Pench Tiger Reserve

Status of Tigers, Co-Predators & Prey

2021

Report Title:
Status of Tigers, Co-Predators and Prey in Pench Tiger Reserve

Project Title: Long-term monitoring of tigers, co-predators and prey in tiger bearing areas of Vidarbha Maharashtra

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Executive Summary

The Phase IV monitoring exercise as a part of the project "Long Term Monitoring of Tigers-predators and prey in tiger reserves and other bearing areas of Vidarbha, Maharashtra, for Pench Tiger Reserve was conducted from January 2021-July 2021. This exercise, having three main objectives, the status of prey, estimation of minimum tiger and leopard numbers, and capacity building among staff flagged off with a capacity-building workshop in January 2021.

Line transects surveys aimed to estimate the density of prey species were carried out in two blocks with an effort of 7 days for each transect line. Among all the prey species highest density was recorded for Chitals 24.28 (±4.83)/km^2 in the core. The density of other species are as follows Sambar 6.08 (±0.98), and Gaur 1.56 (±0.39)/km^2, Wild pig 4.31 (±0.90), Langur 17.02 (±3.56), Nilgai 1.91 (±0.41), Barking Deer 0.59 (±0.15), Hare 0.81 (±1.12), Peafowl 2.49 (±0.60). In the buffer area, the density of Chital was 8.63 (±4.15) and of Sambar was 1.36 (±0.40).

Camera trapping based on the spatial capture-recapture framework was conducted on the same locations of the same grids (2 km^2) similar to the previous cycle (2020) which were selected based on a rigorous sign survey that provided sign encounters of tiger, leopard, and other co-predators. This year the trapping was completed in a single block with 311 camera stations resulted in 8415 trap nights during May 2021-June 2021. The minimum number of individual tigers captured was 44 along with 60 leopards. Tiger density based on the Spatially Explicit Capture-Recapture framework was 4.78(±0.7)/100km^2 and the density of leopard was 7.55 (±1.02)/100km^2.

To study space use and activity patterns we have used camera-trapping data from both core and buffer areas of Pench Tiger Reserve. Higher activity overlap was recorded between tigers and leopards (Dhat1=0.88) among predators. Camera trap locations with the number of captures of each species were modeled in a GIS domain using IDW (Inverse distance weighted) interpolation technique to generate spatially explicit capture surfaces. The times recorded on camera trap photos provide information on the period during the day that a species is most active. Species active at the same periods may interact as predator and prey, or as competitors. Sensors that record active animals (e.g. camera traps) build up a record of the distribution of activity over the day. Records are more frequent when animals are more active and less frequent or absent when animals are inactive. The area under the distribution of records thus contains information on the overall level of activity in a sampled population.

1. Introduction

The tiger is one of the biggest symbols of conservation in India. However, the success of tiger conservation is not all about tigers, but it is about the landscapes, biodiversity, rivers, diverse ecosystems that are being given legal protection in a protected area by iconizing tiger as an umbrella species. But protected areas, being only confined to 5.02% area of land is a challenge for conservation and need to be managed well. The Eastern Vidarbha landscape in Maharashtra holds some of the prime tiger habitats along with their dispersal corridors that maintain connectivity among the source and sink. As escalating development has forced the tiger and people to share the same habitats triggering the chances of conflicts, the future of such areas is very much dependent on the success of management efforts for the wellbeing of both people and the tiger.

Pench Tiger Reserve (PTR), Maharashtra is situated in the Vidarbha Landscape (Figure 1)and harbors a broad range of flora and fauna. Being a crucial source population among meta-populations of tigers in the central India landscape it's a prime tiger habitat. This Tiger Reserve includes Pench National Park (257 km2) and Mansingh Deo Wildlife Sanctuary (195 km2) and is located between the longitudes E79° 04' - E79°24' and latitudes N21°04' - N21° 43'. The general topography of PTR is mostly undulating with an elevation ranging from 294 - 591m above sea level, with several seasonal streams and nullahs flowing through it. The reserve is divided into two parts from east to west by the Pench River. The area has a tropical monsoonal climate, with a distinct Monsoon (July to September), Winter (November to February), and Summer (April to June). The mean annual rainfall is around 1400 mm, with the southwest monsoon accounting for most of the rainfall in the region.

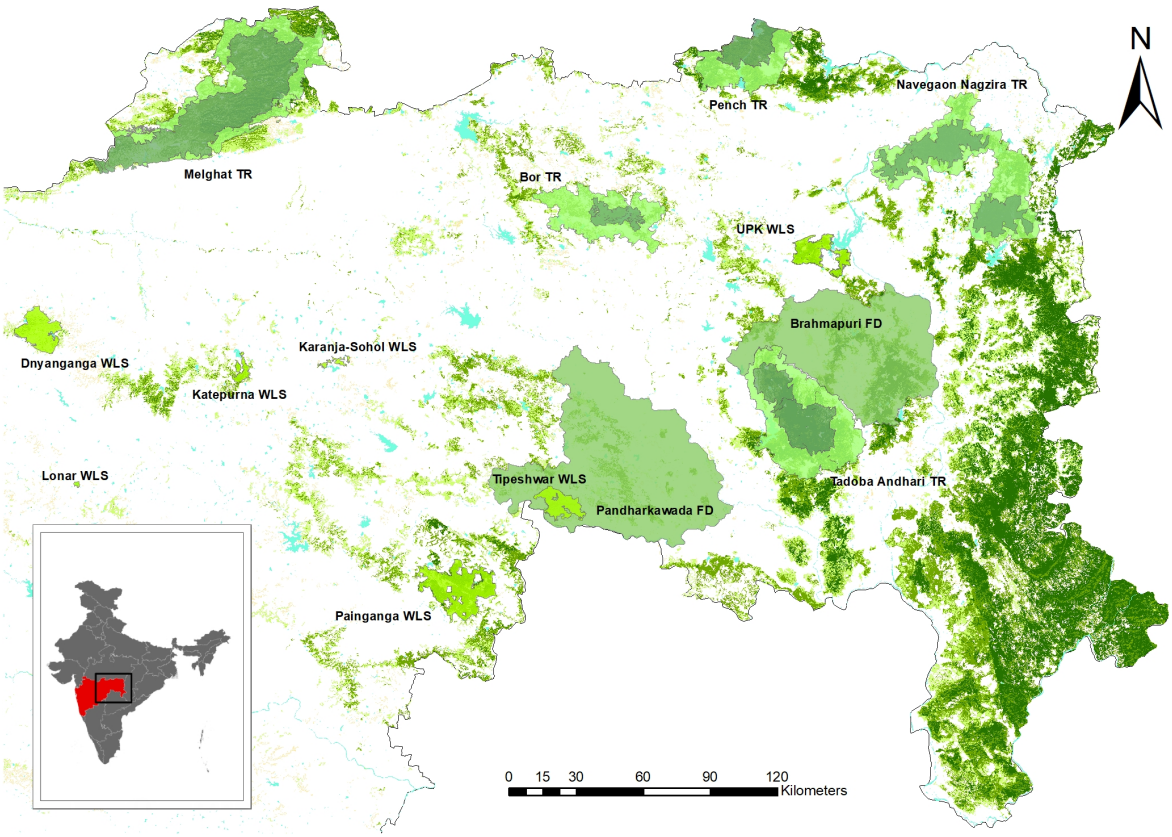


Figure 1: Map showing study sites in Vidarbha Landscape, Maharashtra, India

Flora and Fauna

The forest type in the region is tropical moist and dry deciduous forest and mostly dominated by teak (Tectona grandis). The other associated tree species include Garari (*Cleistanthus collinus*), Bherra (*Chloroxylon swietenia),* Dhawada (*Anogeissus latifolia),* Arjuna (*Terminalia arjuna),* Ain (*Terminalia elliptica*), Mahuwa *(Madhuca longifolia),* Salai (*Boswellia serrata*), Tendu (*Diospyros melanoxylon*), Palash (*Butea monosperma*), Bael (*Aegle marmalos*), Bamboo (*Dendrocalamus strictus*.), etc.

Pench tiger reserve is comprised of a wide range of fauna. The Tiger (*Panthera tigris*) holds its place as the top predator followed by other co-predators, Leopard (Panthera pardus), Dhole (*Cuon alpinus*), Wolf (*Canis lupus)*, Jackal (*Canis aureus*), etc, Jungle Cat (*Felis chaus*) Rusty-spotted Cat *(Prionalurus rubiginosus*), Indian Fox (*Vulpes bengalensis*), Sloth Bear (*Melursus ursinus*). The Ungulate community, supported by diverse habitats is represented by Chital (*Axis axis*), Sambar (*Rusa unicolor*), Gaur (*Bos gaurus*), Chausingha (*Tetracerus quadricornis),* Wild Pig (*Sus scrofa)*, Barking Deer *(Munticus muntjac*) etc. Being one of the major hotspots for birds in the state, this tiger reserve possess about 255(ebird database) species of birds of which, White Eyed Buzzard *(Butastur teesa*), Yellow-footed Green Pigeon (*Treron Phoenicopterus*), Greater Racket-tailed Drongo (*Dicrurus paradiseus*) etc. are predominant.

Pench tiger reserve (Figure 2) has added different success stories in the conservation of wildlife. From solving the illegal fishing problem to managing tigers in a human-dominated landscape it has shown promising efforts that have ultimately helped to maintain a source population of tigers in the area.

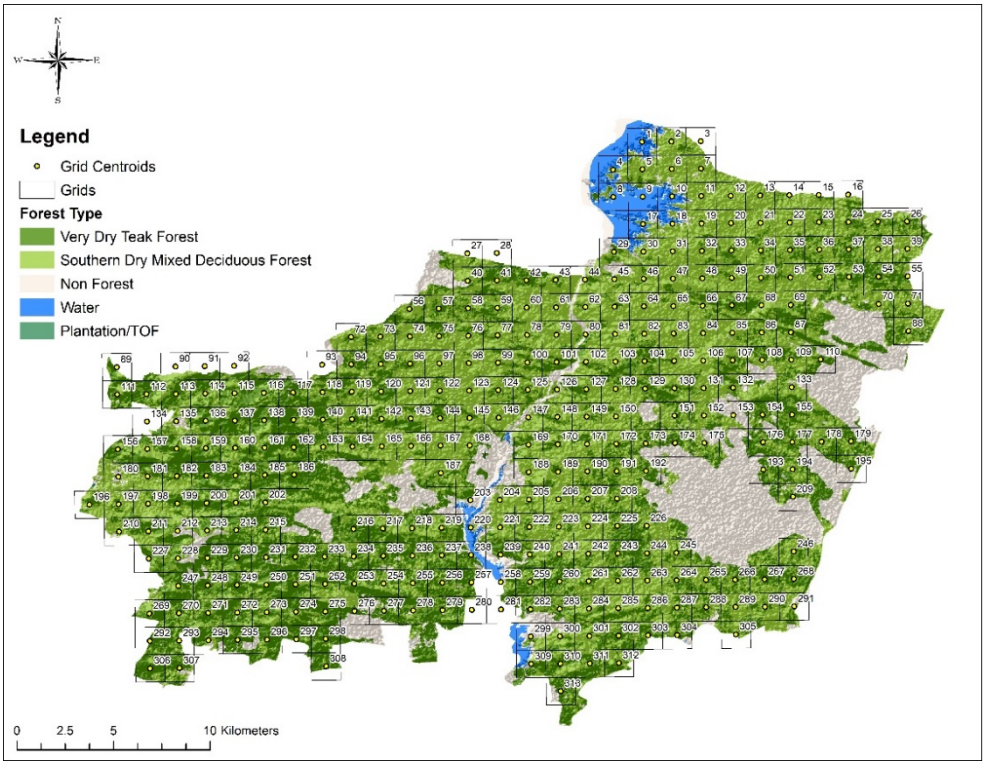


Figure 2: Map depicting Grids with Forest types of Pench Tiger Reserve

As a part of the research project titled “Long-term monitoring of Tigers, Co-predators and prey in Tiger reserves and other Tiger bearing areas of Vidarbha, Maharashtra”, the Wildlife Institute of India has initiated this study in 2019 having the objectives that are as follows

Objective 1: Status of tigers, co-predators and their prey in the landscape

a) Field surveys will be conducted to detect the presence of tigers, co-predators and prey species using animal signs (tracks, scats, direct sightings, calls etc) in occupancy-based framework. The data will be analyzed in the occupancy framework to estimate the occupancy of the target species. Single season or multiple season occupancy models will be used depending on data collection approaches. These occupancy field surveys will be carried in all the tiger areas. The data collection will be followed by modelling and estimation approaches described in detail by Mackenzie et al., (2002, 2006).

b) Density, abundance and demography of tigers and co-predators will be carried by using camera traps in all the tiger areas followed by analyzing the data in capture–recapture frame work. Rigorous field methods will be followed to achieve a small CV and high precision. These field surveys will be conducted in all the tiger areas.

c) Estimation of abundance and density of the key ungulate species will be conducted using distance sampling employing line-transect survey protocols. The survey protocols and analyses of this data set will be based on modelling and estimation approaches developed by Buckland et al. (2001, 2004).

d) Estimation of recruitment, survival, transience, temporary emigration, permanent emigration and dispersal rates of tigers and leopards will be based on data collected from camera trapping and radio-telemetry.

e) Scat analysis is indirect, non-invasive and unbiased technique for recording frequency of occurrence of prey in the diet of large carnivores and hence it is most widely used (Johnson et al., 1983; Leopold and Krausman, 1986; Jhala, 1993; Mukherjee et al., 1994a, b; Spaulding et al., 1997; Jethva, 2002; Biswas and Sankar, 2002). Scats will be collected at regular time intervals, generally every week. The scats will be collected in polythene bags, labelled and sun-dried in the field. Information on habitat, substratum where scat will be found and its GPS location will also be recorded.

Objective 2: Development of database on tigers across the landscape

a) The photo database generated by the methodology delineated in 1b above will be collated at every tiger area level. Identification of unique individuals will be done from these collated photographs and a database of identified tiger individuals will be generated. New photographs from every camera trapping session will be compared with the existing database, whereby recaptured individuals will be noted and any new individuals found will be added to the database.

Objective 3: Identification of tiger dispersal in the landscape

a) On an event when a previously captured individual goes missing in pictures from the current camera trapping exercise, or when a new individual is discovered, it will be cross-checked against tiger databases of adjoining areas. This will enable us to find out if a missing individual has dispersed to a new area.

Objective 4: Development of feedback for management intervention at reserve and landscape level

a) The outputs of the project will help in developing management feedback for the State of Maharashtra to effectively manage tiger populations.

2. Status of Prey Species in Pench Tiger Reserve

Introduction:

To maintain a viable population, large carnivores require sufficient prey species. On the other side, the diversity of prey is dependent on the soil property and vegetation characteristics of an area. The presence of different size class ungulates is very much required to facilitate the existence of multi carnivore species in an ecosystem. Prey depletion is a major threat to the decline of large carnivores. Therefore, it is imperative to know the status of prey species in an area for planning conservation efforts in the right direction.

Distance Sampling:

Distance sampling is a popular method in conservation biology to estimate prey species. Line transect, being one among such applications is practiced widely to estimate the abundance and density of prey species. In this survey an observer walks through a line of predetermined length and records animal sightings on both sides along with its number, bearing, angle and GPS.

Line transect surveys were carried out in two blocks during December after a brief theoretical & practical training about the same. Each transect was walked for 7 consecutive days in the early morning hours (Figure 3). A total of 50 transects were conducted in core ranges along with 28 in buffer areas resulting in a total effort of 1092 km. A wide range of prey species of different body size was recorded during these surveys like Chital (*Axis axis*), Sambar *(Rusa unicolor*), Wild Pig (*Sus scrofa*), Nilgai (*Boselaphus tragocamelus*), Barking Deer (*Muntiacus muntjak*), Langur (*Semnopithecus entellus.*), Peafowl (*Pavo cristatus*), and Grey Jungle Fowl (G*allus sonneratii*).

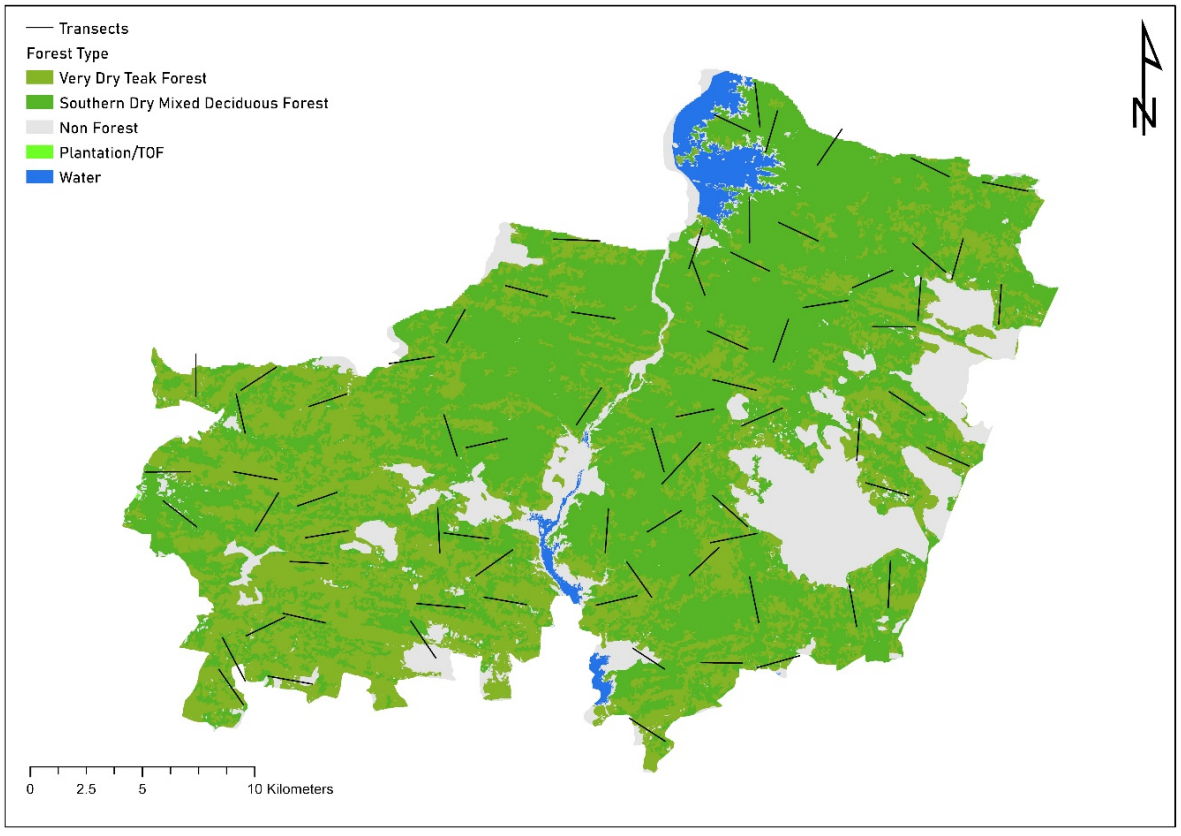


Figure 3: Map showing transect lines surveyed during Phase IV monitoring 2021 of Pench Tiger Reserve

In addition to the number of animals, their group composition, sex, habitat type, terrain type, etc. were also recorded. For density estimation data has been analyzed on Distance 7.0 software and the best fit model was chosen as per AIC Value. Species with less than 19 observations were not used in the analysis. The results of the analysis are provided in Table 1 – 4 and Figures 4 & 5.

Table 1: Line Transect monitoring effort and species reported from Core and Buffer Area in Pench Tiger Reserve, Maharashtra during Phase IV monitoring 2021

Survey Details	Core	Buffer
Number of transects	50	28
Length of each transect	2 km	2 km
Number of replicates	7	7
Total distance covered	700	392
Number of species recorded	10	9

Table 2: Summary of species recorded on line transects during Phase IV monitoring – 2021 in Pench Tiger Reserve, Maharashtra, India

	Core		Buffer	
Species	**Number of observations**	**Individuals recorded**	**Number of observations**	**Individuals recorded**
Chital	228	2044	19	113
Sambar	134	359	12	29
Gaur	54	161	11	36
Nilgai	74	160	25	55
Wild Pig	79	362	14	67
Barking Deer	34	34	9	14
Langur	100	917	17	133
Hare	28	28	4	4
Peafowl	65	179	4	7
Rhesus Macaque	2	10	-	-

Table 3: Individual Density, Group Density, Effective Strip Width, Average Group Size of Prey Species Reported during the Phase IV Monitoring 2021 in the Core Area of Pench Tiger Reserve, Maharashtra

Parameters	Chital	Sambar	Gaur	Wild Pig	Langur	Nilgai	Barking Deer	Hare	Pea Fowl
Density(individual/sq.km)	24.28	6.08	1.56	4.31	17.02	1.91	0.59	1.12	2.49
Standard error	4.83	0.98	0.39	0.90	3.56	0.41	0.15	0.32	0.60
Percent CV	19.89	16.11	25.56	20.89	20.96	21.77	26.38	28.62	24.39
95%CI	16.44-35.85	4.43-8.35	0.95-2.57	2.86 6.48	11.29-25.67	1.25-2.93	0.35-0.99	0.64-1.96	1.54-4.02
Group density (no of groups/sq.km)	3.04	2.25	0.71	1.03	1.75	0.90	0.60	1.12	1.02
Standard error	0.57	0.33	0.15	0.16	0.32	0.18	0.15	0.32	0.23
Percent CV	18.80	14.92	22.50	15.62	18.77	20.16	26.30	28.62	22.98
95%CI	2.10-4.40	1.67-3.02	0.45-1.10	0.76-1.41	1.20-2.53	0.60-1.33	0.36-1.01	0.64-1.96	0.65-1.60
Effective strip width (ESW)	50.47	40.08	51.18	51.34	38.07	55.29	37.73	16.21	42.75
Standard error	5.38	2.99	6.94	4.16	3.13	6.69	5.70	2.85	4.95
Percent CV	10.66	7.47	13.57	8.12	8.23	12.12	15.12	17.60	11.58
95%CI	40.93-62.23	34.58-46.45	39.03 67.10	43.69-60.33	32.34-44.82	43.46-70.33	27.79-51.23	11.32-23.22	33.94-53.84
Average group size	7.98	2.70	2.20	4.16	9.72	2.12	0.98	1.00	2.43
Standard error	0.51	0.16	0.26	0.57	0.90	0.17	0.02	-	0.19
Percent CV	6.48	6.08	12.12	13.87	9.32	8.22	2.14	-	8.17
95%CI	7.02-9.06	2.39-3.04	1.72-2.80	3.16-5.47	8.08-11.69	1.80-2.50	1.00 1.02	-	2.07-2.86
Probability of a greater chi square value, P	0.62	0.77	0.83	0.70	0.84	0.65	0.90	0.33	0.99

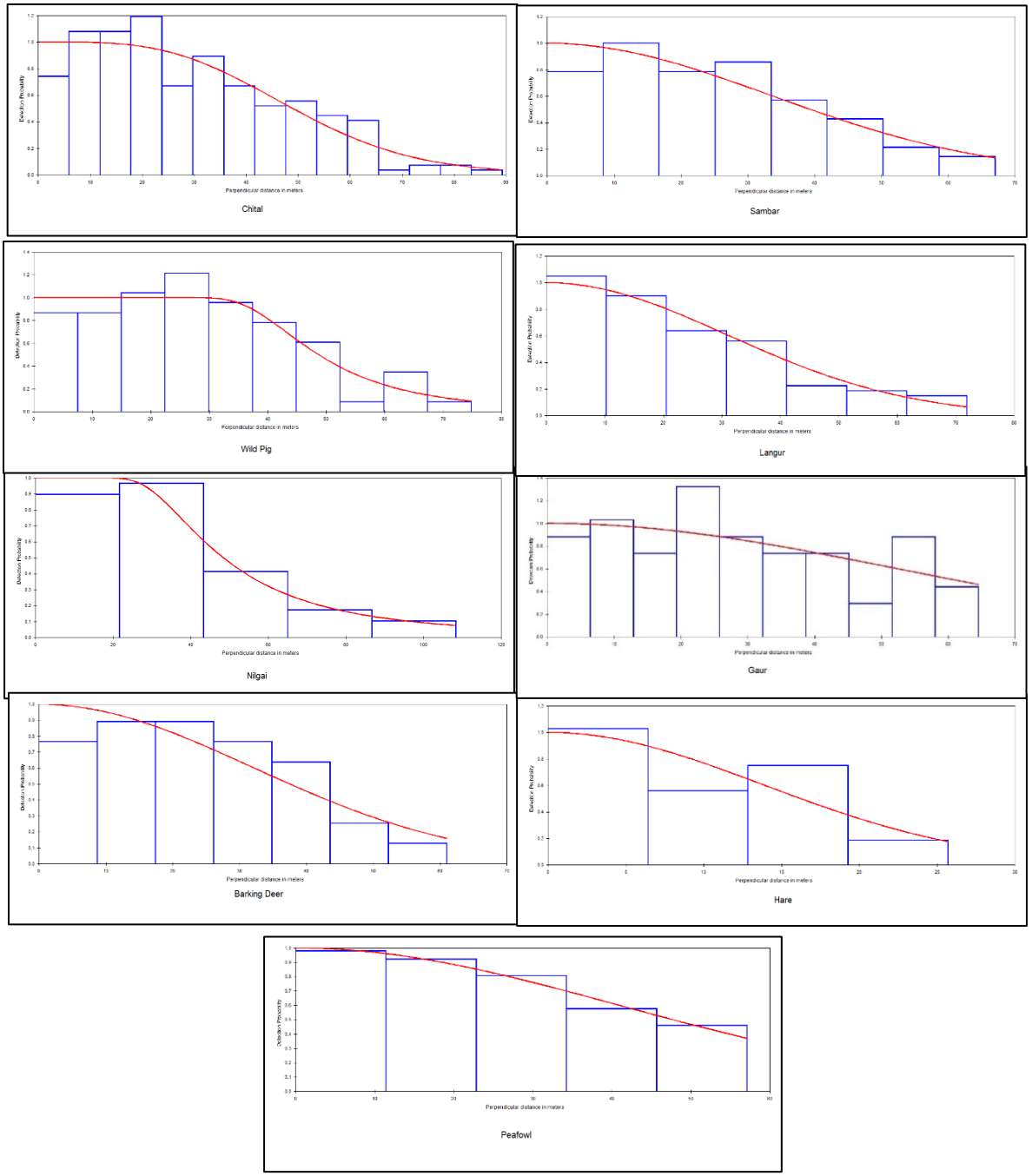
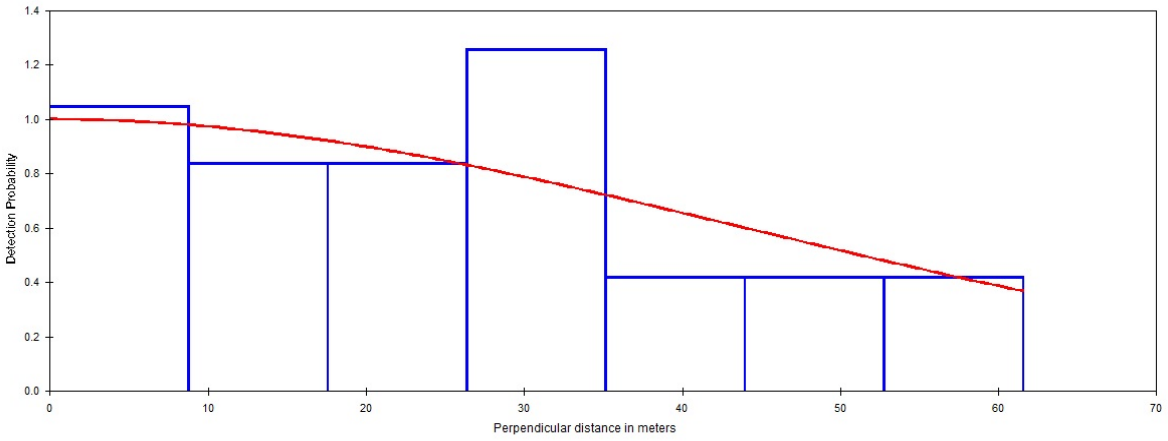


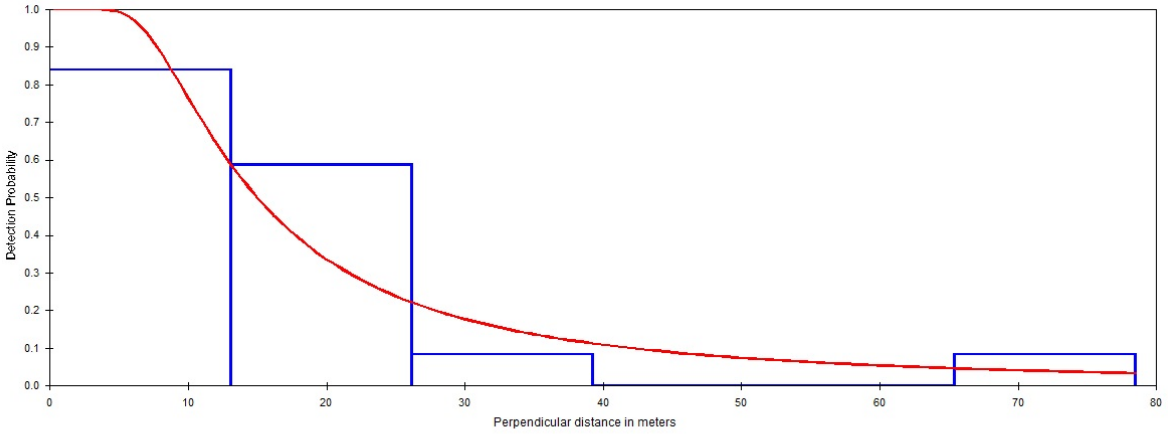
Figure 4: Detection functions of the best-selected model for prey species in the Core Area of Pench Tiger Reserve during line transect survey 2021.

Table 4: Individual Density, Group Density, Effective Strip Width, Average Group Size and Encounter Rate of all Prey Species Reported during the Phase IV Monitoring 2021 in the Buffer Area of Pench Tiger Reserve, Maharashtra

Parameters	Chital	Nilgai
Density(individual/sq.km)	8.63	1.36
Standard error	4.15	0.40
Percent CV	48.14	29.76
95%CI	3.45-21.55	0.76 -2.43
Group density (no of groups/sq.km)	1.16	0.69
Standard error	0.48	0.18
Percent CV	41.75	26.65
95%CI	0.51-2.61	0.40-1.17
Effective strip width (ESW)	20.85	46.04
Standard error	6.57	8.81
Percent CV	31.51	19.15
95%CI	10.89-39.91	31.11-68.12
Average group size	7.42	1.96
Standard error	1.78	0.26
Percent CV	23.98	13.26
95%CI	4.51-12.23	1.49-2.58
Probability of a greater chi square value, P	0.22	0.89



Nilgai



Chital

Figure 5: Detection functions of the best-selected model for prey species in the Buffer Area of Pench Tiger Reserve during line transect survey 2021.

3. Status of Predator in Pench Tiger Reserve

Introduction

In modern-day conservation biology, camera traps play an important role in the study of populations in the wild. It is one of the cost-effective methods to sample larger areas and is useful for different types of ecological studies, ranging from population estimation (e.g. abundance, density, demography) to behavioural studies (e.g. activity, social behaviour), etc. Also, cameras are major tools to monitor naturally marked species like tigers and leopards at an individual level.

For Phase IV exercise a total of 311 camera traps were deployed in Pench Tiger reserve in a grid of 2 km^2 (Figure 6). A pair of camera traps were deployed in each location and were kept for 25-30 days in the field that resulting in 8415 trap nights. For this year's study three different types of camera models Cudde Back C1, Cudde Back Professional, and Ambush were used. All the traps were assigned an ID number the same as the Grid and the locations of each station were recoded for spatial analysis. Individual tigers and leopards were identified based on their flanks, for tigers left flank and for leopards right flanks were used for analysis because of maximum captures of that flank. The data of the present exercise have been analysed on the Camtrap R package in R and density was estimated by using the SECR package in R. The need for long term scientific monitoring of large carnivore populations arises from three considerations:

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

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

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

Population Estimation for Tigers and Leopards:

For estimating the density and population we used "SECR" instead of the conventional capture-recapture model. Spatially explicit capture-recapture (SECR) is a set of methods for modeling 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 the 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, 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.

In SECR the basic parameter for the population is density instead of the number. The detectors in this case are the camera traps. The photographs are then manually scanned for identification of individuals based on their stripe or rosette pattern. SECR combines both the state model and the 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. The distances are not observed directly (usually we don't know the range centers), so conventional distance sampling that we would normally apply to study prey species do not apply (Efford, 2017).

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 km2 based on SECR. Best model for the density estimate is chosen according to the AIC (Akaike Information Criterion). The details are provided in Tables 5 - 9 along with the comparison of capture and density estimates from previous years. 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 the average movement of the animal. It increases if the individuals are captured at very far away locations. Figure 7 (a -f) shows the MCP of tigers and leopards in Pench Tiger Reserve.

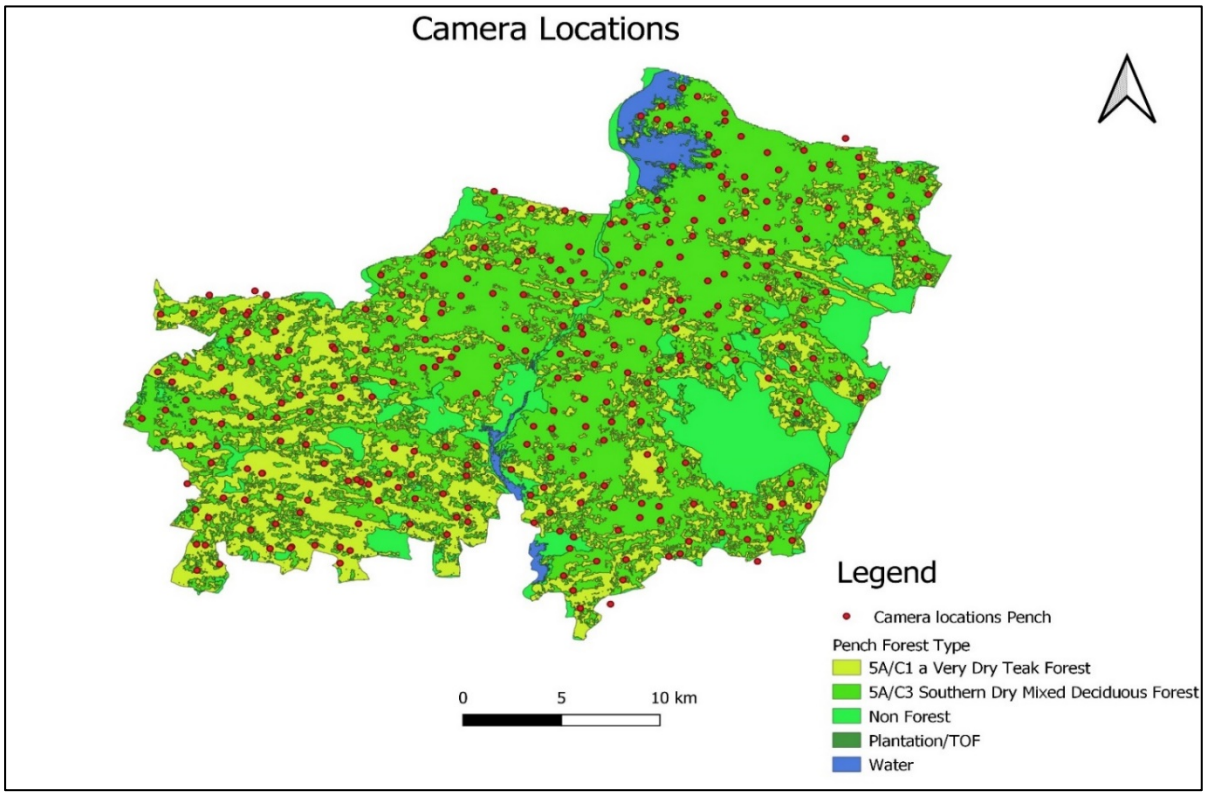


Figure 6: Map Showing Camera trap locations of Pench Tiger Reserve during Phase IV monitoring - 2021

Table 5: Density estimates of Tigers using Spatially Explicit Capture-Recapture Models Pench Tiger Reserve, Maharashtra, India for the year 2020-2021.

Parameters	Tiger 2020	Tiger 2021
Model	Heterogeneity	Heterogeneity
Detection Function	Half Normal	Half Normal
Density Estimate	6.26	4.78
Density Standard Error	1.01	0.72
Density Confidence Interval	4.57-8.57	3.55-6.43
g0 Estimate	0.07	0.06
g0 Standard Error	,0.009	0.01
g0 Confidence Interval	0.06-0.09	0.04-0.08
Sigma Estimate	1.26	1.29
Sigma Standard Error	0.062	0.088
Sigma Confidence Interval	1.14-1.39	1.12-1.47

Table 6: Estimates of Tigers using Spatially Explicit Capture-Recapture Models in Pench Tiger Reserve, Maharashtra

Year	Species	No of individuals captured	Estimates	Density per 100 km2
2020	Tiger	39	39.00(±0.74)	6.26 (±1.01)
2021	Tiger	44	45 (±1.63)	4.78 (±0.7)

Table 7: Comparison of density of tigers across the years 2020 – 2021 for Pench Tiger Reserve, Maharashtra

Details	2021
Tigers (Exclusively Core)	29
Tigers (Exclusively Buffer)	1
Tigers (Core and Buffer)	14

Table 8: Density estimates of Leopards using Spatially Explicit Capture-Recapture Models Pench Tiger Reserve, Maharashtra, India for the year 2020-2021.

Parameters	Leopard 2020	Leopard 2021
Model	Heterogeneity	Heterogeneity
Detection Function	Half Normal	Half Normal
Density Estimate	10.01	7.55
Density Standard Error	1.31	1.02
Density Confidence Interval	7.88-13.0	5.80-9.82
g0 Estimate	0.0080	0.012
g0 Standard Error	0.009	0.017
g0 Confidence Interval	0.0063-0.0102	0.009-0.016
Sigma Estimate	2.63	3.30
Sigma Standard Error	0.089	0.018
Sigma Confidence Interval	2.46-2.81	2.94-3.70

Table 9: Estimates of Leopards using Spatially Explicit Capture-Recapture Models in Pench Tiger Reserve, Maharashtra

Year	Species	No of individuals captured	Estimates	Density per 100 km^2
2020	Leopard	61	63 (±1.83)	10.01 (±1.31)
2021	Leopard	60	72 (±4.77)	7.55 (±1.02)

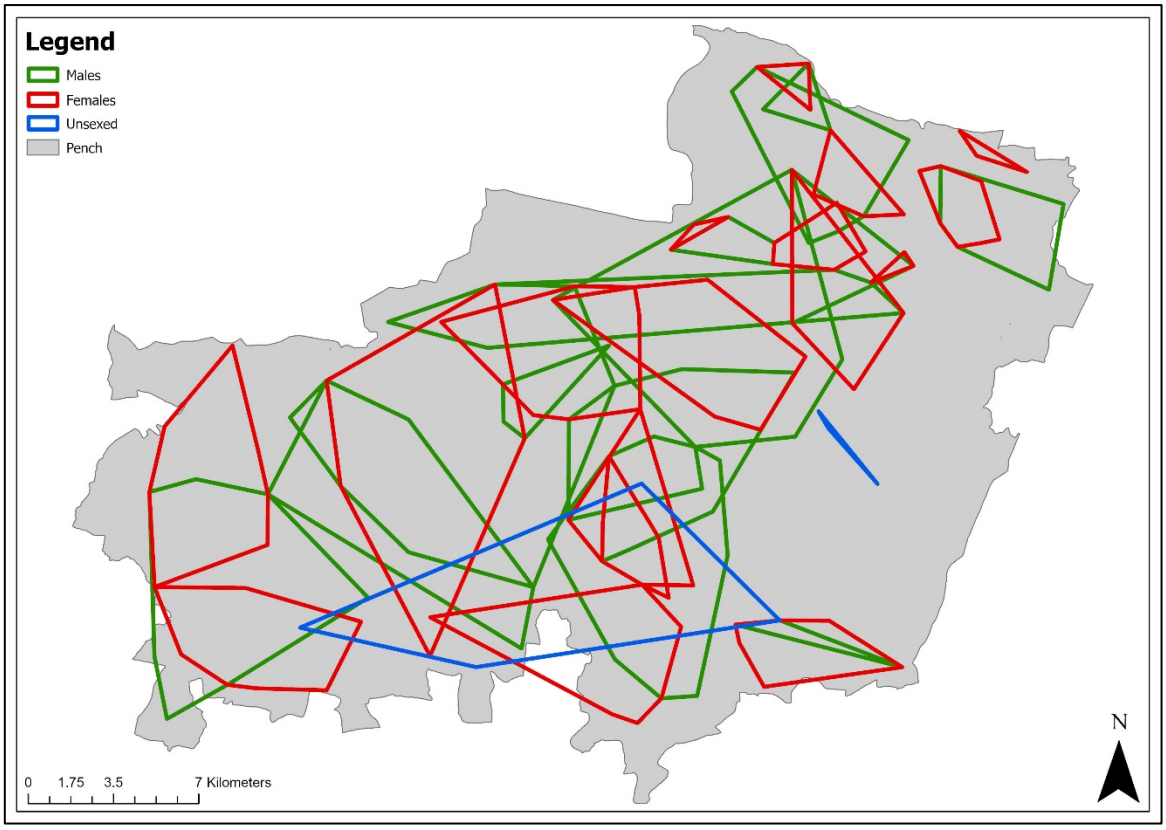


Figure 7(a): Minimum Convex Polygon of all Tigers in Pench Tiger Reserve during Phase IV monitoring 2021.

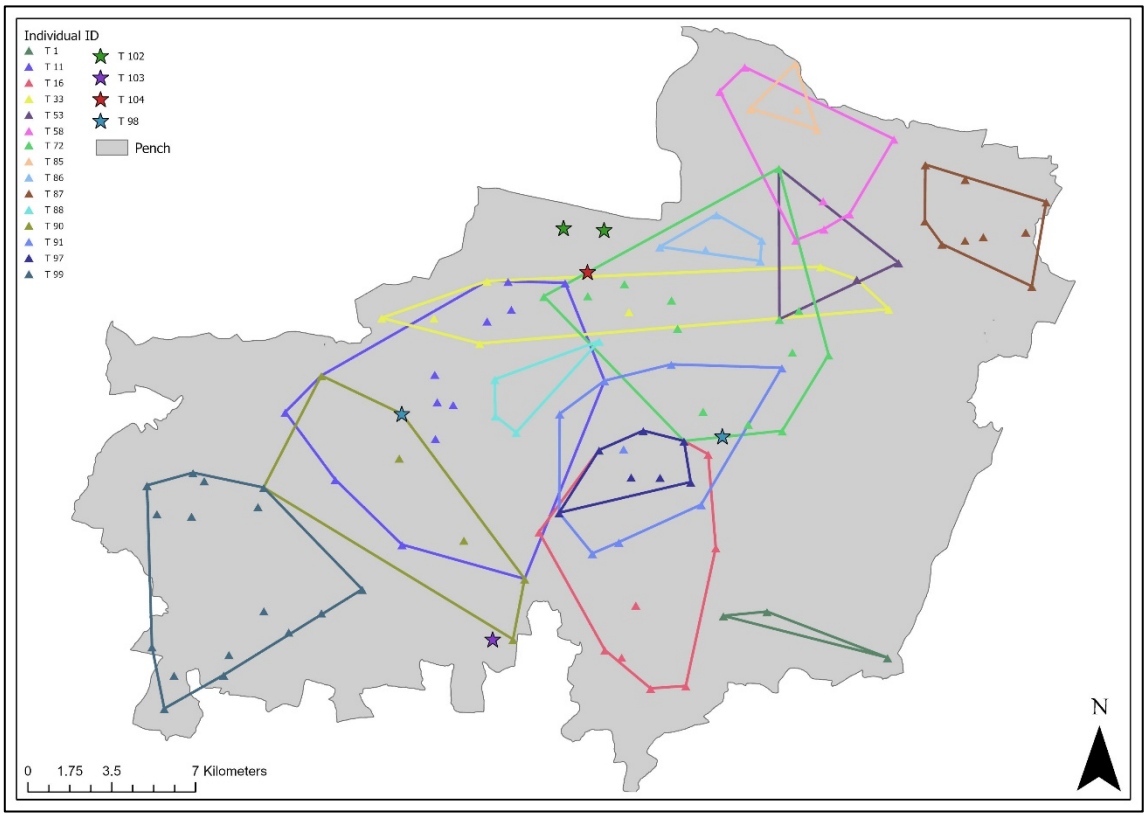


Figure 7(b): Minimum Convex Polygon of Tigers (Males) in Pench Tiger Reserve during Phase IV monitoring 2021.

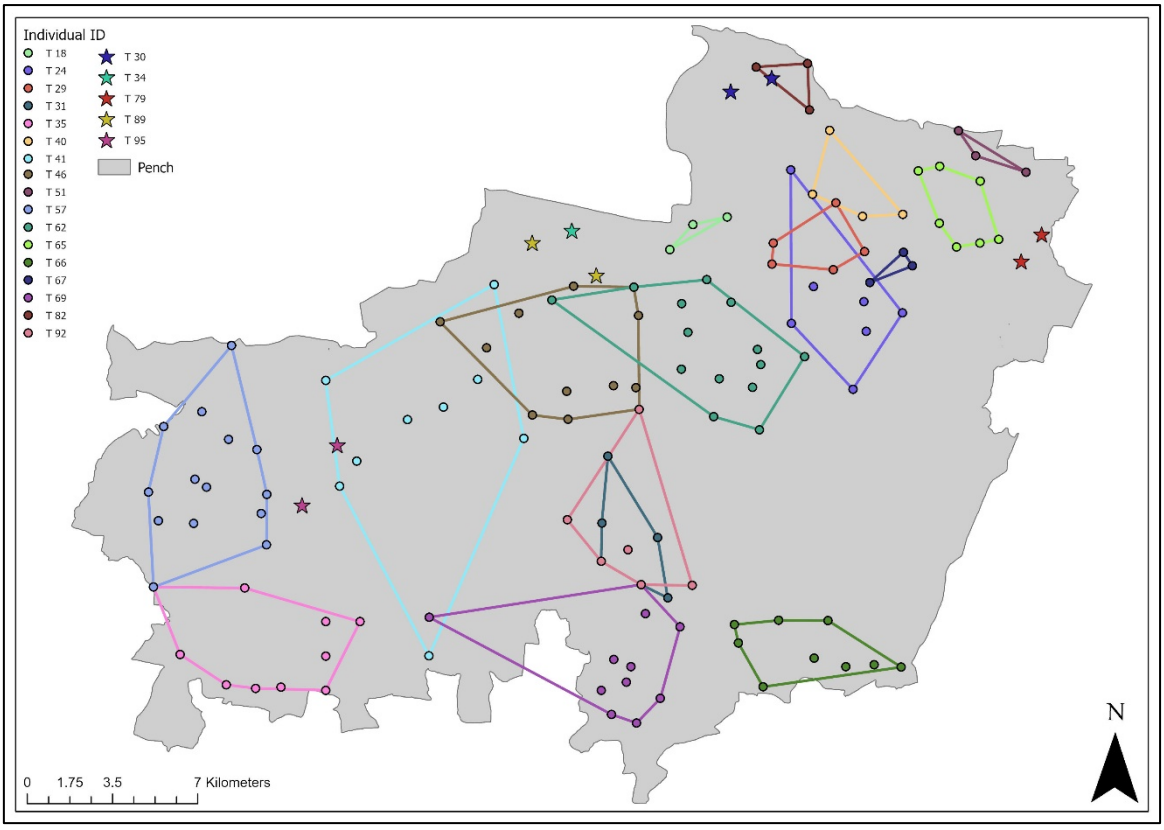


Figure 7(c): Minimum Convex Polygon of Tigers (Females) in Pench Tiger Reserve during Phase IV monitoring -2021

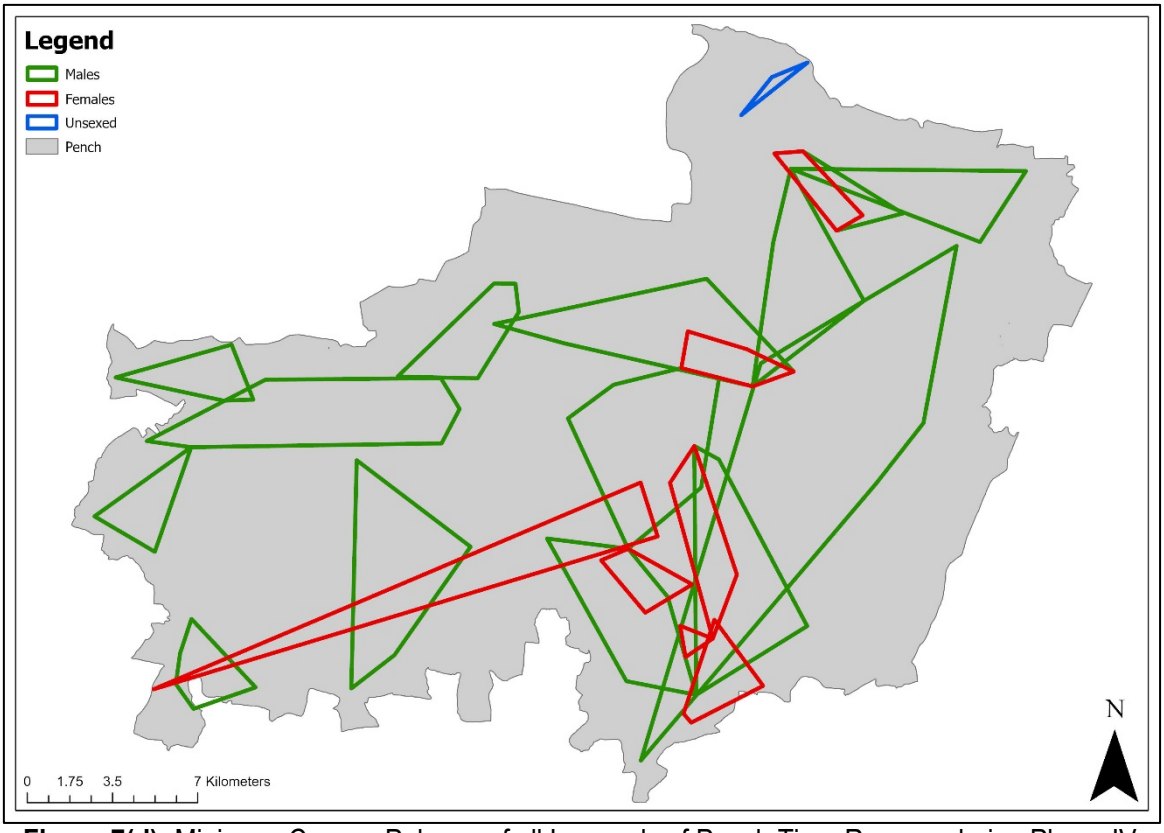


Figure 7(d): Minimum Convex Polygon of all Leopards of Pench Tiger Reserve during Phase IV monitoring -2021.

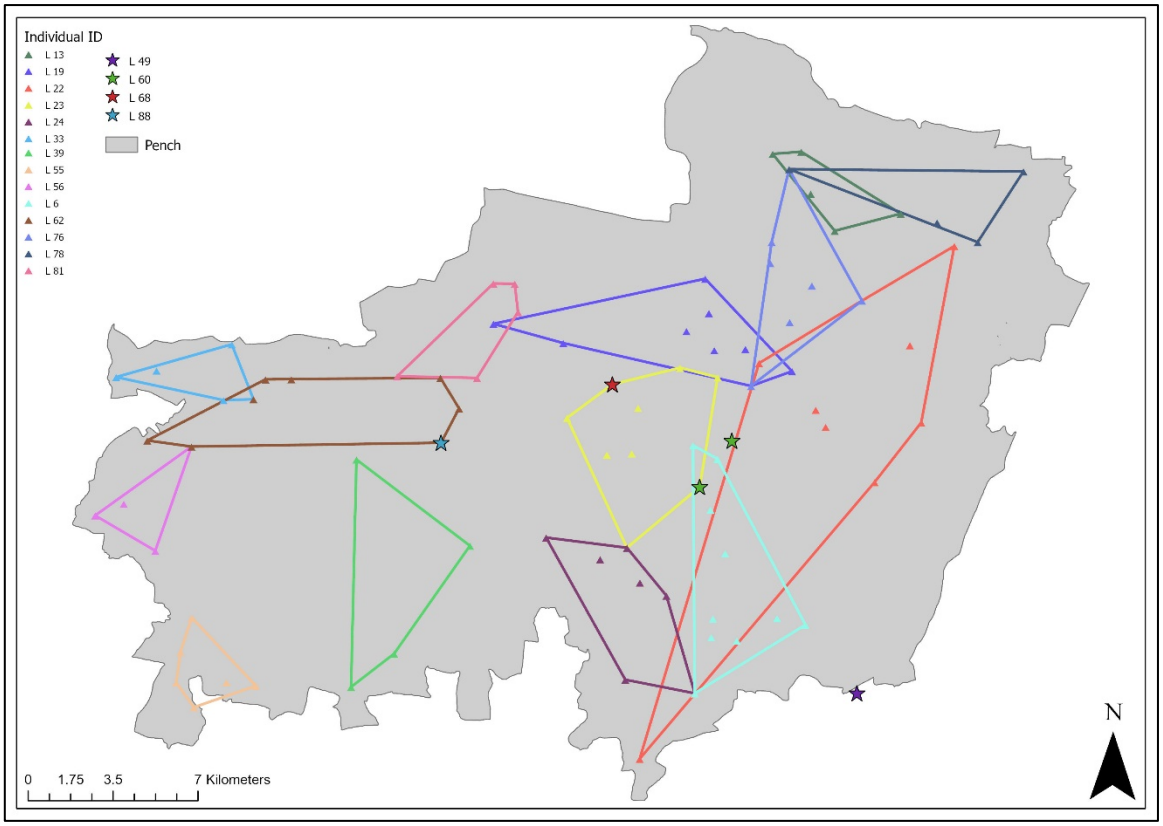


Figure 7(e): Minimum Convex Polygon of Leopards (Males) of Pench Tiger Reserve during Phase IV monitoring-2021.

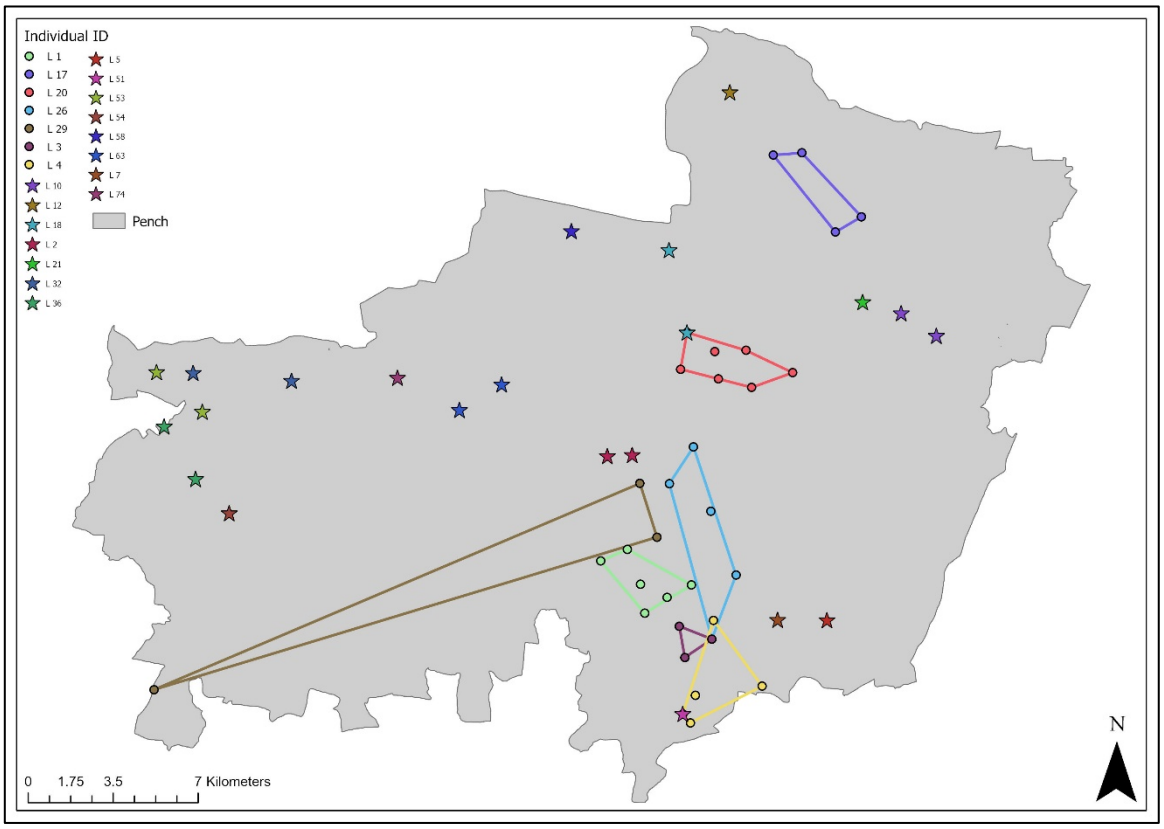


Figure 7(f): Minimum Convex Polygon of Leopards (Females) of Pench Tiger Reserve Phase IV monitoring-2021.

4. Temporal Activity of Predators and Prey Species in Pench Tiger Reserve

Introduction:

To know how prey species interact with each other over time and space, it is imperative to study their activity patterns as well as their overlap. Camera traps being an excellent tool provides capture timings that have been used to determine the peak activity period among sympatric predators and prey of the study area.

Methods and Results

The temporal pattern of the predators and their prey was analysed using R Studio in R statistical software (version 3.6.2). The approach established by Linkie and Ridout (2009) was used to study temporal activity patterns and the package "overlap" which estimates the coefficient of temporal overlap non-parametrically using kernel density estimates was used. In the package 'overlap', data are regarded as a random sample from the underlying distribution that describes the probability of a photograph being taken within any particular interval of the day. The probability density function of this distribution is then referred to as the activity pattern, which assumes that the animal is equally likely to be photographed at all times when it is active (Ridout & Linkie 2009). It is a two-step process. In the first step, each activity pattern is estimated nonparametrically, using kernel density estimation. 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–Δ. 1000 bootstrap samples are used to derive the confidence intervals.

These estimators use kernel density estimates fitted to the data to approximate the true density functions f(t) and g(t). Schmid & Schmidt (2006) propose five estimators of overlap:

Dhat1 is calculated from vectors of densities estimated at T equally-spaced times, t, between 0 and 2π:

$$\hat{\Delta}_1 = \frac{2\pi}{T} \sum^{T} \min\{\hat{f}(t_i) - \hat{g}(t_i)\}$$

For circular distributions, Dhat2 is equivalent to Dhat1, and Dhat3 is inapplicable. Dhat4 and Dhat5 use vectors of densities estimated at the times of the observations of the species, x and y:

$$\hat{\Delta}_4 = \frac{1}{2}\left(\frac{1}{n}\sum_{i=1}^{n}\min\left\{1, \frac{\hat{g}(x_i)}{\hat{f}(x_i)}\right\} + \frac{1}{m}\sum_{j=1}^{m}\min\left\{1, \frac{\hat{f}(x_j)}{\hat{g}(x_j)}\right\}\right)$$

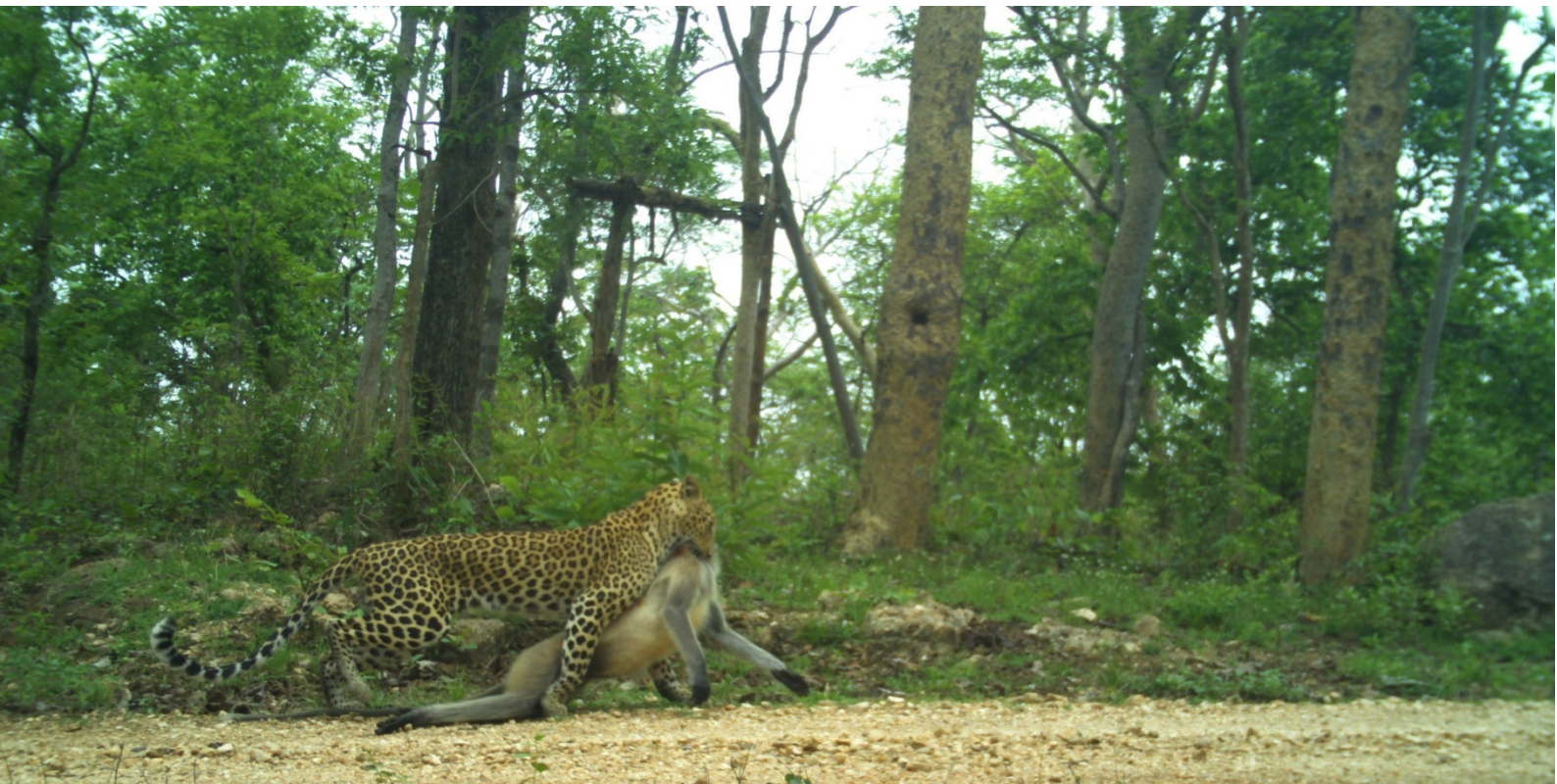
$$\hat{\Delta}_5 = \frac{1}{n}\sum_{i=1}^{n} I\{\hat{f}(t_i) < \hat{g}(t_i)\} + \frac{1}{m}\sum_{j=1}^{m} I\{\hat{f}(y_j) \geq \hat{g}(y_j)\}$$

Where n, m are the sample sizes and I is the indicator function (1 if the condition is true, 0 otherwise).

The Kernel density estimates of daily temporal activity patterns of different predator species are shown in Figure 8-11. From the kernel density estimators, the tiger and leopard were observed to have a high degree (0.82) of overlap as indicated by the estimated overlap coefficients in Table 10.

Table 10: Activity Overlap Proportion among Prey and Predator Species in Pench Tiger Reserve, Maharashtra

Species	Tiger	Leopard	Dhole
Sambar	0.73	0.78	0.54
Chital	0.46	0.51	0.72
Gaur	0.74	0.75	0.6
Wild Boar	0.49	0.53	0.8
Hare	0.74	0.73	0.28
Barking Deer	0.48	0.49	0.54
Chousingha	0.37	0.38	0.43
Nilgai	0.54	0.59	0.73
Langur	0.3	0.35	0.65
Tiger	-	0.88	0.49
Leopard	0.88	-	0.55
Dhole	0.49	0.55	-



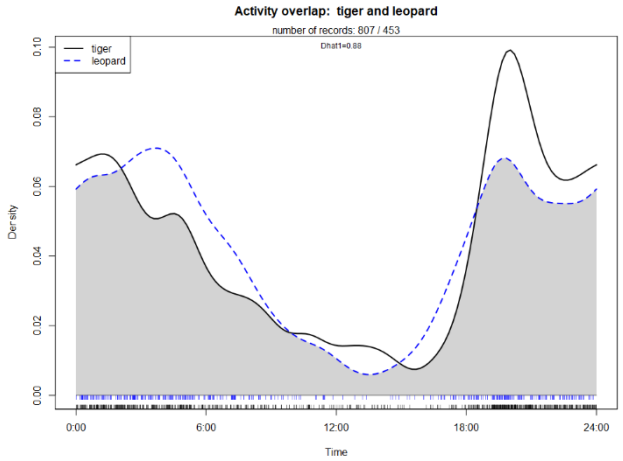


Figure 8(a): Tiger - Leopard

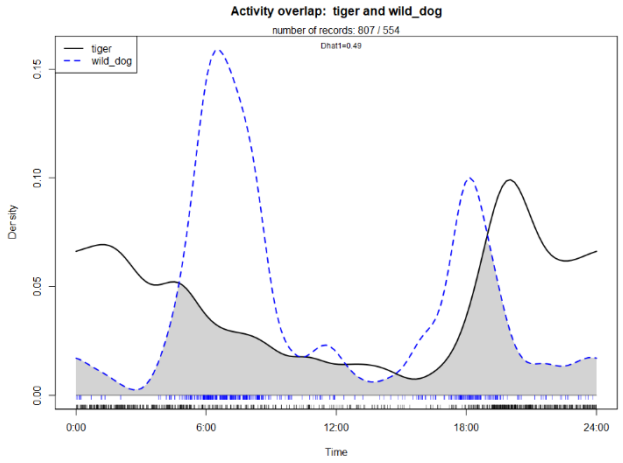


Figure 8(b): Tiger – Dhole

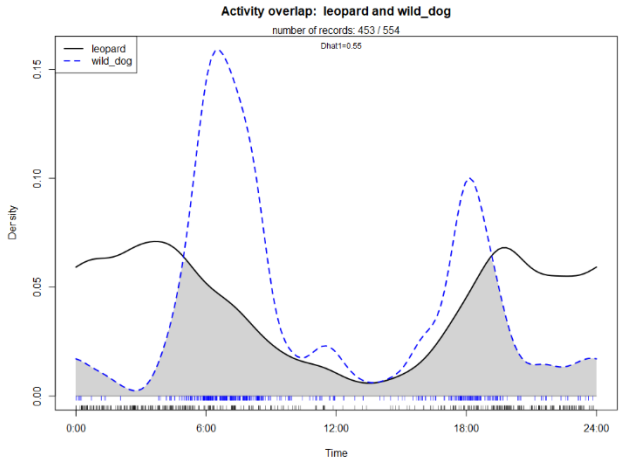


Figure 8(c): Leopard – Dhole

Figures 8 (a-c): Temporal activity overlap between co-predators. a) Tiger vs. leopard; b) tiger vs. dhole; c) leopard vs. dhole in Pench Tiger Reserve, Maharashtra. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot.

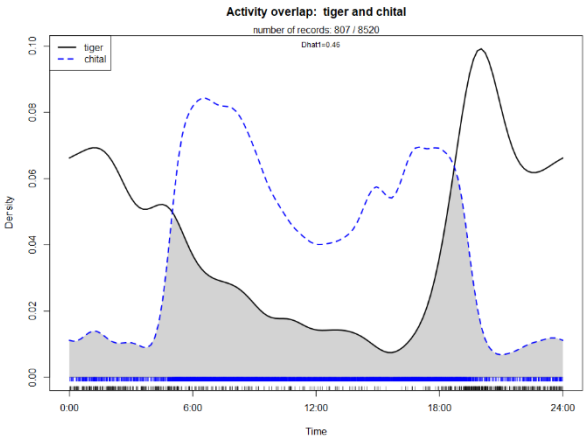


Figure 9(a): Tiger - Chital

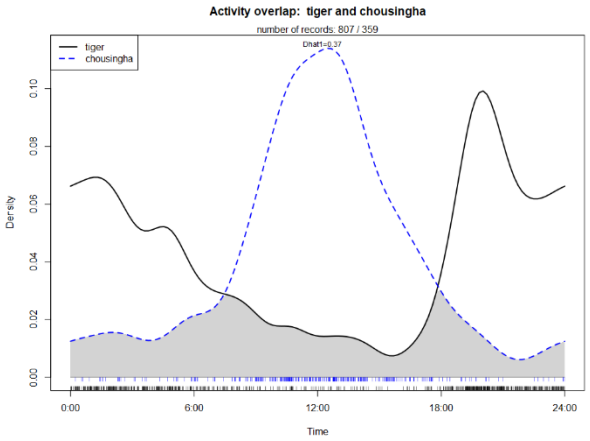


Figure 9(b): Tiger - Chousingha

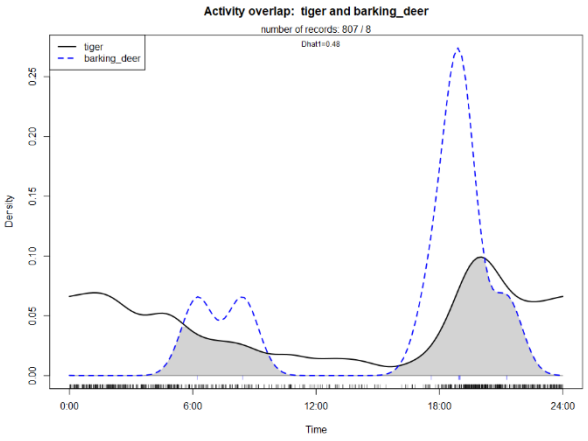


Figure 9(c): Tiger - Barking Deer

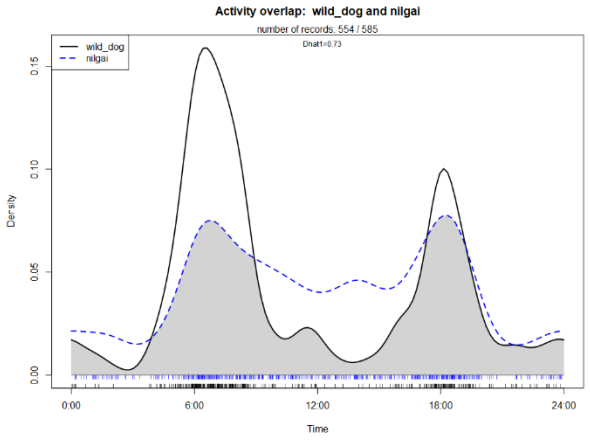


Figure 9(d): Tiger- Nilgai

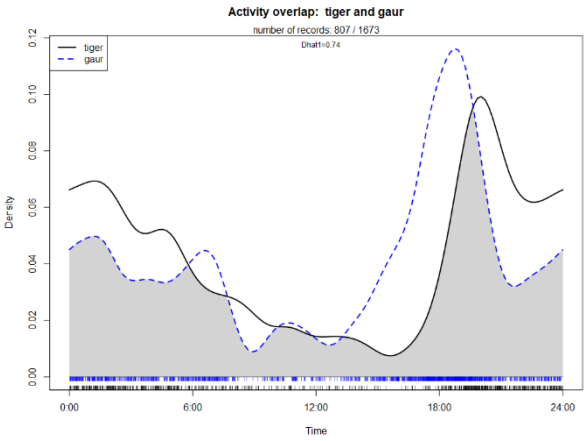


Figure 9(e): Tiger - Gaur

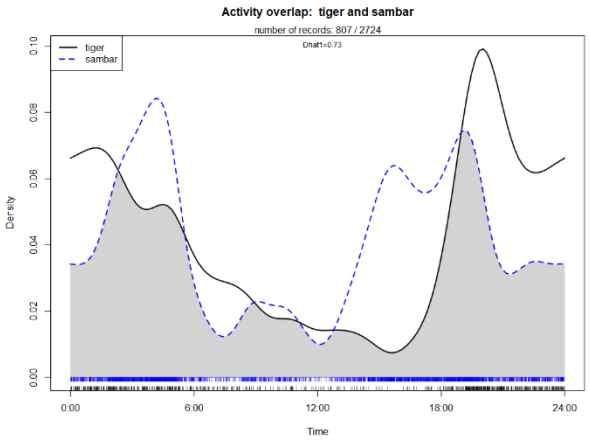


Figure 9(f): Tiger -Sambar

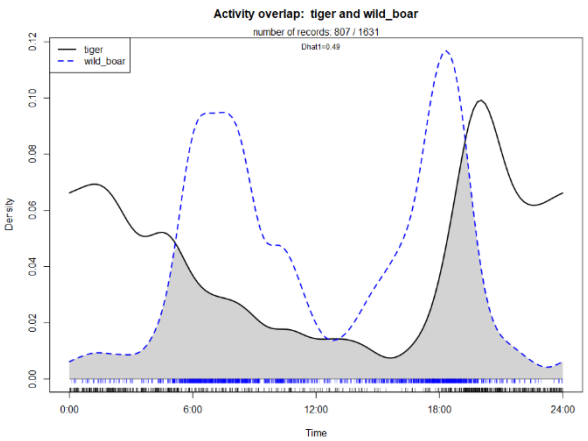


Figure 9(g): Tiger - Wild Boar

Figures 9 (a-g): Temporal activity overlap of Tiger vs. prey species in Pench Tiger Reserve, Maharashtra during the year 2021.The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot.

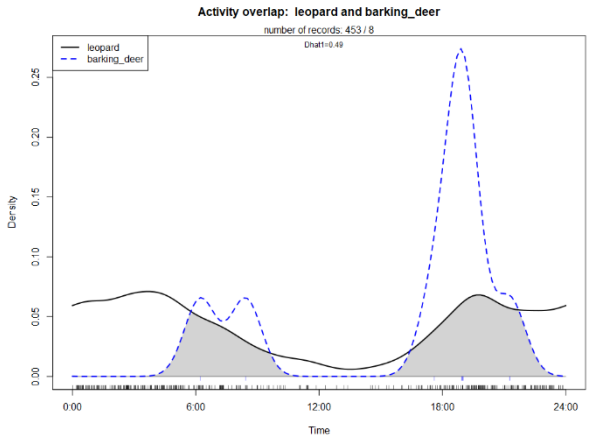


Figure 10(a): Leopard - Barking Deer

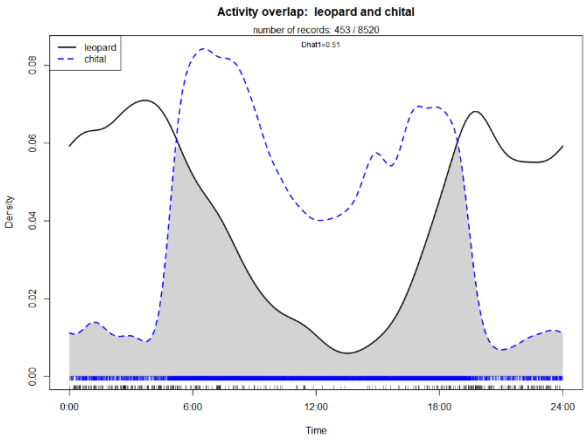


Figure 10(b): Leopard - Chital

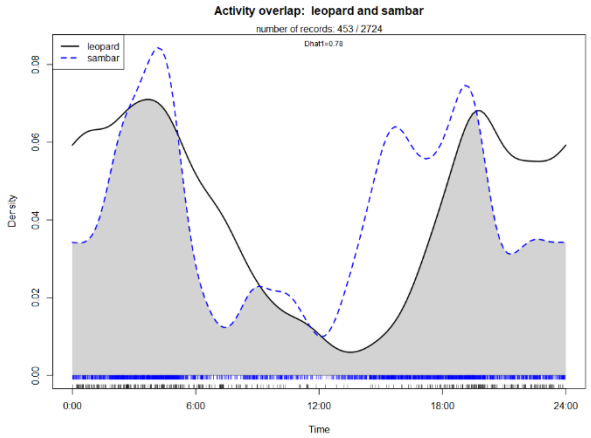


Figure 10(c): Leopard - Sambar

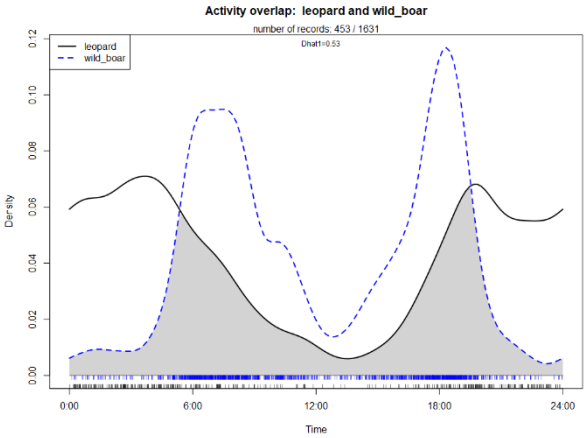


Figure 10(d): Leopard - Wild Pig

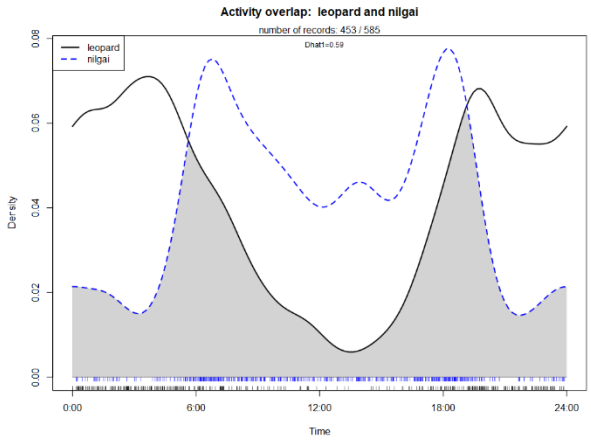


Figure 10(e): Leopard - Nilgai

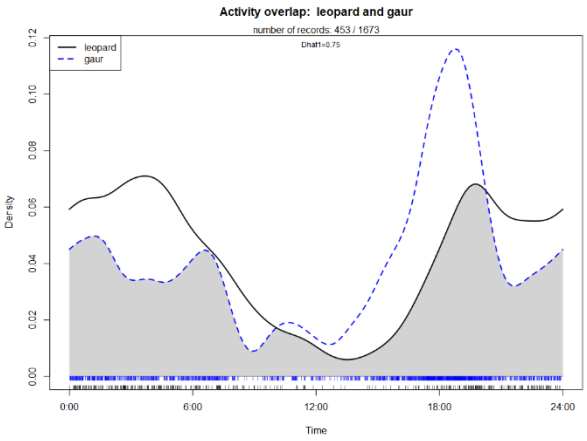


Figure 10(f): Leopard - Gaur

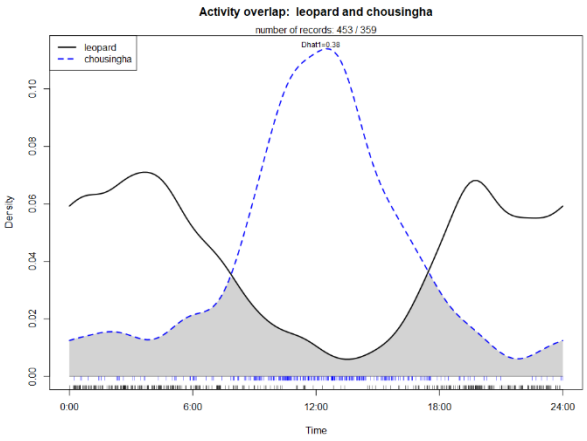


Figure 10(g): Leopard - Chousingha

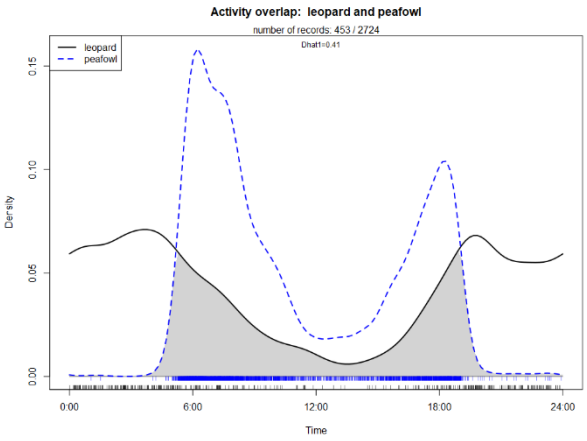


Figure 10(h): Leopard - Peafowl

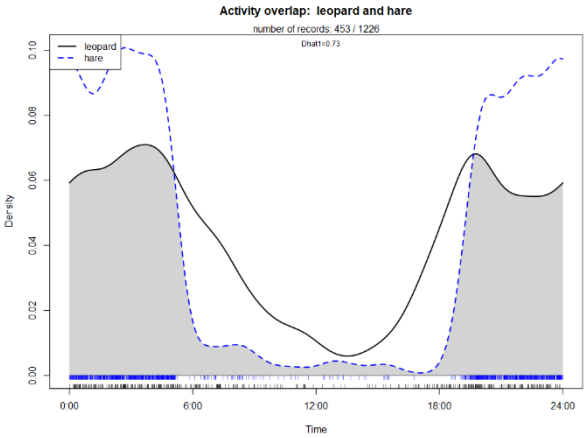


Figure 10(i): Leopard - Hare

Figures 10 (a-l): Temporal activity overlap of Leopard vs. prey species in Pench Tiger Reserve, Maharashtra during the year 2021. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot.

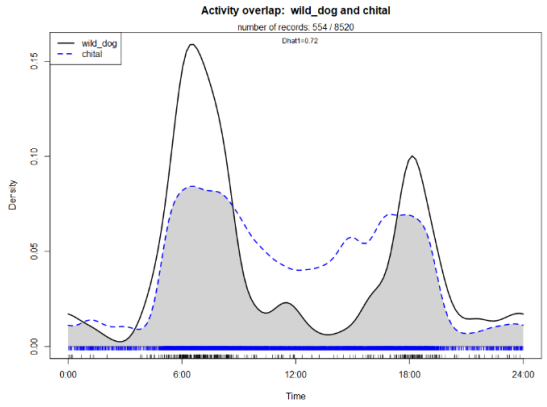


Figure 11(a): Wild Dog - Chital

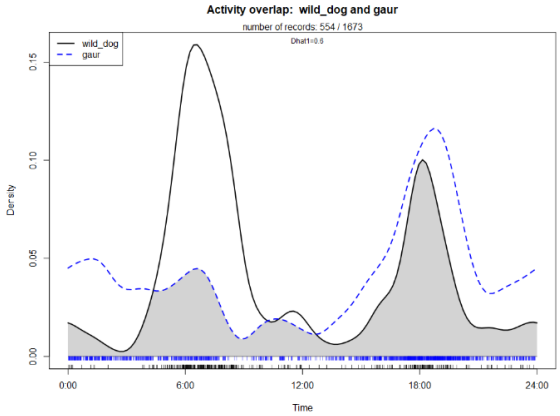


Figure 11(b): Wild Dog - Gaur

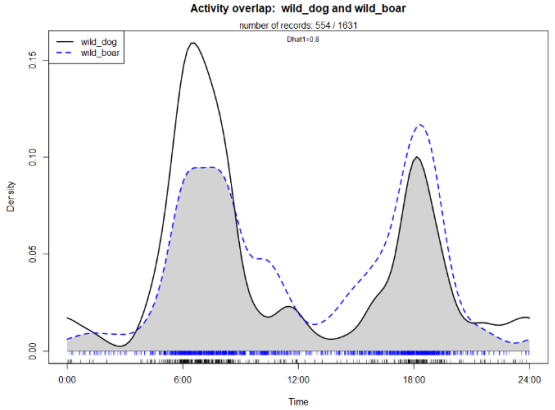


Figure 11(c): Wild Dog - Wild pig

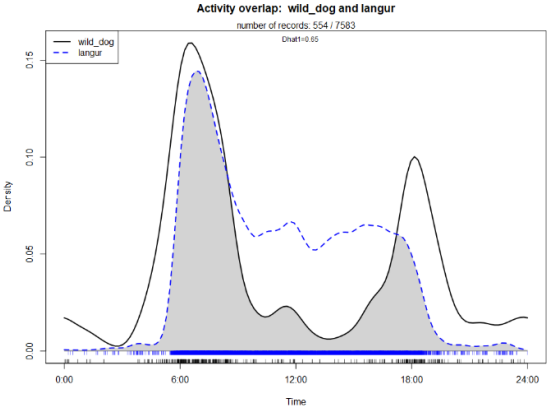


Figure 11(d): Wild Dog - Langur

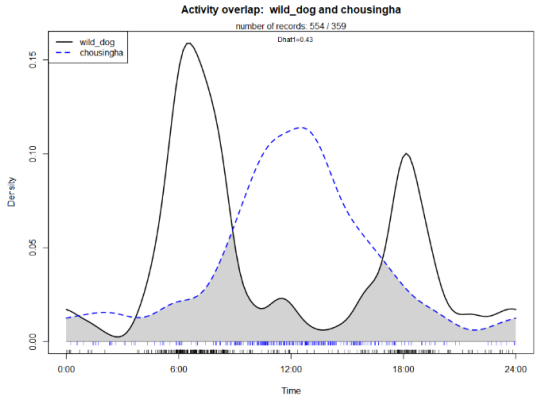


Figure 11(e): Wild Dog - Chousingha

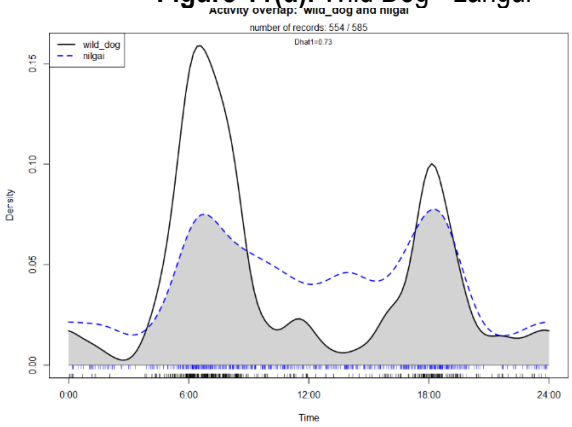


Figure 11(f): Wild Dog - Nilgai

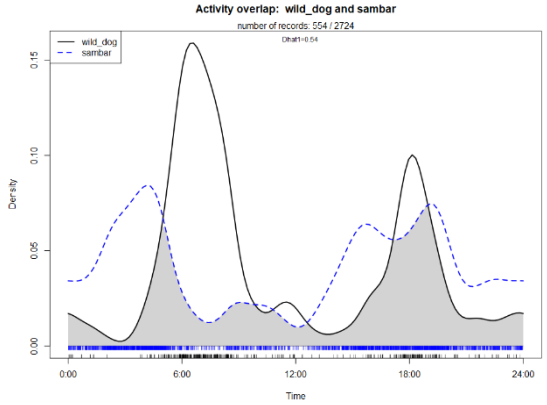


Figure 11(g): Wild Dog - Sambar

Figures 11 (a-g): Temporal activity overlap of Wild dog vs. prey species in Pench Tiger Reserve, Maharashtra during the year 2021. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot.

5. Modelling Spatially Explicit Intensive Use Areas: Predator & Prey Species

Introduction:

Camera trap locations with number of captures of each species were modelled in a GIS domain using IDW (Inverse distance weighted) interpolation technique to generate spatially explicit capture surfaces. Inverse Distance Weighting (IDW) interpolation is mathematical (deterministic) assuming closer values are more related than further values with its function. IDW function is used when a set of points is dense enough to capture the extent of local surface variation required for the analysis. IDW assumes that each measured point has a local influence that diminishes with distance. It gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, hence the name inverse distance weighted. IDW is an exact interpolator, where the maximum and minimum values (see Figure 6.1 below) in the interpolated surface can only occur at sample points. The output surface is sensitive to clustering and the presence of outliers. IDW assumes that the phenomenon being modelled is driven by local variation, which can be captured (modelled) by defining an adequate search neighbourhood.

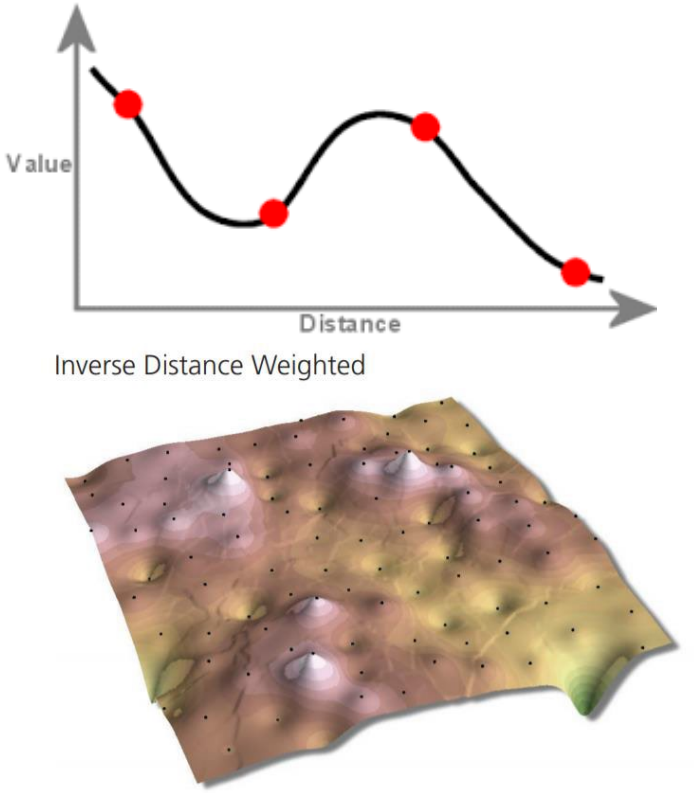


Figure 12: An example of IDW surface from points.

Using IDW technique spatially explicit intensive use area maps (Based on camera trap location and number of photographs at each location) has been developed for predator and prey species, Figures 13 (a-r) show intensive use areas by different species in Pench Tiger Reserve

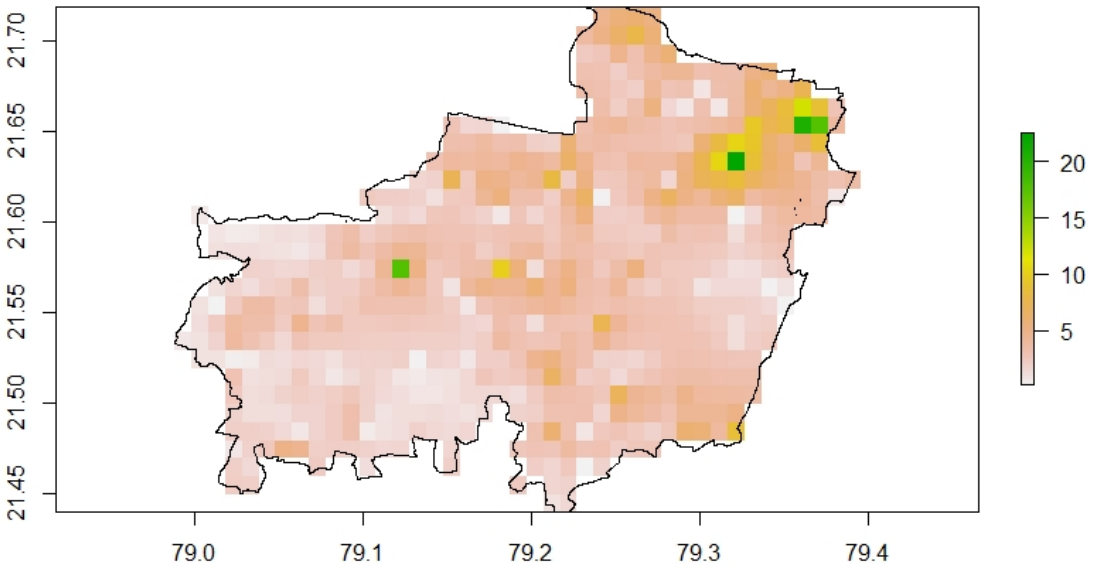


Figure 13(a): Intensive Area use by Tiger

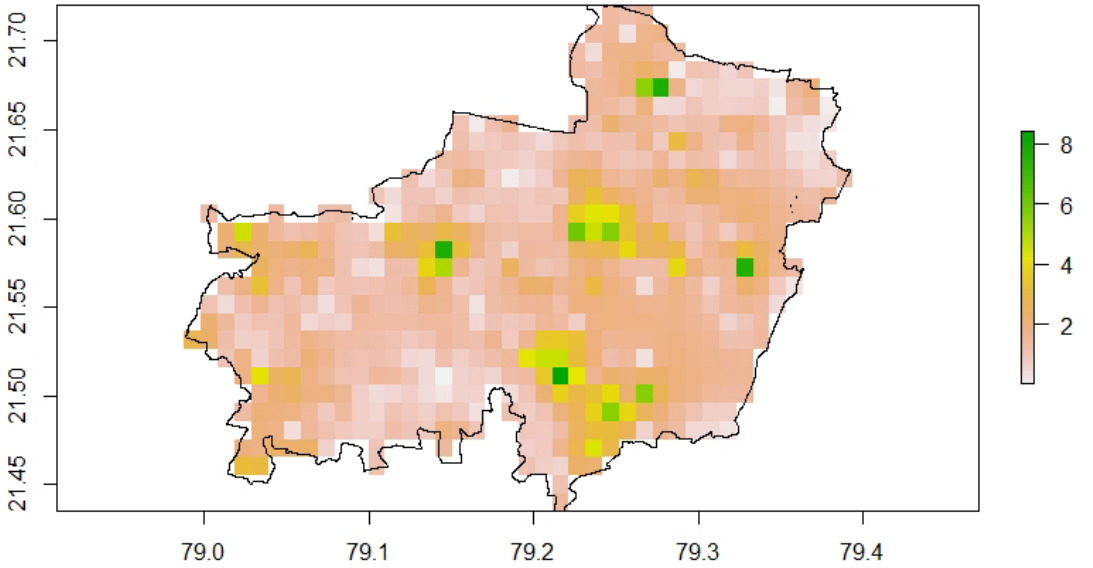


Figure 13(b): Intensive Area use by Leopard

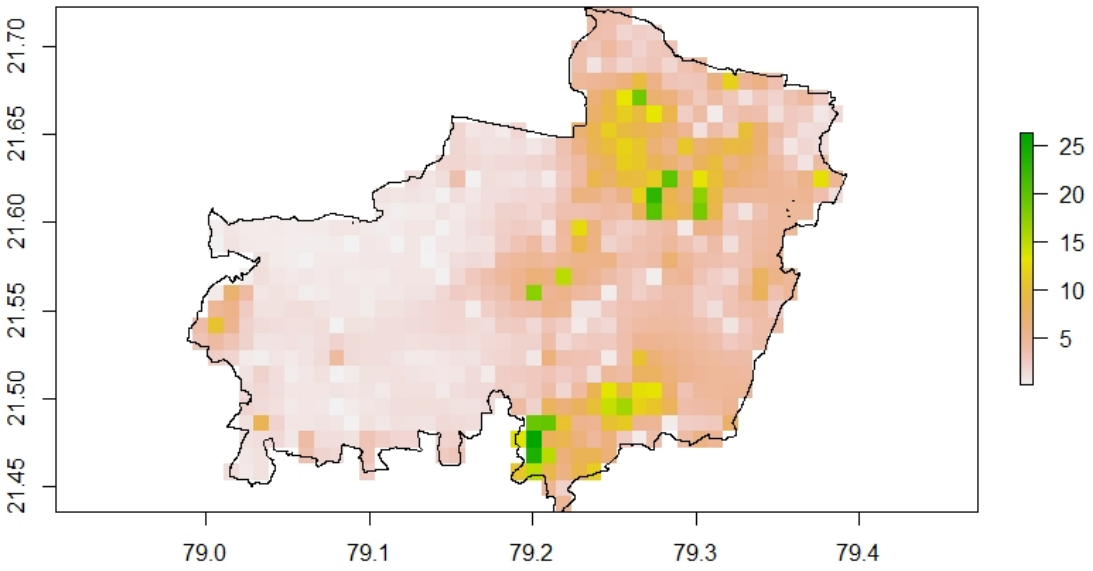


Figure 13(c): Intensive Area use by Wild Dog

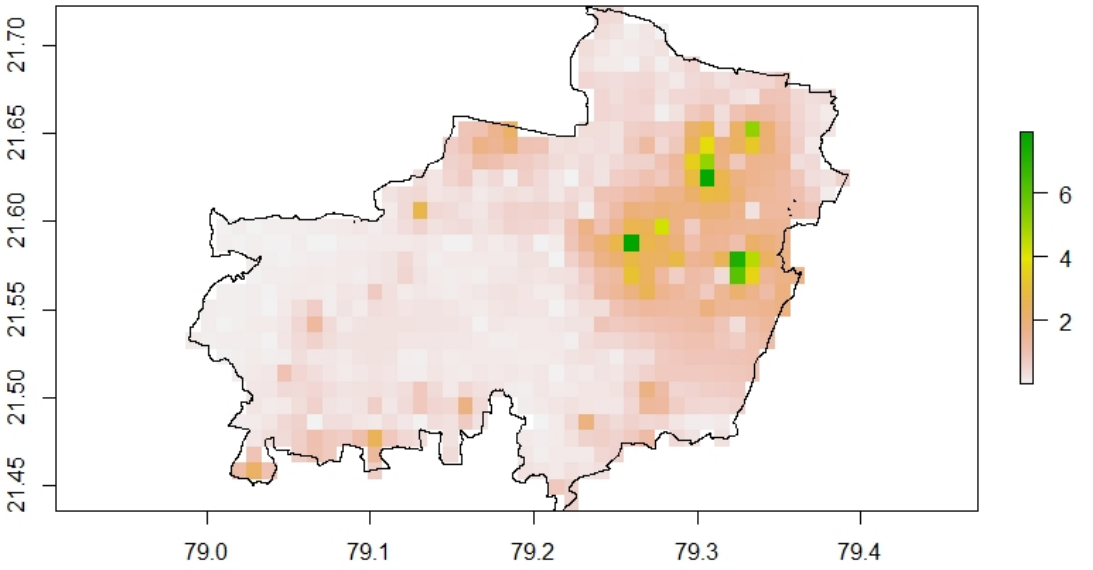


Figure 13(d): Intensive Area use by Sloth Bear

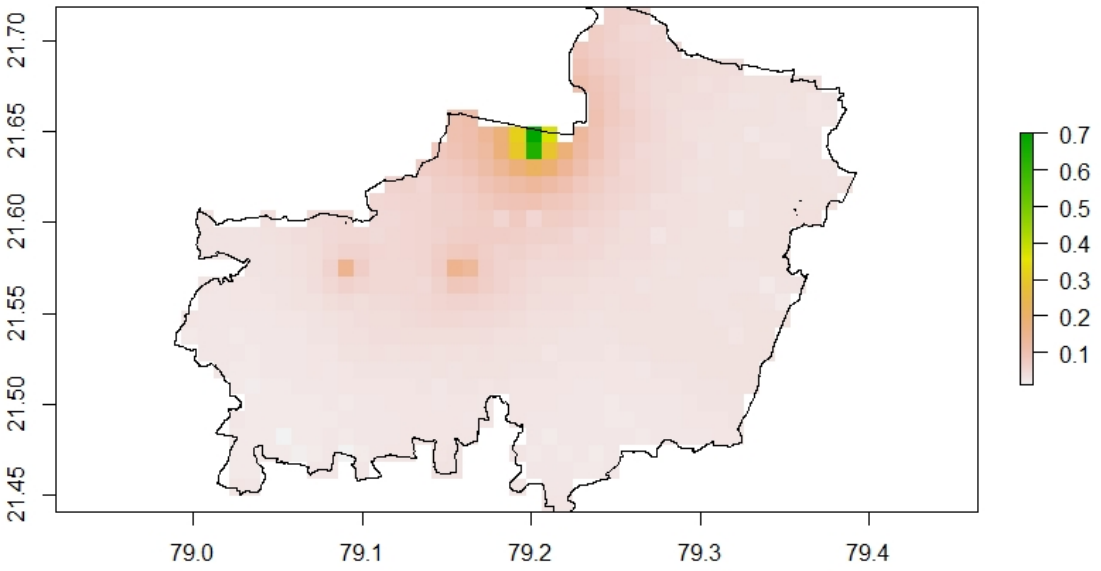


Figure 13(e): Intensive Area use by Barking Deer

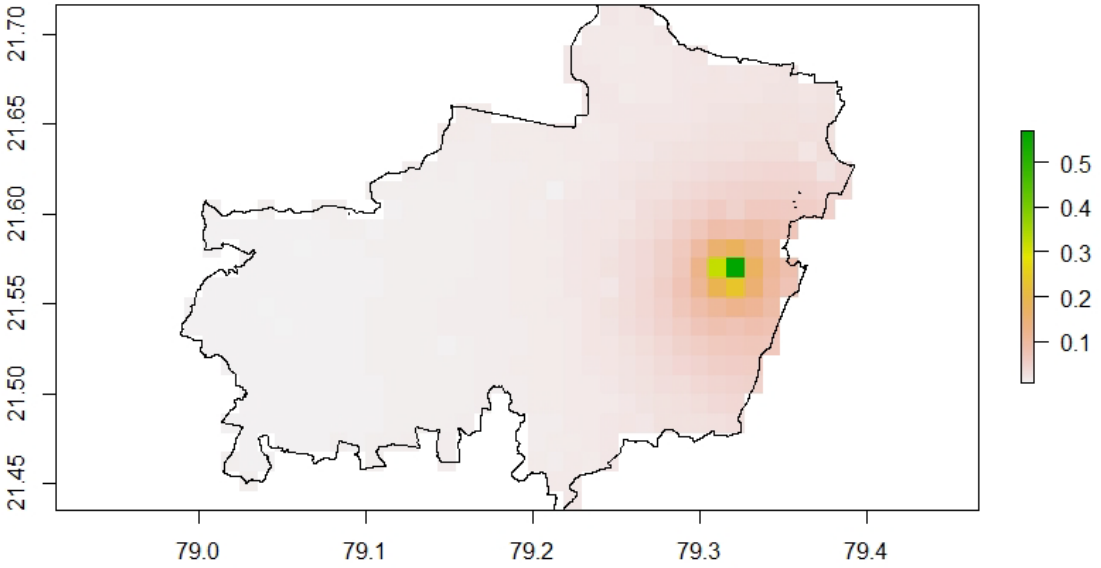


Figure 13(f): Intensive Area use by Chinkara

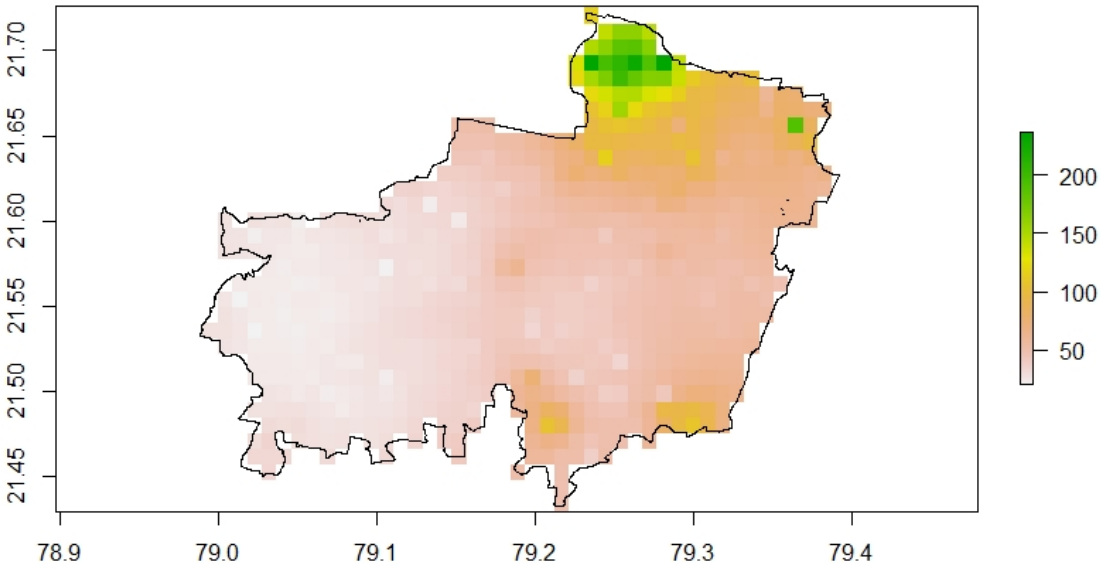


Figure 13(g): Intensive Area use by Chital

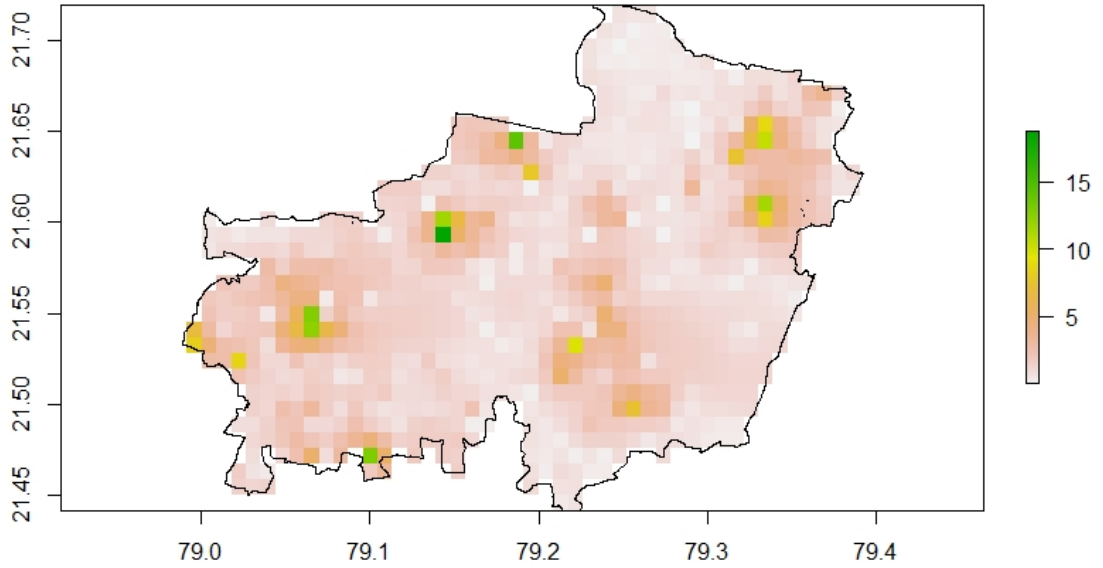


Figure 13(h): Intensive Area use by Chousingha

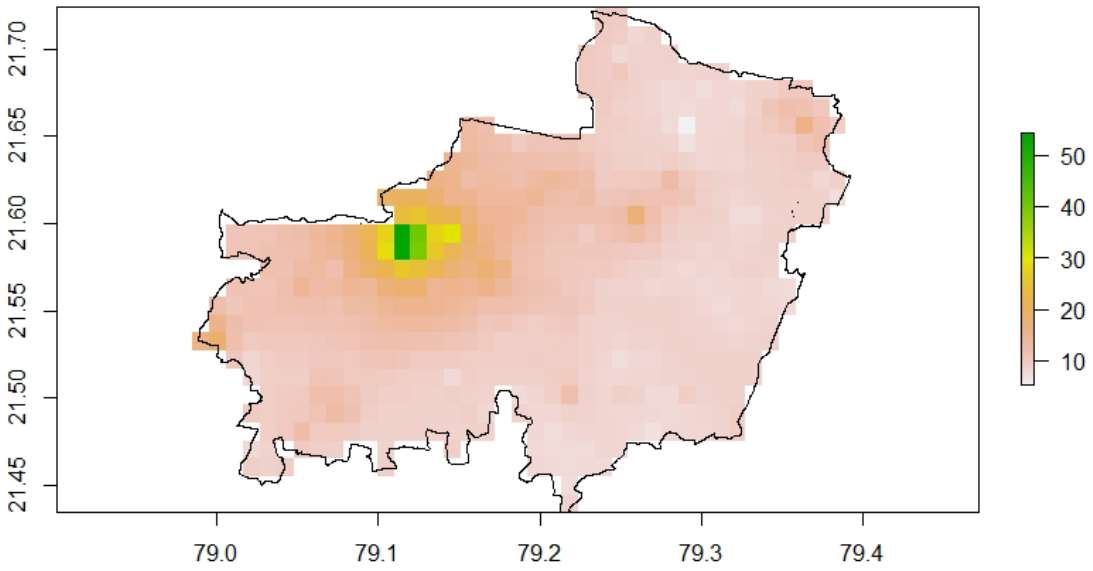


Figure 13(i): Intensive Area use by Gaur

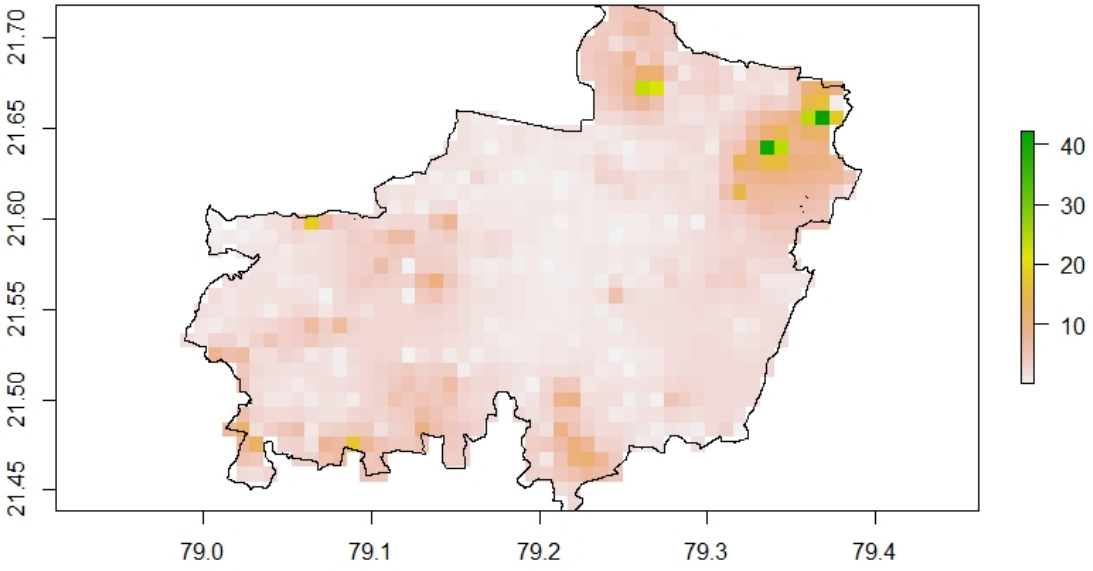


Figure 13(j): Intensive Area use by Nilgai

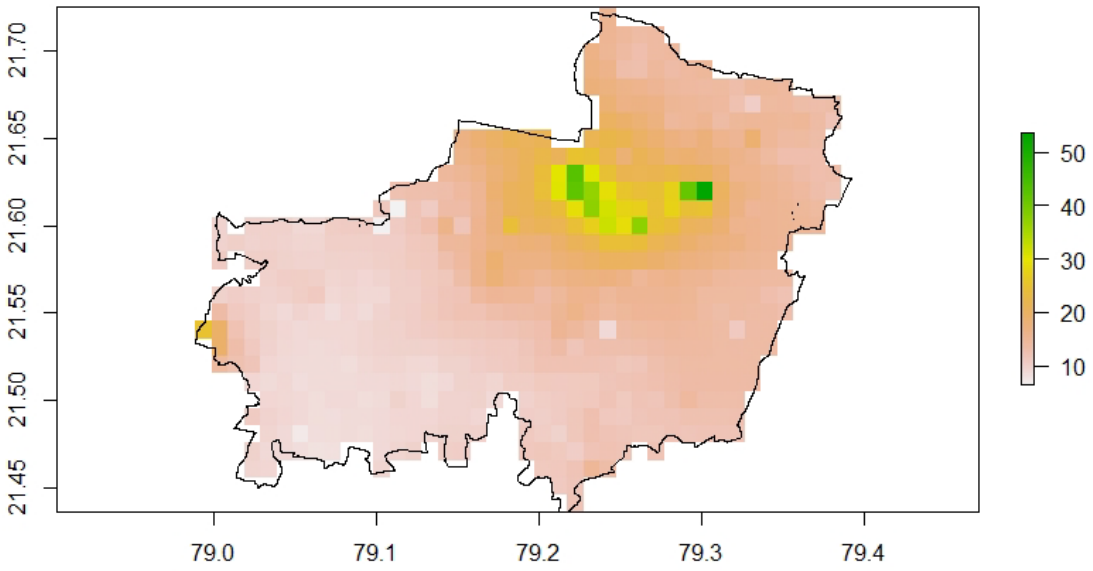


Figure 13(k): Intensive Area use by Sambar

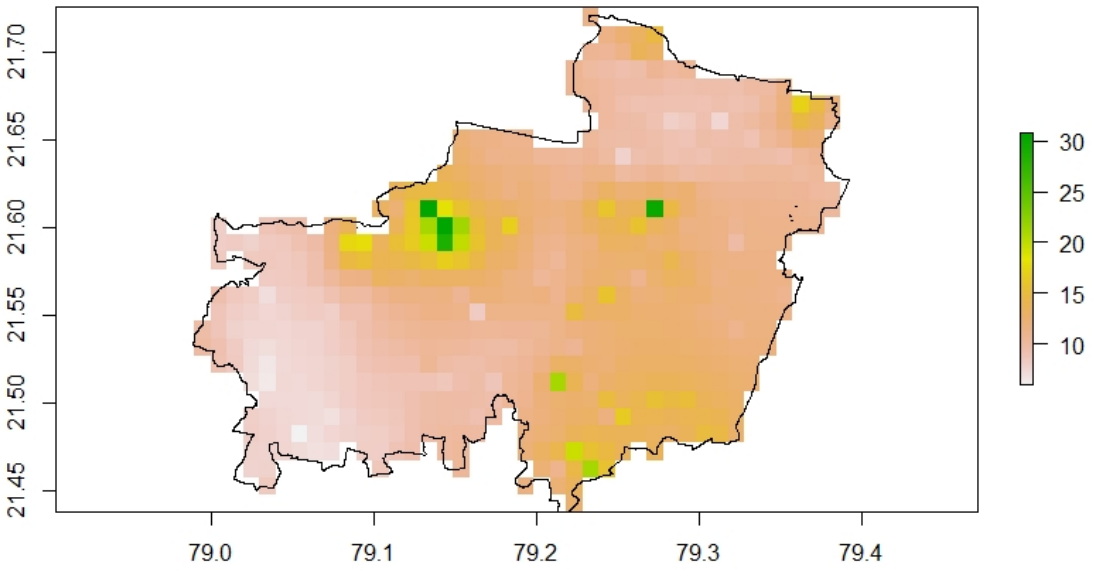


Figure 13(l): Intensive Area use by Wild Pig

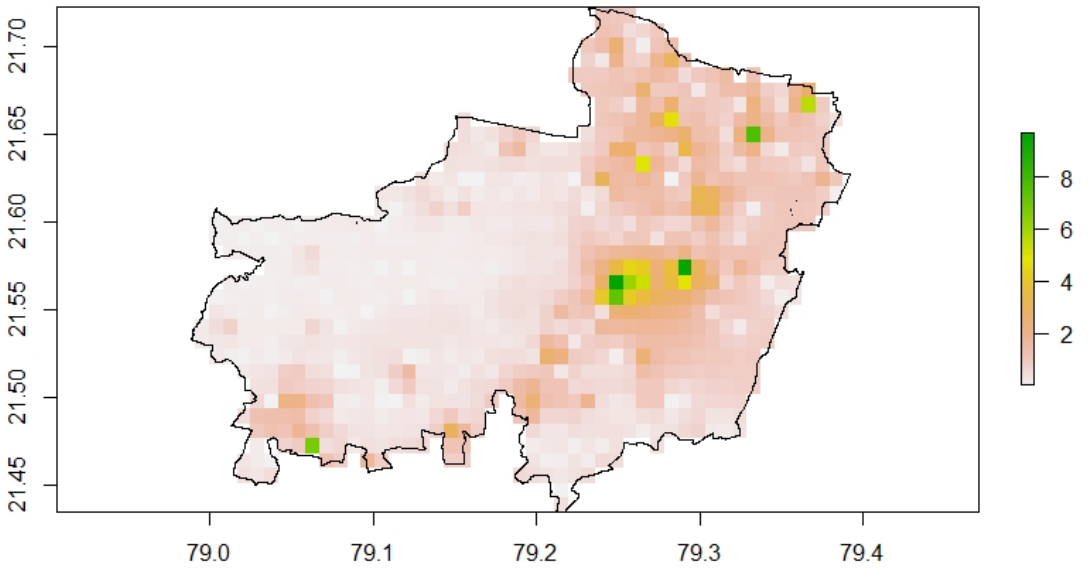


Figure 13(m): Intensive Area use by Jungle Cat

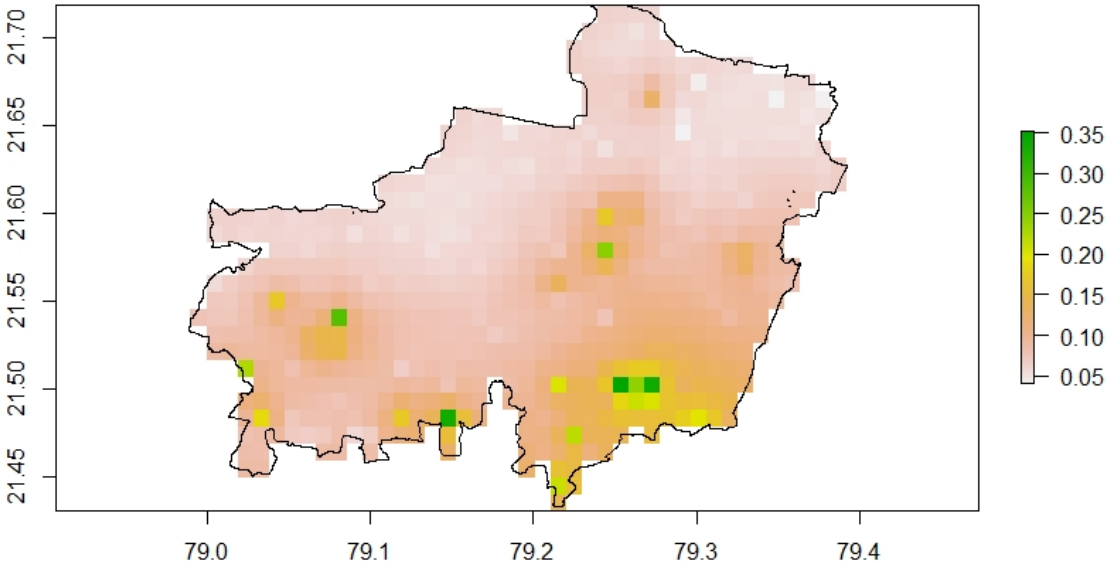


Figure 13(n): Intensive Area use by Rusty Spotted Cat

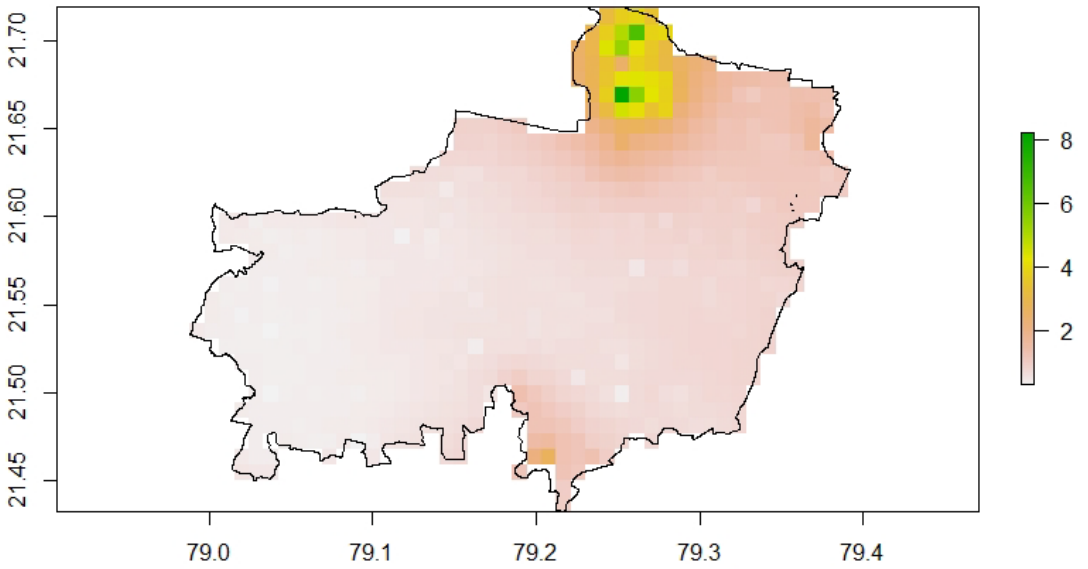


Figure 13(o): Intensive Area use by Jackal

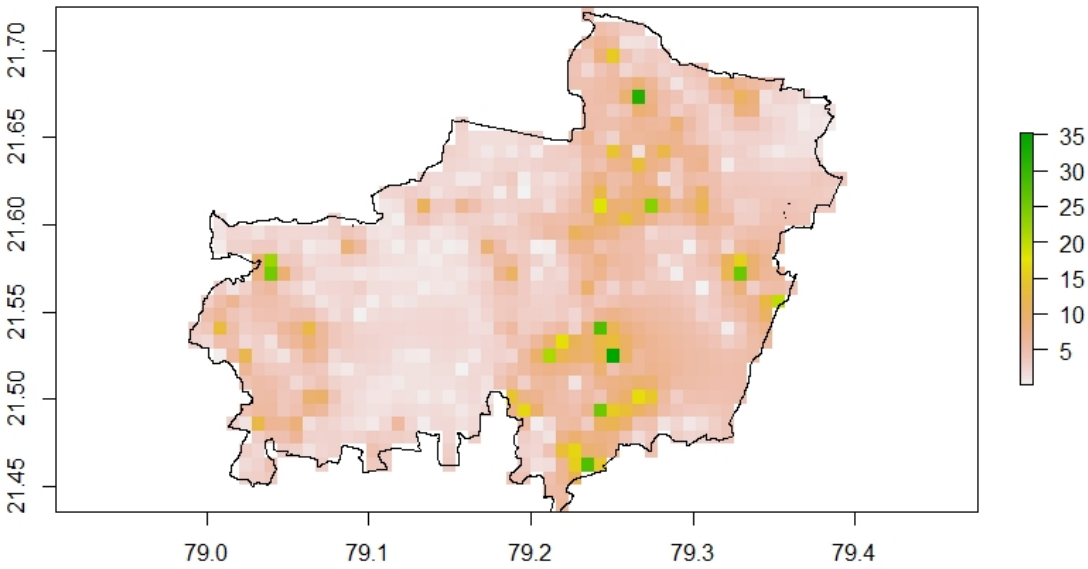


Figure 13(p): Intensive Area use by Hare

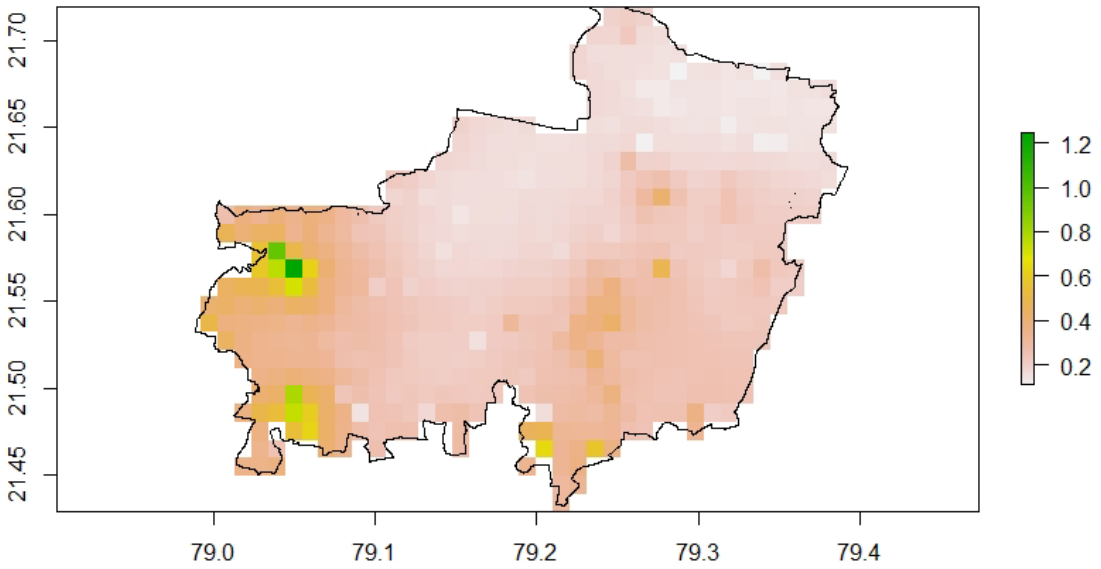


Figure 13(q): Intensive Area use by Ratel

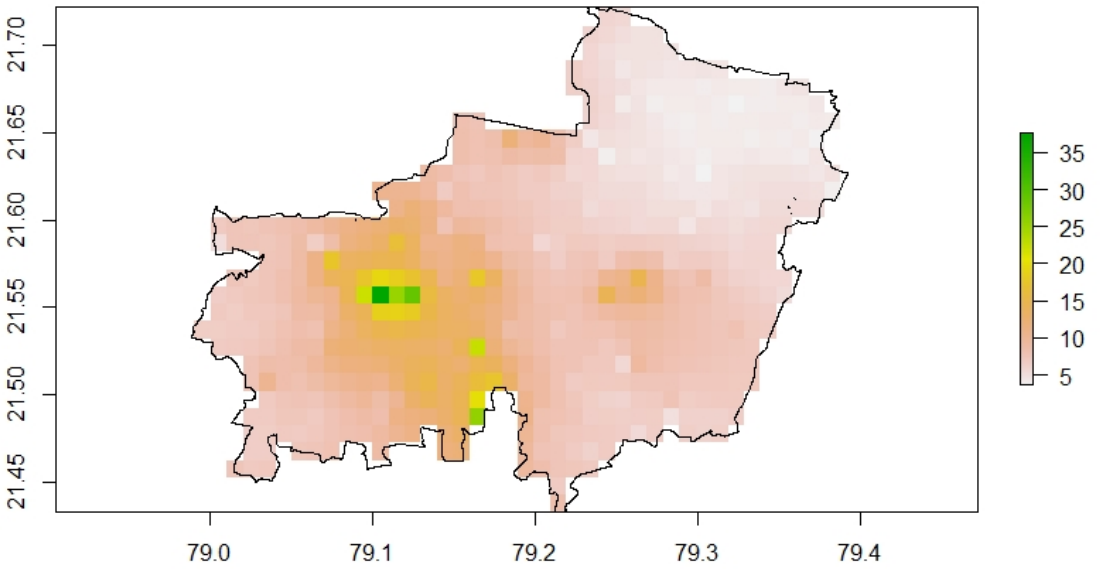


Figure 13(r): Intensive Area use by Livestock

Figures 13 (a – r): Intensive area use by various species from camera trap data at Pench Tiger Reserve, Maharashtra, during the Phase IV 2021 Monitoring

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