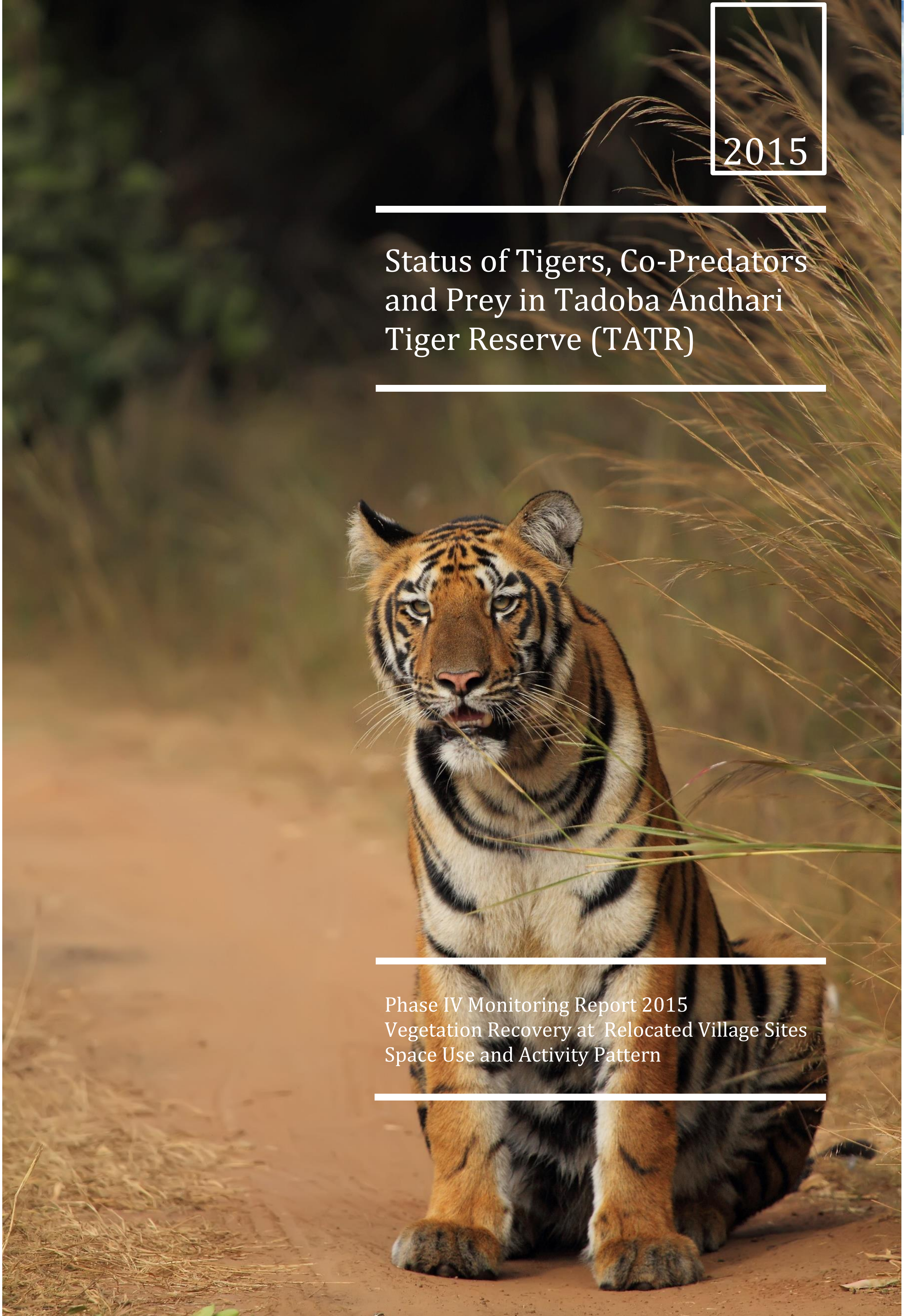

2015

Status of Tigers, Co-Predators and Prey in Tadoba Andhari Tiger Reserve (TATR)

Phase IV Monitoring Report 2015
Vegetation Recovery at Relocated Village Sites
Space Use and Activity Pattern

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Pic: Nilanjan Chatterjee

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Executive Summary

*As a part of the project **"Long Term Monitoring of Tigers, Co-Predators and Prey species in Tadoba-Andhari Tiger Reserve and Adjoining Landscape, Maharashtra India"**, Phase IV monitoring for the TATR core and buffer was conducted from January – May 2015 covering an area of 1700 km². The objective of the Phase IV Monitoring is to estimate the minimum number of tigers in the reserve using Capture-Recapture Sampling and density estimation of prey base using Distance Sampling.*

*381 camera traps were placed in the core and buffer area of TATR following a sampling grid of 2.01 sq. km in four blocks. In each sampling block camera traps were active for 20 – 24 days. During 120 days of camera trapping survey with sampling effort of 9144 trap nights, **51 adult individual tigers** were photographed in the **core area (exclusively)** and **14 individuals** in the **buffer area (exclusively)** of TATR. **06 individuals** were seen to use both core and buffer are of TATR. Population size (N) based on suggested model M_h Jackknife for right flank was **88 (SE ± 4.91) for Tadoba-Andhari Tiger Reserve.** For **leopards we report a population estimate of 49 individuals from 44 right flanks.** Tiger density per 100 km² based on Spatially Explicit Capture-Recapture (SECR) model was 5.67 (SE ± 0.69) in the Tadoba Andhari Tiger Reserve.*

In order to estimate prey density, 57 line-transects in core area and 38 line transects in buffer area were sampled 5 times during the sampling period, with a total walking effort of 570km and 380 km in core and buffer area respectively. Overall during the sampling, 684 animal/bird groups were sighted. The overall density of major prey species (Gaur 1.42/km², Sambar 4.27/km², Chital 6.56/km², Wild-boar 3.63/km², Langur 10.2/km², Barking-deer 0.90/km² Nilgai 0.80/km²) as estimated using distance sampling was 32.68 /sq. km.

In order to study space use pattern, we used data from camera traps and also radio-collared two tigers and one leopard in core area of Tadoba-Andhari Tiger Reserve. On an average the home range of male tiger is almost double as compared to the space use pattern of the female tiger.

A basic understanding of sympatric carnivore ecology with asymmetric competition enables us to hypothesize that in order to coexist and not just co-occur, there must be a

niche segregation on at least one of the three axes: space, time and/or diet. To understand how three large sympatric predators, co-occur in space and in time, camera trapping was carried out and carnivore scats were analysed to complement the activity data with an idea of the actual consumption of prey species. Temporal activity overlaps were derived by using kernel density estimates whereas multiple response permutation procedure test was used to study the space use of the animals. Diet analysis was carried out following Mukherjee et al. (1994) to study prey biomass, prey selectivity and diet overlap amongst carnivores.

All the sympatric predators were found to co-occur in the small area of TATR. There was a similar space use pattern observed for all three carnivores, however there was no strong spatial segregation/overlap pattern found except that the Dholes and leopards showed a significant segregation and avoidance of each other's space. There was a significant overlap between the temporal activity pattern of the tiger and the leopard. Both tiger and the Dhole showed a bimodal, crepuscular activity pattern but the peaks were different suggesting that the tigers were more active during the dusk whereas Dholes during the dawn. The diet analysis indicated that there was no significant difference in the prey species consumed by the predators. However, it indicated that they were consumed differently. This simply means that the major prey species of the tiger, leopard and dhole, though remained more or less similar, the proportions in which the prey were harvested differed significantly.

1. Introduction

While tigers are generally found throughout Southeast Asia and China, India remains the most prolific home of these magnificent animals and also boasts of having the highest population. The survival of these big cats however, is at stake as their habitat becomes more and more fragmented over time. Being a charismatic umbrella species, the tiger is also a crusader for the protection of other species. India is known to harbor the highest population of tigers amongst the 13 range countries in Asia; Central India being one of the last strong holds of the big cat. As a top predator, tiger shapes the community structure of an ecosystem. They also prevent over - grazing by limiting herbivore numbers and maintain the ecological integrity of an ecosystem.

Tadoba-Andhari Tiger Reserve (TATR) is considered one of the potential source populations of tigers in the Central Indian Tiger Landscape. This tiger population connects the adjoining tiger populations such as Indravati Tiger Reserve through the forests of Chandrapur - Gadchiroli districts. This connectivity extends all the way to Kanha National Park in north-west through the forests of Navegaon National Park and also to Pench National Park through the forests of Bor and Umred-Karhandla Wildlife Sanctuaries (Figure 1.1). It is situated in the Chandrapur district in the eastern part of Maharashtra state, between 20° 04′ 53″ to 20° 25′ 51″ N and 79° 13′ 13″ to 79° 33′34″ E.

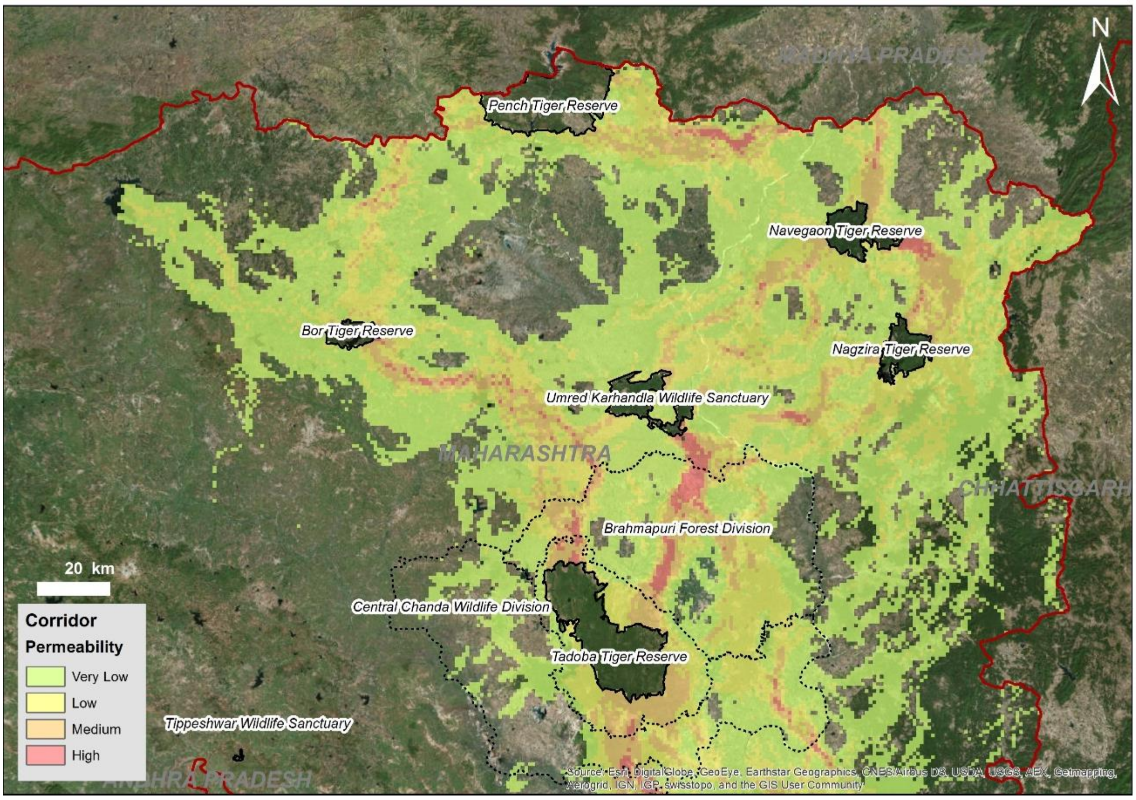


Figure 1.1: Map of Tadoba0Andhari tiger Reserve showing connectivity with other Protected Areas with eastern Vidarbha Tiger Landscape Complex.

The Tiger Reserve comprises of the Tadoba National Park and Andhari Wildlife Sanctuary which extends over an area of 625 km^2 comprising a core and a buffer area of around 1170 km^2, covering a landscape that is an interspersion of grasslands, riverine patches, water bodies and dry tropical deciduous forests along with bamboo thickets. The vegetation is Southern Tropical Dry Deciduous (Champion and Seth1968) type having Teak (*Tectona grandis*) as the dominant species. Some of the other major tree species found within the protected area are, Ain (*Terminalia elliptica*), Arjun (*Terminalia arjuna*), Bhera (*Chloroxylon swietenia*), Dhawada (*Anogeissus latifolia*), Mahua (*Madhuca indica*), Rohan (*Soymida febrifuga*), Salai (*Boswellia serrata*), Tendu (*Diospyros melanoxylon*) etc.

Although the major attraction is the tiger; other species like the wild dogs, leopard, chital, sambar, barking deer, chausinga, gaur, nilgai, sloth bear, wild boar, etc. make lasting impressions on the visitors of this Reserve. Two main rivers drain the region, the Erai River in the west and the Andhari River in the east. The northern part of the reserve is undulating and hilly in topography, with the foothills of the Chimur range gradually giving way to the plains as one moves south. The Tadoba and Kolsa lakes constitute the largest water bodies in the TATR core while the Erai dam and Naleswar dam is the principal source of water in the buffer area. Most of the annual rainfall (1175 mm) is received between June and September, with a minimum temperature of about 3^{0}C in December, rising to a maximum of about 48^{0}C in May (Khawarey & Karnat, 1997; Marathe, Goel, Ranade, Jog, & Watve, 2002).

As a part of the research project titled “Long term monitoring of tigers, co-predators and prey species in Tadoba-Andhari Tiger Reserve, Maharashtra”. The Wildlife Institute of India has been monitoring this landscape intensively for over 3 years. The objectives of the project as approved were as follows:

1. Mapping of current Landuse pattern, infrastructure, mining areas, villages, roads, power transmission lines, demographic profile, livestock population, dispersal corridors, prey and predator occupancy etc, within landscape surrounding TATR. TATR has been extensively mapped. The landscape surrounding TATR will be mapped during the first year of the project to evaluate land use pattern, infrastructure development and other impacts which will provide crucial information about the surrounding landscape in term of capability to sustain tiger dispersal or act as corridor for tigers dispersing from TATR.

2. Spatial distribution and temporal dynamics of habitat occupancy of tigers, co-predators and prey species. Relationship of these parameters to habitat related variables. Occupancy based sampling approaches will be followed to achieve this objective. This exercise will be conducted on biannual basis.

3. Population density, abundance and demographic structure of Tigers and co-predators in landscape. Capture –recapture sampling method and spatially explicit CR approaches will be used to achieve this objective. This exercise will be carried on annual basis. Once this exercise is carried on annual basis there is no need to carry out the Phase IV of regular tiger monitoring during the duration of the project.

4. Population density and abundance estimation of key prey species in landscape. Distance sampling method will be used to achieve this objective. This exercise will be carried on annual basis.

5. Estimation of vital rates (survival, recruitment, temporal emigration, dispersal, etc) of tigers and co-predators. For this exercise Five Tigers and Five Leopards will be fixed with Satellite collars within one study cycle. As discussed with FD not more than 5 tigers and 5 leopards will be radio-collared at one time within TATR. During the entire monitoring programme 2 – 3 such cycles will be carried which will produce valid sample size for statistical considerations. Open model capture – recapture methods and spatially explicit CR approaches will also be used to achieve this objective.

6. Study Tiger/Leopard Conflict and socio-economic aspects. Village surveys once in three years and conflict survey on annual basis will be carried. Conflict report on annual basis and village survey report on 3-year basis.

7. Monitoring of village translocation sites. Tadoba provides an opportunity to study the impact of village translocation. Sites of different time scales are available in TATR to monitor the change. First relocation in TATR happened in 1975 followed by relocation in 1993 and 2012.

8. To investigate food habits of Tigers and Co-predators in TATR landscape complex.

9. Training of field staff for managing human-wildlife conflict and emergency situations.

This report details the progress of work carried out during the year 2015. As a part of the long term monitoring program the focus of the research during the said year was:

1. To evaluate the vegetation structure of village relocation sites in Tadoba-Andhari Tiger Reserve.

2. Population density and abundance estimation of key prey species in landscape.

3. Population density, abundance and demographic structure of tigers and co-predators in landscape.

4. Activity pattern of tigers, co-predators & prey species in Tadoba-Andhari Tiger Reserve.

2. Evaluation of vegetation structure of relocated village sites at Tadoba–Andhari Tiger Reserve

2.1 Background:

As a tiger reserve, the Tadoba Andhari Tiger Reserve has shown a tremendous improvement in terms of overall health of a habitat. This is well reflected by the persistent and growing sightings of the big cats in the reserve. As a part of the mandate of the National Tiger Conservation Authority, most of the core critical areas should be free from human disturbance. In order to achieve this goal, the TATR authorities and the Maharashtra Government in particular has been very keen on aiding the relocation of villages from core areas of TATR. TATR represents a classic tropical dry deciduous ecosystem. Earlier attempts at floristic studies and qualitative description of vegetation in Tadoba National Park include Haines (1916), Kunhikannan (1999). Dubey (1999), Malhotra & Moorthy (1992). Mathur (1991) studied the ecological interactions between habitat parameters and wild ungulate abundance, in Tadoba. Therefore, Tadoba provides an excellent opportunity to study the impact of village relocation sites on the floristic composition in temporal and spatial scale. Tadoba has had a history of village translocations. The first village relocation was carried out during the year 1975 (Khatoda and Pandherpouni), followed by Botezari (2007), Navegaon (2012) and Jamni (2014). Figure 2.1 shows locations of relocated sites on Google imagery.

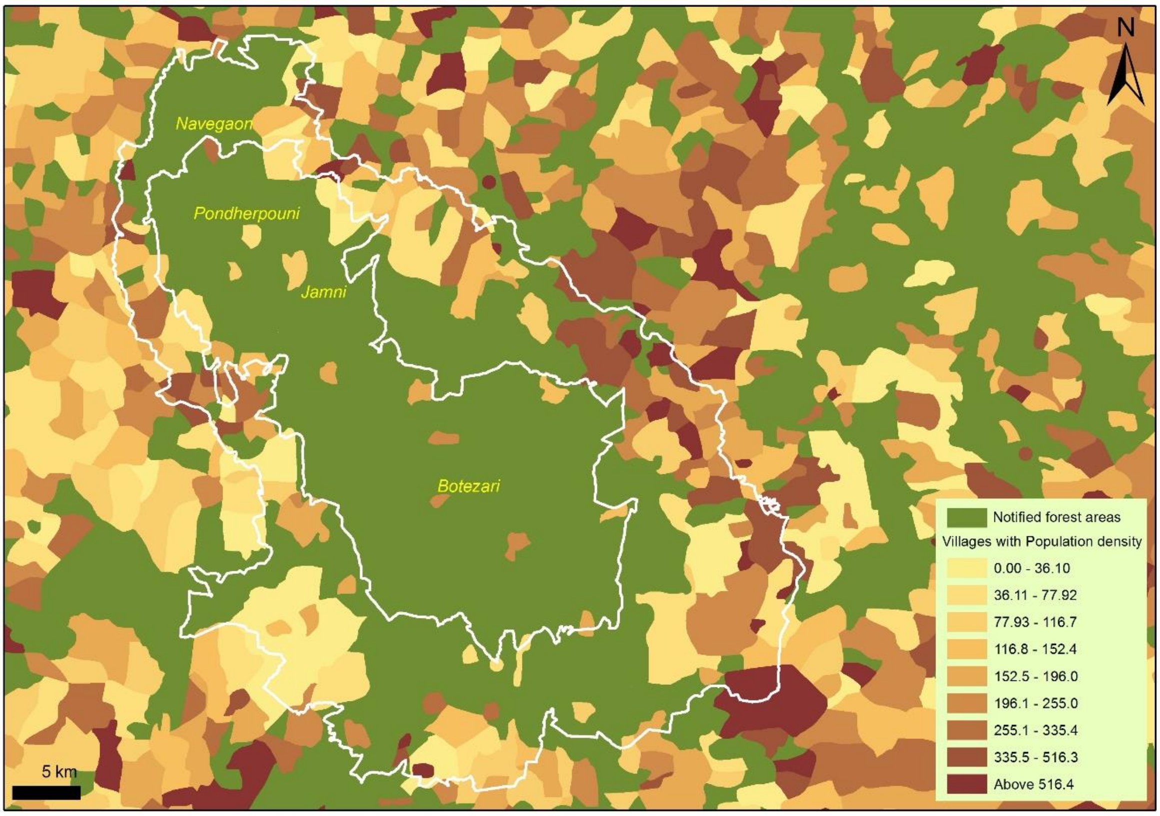


Figure 2.1: Map showing locations of villages relocated from Tadoba–Andhari Tiger Reserve, Maharashtra, India

2.2 Evaluation of the study sites:

Standard vegetation quantification methods were used to evaluate species diversity and density across all relocated sites. In order to study the effect of grazing on vegetation recovery, 100m x 100m enclosures were set up at two relocated sites namely Navegaon and Botezari. The grass and herb species diversity and density was recorded following Mueller-Dombois and Ellenberg (1974) and Zobel *et al.,* (1987). A total of 60 (1m x 1m) plots were sampled across the sites during the study period.

14 communities of grass were recorded from the relocated village sites. A total of 124 different species belonging to 23 different families were reported from all the study sites. The details of 14 communities of grass species are given in the table 2.1, along with the site name. Jamni which has witnessed village relocation very recently reported highest number of species (77), whereas oldest relocated site Pandherpouni, from which village relocation was carried out during the year 1975 has least number of species (35). The comparison of the grass species density and herb species density across the four relocated sites is shown in figure 2.2 and 2.3 respectively.

Table 2.1: Dominant community types as reported from various relocated sites from Tadoba-Andhari Tiger Reserve during the yare 2015

Dominant Community	Site Name
Iseilema laxum- Ischaemum indicum	Jamni, Navegoan,Pandherpouni
Themeda triandra- Seteria pumila	Jamni, Navegoan
Themeda triandra- Seteria pumila	Jamni, Navegoan,Pandherpouni
Apluda mutica- Saccharum spontaneum	Jamni
Dichanthium annulatum- Heteropogon contrortus	Jamni, Navegoan
Cynodon dactylon- Ischaemum indicum	Jamni, Navegoan, Botezari
Themeda triandra- Dichanthium annulatum	Navegoan
Dichanthium annulatum- Eragrostis species	Navegoan, Pandherpouni
Cynodon dactylon- Digiteria cliaris	Jamni, Navegoan
Imperata cylendrica- Coix lacryma-jobi	Botezari
Chloris dolystyca- Themeda triandra	Pandherpouni
Aristida stricts- Crysopogon fulvus	Pandherpouni
Ischaemum indicum- Eragrostis uniloides	Botezari
Coix lacryma-jobi- Ischaemum indicum	Botezari, Navegoan, Pandherpouni

Pic: Dhritiman Mukherjee

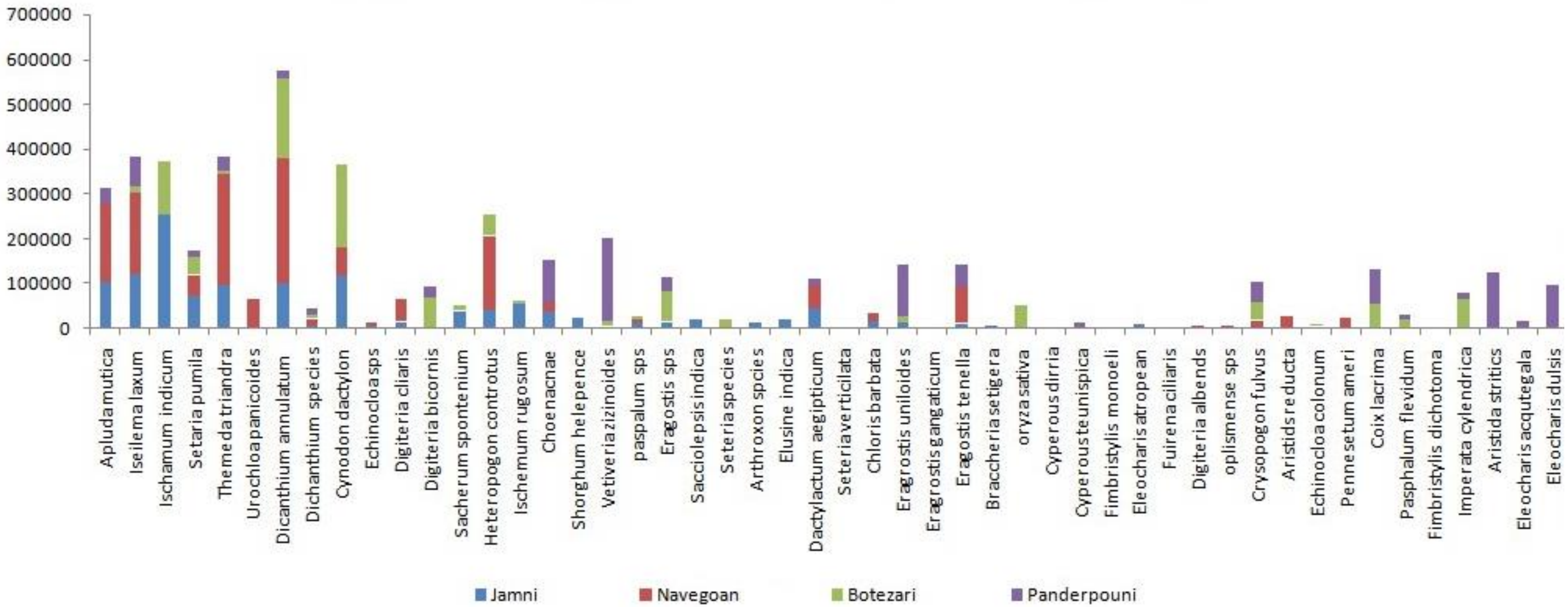


Figure 2.2: Grass species density per hectare across four relocated sites, Tadoba Andhari Tiger Reserve as reported during the year 2015

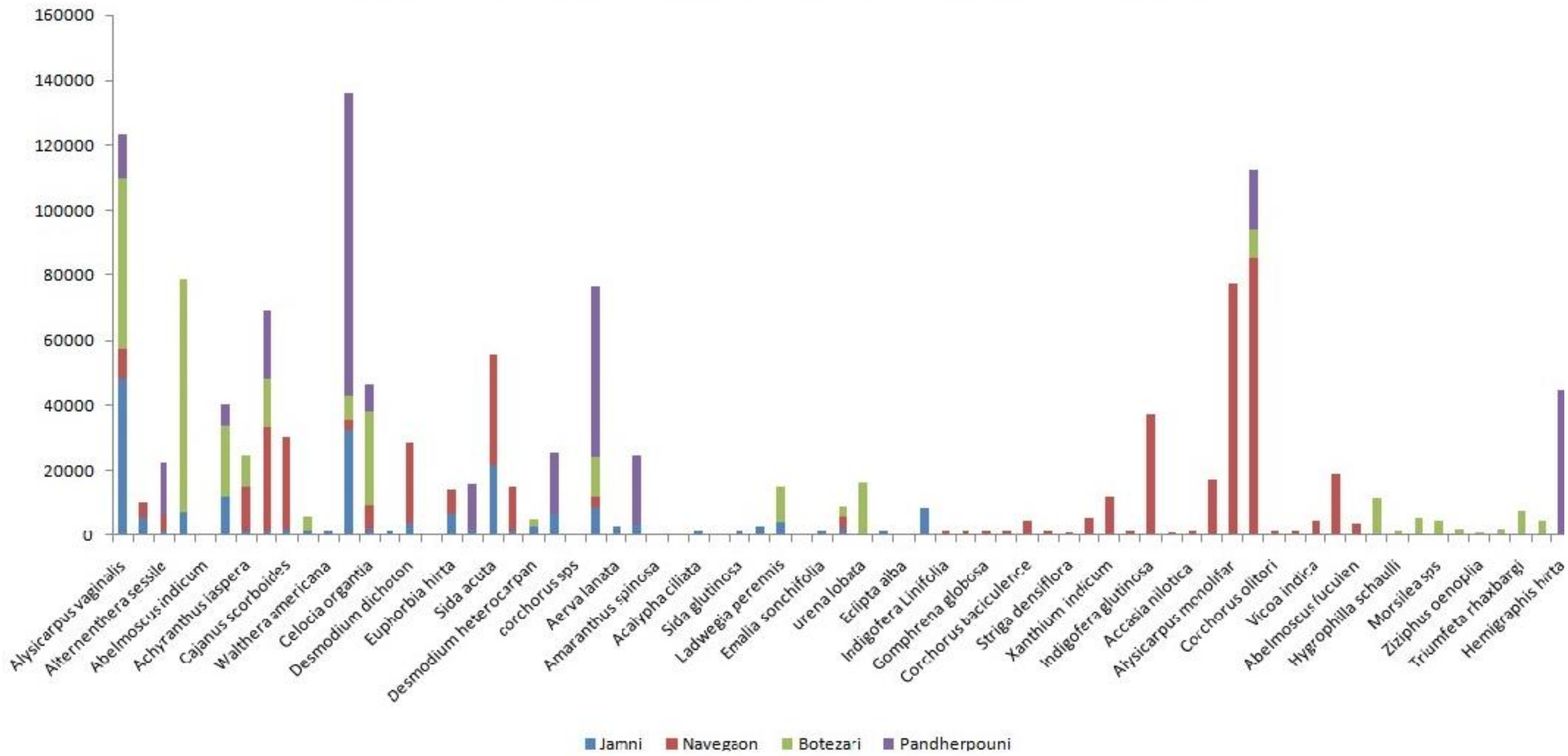


Figure 2.3: Herb species density per hectare across four relocated sites, Tadoba Andhari Tiger Reserve as reported during the year 2015

The 100m x 100m enclosure at Navegaon village relocated site (relocated during 2012) showed low grass and shrub species diversity (21 species) and density 1168000 per ha as compared to surrounding areas within the relocated site. The species diversity outside enclosure was high (58 species) and density of grasses was 2109011 per ha. The pattern was similar to the Botezari village relocated site as well. The dominant species along with other details are provided in table 2.2.

The relocation of Jamni village was carried during the year 2013. A total of 77 grasses and herbs were recorded from this site during the present evaluation. Out of the 77 species reported 38 are palatable, which is almost 49% of the total reported species. The palatable species include species like *Dichanthium annulatum, Cynodon dactylon, Ischaeumum indicum, Digiteria cliaris* etc. Species diversity was highest at this site as compared to other relocated sites.

Navegoan Botezari and Pandherpouni were relocated during the years 2012, 2007 and 1975 respectively. The ratio of total number of species to palatable species increased from 49.35% during the year 2013 to 56.89% for the site relocated during the year 2012, to 58.33.5 for the site relocated during the year 2007 and 68% for the site relocated in the year 1975. The ratio was highest for the site where relocation of village was carried out almost 40 years before (1975). Native tree species like *Ziziphus mauritiana*, *Dendrocalamus strictus*, *Temierendus indicus*, *Tectona grandis*, *Acacia catachu* etc. have only been reported from sites where relocation was carried 40 years before. The comparison of total species recorded across site and number of palatable species is provided in the figure 2.4.

In order to maintain and sustain a healthy herbivore population in Tadoba-Andhari Tiger Reserve, it is advised to maintain all relocated sites as grasslands. Management interventions in terms of uprooting of unpalatable species and eradication of weeds across the sites are important for long term management and conservation of the ecosystem.

Pic: Dhritiman Mukherjee, TATR landscape

Table 2.2: Comparison between species density, diversity and dominant species of the two relocated sites of Navegaon and Botezari village from TATR

Village Relocated site	Parameters	Within Enclosure	Outside Enclosure
Navegaon	Species diversity	21	58
	Density/ha	1168000	2109011
	Dominant species	*Iseilema laxum*	*Dichanthim annulatum*
		Themeda triandra	*Iseilema laxum*
		Heteropogon controtus	*Themeda triandra*
		Themeda quandriangularis	*Heteropogon controtus*
		Aristids reducta	*Themeda quandriangularis*
		Hyptis sauvelens	*Hyptis sauvelens*
			Dichanthim annulatum
			Eragostis tenella
			Apluda mutica
Botezari	Species diversity	18	48
	Density/ha	1856000	1652308
	Dominant species	*Dichanthim annulatum*	*Dichanthim annulatum*
		Cynodon dactylon	*Ischaemum indicum*
		Crysopogon fulvus	*Cynodon dactylon*
		Digiteria bicornis	*Imperata cylendrica*
		Eragostis sps	*Digiteria bicornis*
		Ischaemum indicum	*Coix lacryma*
			Commelina benghalensis
			Smithia corberata

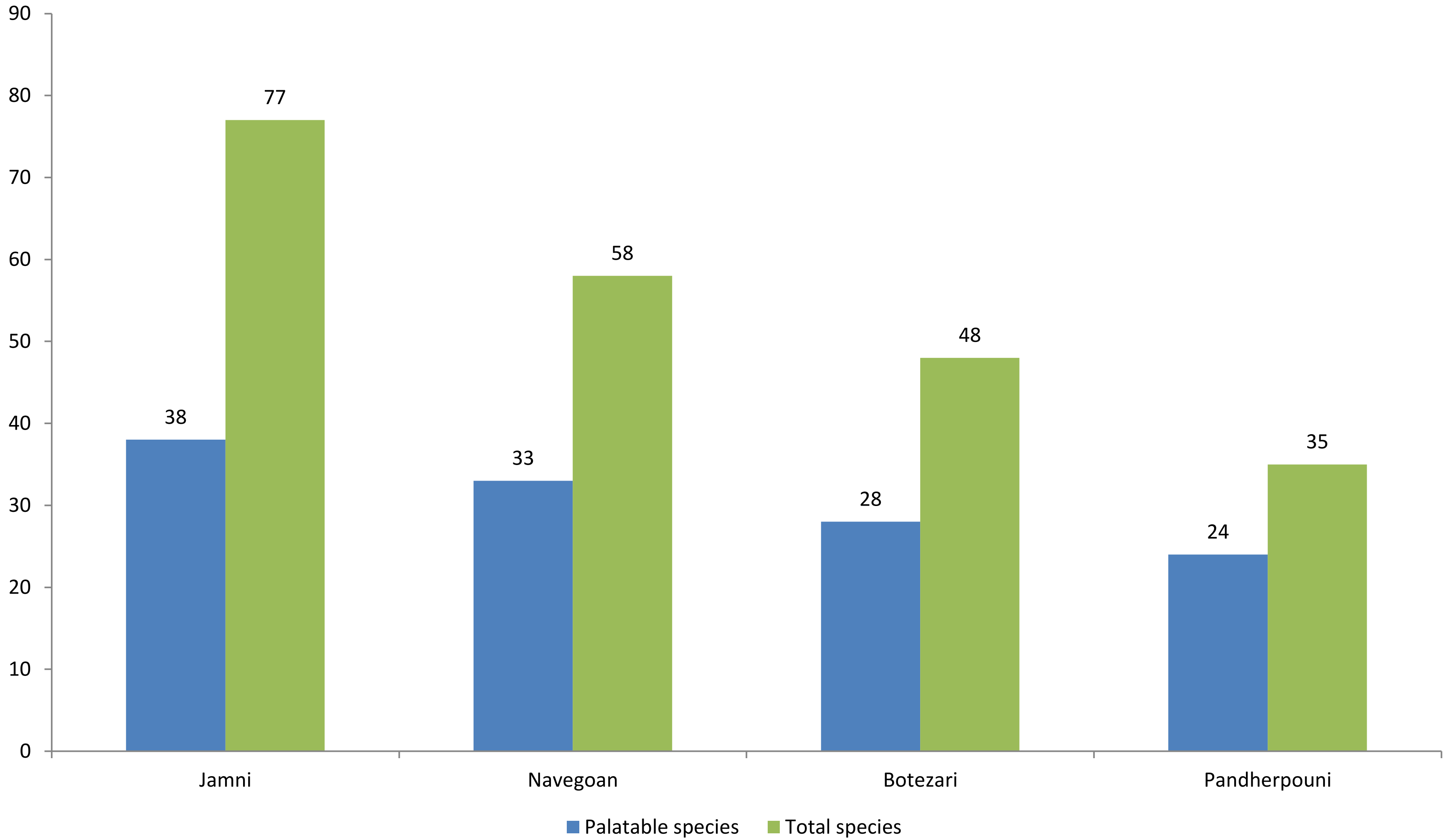


Figure 2.4: Comparison of total number of species and palatable species across four relocated village sites in Tadoba-Andhari Tiger Reserve as reported during the year 2015

3. Status of Prey Species in Tadoba-Andhari Tiger Reserve

3.1 Introduction:

Availability of wild ungulate prey is one of the most important determinants of large carnivore density (Karanth et al. 2004). Ungulates also play an important role in maintaining ecosystems by influencing the vegetation structure, plant species composition and nutrient cycling (McNaughton 1979; Bagchi and Ritchie 2010). Maintaining and monitoring ungulate populations is therefore an important objective of conservation management. Although several techniques have been developed for monitoring of ungulate and large herbivore populations (eg. distance sampling using line transect or point counts; Burnham et al. 1980, Strip transect; Eberhardt 1978, Track count; Sulkava and Luikko 2007, Dung count; Laing et al.2003), they appear to perform differently under different field conditions (Singh and Milner-Gulland 2011). Estimating ungulate abundance in dense forested areas especially remains a challenge due to their low visibility and low detection probability.

3.2 Distance Sampling:

Distance sampling is the most established method to estimate the density of ungulates in an area using line transect method. Line transects are laid randomly over the total forest area considering that all vegetation types existing in the area are represented while marking these lines. Sightings of prey species observed while walking on these lines are recorded along with habitat and terrain features.

A total of 57 transects in the 34 beats of core –zone and 38 transects in 58 beats of buffer-zone of 2 km length were marked in Tadoba-Andhari Tiger Reserve. Figure 3.1 show distribution of line transect across TATR. Transects are well spread over an area of 1700 sq. km. of the area of Tadoba – Andhari Tiger Reserve covering almost all the vegetation types in the area. Each line transect was walked 5 times during the period from 19th January 2015 to 23rd January 2015 to record prey species across the whole area of TATR. Thus a total of 950 km effort have been invested on line transect surveys which generated a total of 685 observations of all types of prey Species. This includes the major prey species like Gaur (*Bos gaurus*), Sambar (*Rusa unicolor*), Chital (*Axis axis*), Wild Pig (*Sus scrofa*), Nilgai (*Boselaphus tragocamelus*), Barking Deer (*Muntiacus muntjak*), Langur (*Semnopithecus sp.*), Peafowl (*Pavo cristatus*), Grey Jungle Fowl (G*allus sonneratii*) and Black-naped Hare (*Lepus nigricollis*).

During the transect walk data on species, number of animals seen, group composition, bearing of the animal and angular sighting distance were recorded. To record the distances accurately Laser Range Finders were used and to give spatial reference to each and every observation Global Positioning System (GPS) was used. The GPS co-ordinates of transect were also recorded.

Total sightings of all prey species numbered to 476 and 209 in core area and buffer area respectively. Table 3.1 give details of line transect and species reported during the survey period. Sambar and Chital were the most sighted ungulates in the core and buffer area of TATR followed by Wild boar and Langur. Nilgai was the least sighted species on the transects of core area, where as Grey jungle fowl was the least sighted species in the buffer area. It is worth the mention that species like Four-horned Antelope was not at all sighted while walking the transects in both core and buffer area of TATR.

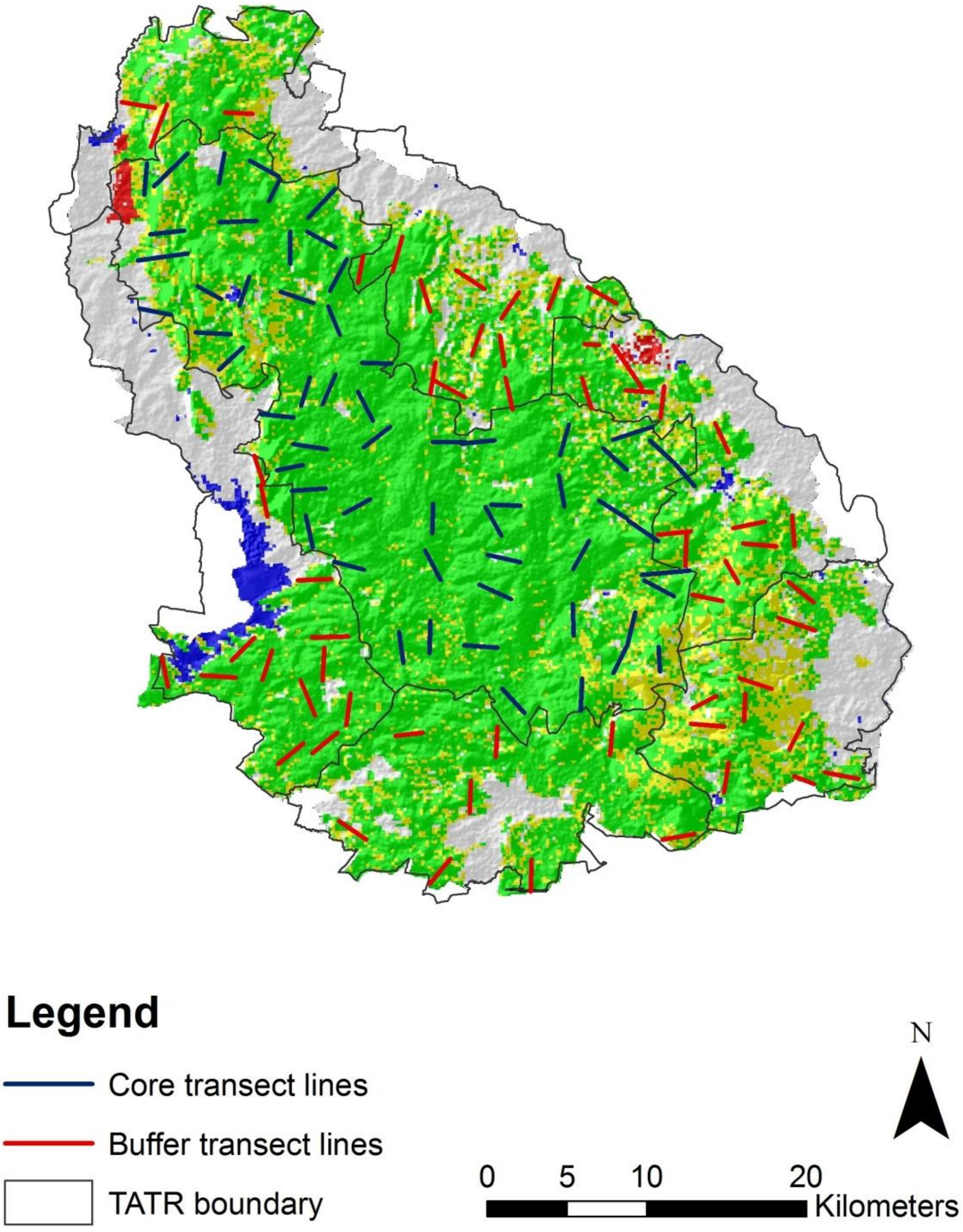


Figure 3.1: Map showing location of line transects in the Core and Buffer area monitored during the year 2015 (Tadoba –Andhari Tiger Reserve, Maharashtra, India)

Table 3.1: Transect Monitoring Effort and Species Reported from Core and Buffer Area of TATR during Phase IV Monitoring 2015

		Core		Buffer		
Number of transect		57		38		
Length of each transect		2 km		2 km		
Number of replicates		5		5		
Total distance covered		570 km		380 km		
Number of species recorded		10		10		
	Core			Buffer		
Species Recorded	Number of sightings	Individuals recorded	Average group size (min-max)	Number of sightings	Individuals recorded	Average group size (min-max)
Sambar	99	232	2(1-8)	30	58	2(1-5)
Chital	75	411	5(1-27)	37	186	5(1-12)
Nilgai	27	71	3(1-9)	18	37	2(1-4)
Gaur	35	103	3(1-12)	26	120	5(1-19)
Wild boar	33	204	6(1-22)	19	190	11(1-22)
Langur	50	550	11(3-41)	19	238	13(5-31)
Barking deer	39	47	1(1-3)	12	18	2(1-2)
Hare	28	31	1(1-2)	19	22	1(1-2)
Peafowl	54	122	2(1-7)	22	59	3(1-9)
Grey junglefowl	35	75	2(1-6)	7	9	1(1-2)

All prey (sum of all the individual prey species density) density estimated is 32.68 per km^2, which would increase to 38.62 per km^2 if Peafowl and Grey Jungle Fowl are included. In the core area of TATR, the density of Langur (9.70 ± 2.42) was highest followed by Chital (7.42 ± 2.36), Sambar (5.27 ± 1.16), Wild boar (4.49 ± 1.73), Peafowl (3.36 ± 0.81) respectively. In the buffer area the density of wild boar (4.56 ± 2.03) was highest followed by chital (4.09 ± 0.92), sambar (1.88 ± 0.71), gaur (1.63 ± 0.59) and nilgai (0.74 ± 0.29). The Individual Density, Group Density, Effective Strip Width, Average Group Size and Encounter Rate of 10 species reported during the Phase IV Monitoring 2015 in the Core and Buffer Area of Tadoba Tiger Reserve, Maharashtra, India is given in Table 3.2, 3.3 and 3.4 and the comparison of ungulate density with previous estimates is given in Table 3.5. It is evident from the Table that the major prey species are showing positive increment in last 12-13 years in Tadoba Tiger Reserve.

Pic: Vinit Arora

Table 3.2: Individual Density, Group Density, Effective Strip Width, Average Group Size and Encounter Rate of all Prey Species Reported During the Phase IV Monitoring 2015 in the Tadoba-Andhari Tiger Reserve, Maharashtra, India

Parameters	Sambar	Chital	Gaur	Wild boar	Langur	Nilgai	Barking Deer	Hare	Peafowl	Grey Junglefowl
Individual density (No of Animals/Km^2)	4.27	6.56	1.42	3.63	10.2	0.80	0.90	1.80	2.80	1.81
Standard error	0.82	1.49	0.33	1.13	2.18	0.24	0.19	0.45	0.54	0.51
Percent CV	19.21	22.71	23.09	31.09	21.37	29.52	20.93	24.88	19.35	28.30
95% confidence interval	2.94 – 6.22	4.21 – 10.21	0.91 – 0.23	1.99 – 6.61	6.72 – 15.47	0.45 – 1.41	0.60 – 1.35	1.11 – 2.93	1.91 – 4.08	1.05 – 3.13
Group density (No of groups/Km^2)	1.91	1.28	0.60	0.50	1.05	0.32	0.65	1.60	1.20	1.05
Standard error	0.35	0.27	0.11	0.12	0.21	0.09	0.13	0.39	0.21	0.28
Percent CV	18.40	21.11	18.62	23.86	19.48	26.76	20.37	24.61	17.81	26.37
95% confidence interval	1.33 – 2.74	0.84 – 1.93	0.42 – 0.87	0.32 – 0.80	0.72 – 1.54	0.19 – 0.54	0.44 – 0.97	0.99 – 2.59	0.85 – 1.70	0.63 – 1.75
Effective strip width	35.29	44.93	50.64	50.25	32.95	67.63	38.64	15.09	33.31	19.57
Standard error	3.05	3.84	5.74	6.98	3.60	11.46	5.04	2.49	3.24	2.56
Percent CV	9.64	8.54	11.34	13.90	10.91	16.95	13.05	16.51	9.72	13.06
95% confidence interval	29.75 – 41.86	37.94 – 53.21	40.37 – 63.51	38.05 – 66.38	26.52 – 40.95	48.13 – 95.03	29.76 – 50.19	10.85 – 21.01	27.46 – 40.41	15.04 – 25.46
Average group size	2.25	5.13	2.35	7.22	9.67	2.50	1.37	1.12	2.33	1.72
Standard error	0.12	0.43	0.32	1.44	0.85	0.31	0.07	0.04	0.18	0.18
Percent CV	5.47	8.39	13.66	19.94	8.79	12.47	4.81	3.69	7.57	10.26
95% confidence interval	2.01 – 2.51	1.35 – 6.07	1.79 – 3.10	4.86 – 10.75	8.12 – 11.53	1.85 – 3.21	2.21 -1.51	0.14 – 1.21	2.00 – 2.71	1.40 – 2.12
Encounter rate	0.13	0.11	0.06	0.05	0.07	0.04	0.05	0.05	0.08	0.04
Percent CV	16.24	19.30	14.77	14.39	16.13	20.70	15.64	18.25	14.92	22.91
95% confidence interval	0.09 – 0.19	0.08 - 0.17	0.04 – 0.08	0.03 – 0.07	0.05 – 0.10	0.03 – 0.06	0.04 – 0.07	0.03 – 0.07	.06 – 0.11	0.03 – 0.06
Probability of a greater chi-square value, P	0.41	0.50	0.88	0.77	0.78	0.94	0.88	0.78	0.79	0.76

Table 3.3: Individual Density, Group Density, Effective Strip Width, Average Group Size and Encounter Rate of all Prey Species Reported During the Phase IV Monitoring 2015 in the Core Area of Tadoba-Andhari Tiger Reserve, Maharashtra, India

Parameters	Sambar	Chital	Gaur	Wild boar	Langur	Nilgai	Barking Deer	Hare	Peafowl	Grey Junglefowl
Individual density (No of Animals/Km²)	5.27	7.42	1.58	4.49	9.70	1.01	0.98	2.23	3.36	2.58
Standard error	1.16	2.36	0.45	1.73	2.42	0.37	0.21	0.65	0.81	0.78
Percent CV	22.01	31.82	28.33	38.57	24.94	36.63	21.56	29.38	24.17	30.21
95% confidence interval	3.42-8.11	4.01-13.76	0.91-2.75	2.14-9.39	5.97-15.77	0.50-2.04	0.65-1.51	1.26-3.96	2.09-5.39	1.43-4.64
Group density (No of groups/Km²)	2.20	1.31	0.61	0.72	1.04	0.37	0.76	1.99	1.60	1.36
Standard error	0.14	0.39	0.14	0.21	0.24	0.12	0.16	0.58	0.36	0.38
Percent CV	6.42	29.93	22.41	29.47	22.54	31.73	21.00	29.14	22.66	27.81
95% confidence interval	1.94-2.50	0.73-2.34	0.39-0.96	0.40-1.27	0.67-1.63	0.20-0.68	0.50-1.14	1.13-3.52	1.03-2.50	0.79-2.35
Effective strip width	36.09	50.39	45.70	38.01	41.84	64.29	45.06	11.88	28.44	21.16
Standard error	2.96	5.19	3.05	5.51	5.25	7.55	4.89	1.92	3.65	2.95
Percent CV	8.14	10.31	6.68	14.51	12.54	11.75	10.85	16.12	12.84	13.95
95% confidence interval	30.90-42.67	41.05-61.85	38.88-52.37	28.31-51.05	32.55-53.79	50.54-81.79	36.19-56.09	8.55-16.51	21.99-36.76	15.95-28.08
Average group size	2.39	5.69	2.58	6.28	9.25	2.75	1.3	1.12	2.10	1.89
Standard error	0.50	0.61	0.45	1.56	0.99	0.50	0.06	0.04	0.18	0.22
Percent CV	21.06	10.79	17.34	24.87	10.69	18.30	4.87	3.71	8.41	11.80
95% confidence interval	1.58-3.62	4.59-7.05	1.82-3.67	3.80-10.40	7.47-11.46	1.89-3.99	1.17-1.43	1.04-1.21	1.77-2.48	1.48-2.39
Encounter rate	0.17	0.13	0.05	0.05	0.08	0.05	0.07	0.05	0.09	0.06
Percent CV	19.42	28.10	21.39	25.65	18.73	29.47	17.98	24.28	18.67	24.05
95% confidence interval	0.12-0.26	0.07-0.22	0.04-0.08	0.03-0.09	0.06-0.12	0.03-0.08	0.05-0.09	0.03-0.08	0.06-0.13	0.04-0.09
Probability of a greater chi-square value, P	0.56	0.61	0.45	0.87	0.53	0.68	0.80	0.72	0.50	0.64

Table 3.4: Individual Density, Group Density, Effective Strip Width, Average Group Size and Encounter Rate of all Prey Species Reported During the Phase IV Monitoring 2015 in the Buffer Area of Tadoba-Andhari Tiger Reserve, Maharashtra, India

Parameters	Sambar	Chital	Gaur	Wild boar	Langur	Nilgai	Barking Deer	Hare	Peafowl	Grey Junglefowl
Individual density (No of Animals/Km²)	1.88	4.09	1.63	4.56	14.64	0.74	0.68	0.99	2.28	0.59
Standard error	0.71	0.92	0.59	2.03	5.98	0.29	0.31	0.37	0.79	0.41
Percent CV	38.07	22.43	36.50	44.53	40.82	39.22	45.69	37.60	39.40	68.57
95% confidence interval	0.90-3.91	2.63-6.34	0.80-3.29	1.95-10.69	6.68-32.06	0.34-1.57	0.28-1.64	0.48-2.06	1.07-4.87	0.17-2.11
Group density (No of groups/Km²)	0.88	0.82	0.47	0.34	0.96	0.30	0.42	0.77	0.63	0.46
Standard error	0.32	0.15	0.13	0.11	0.36	0.11	0.18	0.28	0.22	0.31
Percent CV	36.69	18.21	26.80	33.52	37.55	36.36	43.62	36.99	35.48	67.46
95% confidence interval	0.43-1.79	0.57-1.17	0.28-0.80	0.17-0.64	0.47-1.99	0.15-0.62	0.18-0.99	0.37-01.58	0.32-1.26	0.13-1.61
Effective strip width	45.04	59.51	72.05	70.51	23.20	77.96	34.17	30.86	43.86	19.99
Standard error	13.06	6.36	13.49	13.74	5.23	15.35	10.25	7.71	9.62	8.19
Percent CV	28.99	10.69	18.72	19.48	22.53	19.69	30	24.99	21.93	40.95
95% confidence interval	25.17-80.59	47.94-73.89	49.16-105.6	46.83-106.16	14.48-37.19	51.66-117.63	17.76-65.72	18.36-51.88	27.91-68.92	7.63-52.41
Average group size	2.14	4.99	3.43	13.59	15.18	2.44	1.61	1.29	2.28	1.29
Standard error	0.22	0.65	0.85	3.98	2.43	0.36	0.22	0.09	0.62	0.18
Percent CV	10.15	13.10	24.77	29.31	16.02	14.71	13.59	6.73	17.15	14.34
95% confidence interval	1.74-2.64	3.83-6.51	2.07-5.67	7.39-24.97	10.82-21.32	1.79-3.32	1.19-2.19	1.12-1.49	2.54-5.18	1.00-1.82
Encounter rate	0.08	0.09	0.07	0.05	0.04	0.05	0.03	0.04	0.05	0.02
Percent CV	22.49	14.74	19.18	27.28	30.04	30.57	31.67	27.28	27.89	53.61
95% confidence interval	0.05-0.12	0.07-0.13	0.05-0.10	0.03-0.08	0.02-0.08	0.03-0.09	0.01-0.05	0.02-0.08	0.03-0.10	0.01-0.05
Probability of a greater chi-square value, P	0.51	0.43	0.76	0.33	0.99	0.89	0.69	0.90	0.87	--

Table 3.5: Comparison of ungulate density of Core Area of Tadoba –Andhari Tiger Reserve, Maharashtra, India (2002 – 2016)

Species	2002	2012	2013	2014	2015
Sambar	3.33	6.5 (± 1.1)	3.9 (± 1.1)	4.68 (± 0.76)	5.27 (± 1.16)
Chital	3.2	8.6(± 1.8)	6.3 (± 1.5)	5.10 (± 1.22)	7.42 (± 2.36)
Gaur	1.8	6.6(± 1.4)	1.7 (± 0.3)	2.03 (± 0.56)	1.58 (± 0.45)
Langur	-	-	-	9.47 (± 1.90)	9.70 (± 2.42)
Wild boar	2.6	7.3(± 1.6)	3.7 (± 1.5)	5.42 (±2 .08)	4.49 (± 1.73)
Nilgai	0.7	-	1.3 (± 0.5)	1.09 (± 0.36)	1.01 (± 0.37)
Barking deer	0.9	5.2(± 1.2)	-	0.96(± 0.23)	0.98 (± 0.21)
Hare	-	-	-	1.70 (± 0.36)	2.23 (± 0.65)
Peafowl	-	-	-	3.92 (± 0.72)	3.36 (± 0.81)
Grey Junglefowl	-	-	-	1.43 (± 0.53)	2.58 (± 0.78)

Pic: Vinit Arora

4. Status of Tigers and Co-Predators in Tadoba-Andhari Tiger Reserve

4.1: Introduction:

Monitoring of large carnivore populations is important to guarantee their survival, to adapt management practices to changing situations and to fulfill obligations for the conservation of habitat. It is also a very demanding exercise because of the large scales over which it must be conducted, often stretching across huge areas, and because of the low densities and elusive behavior of large carnivores. The need for long term scientific monitoring of large carnivore populations arises from three considerations:

1) To objectively audit or evaluate success or failure of earlier management measures and conservation interventions so as to react adaptively and solve problems (Walters, 1986; Nichols et al., 1995).

2) To establish benchmark data that can serve as a basis for specific objectives for management and conservation efforts and

3) To improve our basic understanding of tiger, co-predator and prey ecology through rigorous field studies, so as to develop a body of theoretical knowledge which can generate predictive capacity to deal with new situations and contributes to the general advancement of scientific knowledge.

However, in the absence of scientifically rigorous baseline data or regular monitoring of tigers and the co-predators across most of their distribution range in India, how these animal communities are being affected by adverse environmental, demographic, and genetic factors remains largely unknown. Protecting wide range mega fauna requires taking the "representation" approach designed for habitat conservation and adapting it to species conservation, so that we not only conserve individual population but also the suite of adaptations and ecological interactions associated with them. Effective conservation of large predators requires the assessment of a complex mix of ecological, ethical and symbolic interrelation ships. The combination of biological characteristics of tigers - extensive distributional range, low densities, secretiveness, wide ranging behaviors, low detectability of tiger sign in most situations – poses major challenges to the task of monitoring tiger populations. Typically, over large regions, even results of mere presence or absence surveys tend to be equivocal or indeterminate. In particular, it is difficult to infer absence of tigers based on absence of tiger sign. Collection of quantitative data on abundance of tigers or tiger sign is usually handicapped by small sample sizes, low detection probabilities and numerous logistical and physical constraints. These species occur under a diversity of situations across TATR and their monitoring hence represents a variety of challenges. The long term monitoring projects are effective in understanding population trends in great details.

4.2: Camera Trapping:

The success of camera-trapping depends on the selection of ideal locations to deploy the camera traps so as to maximize the number of captures. Prior to camera placement, a survey is done along the forest paths, animal trails, dirt-tracks, dried stream bed to record carnivore presence through indirect signs (pugmarks, tracks, scat, scraps, rake mark, scent deposits and kills). Since there is a system of routine patrolling already in place in Tadoba, there is a record of animal movements for each beat in TATR. However, locations followed for the camera trapping in the year 2012, 2013 and 2014 were again referred and revised if there was any change in the existing movement pattern of animals. This exercise followed the protocol prescribed by Karanth and Nichols (2002) and Jhala *et al.*, (2010). Potential locations of camera trap stations were then mapped using ArcGIS 9.3 (ESRI, Redlands, CA, USA). This year we have chosen a sampling grid of 2.0164 sq km (1.42 km x 1.42 km) for camera trapping. A total of 381 sites were selected for deployment of camera traps in the core area and buffer area of TATR. The location of the camera traps overlaid on the forest cover map of TATR has been shown in the figure 4.1. A pair of Moultrie D-55 (www.moultriefeeders.com/gamespy-d55) and Cuddeback Ambush (http://cuddeback.com/cameras/ambush.aspx) camera traps was placed opposite to each other so as to photograph both flanks of tiger and leopard simultaneously during the camera-trap exercise.

The camera delay was set at multi-shot mode with delay of 15 seconds. Cameras were tied up on tree trunks or poles at the height of 25-35 cm opposite to each other. It is advised not to put the cameras facing each other exactly so as to miss the animal sight in photograph in case of over illumination of flashes if triggered at the same time. We used the flank which yielded maximum unique individuals for abundance estimation. For the present analysis all photographs of the right flank have been used to identify the individual tigers.

Camera trapping exercise extended from 1st February to 30th May for around 120 days. The total area was divided into four blocks and the sampling period was 22-24 days for each block. The cameras were active for 24-h period that accounted for one sampling occasion. Each camera was assigned a unique identification number. Date, time, temperature and camera-ID was recorded for every capture. An effort of 9144 camera trap nights was used during the 2015 Phase IV monitoring in Tadoba Andhari Tiger Reserve.

Pic: Pallavi Ghaskadbi

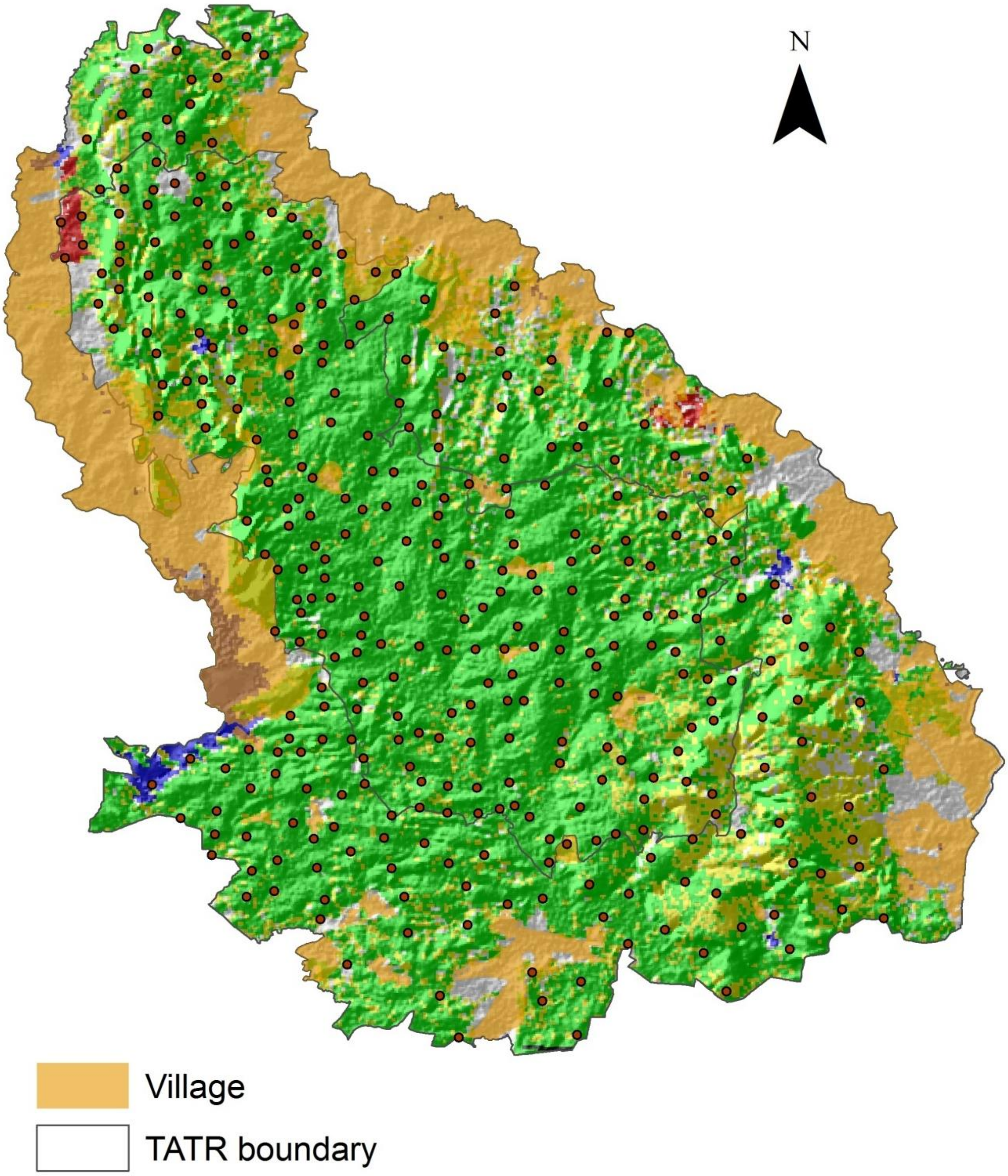


Figure 4.1: Map showing locations of camera traps for the year 2015 Core and Buffer area of Tadoba –Andhari Tiger Reserve, Maharashtra, India

Every tiger and leopard photograph was given a unique identification number after examining the stripe and rosette pattern on the flanks, limbs and forequarters (Schaller 1967; McDougal 1977; Karanth 1995). Individual capture histories of tiger and leopard were developed in a standard "X-matrix format" (Otis et al., 1978; Nichols 1992). One critical assumption for closed population estimate is that the population should be demographically and geographically closed (Otis et al., 1978; Rexstad and Burnham 1991) to follow our closure assumption the sampling duration was kept as minimum. Capture histories were analyzed using the software R package 'secr' (Efford M.G. 2015) using model developed for closed populations. The appropriate model was selected based on the Akaike Information criterion. The density was estimated with the maximum likelihood obtained from the model fitted with 'secr'.

4.3: Population Estimation for Tigers and Leopards:

During 120 days of camera trapping for tigers, a total sampling effort of 9144 trap nights 71 adult individual tigers where photographed within the core and buffer area of TATR. 44 adult leopards were identified based on the rosette pattern of the left flank. For estimating the density and population we used "secr" instead of conventional capture-recapture model.

Spatially explicit capture–recapture (SECR) is a set of methods for modelling animal capture–recapture data collected with an array of 'detectors'. The methods are used primarily to estimate population density, and have advantages over non-spatial methods when the goal is to estimate population size (Efford and Fewster 2013). SECR methods overcome edge effects that are problematic in conventional capture–recapture estimation of animal populations (Otis et al. 1978). Here detectors are camera traps that take photographs of tigers and leopards and they are recognized by their natural marks and stripes. Camera-traps are proximity detectors because they can detect multiple animals within an occasion, and they do not detain detected animals, which remain free to be detected by other camera-traps within each occasion. Like other statistical methods for estimating animal abundance (Borchers et al. 2012), SECR also combines a state model and an observation model. The state model describes the distribution of animal home ranges in the landscape, and the observation model (a spatial detection model) relates the probability of detecting an individual at a particular detector to the distance of the detector from a central point in each animal's home range. Unlike the maximum-likelihood and Bayesian estimation methods, it is not based on an explicit likelihood function and does not have the same inference foundation as these methods.
The key additional data that SECR analyses require, over and above the data used in non-spatial capture–recapture studies, are the locations of traps at which individuals were captured. Hence, to develop SECR models, we need some notation for trap location.

Tiger density per 100 km^2 based on secr Heterogeneity model was estimated to be 5.67 (SE ±0.69) for the area of TATR. Best model for the density estimate are chosen according to the AIC (Alkaike Criterion information). The details are provided in Table 4.1 and Table 4.2 along with the comparison of capture and density estimate from previous years. Table 4.3 give details of tigers captured within core and buffer area of tiger reserve. g0 is the detection probability for the species, it is assumed to be constant or variable depending on the distribution. Sigma is the distribution of average movement of the animal. It increases if the individuals are captured at very far away locations. The SECR generated density maps are provided in figure 4.2 and 4.3 for the year 2014 and 2015 respectively.

Table 4.1: Density estimates of tigers using Spatially Explicit Capture-Recapture Models in Tadoba Andhari Tiger Reserve, Maharashtra, India for the year 2014 - 2015

Parameters	2014	2015
Model	Heterogeneity	Heterogeneity
Detection function	Half normal	Half normal
Density estimate	5.609	5.673
Density standard error	0.773	0.698
Density confidence interval	4.285-7.340	4.461-7.214
g0 estimate	0.305	0.499
g0 standard error	0.022	0.098
g0 confidence interval	0.264-0.352	0.340-0.731
Sigma estimate	4.283	3.309
Sigma standard error	0.305	0.239
Sigma confidence interval	3.725-4.925	2.871-3.814

Table 4.2: Comparison of density of tigers and leopards across the years 2010 – 2015 for Tadoba-Andhari Tiger Reserve, Maharashtra, India

Year	Effective trapping area	Species	No of individuals captured	Estimate	Density per 100 km²
2010	321	Tiger	15	17(SE 3.6)	5.29 (SE 1.12)
2012	603	Tiger	47	49(SE 4.6)	5.40 (SE 0.60)
2013	603	Tiger	50	51(SE 7.5)	5.62 (SE 0.82)
2014	1170	Tiger	65	72(SE 5.37)	5.60 (SE 0.77)
2015	1310	Tiger	71	88(SE 4.91)	5.67 (SE 0.69)
2013	603	Leopard	17	24(SE 5.37)	3.82 (SE 0.81)
2014	1170	Leopard	34	37(SE 5.37)	4.08 (SE 0.63)
2015	1310	Leopard	44	49(SE 5.37)	4.31 (SE 0.83)

Table 4.3: No. of individual tigers captured from core and buffer area of Tadoba-Andhari Tiger Reserve, Maharashtra, India during the 2015 Phase IV Monitoring

Details	No. of Tigers
Tigers captured exclusively from Core Area of Tadoba Andhari Tiger Reserve	**51**
Tigers captured exclusively from Buffer Area of Tadoba Andhari Tiger Reserve	**14**
Tigers sharing boundary across the Core and Buffer Area of Tadoba-Andhari Tiger Reserve	**06**

Figure 4.1: Spatially explicit capture recapture density surface of tigers photo-captured during Phase IV camera trapping during the 2014 in Tadoba Andhari Tiger Reserve, Maharashtra, India

Figure 4.2: Spatially explicit capture recapture density surface of tigers photo-captured during Phase IV camera trapping during the 2015 in Tadoba Andhari Tiger Reserve, Maharashtra, India

5. Space Use Pattern of Tiger and Leopard in Tadoba Andhari Tiger Reserve

5.1 Introduction

The area used by an animal in a particular time-period is known as the space used by the animal. Animal space use is the result of physiological and behavioral adaptations to particular environmental characteristics. The space use pattern is very important tool for conservation and management of the species. Among the most prominent and widespread factors affecting the space use are the following:

1) The tendency for animals to remain in a particular area or home range due to site fidelity, territorial behaviour;
2) The distribution of required or selected resources; and
3) The location of other animals (e.g., mates, competitors, predators and prey).

One of the most common factors affecting animal space use is the tendency for most animals to confine their activities to a particular area or home range. This tendency might be the result of territorial behaviour, the need to continually provision a den or nest site, or behaviour designed to increase knowledge of the location of important resources or escape routes.

Animal space use is inherently a multivariate process and we believe an understanding of this process is best achieved by explicitly modelling the utilization distribution as a function of several interacting ecological processes and environmental pressures. Two general approaches have been taken for studying animal space use. One is a mechanistic approach that seeks to model animal space use using fundamental models of animal movement processes. The second approach is to estimate relevant parameters from a general, statistical model fit to observed location data. For example, animal home ranges are often estimated by fitting one or more statistical models (e.g., bivariate normal, kernel density) to location data obtained on a particular individual. Here we provide a very simple way to represent space use of animals during the camera trapping exercise.

5.2 Space use of Tiger and Leopards from camera traps:

Camera traps are generally used to estimate the population of individually identifiable animals or to monitor elusive species. But a camera trap can also be used to know the ranging pattern and space use of an animal. Cameras used for a short time period can give us the area used by the animal in that time period. Here we tried to map the area used by the tigers in our camera trapping season. If one animal is captured at three or more than three sites, then we can make minimum area use polygons. Table 5.1 shows details of tiger and leopard captured across the trapping exercise and Figure 5.1 – 5.6 shows the distribution pattern of minimum area use polygons of tigers (male and female) and leopards across the years 2014 and 15 in Tadoba Andhari Tiger Reserve Maharashtra, India.

Table 5.1: Minimum area used by Tigers in TATR during Phase IV Camera Trapping 2014 and 2015

Year	Species/Sex	Number of individuals captured at more than three camera traps	Minimum area use (km²)	Maximum area use (km²)	Average area use (km²)
2014	Tigers (Male)	14	8.58	120.45	45
	Tigers (Female)	22	1.49	90.29	21
2015	Tigers (Male)	17	4.65	95.52	32
	Tigers (Female)	25	1.74	38.09	14
2014	Leopard	10	3.66	34.46	17.38
2015	Leopard	3	2.86	35.71	13.87

Pic: Vinit Arora

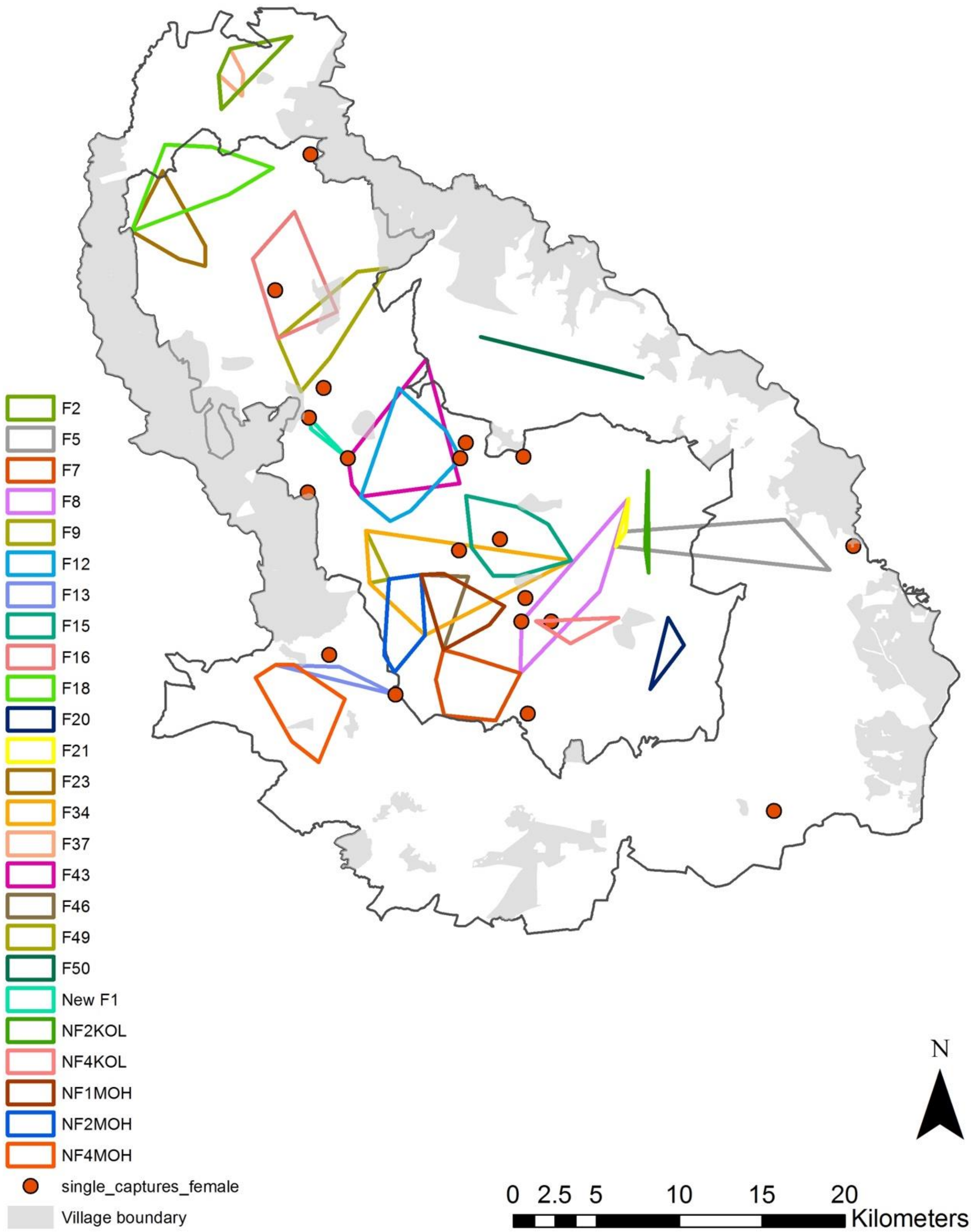


Figure 5.1: Minimum area use polygons of 25 Female Tigers captured at more than 3 camera locations during the year 2015 camera trapping exercise at Tadoba Andhari Tiger Reserve, Maharashtra, India

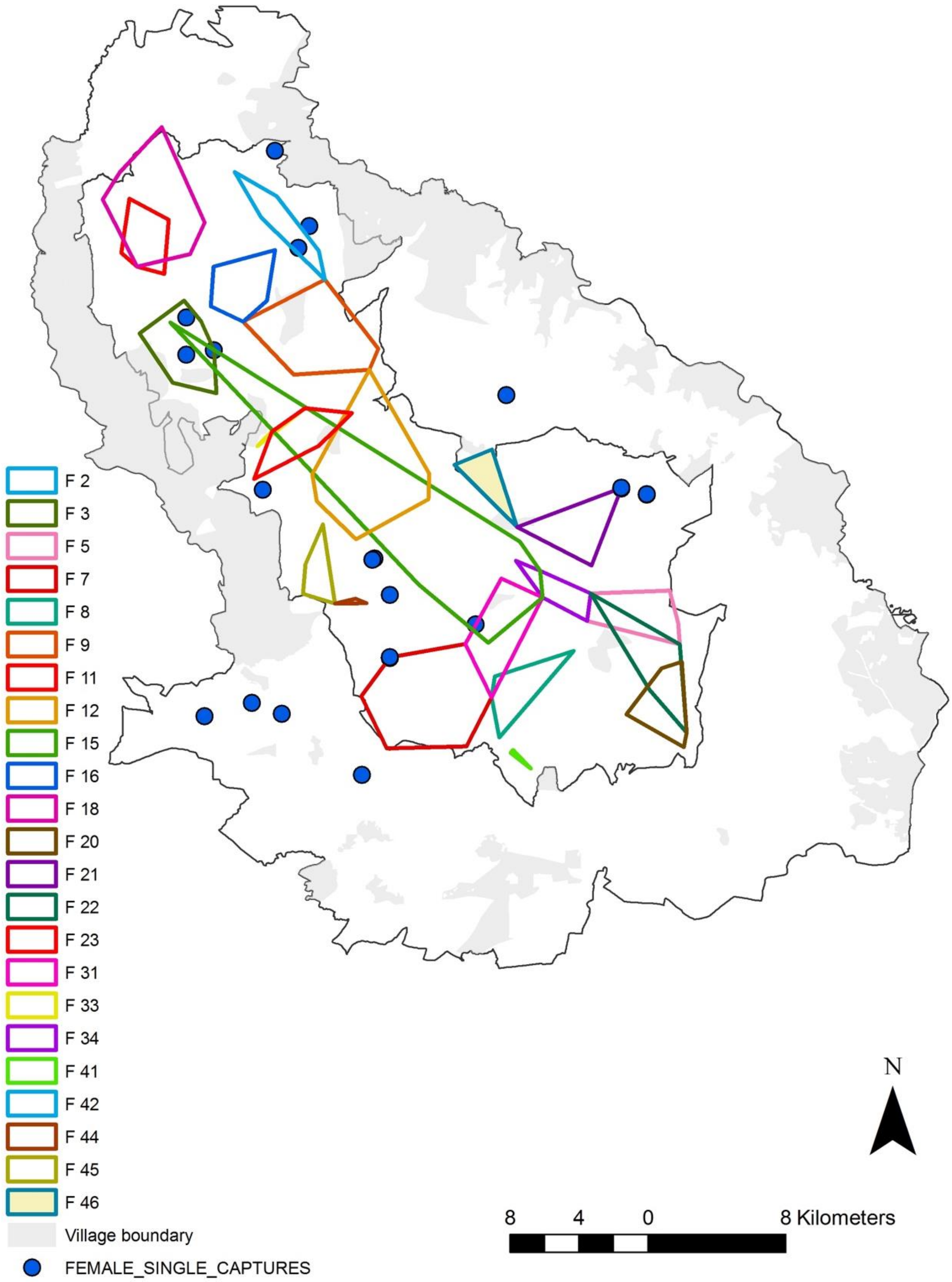


Figure 5.2: Minimum area use polygons of 22 Female Tigers captured at more than 3 camera locations during the year 2014 camera trapping exercise at Tadoba Andhari Tiger Reserve, Maharashtra, India

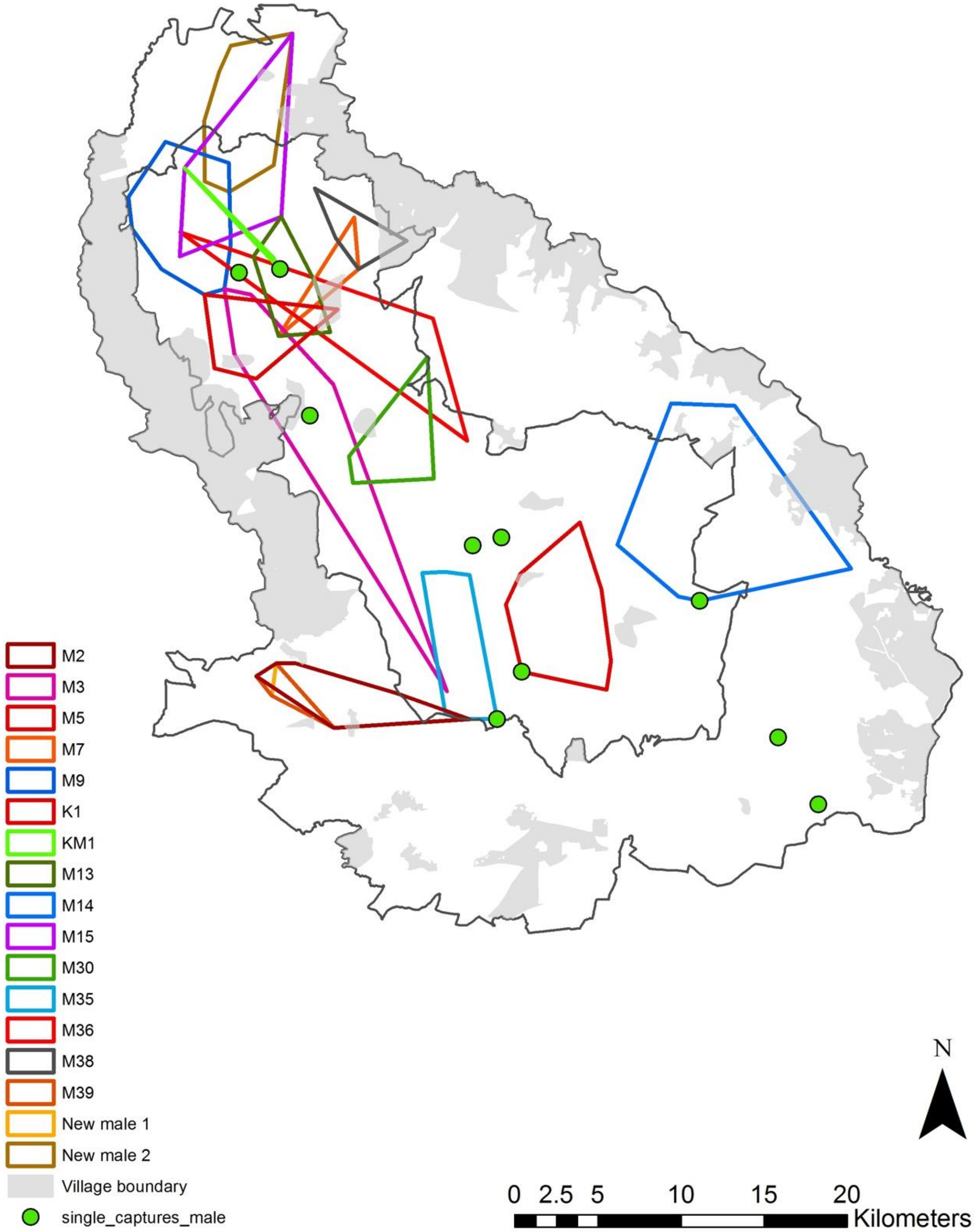


Figure 5.3: Minimum area use polygons of 17 Male Tigers captured at more than 3 camera locations during the year 2015 camera trapping exercise at Tadoba Andhari Tiger Reserve, Maharashtra, India

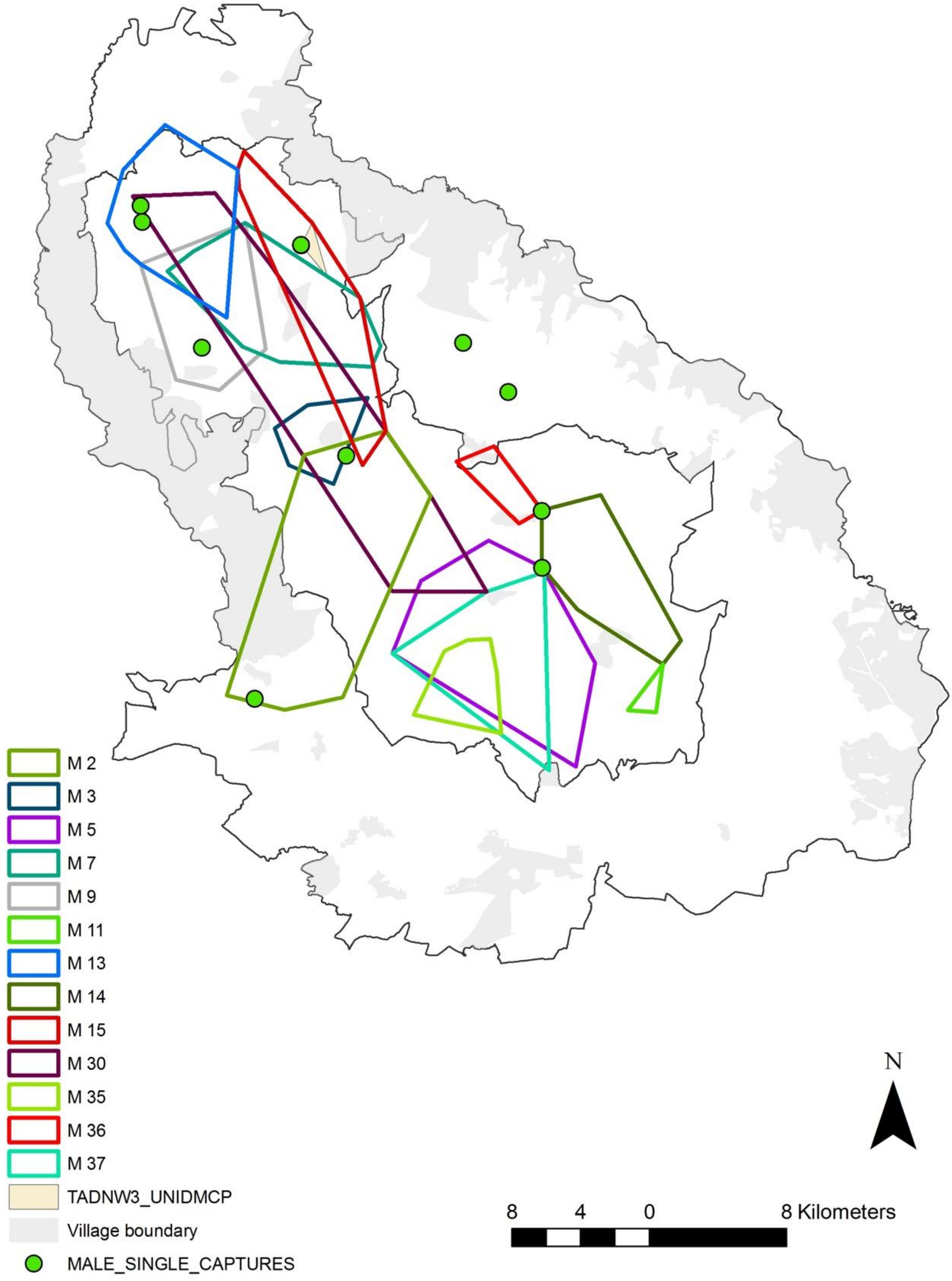


Figure 5.4: Minimum area use polygons of 14 Male Tigers captured at more than 3 camera locations during the year 2014 camera trapping exercise at Tadoba Andhari Tiger Reserve, Maharashtra, India

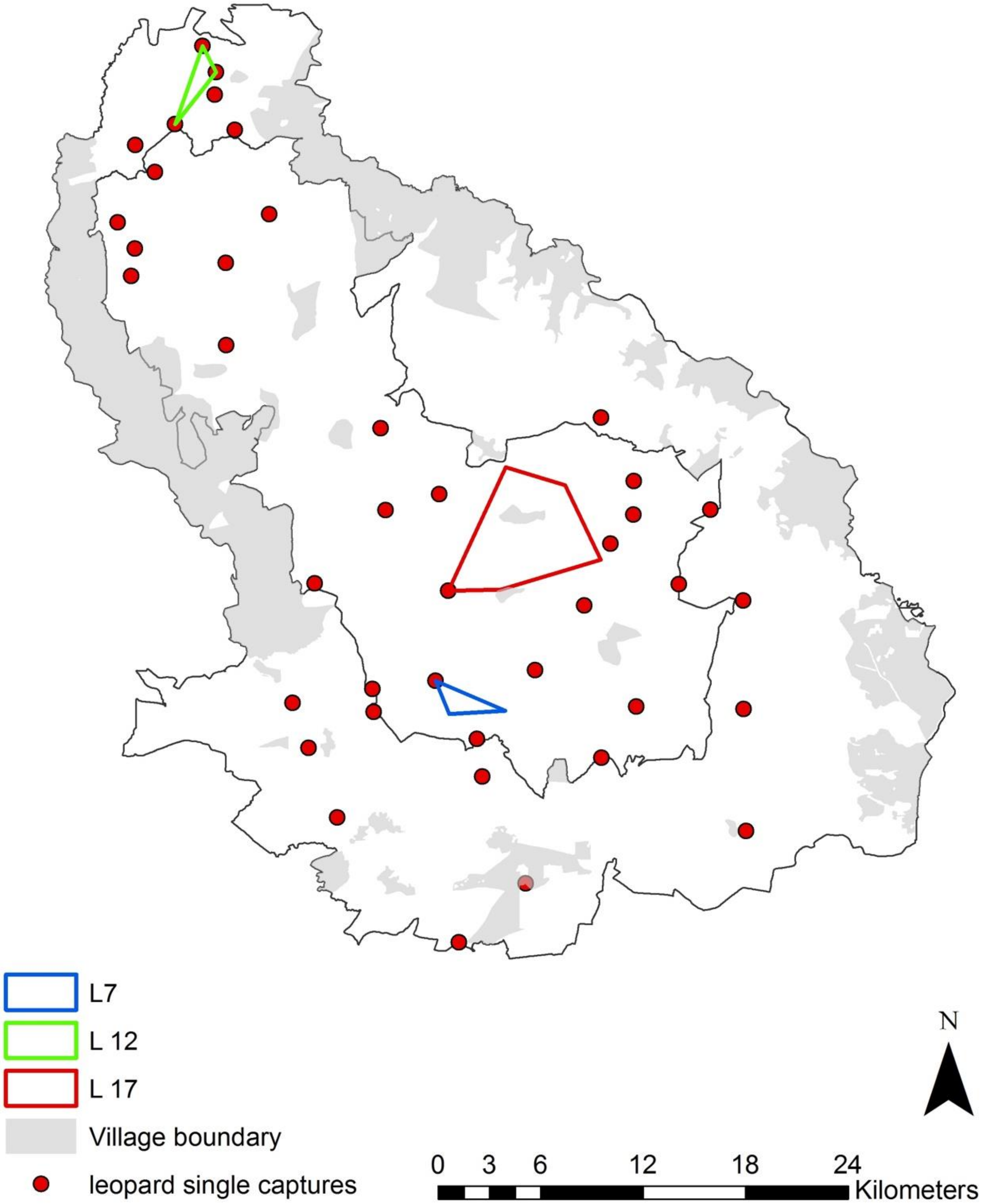


Figure 5.5: Minimum area use polygons of 3 Leopards captured at more than 3 camera locations during the year 2015 camera trapping exercise at Tadoba Andhari Tiger Reserve, Maharashtra, India

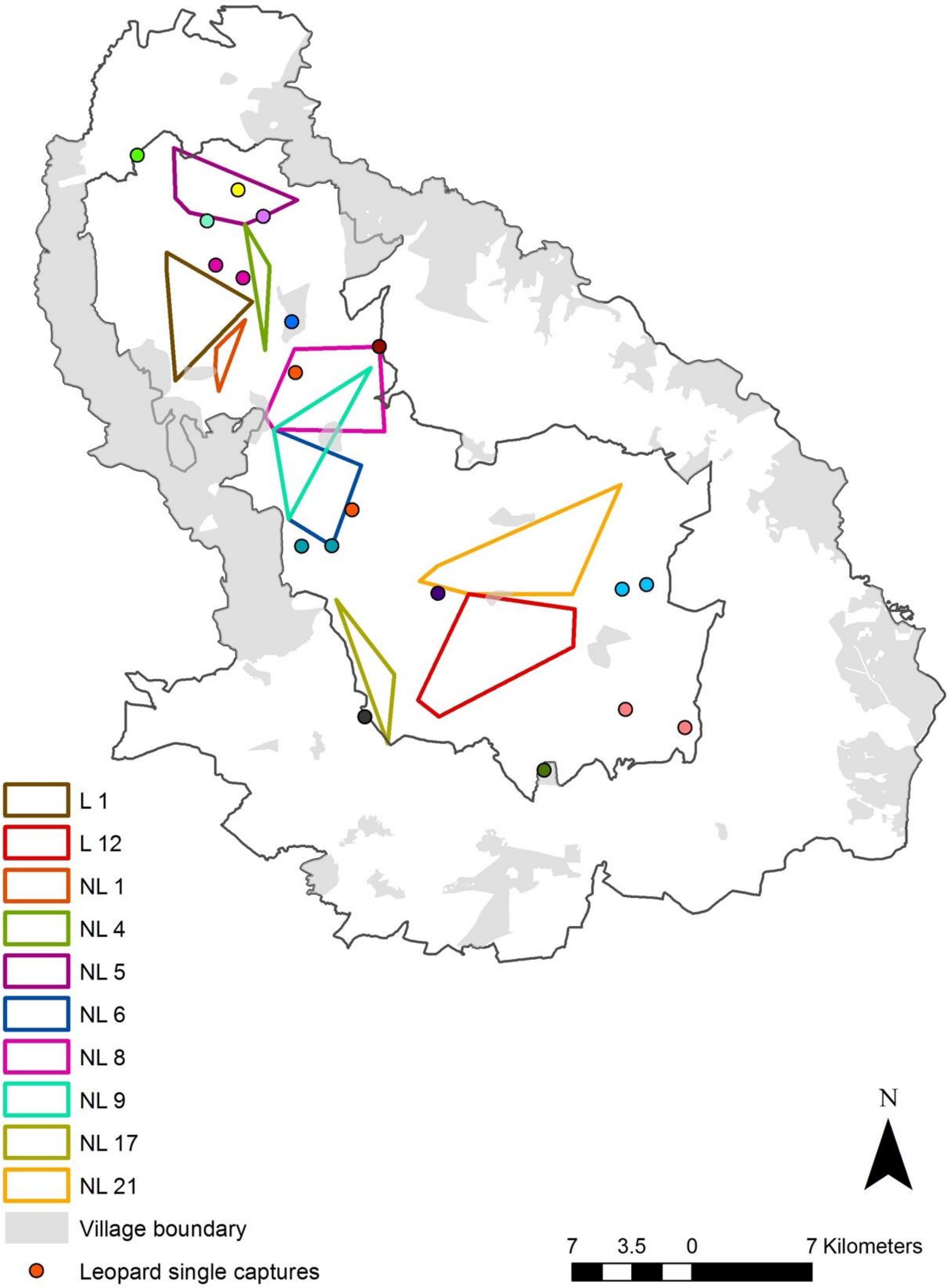


Figure 5.6: Minimum area use polygons of 10 Leopards captured at more than 3 camera locations during the year 2014 camera trapping exercise at Tadoba Andhari Tiger Reserve, Maharashtra, India

5.3 Space use of tigers from radio-telemetry:

The home range of an animal can be defined as the area traversed by the animal in the activities of gathering food, finding partner and caring for young. It satisfies the various need of the animal and provides important information about the prey species and inter-species and intra-species competition. Though a number of studies tried to look into the ranging pattern of the elusive cat, new studies with advanced use of technology, give us important insights into the ecology of the animal. To study the home-range and the activity pattern of the tiger in TATR, two tigers have been fitted with GPS Plus 3D Collars with activity and mortality sensors programmed to record GPS location at an interval of 5hrs and activity information at 5-minute interval. The details of number of locations and home range as reported is given in table 5.2 and figure 5.7 shows movement details and home range polygon on google earth imagery.

Table 5.2: Home range and movement details of two radio-collared tigers from Tadoba-Andhari Tiger Reserve, Maharashtra, India

Details	Female Tiger 14616	Male tiger 14617
Radio-collared	17th October, 2014	19th October, 2014
Number of locations	1592 (till September)	1353
Home-range (95% kernel)	43.98 sq. km	105.18 sq. km
Home- range (75% kernel)	25.14 sq. km	49.54 sq. km
Home-range (50% kernel)	11.74 sq. km	21.87 sq. km
Total distance moved	1137.472 km	693.735 km
Inter-fix distance	827.25 m	462.182 m
Daily distance method	3.94 km	4.23 km

Pic: Nilanjan Chatterjee

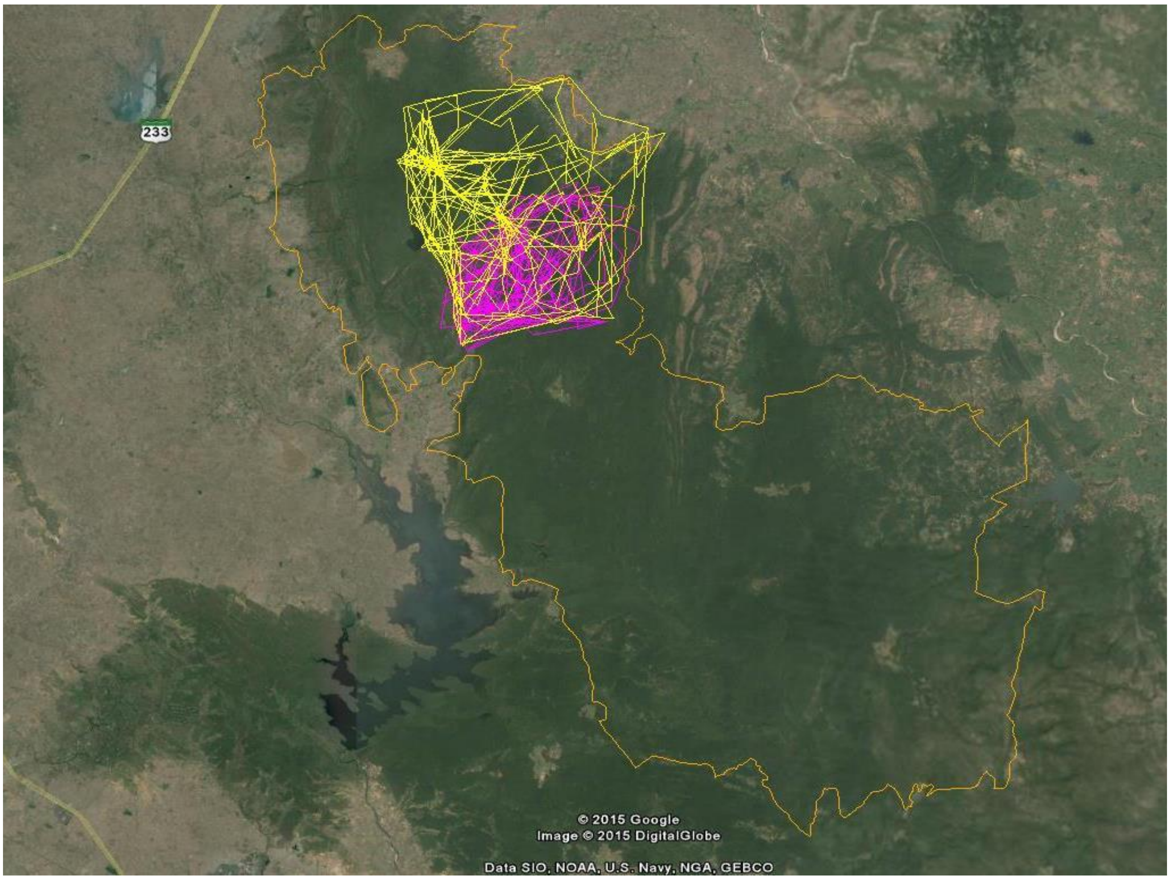


Figure 5.7: Home range polygon of Male (Yellow) and Female (Purple) on Google Earth Imagery showing home range polygons with respect to Tadoba Andhari Tiger Reserve

Figure 5.8 shows the home range polygons of collared tigers as reported by camera trap exercise during the year 2015 and 95% kernel Estimate of the home range with respect to core area of Tadoba Andhari Tiger Reserve. Figure 5.9 and 5.10 shows home range stabilization curve of female radio-collared tiger (14616) (Black lines – 75%, Red lines – 50 % & 95 % and Blue lines – 25% & 100%) and home range stabilization curve of male radio-collared tiger (14617) (Black lines – 75%, Red lines – 50 % & 95 % and Blue lines – 25% & 100%) respectively. For both male and female the home range stabilization was achieved at 250 locatiosns.

It is important to mention that the polygon as drawn from camera trap locations of male tiger during the year 2015 is much smaller than female tiger. The reason for this could be that the male tiger was critically injured during this period due to a territorial fight with another male tiger. During our camera trapping exercise he changed his activity pattern and used very small areas within the core of TATR. After his recovery, the male started using a larger area again as was observed prior to the injury.

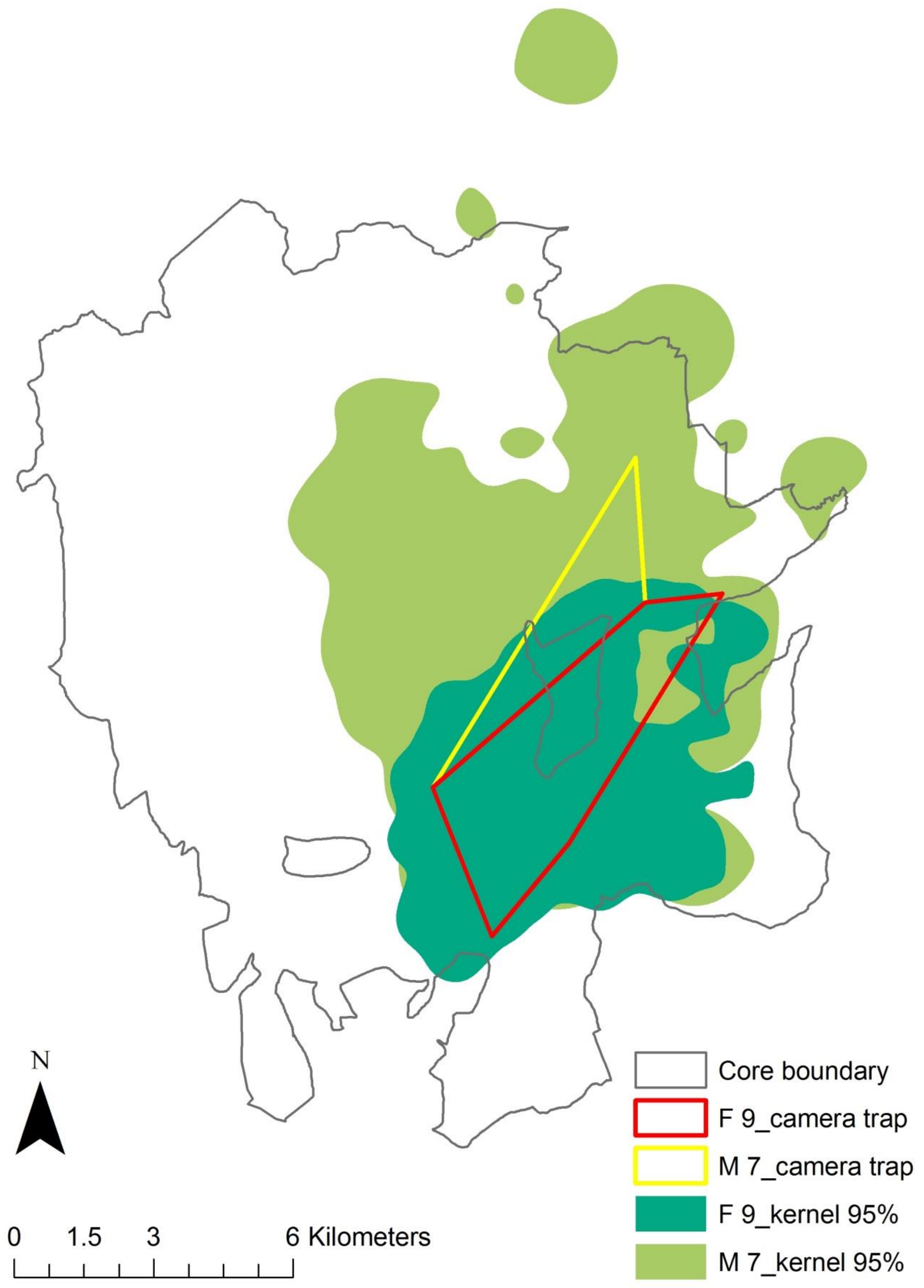


Figure 5.8: Map showing kernel home range overlap of the female radio-collared and the male radio-collared tiger from radio-telemetry and camera trap

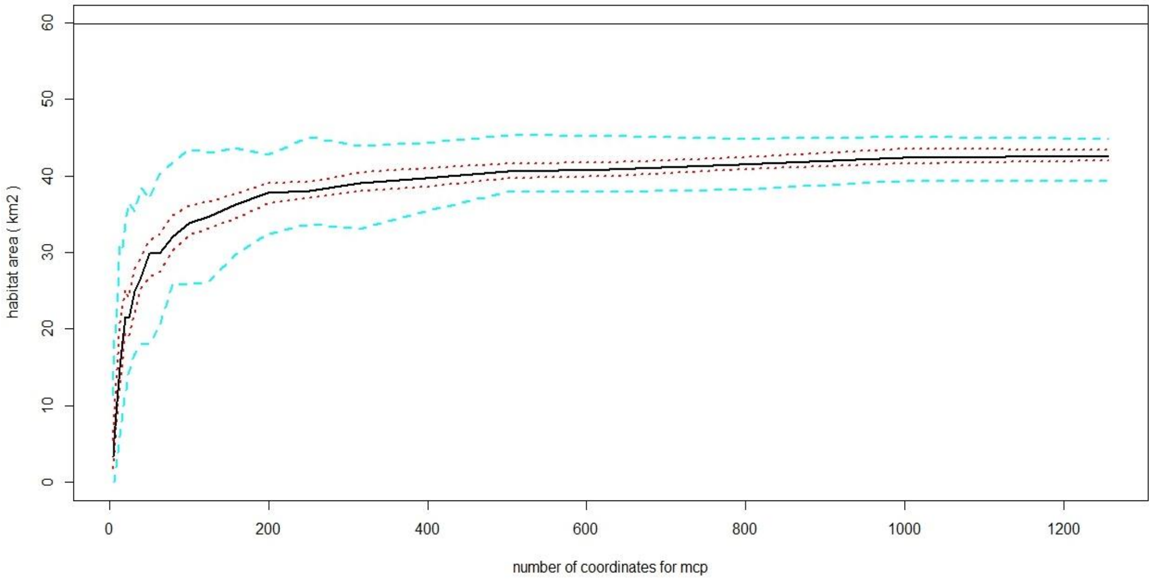


Figure 5.9: Home range stabilization curve of female radio-collared tiger (14616) (Black lines – 75%, Red lines – 50 % & 95 % and Blue lines – 25% & 100%)- home range stabilization was achieved at 250 locations

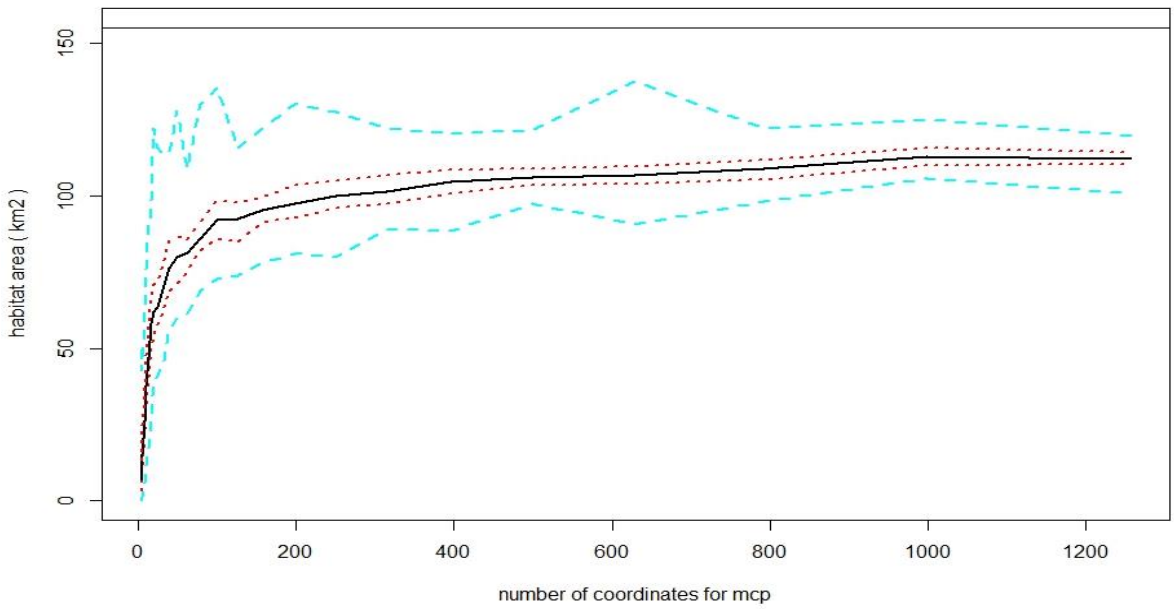


Figure 5.10: Home range stabilization curve of male radio-collared tiger (14617) (Black lines – 75%, Red lines – 50 % & 95 % and Blue lines – 25% & 100%)- home range stabilization was achieved at 250 locations

5.4 Space use of leopards using radio-telemetry:

To study the niche separation and ranging pattern among large carnivores, we collared one male tiger from core area of TATR. Leopards are solitary and elusive, making it very difficult to immobilize them from a vehicle. We used cages with drop-door mechanism to capture the leopard with live goat as bait. The trapped leopard was then chemically immobilized by a trained wildlife veterinarian using a combination of ketamine and xylazine drugs. With an effort of 12 trap nights in the month of April, 2015 the individual was trapped near Jamni village in the Tadoba range of the core zone of TATR on 22nd April, 2015. Post capture, the animal was released in the same area where he was trapped. The leopard was fitted with a GPS – Vectronics Satellite collar (GPS 1D) with the ID 13641. The collar was programmed to give a location of the animal every five hours. The animal was also tracked on ground with the help of VHF tracking. Till September 2015, a total of 101 locations were received from the GPS collar. The animal showed erratic movement in and around the area where it was collared. The animal is a sub-adult male in search of his own territory. The movement and activity details of the individual are given in the Table 5.3. Figure 5.11 shows the home range stabilization curve of the male radio-collared leopard (13641) (Black lines – 75%, Red lines – 50 % & 95 % and Blue lines – 25% & 100%). The home range stabilization of the leopard has not stabilized as the animal is probably still in seach of his own territory.

Table 5.3: Home range and movement details of radio-collared male leopard from Tadoba-Andhari Tiger Reserve, Maharashtra, India

Details	Rama (13641)
Number of locations	101 (Till September)
Home range (95% kernel)	53.43 sq. km
Home range (75% kernel)	24.34 sq. km
Home range (50% kernel)	10.43 sq. km
Total distance moved	100.592 km
Daily distance moved	1143.1 m

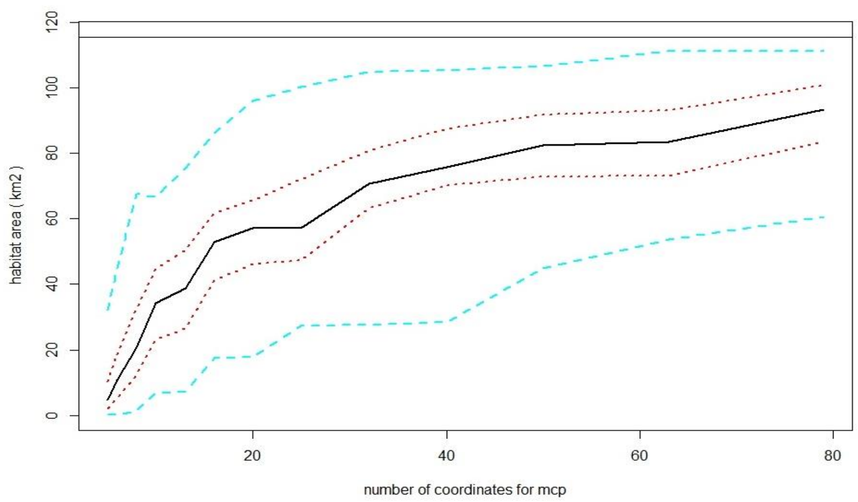


Figure 5.11: Home range stabilization curve of male radio-collared leopard (13641) (Black lines – 75%, Red lines – 50 % & 95 % and Blue lines – 25% & 100%)- home range stabilization was not achieved yet

Figure 5.12 shows 95 % kernel home range of male leopard with respect to core and buffer area of Tadoba Andhari Tiger Reserve. As is evident from map, the animal is using much larger area and has shown erratic movement pattern till date from the time of collaring.

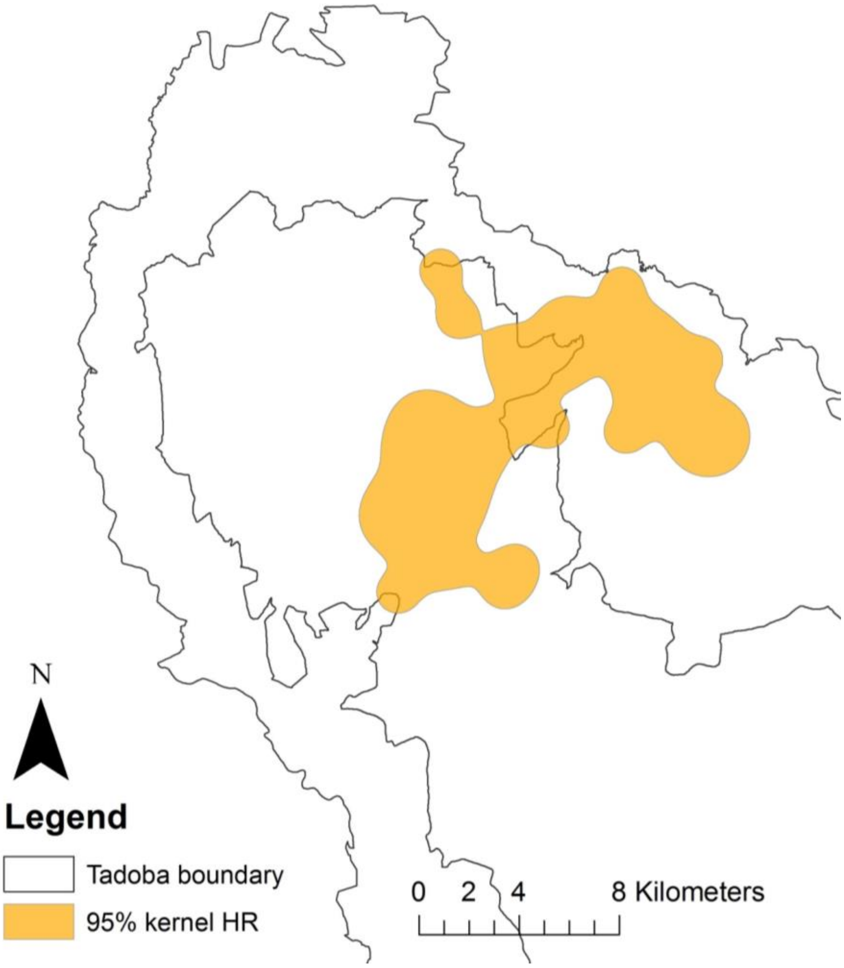


Figure 5.12: 95% Kernel home range map of the male radio collared leopard

Pic: Nilanjan Chatterjee

6. Resource Partitioning between Tiger, Leopard and the Dhole

6.1 Introduction:

Over the years, a constant evolutionary arms race between the prey and predator has shaped their adaptations or traits in a system (Matter & Mannan 2005; Eriksen et al. 2011). Exploitative as well as interference competition has been studied extensively on the basis of three axes- temporal, spatial and diet partitioning (Carothers & Jaksic 1984). On an evolutionary scale, traits such as activity patterns have been shaped for both prey as well as predators, however, these may be flexible to a certain extent depending on the site-specific environmental conditions (Monterroso et al. 2013). Activity time for an animal is a tradeoff between risk of starvation and predation risk (Lima 1988; Bednekoff 2007). Depending on the intensity of competition among predators and predator-prey interactions, activity peaks may be dynamic (Lima 1988) and site-specific conditions 'can override the endogenous regulation of an animals' circadian clock' (Monterroso et al. 2013). Furthermore, the presence of multiple predators in a system can influence behavioural decisions of both the prey as well as amongst predators themselves to optimize their activity times. Fundamentally, animals move in search of resources like food, mates or refuges which, to a great level, are interdependent. However, on an individual level, most activity of animals is dedicated to foraging or rather acquisition of food (Suselbeek et al. 2014). Thus it makes sense to study the activity patterns of prey and predators both spatially and temporally complimenting it with an understanding of their actual diet through scat analysis. Camera traps have been used widely to study population densities and spatial ecology of various animals but there have been only few comparative studies of activity patterns between the three large sympatric carnivores with respect to their prey in India (Ramesh et al. 2012).

The dietary profiles of carnivores have been predominantly studied by examining the scats for undigested recognizable parts of prey like hair (Koppikar & Sabnis 1976; Putman 1984). Although scats may not be the true representation of the diet of a carnivore, it is nevertheless, a snapshot of the types of prey consumed. This method also has an advantage over other techniques such as gut content analysis (Smuts 1979), spoor tracking (Mills & Mills 1978) or direct observation of feeding (Schaller 1972; FitzGibbon & Fanshawe 1989) because of the relative ease of obtaining samples and the non-invasive nature of the sampling procedure (Andheria et al. 2007). Furthermore, complimenting the activity pattern data of predators and their prey with the dietary profiles would lead to a better understanding of the mechanism of co-existence.

6.2 Methods

Field and Laboratory methods

Temporal activity pattern and spatial segregation:

In order to study the temporal activity and the space use among three carnivores and their prey, camera trapping was carried out. Typically, camera traps record the date and time of a photograph which can be used to study these patterns of interest. Camera trap data were collected between January and April 2015 as a part of research on sympatric large carnivores – tiger, leopard and Dhole. Intensive camera trapping was done in TATR with camera traps deployed in 1.4 x 1.4 sq. km grids. Camera stations were placed along roads, trails or stream-beds to maximize photo-captures. Camera trapping was done for 40 days at the beginning of the summer season. The mean inter-trap distance between a two camera trap stations was 1 km. Each station comprised a pair of passive white flash cameras (Cuddeback Attack Model 1149 or the Moultrie Game Spy D55) to maximize capture probability. Camera traps were active throughout the day and night for the entire duration of trapping sessions.

Collection of scats for Dietary Analysis:

Scats were collected opportunistically as well as actively by searching for them along forest roads and animal trails in the study area. Identification and differentiation of tiger and leopard scats was based on associated tracks or sign and only those scats which could be identified correctly were analyzed further. The Dhole scats were easy to identify as they were deposited mainly at junctions or across the roads. Communal defecation sites (Johnsingh 1983) and the typical scent of these scats made it even easier to correctly identify the Dhole scats.

Analytical Methods

Temporal activity pattern:

In order to study the temporal pattern of the three predators and their prey, the temporal data was analyzed in the statistical software R (version 3.0.1) (R Development Core Team 2013 http://www.R-project.org) and Microsoft Excel 2013. I used the package 'overlap' which estimates the coefficient of temporal overlap non-parametrically using kernel density estimates, following the approach of Linkie and Rideout (2009). In the package 'overlap', data are regarded as a random sample from the underlying distribution that describes the probability of a photograph being taken within any particular interval of the day. The probability density function of this distribution is then referred as the activity pattern, which assumes that the animal is equally likely to be photographed at all times when it is active (Ridout & Linkie 2009). It is a two-step process. In the first step, each activity pattern is estimated non-parametrically, using kernel density estimation (Fernandez-Duran 2004). The kernel density estimates used a bandwidth parameter, which is selected following the procedure developed by Taylor (2008). For the second step, a measure of overlap between the two estimated distributions was calculated. Ridout and Linkie (2009) reviewed several alternative measures of overlap between two probability distributions, favouring the coefficient of overlapping, Δ (Weitzman 1970), which ranges from 0 (no overlap, e.g. one species entirely diurnal, the other entirely nocturnal) to 1 (complete overlap). This is defined as the area under the curve that is formed by taking the minimum of the two density functions at each time point. A useful interpretation of the coefficient of overlapping is that for any time period during the day the proportion of activity that occurs during that period differs between the two distributions by $<1–\Delta$. 1000 bootstrap samples are used to derive the confidence intervals.

Program Oriana 4.0 (Kovach Computing Services, Wales, UK) was used to plot the mean activity of large carnivores and their prey on a 24 hour circular distribution scale. Oriana analyses orientations and other circular data. It calculates a variety of statistics necessary for working with data measured in degrees, time of day or other circular scales and graphs the data in a number of different ways. The data available from last year's camera trap sampling in the same area during the same season were compared to test if there was a significant difference in the temporal patterns. Per hour captures of the three carnivores were plotted in the form of a rose diagram. Hours with the greater number of captures showed higher activity peaks. Oriana calculates basic statistics such as the circular mean and median, various measures of circular dispersion such as mean vector length (r), concentration and circular variance and standard deviation, along with confidence intervals for the mean.

Space use:

To account for spatial overlap between large carnivores, a multiple response permutation procedure (MRPP) test was performed. MRPP is a nonparametric procedure for testing the hypothesis of no difference between two or more groups of entities. In this case, it would translate as null hypothesis is that there is no spatial segregation between two species. The weighted mean within group distance is calculated as the first step of the analysis.

The weighted mean within group distance (δ) is given by the following formula:

$$\delta = \sum_{i=1}^{g} C_1 x_1$$

for g groups where C is a weight that depends on the number of items in a group.

The test statistic T is the difference between the observed and the expected deltas divided by the square root of variance in delta. It is calculated as

$$T=(\delta-m_\delta)/s_\delta$$

where m_δ and s_δ are the mean and standard deviation of δ under the null hypothesis.

The p value is useful for evaluating how likely it is that an observed difference is due to chance, but a description of the effect size is required which is independent of the sample size. This is provided by the chance corrected within-group agreement (A).

$$A= 1 - \frac{Observed\ \delta}{Expected\ \delta}$$

The agreement statistics A describes within group homogeneity, compared to the random expectation. When all items are identical within groups, then the observed δ = 0 and A=1, the highest possible value for A. If heterogeneity within groups equals expectation by chance, then A=0. Statistical significance may result even when the "effect size" (A) is small if the sample size is large. In such cases, the ecological significance of the result should be considered and not just the statistical significance. Data was analyzed using the software Blossom Statistical Package.

To test whether animals are avoiding each other, a simple species interaction factor was calculated in Microsoft Excel 2007. The following formula was used,

SIF= Probability of co-occurrence for Group A/ Probability of co-occurrence of Group B

The probability of 2 species occurring together at the same camera trap location was calculated from the number of camera traps where the species have occurred independently vs. together. This was then divided by the expected value of their co-occurrence. If the observed co-occurrence was more expected, the species were said to have no apparent avoidance towards each other ace and versa. The standard error estimator for proportion: **sqrt[p(1-p)/n]** and delta-variance method to combine SE's across the proportions was used.

The space use was graphically represented by generating weighted kernel density maps of camera trap captures at each location in GIS (Silverman 1986).

Diet analysis

All collected scat samples were dried and broken down and teased apart with forceps to collect the undigested contents in them. The prey remains included hair, claws and plant material. All the prey remains apart from hair were identified macroscopically. The hair samples were microscopically examined to identify the species based on the medullary pattern of the hair by comparing them with the reference collection of hair at the Wildlife Institute of India following a standard protocol (Mukherjee et al. 1994). In all 185 Dhole scats, 54 tiger scats and 11 leopard scats collected during field work were analyzed.

Prey biomass and number:

In order to estimate prey biomass and number, the percentage frequency of occurrence of all the major prey species was calculated. I used the density of prey estimated during the 2014 sampling session as the sampling was done in the same season The frequency of occurrence is biased towards smaller sized prey, since relatively more scats are produced for smaller prey than larger prey. To correct for this bias, relative frequencies of prey were converted to relative biomass consumed for tigers and leopards using an equation estimated for cheetahs (Wachter 2012), and for Dholes using an equation estimated for wolves (Jethwa & Jhala 2003). These regression equations estimate the number of field collectable scats for a given weight of prey biomass. The equations are given below:

$y = 0.38 + 0.020x$ (for Dhole) and
$y = 2.358(1\text{-}\exp(-0.075x)$ (for tigers and leopards) where,

the independent variable x is the average weight of the prey and the dependent variable y is the number of field collectable scats for that weight of prey. The dependent variable can then be converted into the relative biomass of prey consumed by multiplying it by the relative frequency of each prey species found in the scats. The relative number of each species consumed is obtained by dividing relative biomass by the average weight of the prey species. The weight of various prey species killed by tiger, leopard and Dhole was assumed to be similar to that used in previous research (Karanth & Sunquist 1995).

Dietary overlap:

The extent of dietary overlap between all three species was calculated by Pianka's Index (Pianka 1973). The Pianka index is a single numeric value on a 0 to 1 scale that summarizes the average pair wise niche overlap in an assemblage. Software EcoSim (Gotelli & Entsminger 2001) was used for null model analysis. These null model tests have wide applicability in both applied and basic ecology.

For species 1 with i = 1 to n resource categories, the proportional resource utilization *p* of resource state *i* by species 1 is defined such that:

$$\sum_{i=1}^{n} p\,i = 1.0$$

Niche overlap indices are always calculated by first dividing each entry in the utilization matrix by the corresponding row total, so that all entries are proportional utilization values (p) for each species. The Pianka niche overlap index O for the pair of species (1, 2) is calculated as

$$O_{12} = O_{12} = \frac{\sum_{i=1}^{x} p_{2i}\; p_{1i}}{\sqrt{\sum_{i=1}^{x} (p_{2i}{}^{2})(p_{1i}{}^{2})}}$$

EcoSim allows the user to incorporate additional data on the availability of resources. In nature, resources are not equally abundant (or usable) by all species. If this assumption is not true, the analysis will tend to over-estimate niche overlap because species will tend to use common resource states even if there is niche segregation. Assuming the resources are equally available would lead to a less robust inference if there are very common/ very rare resources. Hence a user- defined resource state was used which incorporated the density of prey as well.

Prey selection:

A prey is said to be 'selected' if it is consumed at frequencies more than is expected by chance. These expected frequencies are estimated from the densities of the prey species. I used the density of prey estimated during the 2014 sampling session (Habib et al. 2014) (ref. Table 1) as the sampling was done in the same season. Ivelev's selectivity index was used to estimate 'selectivity' of prey species by a predator (Ivelev 1961; Acharya et al. 2007; Majumder 2011).

A two-way ANOVA was performed to investigate if there is a difference between the occurrence of species of prey in the diet of three predators and the proportions of the species being harvested by the three carnivores. The two-way analysis of variance (ANOVA) examines the influence of two different categorical independent variables on one continuous dependent variable. It not only aims at assessing the main effect of each independent variable but also if there is any interaction between them.

6.3 Results

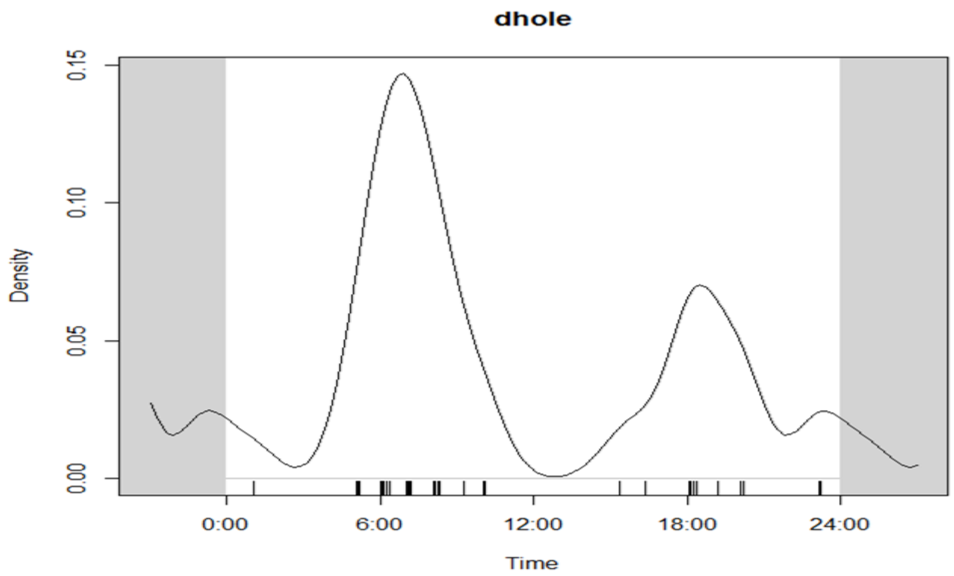
Activity Pattern:

An effort of 3420 trap nights resulted in 360 photographs of tiger, 113 photographs of leopard and 34 photographs of Dhole were obtained. Tiger showed bimodal peak activity; a smoother early morning peak and a steeper one at dusk, thus tending towards a typical crepuscular activity pattern. The Dhole showed a similar bimodal peak, however, it was smoother at dusk than at dawn which is exactly opposite to the tiger. The leopard was seen to be active throughout the day except for the hottest hours from noon till early evening. 55% of tiger captures were between 1800 hrs to 0600 hrs with peaks at dawn and dusk. The leopard was strongly nocturnal (72% captures between 1800 hrs to 0600 hrs) whereas the Dhole tending towards a crepuscular pattern of activity (41% captures between 1800 hrs to 0600 hrs). Amongst the prey species, sambar also had peaks at dawn and dusk with 66% captures from 1800 hrs to 0600 hrs similar to the temporal activity pattern of the tiger. Chital and wild pig showed 28% and 31% captures between 1800 hrs to 0600 hrs whereas the barking deer was fairly diurnal (39% captures between 1800 hrs and 0600 hrs) and the hare was strongly diurnal (99% captures between 1800 hrs and 0600 hrs) similar to the activity pattern of the leopard. (Fig. 6.1 and 6.2)

The circular distribution of temporal pattern was plotted in Oriana to compare data of this season with the last season's data. A significant shift was seen in the temporal pattern of the tiger from a highly nocturnal activity peak to a more crepuscular pattern. This could probably be due to the coinciding activity peaks of the sambar which is a major prey species for the tiger. The Dhole did not show much difference in the temporal activity. The leopard did show a shift in the activity peak from dusk in 2014 to dawn in 2015 and seems to be avoiding the activity peak of both the tiger and Dhole (Fig. 6.3).

From the kernel density estimators, the sambar and gaur were observed to have a high degree (>0.8) of overlap with the tiger as indicated by the estimated overlap coefficients in Table 6.1. The Dhole showed a high coefficient of overlap with the wild pig and barking deer [0.78 (0.66-0.87) and 0.70 (0.49-0.82) respectively]. The leopard and the tiger had a high coefficient of overlap 0.80 (0.73-0.88) (Fig. 6.4 a to e).

a)



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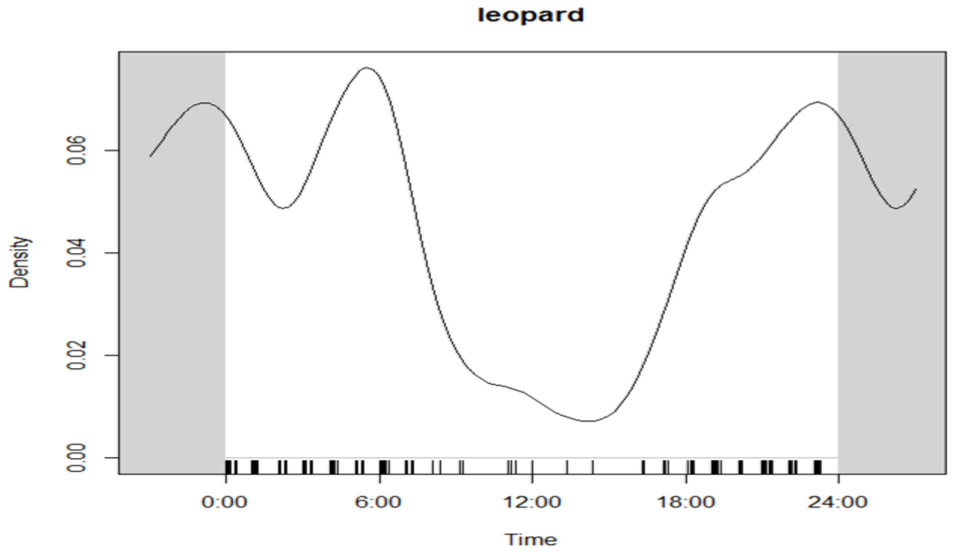

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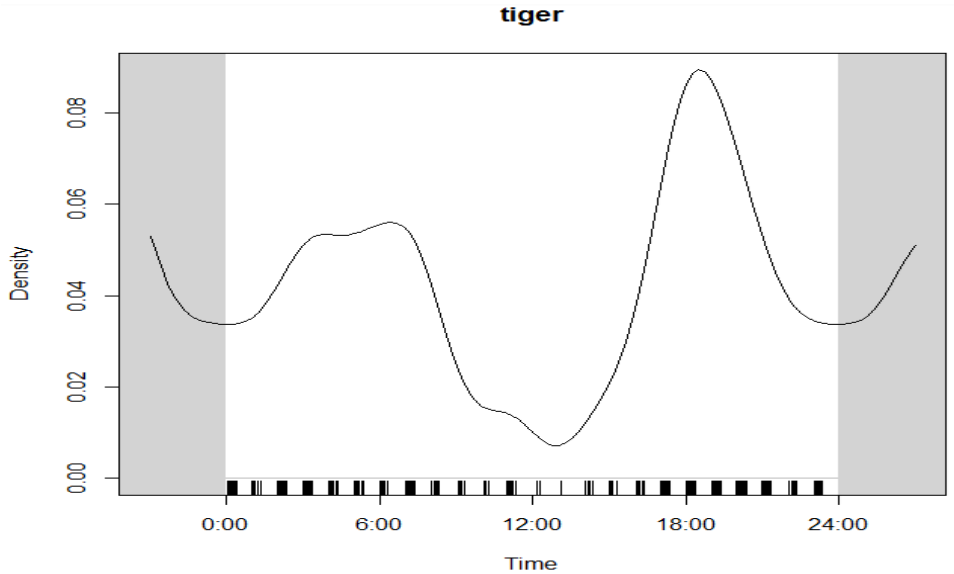


Figure 6.1: Kernel density estimates of daily temporal activity patterns of (a) Dhole, (b) tiger and (c) leopard - sympatric carnivores in TATR

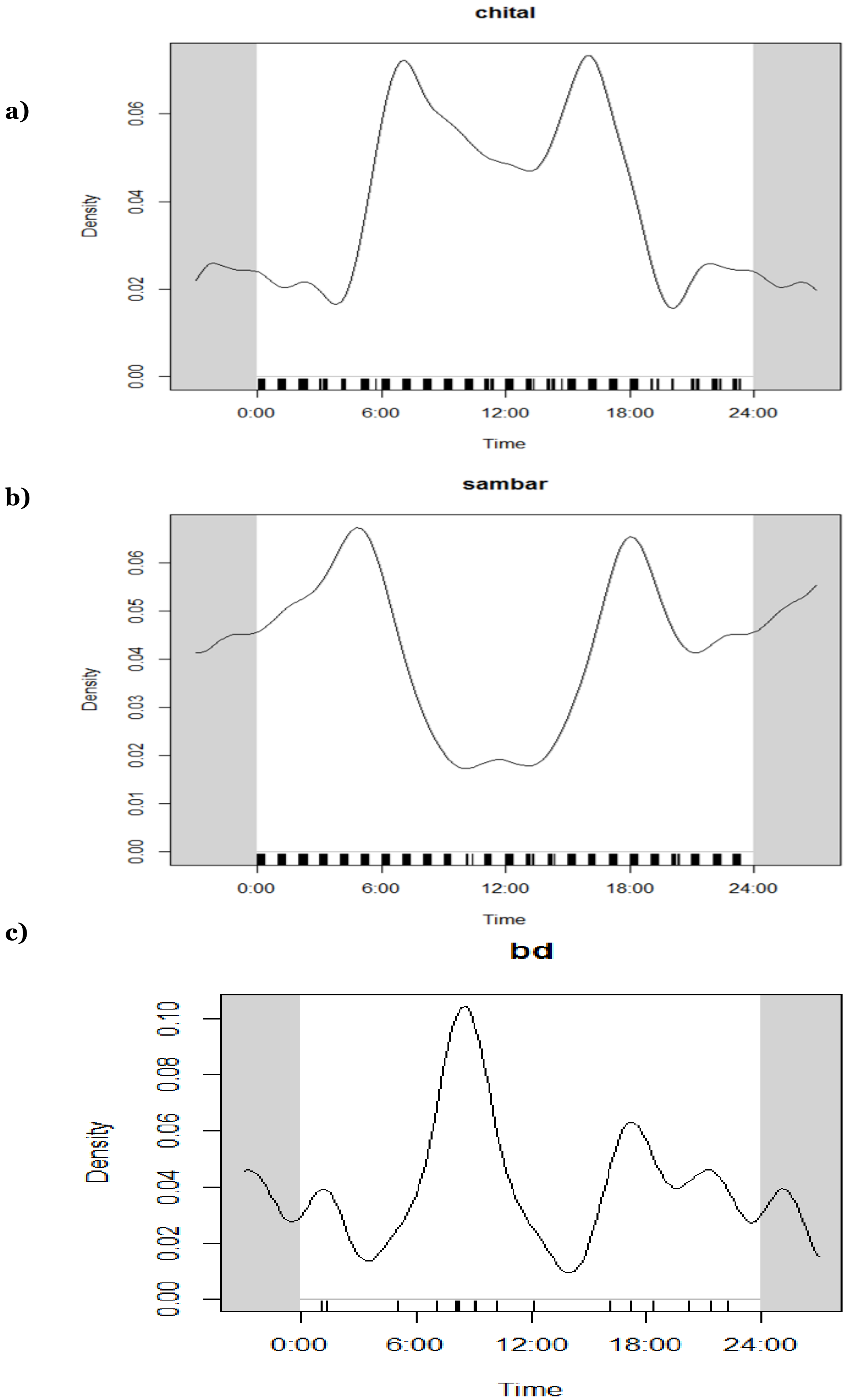


Figure 6.2: Kernel density estimates of daily temporal activity patterns of major prey species namely, (a) chital, (b) sambar and (c) barking deer in TATR

d)

e)

f)

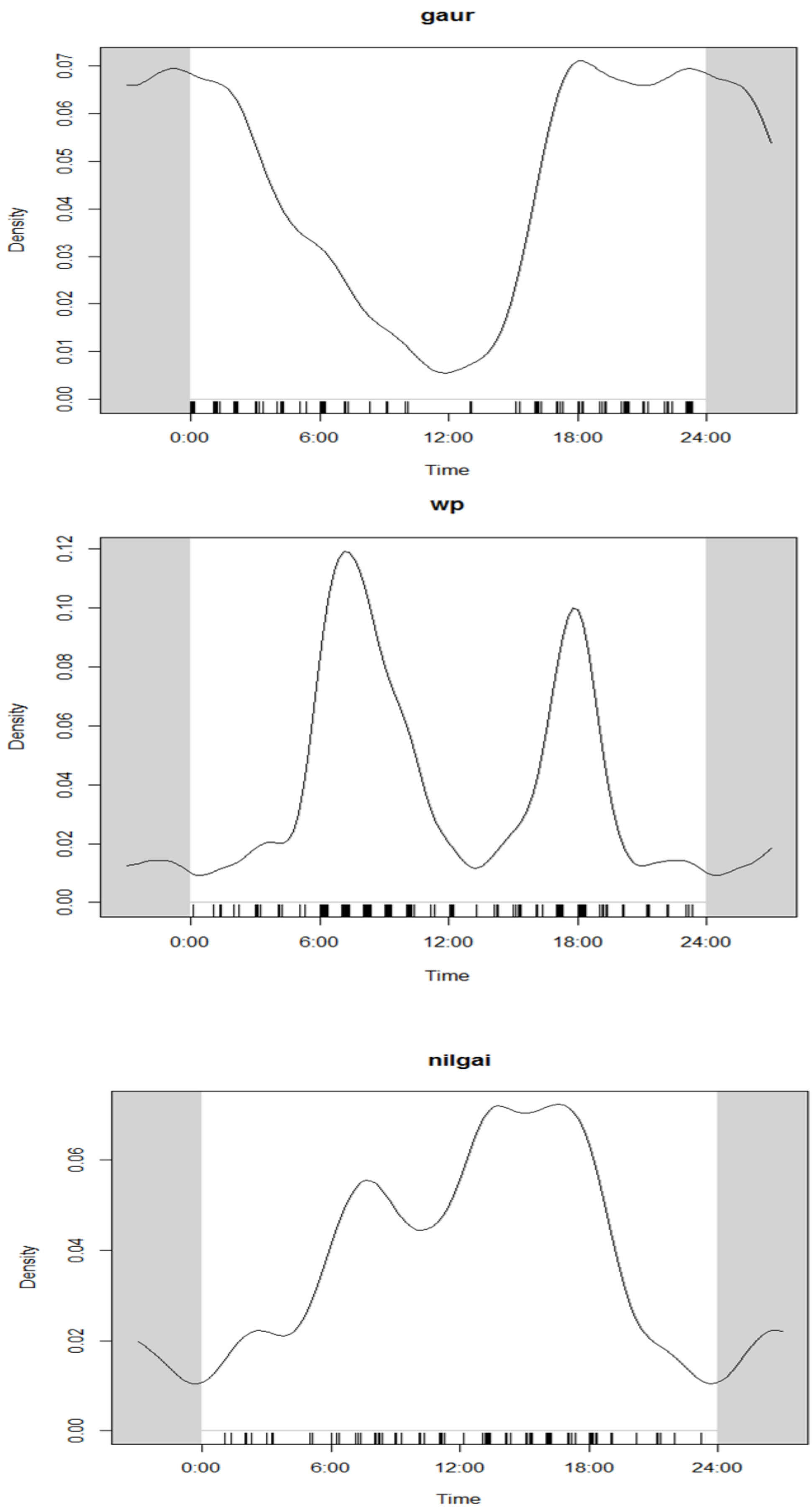


Figure 6.2: Kernel density estimates of daily temporal activity patterns of major prey species namely, (d) gaur, (e) wild pig and (f) nilgai in TATR

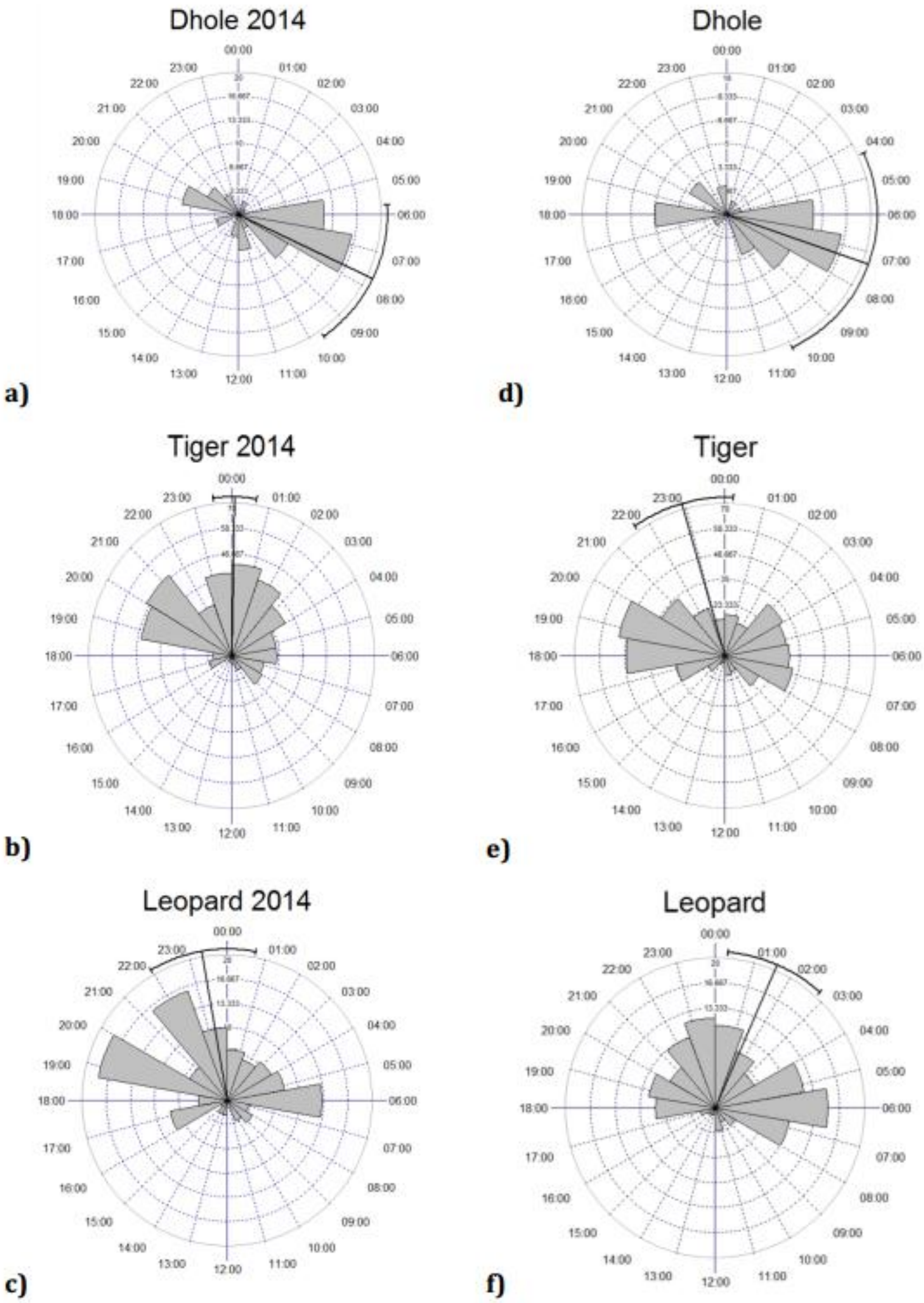
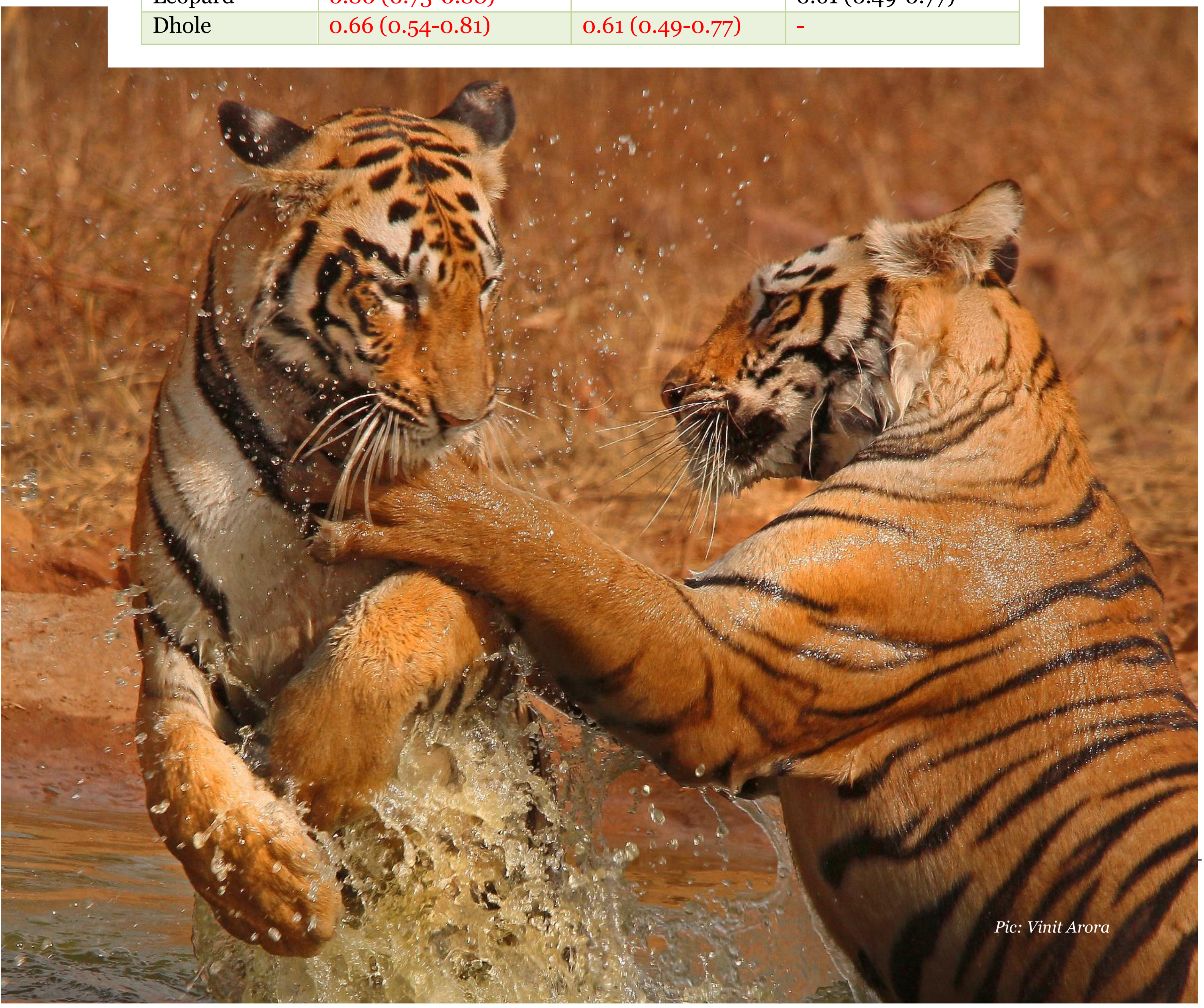


Figure 6.3: The temporal activity pattern of (a) Dhole, (b) tiger and (c) leopard respectively as observed in 2014 in TATR and the temporal activity pattern of (e) the Dhole, (f) tiger and (g) leopard respectively as observed in 2015 in TATR

Table 6.1: Kernel density overlap co-efficient of the three predators with the prey species in TATR, India

Prey Species	Kernel density estimates of co- efficient of temporal overlap		
	Tiger	Leopard	Dhole
Sambar	0.87 (0.83-0.92)	0.84 (0.78-0.91)	0.62 (0.51-0.78)
Chital	0.64 (0.61-0.71)	0.56 (0.52-0.66)	0.63 (0.54-0.77)
Gaur	0.82 (0.75-0.88)	0.81 (0.71-0.89)	0.54 (0.40-0.70)
Wild Pig	0.66 (0.62-0.74)	0.53 (0.49-0.66)	0.78 (0.66-0.87)
Chausinga	0.44 (0.38-0.59)	0.41 (0.35-0.57)	0.62 (0.47-0.75)
Barking Deer	0.72 (0.51-0.85)	0.64 (0.51-0.67)	0.70 (0.49-0.82)
Nilgai	0.63 (0.57-0.74)	0.52 (0.47-0.66)	0.59 (0.48-0.74)
Porcupine	0.60 (0.56-0.69)	0.68 (0.62-0.78)	0.37 (0.29-0.56)
Hare	0.64 (0.60-0.75)	0.78 (0.70-0.87)	0.43 (0.35-0.61)
Tiger	-	0.80 (0.73-0.88)	0.66 (0.54-0.81)
Leopard	0.80 (0.73-0.88)	-	0.61 (0.49-0.77)
Dhole	0.66 (0.54-0.81)	0.61 (0.49-0.77)	-



Pic: Vinit Arora

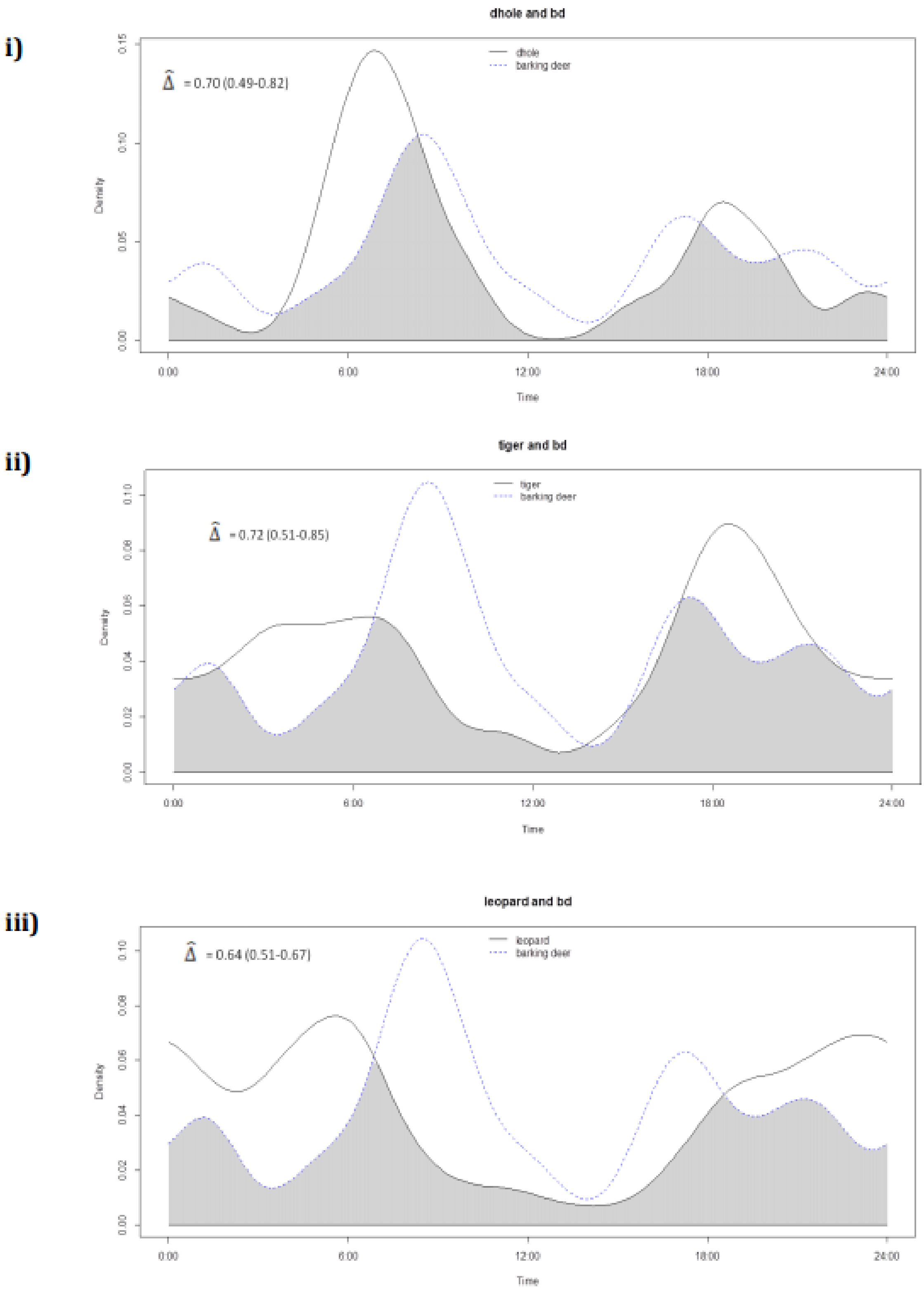


Figure 6.4 a: Daily temporal activity patterns of (i) the Dhole, (ii) leopard, (iii) tiger vs. barking deer respectively in TATR, India. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot. The coefficient of overlap is given with 95% bootstrap confidence interval in parentheses

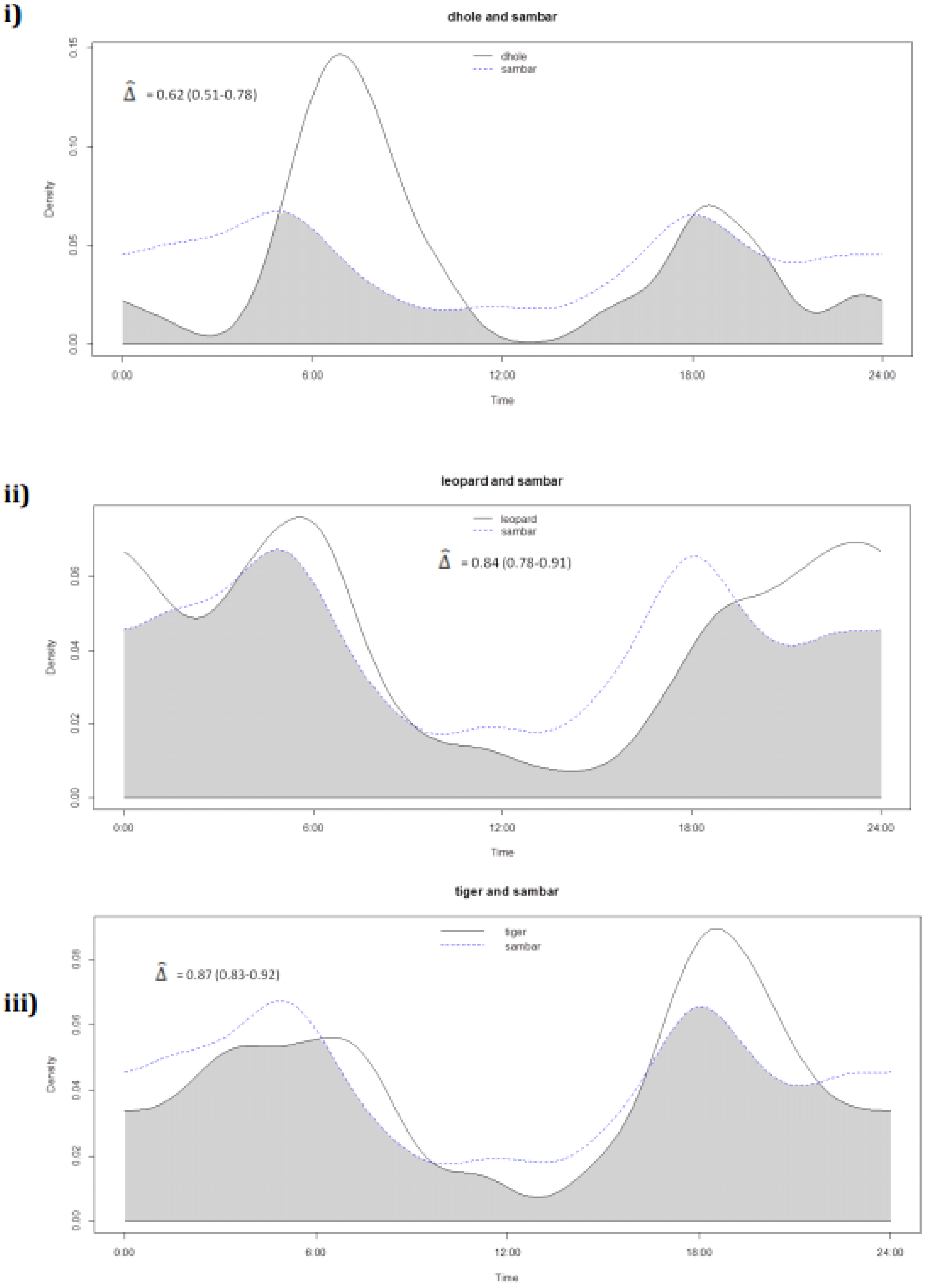


Figure 6.4 b: Daily temporal activity patterns of the (i) Dhole, (ii) leopard, (iii) tiger vs. sambar respectively in TATR, India. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot. The coefficient of overlap is given with 95% bootstrap confidence interval in parentheses

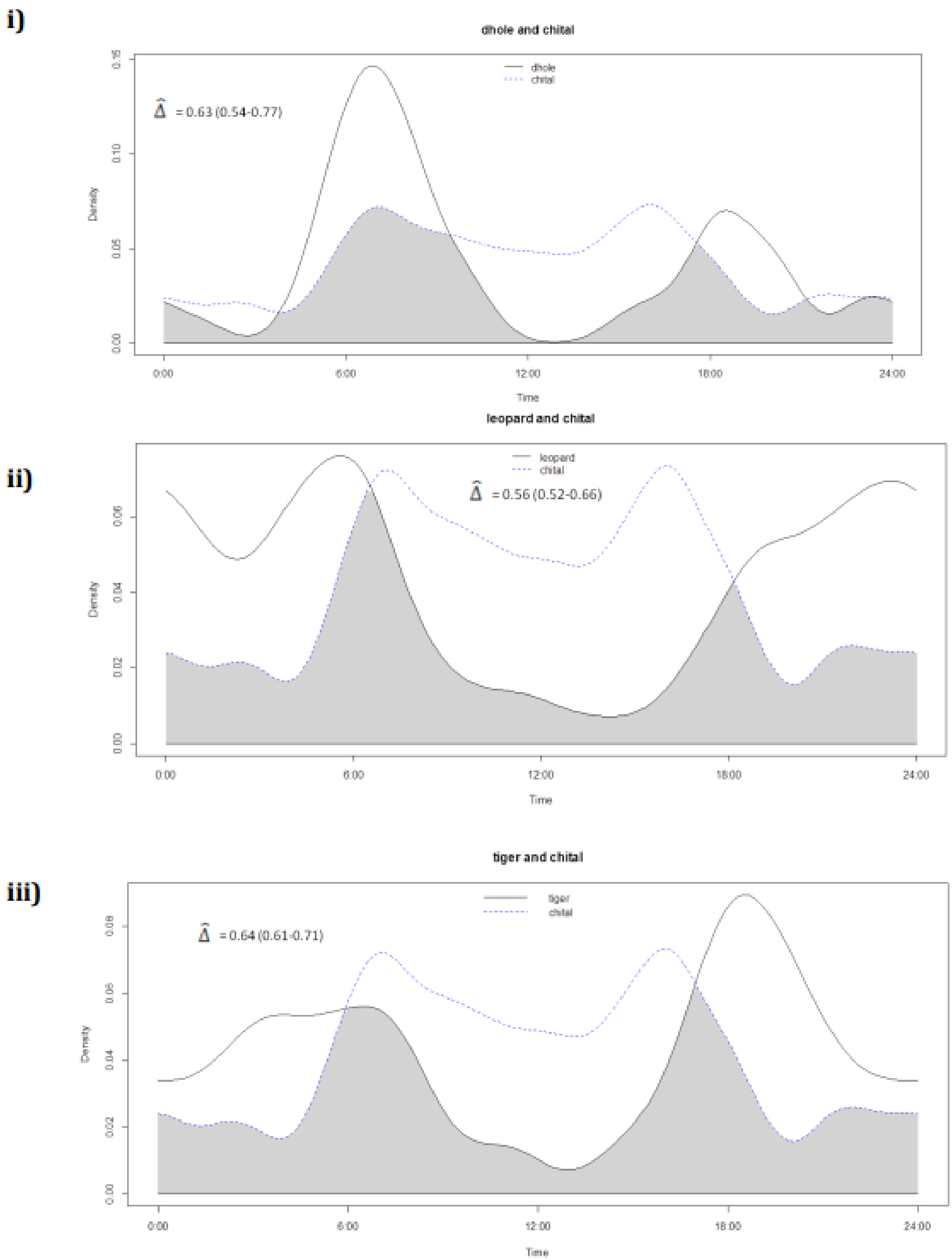


Figure 6.4 c: Daily temporal activity patterns of (i) the Dhole, (ii) leopard, (iii) tiger vs. chital respectively in TATR, India. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot. The coefficient of overlap is given with 95% bootstrap confidence interval in parentheses

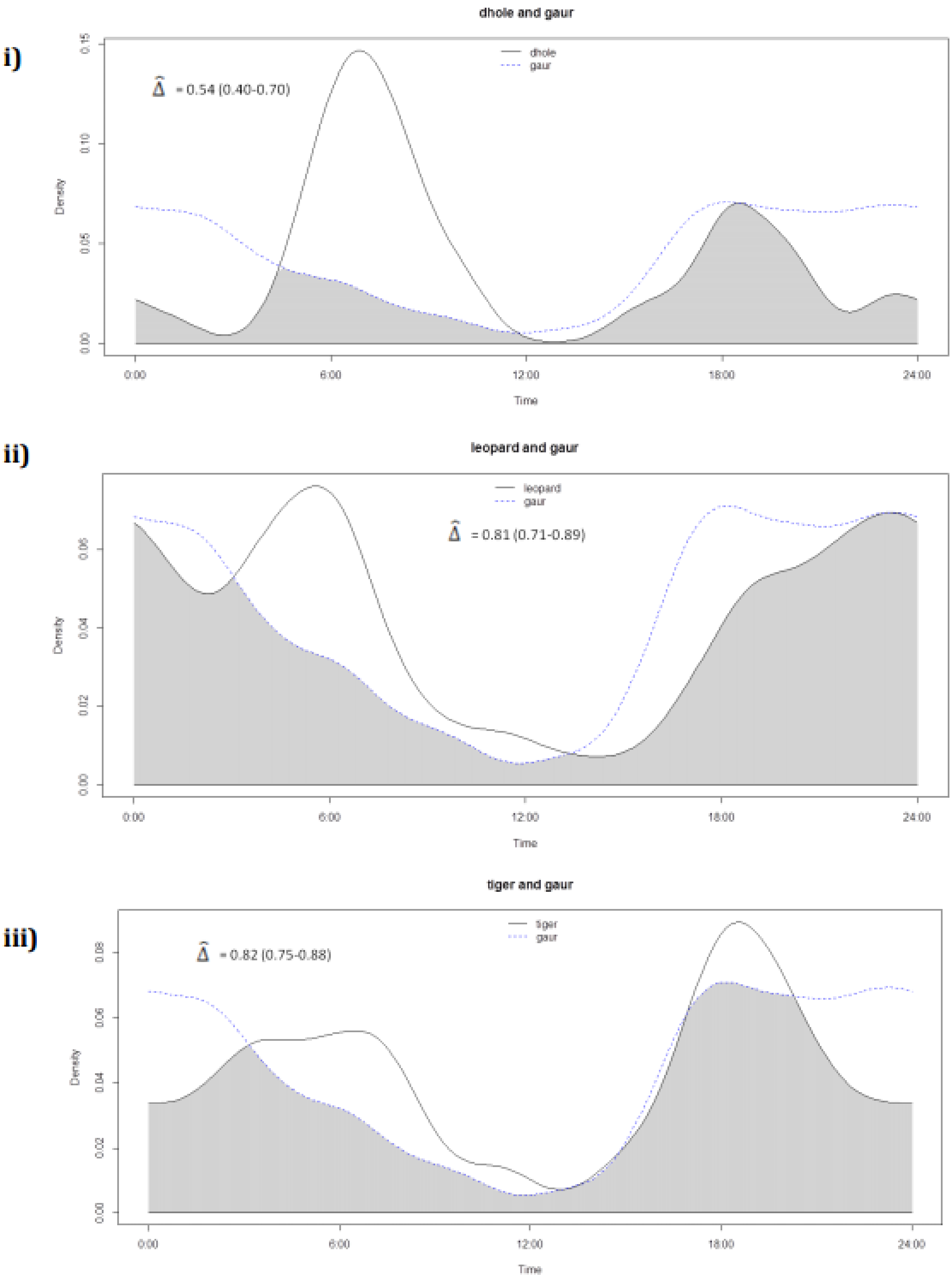
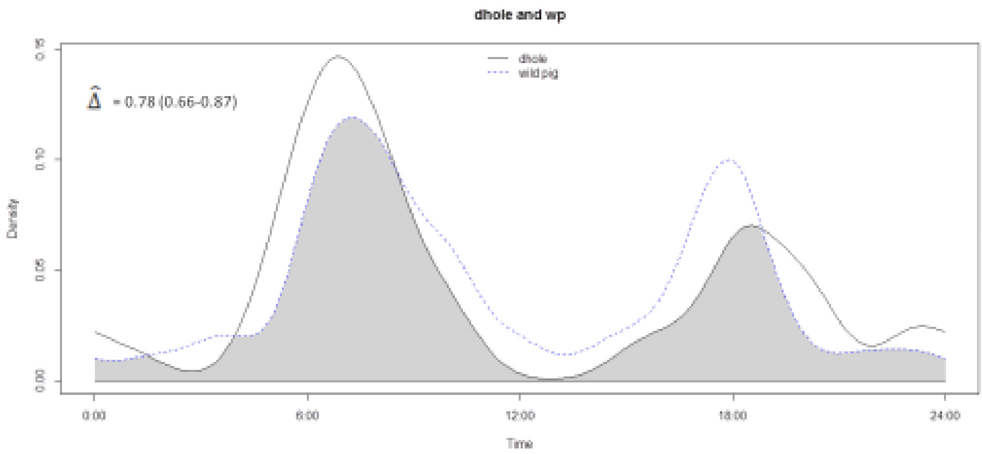
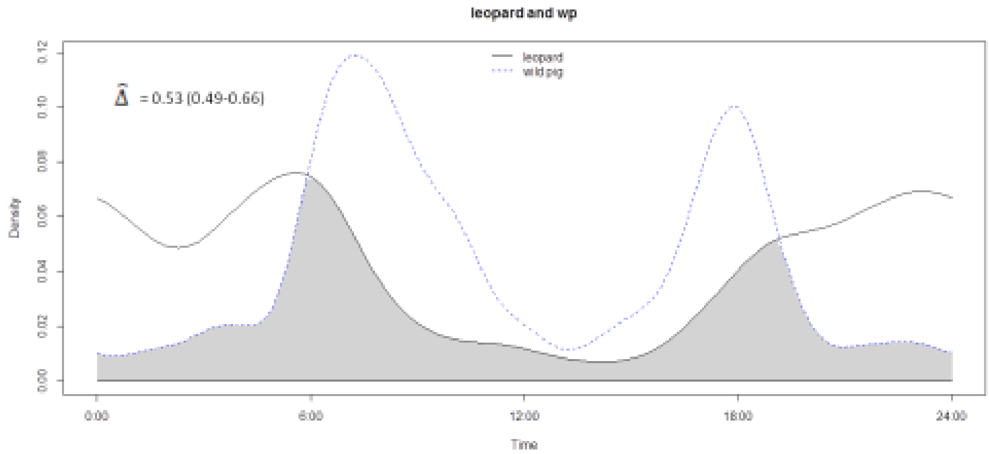


Figure 6.4 d: Daily temporal activity patterns of (i) the Dhole, (ii) leopard, (iii) tiger vs. gaur respectively in TATR, India. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot. The coefficient of overlap is given with 95% bootstrap confidence interval in parentheses

i)



ii)



iii)

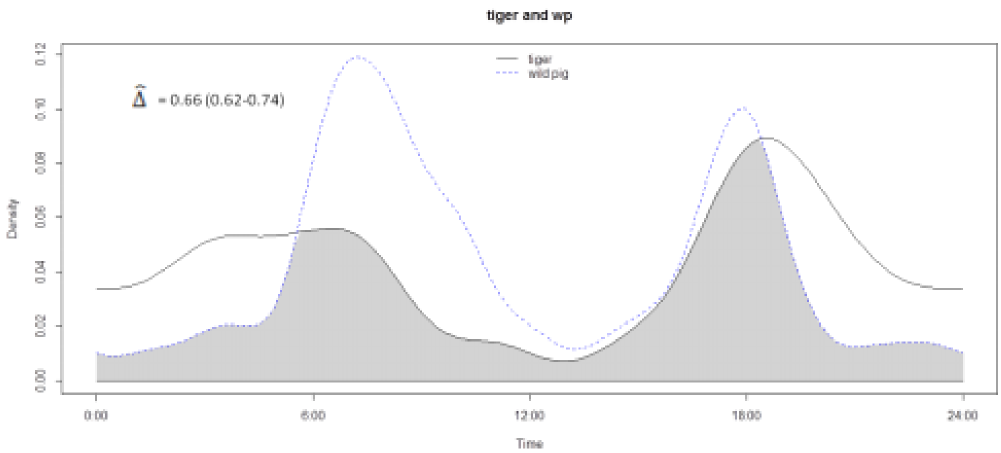


Figure 6.4 e: Daily temporal activity patterns of (i) the Dhole, (ii) leopard, (iii) tiger vs. wild pig respectively in TATR, India. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot. The coefficient of overlap is given with 95% bootstrap confidence interval in parentheses.

Spatial Activity Pattern

Comparisons between tigers and Dholes show that we cannot reject the null hypothesis (T=-0.46, *p*=0.22, A=0) (Table 6.2 and 6.3) that there is no difference between the groups being compared. Therefore, a significant p value for the interaction between tiger and Dholes suggests that there is no difference in the space use. In contrast to this, the null hypothesis is rejected in the case of leopard and tiger (T=-9.11, p=8.27E-05, A=0.01) (Table 6.3). In the case of comparison between Dhole and leopard as well, the null hypothesis is rejected (T=-3.50, p=0.01, A=0.02) (Table 6.3). However, the A values or the effect size is very low for all the groups. This signifies that there is a co-occurrence of all the three predators and we cannot infer much from the above test as it involves only the presence absence data and not the weight of a point. To understand the spatial pattern better, kernel density maps were generated. Based on the kernel density estimate of the number of species specific photographs at each camera trap location, the three sympatric carnivores show different hotspots of spatial activity (Figure 6.5). In light of the kernel density maps, the results obtained from the MRPP test need to be interpreted with caution.

To further test whether there is a spatial segregation of particular areas by a predator due to the other, a simple species interaction factor was calculated which is basically the probability of capturing a particular species at a location w.r.t. the probability of capturing another species at the same location (Table 6.4). This clearly signifies that the leopard and the Dhole are avoiding each other but there is less intense pattern seen between the leopard and the tiger; whereas there seems to be a very weak spatial segregation between the tiger and the dhole.

Table 6.2: Average within-group distance calculated from Euclidean distance matrix. The average within-group distance is used as the test statistic

Species	Average within group distance
Tiger	1.48
Leopard	1.71
Dhole	1.19
Average	1.46

Pic: Vinit Arora

Table 6.3: Summary statistics for MRPP: Results are given comparing across all groups as well as multiple pair wise comparisons

	δ under null hypothesis						
	Observed	**Expected**	**Variance**	**Skewness**	**T**	**P**	**A**
Tiger-Leopard-Dhole	1.52	1.54	8.86E-06	-1.61	7.15	0.0001	0.02

	δ under null hypothesis						
	Observed	**Expected**	**Variance**	**Skewness**	**T**	**P**	**A**
Tiger-Leopard	1.52	1.54	5.09E-06	-2.31	-9.11	8.27E-05	0.01
Tiger-Dhole	1.54	1.54	7.25E-06	-2.2	-0.46	0.22	0
Dhole-Leopard	1.50	1.53	5.42E-05	-2.21	-3.50	0.12	0.02

Table 6.4: Species Interaction Factor (SIF) calculated as the ratio of observed to expected probabilities of occurrence of Species 1 (X1) and Species 2 (X2) occurring together

	No. of captures	**p(X1)**	**P(X2)**	**p(X1X2)) Expected**	**(X1X2) Observed**	**SIF**	**SE**
Tiger	113	0.95	0.46	0.44	0.41	0.94	±0.14
Leopard	55						
Tiger-Leopard	49						
Leopard	55	0.46	0.17	0.08	0.04	0.54	±0.27
Dhole	20						
Leopard-Dhole	5						
Tiger	113	0.95	0.17	0.16	0.17	1.05	±0.30
Dhole	20						
Tiger-Dhole	20						

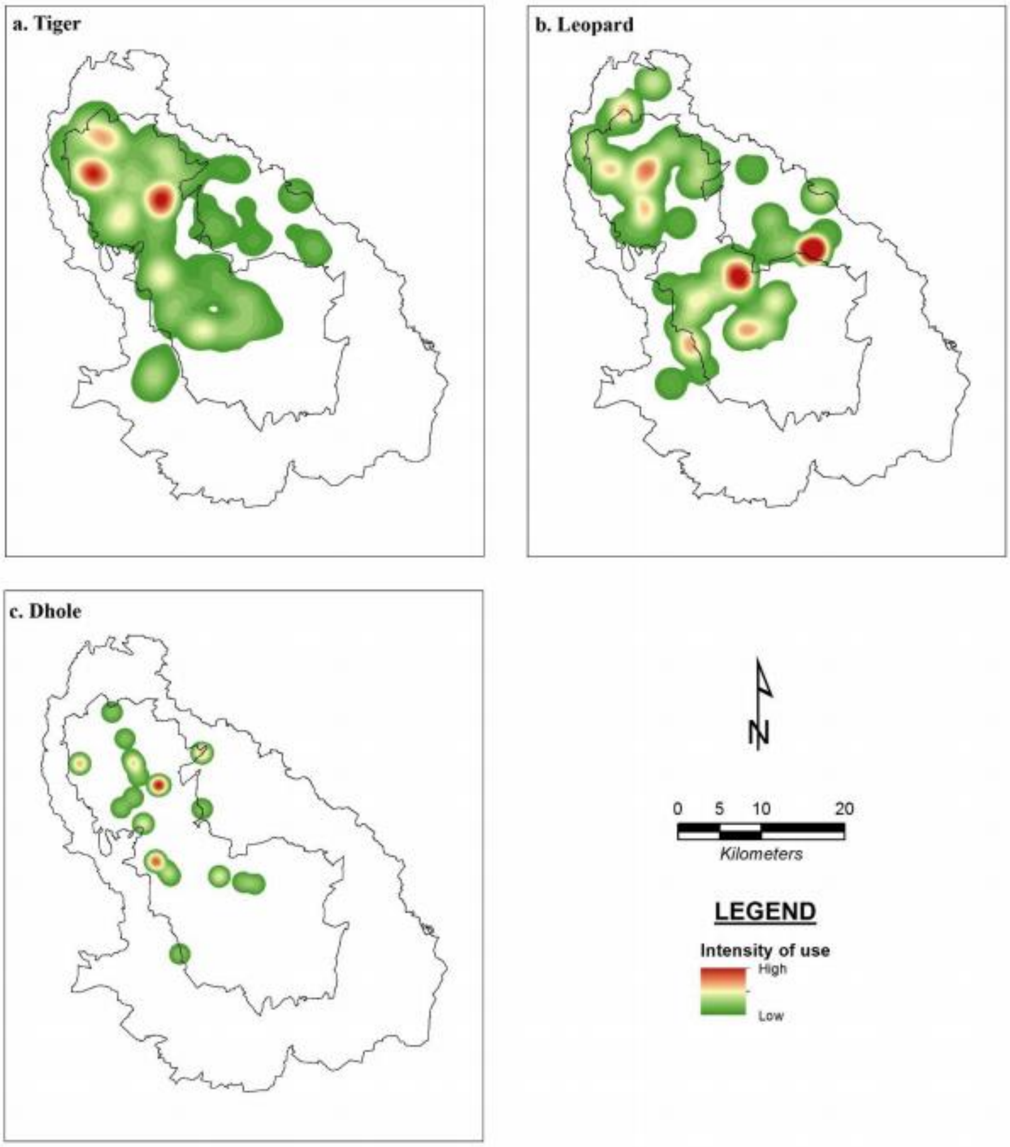


Figure 6.5: Kernel density maps showing intensity of use of the three predators a) tiger, b) leopard and c) Dhole

Diet analysis

Relative occurrence and biomass consumed:

A total of 54 tiger scats, 11 leopard scats and 185 Dhole scats were collected during the field work that could be analyzed. Avoidance of trails regularly utilized by the tiger and the Dholes by the leopards could be one reason of low detection of leopard scats. The major prey species found in the tiger scats were sambar (42.10%), chital (15.78%) and gaur (8.77%). The major prey species found in the scats of Dhole were sambar (42.66), chital (28.0) and barking deer (10.66). Since the sample size for leopards was low (n=11), strong inferences could not be drawn for the leopard diet. 7.14% of the tiger scats contained double prey items whereas 45% of the leopard scats contained double prey items. 21.62% scats of Dholes contained double prey items and 0.54% contained 3 prey items. The high occurrence of double prey items in the leopard diet is because the leopard was seen to prey on smaller species like rodents and hare. About 5.4% of tiger scats and 27.02% of Dhole scats contained varying amounts of bamboo leaves. The frequency of occurrence, relative biomass and estimates of relative number of individuals of prey consumed by the three sympatric carnivores based on the analyses are presented in Table 6.5.

Table 6.5: Frequency of occurrence (A), relative biomass consumed (D) and relative number of prey individuals consumed (E) by tiger, Dhole and leopard, based on 54, 185 and 11 scats respectively

Predator	Prey	X kg	A %	Y	D%	E%
Tiger	Chital	55	15.78	36.61	16.52	19.36
	Sambar	212	42.10	99.27	44.80	13.62
	Barking Deer	20	0.00	0.00	0.00	0.00
	Hare	3	0.00	0.00	0.00	0.00
	Gaur	287	8.77	20.68	9.33	2.10
	Nilgai	212	3.50	8.25	3.72	1.13
	Langur	8	1.75	1.86	0.84	6.77
	Wild pig	38	22.80	50.65	22.86	38.77
Dhole	Chital	55	28.00	34.10	30.18	6.39
	Sambar	70	42.66	63.61	56.29	9.36
	Barking Deer	20	10.66	6.19	5.48	3.19
	Hare	3	1.33	0.36	0.32	1.24
	Gaur	75	0.88	1.39	1.23	0.19
	Nilgai	70	1.33	1.98	1.76	0.29
	Langur	8	1.33	0.48	0.43	0.62
	Wild Pig	31	0.00	0.00	0.00	0.00
Leopard	Chital	48	12.50	28.67	16.63	7.42
	Sambar	62	12.50	29.19	16.94	5.85
	Barking Deer	20	6.25	11.45	6.64	7.11
	Hare	3	6.25	2.97	1.72	12.30
	Gaur	85	12.50	29.42	17.07	4.30
	Nilgai	62	12.50	29.19	16.94	5.85
	Langur	8	12.50	13.30	7.71	20.66
	Wild Pig	37	12.50	27.64	16.03	9.28

Two-way Analysis of Variance (ANOVA) with predator and prey items showed that there was no significant difference (F= 0.03; df= 2; p=0.9717) in the occurrence of the major prey species in the diet of the three large carnivores at TATR. However, the magnitude at which they were harvested showed a significant variation (F= 3.24; df = 7; p=0.03) (Table 6.6).

Table 6.6: Analysis of variance of diet between and amongst predators and prey in TATR, India

Source of Variation	SS	df	MS	F	p-value
Predators	5.270973	2	2.635486	0.028731	0.97173491
Prey	2082.214	7	297.4592	3.242783	0.029034095
Error	1284.214	14	91.72959		
Total	3371.7	23			

Prey selection:

Prey selectivity was estimated by comparing the available densities of prey to the actual biomass consumed. The results indicate that the Dhole killed sambar (0.90) and chital (0.75) more than available, hence strongly preferred and hardly consumed the wild pig (-1). The tiger consumed wild pig (0.45) and chital (0.17) more than expected by sheer chance and were thus, preferred over other prey. Sambar which is considered to be the primary diet of the tiger (Johnsingh & Negi 2003) was not harvested more than its availability, however it was the principal prey of the tiger. The leopard seems to prefer, barking deer (0.6) and langur (0.49) (Figure 6.6).

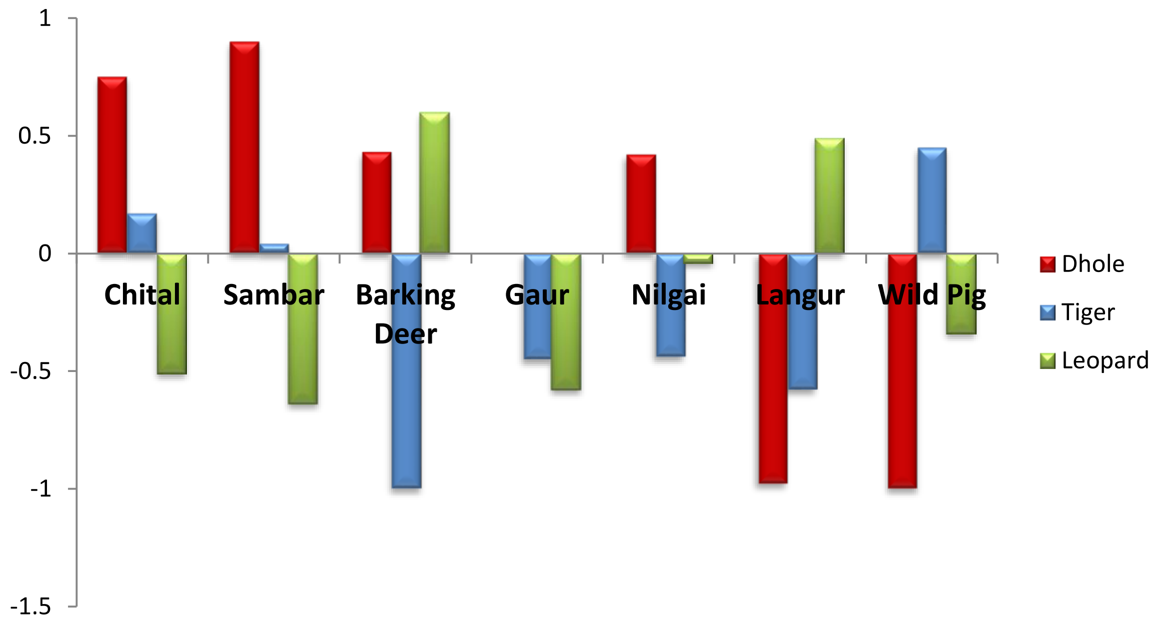


Figure 6.6: Ivelev's index of prey preference by tiger, leopard and Dhole in TATR, India

Observed kills:

Kills made by the three carnivores were recorded opportunistically. For identifying the predators, direct and indirect signs (pugmarks, tracks, known refuge areas of the collared tigers) were used. Sex and age class was recorded for each kill. The sample size was too low to make a strong inference due to the short duration of my study; nonetheless, the presented data may give some idea of the prey being consumed and be useful for interpreting the other data on diet analysis (Figure 6.7).

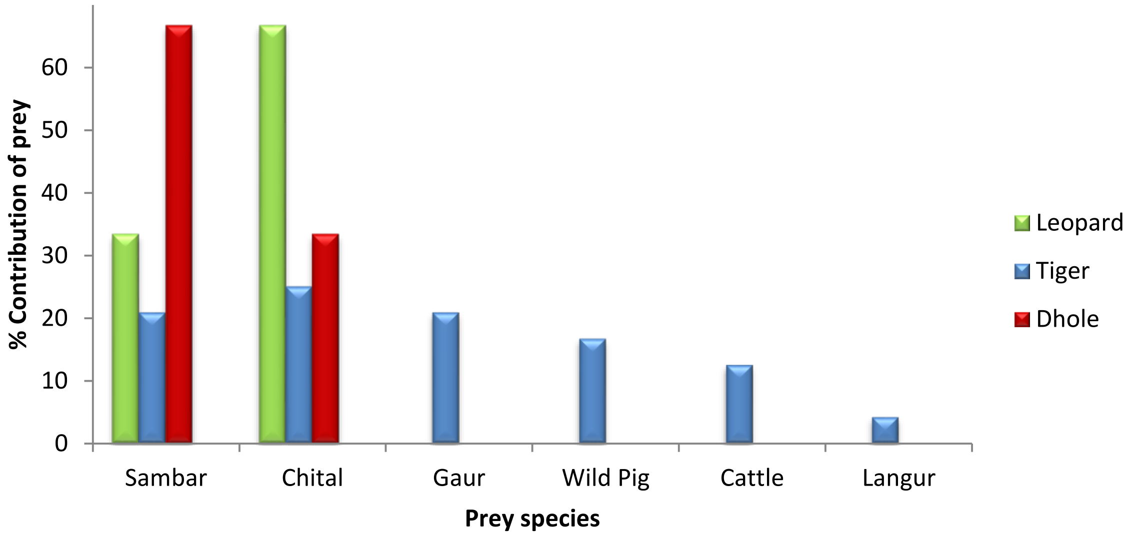


Figure 6.7: Percent contribution of prey taken by tiger, leopard and Dhole based on field observations in TATR, India

Diet overlap:

A variety of diet overlap indices are used in field measurements of ecological niche separation (Pianka 1973). Pianka's index was used for measuring diet overlap between predators. This index ranges in value from 0 (indicating no overlap between two predator species) to 1.0 (complete overlap). The overlap indices for the three predators were 0.61 between tiger and leopard, 0.80 between tiger and Dhole and 0.46 between leopard and Dhole. This suggests that the diet of tiger and dhole, in terms of the prey species shows a strong similarity in the diet. Leopard and tiger show a less similarity whereas the leopard and the Dhole show dissimilarity in the dietary niche.

6.4 Discussion:

Prey animals optimize the balance between food acquisition and predator avoidance by concentrating their foraging activity at times of relatively low predation risk to a certain level (Whitham & Mathis 2000). In a system where more than a single predator operates, co-predators may segregate themselves based on their peak activity times. The results suggest that the peak activity time of the tiger has a strong overlap with the sambar and a significant overlap with chital which also happen to be two of the tiger's major prey species in the Reserve based on the results of the diet analysis. The wild pig is one of the major prey selected by the tiger according to the dietary analysis and shows a significant overlap of activity times as well. The leopard showed a nocturnal activity pattern which strongly overlapped with sambar and hare. According to the diet analysis of the leopard, hare and barking deer were preferred prey species. Although, sambar was not seen as the preferred prey species, its activity peak overlapped strongly with that of the leopard. This could be an artifact of sampling as the sample size for leopard scats was very low. The activity peaks of the Dhole, overlapped strongly with the wild pig and the barking deer. According to the dietary analysis however, wild pig was not preferred. Sambar, chital and the barking deer were preferred by the Dhole. Although the Dhole is a pack hunter, it is risky for a pack to take down a prey like the wild pig as any injury to a pack member would bring down the chances of the pack to hunt efficiently in future and hence it seems to be hardly consumed. Although the density of the wild pig (5.42) was higher than that of both the sambar and chital it was consumed less by the predators as it is very difficult to take down owing to its sheer strength and low centre of gravity (Hayward et al. 2012, 2014).

The spatial analysis results indicate a co-occurrence of tiger, leopard and Dhole. The leopards and Dholes seem to strongly segregate in space however no such significant interaction was observed between the other carnivores. Owing to a large number of tigers in the Reserve and a small area, the three carnivores cannot avoid each other spatially but might do so on temporal and dietary axes to reduce competition. Also, interference competition is operating in the Reserve as there have been observations of tigers chasing Dholes and even hunting the pups, Dholes treeing leopards and tigers avoiding the areas when a pack of Dholes is spotted at a distance. There have been instances of Dholes stealing a sambar carcass killed by a leopard and a tiger stealing sambar fawn carcass from a pack of Dholes. The diet analysis also indicates that bamboo, which is a dominant species in the Reserve, is consumed by all three predators. On a number of occasions, the Dhole scats had very little mass and only undigested bamboo leaves entangled and binding the scat. This is usually done as self-medication to tackle the parasitic load and could also be due to some deficiencies. The scat would be further examined to study the parasitic load. Remains of a sloth bear, which is a large bodied omnivore in the Reserve, were also found in one of the tiger scats. At the time of my study, there were around 20 tiger cubs in the Reserve. Tigresses with grown up cubs were seen taking down large prey like the gaur. The Dhole packs were observed to be not more than 5 adult individuals although a pack of nine adults was reported. At relatively smaller pack sizes as compared to the South Indian forests, the Dholes in the Reserve were observed to take down mainly the fawns of Sambar and Chital. It was also observed that the leopard, similar to the leopard in the savannahs of Africa, dragged its kill to a tree or a vantage point probably to safeguard the kill from the co-predators. All three predators were seen to scavenge at kills once it had been abandoned by the primary predator. Interestingly, the Reserve has no specialist scavengers except the Long-billed crows. The Ruddy mongoose has been observed scavenging on old carcasses whereas the three large predators themselves scavenge if the quarry is not too old. Scavengers like Striped hyena, Golden jackal and vultures which were previously reported are no longer found in TATR.

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