56	102
Satpuda	158	278	114	13	224	37	71
GBM	182	138	57	23	3	106	41

Since the civet has completely separate niche compared to other meso-predator, it was excluded from the study.

Table 5.2 TRAP EFFORT AT STUDY SITES

Sites	Kawal	Umred	NSTR	NNTR	Bor	Satpuda	Pench MH	Melghat	Tadoba
Effort	39	34	93	65	50	78	70	105	97

Table 5.3 Relative Abundance Index for individual species (RAI)

Sites	Tiger	First Trophic	Meso-predator
Kawal	0	5.74359	1.717949
Umred	1.617647	4.794118	1.617647
NSTR	1	2.290323	6.301075
NNTR	1.276923	9.984615	1.323077
Bor	1.7	2.92	3.42
Satpuda	2.025641	5.833333	7.923077
Pench MH	3.757143	2.142857	2.514286
Melghat	1.085714	2.247619	2.952381
Tadoba	5.443299	2.628866	0.690722

The hypothesis is:

The beta predator would have negative interaction with alpha predator while meso-predator would have positive interaction with alpha predator.

The sub-ordinate predator is leopard and dhole and meso-predator are badger, jungle cat, Common Indian Civet and Asian Palm civet. The capture of leopard and dhole was merged to calculate RAI of sub-ordinate/ beta predator and jungle cat, badger, civets for meso-predator per 100 trap nights. It was then used to plot against tiger RAI/100trap nights.

Table 5.4 Relative Abundance Index for carnivore group (RAI)

Sites	Tiger capture	Sub-ordinate predator capture	Meso-predator capture	Tiger RAI/100trapnight	Sub-ordinate predator RAI/100trapnights	Meso-predator RAI/100trapnight
Kawal	0	224	67	0	574	172
Umred	55	163	55	162	479	162
NSTR	93	213	586	100	229	630
NNTR	83	649	86	128	998	132
Bor	85	146	171	170	292	342
Satpuda	158	455	618	203	583	792
Pench MH	263	150	176	376	214	251
Melghat	114	236	310	109	225	295
Tadoba	528	255	67	544	263	69

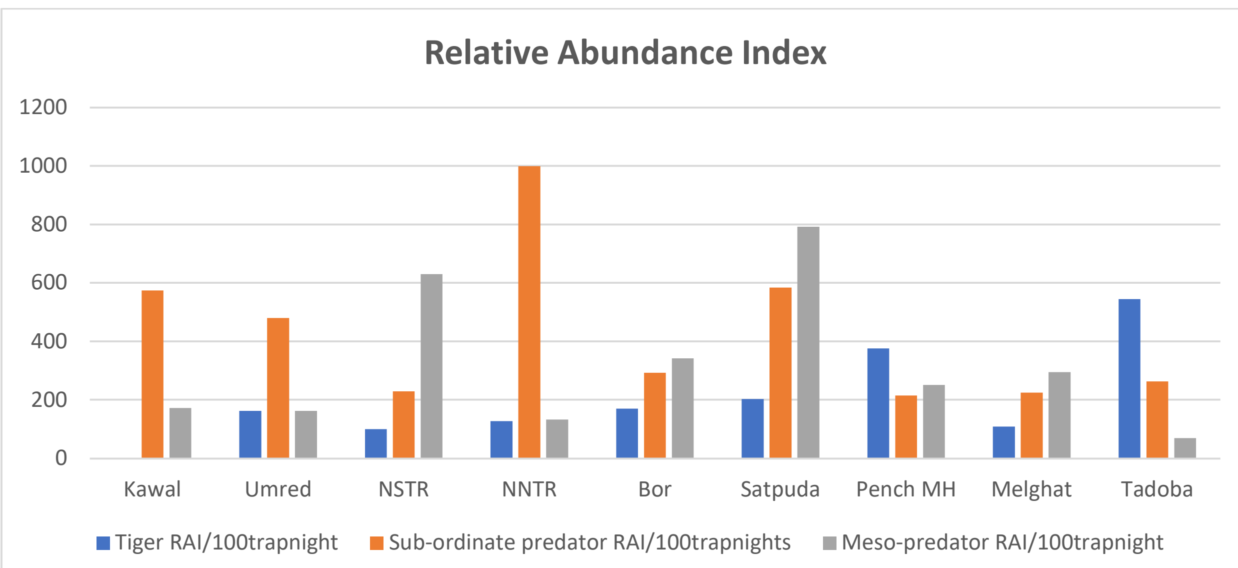

Figure 5.1 Relative Abundance Index (RAI) across study sites

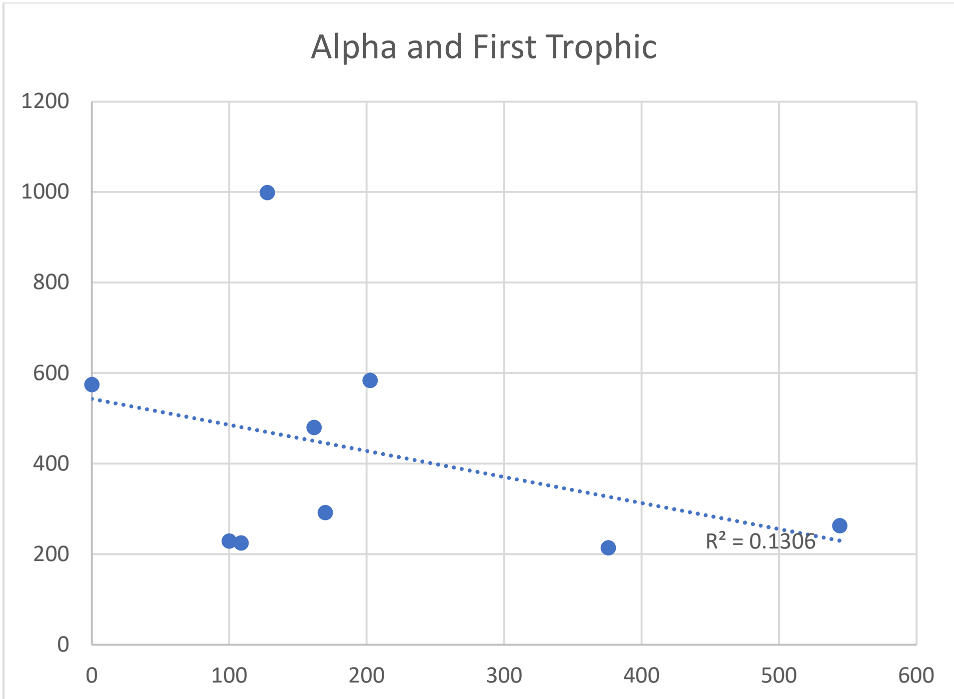

Figure 5.2 Relative Abundance Index (RAI) of beta predator plotted against alpha predator across study sites

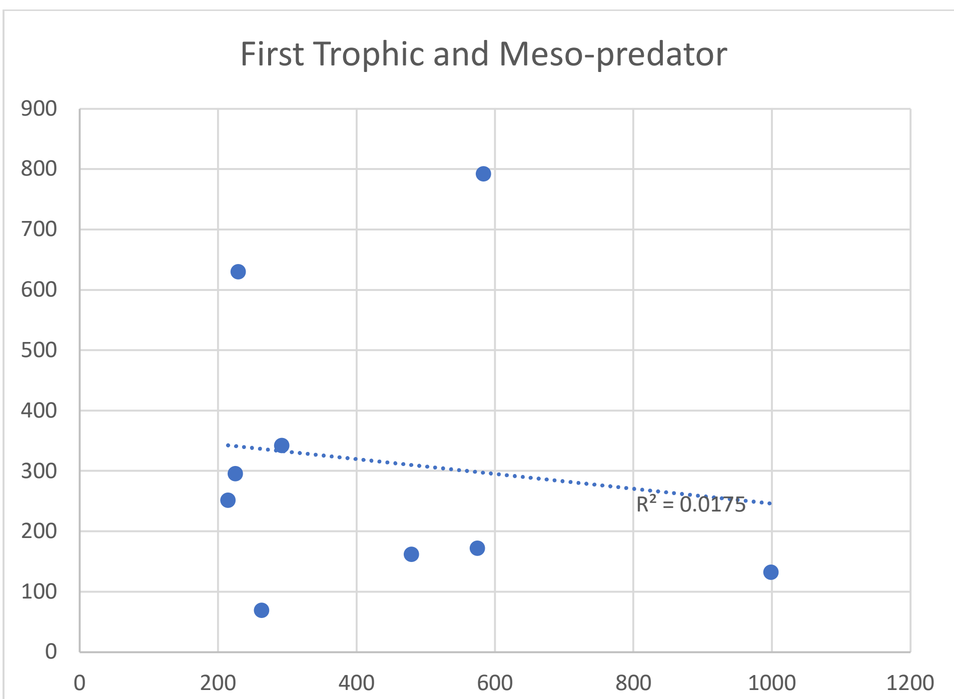

Figure 5.3Relative Abundance Index (RAI) of meso predator plotted against beta predator across study sites

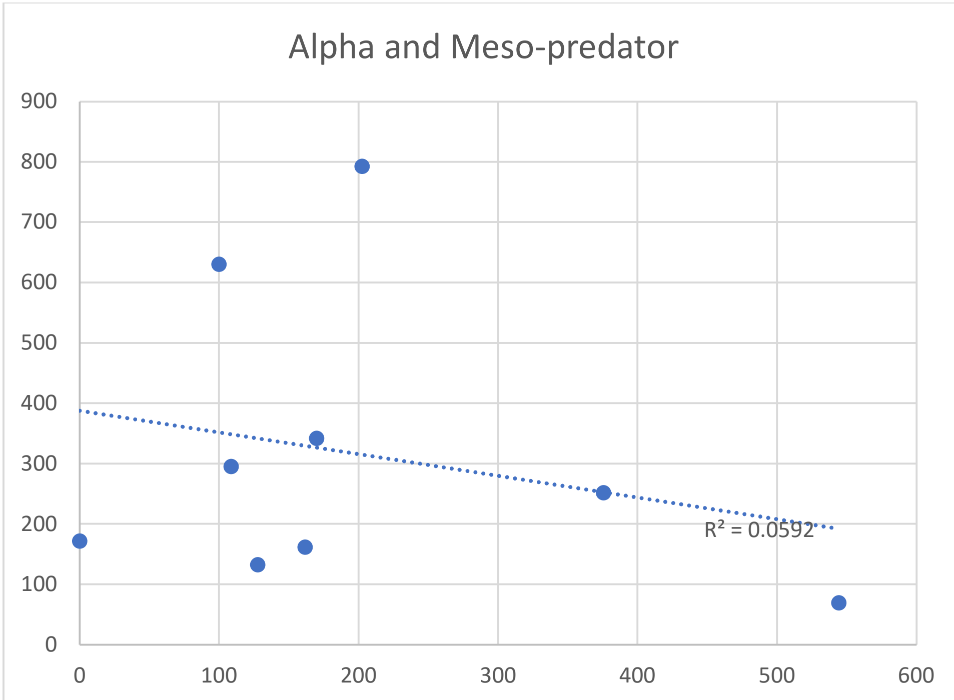

Figure 5.4Relative Abundance Index (RAI) of meso predator plotted against alpha predator across study sites

Discussion and Conclusion:

From cameratrap survey data, the initial data mining and analysis proffered a trend supportive to the hypothesis. Tiger density suggest a negative relation with first trophic i.e., leopard and dhole. However, the second part of the hypothesis is not expressed through the one season data analysis. Although the relative abundance index for tiger and beta predator as well as with meso-predator did not show any significant relationship, the low tiger density sites like Umred, NSTR, NNTR RAI/100 trap night of first trophic is higher than RAI/100 trap night of tiger. Umred where only 2 tiger exists shows first trophic RAI/100 trap night comparable to Kawal which was no tiger presence area. However, in medium tiger density area like Bor and Satpuda the difference in tiger and first trophic RAI does not follow the hypothesis. Wherein, Bor show slightly higher First trophic RAI/100 trap night than Tiger RAI/ 100 trap night, Satpuda gives an anomaly to this trend where First trophic predator RAI/100 nights are much higher than tiger. In high density area like Pench MH and Tadoba, the trend according to the hypothesis justifies for tiger and leopard. The first trophic RAI/100 nights are much lower compared to tiger. Although in high tiger density region also, Melghat disagrees with the hypothesized trend.

Kawal being the no tiger area shows much lower RAI/100 trap night compared to first trophic RAI/100 trap nights. Similarly, in low tiger density area like Umred and NNTR, the meso-predator suggests limited activity and encounter rate at camera-trap. However, low Tiger density area like NSTR, the meso-predator show very high RAI/100 trap nights. Yet in medium tiger density area like Bor and Satpuda the meso-predator is RAI/ 100 trap nights is high and does not follow the hypothesized trend. In high tiger density area like Pench MH and Melghat, meso-predator RAI/100 trap nights are higher than first trophic. Tadoba shows an anomaly to this trend.

It can be concluded by Relative Abundance Index and baseline data analysis that first trophic predator activity is expressed more in absence or low tiger density. In medium tiger density area also first trophic predator activity is more than tiger according to cameratrap capture. However, in high tiger density area this activity of first trophic is limited. Yet the density and spatial distribution of large prey and presence of human disturbance inside core might could be driving force for limiting activity of tiger and expression of first trophic as in case of Melghat. There are some 21 villages inside core occupying the flat valley and important water source in Melghat (Mathur et al 2014). This brings a competition for wild prey of tiger with livestock and and in turn its less density and spatial segregation in the park. Tiger has known to avoid human presence. This limits the presence and activity of tiger and in turn bring higher activity of first trophic.

It can also be concluded with the RAI analysis that in low tiger density areas the meso-predator is suppressed (exception being NSTR). In medium and high tiger density areas, the suppression of activity of first trophic can be concluded from initial analysis. Less activity of first trophic in medium and high tiger density area allows the meso-predator to have a higher activity.

The size of the protected area is contributing to diversity of meso-predator cannot be said conclusively by initial analysis. Bor is very small sized park yet it shows high meso-predator RAI/ 100 trap nights. Although Bor shows meso-predator RAI/100 trap nights at par with Melghat, yet diversity is very low (only Jungle cat presence as per cameratrap). The meso-predator diversity can be concluded to be positively affected by tough terrain, diverse topography and human presence inside park (as in NSTR, Satpuda and Melghat). The presence of 29 village inside core of Satpuda, relocation underway, might not only suppressing tiger activity and expression of first trophic but also provide refuge and resource for meso-predator. The camera trap survey of Satpuda revealed presence of Jackal and fox and contributing to higher meso-predator diversity and activity.

Interference competition might be underlying process for the interaction **between first trophic and meso-predator in low tiger density area** and between **tiger and first trophic in high tiger density area** according to Relative Abundance Index.

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LEOPARD IDENTIFICATION AND DENSITY ESTIMATION

A species common and adaptable yet so less researched

- *Panthera pardus fusca* (Meyer, 1794), one of the nine subspecies recognized
- Leopard population (pugmark census) in 2001 was estimated to be 9,844
- highly adaptable found upto 5200m in Himalayas
- poaching cases of leopard was 111death (2015) and 116 death (2014)

Objective: Density estimation of P*anther pardus* in study sites in central Indian landscape

1. Introduction and literature review about leopard
2. Introduction about available Species ID software
3. Identification of leopard by Hotspotter
4. The Species area curve calculation
5. Density estimation using SECR

Introduction: IUCN defines *Panthera pardus* as Near Threatened and its population decreasing. Of the nine subspecies of *Panther pardus fusca*; the one found in Indian subcontinent; has not been ever assessed nationwide; apart from the pugmark technique which concluded 6,252 in 1997 and 9844 in 2001 (Singh, 2005). Though due to questioning of reliability of the estimation technique (pugmark method), these estimates were not depended on.

The Photo identification technology has been useful for quantitative estimate of population parameters like abundance and survival. The technology has evolved in animal identification from manual to computerized, from natural markings/pugmark/invasive to non-invasive camera-trap captures, from small database to large database maintenance for posterity and from protected area management research to large landscape management and corridor identification.

Various photo-recognition method has been developed over the years (Table 6.1:)

Table 6.1: Photo Identification tools available for wildlife population studies.

Kelly 2001	cheetah	pelage pattern	3-dimensional similarity score
Speed et al 2007	whale shark	spot-recognition program (I3S)	information-theoretic approach
Tienhoven et al 2007	ragged tooth shark	spot pattern	2-dimensional similarity score
Gamble et al 2008	marbled salamanders	dorsal pattern	similarity score
Hiby 2009	tiger	pelage pattern	3-dimensional similarity score
Jewell 2016	cheetah	footprint	cross-validated pairwise discriminant analysis
Murakami 2016	mesocarnivore	noseprint	similarity score
Alibhai et al 2017	puma	footprint	clustering method

The animal is catholic in terms of diet as well as habitat(Daniel, 1996) resulting in no defined management and protection protocols for its conservation. The paucity in population information invariably constitutes impuissance for management decisions. There have been studies highlighting human-leopard conflict in India (Madhusudan, 2003, Chauhan, 2000, Kumar, 2011, Bhattacharjee, 2013). The conflict is elevated in states of Gujarat, Jammu & Kashmir, Assam, Uttaranchal, Maharashtra and Himachal Pradesh (Marker 2009).The reasons for the leopard conflict in India have been credited to the dearth of habitat loss and wild prey and corridors for movement (Pati et al, 2004). The conflicts are two-way with attack on humans and livestock and retaliation killing of leopard. WPSI shows statistics of leopard death as 271 in 2015 and 329 in 2013 (including poaching and mortality) clearly presenting status of the species in conservation arena. Despite many researches on high conflict with leopard, another school of thought believes that the feline can co-exist with humans with proper management and awareness intact (Seidensticker 1990, Athreya &Belsare 2006)

Few studies have been undertaken in India to study behavior of leopard through genetic (Mukherjee et al, 1994, Dutta et al 2012) and radio-collaring (Edgaonkar and Chellam, 1998, Mondal et al 2013).The pugmark method of identifying individuals of leopard and subsequent density estimation has been found to be unreliable (Johnsingh 2003, Karanth , 1987) instead analyzing in capture-recapture framework(Otis *et al.,*1978, Pollock *et al.,* 1990) from camera-trap data was suggested (Karanth, 1995) and successfully executed for tigers. The first attempt to estimate leopard population in India through capture-recapture was undertaken by Wildlife Institute of India (Chauhan et al, 2005).Since the initiation of camera-trapping, the individual identification of leopard through the non-invasive method has been found useful and reliable (Chauhan et al 2005, Harihar et al 2009). The identification of pelage pattern provides difficulty with a large dataset hence the proclivity towards pattern recognition software (Hibby, 2009, Bolger, 2012, Crall, 2013). Attempts have been made to identify leopard through spot variation with consequent algorithm (Smallwood, 1989) but no document has been found in India of the application.

Leopard status in four landscape in India

Shiwalikh Hills and Gangetic Plains landscape:

Leopard presence was found throughout sampled Shivalik hills and Gangetic plains, it is known to occur at higher altitudes in the Himalayas, but these areas were not sampled during 2013–14. Leopard presence was sparser in the *terai* grasslands. The major prey species available in this landscape were chital, sambar, hog deer, barking deer and wild pig. The leopard was most widespread carnivore in this landscape and it is reported to use non forested areas that include townships and sugarcane fields as corridors. If the people of same area are kept unaware of the importance of leopard conservation, it may lead to negative interactions.

Few studies conducted in Terai Arc landscape has focused on leopard. The Chilla range of Rajaji national park had reported the density of leopard post Gujjar relocation as 9.76/100 sq km (Hariahar et al 2011). It is concurrent to another region of same landscape, the Nandour Valley where it was reported as 9.57 /100 sq km. (WWF-India 2013). In our current study also the density is consistent 9.35/100 sq km. In a study in Bhabhar in Parsa Wildlife reserve, Nepal, the leopard density was reported to be 3.78(0.85) through SECR (Thapa et al, 2014) and in current study the adjacent Valmiki has 3.05 (0.45). Through sign survey, leopard high density was concluded in Suhelwa by Johnsingh et al 2004 (8.2 % frequency of encounter) and WWF India 2014(12.8 % frequency of encounter). Leopard density inside PA in shiwalikh is less but high conflict with humans presents their probable high distribution near human habitation. In Uttarakhand alone in the past decade 722 leopard have been reported dead mainly due to unnatural means and reciprocally large number of humans were killed as well as injured in same period(Chauhan,2000).

Central India Landscape

Leopard distribution was almost contiguous across the forested landscape of central India. Major source sites were observed to coincide with PAs. Eastern portion of Rajasthan (Ranthambhore, Ramgarh Bisdhari) along with North-western part of Madhya Pradesh (Kuno) comprises a distinct population whereas; rest of the Madhya Pradesh, eastern Maharashtra, Chhattisgarh, Jharkhand, Odisha, and northern Andhra Pradesh comprises a contiguous large-scale meta-population. The Northern Western Ghats in Maharashtra population were almost contiguously occupied with the species. In the eastern parts of this region, leopard in known to occupy the agro pastoral landscape and fragmented forest and scrub patches. There might be a potential connectivity amongst different populations of leopards in central India through Vindhyan ranges, Aravalli hill ranges and central highlands; which are connected by forested landscape and at time by human used agro-pastoral matrix. Though the community tolerance to leopard presence in proximity of their settlements is positive, at time, increased interaction in urbanizing human population and leopard may turn negative. Hence the concerned department in addition to increased awareness should also evolve mitigation strategies.

In central India landscape, Sariska TR has the density of leopard as 23.5/ 100 sq km. (Chauhan, 2005). Another study estimated the density as 30.9/100 sq km using MMDM/2 (Edgaonkar, 2008). The same study provides the density estimation of leopard in Satpura ranging from 7.3 to 9.3/100 sq km. and the current study estimate is 8.27/100 sq km. The leopard density was also estimated in human-dominated landscape in Maharashtra as 4.8/ 100 sq km (Athreya, 2013).

Western Ghats Landscape:

Major contiguous leopard occupied habitat blocks wereAnshiDandeli, Sharavathi Valley – Kudremukh – Bhadra, Nagarhole – Mudumalai – Wayanad – BiligiriRanganatha Temple – Cauvery Wildlife sanctuary, Peechi – Vazhani – Perambikulam – Indira Gandhi Wildlife Sanctuary and Periyar – Srivilliputhur – KalakadMundanthurai. Signs of leopards were sparsely reported from the forested areas joining these blocks. However, leopard known for its occupancy in human used areas is reported to use tea and coffee plantations and other agricultural fields in these distribution gaps. Leopard was also reported from fragmented forest patches of central Karnataka and North Eastern Tamil Nadu. Leopard was also reported from fragmented forests of Bengaluru urban and rural area, which harbor majority of urban sprawl and human densities. In case of direct interaction of leopard and human, which potentially may turn negative, guidelines for avoiding such interactions and mitigation strategies should be evolved and followed by the concern administrative departments.

A multiseasonstudy in Mudumalai Tiger Reserve yielded 29 leopards in a sampling area of 107 sq km. Spatially explicit maximum likelihood and Bayesian model estimates were 13.17 (SE = ±3.15) and 13.01 (SE = ±2.31) per 100 $km^2$for leopards. Leopard density for MMDM models ranged from 13.41 (SE = ±2.67) to 28.91 (SE = ±7.22) per 100 km^2. (Kalle*et al*. 2011). Another multiseason study conducted in Kalakad-Mundanthurai Tiger Reserve (KMTR), Western Ghats. Spatially explicit maximum likelihood and Bayesian model estimates (individuals 100 km-2) were 2.8 ± 2.0 and 2.4 ± 1.3 for leopards, respectively. (Ramesh *et al*. 2012). In Parambikulum Wildlife Sanctuary, the relative abundance of leopard was found to be higher compared to dholes and tigers which was measured by counting the number of scats encountered per km walk (Leopard – 188 scats, Tiger – 103 scats and Dholes – 86 scats). (Joseph *et al*. 2007). The human leopard conflict arises due to translocation of leopard in forest area where already established population of leopard exist resulting in their movement to next-dense vegetation area/ cropland (Athreya *et al*. 2007) and (Athreya *et al*. 2012). In the Western Ghats the leopards were the primary predator of livestock around the forest area in BiligiriRangaswamy Temple Tiger Reserve (69%), Bandipur Tiger Reserve (62%) and Nagarhole Tiger Reserve (62%) and second highest predator after tiger in Dandeli-Anshi (22%) and Bhadra (21%). Losses were attributed to nine species, with tiger (8%) and leopard (7%) being top ranked predators. (Karanth*et al*. 2013)

North East landscape:

Leopard presence was contiguously recorded from Buxa – Manans, Pakke – Nameri, and is believed to be throughout the foothills of Arunachal Pradesh. Leopard distribution was continuous in Kaziranga and KarbiAnglong hills. It was also recorded in forested areas of Dampa. Leopard signs were also recorded from Dibru – Saikhowa National Park, Tinsukia, Dibrugarh, Diphu, and North Cachar forests. Hardly any study has been conducted in North Eastern states of India to estimate density of leopard. In a study in Manas National Park, density of leopard was reported as 3.4(0.89)/ 100 sq km (Jimmy et al 2013)

Methodology

Identification of leopard: The current study used a relatively new pattern recognition software Hotspotter © for identification of leopard.The images of leopard are separated into left and right flank. the non-identifiable images were discarded and not used for the analysis. The flank was cropped to obtain the best pattern and was entered in database of the software (separately for left and right flank). Hotspotteruses two step methods for pattern recognition in animal, first by running a query and sequentially matching with each image in database and scoring it separately; second step is using a fast nearest neighbor search to check the queried image with the database. The software was at par in time and resource efficiency and large dataset was analyzed in limited timeframe. Post identification of individuals of leopard for each site through software, visual cross-checking was done.

Result:

Using Hotspotter, leopard was identified for the 9 study sites. Kawal TR has no tiger presence till (September 2015) and hence leopard is top predator for the park. NSTR and Umred has low tiger density. Rest all the sites have tiger as top predator with medium or high density of the same.

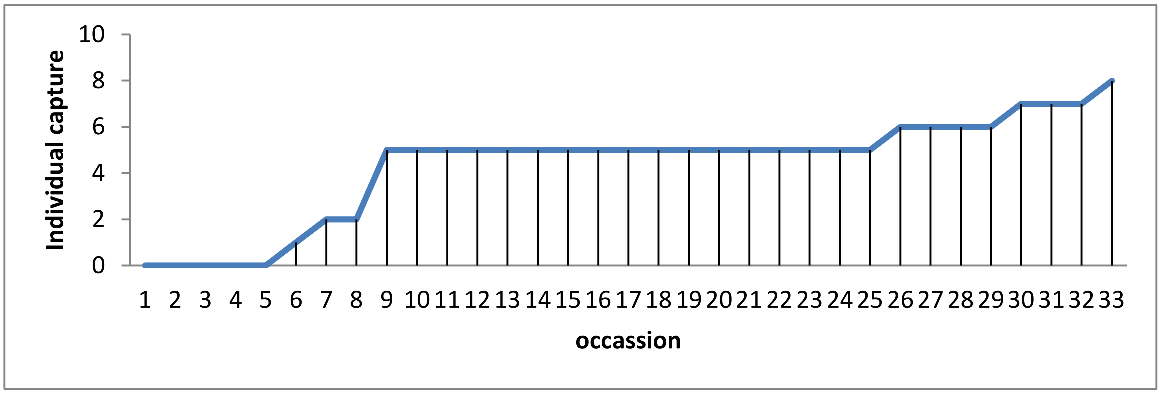
Table 6.2: Identified leopard individual through Hotspotter

S.no.	Site	Total capture	Identified individual
1	Kawal TR	57	8
3	Umred WLS	144	13
2	NSTR TR	792	36
6	Nagzira TR	381	28
4	Bor TR	138	18
5	Satpuda TR	287	62
7	Pench(MH) TR	210	26
8	Melghat TR	270	23
9	Tadoba TR	301	48
		2580	**262**

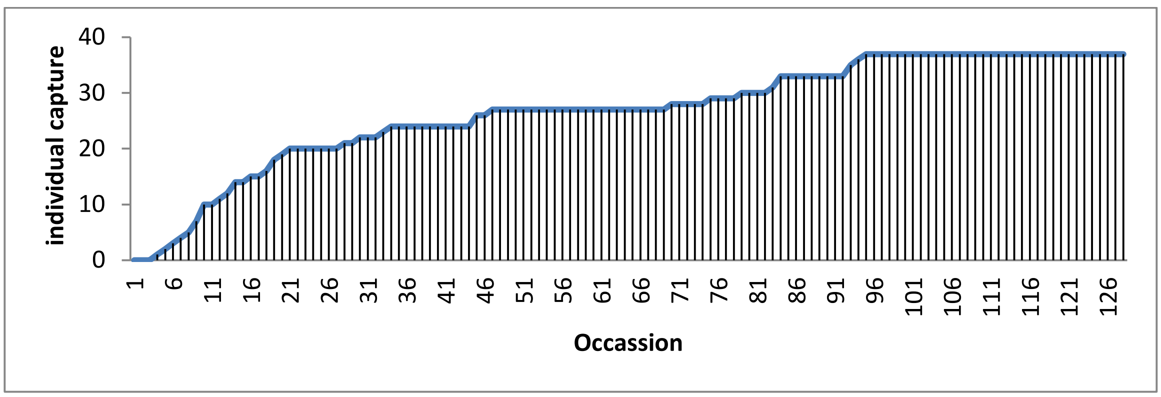
However, a major issue arose while identification of leopard that of single capture of individual. The camera-trap session for leopard had many single captures, hence a species area curve was developed for each site to suggest sampling occasion for leopard.

To check the saturation of population

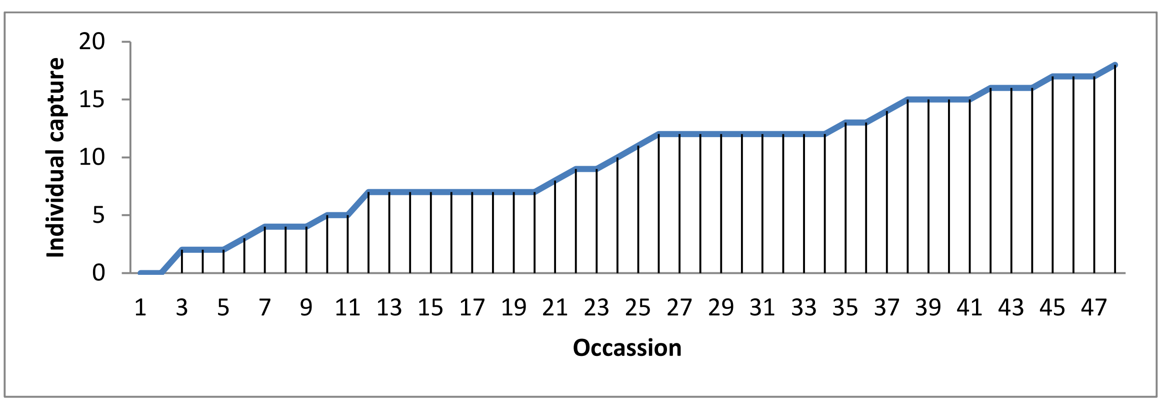
1. Kawal Tiger Reserve (Telangana): species area curve did not reach saturation in the sampling period (till 33rd occassion).



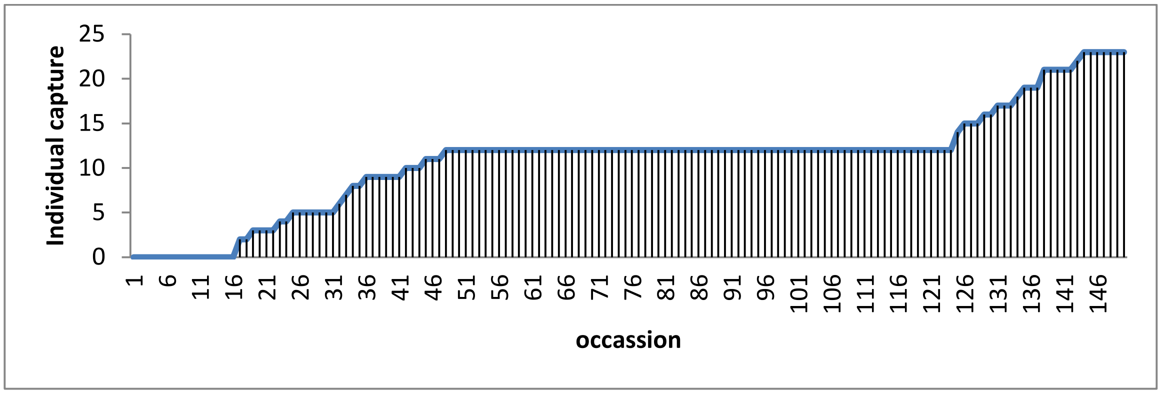
2. Nagarjunasagar Tiger Reserve (A.P.): species area curve showed saturation with sampling period (at 95th occasion).



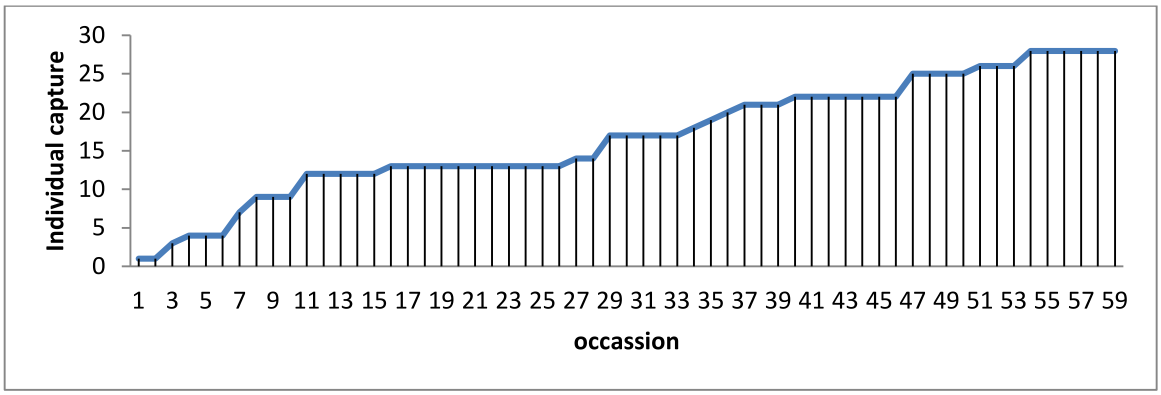
3. Bor Tiger Reserve (Maharashtra):species area curve did not reach saturation in the sampling period (till 48th occasion).



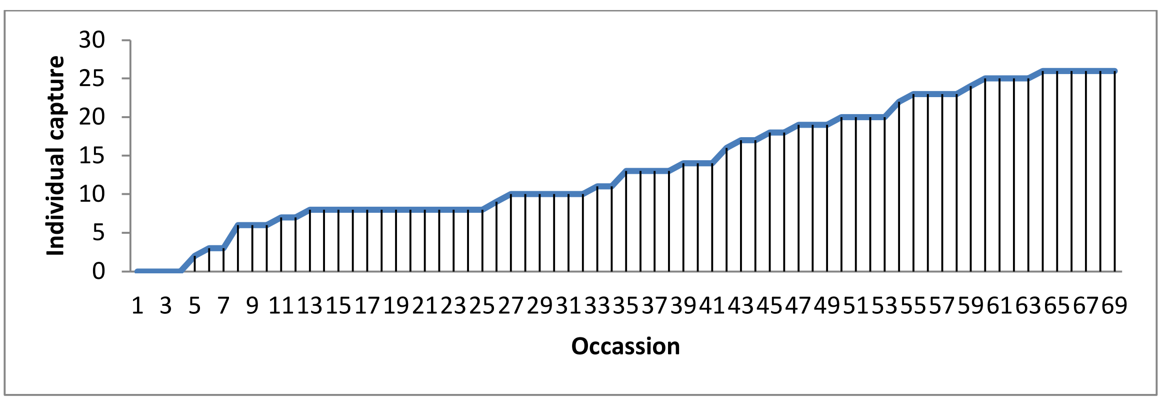
4. Melghat Tiger Reserve (Maharashtra):species area curve showed saturation within sampling period (at 48th occasion and second saturation on 144th occasion).



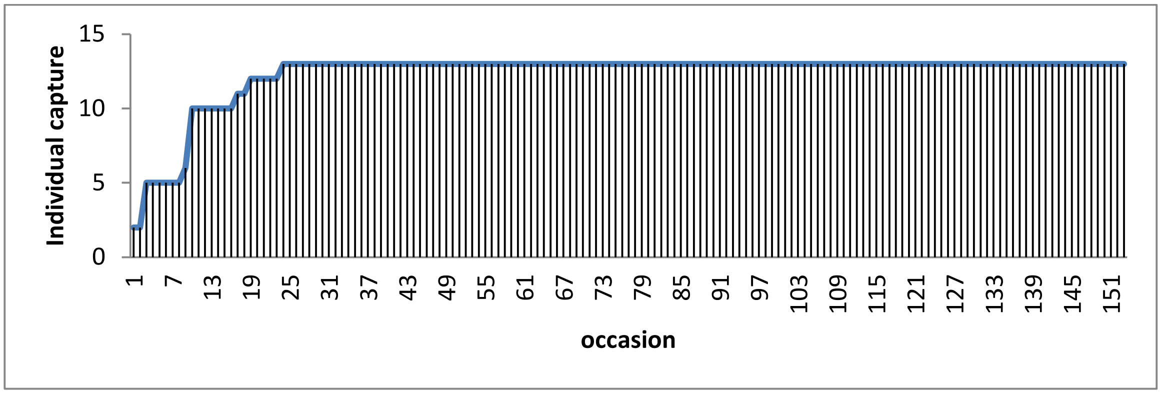
5. Nagzira Tiger Reserve (Maharashtra):species area curve showed saturation within sampling period (at 54th occasion).



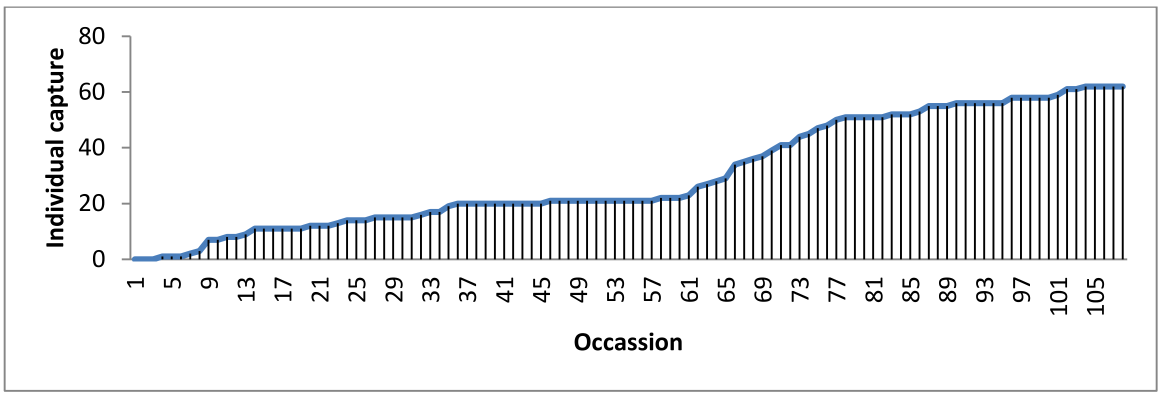
6. Pench Tiger Reserve (Maharashtra):species area curve showed saturation within sampling occasion (at 64th occasion).



7. UmredWLS (Maharashtra):species area curve showed saturation within sampling occasion (at 24th occasion).



8. Satpuda Tiger Reserve (Madhya Pradesh):species area curve showed saturation within sampling period (at 104th occasion).



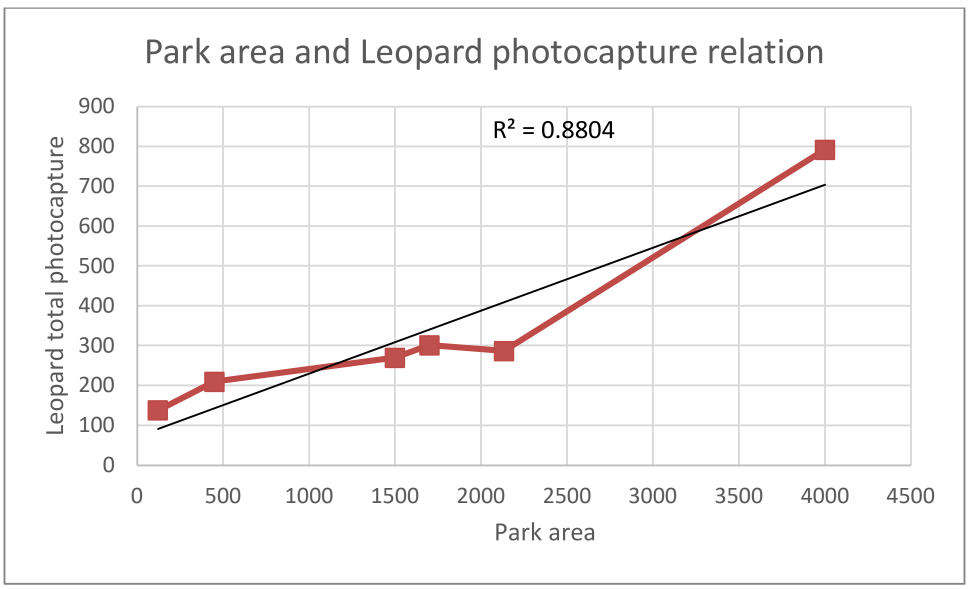
Leopard Capture and Protected Area size

The sampling occasion and size of PA should be taken into consideration when camera-trapping for leopard. It was concluded that with increase in park area, number of photo-capture of leopard increases too (Figure 6.1).

Table 6.3: Relation of Protected area size and Leopard photo-capture

SITE	PA AREA (sq km)	TOTAL CAPTURE OF LEOPARD	NUMBER OF OCCASION ON WHICH NEW INDIVIDUAL WAS CAPTURED
Bor	121	138	47th
Pench MH	450	210	64th
Melghat	1500	270	47th
Tadoba	1700	301	
Satpuda	2133	287	104th
NSTR	4000	792	60th

Figure 6.1. Relation of Protected area size and Leopard photocapture



Density analysis: Since the area sampled were not of equal size so for comparison, we used to divide the abundance data with sampled area and calculate the density. Conventionally, the area was calculated by identifying a buffer equivalent to Mean maximum distance moved (MMDM, Dillon and Kelly, 2008) or half-Mean maximum distance moved (1/2MMDM, Karanth 1995) by the subject animal in the sampled area. The conventional method estimates density of animal through capture-recapture method had issues due to "edge effects" (Otis et al, 1978). We use an improved method Spatially explicit capture–recapture (SECR) which is a set of methods for modelling animal capture–recapture data collected with an array of 'detectors' and uses the spatial information of the animal capture (Efford and Fewster 2013, Efford, 2009). SECR is different from the conventional method of density estimation by capture –recapture method in using the spatial information of animal capture. In this study, we have used SECR method to estimate density of leopard. The method follows the assumption that detection probability (g0) will be maximum at the activity center of the animal and decreases as we move distance away (Sigma) from this activity center.

The primary data for SECR are (i) the locations of the detectors or traps, and (ii) detections of known individuals on one or more sampling occasions (i.e., their detection histories) or capture.

Table 6.3 Density Estimate of Leopard through SECR

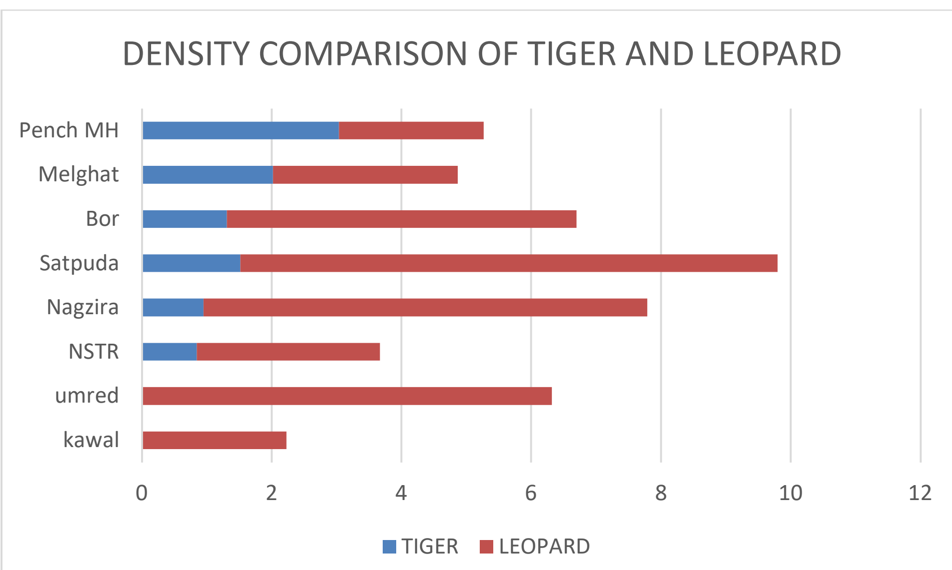
S.no.	Site	Cameratrapped area	Camera trap No.	Effort	$\hat{D}$ ML SECR (per 100 km^2)	Sigma (SE) (km)	g0 (SE)
1	**Kawal TR**	135.42	56	2184	2.23(-0.84)	2.93 (-0.38)	0.01(-0.004)
2	**Umred WLS**	102.63	141	4089	6.32 (1.790)	1.95 (0.17)	0.018 (0.003)
3	**NSTR TR**	1233.64	449	20777	2.82 (0.35)	2.52 (0.23)	0.99(-0.09)
4	**Nagzira TR**	400.35	205	13940	6.84 (1.48)	4.09 (0.59)	0.08(-0.02)
5	**Satpuda TR**	504.38	276	5868	8.28 (1.08)	2.50 (0.11)	0.01(-0.001)
6	**Bor TR**	95.5	135	4392	5.39 (1.31)	2.98 (1.11)	0.22 (0.003)
7	**Melghat TR**	477.64	364	8309	2.85(-0.62)	2.74(-0.2)	0.56(-0.08)
8	**Pench(MH) TR**	322.72	176	14256	2.23 (0.44)	1.47 (0.23)	0.12(-0.02)

Comparison of tiger and leopard density of the study area

Table 6.4 Density Estimate of Leopard through SECR (from current study) and tiger density estimate through SECR (Tiger estimation, 2014 report)

S.no.	Site	Tiger density (per 100 km^2)	Leopard density (per 100 km^2)
1	**Kawal TR**	NA	2.23(-0.84)
2	**UmredWLS**	NA	6.32 (1.790)
3	**NSTR TR**	0.85(0.16)	2.82 (0.35)
4	**Nagzira TR**	0.95(0.41)	6.84 (1.48)
5	**Satpuda TR**	1.52(0.42)	8.28 (1.08)
6	**Bor TR**	1.31(0.62)	5.39 (1.31)
7	**Melghat TR**	2.02(0.51)	2.85(-0.62)
8	**Pench(MH) TR**	3.04(0.62)	2.23 (0.44)

Figure 6.2. Density comparison of tiger and leopard



Discussion and conclusion:

Leopard identification through Hotspotter proved to be user friendly and less time consuming. During the field survey, the decision to run the survey requires to check the species area curve which need identification of leopard individual. However, the large photo-capture of leopard and difficulty in identification poses a big issue to execute this exercise in field. A relatively easy algorithm which require minimum configuration of laptop like hotspotter can be used for leopard identification in field and understand the species areas curve for survey. Since this software was used post data collection hence in most of the surveyed study sites, the species area curve did not reach a saturation curve. An analysis of species area curve for leopard varied for study sites. A new Leopard was added during sampling survey at much higher sampling occasion than 45th (the minimum sampling occasion for tiger census protocol). The species area curve for leopard did not reach saturation till 47th occasion in Bor, 46th occasion in Melghat (and further addition of new individual at 121st occasion), 53rd occasion in NNTR, 61st occasion in Pench MH, 91st in NSTR and 101 in Satpuda. Only Umred showed species area curve saturation on 26th occasion. However, the software Hotspotter has its limitation. Since it can compare pattern of one flank at a time, many individuals can be missed. Secondly a huge dataset to compare individual from different sites to understand corridor movement does not provide solution here as database maintenance is a limitation. However, for field survey it is fast and reliable and can be used with ease compared to the other available softwares.

Protected area size should be taken into consideration while planning cameratrap survey for leopard. A positive relation of leopard photocapture with park size (Figure 6.1) and no saturation in species area curve till 100th occasion for large size of park suggest to design a protocol of higher sampling occasion for leopard.

Leopard density is comparable to tiger density in high tiger density area like Melghat and Pench MH and increases with decrease in tiger density areas (exception NSTR and Kawal) (Figure 6.2). Low prey density and sampling occasion might influence the low leopard density in these areas.

The tiger being dominant predator will restrict the occurrence and movement of lower predator like leopard. Where tiger is absent or very low density there leopard would be suggested to have high density if the environment is suitable (i.e high prey base and low human pressure). This result was not in concordance in case of Kawal and NSTR where low leopard density was found. Both these sites have low prey base and rampant human pressure. However, in Umred, leopard density was found to be high indicating a good prey base for the animal to survive. In Satpuda TR also which has low tiger density, highest leopard density was found in the comparable sites. Same is with Bor TR and Navegaon-Nagzira TR has high leopard density where tiger density is medium. Pench (MH), Melghat had comparable tiger and leopard density due to probable reason of high prey availability and range of prey available for the two carnivores to co-exist.

- @inproceedings{crall2013hotspotterWACV , author = {Crall, Jonathan P and Stewart, Charles V and Berger-Wolf, Tanya Y and Rubenstein, Daniel I and Sundaresan, Siva R} , title = {HotSpotter - Patterned Species Instance Recognition} , booktitle = {WACV} , year = {2013} , pages = {230--237} , organization = {IEEE} }
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TEMPORAL SEGREGATION AMONGST TIGER AND LEOPARD, DHOLE AND MESOPREDATOR

- **Temporal overlap between alpha predator and leopard**
- **Temporal overlap amongst alpha, beta and gamma predators**
- **Temporal overlap between alpha and beta predators and its prey**

The niche differentiation is based on three axes i.e. habitat, food and time (Schoener 1974). The initial studies of niche differentiation treated exploitative competition as the basis of niche differentiation; hence time was not treated as independent axis (Carothers 1984, Schoener 1974). The concept of diel differences in activity time is a major axis of niche differentiation was introduced by MacArthur & Levins (1967). The sympatric and ecologically similar species have been found to differ in their activity pattern; the argument being that evolutionary the competing species avoid the same part of the diel cycle (Johnston & Zucker 1983, Kronfeld-Schor & Dayan 2003, Gutman 2005). The temporal separation has been considered uncommon in nature yet its expression has been attributed to high predation and low resource abundance (Schoener 1974, Fellers, 1989, Janis 1976).

Temporal activity studies have focused on understanding seasonal effect on animal activities (Rabinowitz 1991, Zang 1991, Chen et al), animal activity response to human disturbance (Gray et al 2011). Amongst plant also it was observed that the peak release of pollen in species of Acacia in Tanzania was more regularly spaced in time to reduce the competition (Stone et al 1996). Similarly, temporal partitioning was observed in ectomycorrhizal fungal community (Koide et al 2007). In spiny mice where experimental observation concludes that the diurnal golden spiny mice shift its foraging activity to both nocturnal and diurnal in absence of common spiny mice (Gutman 2005). Hawkmoth showed crepuscular activity rather than diurnal in the presence of hummingbird (Carpenter 1979). In ungulates, temporal partitioning was observed utilizing waterhole resource (Ayeni, 1975, Weir and Davison, 1965). In study of waterhole at Zimbabwe, Impala, Kudu, Roan, Sable shifted their temporal activity at waterhole according to Elephant to avoid interference competition (Valeix er al 2007). In same study buffalo was observed to avoid temporal activity with elephant to avoid space crunch. It is observed that ungulate divide the activity at waterhole according to water size where larger bodied animal use waterhole from dusk to dawn while small sized from dawn to dusk (Ayeni 1976).

On a macro scale the overlap is visible between large home range carnivores. But to understand the co-existence in the unilateral dominance (top-down control) of carnivores many micro-scale studies have been undertaken and tried to identify the factors responsible to carnivore co-existence. The studies here have focused on animal activity according to the prey. Puma and Jaguar activity coincides with their prey (Scognamillo et al 2003, Harmsen et al, 2011). Coyotes showed temporal variations independent of wolf densities (Burger & Geese, 2007). Temporal segregation was found amongst similar Pampa and Andean cats but with top predator Puma, both the less dominant species showed overlap as they might be segregating on basis of diet (Lucherini et al 2009). Leopard as a subordinate to coexist with large predator in many areas of range overlap must have the ability to exist within a decrease niche breadth or else shift to areas where tiger is absent (Seidensticker 1976)

Method:

The temporal activity of carnivores and herbivores is analysed to fit kernel density function to times of observations of animals (Ridout and Linkie 2009). Temporal activity has been used to find the peak activity of animals and also to see the overlap in activity pattern to understand the predator-prey relation as well as avoidance amongst co-predators (Ramesh et al 2012, Farris, 2015, Carter 2015). The overlap package in R (Meredith and Ridout 2018) is used to estimate the overlap co-efficient between temporal activity of tiger with its co-predators (leopard and wild dog) and its prey (gaur, sambar, nilgai, chital and livestock) in central India. The temporal activity of beta and gamma carnivores was also analysed for central India. The coefficient of overlap is the area under the curve that is formed by taking the minimum of the two density functions at each time point. The temporal activity is measured quantitatively ranging between 0 (no overlap) and 1(complete overlap).

Out of 5 estimator of co-efficient of overlap (Schmid and Schmidt, 2006), $\Delta 4$ is used as it worked best for circular distribution and when the sample size is more than 75. For estimating confidence interval, 1000 smoothed bootstrap was generated samples for tiger and leopard. For 95% confidence interval confidence interval was extracted.

The camera-trap capture of these carnivores was clubbed at an interval of one hour to remove overrepresentation of one particular time. (Table 7.1).

Table 7.1: Unique capture of camera trapped species used for temporal activity analysis

SPECIES	TOTAL CAPTURE	UNIQUE CAPTURE
TIGER	2450	1306
LEOPARD	1858	1197
DHOLE	2265	523
JUNGLE CAT	1177	794
RATEL	418	275

The data was further analysed for High tiger density area (Melghat , Pench MH and Tadoba), Medium tiger density area (Bor and Satpuda) and low Tiger density area (Nagzira Nawegaon and NSTR) to understand the temporal interaction of tiger with its co-predators leopard. Leopard temporal activity was also analysed for no tiger area like Kawal. The activity of leopard could be basis of tiger interference or activity of its resources. The activity of tiger could be influenced by human activity (i.e. human movement as well as livestock movement) or its prey activity (i.e Gaur, Nilgai, Sambar, Chital).

Result:

In central Indian landscape, the peak activity of tiger was observed to be at dusk while leopard was observed to be active both at dusk and dawn and a high temporal overlap (0.90)

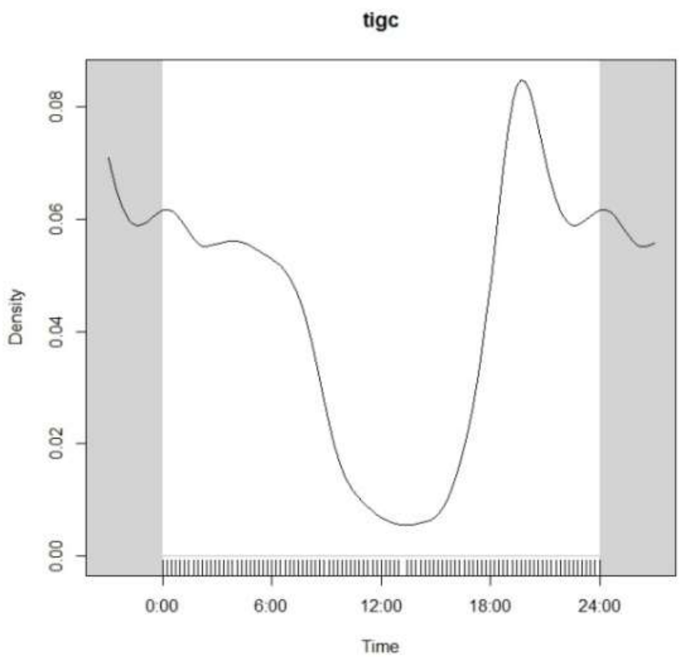


Figure 7.1. Temporal activity of tiger in central India

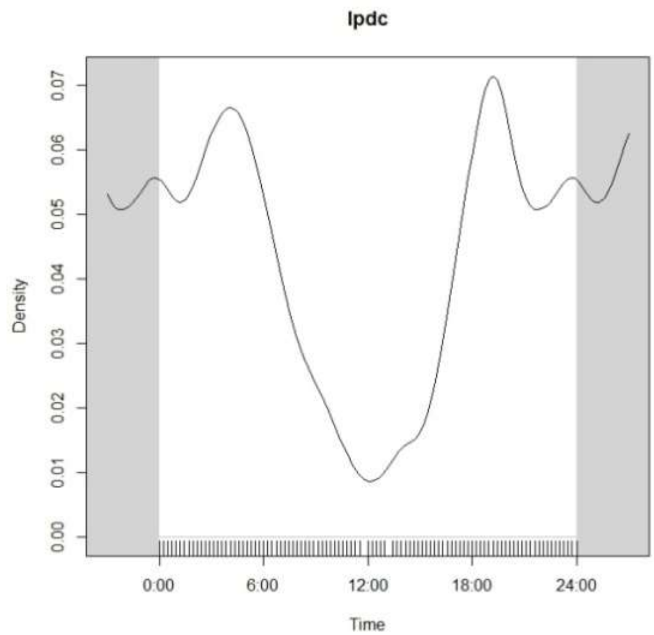


Figure 7.2. Temporal activity of leopard in central India

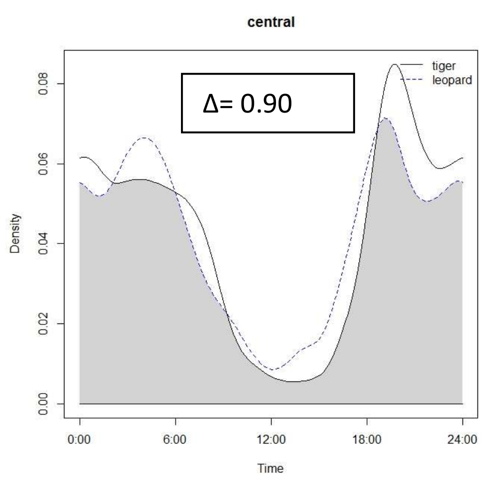


Figure 7.3. Temporal activity overlap between tiger and leopard in central

Table 7.2 TEMPORAL OVERLAP BETWEEN TIGER AND LEOPARD

Site	Melghat	Pench MH	Bor	Satpuda	NSTR	NNTR	Umred	kawal
Overlap (DAT)	0.9	0.83	0.84	0.86	0.81	0.82	0.82	NA

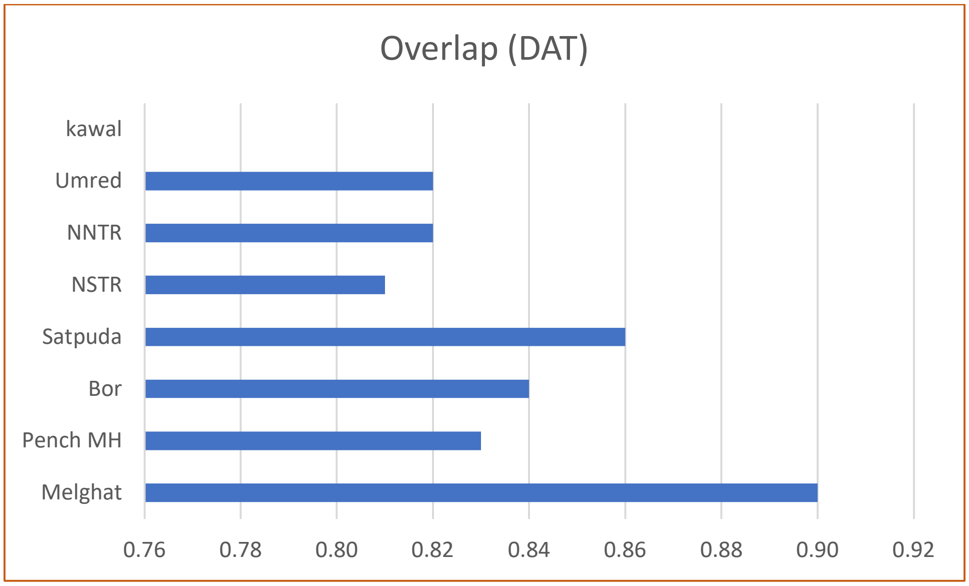


Figure 7.4. Temporal activity overlaps between tiger and leopard across various sites in central

1. Nagarjuna Sagar Tiger Reserve

NSTR, the leopard activity was at peak before dawn and most active at dusk 1800hrs whereas tiger peak activity was found to be pre dawn and post dusk (22:00- 23:00). The coefficient of overlap was found to be 0.81.

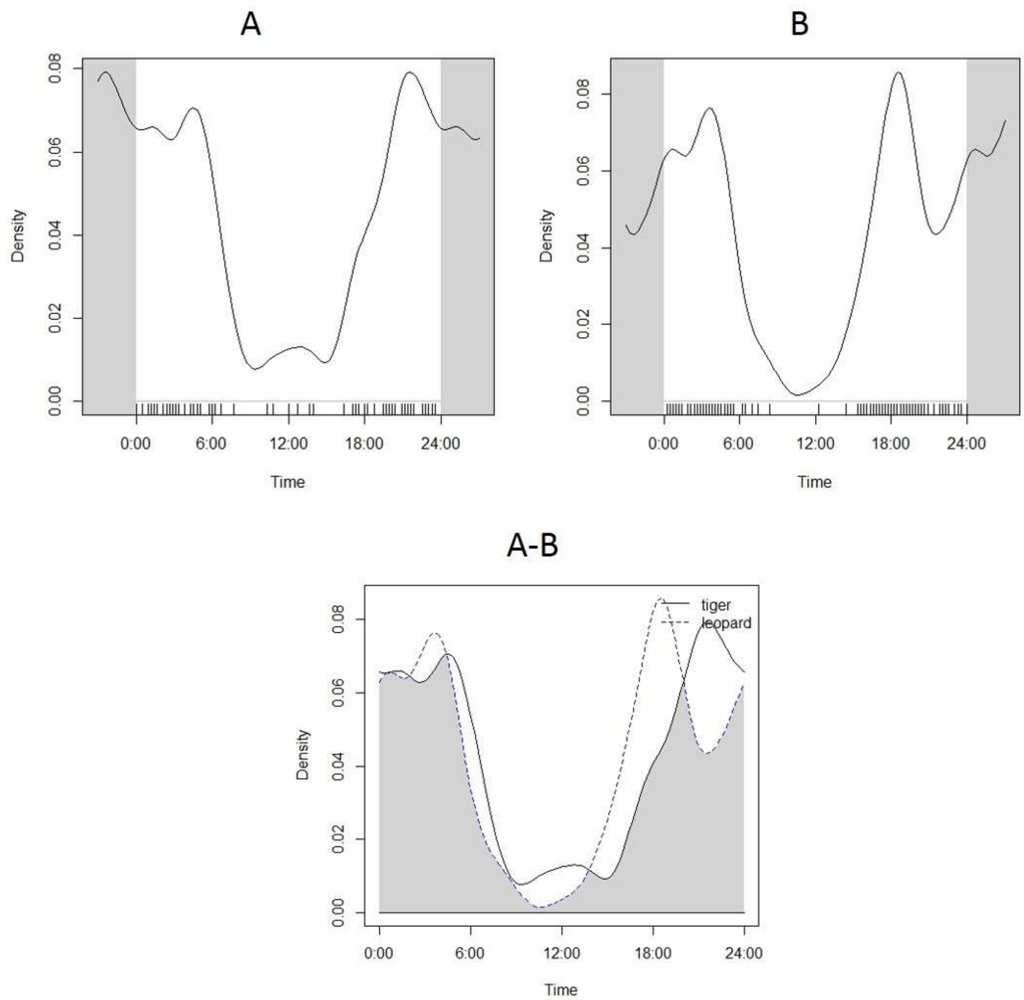


Figure 7.5 Temporal activity of tiger (A) leopard (B) and activity overlap between tiger and leopard (A-B) in NSTR

2. **Umred WLS** the leopard peak period was before dawn (before 6000hrs) but dusk and post dusk activity of leopard very low whereas tiger was active pre dawn but maximum activity was observed at dusk (1800 hrs). The reduced activity for leopard at dusk could be attributed to active peak of tiger. The overlap coefficient was 0.82 (CI:0.72-0.90).

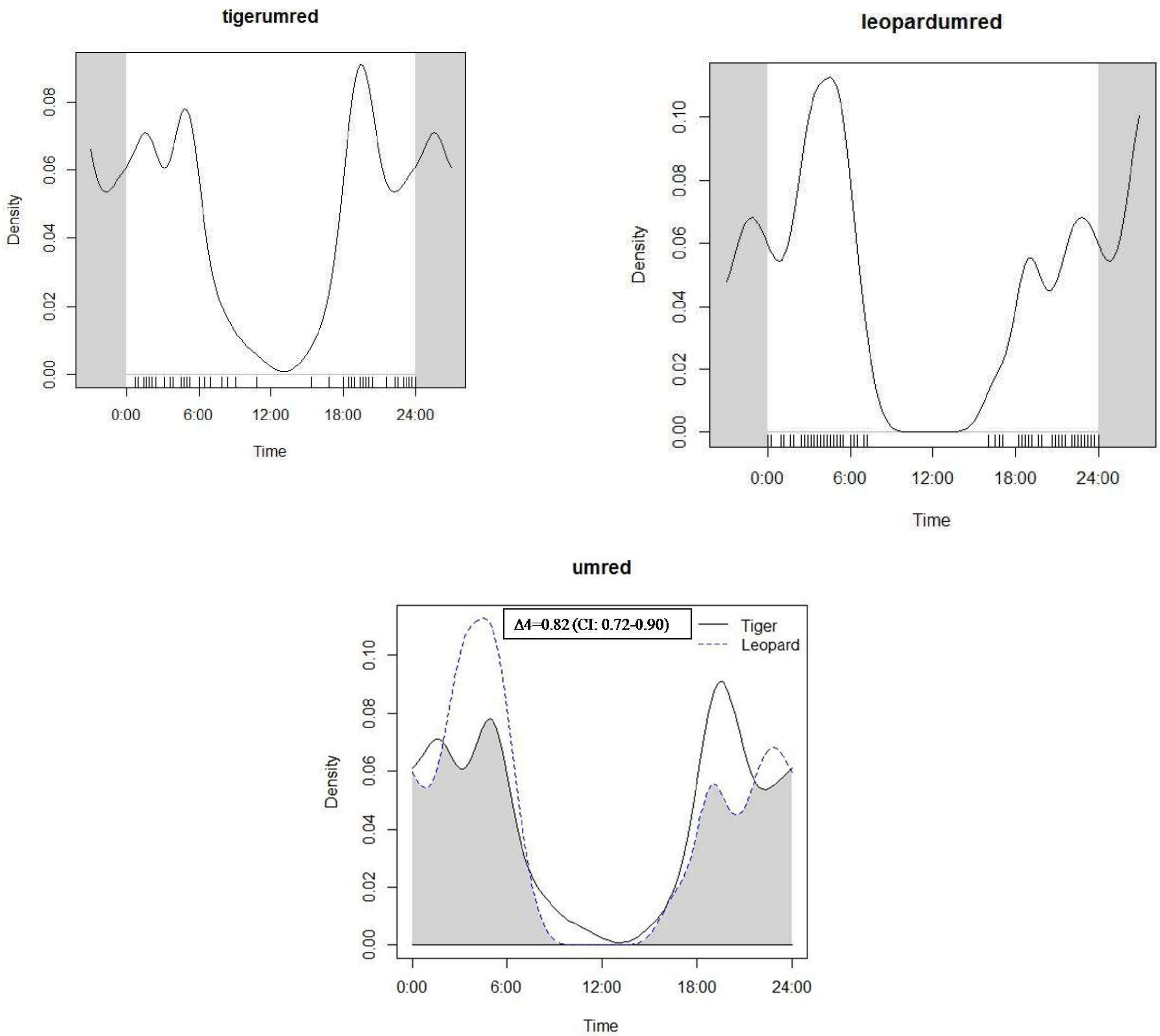


Figure 7.6 Temporal activity of tiger (A) leopard (B) and activity overlap between tiger and leopard (A-B) in Umred

3. **NNTR,** the leopard activity was at peak at dusk 1800hrs whereas tiger peak activity was found to be pre dawn and post dusk. The coefficient of overlap was found to be 0.82

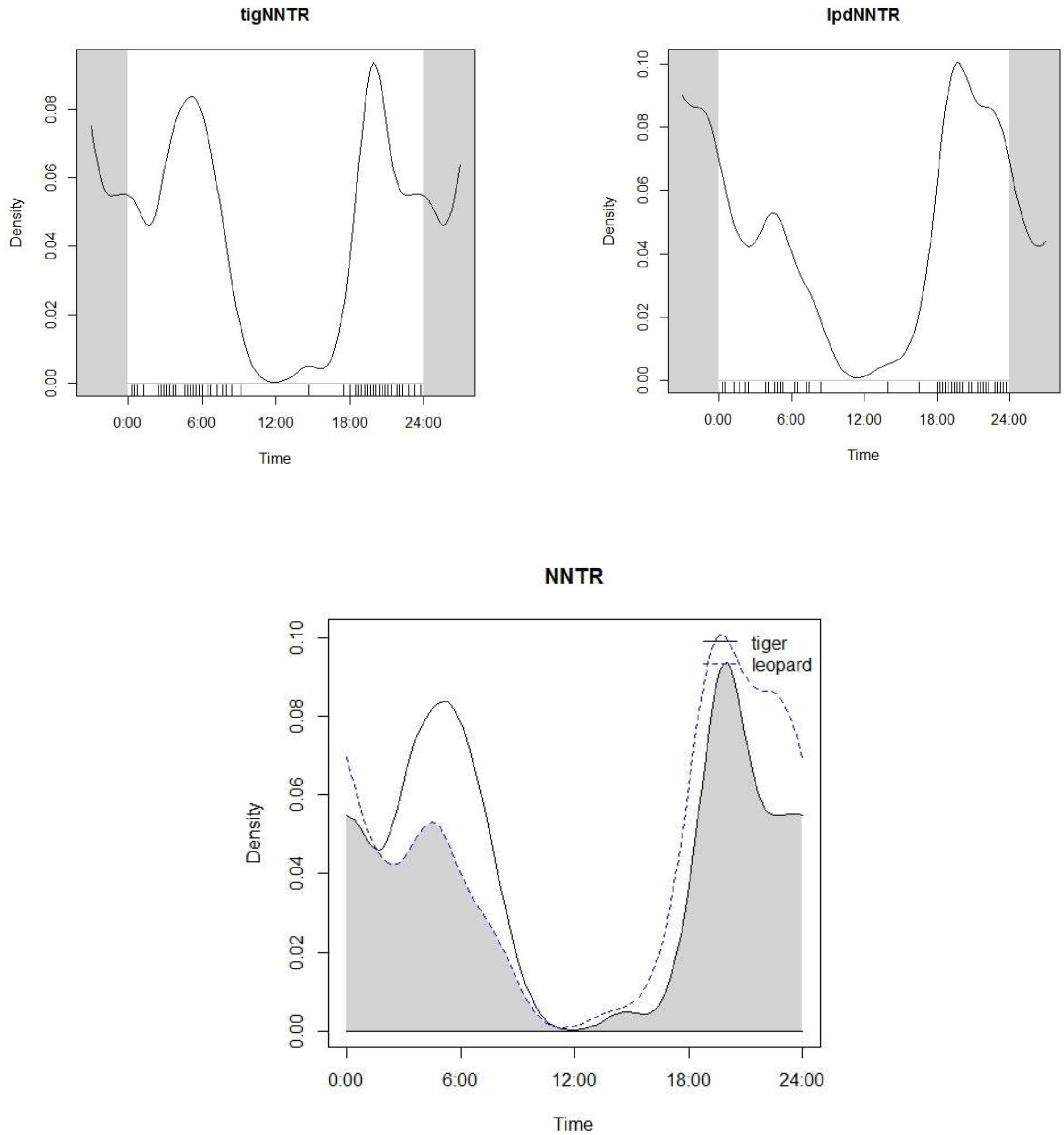


Figure 7.7 Temporal activity of tiger (A) leopard (B) and activity overlap between tiger and leopard (A-B) in NNTR

4. Bor TR:

A high overlap was observed between tiger and leopard. In **Bor TR** the peak activity of leopard was found to be before dawn (before 6000hrs) and at dusk (at 1800hrs) whereas the tiger activity was found to at dawn and dusk (6000hrs and 1800hrs). The coefficient of overlap for tiger and leopard activity period was Δ4=0.84 (CI: 0.75-0.92) showing high overlap between activity of tiger and leopard in Bor TR.

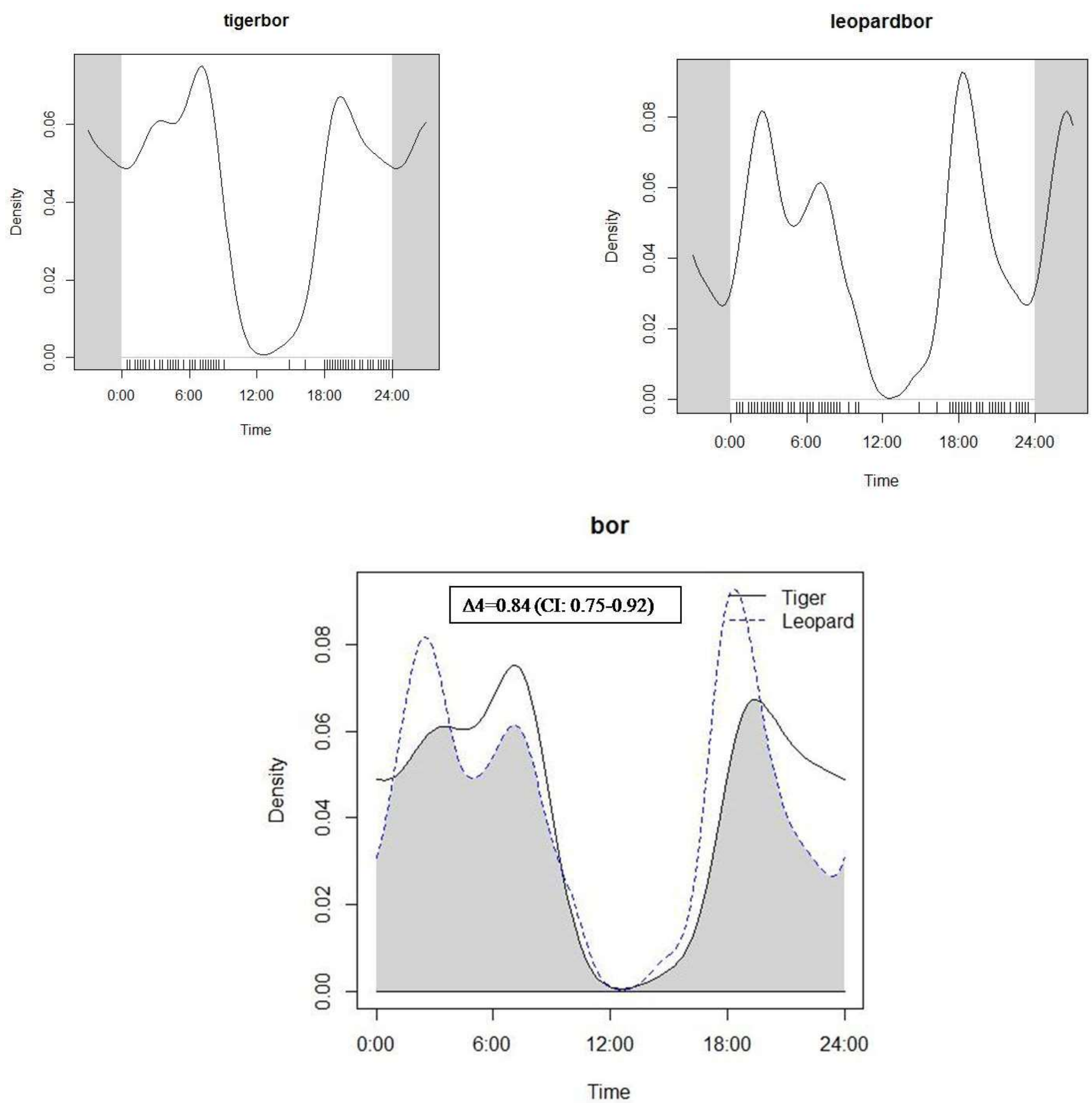


Figure 7.8 Temporal activity of tiger (A) leopard (B) and activity overlap between tiger and leopard (A-B) in Bor

5. **Satpuda,** the leopard activity was at peak at dusk 1800hrs. Similarly tiger peak activity was found to be at dusk . The coefficient of overlap was found to be 0.86

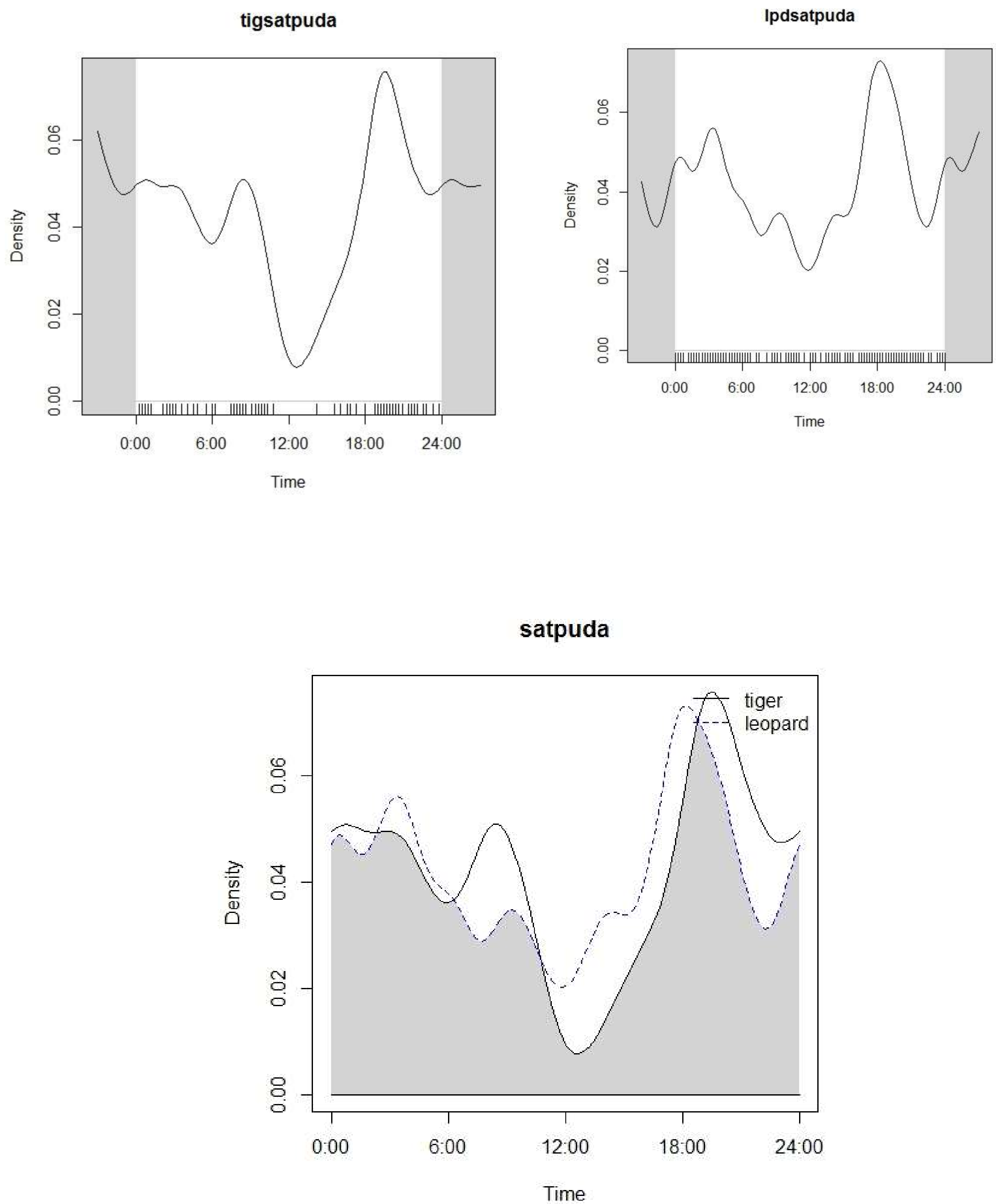


Figure 7.9 Temporal activity of tiger (A) leopard (B) and activity overlap between tiger and leopard (A-B) in Satpuda

6. **Pench MH** the leopard was found to be active at dawn and pre dawn but at dusk and post dusk the activity for leopard is very low whereas tiger was found to be active pre dawn (before 6000hrs) but very high activity peak was observed post dusk (post 1800hrs). The leopard low activity post 1800hrs can be explained by high activity of dominant predator (tiger) at same time. The coefficient of overlap was found to be 0.87(CI: 0.80-0.93).

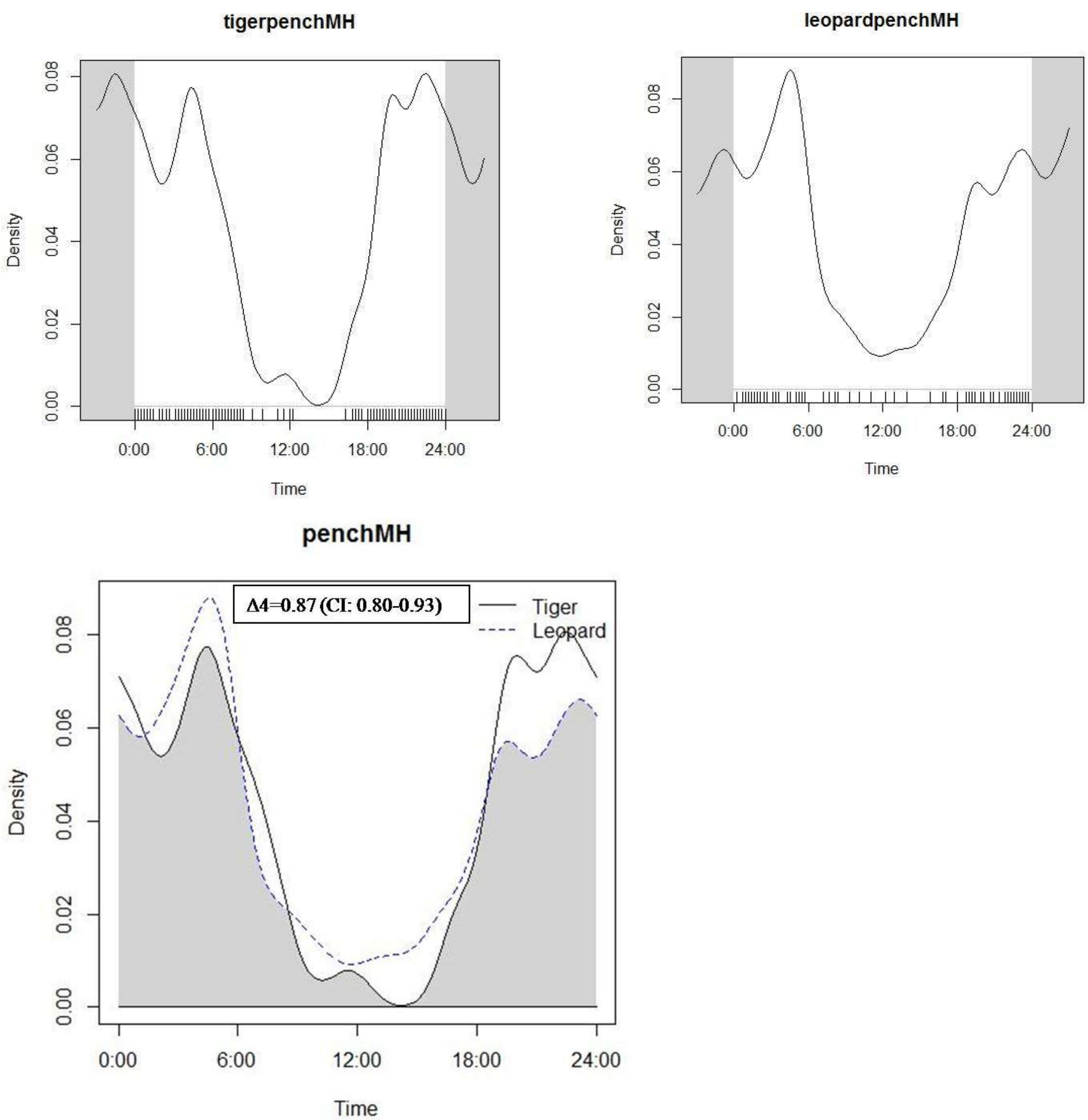


Figure 7.10 Temporal activity of tiger (A) leopard (B) and activity overlap between tiger and leopard (A-B) in Pench MH

8. **Melghat TR,** the leopard activity was at peak at dawn (6000hrs) and post 1800hrs whereas tiger peak activity was found to be pre dawn and post dusk. The coefficient of overlap was found to be 0.89(CI:0.83-0.94)

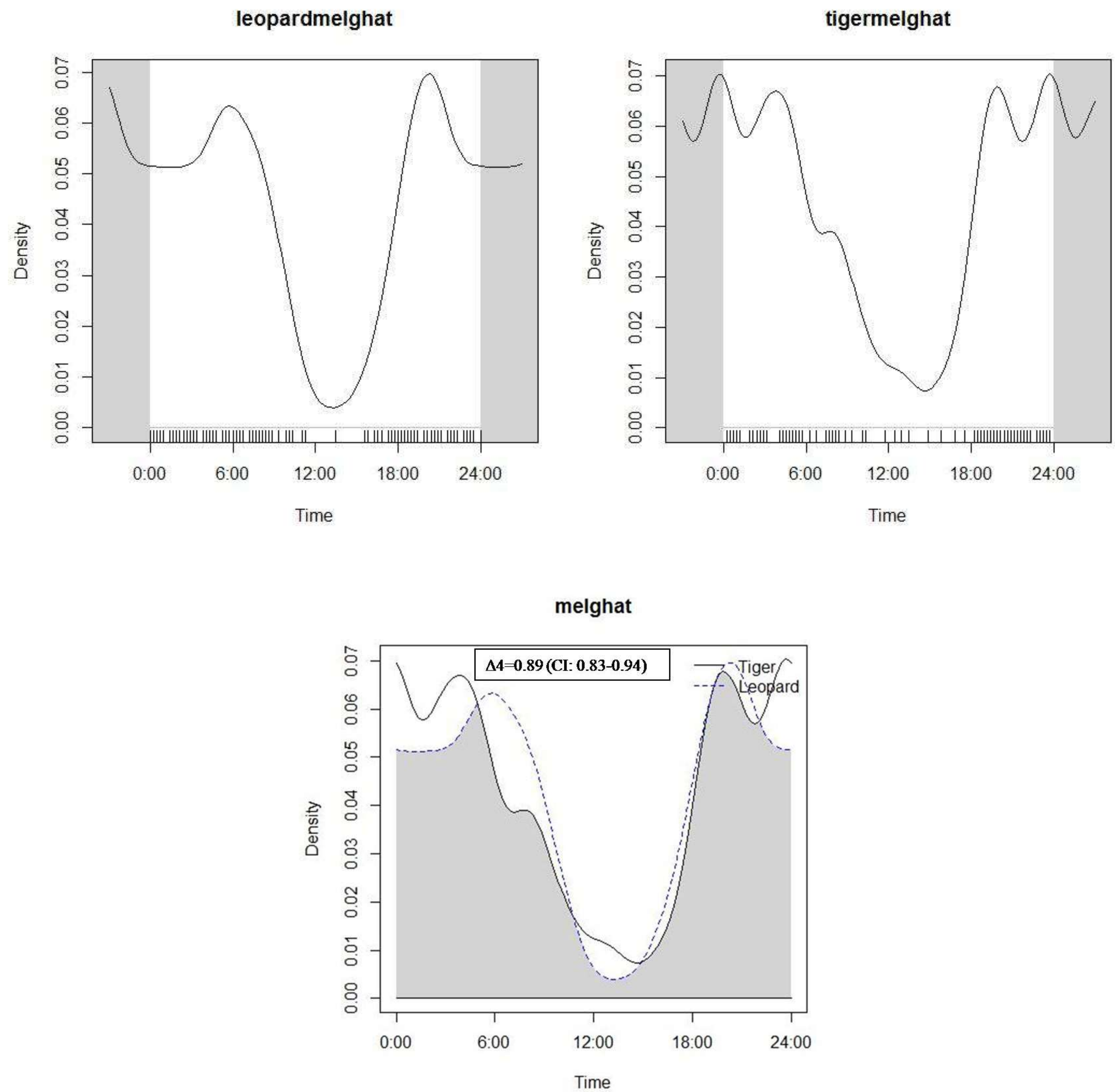


Figure 7.11 Temporal activity of tiger (A) leopard (B) and activity overlap between tiger and leopard (A-B) in Melghat

The tiger interaction with its co-predator leopard is one of the primary objectives of the study. To understand this, leopard temporal activity in high density tiger areas and no tiger presence area was compared.

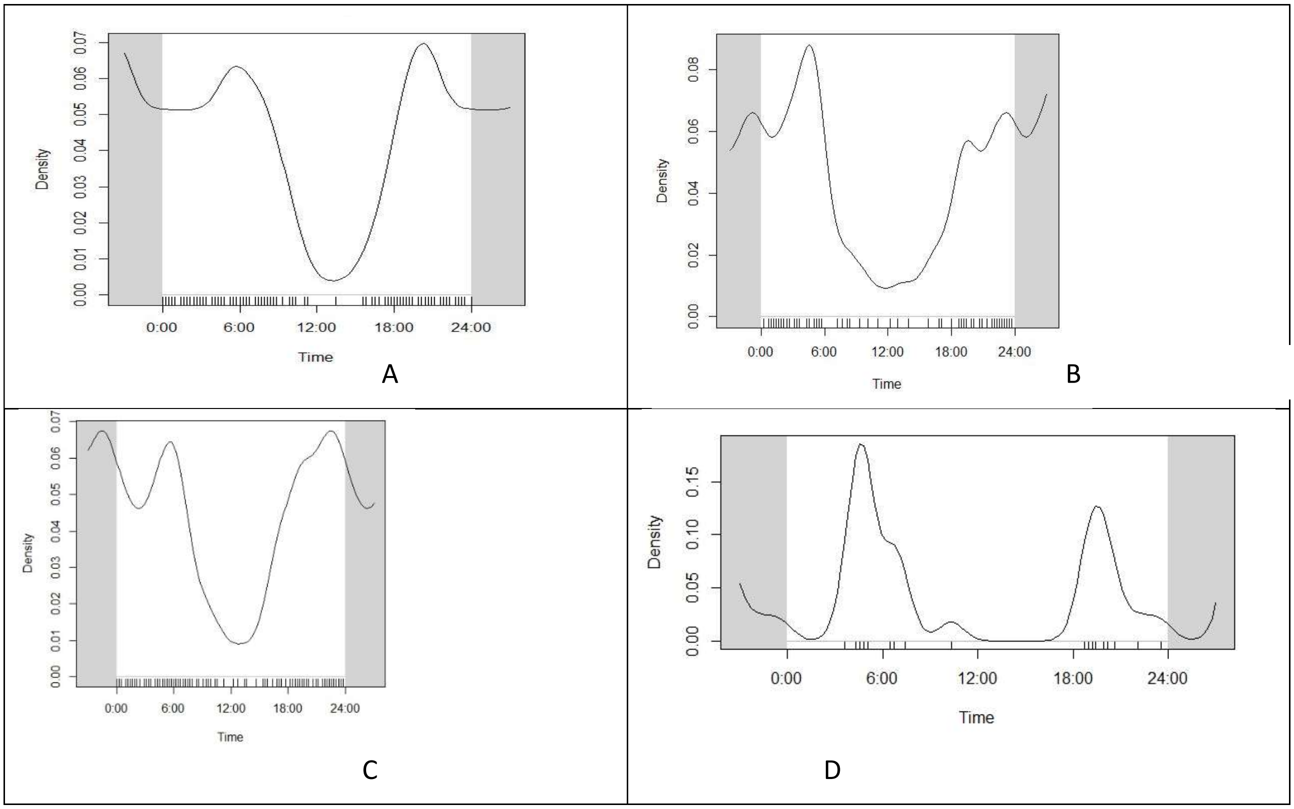


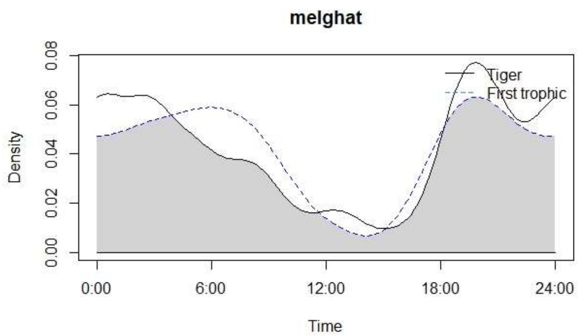
Figure 7.12Temporal activity of leopard in Melghat (A) , Pench MH (B) , Tadoba (C) and Kawal (C)

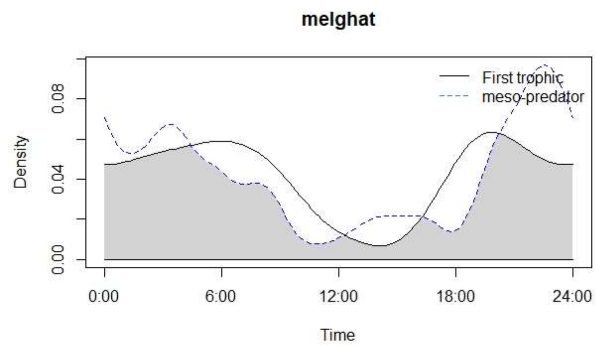
The temporal activity of leopard in high tiger density area (Melghat, Pench MH and Tadoba) covers a longer span with peak activity at at dawn (6000hrs) and post 1800hrs. However, in Kawal where tiger is not present since long, the leopard activity is majorly corresponds with the peak time of prey i.e. Sambar.

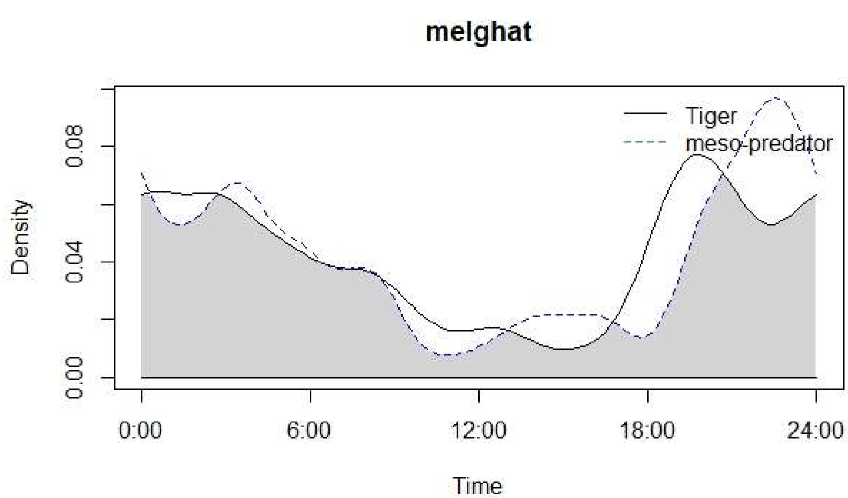
The temporal segregation between the three trophic was calculated in varying tiger density areas.

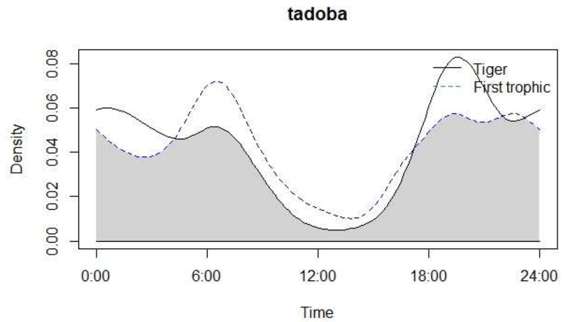
SITE	TIGER X FIRST TROPHIC	FIRST TROPHIC X MESO-PREDATOR	TIGER X MESO-PREDATOR
MELGHAT	0.88	0.79	0.85
TADOBA	0.86	0.72	0.77
PENCH MH	0.76	0.79	0.88
SATPUDA	0.82	0.63	0.77
NSTR	0.75	0.81	0.72
KAWAL		0.72	

High tiger density area:








tadoba
Tiger
First trophic
Density
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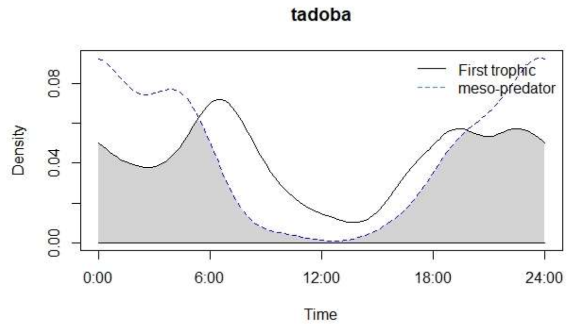
Time


tadoba
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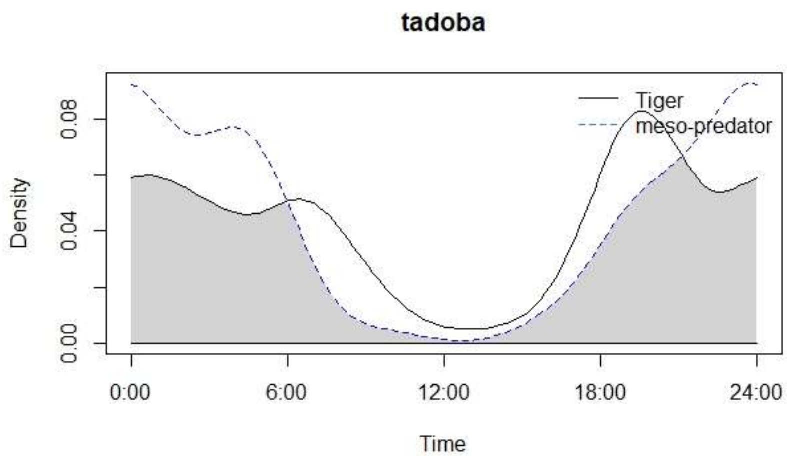
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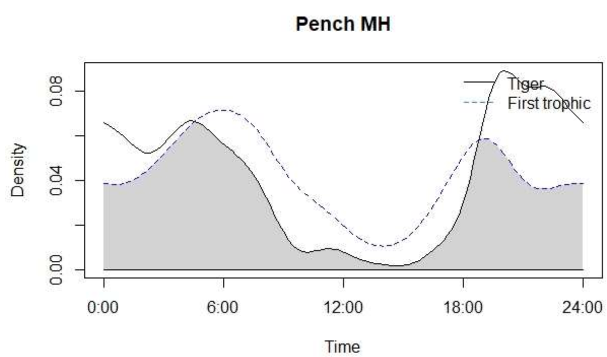
Pench MH
Tiger
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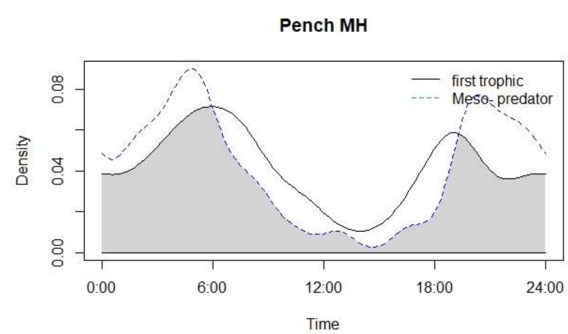
Pench MH
first trophic
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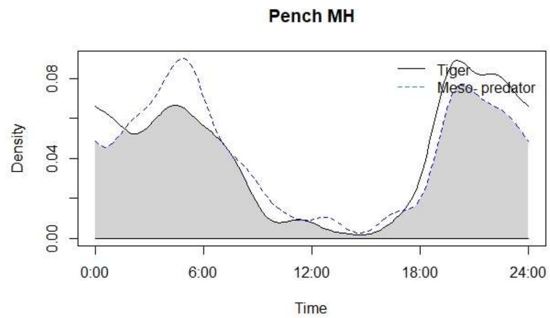
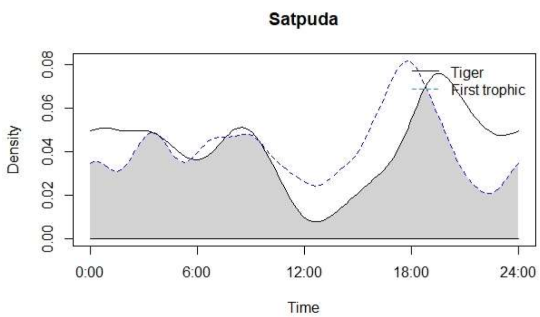
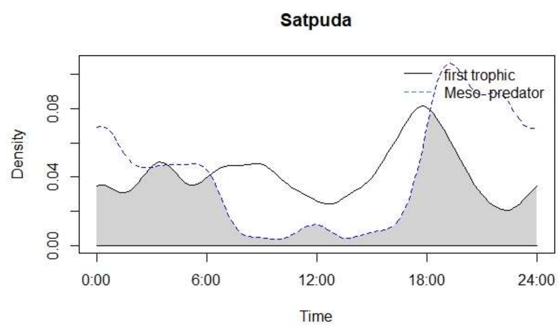
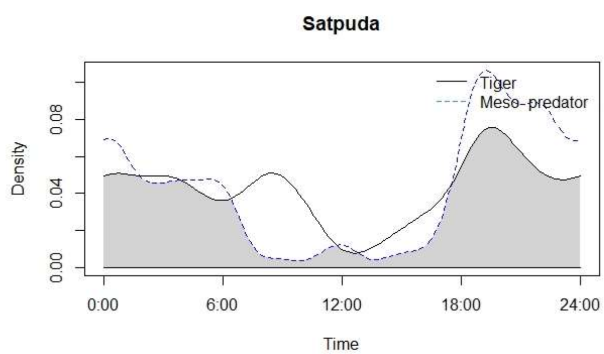


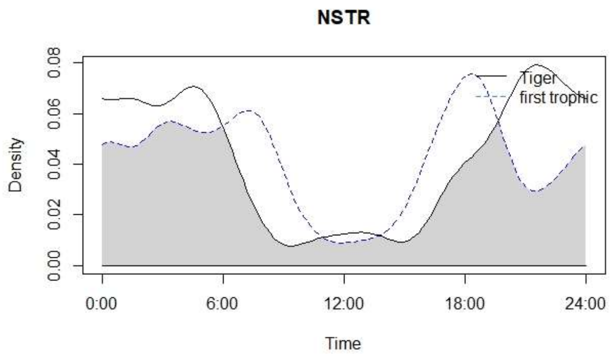
Medium tiger density area

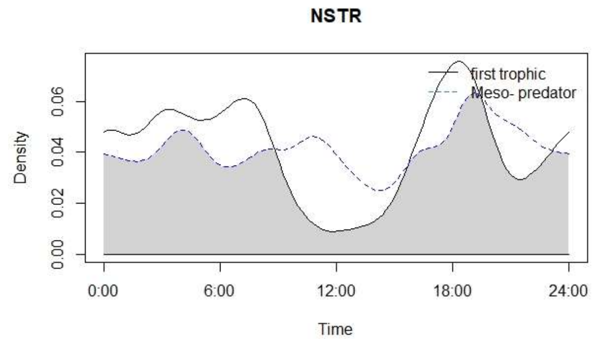


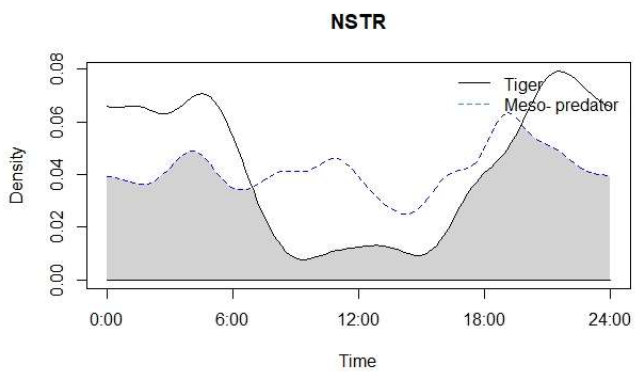




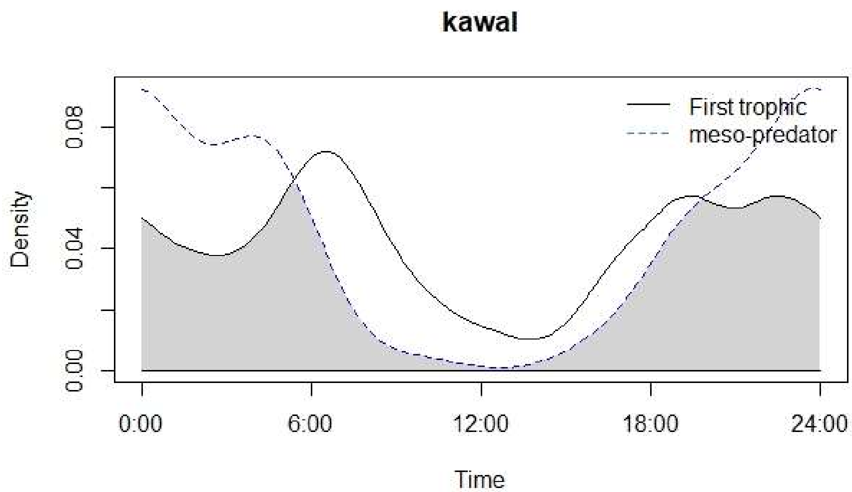
Low tiger density area







No tiger area



In central Indian landscape, the peak activity of tiger was observed to be at dusk while the wild dog has been observed to be most active at dawn. A relatively low temporal overlap coefficient for the central Indian landscape was observed between tiger and dhole (59) and leopard and dhole (63).

Table 7.3Temporal overlap across species in central Indian landscape (cumulative data)

	TIGER	LEOPARD	DHOLE	JUNGLE CAT	RATEL	SMALL INDIAN CIVET	ASIAN PALM CIVET
TIGER	*	90	59	84	82	74	71
LEOPARD	**90**	*	63	80	78	71	69
DHOLE	59	63	*	44	43	35	34
JUNGLE CAT	84	80	44	*	90	89	84
RATEL	82	78	43	**90**	*	86	81
SMALL INDIAN CIVET	74	71	35	89	86	*	93
ASIAN PALM CIVET	71	69	34	84	81	**93**	*

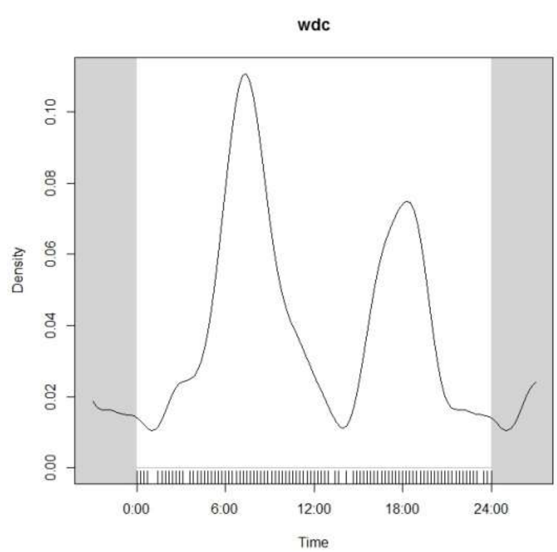


Figure 7.13 Temporal activity of dhole in central Indian landscape

The high temporal overlap was also observed between two other ecologically similar species 1) jungle cat and honey badger 2) small Indian civet and Asian palm civet

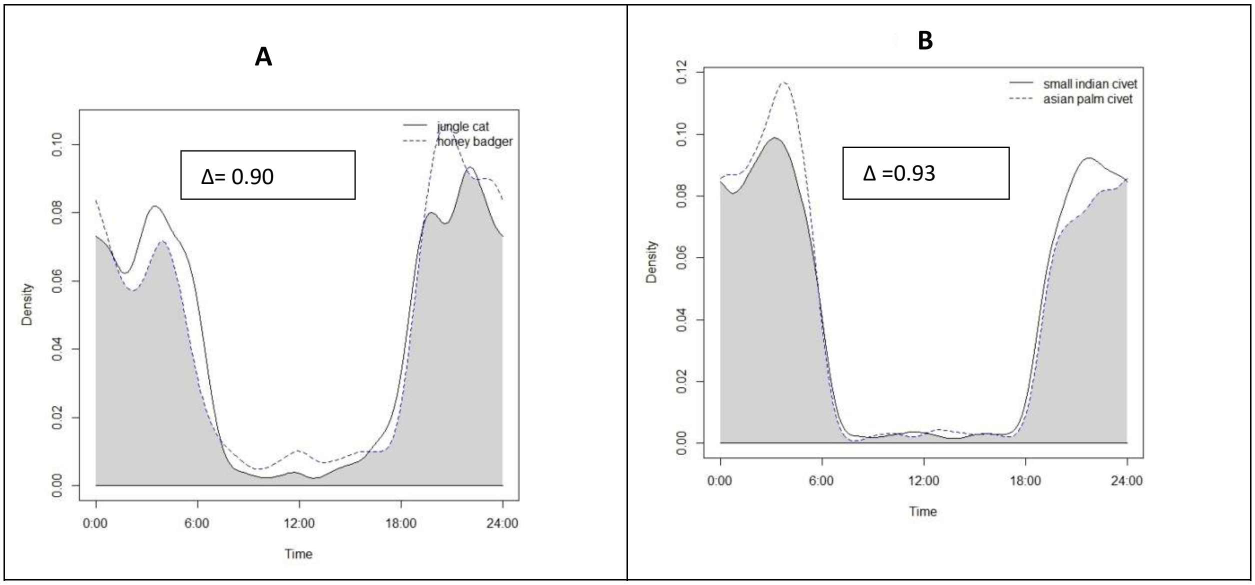


Figure 7.14 Temporal overlap (A) jungle cat and honey badger (B) Small Indian Civet and Asian Palm Civet

The temporal activity of tiger and leopard was studied with relation to wild dog in Melghat, PenchMH ,Satpuda, Bor, NNTR, NSTR, and Kawal.

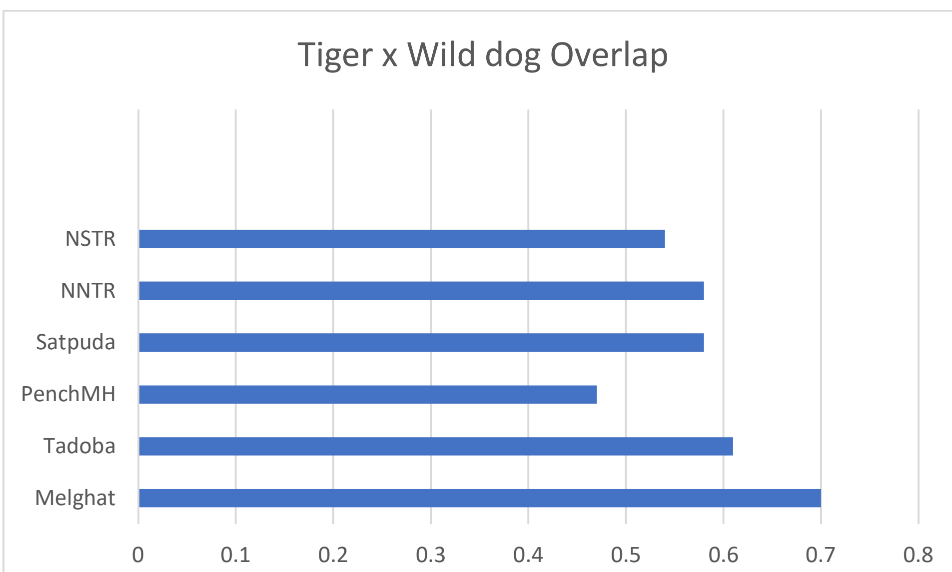


Figure 7.15 Temporal overlap between tiger and dhole across study sites

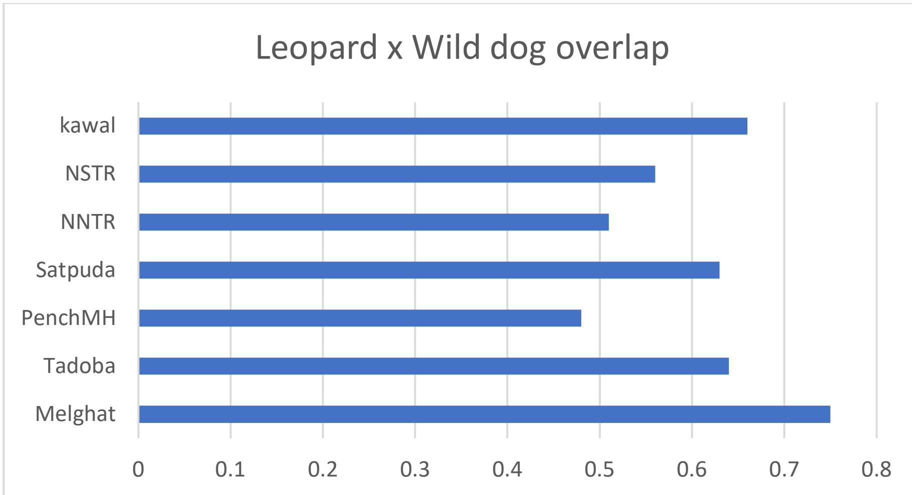


Figure 7.16 Temporal overlap between leopard and dhole across study sites

The temporal activity of the predators was also studied for alpha and beta predators along with its prey across the landscape as well as site wise.

Table 7.4 Diel overlap of tiger with co-predator and prey

	Wild dog	Chital	Gaur	Livestock	Nilgai	Sambar
Melghat	0.7	0.53	0.77	0.31	0.44	0.8
PenchMH	0.47	0.65	0.84	0.17	0.54	0.8
Satpuda	0.58	0.62	0.86	0.42	0.66	0.89
Bor		0.62	-	0.16	0.58	0.86
NNTR	0.58	0.55	0.74	0.31	0.68	0.86
NSTR	0.54	0.56	-	0.28	0.59	0.87
Umred	-	0.7	0.8	-	0.6	0.85

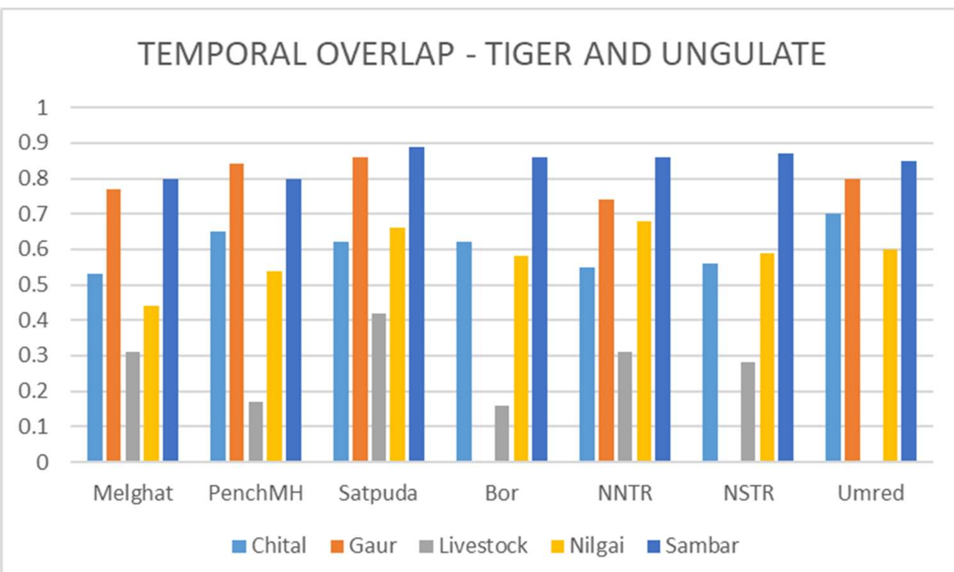


Figure 7.17 Temporal overlap between tiger and prey across study sites

Table 7.5 Diel overlap of leopard with co-predator and prey

Sites	Wild dog	Chital	Livestock	Nilgai	Sambar
Melghat	0.75	0.55	0.32	0.49	**0.85**
Tadoba	0.64	0.62	-	0.63	**0.88**
PenchMH	0.48	0.69	0.22	0.58	**0.87**
Satpuda	0.63	0.65	0.5	0.72	**0.82**
Bor		0.62	0.21	0.59	**0.85**
NNTR	0.51	0.56	0.33	0.69	**0.81**
NSTR	0.56	0.58	0.33	0.59	**0.8**
Umred	-	0.69		0.59	**0.87**
kawal	0.66	0.54	0.2	0.55	0.56

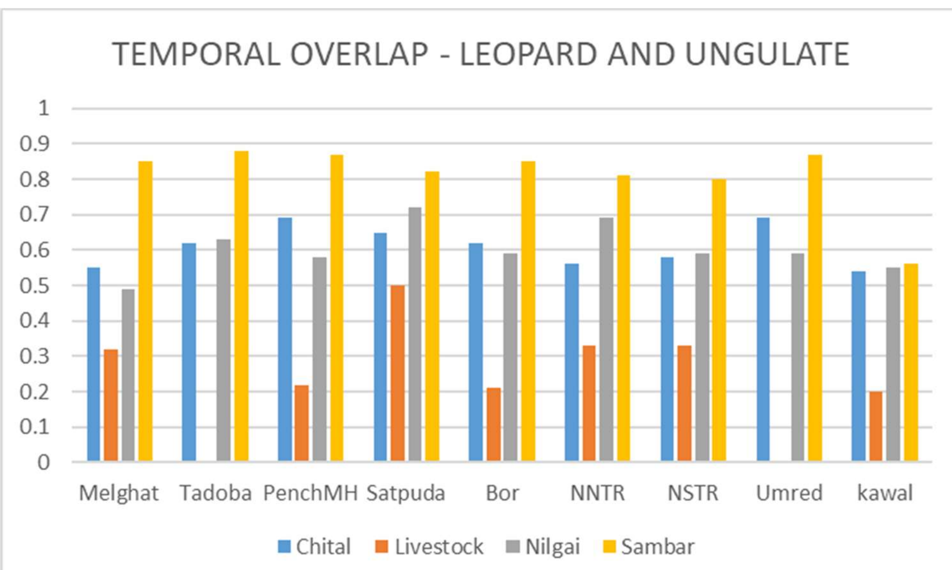


Figure 7.18 Temporal overlap between leopard and prey across study sites

Table 7.6 Diel activity overlap of dhole with the prey activity

	Gaur	Chital	Livestock	Nilgai	sambar
Bor	Less data				
Kawal	0.70	0.69	0.36	0.72	0.66
Melghat	0.74	0.65	0.46	0.67	**0.88**
NNTR	0.57	0.67	0.51	0.56	0.50
NSTR	NA	**0.80**	0.47	0.76	0.55
PenchMH	0.56	0.65	0.42	0.69	0.52
Satpuda	0.69	0.59	0.65	0.80	0.55
Tadoba	0.52	0.74	-	**0.83**	0.65
Umred	Less wd data				

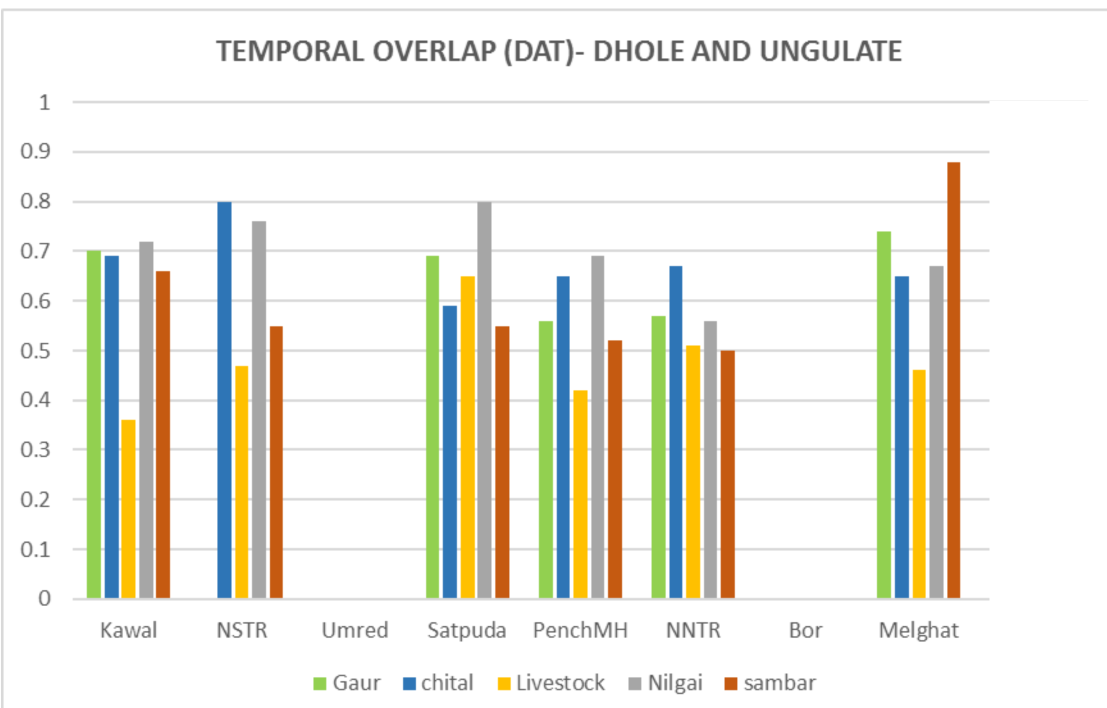
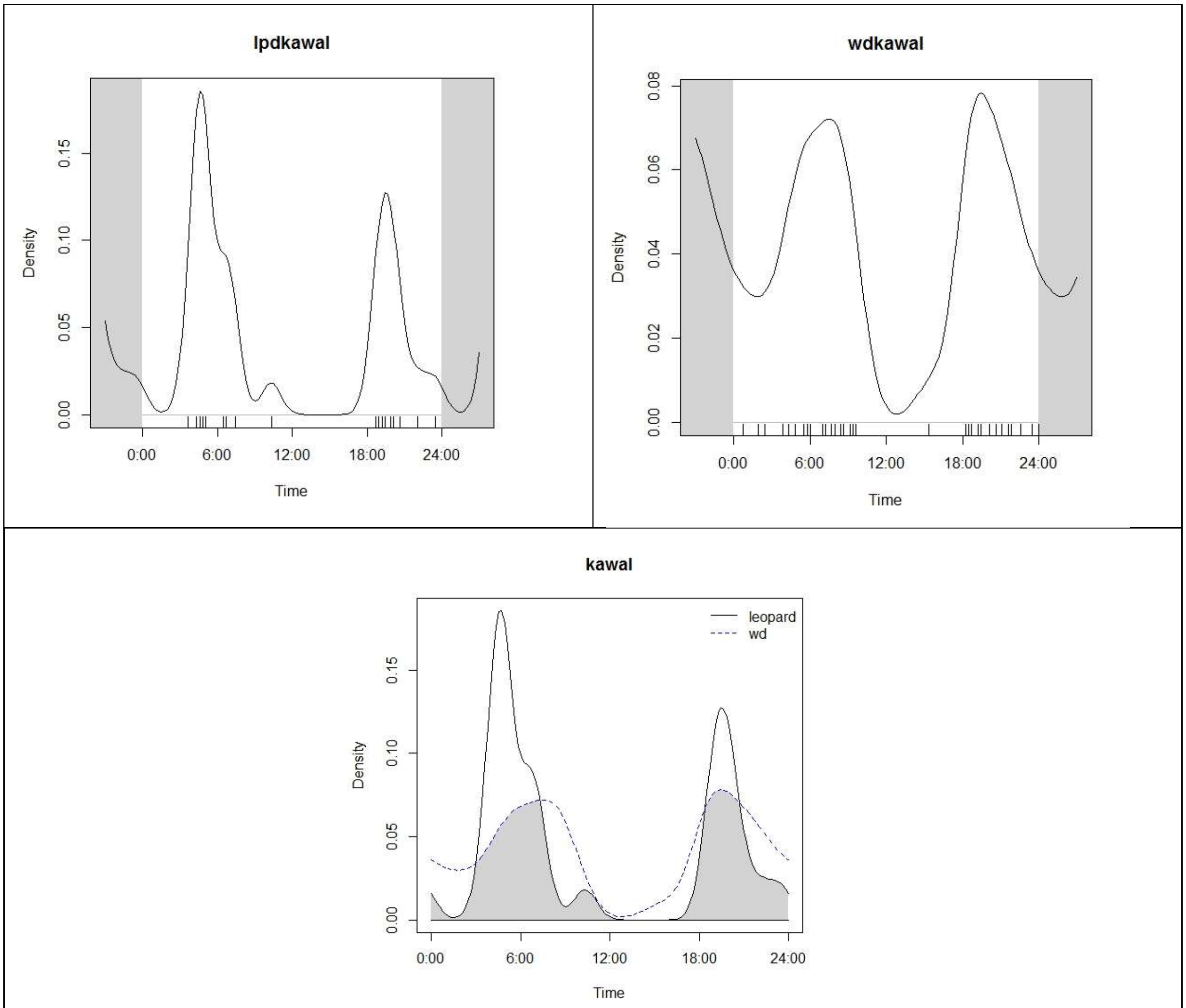


Figure 7.19 Temporal overlap between leopard and prey across study sites

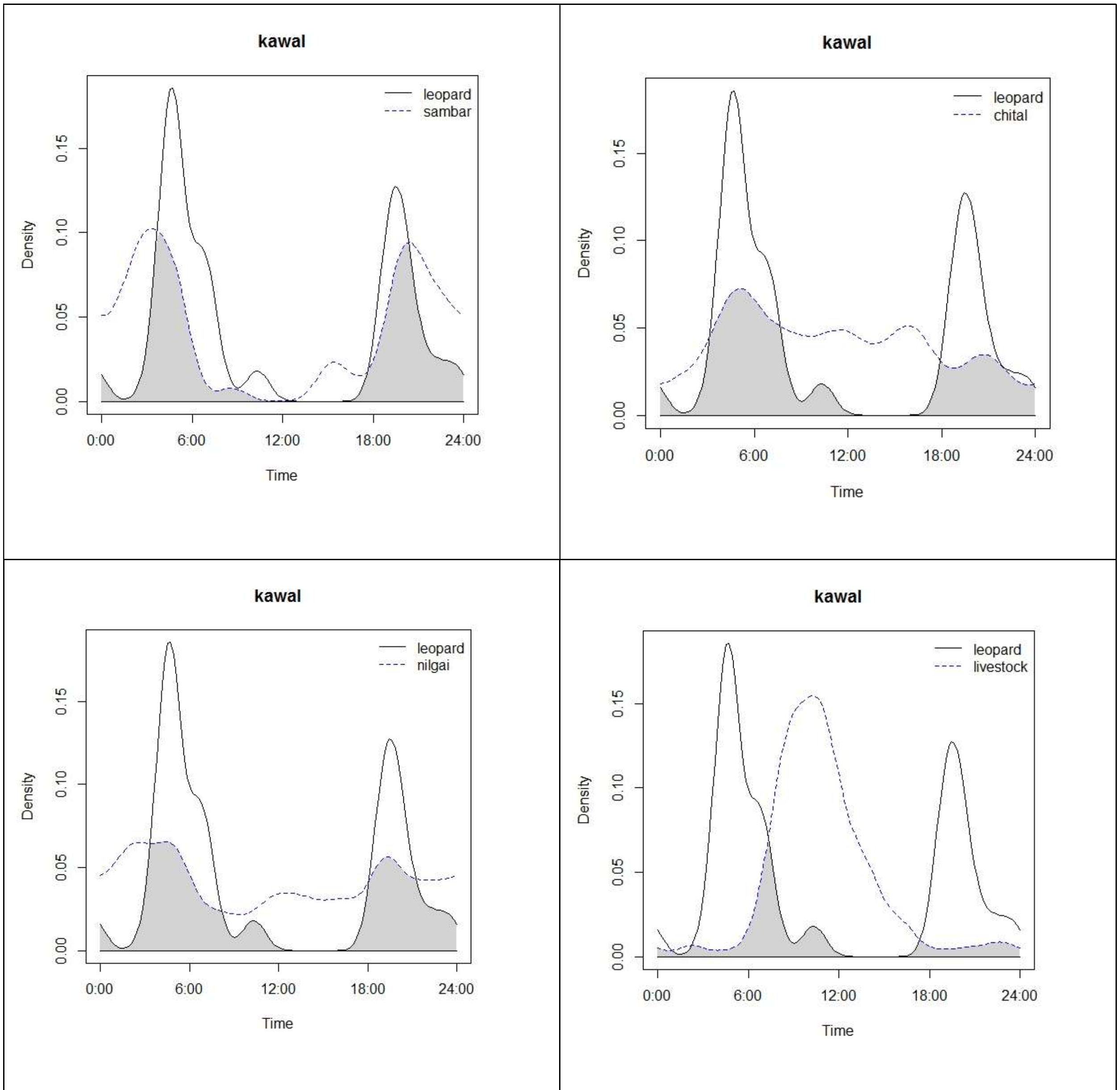
KAWAL TIGER RESERVE



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND DHOLE	0.6626076	0.6489549	0.7071429

Figure 7.20 Temporal overlap between predators in Kawal

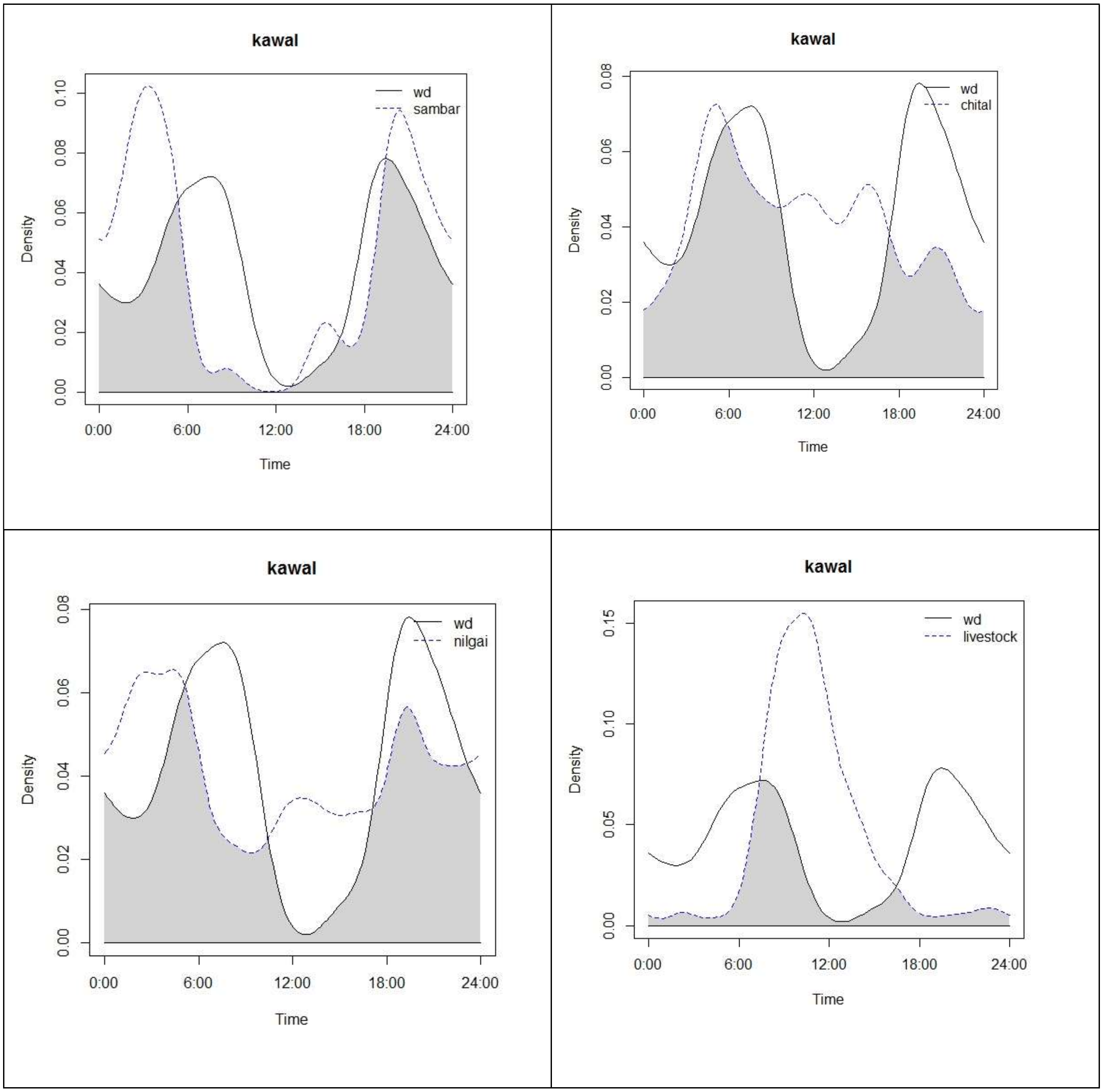
TEMPORAL OVERLAP OF LEOPARD WITH PREY

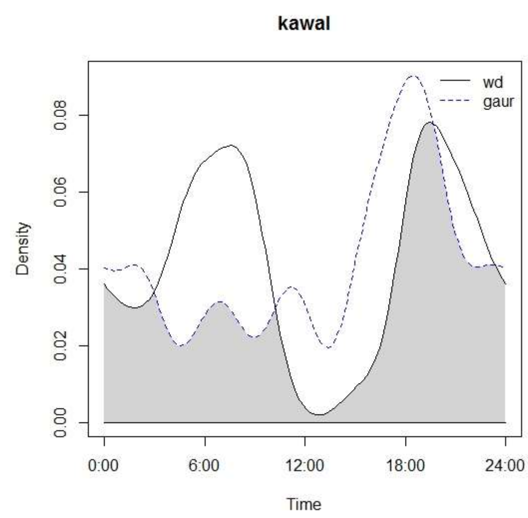


	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.5696371	0.5597112	0.5411051
LEOPARD AND CHITAL	0.5445957	0.494583	0.4714286
LEOPARD AND LIVESTOCK	0.2020279	0.1836067	0.1649538
LEOPARD AND NILGAI	0.5545948	0.5243736	0.5916149

Figure 7.21 Temporal overlap between Leopard and prey in Kawal

TEMPORAL OVERLAP OF DHOLE WITH PREY



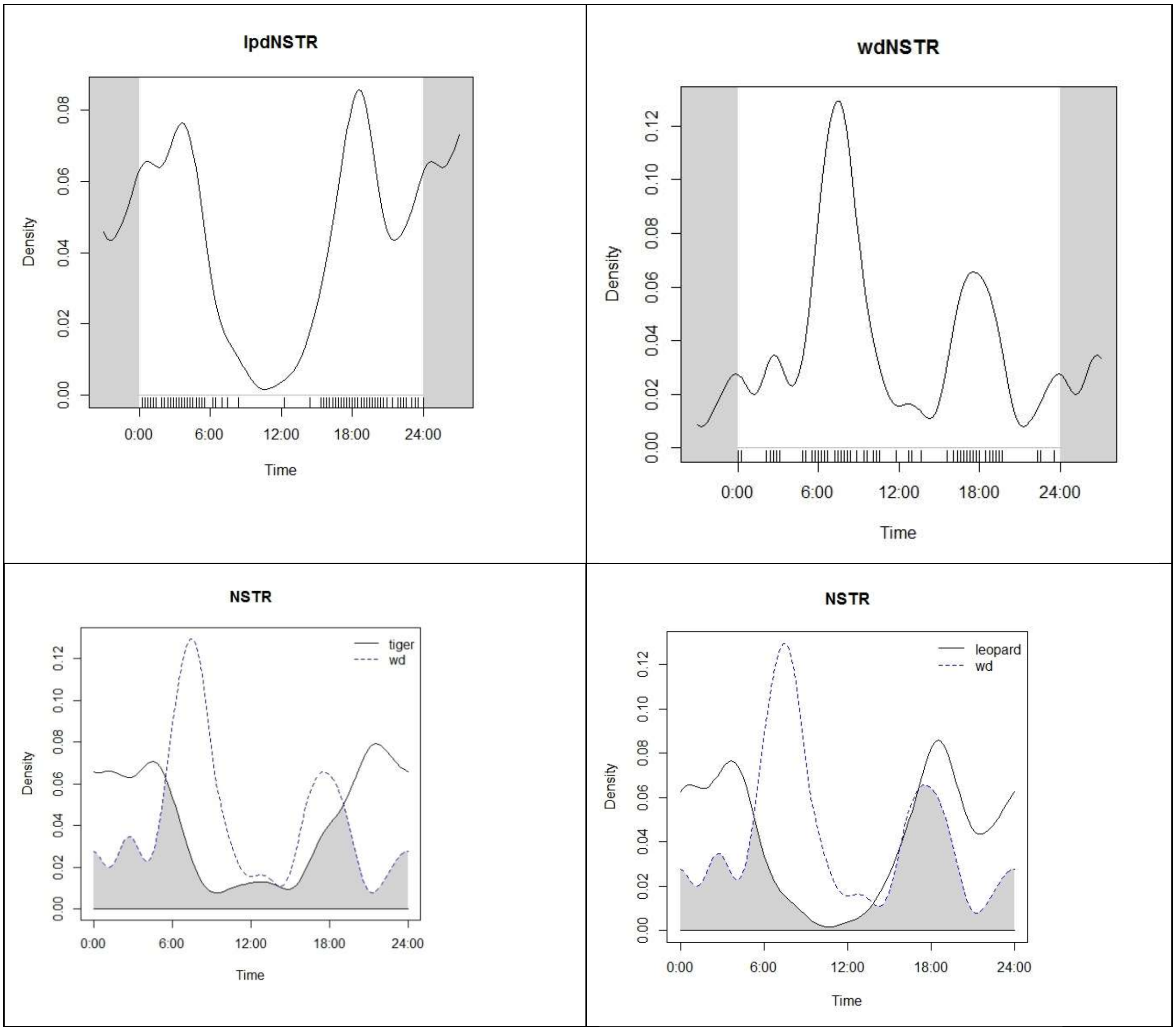


	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
DHOLE AND SAMBAR	0.6668942	0.6699904	0.5943396
DHOLE AND CHITAL	0.6910873	0.6671258	0.725
DHOLE AND LIVESTOCK	0.3610683	0.3518024	0.3757194
DHOLE AND NILGAI	0.7234727	0.7152352	0.697205
DHOLE AND GAUR	0.707479	0.6998971	0.7222222

Figure 7.22 Temporal overlap between dhole and prey in Kawal

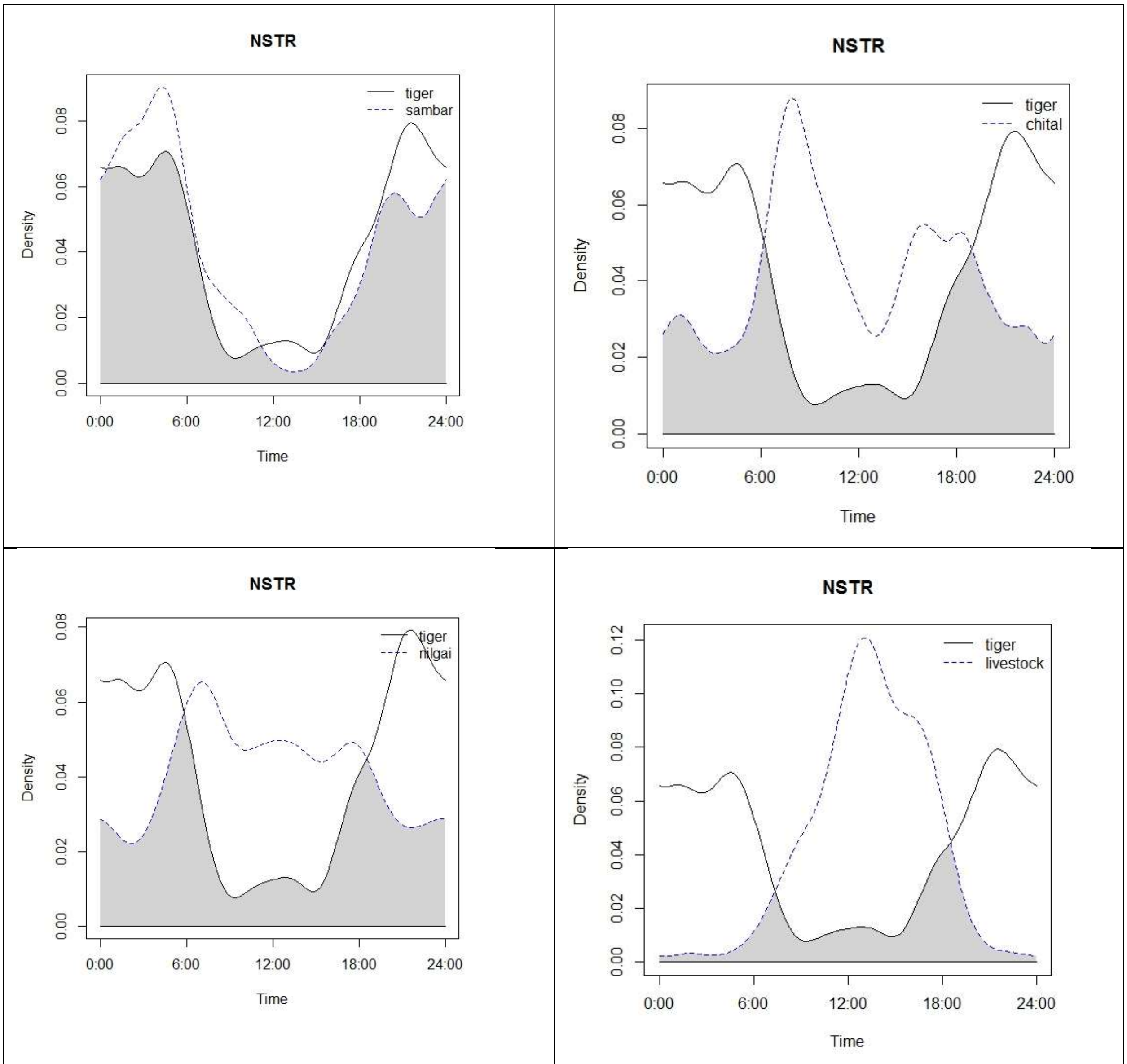
NSTR

TEMPORAL OVERLAP BETWEEN PREDATORS



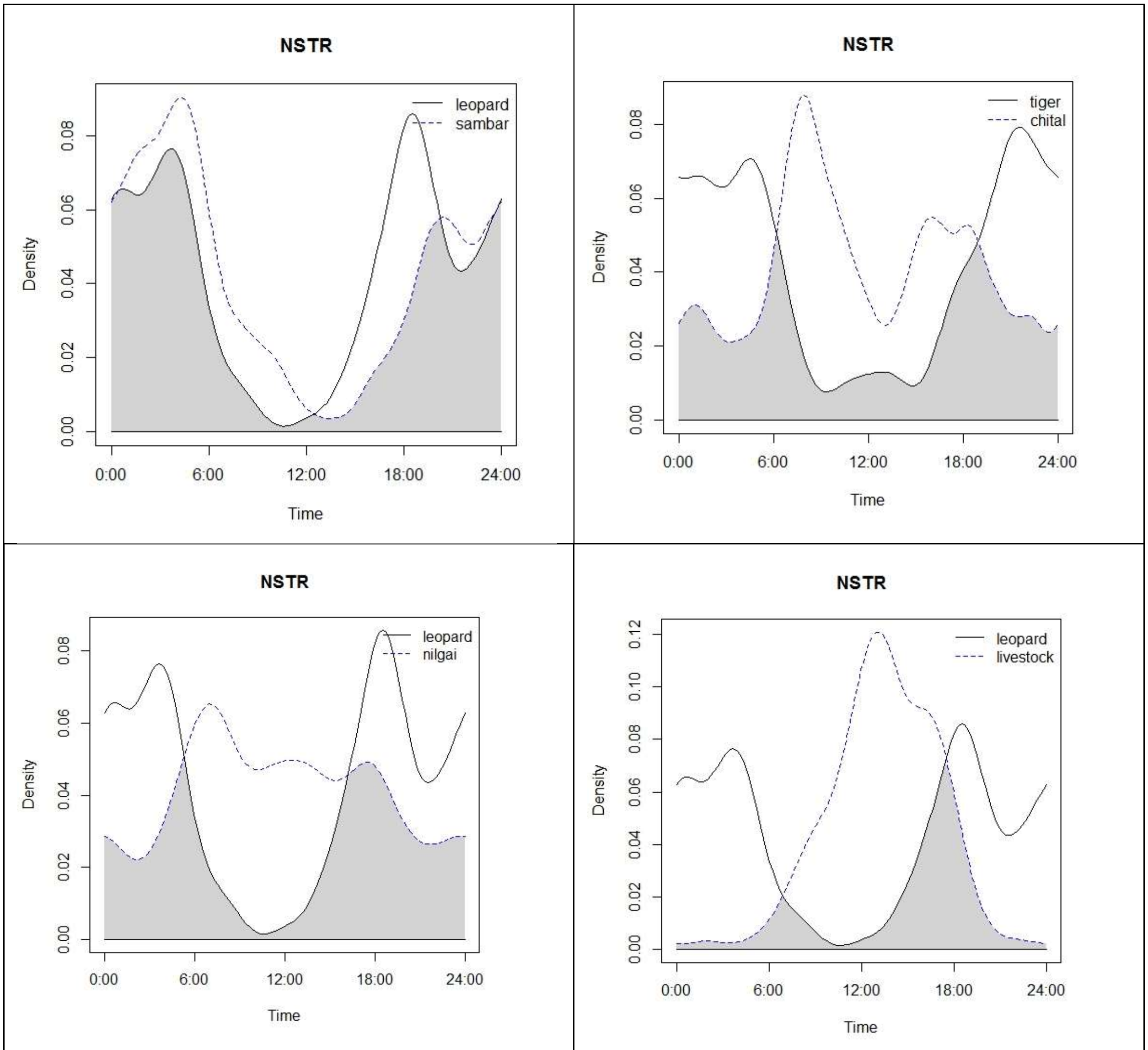
	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND DHOLE	0.546726	0.5302602	0.5295699
LEOPARD AND DHOLE	0.5677498	0.5631009	0.5518182

Figure 7.23 Temporal overlap between predators in NSTR



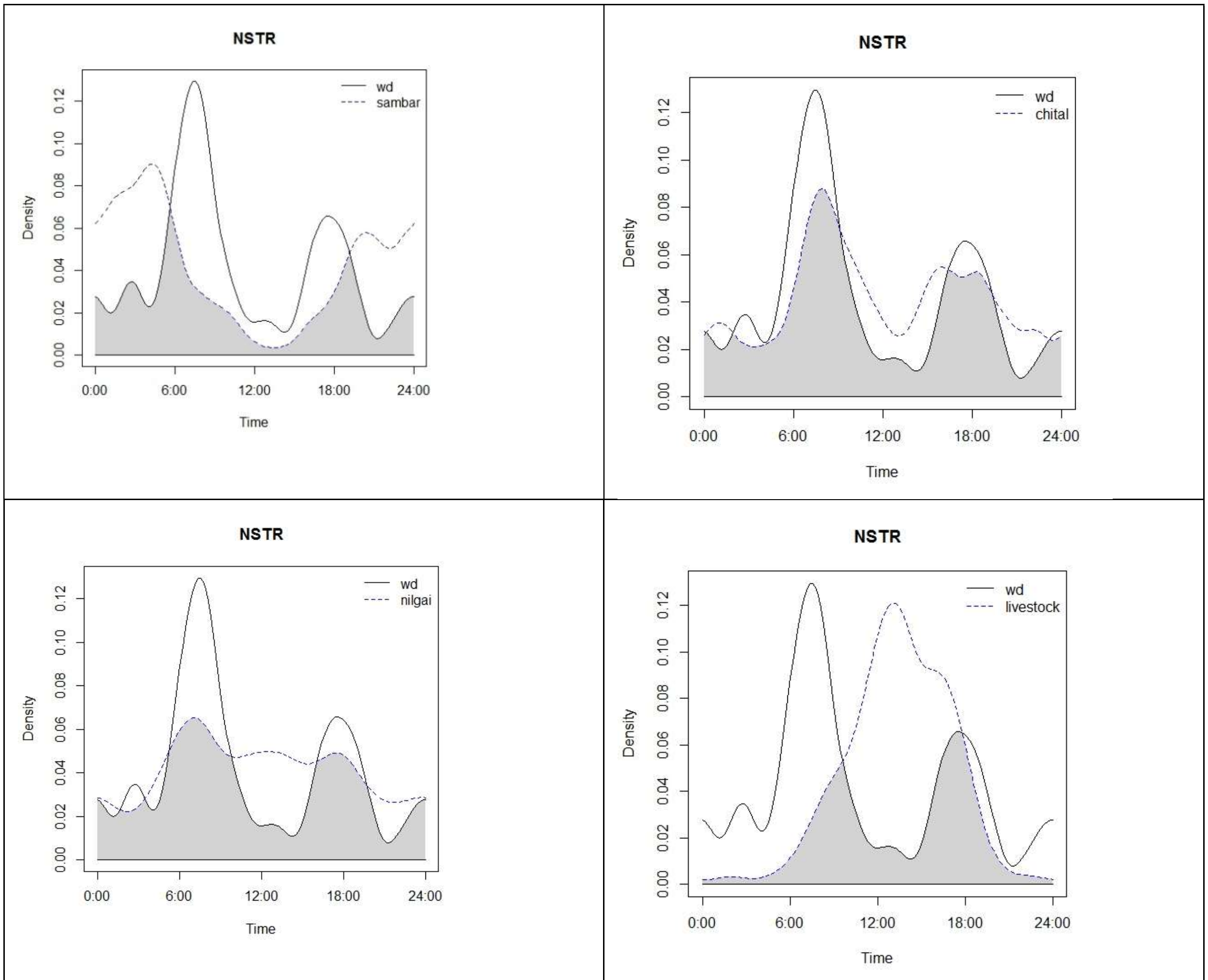
	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND SAMBAR	0.874251	0.8691783	0.8811968
TIGER AND CHITAL	0.5673072	0.5618117	0.5686691
TIGER AND LIVESTOCK	0.2840104	0.2728795	0.2741097
TIGER AND NILGAI	0.5920085	0.5963325	0.5776583

Figure 7.24Temporal overlap between tiger and prey in NSTR



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.8017859	0.8023693	0.8374805
LEOPARD AND CHITAL	0.5857843	0.5788523	0.5491737
LEOPARD AND LIVESTOCK	0.3391136	0.3347757	0.2994031
LEOPARD AND NILGAI	0.593788	0.5875493	0.5354074

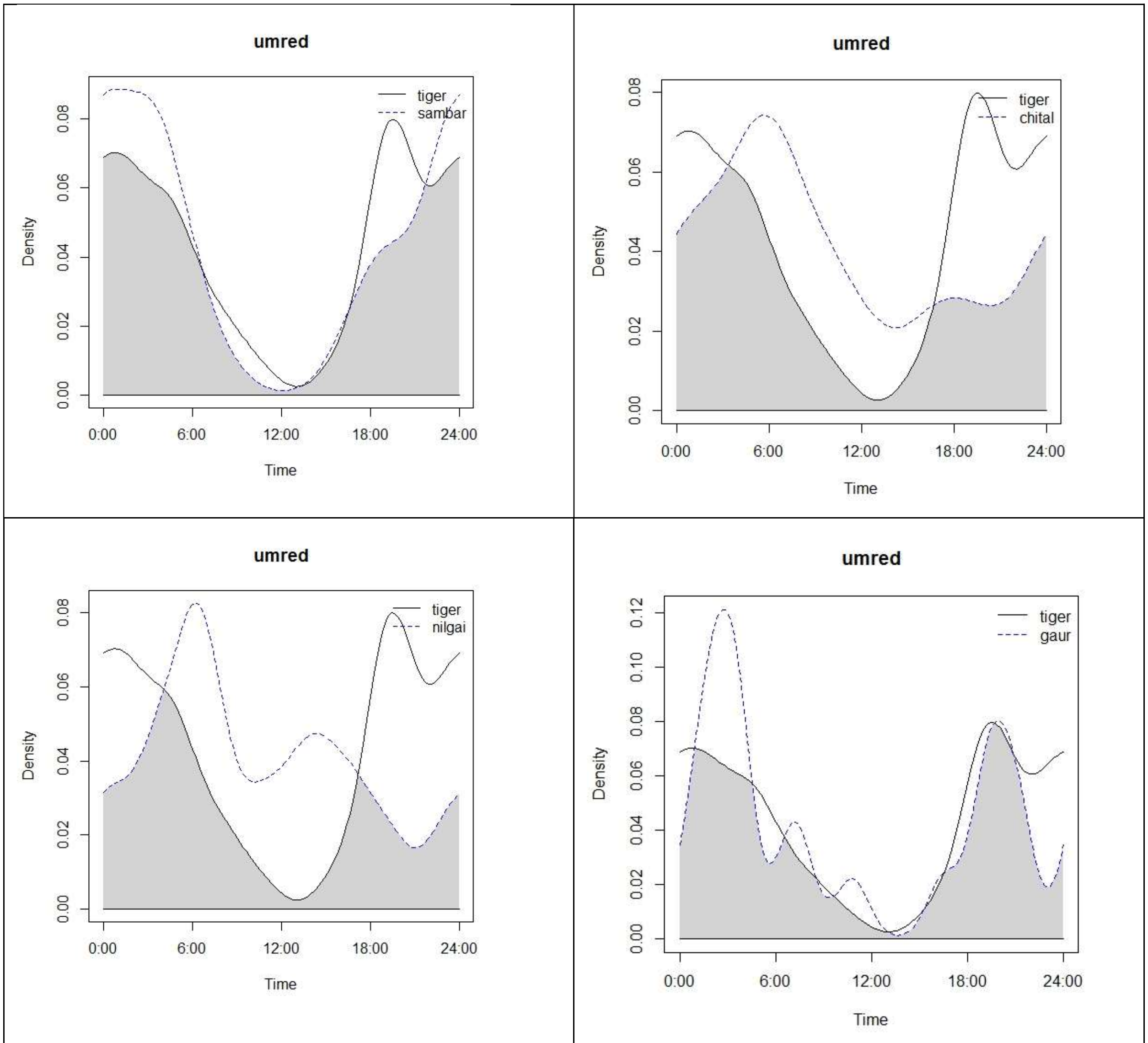
Figure 7.25Temporal overlap between leopard and prey in NSTR



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
DHOLE AND SAMBAR	0.5514708	0.542646	0.5178571
DHOLE AND CHITAL	0.8006916	0.8003272	0.832857
DHOLE AND LIVESTOCK	0.4790925	0.4716471	0.4734005
DHOLE AND NILGAI	0.7610638	0.7560234	0.7882997

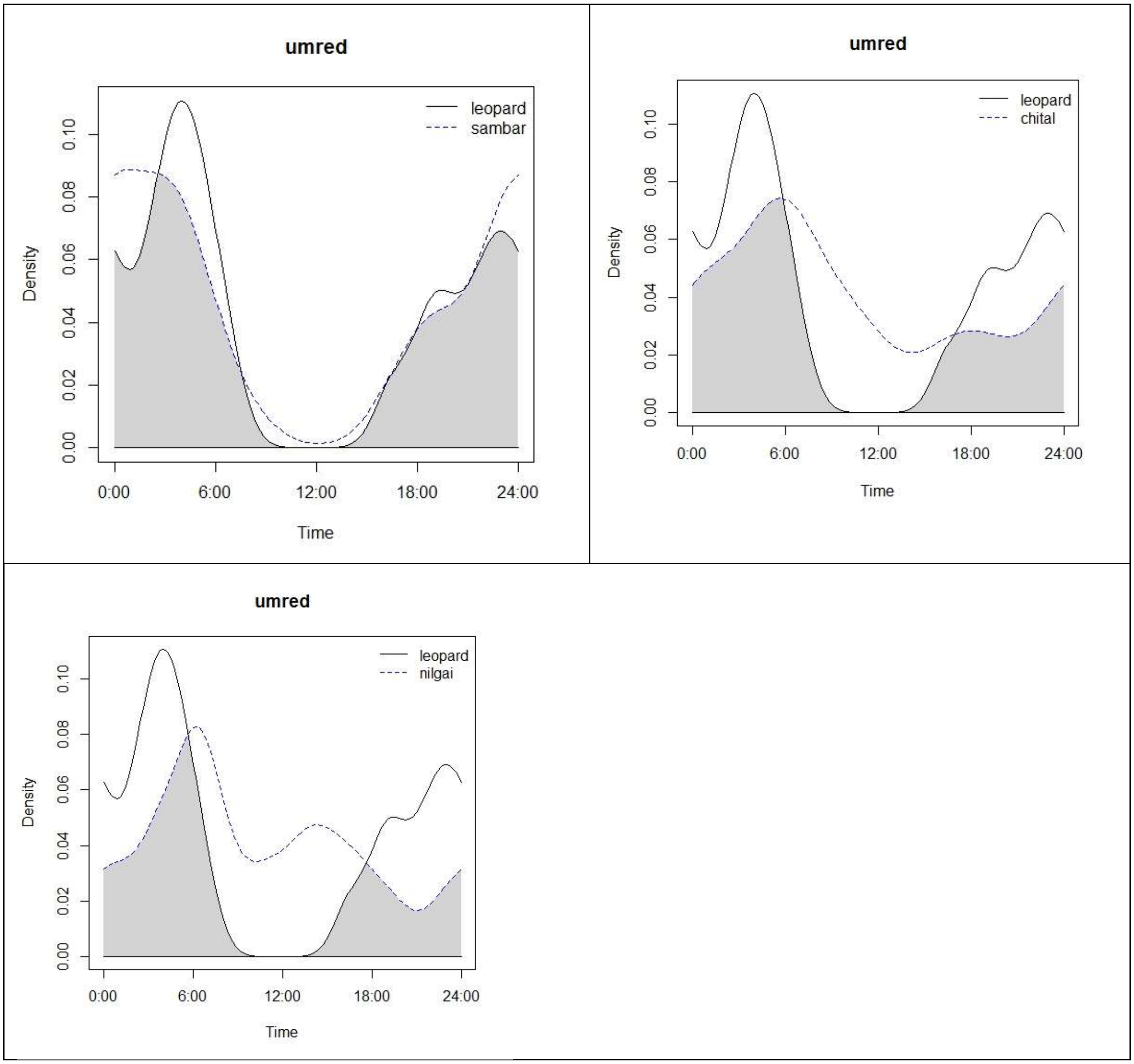
Figure 7.26 Temporal overlap between Dhole and prey in NSTR

UMRED TIGER RESERVE



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND SAMBAR	0.850007	0.845748	0.940668
TIGER AND CHITAL	0.701072	0.704582	0.66804
TIGER AND NILGAI	0.606207	0.599056	0.58478
TIGER AND GAUR	0.800327	0.796616	0.817227

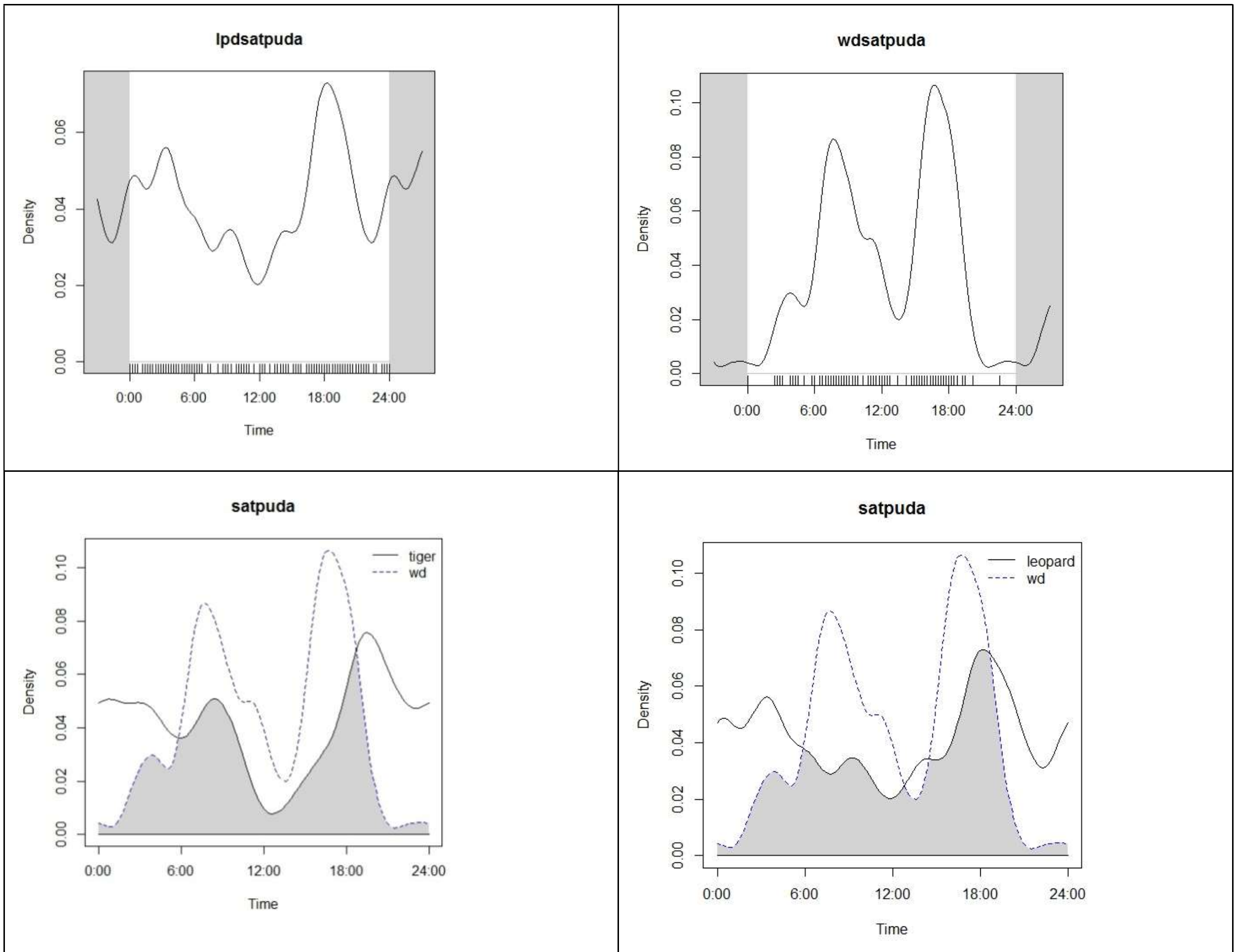
Figure 7.27 Temporal overlap between tiger and prey in Umred



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.879731	0.888676	0.901167
LEOPARD AND CHITAL	0.699807	0.712607	0.67485
LEOPARD AND NILGAI	0.593365	0.594587	0.569497

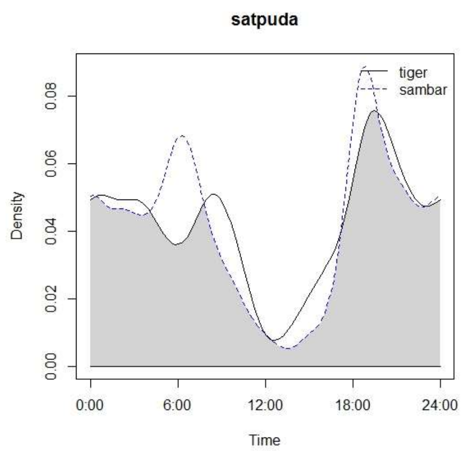
Figure 7.28 Temporal overlap between leopard and prey in Umred

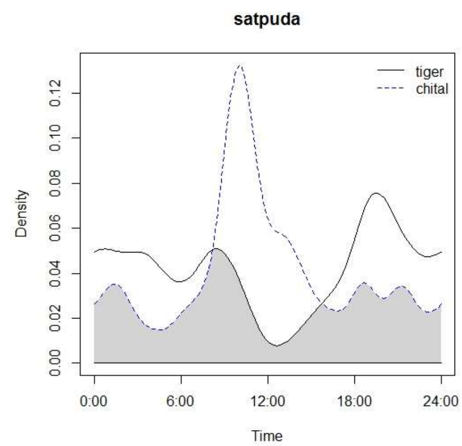
SATPUDA TR:

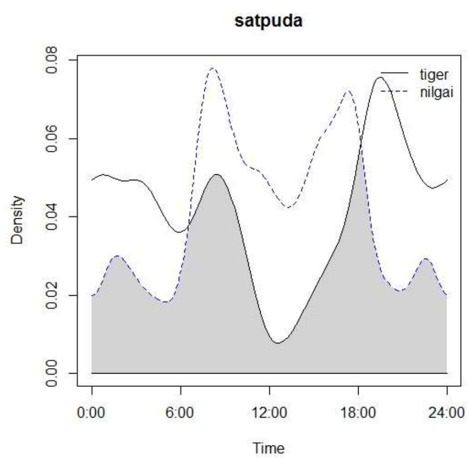


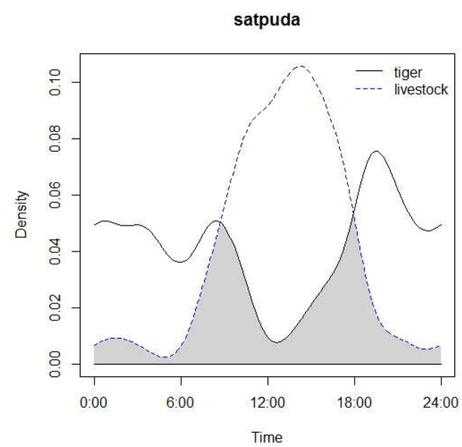
	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND DHOLE	0.5881007	0.5872863	0.570833
LEOPARD AND DHOLE	0.638385	0.6339075	0.644809

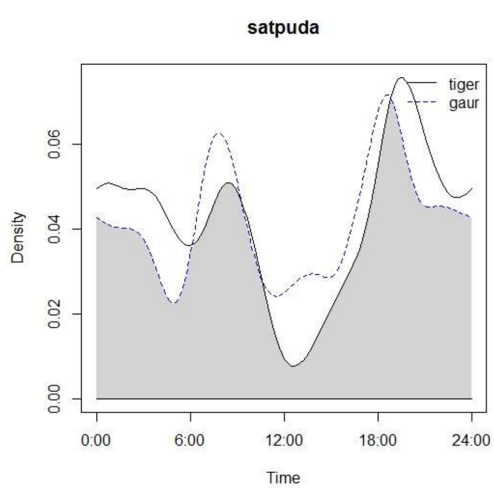
Figure 7.29 Temporal overlap between predators in Satpuda







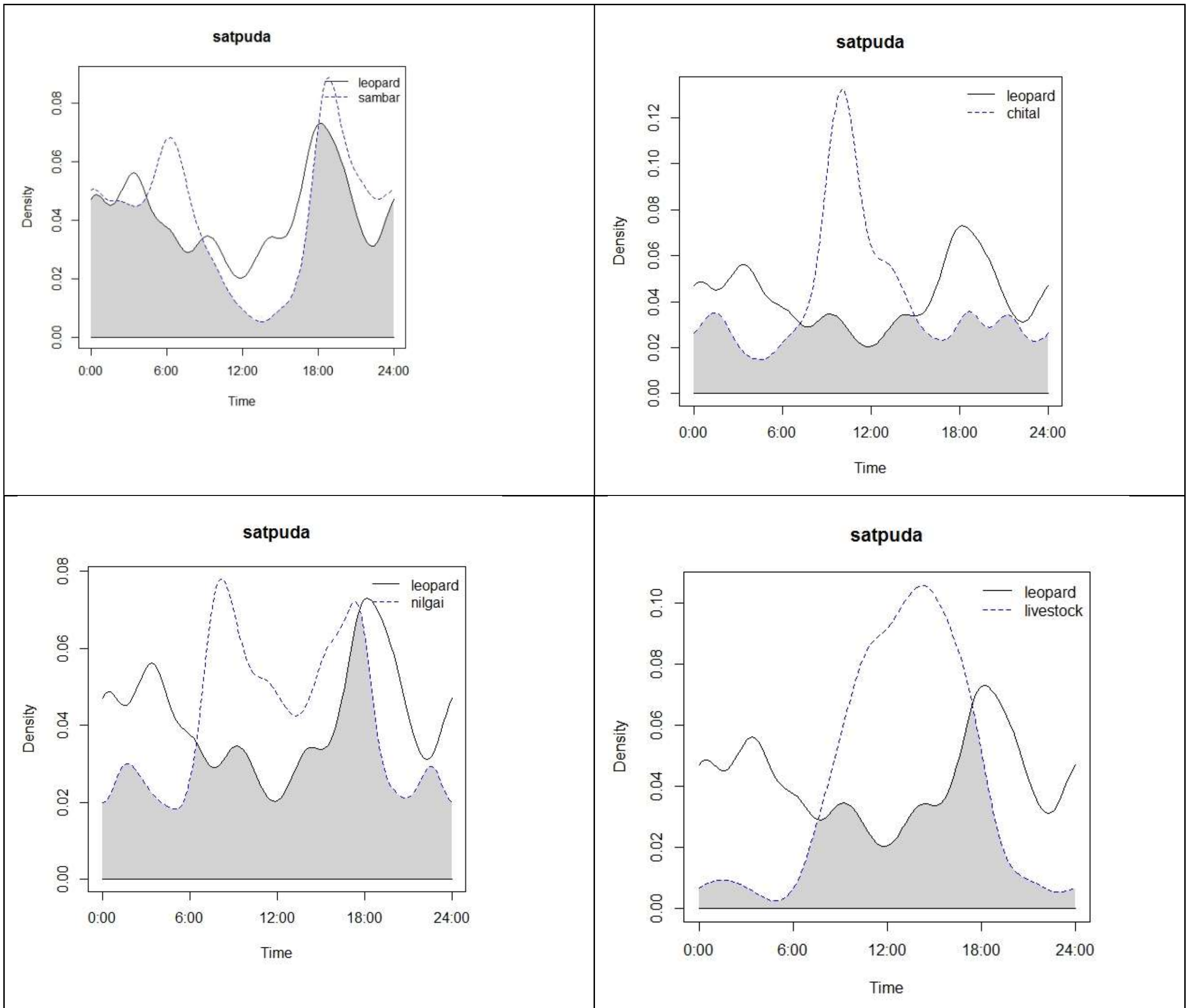




	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND SAMBAR	0.8902116	0.8900739	0.934522
TIGER AND CHITAL	0.6256686	0.6184621	0.654624
TIGER AND LIVESTOCK	0.4272735	0.419666	0.401904

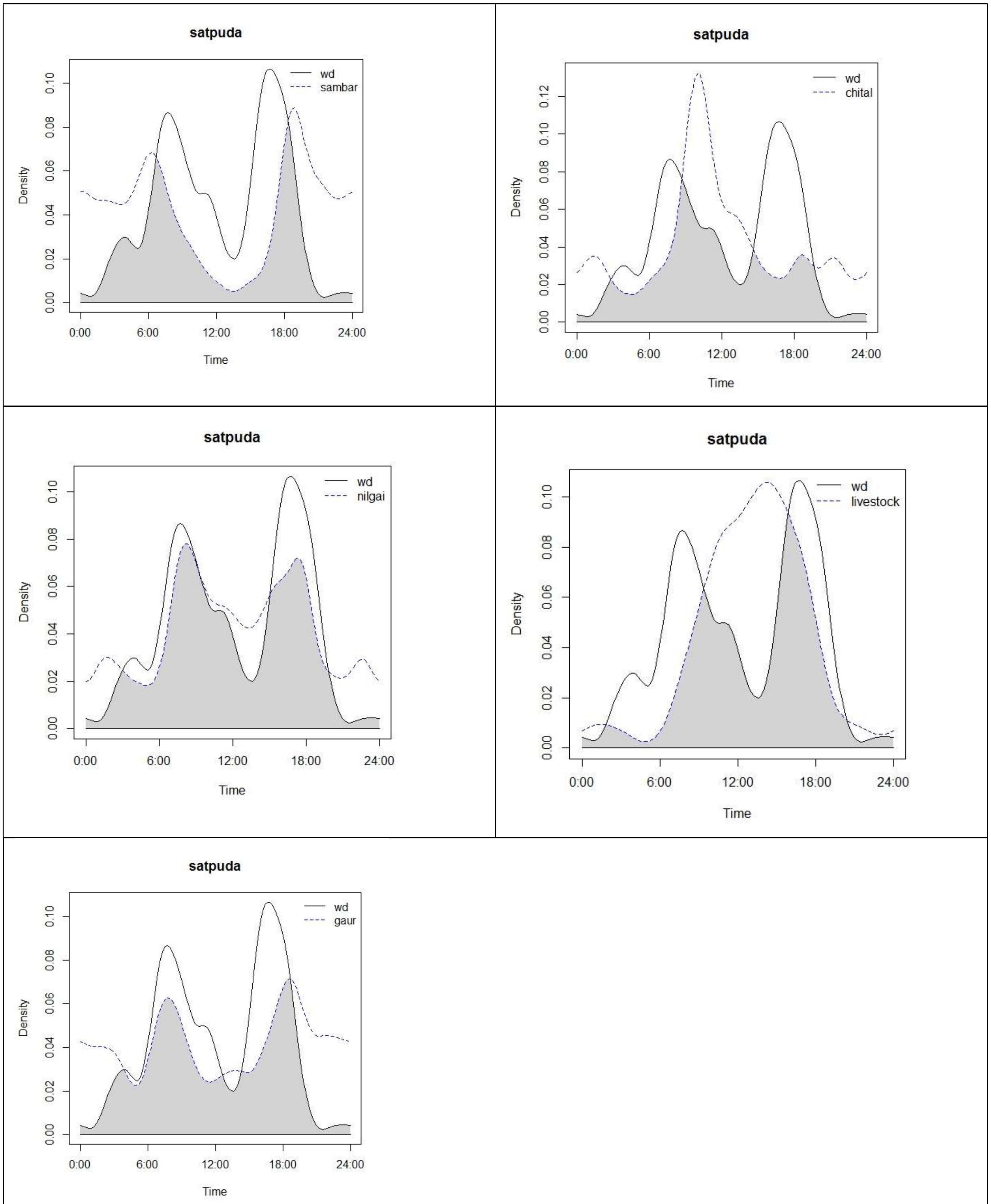
TIGER AND NILGAI	0.664474	0.6553992	0.619546	
TIGER AND GAUR	0.8666816	0.870891	0.842857	

Figure 7.30 Temporal overlap between tiger and prey in Satpuda



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.8242964	0.8280417	0.8404855
LEOPARD AND CHITAL	0.6552177	0.6426704	0.6316308
LEOPARD AND LIVESTOCK	0.5033007	0.5016879	0.4565699
LEOPARD AND NILGAI	0.7223795	0.7175208	0.7217884

Figure 7.31 Temporal overlap between leopard and prey in Satpuda

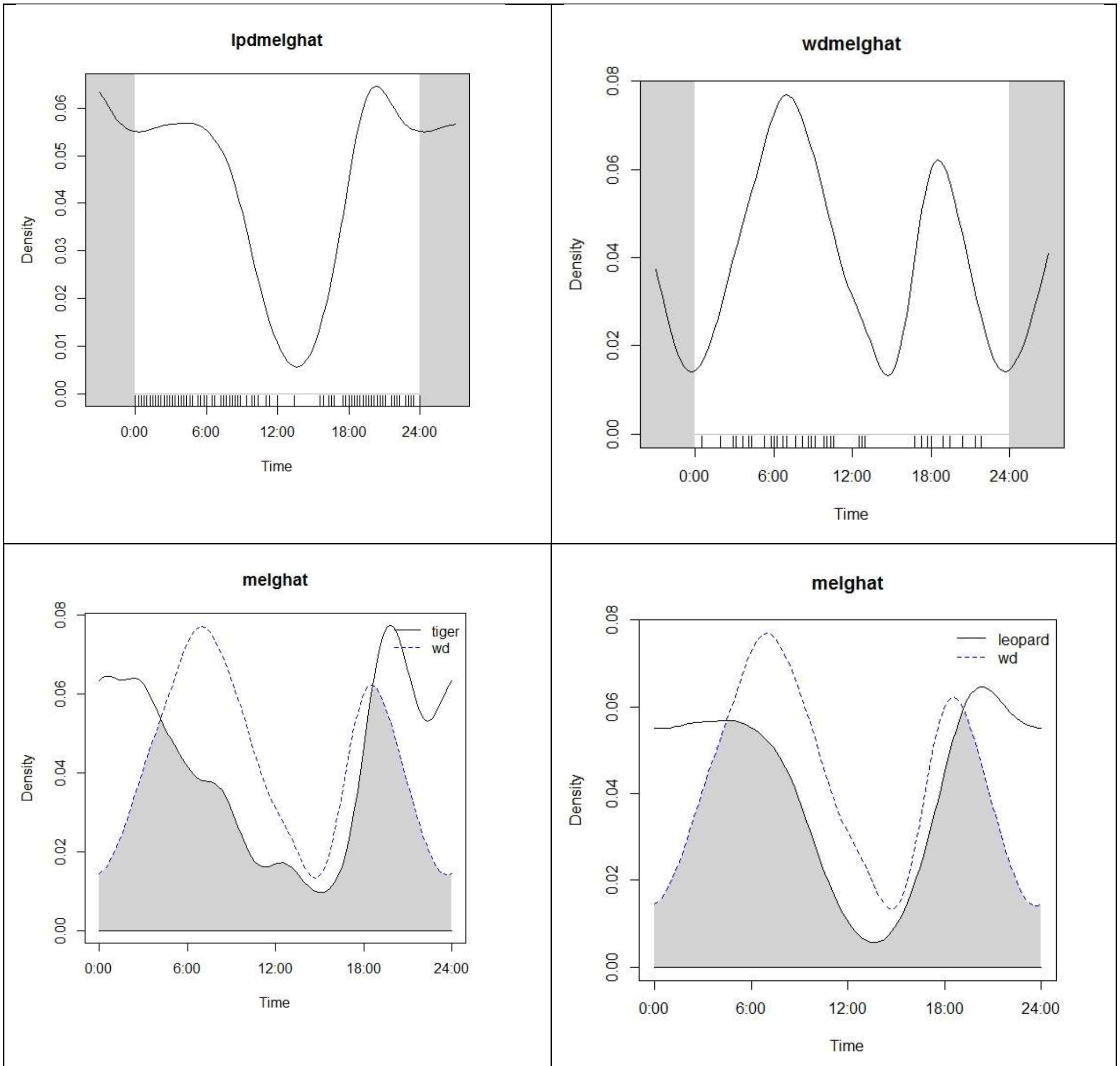


	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
DHOLE AND SAMBAR	0.555164	0.5593388	0.5145221
DHOLE AND CHITAL	0.5957343	0.5755582	0.5890173

DHOLE AND LIVESTOCK	0.6522522	0.6472095	0.6270728
DHOLE AND NILGAI	0.8078463	0.8082166	0.7951515
DHOLE AND GAUR	0.6967875	0.6972573	0.6885714

Figure 7.32 Temporal overlap between Dhole and prey in Satpuda

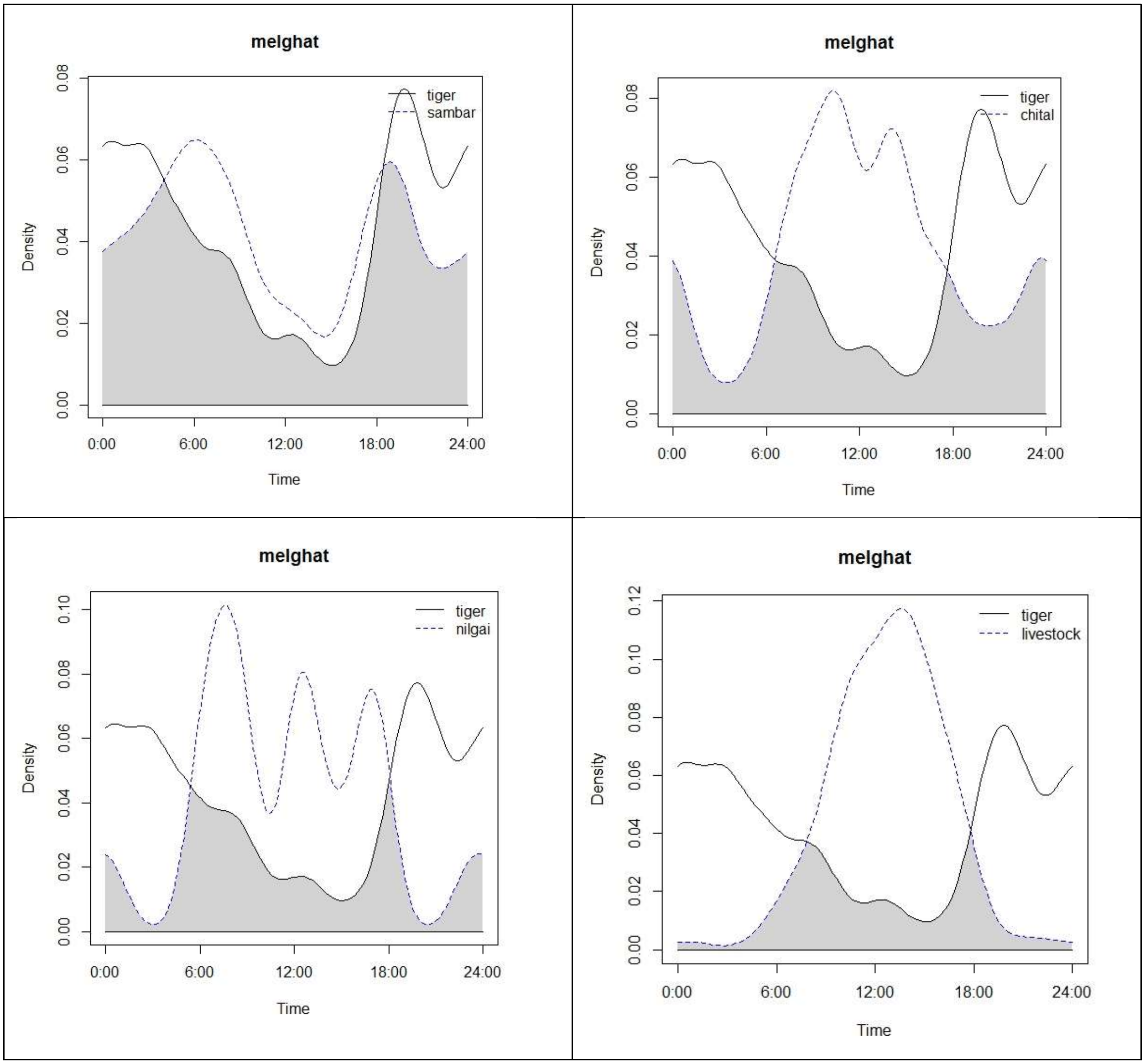
MELGHAT TIGER RESERVE:

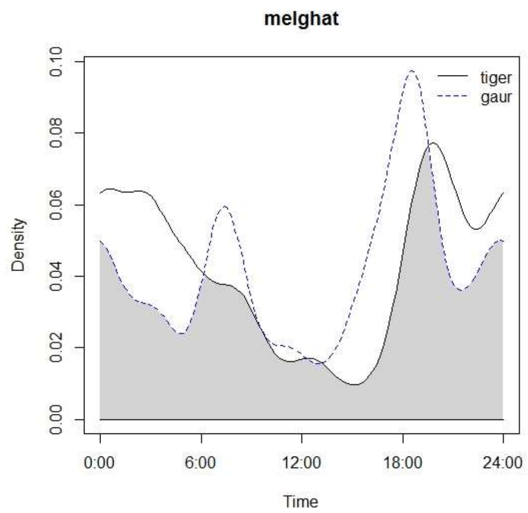


	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND DHOLE	0.7077994	0.710593	0.7462083
LEOPARD AND	0.7563679	0.7604621	0.7167129

DHOLE			

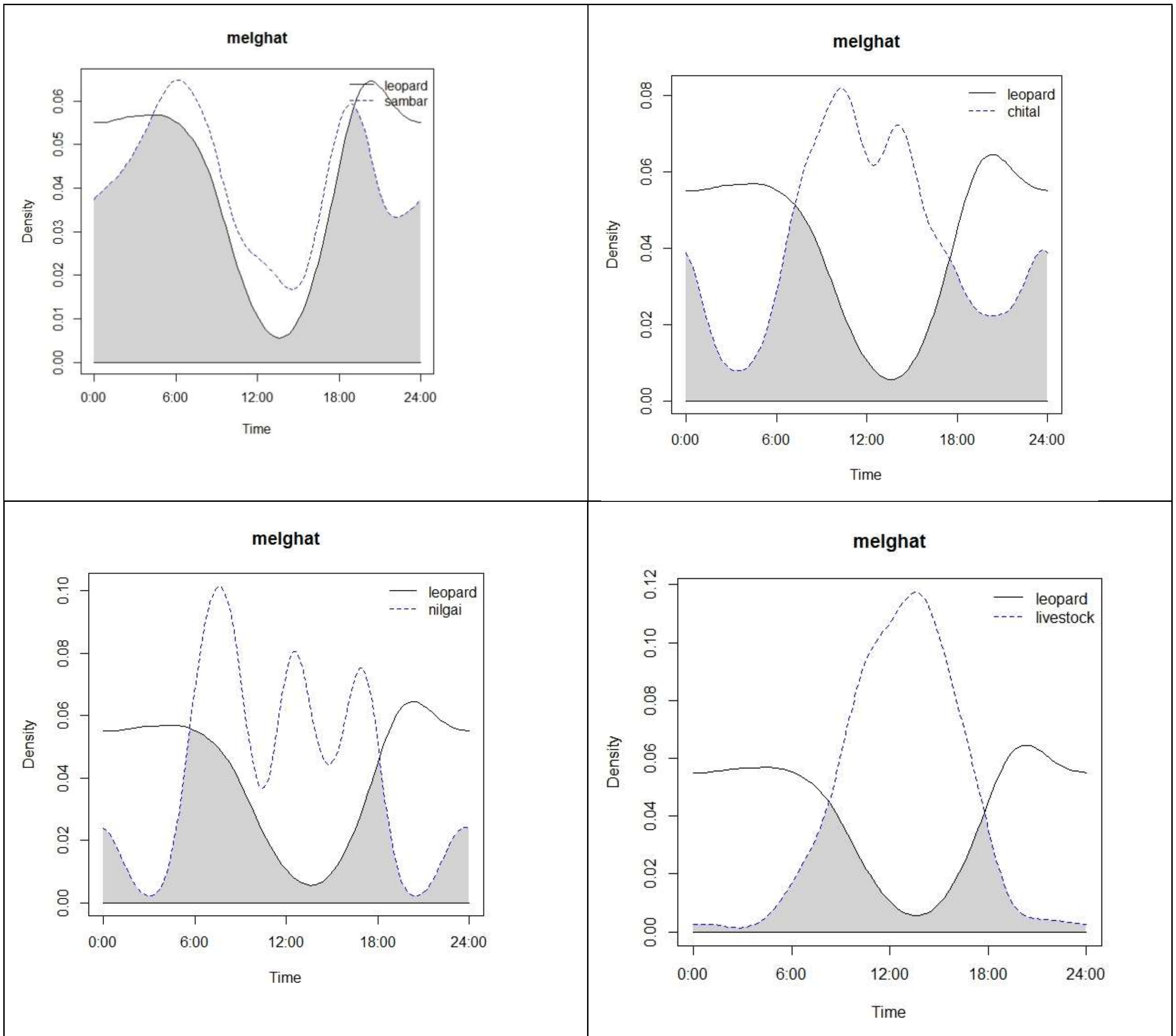
Figure 7.33 Temporal overlap between predators in Melghat





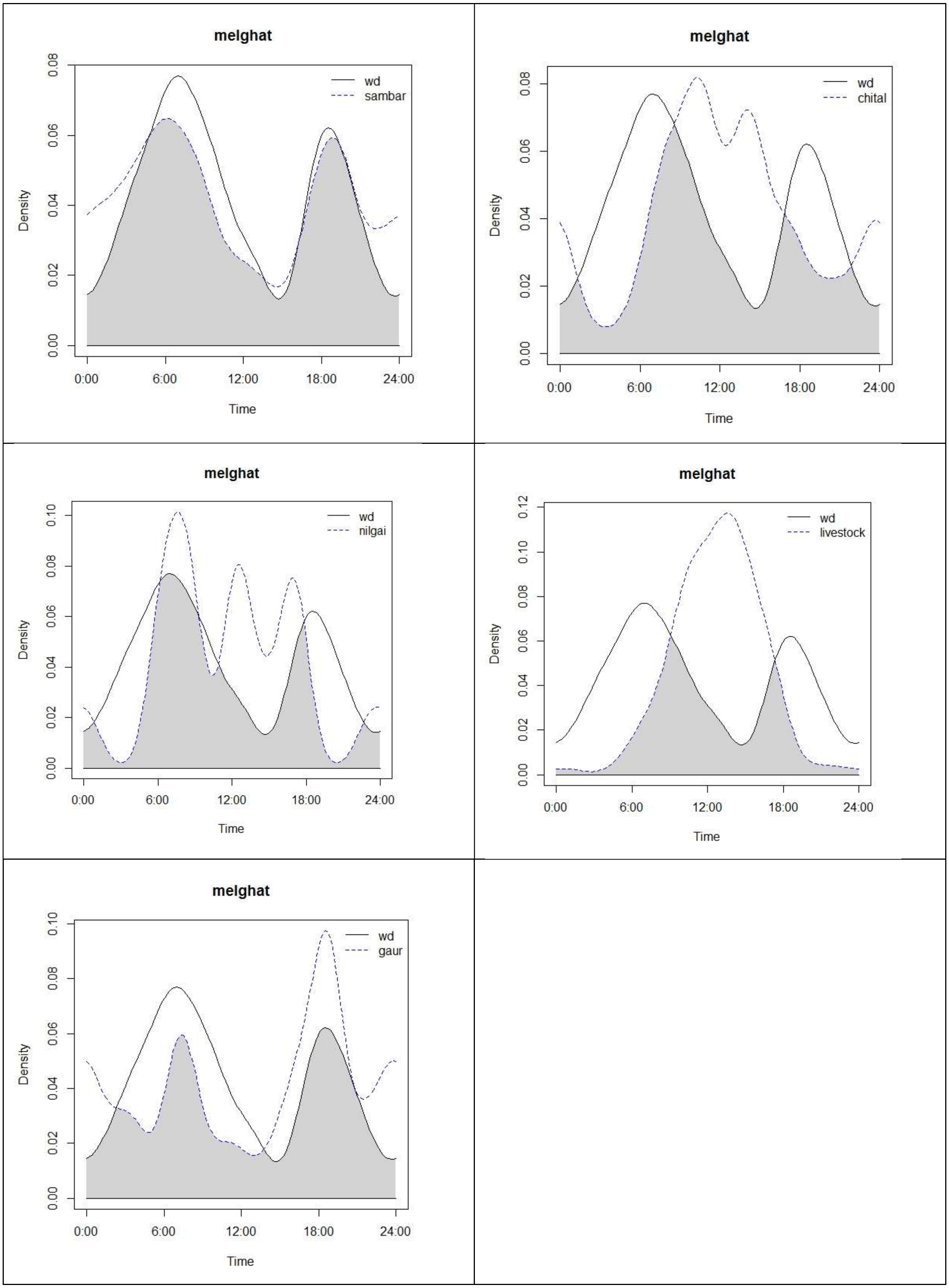
	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND SAMBAR	0.8063106	0.8102421	0.7975302
TIGER AND CHITAL	0.533065	0.5217826	0.5031056
TIGER AND LIVESTOCK	0.3190034	0.3025263	0.2869565
TIGER AND NILGAI	0.4473847	0.4201368	0.3528986
TIGER AND GAUR	0.7703236	0.770506	0.7789984

Figure 7.34 Temporal overlap between tiger and prey in Melghat



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.8573551	0.862512	0.8560873
LEOPARD AND CHITAL	0.5575694	0.5530218	0.5319023
LEOPARD AND LIVESTOCK	0.3271669	0.3135627	0.3045731
LEOPARD AND NILGAI	0.4915561	0.4683914	0.3942142

Figure 7.35 Temporal overlap between leopard and prey in Melghat


melghat
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sambar
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Time
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wd
chital
Density
0.00 0.02 0.04 0.06 0.08
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Time
melghat
wd
nilgai
Density
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Time
melghat
wd
livestock
Density
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Time
melghat
wd
gaur
Density
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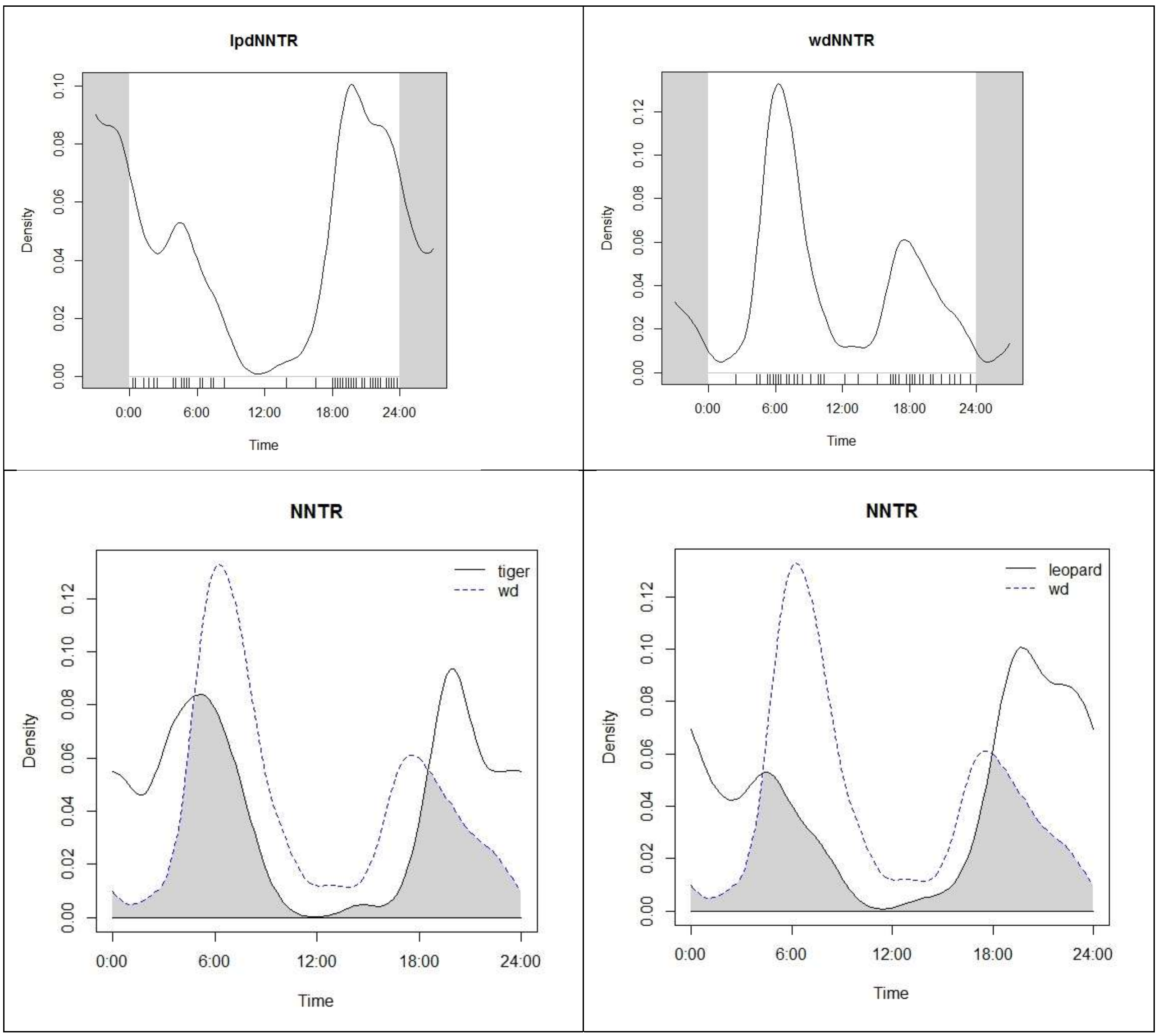
0:00 6:00 12:00 18:00 24:00
Time

	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
DHOLE AND SAMBAR	0.8891091	0.8926244	0.9347048
DHOLE AND CHITAL	0.6520707	0.6399281	0.6647841
DHOLE AND LIVESTOCK	0.4674327	0.4616758	0.4720256
DHOLE AND NILGAI	0.6702464	0.6656984	0.6967054
DHOLE AND GAUR	0.748926	0.7431423	0.7426287

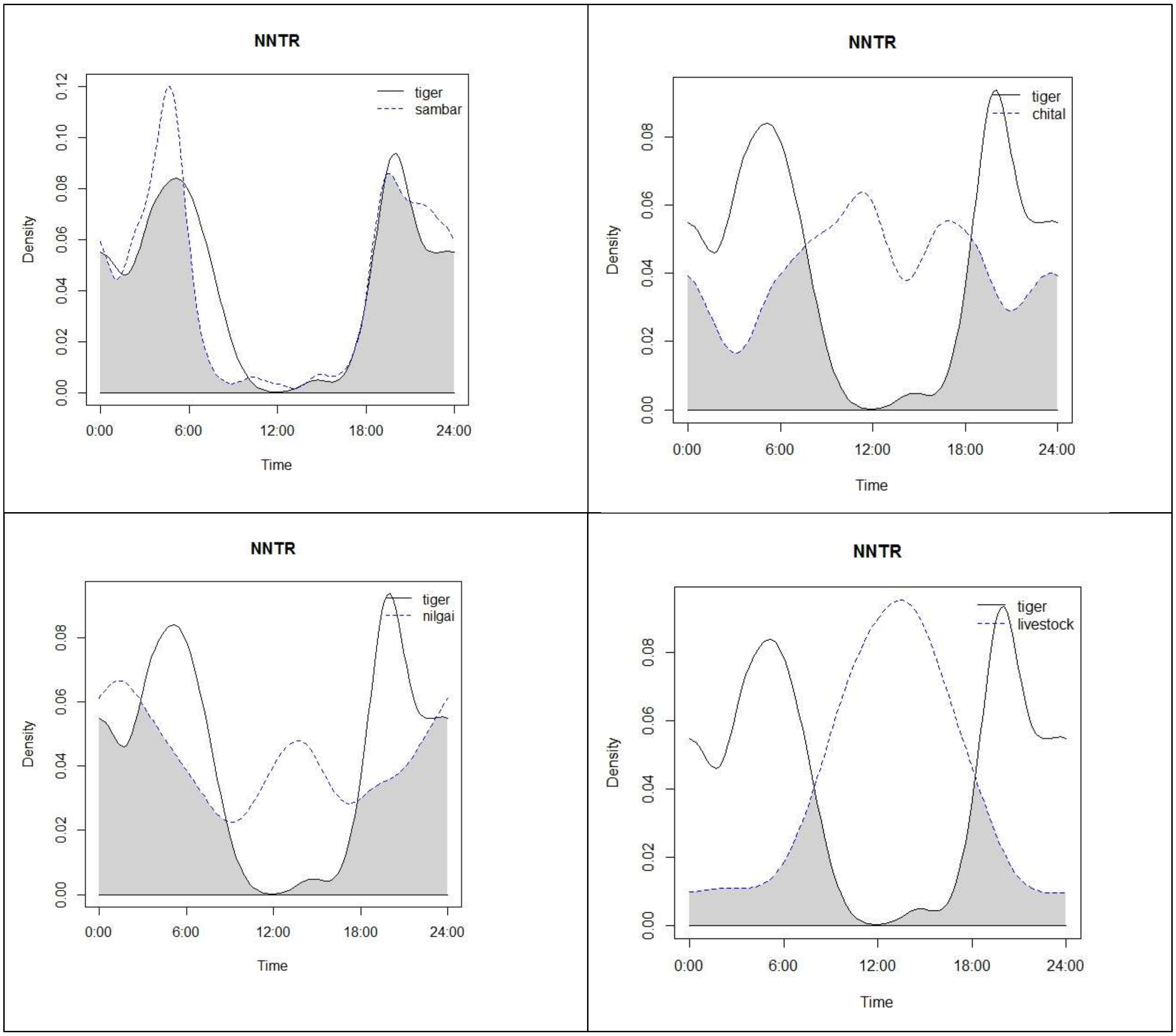
Figure 7.36 Temporal overlap between dhole and prey in Melghat

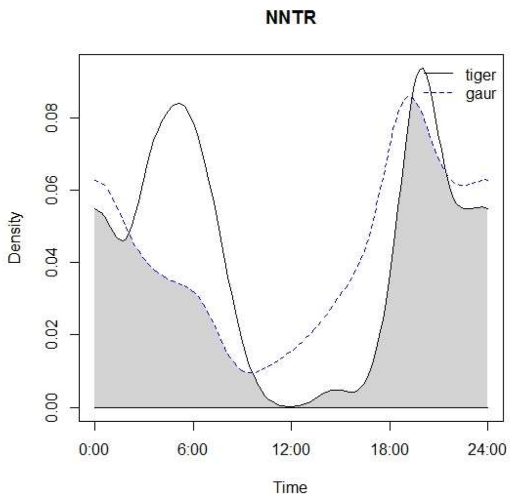
NAGZIRA -NAWEGAON TIGER RESERVE



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND DHOLE	0.5897154	0.5888355	0.5509368
LEOPARD AND DHOLE	0.5178717	0.5182553	0.5372951

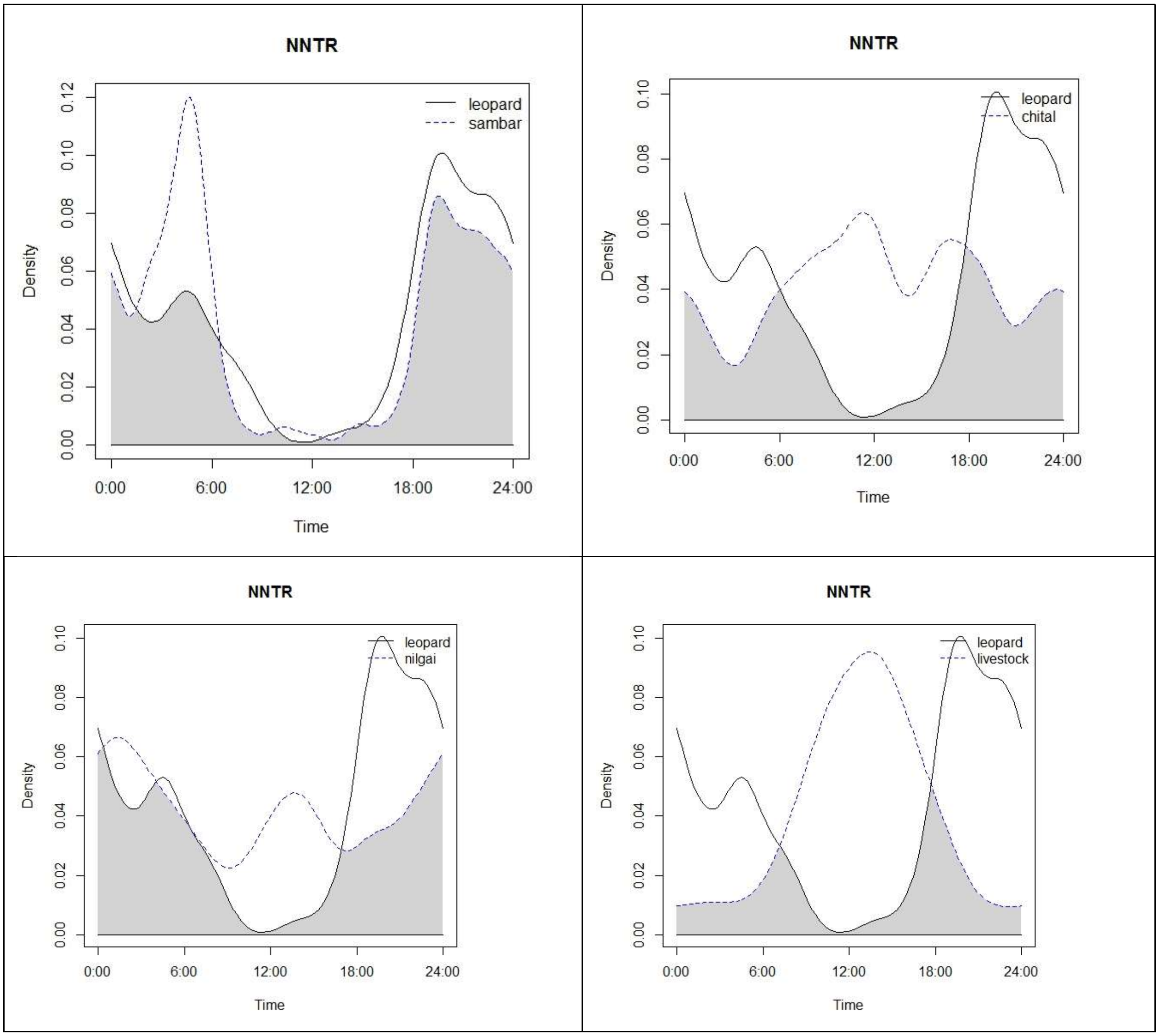
Figure 7.37 Temporal overlap between predators in NNTR





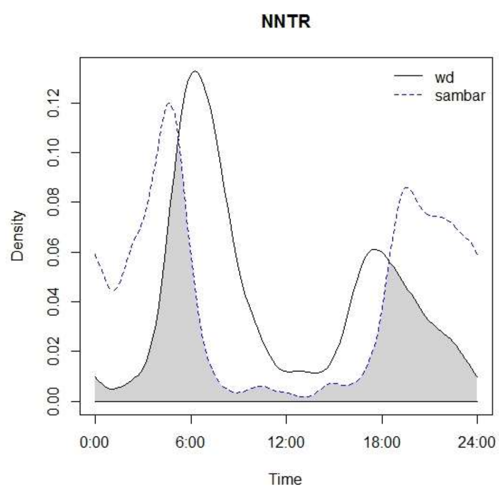
	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND SAMBAR	0.8626903	0.8672202	0.9069814
TIGER AND CHITAL	0.5515653	0.5448676	0.5520833
TIGER AND LIVESTOCK	0.3102709	0.2898065	0.2412399
TIGER AND NILGAI	0.6862143	0.6760681	0.7228651
TIGER AND GAUR	0.745124	0.7489509	0.7797619

Figure 7.38 Temporal overlap between tiger and prey in NNTR



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.8111002	0.8127955	0.796822
LEOPARD AND CHITAL	0.5602196	0.5522438	0.546875
LEOPARD AND LIVESTOCK	0.3343622	0.3113746	0.3011792
LEOPARD AND NILGAI	0.6933657	0.6873837	0.7328212

Figure 7.39 Temporal overlap between leopard and prey in NNTR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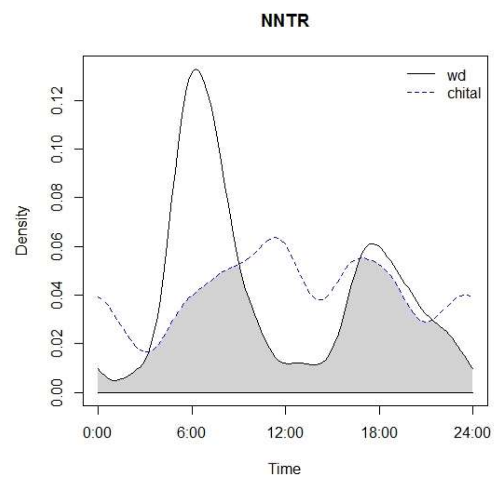
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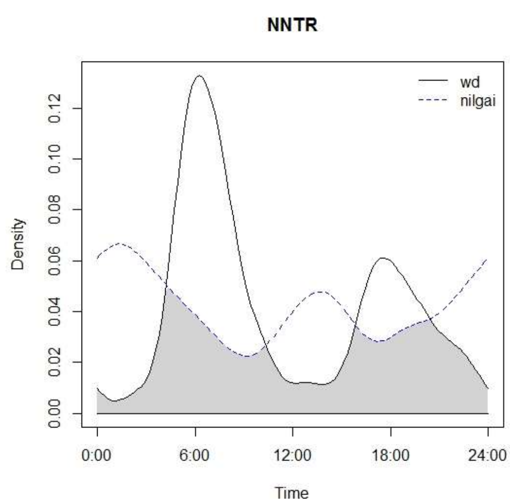
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nilgai
Density
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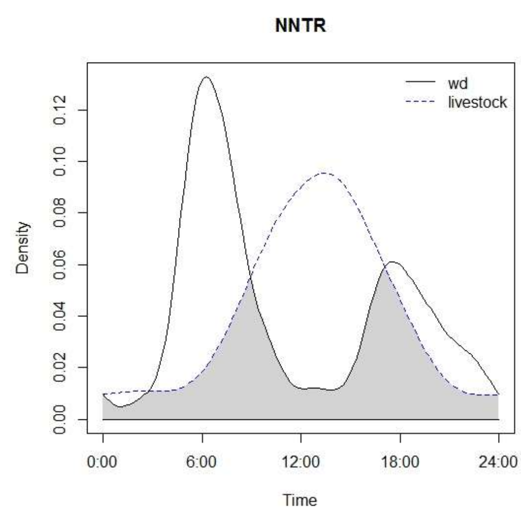
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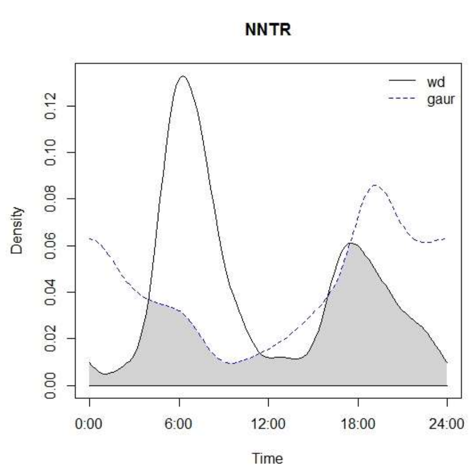
Time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0:00
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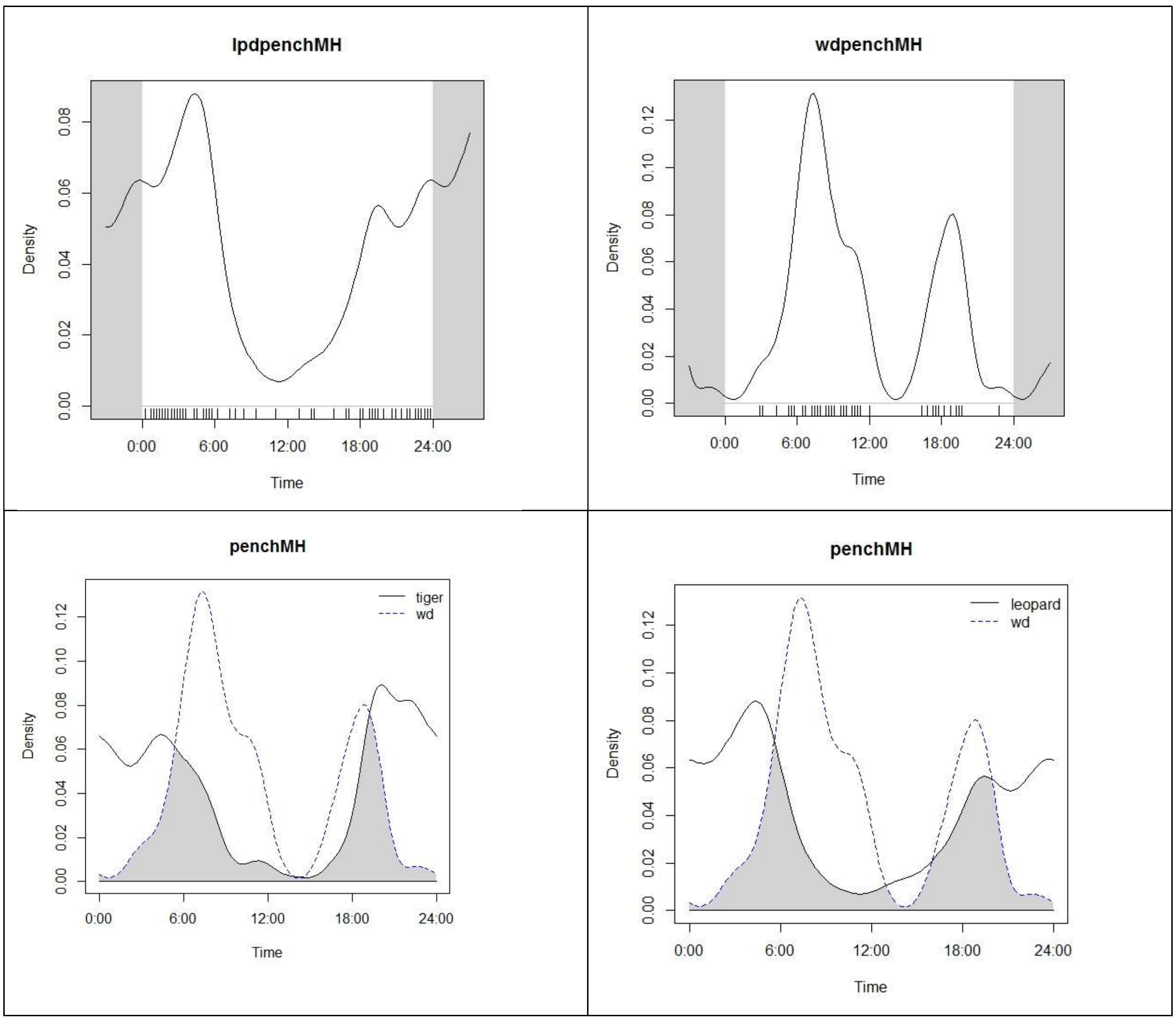
Time

	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
DHOLE AND SAMBAR	0.5036311	0.5081644	0.403237
DHOLE AND CHITAL	0.6713948	0.6630021	0.685707
DHOLE AND LIVESTOCK	0.5129993	0.4925303	0.4747912
DHOLE AND NILGAI	0.5602207	0.5388322	0.5047165
DHOLE AND GAUR	0.5726507	0.5608354	0.5884075

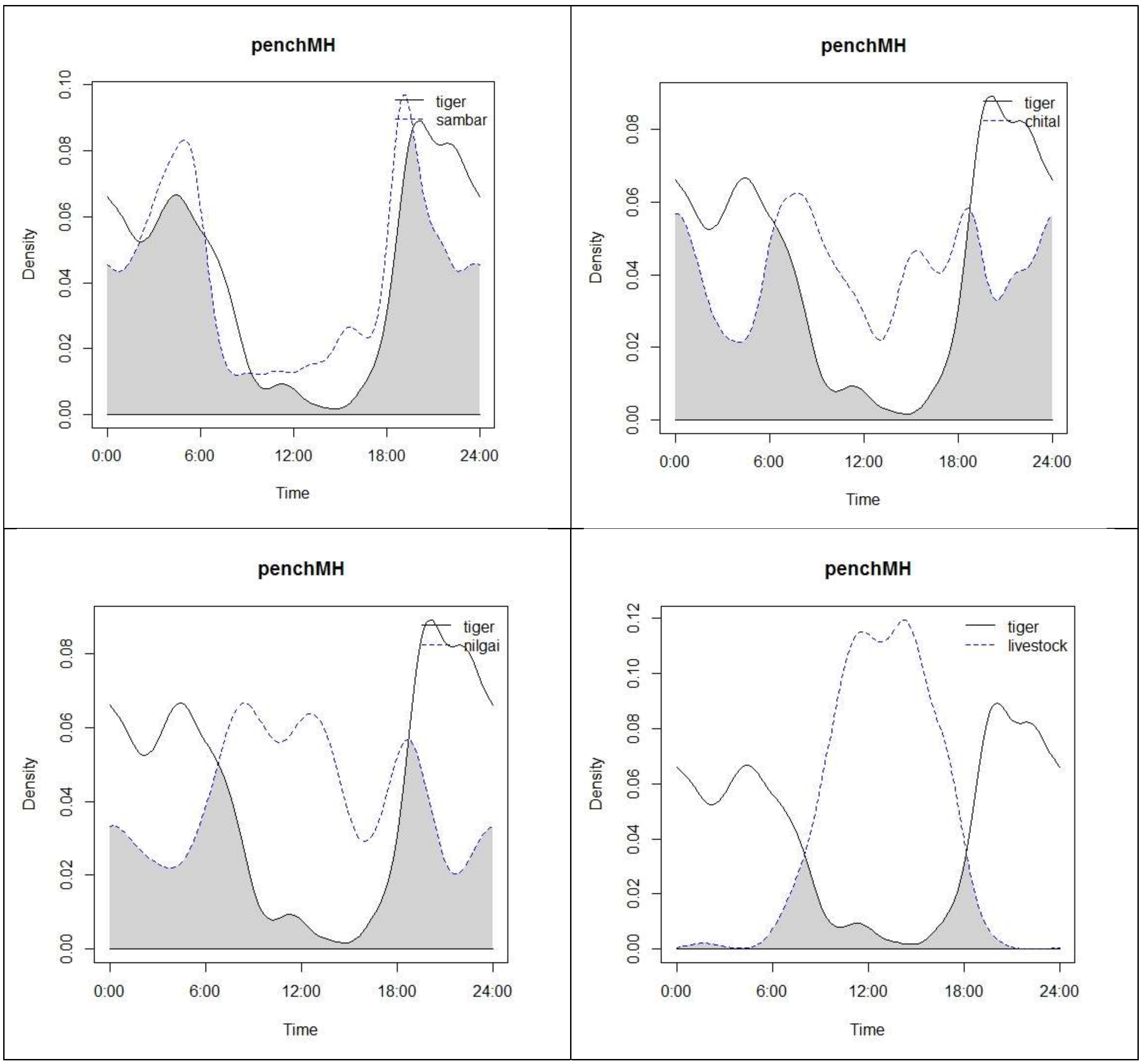
Figure 7.40 Temporal overlap between dhole and prey in NNTR

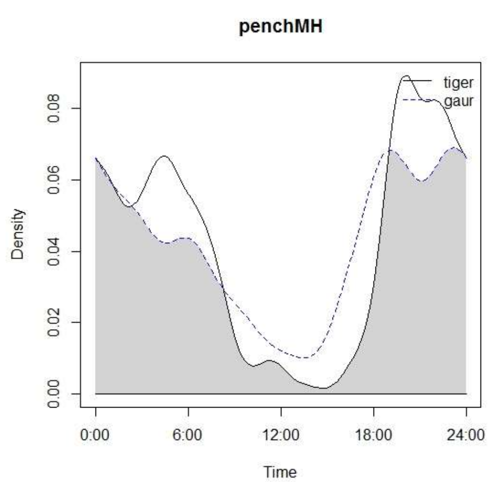
PENCH TIGER RESERVE (MAHARASHTRA)



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND DHOLE	0.479002	0.483832	0.464443
LEOPARD AND DHOLE	0.481688	0.475194	0.494502

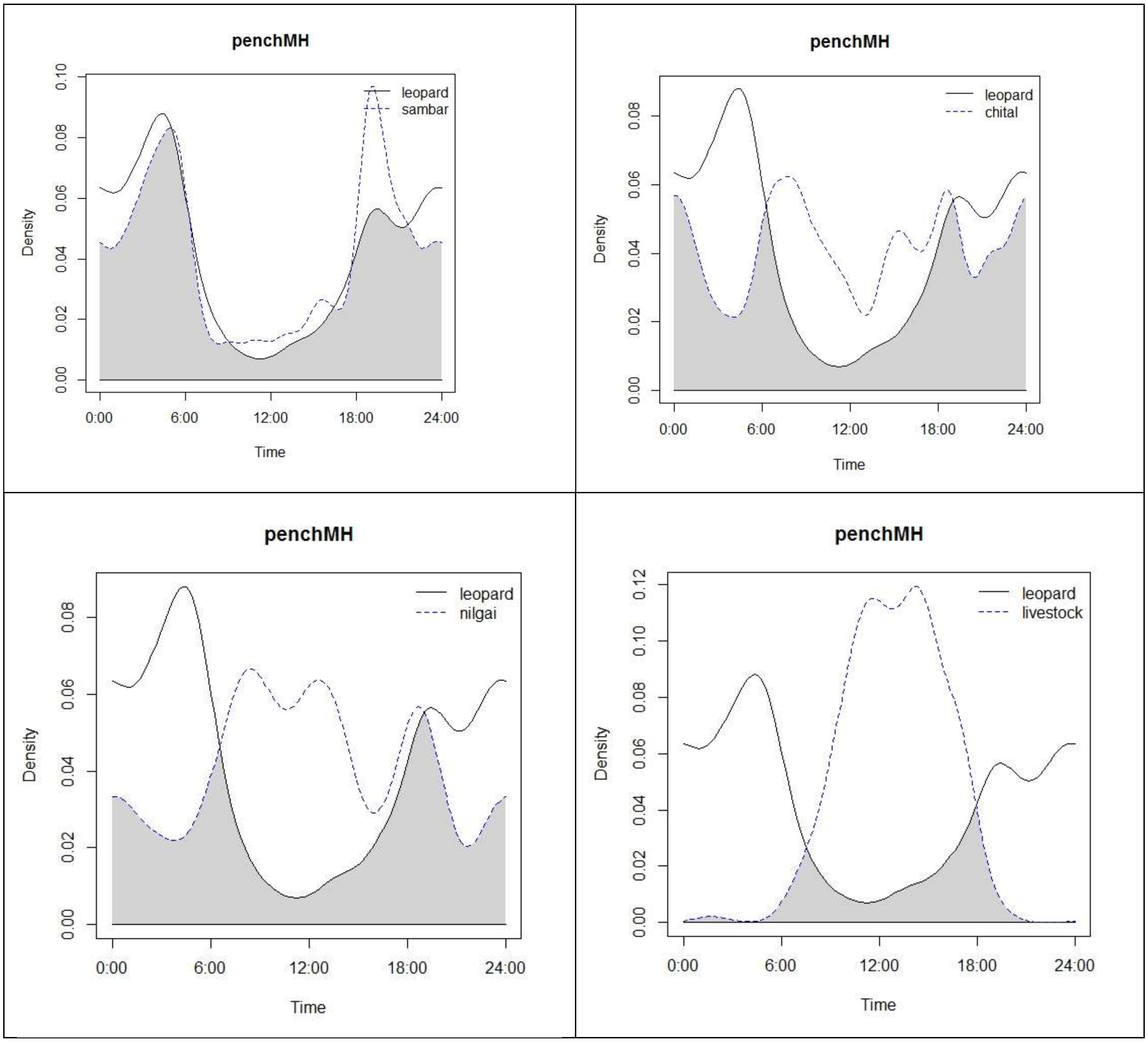
Figure 7.41 Temporal overlap between predators in Pench MH





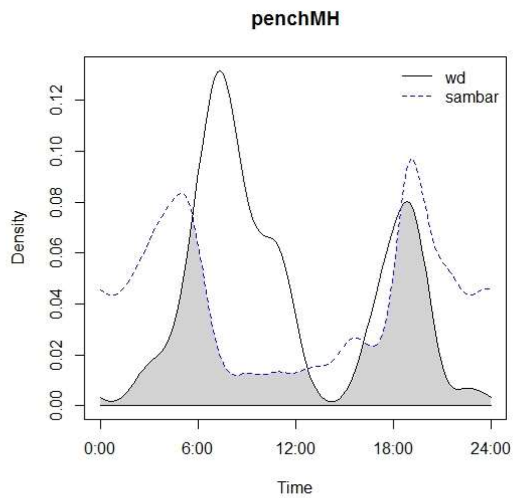
	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER AND SAMBAR	0.805924	0.807093	0.795872
TIGER AND CHITAL	0.652531	0.652803	0.656238
TIGER AND LIVESTOCK	0.171301	0.152487	0.145609
TIGER AND NILGAI	0.544559	0.550964	0.551379
TIGER AND GAUR	0.841512	0.849796	0.818086

Figure 7.42 Temporal overlap between Tiger and prey in Pench MH



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.8783253	0.8769413	0.9015819
LEOPARD AND CHITAL	0.6919833	0.6881756	0.665102
LEOPARD AND LIVESTOCK	0.2273009	0.2088118	0.1986389
LEOPARD AND NILGAI	0.5853878	0.5785437	0.5749806

Figure 7.43 Temporal overlap between Leopard and prey in Pench MH


penchMH
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Density
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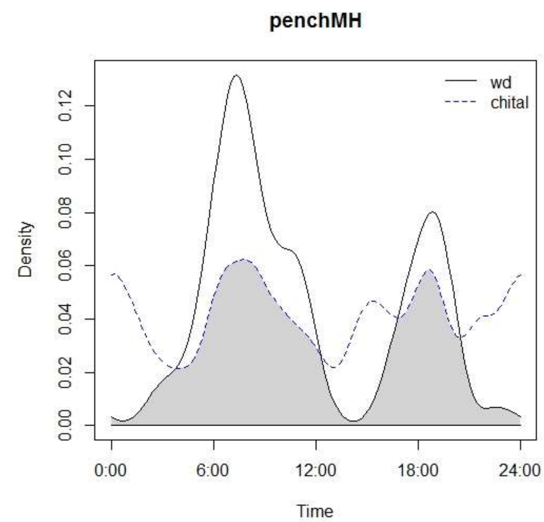
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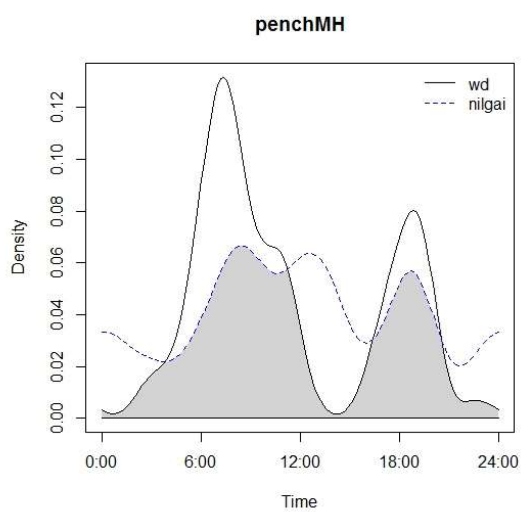
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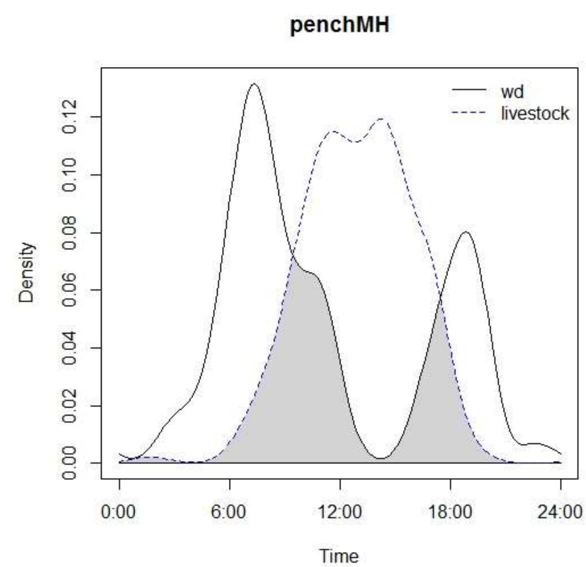
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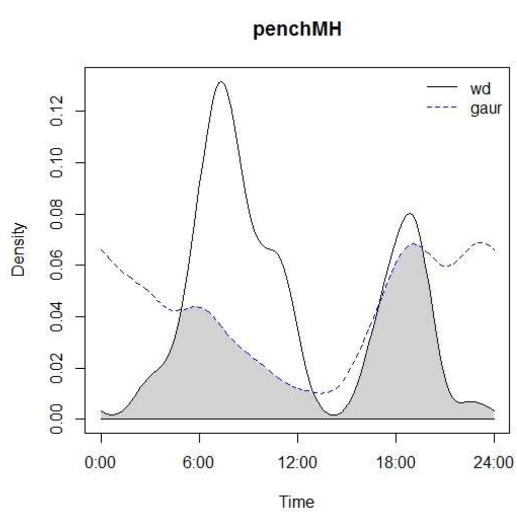
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Time

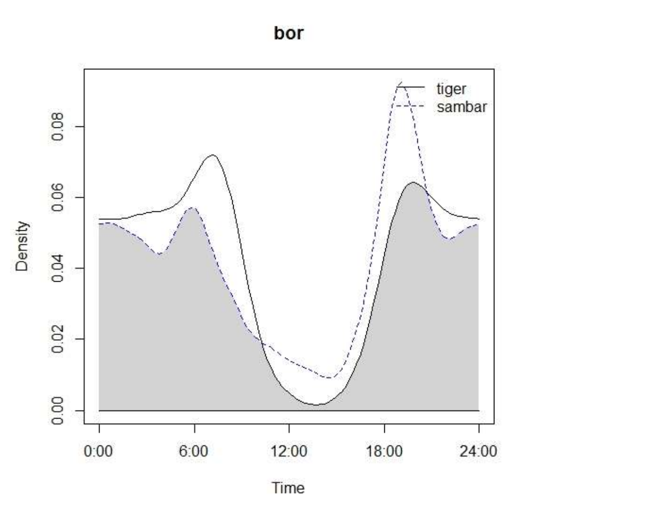
	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
DHOLE AND SAMBAR	0.520885	0.5160882	0.5193975
DHOLE AND CHITAL	0.6574864	0.6465783	0.6332228
DHOLE AND LIVESTOCK	0.4237071	0.4163655	0.3823583
DHOLE AND NILGAI	**0.6991671**	0.6840563	0.6912049
DHOLE AND GAUR	0.5683165	0.5695402	0.5829376

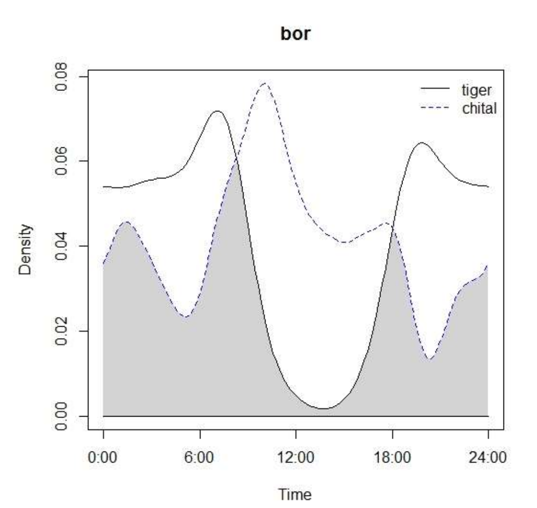
Figure 7.44 Temporal overlap between dhole and prey in Pench MH

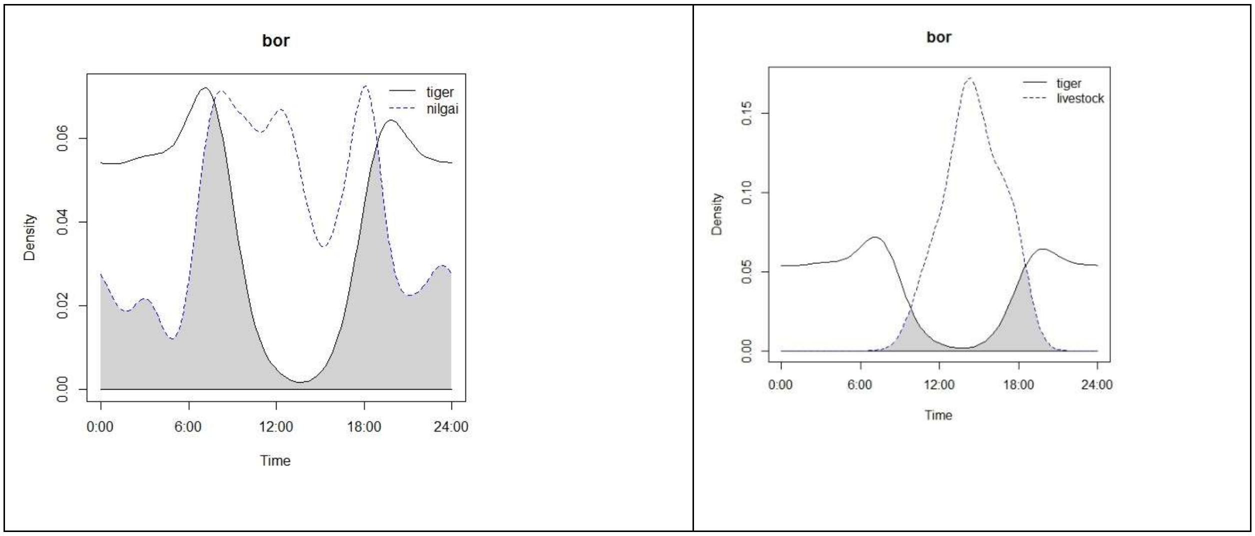
Bor TR:

The capture of dhole is very less in Bor to predict the temporal activity of the same.

Temporal overlap of tiger with prey.



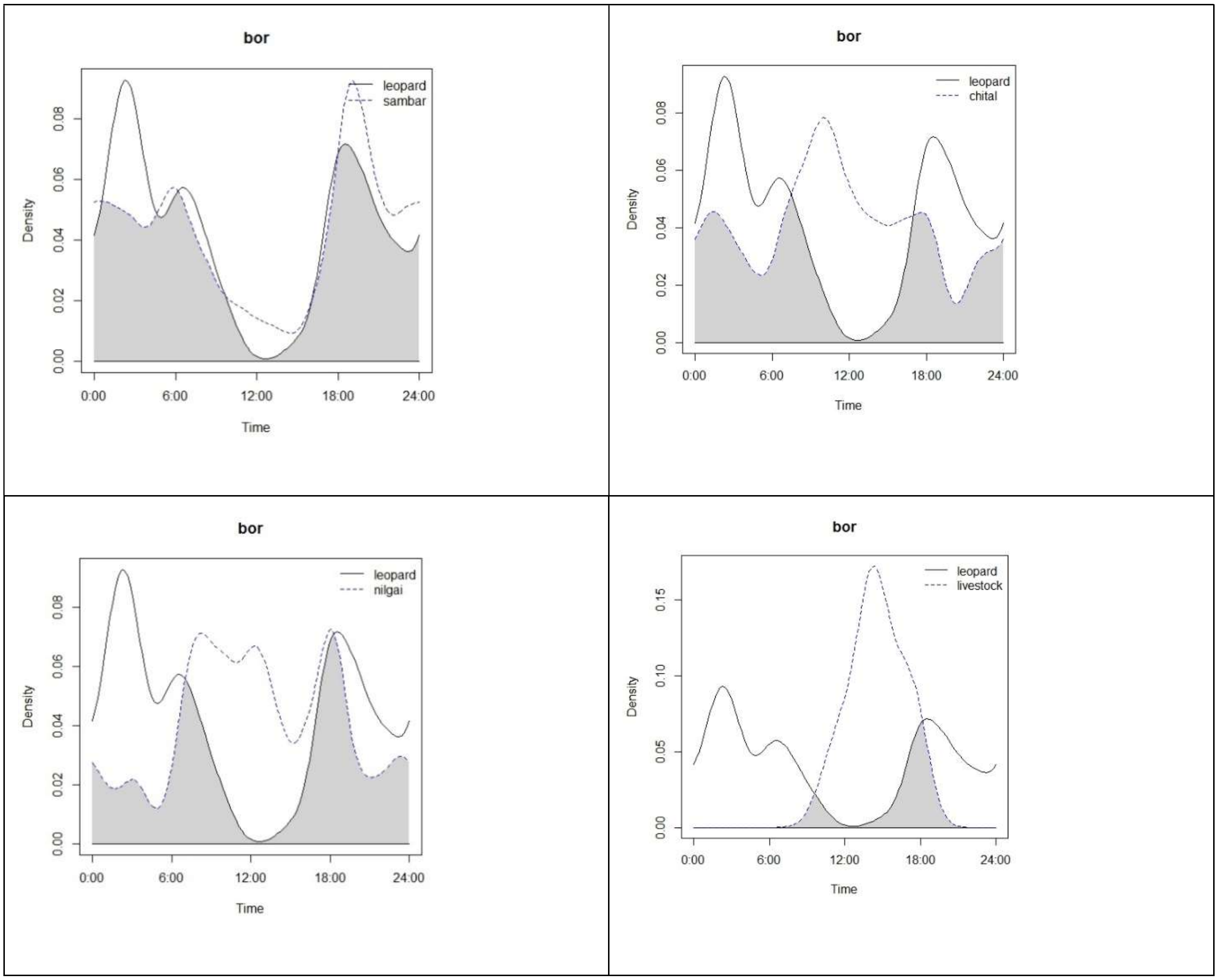




	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
TIGER & LEOPARD	0.8431	0.8428	0.8881
TIGER AND SAMBAR	0.8622	0.8571	0.9291
TIGER AND CHITAL	0.6246	0.6261	0.5718
TIGER AND LIVESTOCK	0.1658	0.1404	0.1294
TIGER AND NILGAI	0.5846	0.5988	0.5786

Figure 7.45 Temporal overlap between tiger and prey in Bor

Temporal overlap of leopard with prey.



	OVERLAP COEFFICIENT	C.I (LOWER)	C.I. (UPPER)
LEOPARD AND SAMBAR	0.8549143	0.8549629	0.8929257
LEOPARD AND CHITAL	0.6246058	0.6260609	0.5717985
LEOPARD AND LIVESTOCK	0.215913	0.2092334	0.2065217
LEOPARD AND NILGAI	0.5974661	0.5990884	0.5886432

Figure 7.46 Temporal overlap between leopard and prey in Bor

Discussion and Conclusion:

The temporal activity overlap of first trophic predator with tiger in high tiger density areas is highest. The 3 sites (high tiger density) used for analysis (Melghat, tadoba and Pench MH) showed high overlap between tiger and first trophic, with Pench MH showing least overlap. **This overlap was found to decrease with the decreasing tiger density region. The temporal overlap was found to be least in NSTR, a low tiger density region.** Compared to tiger and first trophic, the temporal overlap between first trophic and meso-predator was found to be low. In medium tiger density area like Satpuda, the above said temporal overlap was found to be least. **In tiger absent area i.e., Kawal the overlap was found to be low. The temporal overlap between tiger and meso-predator is highest in two of the high tiger dense areas** i.e., Melghat and Pench MH.

In **Melghat**, tiger and first trophic shows high temporal overlap with area under curve being large during peak activity period for both trophic. The meso-predator avoid first trophic during peak activity post dusk time and a high temporal overlap was found between tiger and meso-predator. In **Tadoba,** although temporal overlap is observed between tiger and first trophic yet segregation of first trophic peak activity was at dawn and avoidance at dusk when tiger has peak activity. Similarly, meso-predator avoid first trophic peak activity by segregating before dawn and post dusk and in cohesion with tiger peak activity. But **Pench MH** presents a different picture. Although temporal overlap was observed between tiger and first trophic yet it is lower than as case of Tadoba and Melghat. Although similar to other two sites, higher peak activity was observed post dusk which was avoided by first trophic. Meso-predator are more active before dawn and post dusk which is peak activity of tiger but avoided by first trophic.

In **high tiger density area** like Melghat, Tadoba and Pench MH**, a high overlap between tiger and first trophic was observed yet at finer scale it was observed that while tiger peak activity which was post dusk was avoided by first trophic. the first trophic highest activity was observed during dawn with exception of Melghat where it has independent peak activity at dusk and dawn both.** Melghat has very low prey base and hence a driving force for the temporal activity of predator can be the ungulate density. Gaur is segregated at periphery of the park and other prey of tiger and first trophic, i.e. Sambar and Chital can be concluded to affect the predator activity.

In **medium tiger density area** like Satpuda **the overlap between tiger and first trophic is lower than as observed in high tiger density sites**. **Although in Satpuda also tiger temporal activity is highest post dusk but first trophic is also highly active post dusk unlike high tiger density sites.** The same peak activity is observed in meso-predator. Satpuda witnessed village relocation recently and the prey and habitat recovery process are undergoing. Gaur and Chital preferring the grassland plateau are limited in Satpuda and thus resulting in prey segregation. **A high overlap alongwith overlap in peak activity period between tiger and first trophic might be due to prey segregation and furthermore very low temporal overlap between First trophic and meso-predator. Also, Satpuda has Jackal and fox as meso-predator which might add to this avoidance between first trophic and mesopredator.**

For the study sites in central Indian landscape, the temporal overlap, which ranges from 0-1, across the carnivores suggest **high overlap between tiger and leopard (0.9), jungle cat and ratel (0.9) and Small Indian civet and Asian palm civet (0.93).** Across the **study sites** Tiger and Leopard showed high temporal overlap (0.8-0.9), tiger and dhole(0.4- 0.70) and leopard and dhole overlap (0.4- 0.75) was found to be low. Tiger showed a high temporal overlap with sambar (0.8-0.9) followed by Gaur (0.7-0.8) and chital (0.5-0.7). Tiger showed a very low temporal overlap with Nilgai and Livestock (below 0.6 and 0.4 respectively). Leopard showed high temporal overlap with sambar (0.5-0.9) followed by chital and Nilgai (0.5-0.7). In Kawal , leopard shows a low temporal overlap with Sambar (0.56). With livestock, leopard showed very low overlap (below 0.5). Dhole shows a high temporal overlap with Nilgai and Chital (0.6-0.8), gaur (0.6-0.7), Sambar (0.5-0.8) and low overlap with Livestock (0.4-0.6). Dhole shows highest overlap with Sambar in Melghat (0.88), with Nilgai in Satpuda (0.8) and with Chital in NSTR (0.8). Although presence of livestock inside and outside study sites are observed yet none of the top carnivores showed significant overlap with livestock.

Site-wise temporal activity:

In **Kawal**, a site where tiger doesn't exist, Leopard and dhole are large predator where fragmentation of habitat manages to provide prey and habitat for leopard but segregated habitat is available for dhole. The prey of Dhole i.e., Gaur is found in selected pockets of the park. Wild dog presents activity for larger span of time compared to leopard which has peak activity post dusk. Leopard present narrow activity range with peak being during dawn. In absence of tiger, leopard act as a top predator on temporal niche. It was observed leopard has highest temporal overlap with Sambar> Nilgai> Chital while dhole with Nilgai> Gaur> Chital> Sambar.

NSTR (low tiger density) presented different picture for tiger co-predator compared to Kawal. Here, dhole has smaller temporal peak activity and is maximum active during dawn. Leopard uses larger active time period with peak activity at dusk. The prey temporal overlap for tiger is Sambar> Nilgai> Chital, for leopard it is Sambar > Nilgai and Chital (very low) and dhole it is Chital > Nilgai and Sambar (very low).

NNTR (low tiger density) showed a similar picture as NSTR where dhole has smaller niche width with peak activity being in dawn while leopard has larger niche width with peak activity at dusk. Tiger overlap with prey is Sambar> Gaur > Nilgai, Leopard has temporal over lap with prey as Sambar> Nilgai> Chital (very low) and for dhole it is Chital> Gaur> Nilgai.

Satpuda (medium tiger density) has larger temporal niche width for leopard and smaller for dhole. Tiger prey overlap is Sambar/Gaur> Nilgai> Chital, for leopard the overlap with prey is Sambar> Nilgai> Chital and for dhole it is Nilgai>Gaur>Livestock

Melghat (high tiger density) shows wider activity range for leopard and narrow activity range for wild dog. The peak activity for dhole is at dawn. The prey overlap for tiger is Sambar> Gaur, for leopard it is Sambar> Chital (very low) and for dhole it is Sambar> Gaur> Nilgai/Chital.

In **Pench MH (high tiger density)**, leopard has wider range for temporal niche and dhole has narrow with peak activity at dawn. Tiger has prey overlap with Gaur> Sambar> Chital (very low), Leopard has prey overlap with Sambar > Chital (very low) and for dhole it is very low for Nilgai> Chital> Gaur.

Co-predator and temporal activity:

It is already established that in central Indian landscape, the peak activity of tiger was observed to be at dusk while leopard was observed to be active both at dusk and dawn and a high temporal overlap (0.90). However, a slight avoidance of top predator at the temporal cycle may be observed, leopard corresponds its temporal activity peak with the major/ large prey (Sambar) in Kawal TR. The temporal cycle in absence of tiger is active at peak activity time of prey followed by resting period. In Pench TR the activity of leopard is high at dawn phase but shows activity peaks at dusk phase too. Since dusk is peak activity of Tiger in Pench MH, a slight avoidance at the temporal activity phase is observed. In Melghat the peak activity of leopard corresponds with tiger peak activity which shows a multiple phase owing to the less prey density in Melghat. Leopard in Tadoba also shows larger duration activity peaks corresponding to Tiger. **It can be concluded in high tiger density area, leopard shows a wider temporal activity range with no resting period and in absence of tiger, leopard shows peak activity corresponding to large prey i.e. Sambar with resting period before and after dusk and dawn.**

In high tiger density area , if its major prey i.e. Gaur population and habitat is managed then the niche separation between tiger and first trophic is expressed on temporal scale. Pench MH present a high tiger density area where gaur presence is spatially present and as analyzed its temporal overlap with tiger is also high. Here, the trophic segregation on temporal scale is expressed between tiger-first trophic. Melghat is high tiger density but prey density is poor. It is also expressed by low temporal overlap between Gaur and tiger here. The major contributor of high temporal overlaps between tiger-first trophic here is leopard which itself shows highest temporal overlap between tiger-leopard in Melghat. Melghat is a large area compared to Pench MH (Melghat TR ~1500 sq km and Pench MH ~450 sq km), yet availability of less grasslands, high resource dependency and village presence provide high refuge for leopard but low resource availability for tiger. Hence in spite of low prey availability, leopard density is found to be higher than tiger. Segregation of prey in selected area could be resulting in high tiger-leopard temporal overlap.

A common notion that temporal partitioning facilitates co-occurrence of leopard with tiger by reducing the probability of encounter of the two (Karanth et al 2017) should be looked into ″ fine scale ″. A high temporal overlaps between tiger and leopard as concluded through this study is in accordance to Chaudhary et al 2020, Li et al 2019). Dhole crepuscular activity is similar as elsewhere (Grassman et al 2005) and synchronized with diurnal prey (Karanth and Sunquist 2000).

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SPATIAL SEGREGATION AND CO-OCCURANCEAMONGST TIGER AND LEOPARD, DHOLE AND MESOPREDATOR

- **Spatial segregation on camera-trap; kernel density-TIGER & LEOPARD**
- **Inverse distance weighted interpolation at cameratrap for tiger, leopard, dhole and mesopredator for Kawal, Umred, NSTR, Bor, Tadoba and Melghat.**
- **Single species Occupancy for tiger, leopard, dhole and mesopredator for Kawal, Umred, NSTR, Bor, Tadoba and Melghat**
- **Two Species Occupancy;Species Interaction Factor for tiger, leopard, dhole and mesopredator for Kawal, Umred, NSTR, Bor, Tadoba and Melghat.**

Introduction: The spatial avoidance of subordinate carnivores has been studied in reference to exploitative competition, habitat segregation or segregation due to prey distribution (Seindensticker 1976, 1990, Harihar et al 2011)). However, very few studies on avoidance between carnivores at fine-scale have been observed. Avoidance due to interference competition has been observed in leopards where it avoided space used by tiger (Oden et al 2010, Carter et al 2015).

In another study, Coyotes and Bobcats occupy sympatric home ranges although the species have more niche overlap, whereas red foxes avoid the suitable habitat in coyotes home range (Harrison et al 1989, Major &Sherbourne 1987, Litvaitis& Harrison 1989). Coyotes (8-20kg) are closer to Bobcats (6.4-18.3kg) in body size. Being much smaller in body size, red fox (2.2-14kg) avoids Coyotes to prevent interference competition.

However, in case of tiger and leopard, **the co-existence in space has been observed at most of the Tiger reserve. Yet the segregation in space at fine scale i.e. camera-trap level reveal that leopard do avoid tiger where ever interference competition is evident. To understand such response in meso-predator is very difficult. Robust methods are available to estimate density of large and identifiable predator but for the meso-predator detection rate is low on camera-trap and hence occupancy is mostly relied for the small carnivore studies.**

According to my hypothesis, in case of low availability of prey or absence of large prey (gaur), the interference competition would be expressed and leopard would avoid spaces of high usage by tiger and in turn would present exploitative competition with meso-predator.

Occupancy analysis can enable the robust estimation of community and population parameters from camera-trap data (Burton et al., 2015). The two species occupancy models provide a method to test evidence of competitive exclusion while taking into account the false absences.The two species interaction or the co-occurrence modelling approach is also used to investigate predator prey and community assemblages (Mackenzie et al 2004).

MARK presents two versions of the 2-species occupancy models. The first developed version (MacKenzie et al. 2006) had parameterization which was not found to be robust while incorporating the covariates the parametrization was difficult to use because of a multinomial constraint on the r parameters. The second parametrization, termed as the conditional occupancy model and is stable when covariates are included(Richmond et al. 2010).

The parameterization of the conditional two-species occupancy model, assumes that Species A is the dominant species, and Species B the subordinate species and can be used to examine alternative hypotheses for species' distribution patterns.

The data type is identified in MARK as 137. 2SpecConOccup: Two species Conditional Occupancy Estimation. The parametrization for this 2-species conditional occupancy model follows.

psiA Probability of occupancy for species A

psiBA Probability of occupancy for species B, given species A is present

psiBa Probability of occupancy for species B, given species A is absent

pA Probability of detection for species A, given species B is absent

pB Probability of detection for species B, given species A is absent

rA Probability of detection for species A, given both species are present

rBA Probability of detection for species B, given both species are present and species A is detected

rBa Probability of detection for species B, given both species are present and species A is not detected

Some of the parameters of the McKenzie et al. parametrization can be defined in terms of the conditional :

psiB = psiA*psiBA + (1 – psiA) psiBa

psiAB = psiA*psiBA

psiB and psiAB are included as a derived parameter for this data type.

The co-occurrence model provides nine estimable parameters (see MacKenzie et al. 2004) including a "species interaction factor" (SIF) which is calculated as follows:

Species interaction factor (phi) = (psiA*psiBA)/(psiA(psiA*psiBA+ (1-psiA)*psiBa))

which is a measure of interaction where:

A Phi =1 indicates the two species occur independently

Phi > 1 suggests the two species are more likely to co-occur together than expected,

Phi < 1 suggests the species avoid each other – i.e. species B is less likely to occur with species A

These co-occurrence models

1) take into account imperfect detection of all target species;

2) estimate the occupancy of two or more species; and

3) determine if the presence of one species impacts the occupancy or detection of the other (MacKenzie 2006.

Inverse Distance weighted interpolation is a quick, easy to compute, and straightforward to interpret method (Lu et al 2008). The total capture at camera-trap point are weighted during interpolation such that influence of one point relative to another declines with distance from the unknown point. Spatial autocorrelation is the underlying assumption of IDW which processes as "the attribute value of an unsampled point is the weighted average of known values within the neighborhood, and the weights are inversely related to the distances between the prediction location and the sampled locations ".

The IDW method has disadvantage as it gives maximum and minimum values at sample data points in the interpolated surfaces. Also, if the sample point is uneven then the quality of interpolation decreases.

Method: To understand the co-occurrence pattern in space at fine scale Inverse distance weighted Interpolation method and Two-Species Co-occurrence Interaction Models was used. The tiger, leopard, dhole and meso-predator abundance at camera-trap were interpolated using IDW tool and kernel density tool in QGIS (version 3.4.10) and ArcGIS Desktop (version 10.6.1) To evaluate whether the presence of a particular dominant predator species influenced the occurrence of a sub-dominant species we used a single-season, two-species interaction occupancy model (Richmond et al. 2010, MacKenzie 2006; MacKenzie et al. 2004). The interaction between co-occurring species were modeled in Program R using package "Wiqid" (Mike Meredith, 2005). The two species interaction occupancy models investigate the probability of co-occurrence of two species at a given site and hence in a camera-trap session of the given camera-trap sites and occasions, the presence-absence matrix (1-0) was developed for Kawal, Umred, Satpuda and GBM.

Results:

Alpha Predator (Tiger) Absence site:
Kawal Tiger Reserve:

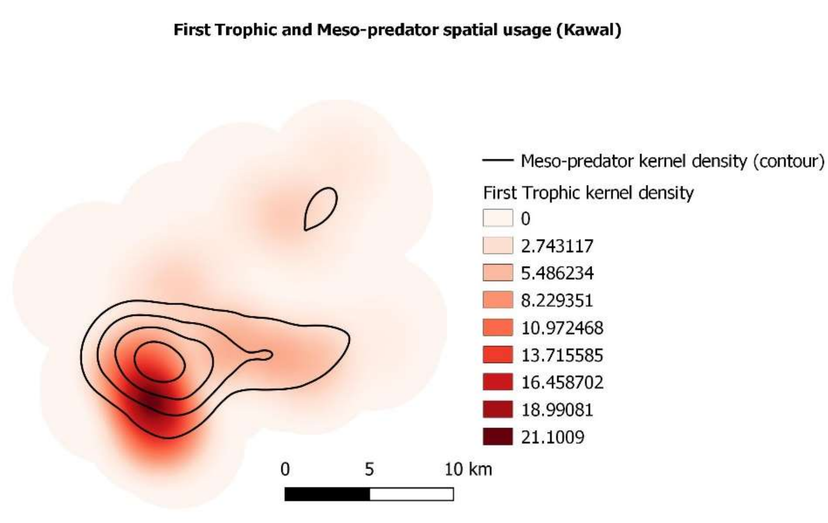


Figure 8.1 Kernel density of abundance of first trophic and meso-predator at cameratrap in Kawal

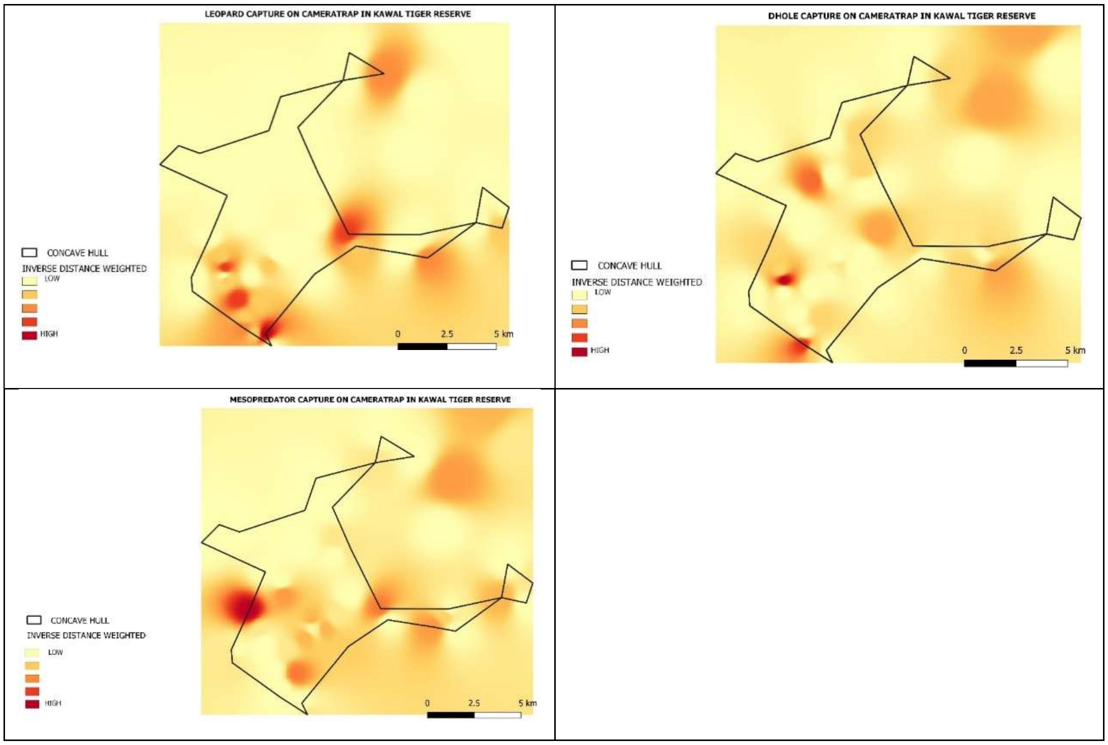
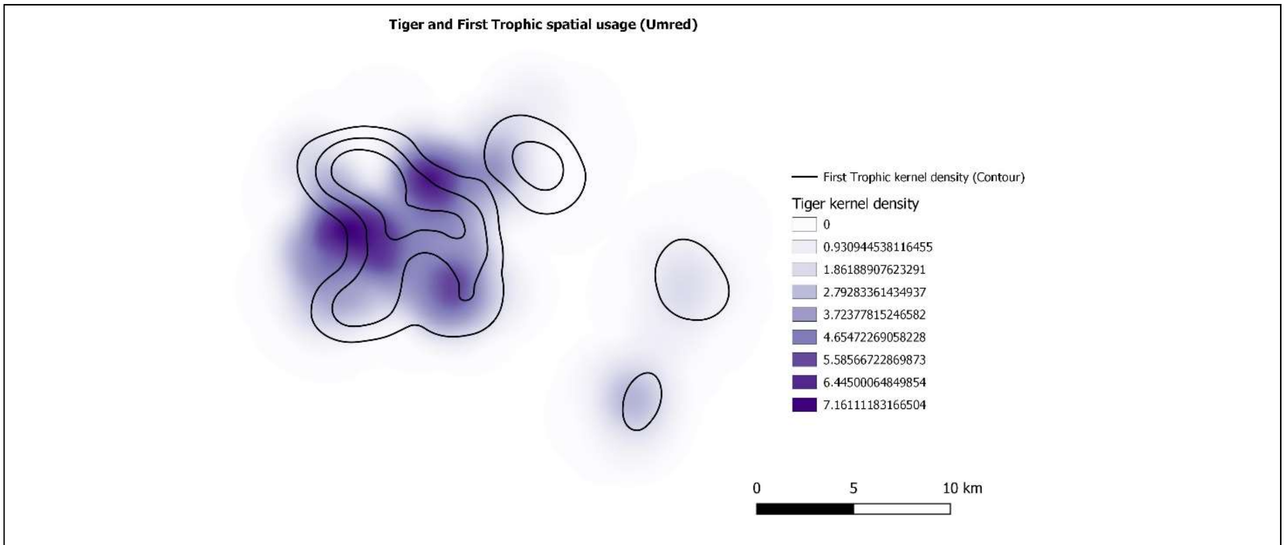
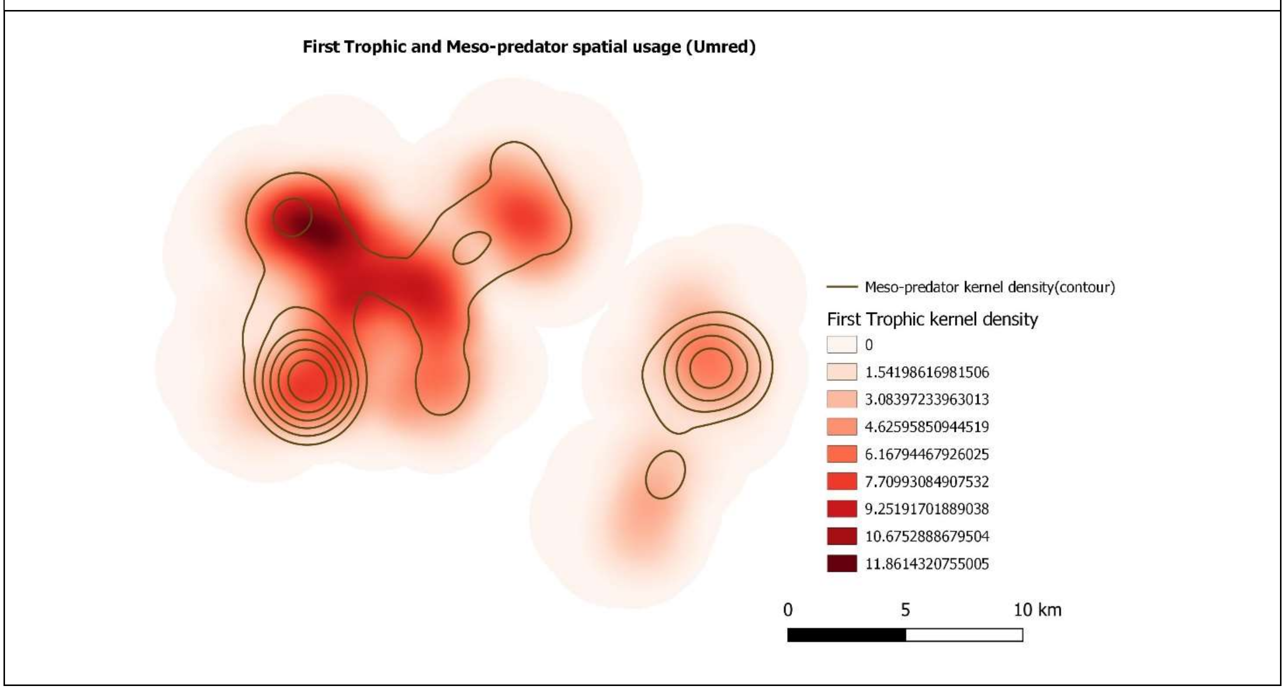


Figure 8.2 Spatial interpolation of abundance of Beta and Gamma predators at cameratrap in Kawal

Low Alpha predator (Tiger) Abundance site:

Umred Wildlife Sanctuary:





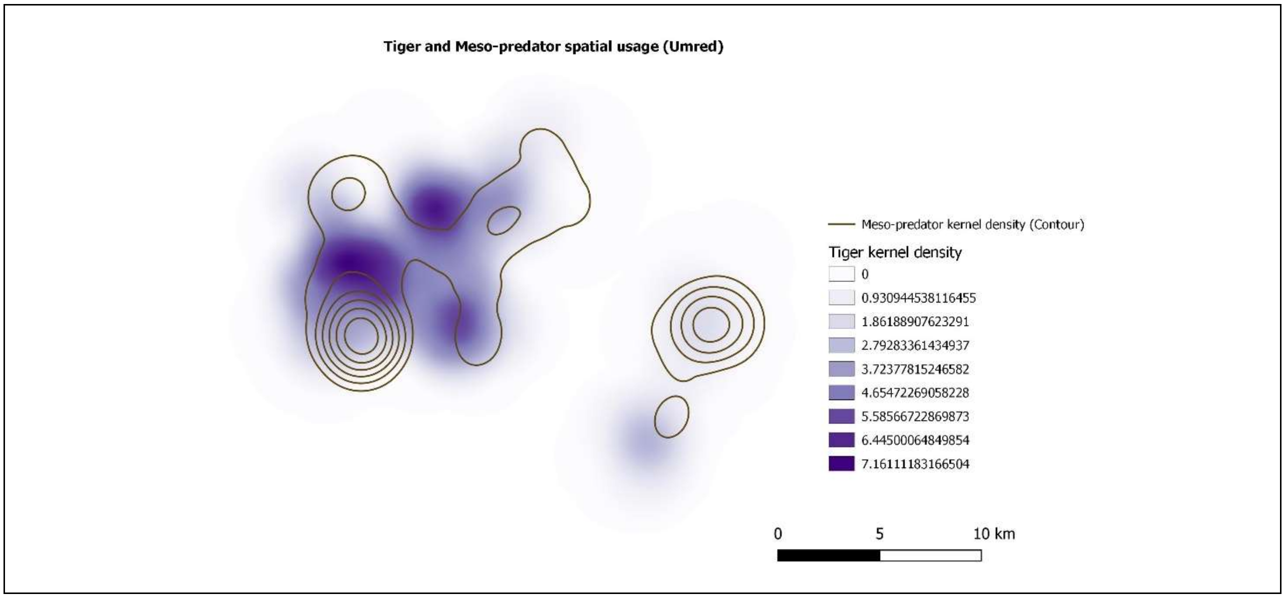
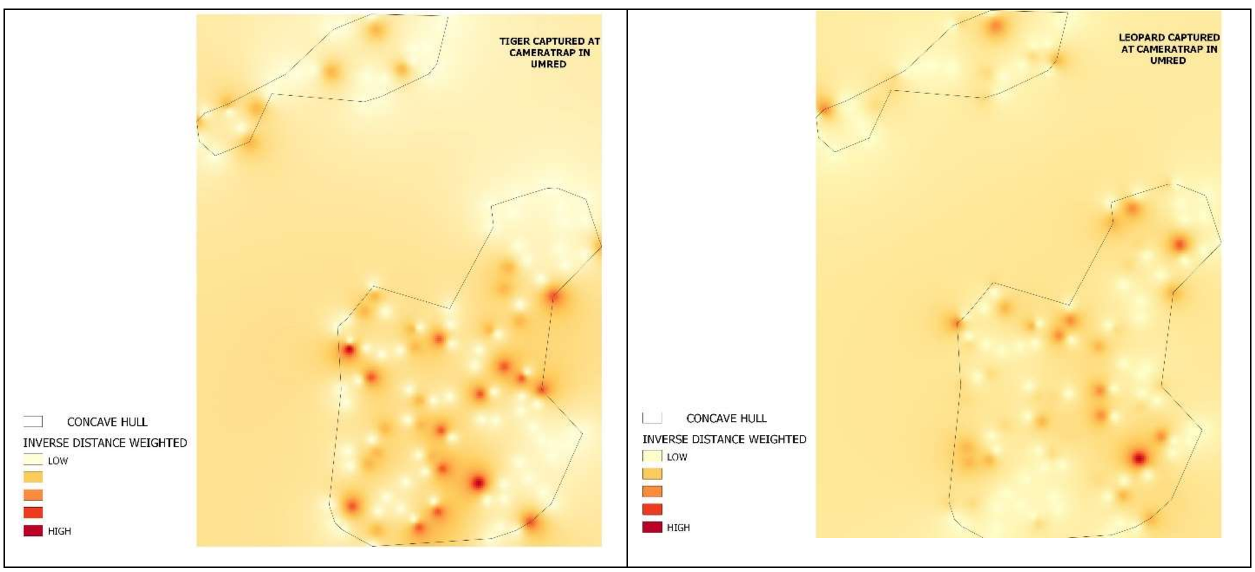


Figure 8.3 Kernel density of abundance of Alpha and leopard at cameratrap in Umred



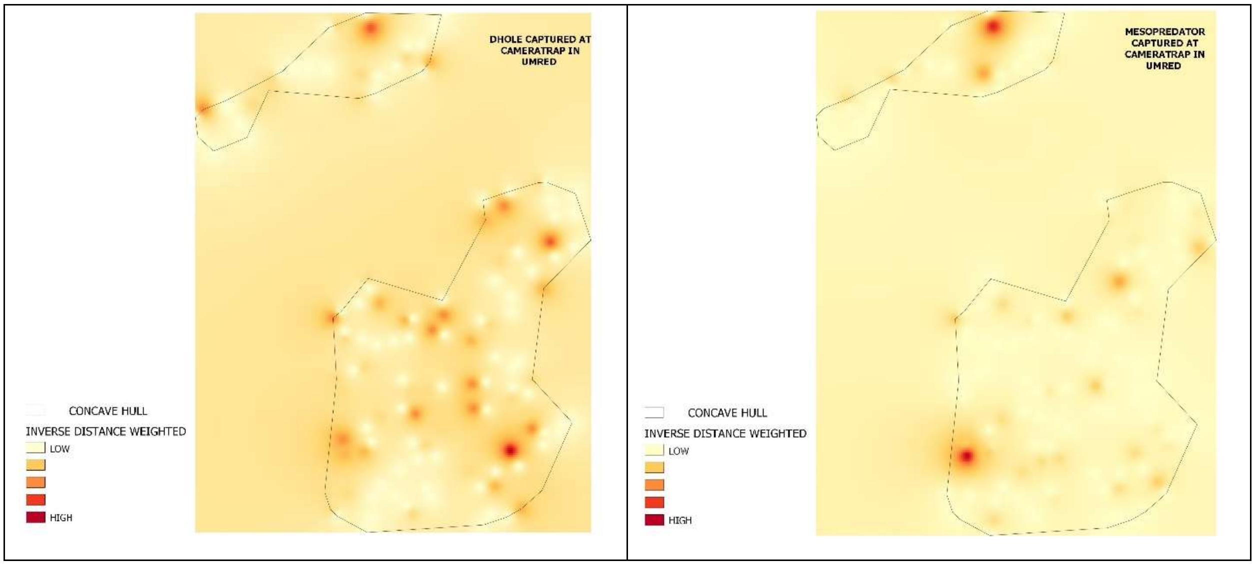
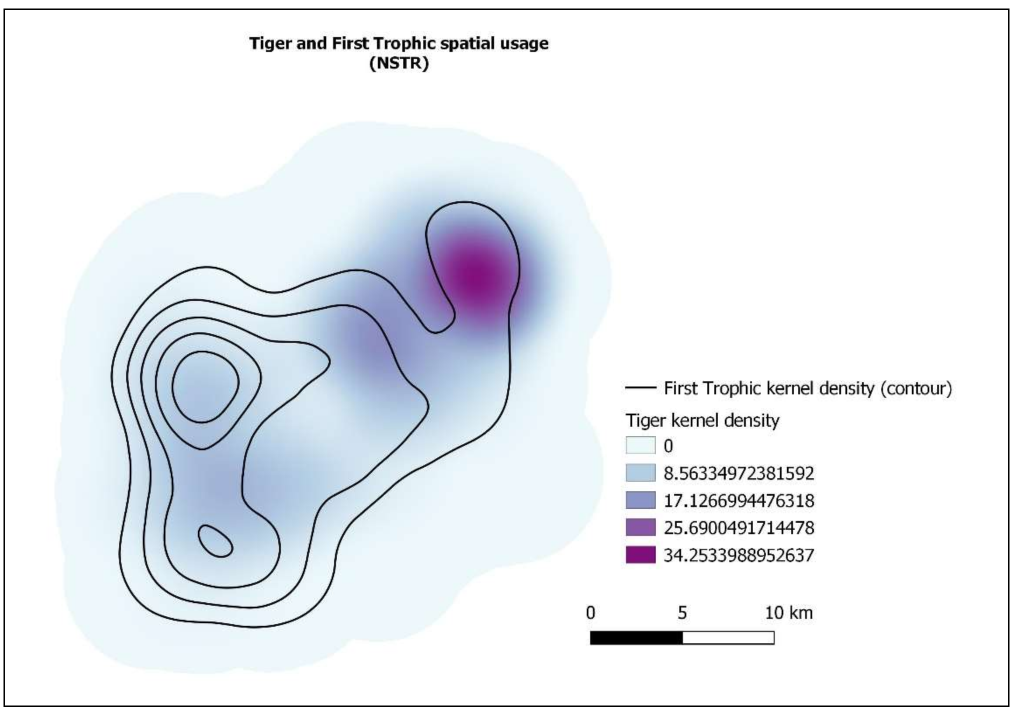


Figure 8.4 Spatial interpolation of abundance of Alpha , Beta and Gamma predators at cameratrap in Umred

Nagarjunasagar- Srisailam Tiger Reserve:



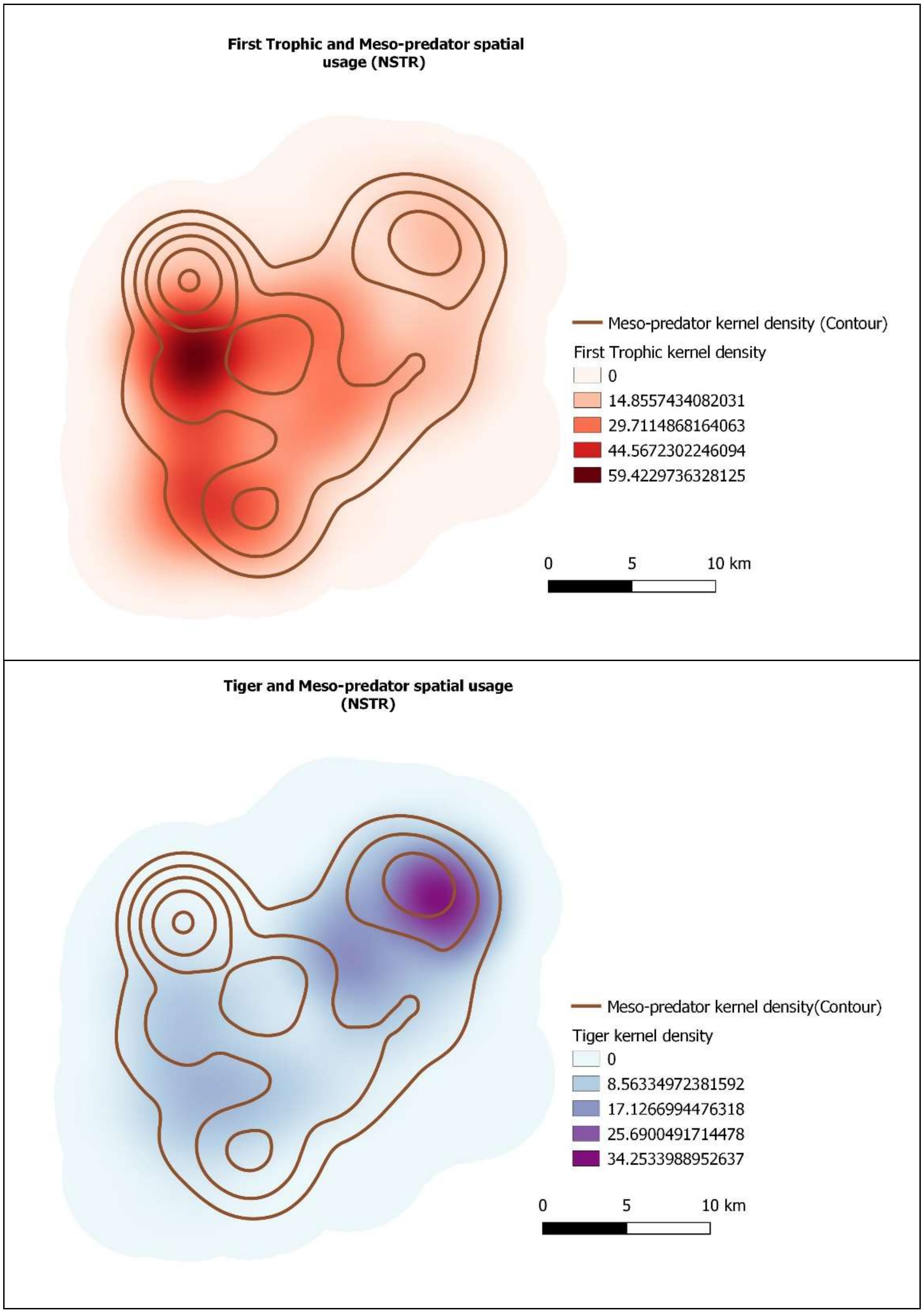
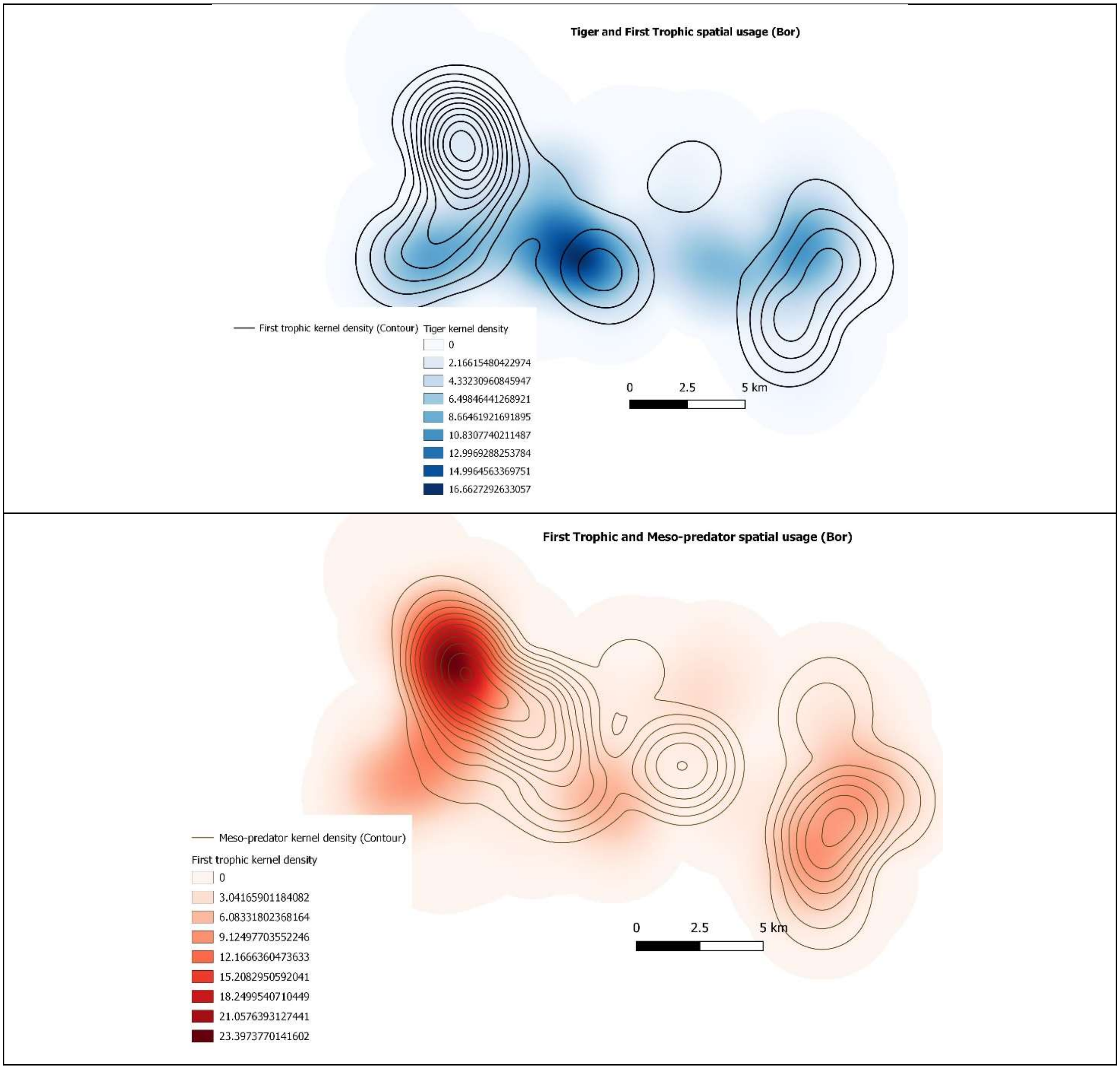


Figure 8.5 Kernel density of abundance of predators at cameratrap in NSTR

Medium Alpha predator (Tiger) Abundance site:

Bor Tiger Reserve



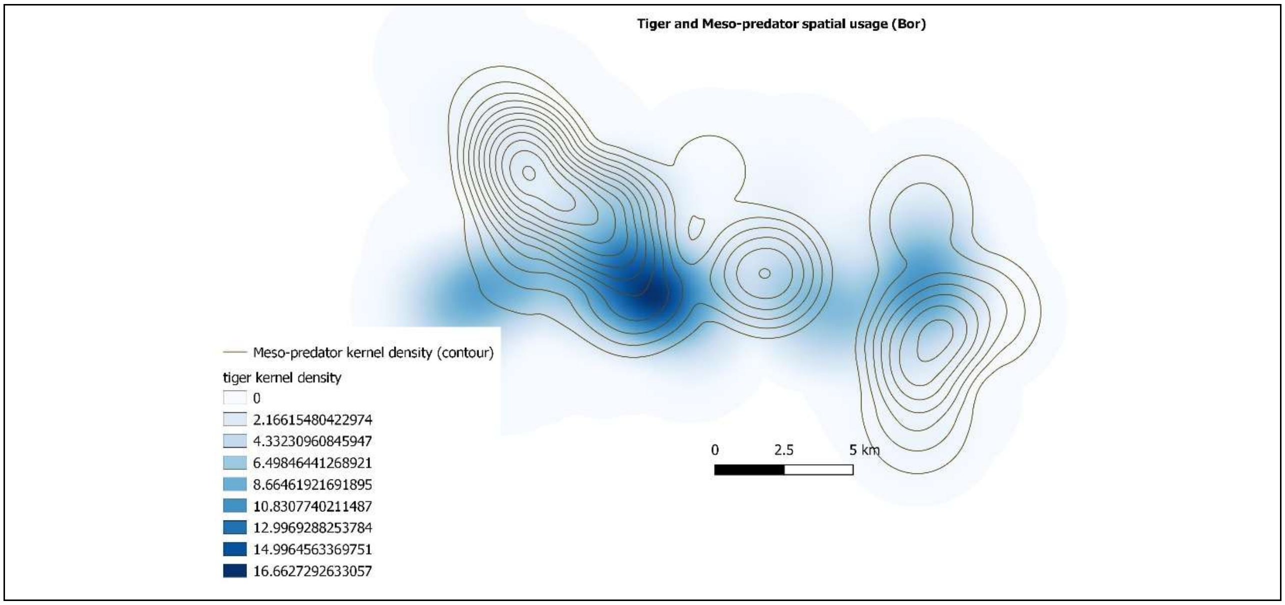
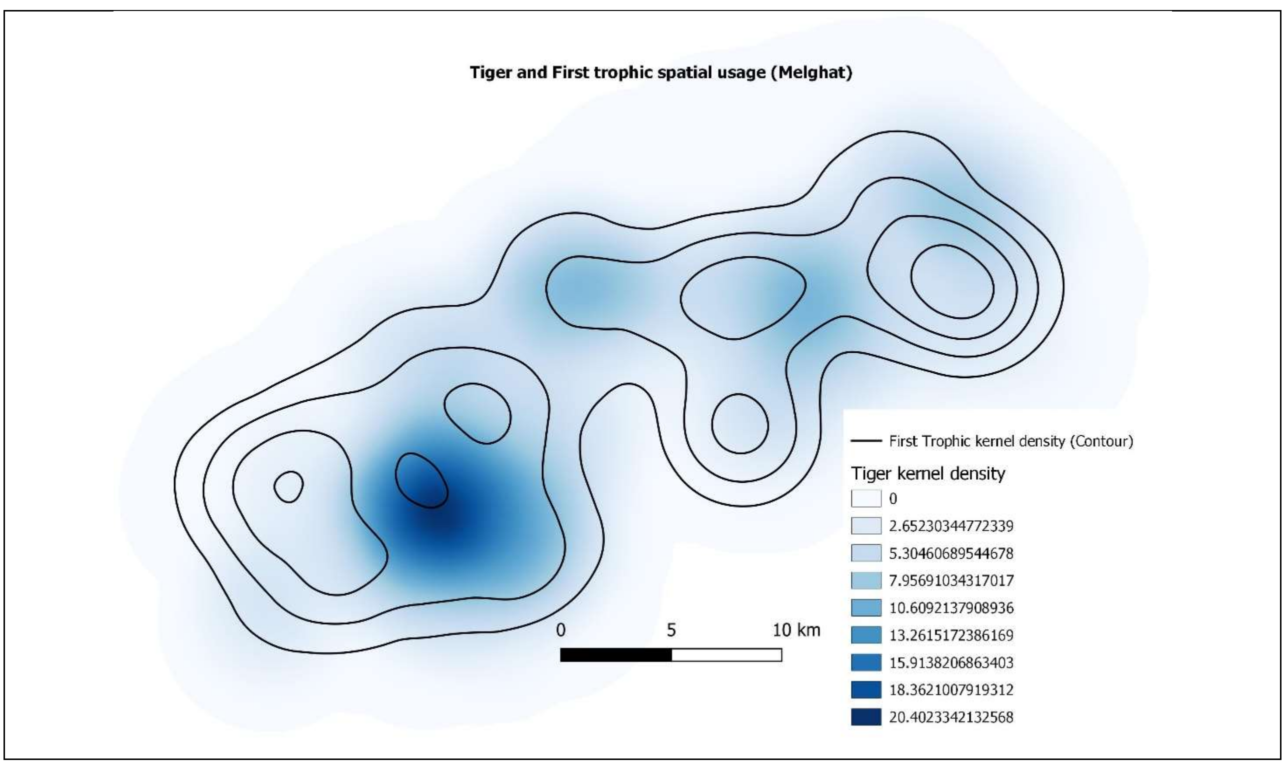


Figure 8.6 Kernel density of abundance of predators in Bor

High Alpha predator (Tiger) Abundance site:

Melghat Tiger Reserve:



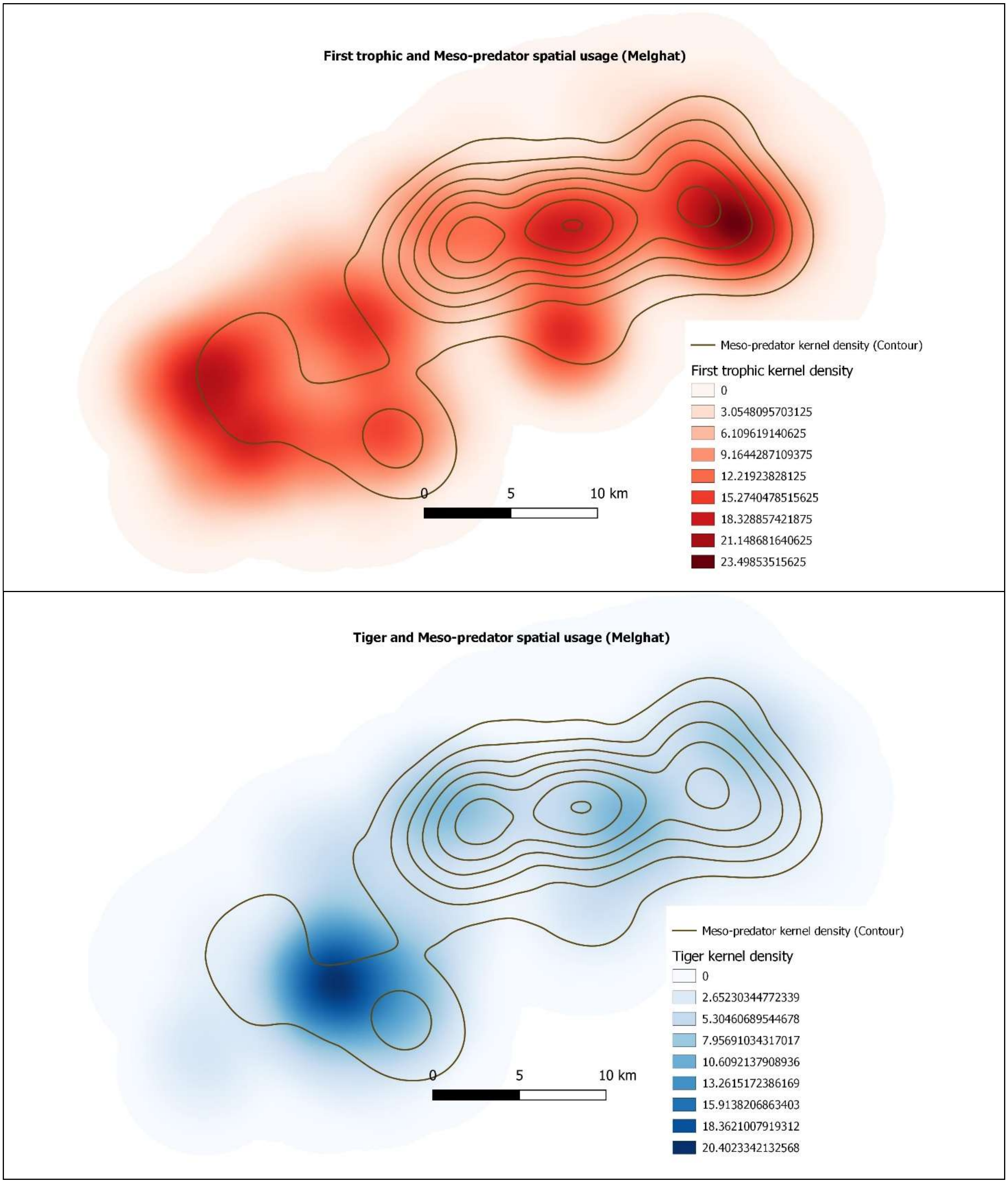


Figure 8.7 Kernel density of abundance of predators Melghat

Table2.1 TWO SPECIES OCCUPANCY RESULT FOR HIGH TIGER DENSITY

	MELGHAT					TADOBA		
		est	lowCI	uppCI		est	lowCI	uppCI
TOP PREDATOR WITH FIRST TROPHIC	psiA	0.53253	0.38354	0.67593	**TOP PREDATOR WITH FIRST TROPHIC** psiA	0.71777	0.63359	0.78904
	psiBa	0.38264	0.2157	0.58278	psiBa	0.2026	0.08606	0.40672
	psiBA	0.75501	0.57163	0.8768	psiBA	0.60751	0.47995	0.7219
	pA	0.01516	0.01109	0.02068	pA	0.04443	0.03939	0.05009
	pB	0.02792	0.02346	0.03321	pB	0.02826	0.02291	0.03482
FIRST TROPHIC AND MESOPREDATOR	psiA	0.58774	0.49172	0.67752	**FIRST TROPHIC AND MESOPREDATOR** psiA	0.49323	0.39569	0.59128
	psiBa	0.29649	0.17022	0.46403	psiBa	0.14539	0.0671	0.28695
	psiBA	0.69628	0.5676	0.80015	psiBA	0.18368	0.092	0.33318
	pA	0.02773	0.02328	0.03299	pA	0.02826	0.02291	0.03482
	pB	0.03113	0.02625	0.03689	pB	0.02137	0.01342	0.03387
TOP PREDATOR AND MESOPREDATOR	psiA	0.54048	0.38764	0.68606	**TOP PREDATOR AND MESOPREDATOR** psiA	0.71778	0.63361	0.78906
	psiBa	0.52508	0.36389	0.68121	psiBa	0.11348	0.03543	0.30851
	psiBA	0.55122	0.4083	0.68615	psiBA	0.18426	0.10606	0.30073
	pA	0.01504	0.011	0.02053	pA	0.04443	0.03938	0.05009
	pB	0.03085	0.02598	0.03659	pB	0.02136	0.01341	0.03387

Table2.2 TWO SPECIES OCCUPANCY RESULT FOR MEDIUM TIGER DENSITY

	BOR			
		est	**lowCI**	**uppCI**
TOP PREDATOR WITH FIRST TROPHIC	psiA	0.50008	0.3684	0.63175
	psiBa	0.49593	0.30876	0.68425
	psiBA	0.77594	0.48186	0.92804
	pA	0.04463	0.03456	0.05746
	pB	0.04933	0.03451	0.07006
		est	**lowCI**	**uppCI**
FIRST TROPHIC AND MESOPREDATOR	psiA	0.66392	0.519252	0.78323
	psiBa	0.29783	0.109477	0.59405
	psiBA	0.49703	0.347487	0.64711
	pA	0.03885	0.030735	0.04901
	pB	0.02986	0.009419	0.09061
		est	**lowCI**	**uppCI**
TOP PREDATOR AND MESOPREDATOR	psiA	0.50504	0.36994	0.6394
	psiBa	0.33278	0.18538	0.52224
	psiBA	0.49107	0.32159	0.66262

	pA	0.04419	0.034	0.05725
	pB	0.06732	0.04262	0.10476

Table2.3 TWO SPECIES OCCUPANCY RESULT FOR LOW TIGER DENSITY

		NSTR		
		est	lowCI	uppCI
TOP PREDATOR WITH FIRST TROPHIC	psiA	0.31799	0.24802	0.39727
	psiBa	0.18843	0.11813	0.28695
	psiBA	0.36359	0.2228	0.5324
	pA	0.02476	0.01982	0.03091
	pB	0.02028	0.01499	0.0274
FIRST TROPHIC AND MESOPREDATOR	psiA	0.24426	0.17686	0.32713
	psiBa	0.49568	0.411	0.58061
	psiBA	0.72529	0.55217	0.84971
	pA	0.02027	0.01498	0.02739
	pB	0.04036	0.03599	0.04524
TOP PREDATOR AND MESOPREDATOR	psiA	0.35168	0.2814	0.42903
	psiBa	0.52727	0.38751	0.66289
	psiBA	0.80258	0.67949	0.88631
	pA	0.02241	0.01817	0.0276
	pB	0.01755	0.01218	0.02522
	rBa	0.05763	0.05046	0.06575

Table2.4 TWO SPECIES OCCUPANCY RESULT FOR LEAST TIGER DENSITY

		Umred		
FIRST TROPHIC AND MESOPREDATOR	psiA	0.67286	0.48633	0.81713
	psiBa	0.13211	0.01913	0.54294
	psiBA	0.44797	0.30487	0.60023
	pA	0.04101	0.03101	0.05403
	pB	0.06934	0.05463	0.08765

Table2.5 TWO SPECIES OCCUPANCY RESULT FOR NO TIGER AREA

		KAWAL		
FIRST TROPHIC AND MESOPREDATOR	psiA	0.49327	0.34437	0.64338
	psiBa	0.55692	0.33451	0.75863
	psiBA	0.42097	0.22758	0.6421
	pA	0.05387	0.03983	0.07249
	pB	0.0552	0.04102	0.07391

Table 8.2. Comparison of Species Interaction Factor across study sites

Sites	Top predator and first trophic	First trophic and Meso-predator	Top predator and meso-predator
Melghat (High Tiger Density)	1.29	1.3	1
Tadoba (High Tiger Density)	1.2	1	1
Bor (Medium Tiger Density)	1.2	1	1.2
NSTR (Low Tiger Density)	1.3	0.9	1.2
Umred (negligible Tiger)	NA	1.3	NA
Kawal (No Tiger)	NA	0.8	NA

Discussion and conclusion:

The spatial concentration of tiger, first trophic and meso-predator when plotted suggested avoidance/overlapping in space. The two species co-occurrence analysis resulted in occupancy of species in presence psiBA and absence psiBa of dominant predator. In tiger absence area like Kawal, the dominance of first trophic is expressed and spatial avoidance of first trophic by meso-predator is visible in space. The two species occupancy result of psiBa (0.55692) more than psiBA(0.42097) concludes that occupancy of meso-predator is more in absence of first trophic. This occupancy difference (suggesting avoidance between trophic) increases when only leopard is representing first trophic. The leopard and dhole species interaction phi>1 suggest attraction of the two species in space. This could be probably due to low prey density in Kawal where prey segregate in the otherwise disturbed landscape. Although kernel density and Species Interaction Factor suggest that this avoidance is very low. The reason for low SIF can also be due to high fragmentation and limited human disturbance free area in Kawal. A major threat for mesopredator in Kawal is domestic dog which pose interference competition.

In Umred, low density of tiger is observed (two tigers were captured in camera-trap session). Since Umred has large prey, i.e. Gaur, hence it was observed that the space usage of tiger and leopard were overlapping. The observation of interference competition would be less evident here.

The small area of Umred suggest the spatial usage of all carnivores occupying the whole protected area by Tiger and first trophic. However, meso-predator shows very limited concentration of habitat usage. Species Interaction factor shows that first trophic and meso-predator are more likely to co-occur together than expected (psiBA (0.44797) is more than psiBa (0.13211)). Since tiger number is very low (two tiger captured) hence two species occupancy was not done for tiger and other trophic.

In the low tiger density area like NSTR, tiger and first trophic area usage is different as per kernel density estimation. While tiger suggest habitat usage at north-eastern area of camera-trapping, first trophic is majorly using habitat on south western area. Meso-predator habitat usage suggest co-occurrence with both tiger and first trophic. The psiBA is higher than psiBa for tiger and First trophic (psiBA= 0.36359 psiBa= 0.18843), for first trophic and meso-predator (psiBA= 0.72529 psiBa= 0.49568), for tiger and meso-predator (psiBA= 0.80258 psiBa= 0.52727). However, the SIF less than 1 for First trophic and meso-predator suggest avoidance of first trophic by meso-predator. The major tiger prey Gaur is absent from this landscape and other prey density is sparse. Hence while first trophic and tiger show co-occurrence on basis of prey habitat usage, the interference competition is visible between first trophic and meso-predator in low density of tiger.

The tiger and first trophic spatial segregation are visible in Bor (medium tiger density area). Leopard mainly represent first trophic and the habitat usage is concentrated on western boundary of Bor while tiger habitat usage is mainly in central and Eastern boundary. The overlap between tiger and leopard is mainly visible on eastern boundary and SIF is slightly more than 1. The psiBA is greater than psiBa for tiger and first trophic, first trophic and meso-predator and tiger and meso-predator. The major tiger prey camera-trapped for Bor TR are chital, sambar and Nilgai. Since Bor lack larger prey (i.e., Gaur) the interference competition can be evident here. Hence it was observed that at finer scale (i.e., came trap), the leopard seems to avoid major tiger usage area and is camera-trapped more on the periphery of the tiger usage area. Bor is smaller than Umred and although slight spatial avoidance between tiger and first trophic is observed through kernel density, occupancy result suggests the two trophic are more likely to co-occur together.

In high tiger density area like Melghat, spatial usage of tiger is concentrated to certain area, first trophic presents a larger habitat usage. Meso-predator also present clustered usage which overlaps with first trophic but not with tiger. Hence while first trophic shows more likely co-occurrence with tiger, it present independent occurrence of meso-predator in presence of tiger. Meso-predator are more likely to co-occur in presence of first trophic hence SIF is greater than 1 for first trophic and meso-predator and tiger and first trophic. the villages inside Melghat occupy flat valley and important water source and hence carnivore prey is disturbed a lot. Large predator avoids human disturbance and are more likely to co-occur with wild prey.

The species interaction factor concludes that in high and medium tiger density area, the predator interaction suggests co-occurrence of large predators (tiger and first trophic) due to prey occurrence and habitat usage. However, in low tiger density area like NSTR and no tiger presence area like Kawal the first trophic has an influence on meso-predator occupancy suggesting dominance playing a role in co-occurrence of species. With varying tiger density, the two species occupancy result and SIF suggests slightly higher co-occurrence evidence between tiger and first trophic but analysis of species capture at camera-trap level by kernel density suggests difference in spatial habitat usage by tiger and first trophic. While first trophic and meso-predator shows almost no interaction in high and medium tiger density (except melghat) as SIF ~ 1 but avoidance in low and no tiger presence (except Umred) as SIF <1. Melghat has high human disturbance inside core which affects wild prey habitat usage. The predators (tiger. First trophic and meso-predator) show overlapping of habitat usage with wild prey. In kawal and Umred both has human disturbance and fragmentation, yet while kawal has dhole and leopard representation for first trophic Umred has only leopard. Additionally, Kawal has more diversity at meso-predator level, while Umred represented only badger and jungle cat during the survey. A less competition for resources between the first trophic (leopard) and meso-predator suggest the reason for higher SIF and more likely co-occurrence of meso-predator with first trophic.

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