Tipeshwar Wildlife Sanctuary

Status of Tigers, Co-Predators & Prey

2021

Report Title:
Status of Tigers, Co-Predators and Prey in Tipeshwar Wildlife Sanctuary

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

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Contents

Executive Summary

Phase IV monitoring for the Tipeshwar Wildlife sanctuary was conducted from March –April (2021) as part of the project "Long Term Monitoring of Tigers, Co-Predators and Prey species in Vidarbha Landscape, Maharashtra, India". The exercise aimed to cover an area of 148.63 km2 of the entire sanctuary. The objective of Phase IV Monitoring is to estimate the minimum number of tigers in the Tipeshwar WLS using Spatially-Explicit-Capture-Recapture Sampling and density estimation of prey base using Distance Sampling. 62 pairs of camera traps were placed in the forested area of Tipeshwar WLS following a sampling grid of 2 sq. km. in one block. The camera traps were active for 30 days yielding a sampling effort of 2206 trap nights of data which is used for further analysis. Tiger density per 100 km. sq. based on the Spatially Explicit Capture-Recapture (SECR) model was 7.07 (SE ± 0.218) in the sanctuary while that of leopards based on the same method was 3.86 (SE ±0.165). To estimate prey density, 13 line-transects were laid randomly all over the division and were sampled 7 times during the sampling period, with a total walking effort of 182 km was invested. The observations include chital (Axis axis), sambar (Rusa unicolor), nilgai (Boselaphus tragocamelus), chousingha (Tetracerus quadricornis), langur (Semnopithecus sp), wild boar (Sus scrofa), chinkara (Gazella bennetii), Blackbuck (Antilope cervicapra), Indian hare (Lepus nigricollis) and peafowl (Pavo cristatus). As per the observations, Nilgai (n=50) is the most observed species followed by Chital (n=27). The overall prey density of Tipeshwar WLS is 17.82 (SE± 3.81). Due to low number of observations densities of chousingha, chinkara, blackbuck, langur, Indian hare, peafowl, sambar, wild boar could not be estimated.

To study the activity, we used the camera trap images. 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.

We used IDW (Inverted distance weighted) to map the intensive area used by different animal species.

1. Introduction

The tiger (*Panthera tigris*) is the largest extant cat species on the earth. 100 years ago it was easy to see a tiger in its natural habitat - around 100,000 of them roamed across Asia, including several sub-species that are now extinct. Today the number of tigers in the wild has declined exponentially. The remaining population of tigers is threatened by habitat destruction and habitat fragmentation. They require large patches of undisturbed territories to sustain their dietary needs. 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.

Being a charismatic umbrella species, the tiger is also a crusader for the protection of other species. India is known to harbour the highest population of tigers amongst the 13 range countries in Asia; Central India is one of the last strongholds of the big cat. As an apex predator, the tiger shapes the community structure of the ecosystem. It also prevents over-grazing by limiting herbivore numbers and maintains the ecological integrity of the ecosystem.

The tiger bearing areas of the Vidarbha landscape (Fig. 1) include Melghat Tiger Reserve, Pench Tiger Reserve Maharashtra, Navegaon Nagzira Tiger Reserve, Tadoba-Andhari Tiger Reserve, the Brahmapuri (Territorial) Forest Division, Umred Karhandla Wildlife Sanctuary, Tipeshwar Wildlife Sanctuary (TWLS), Pandharkawda Forest Division (Territorial), Painganga Wildlife Sanctuary and Bor Tiger Reserve. Vidarbha holds two-thirds of Maharashtra's mineral resources and three-quarters of its forest resources and is a net producer of power. It has a forest cover of 28% and a tiger number of 315 despite having a human population of more than 5.2 million.

Tipeshwar WLS is a small protected area, nestled in the rugged hillocks of Southern Vidarbha. The Sanctuary lies in the Yavatmal district of Maharashtra, within the Pandharkawada Tehsil. The Sanctuary has a geographic area of 148.63 km^2 (Fig. 2) and lies within the confines of 78°20'22'' to 78°47'56'' East (longitude) and 19°50'59'' to 19°55'44'' North (Latitude) (Wanjari et al. 2013). The Sanctuary got its name from 'Goddess Tipai', who is worshipped in the region and also has a temple dedicated to her, inside the sanctuary. The sanctuary lies very close to the state border dividing Telangana and Maharashtra.

There are plenty of rivers such as Purna, Krishna, Bhima, and Tapti that feed into the sanctuary. With water coming in from these rivulets, the sanctuary acts as a 'Green Oasis' in an otherwise dry region. The region is rich in black cotton soil and it is no wonder that cotton is the major cash crop for farmers in the region. The Sanctuary is also home to a diverse set of flora and fauna. The sanctuary is largely isolated and has limited connectivity with Kawal Tiger Reserve in Telangana to the South and Melghat Tiger Reserve to the North.

Majorly, Tipeshwar forests can be classified as tropical dry, and moist deciduous. The forest is dominated by Teak (Tectona grandis) along with other species like Dhawada (*Anogeissus latifolia*), Ain (*Terminalia alata*), Tendu (*Diospyros melanoxylon*), Sehna (*Lagerstroemia parviflora*), Bherra (*Chloroxylon switenia*), Kallam *(Mitragyna parviflora*), Beheda *(Terminalia bellirica*), Salai (*Boswellia serrata*), Bija (*Pterocarpus marsupium*), etc. The forest is a mosaic of woodlands along with lush meadows.

Tipeshwar is also home to a host of faunal species like Tiger (*Panthera tigris*), Leopard (*Panthera pardus*), Dhole (*Cuon alpinus*), Wolf (*Canis lupus*), Golden Jackal (*Canis aureus*), Sloth Bear (*Melursus ursinus*), Striped Hyaena (*Hyaena hyaena*), Jungle Cat (*Felis chaus*), Bengal Fox (Vulpes bengalensis*)*, Honey badger (Mellivora capensis), Wild Boar (*Sus scrofa*), Rhesus Macaque (*Macaca mulatta*), Langur (*Semnopithecus spp.),* Sambar (*Rusa unicolor*), Nilgai (*Boselaphus tragocamelus*), Four Horned Antelope (*Tetracerus quadricornis*), Chinkara (*Gazella bannettii*), Blackbuck (*Antilope *cervicapra*), Ratel (*Mellivora capensis*), and Pangolin (*Manis crassicaudata*). The reserve is home to 180 species of birds, 29 species of mammals, a host of Arachnids and 26 species of reptiles.

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 following objectives:

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 an occupancy-based framework. The data will be analysed 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 modeling 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 the capture-recapture framework. 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. These field surveys will be conducted in the entire Tipeshwar WLS area. The survey protocols and analyses of this data set will be based on the modelling and estimation approached 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 radio-telemetry. The information will be supplemented by data generated by camera trap surveys.

e) Scat analysis is an indirect, non-invasive, and unbiased technique for recording the 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

The photo database generated by the methodology delineated 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

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

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

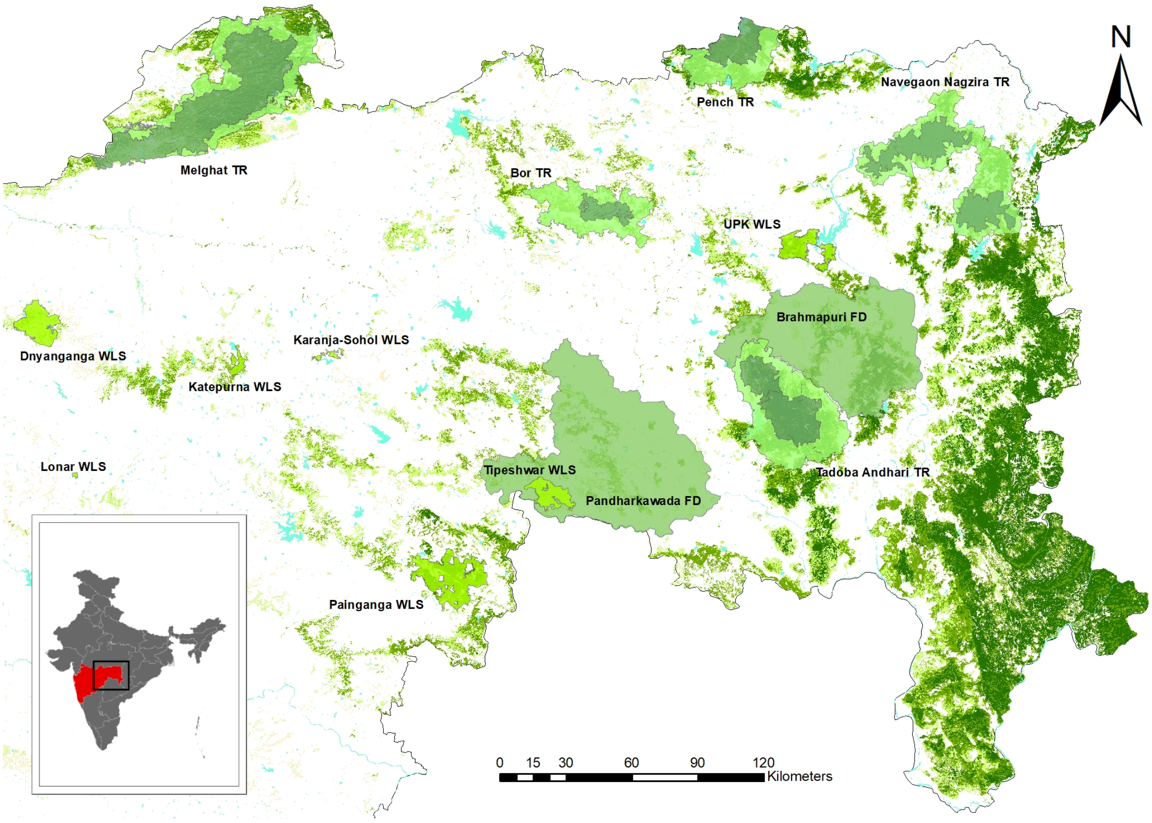


Figure 1: Landscape map of Vidarbha, Maharasthra showing Tipeshwar Wildlife Sanctuary.

2. Status of Prey in Tipeshwar Wildlife Sanctuary

Introduction

The presence of wild herbivores is crucial for the survival of large carnivores (O'brian et al. 2003). It has been observed that herbivore density and abundance play an important role in determining the distribution of large carnivores. Herbivores also play a vital role by influencing the vegetation structure and the nutrient cycle in an ecosystem (Valeix et al. 2007). That is why maintaining a healthy population of herbivores is very important to conserve the predator population and also the habitat of the species. For that, the estimation of the prey density is so important, both for management purposes and ecological study purposes. But, due to many field conditions and the elusive nature of the ungulate, difficulties arise to estimate the population.

Among many techniques like dung count, strip transects, track count, etc. line transect-based distance sampling has been found to be the most robust method to estimate the abundance and density of wild ungulates (Jathanna et al. 2003).

Distance sampling

Distance sampling is the most established method to estimate the density of prey species in an area using line transect. Transects lines of uniform, pre-determined lengths are laid randomly covering all the vegetation and terrain types of the study area. All the animals (species, sex, number, age class) that are observed during the walk are recorded along with the habitat, terrain type features, perpendicular distance from the line and GPS coordinates.

A total of 13 transects of 2km length are marked in 13 beats of Tipeshwar wildlife sanctuary (TWLS) (Table 1). Transects are randomly distributed all over the 148 sq. km. area of the Sanctuary (Figure 2). Each transect is walked 7 times (in January 2021). A total of 182 km of effort has been invested (Table 2) in line transects and a total of 112 observations of all types of major herbivore species have been recorded.

Table 1: No. of transects in each range

Sr. no	Range	Total number of transects in each range
1	Parwa	6
2	Patanbori	7

Table 2: Transect monitoring effort and species reported from Tipeshwar WLS during Phase IV Monitoring,2021

Survey details	
Number of transects	13
Length of each transect	2 km
Number of replicates	7
Total distance covered	182
Beats	13
Number of species recorded	10

The observations include chital (*Axis axis*), sambar (*Rusa unicolor*), nilgai (*Boselaphus tragocamelus*), chousingha (*Tetracerus quadricornis*), Langur (*Semnopithecus sp*), Wild boar (*Sus scrofa*), Indian hare (*Lepus nigricollis)*, peafowl (*Pavo cristatus*), Chinkara (*Gazella bennetii*) and Blackbuck (*Antilope cervicapra*).

As per the observations, Nilgai (n=50) is the most observed species followed by chital (n=27). The table below shows the number of observations for each species and the total number of individuals observed of each species (Table 3).

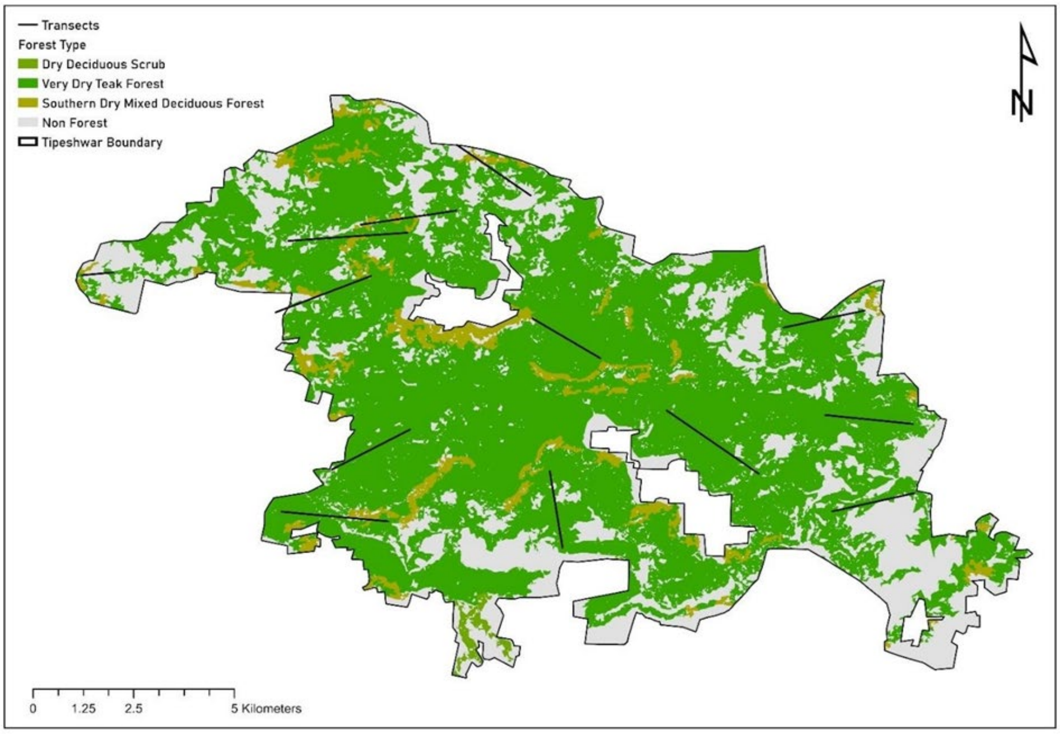


Figure 2: Map of Tipeshwar WLS (Tipeshwar WLS) showing transect lines surveyed during Phase-IV Monitoring 2021

Table 3: No. of observations and the total number of individuals seen of different species

Sr. No	Species	No. of observations	Total no. of individuals observed
1	Nilgai	50	145
2	Chital	27	99
3	Wild boar	3	7
4	Chousingha	5	8
5	Chinkara	2	4
6	Blackbuck	4	16
7	Indian Hare	1	1
8	Langur	8	50
9	Peafowl	11	24
10	Sambar	1	1

Table 4: Density, group density, Effective strip width, average group size, P-value of major prey species in Tipeshwar WLS

Parameters	Overall prey	Nilgai	Chital
Density(individual/sq.km)	17.558	5.9560	9.4669
Standard error	3.8192	1.4473	3.9290
Percent CV	21.75	24.30	41.50
95%CI	11.257-27.387	3.6571-9.700	4.1694-21.495
Group density (Number of groups/sq.km)	5.6812	2.0379	2.1003
Standard error	1.1417	0.43103	0.77862
Percent CV	20.10	21.15	37.07
95%CI	3.7334-8.6451	1.3160-3.156	0.98513-4.4776
Effective strip width (ESW) in meters	52.226	63.359	35.318
Percent CV	8.06	9.94	15.21
95%CI	44.520-61.265	51.890-77.63	25.883-48.191
Average group size	3.2130	2.9574	3.6667
Standard error	0.23499	0.43103	0.84101
Percent CV	7.31	21.15	13.34
95%CI	2.7799-3.7135	1.3160-3.1558	2.7906-4.8178
Probability of a greater chi square value (P)	0.97665	0.86638	0.70814

The overall prey density of Tipeshwar WLS is 17.558 individuals per sq. km (Table 4). Chital has the highest density of 9.46 (± 3.92) individuals per sq. km followed by Nilgai having the density of 5.995 (±1.447). Due to a low number of observations (n<20) density of sambar, chousingha, peafowl, langur, wild boar, blackbuck, and chinkara could not be estimated. Detection function graphs for major prey species are given further ahead in the report (Figure 3). The comparison of densities of prey species in Tipeshwar WLS between 2020 and 2021 is given in Table 5.

Table 5: Comparison of density of prey species in Tipeshwar WLS (2020 and 2021)

Species	Density in 2020	Density in 2021
All species	***NA***	17.558
Chital	1.73	9.4669
Nilgai	9.977	5.9560

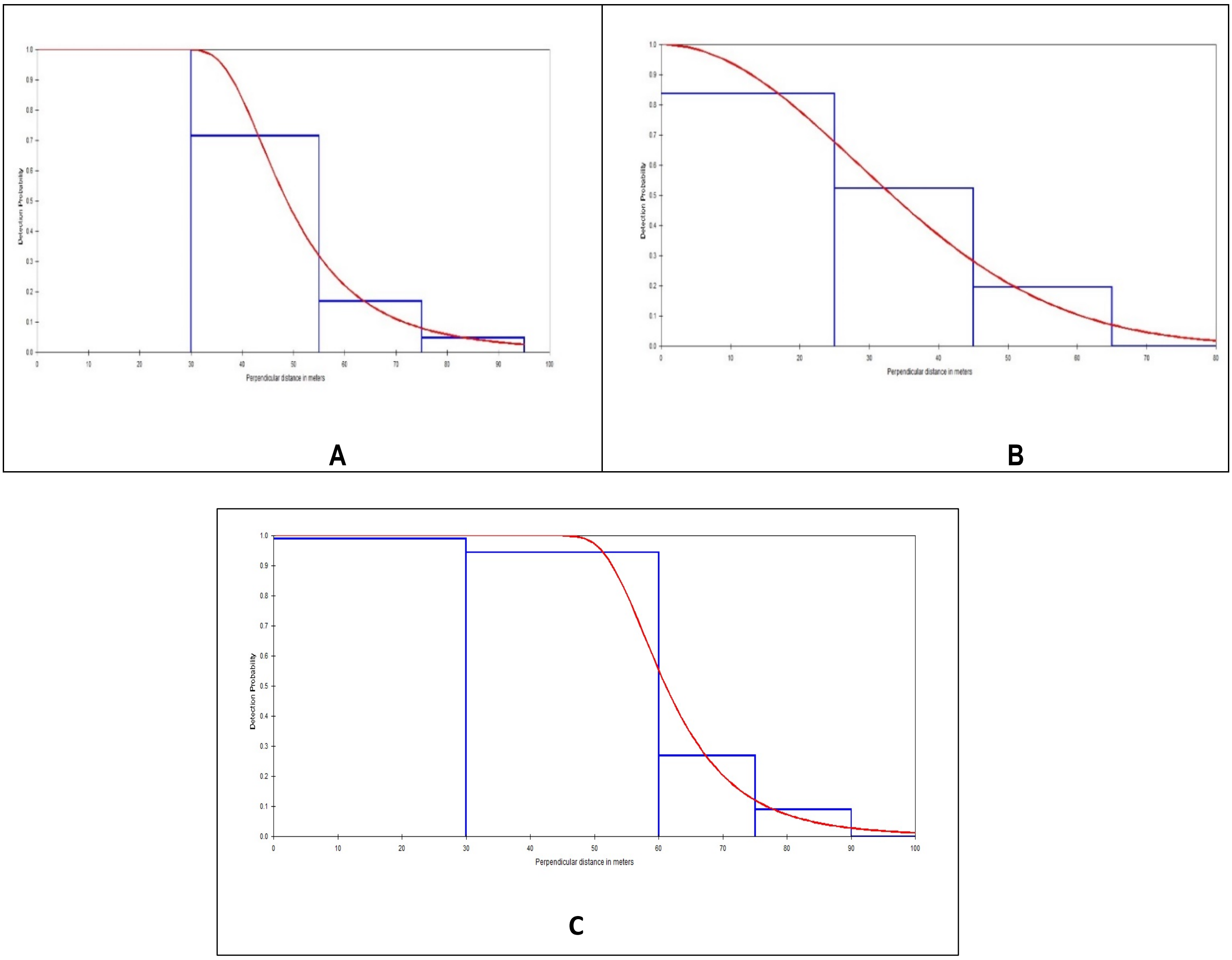


Figure 3: Detection functions of the best-selected model for prey species during prey estimation survey in TWLS, Phase-IV monitoring, 2021 A) All prey species, B) Chital and C) Nilgai.

3. Status of Predator in Tipeshwar Wildlife Sanctuary

Introduction

The persistence of an ecosystem is majorly dependent on its biodiversity. Predators play a crucial role in maintaining the ecosystem's health (Talbot, 1978). The ecological role of predators is widely recognized because they exert a top-down effect that controls the population of other animals. The conservation of tigers is difficult because of their elusive nature, long-ranging behaviour, low detectability of indirect signs. Especially, it is hard to infer the absence of tigers based on the signs. The collection of quantitative data on the abundance of tigers is limited by small data size, low detectability, and many other logistical issues.

Camera Trapping

The success of camera trapping depends on the sites chosen for deploying the camera traps. The traps are deployed at trails, dried streams, dirt roads, etc. to maximize the probability of capturing the target animal. Before camera trapping, a survey is done in the area to look for signs like pugmarks, scat, rake marks, scrape marks, etc. Since there is already an established system of patrolling and recording in Tipeshwar WLS, the camera trap sites were chosen based on the data collected by the forest department staffs. The exercise followed the protocol prescribed by Karanth and Nicholes (1998). Potential locations for the camera traps were mapped using ArcGIS Pro. The size of the grid was 2 sq. km (1.42 km x 1.42 km). A total of 62 sites were chosen for the camera trap deployment (Figure 4). A pair of Cuddeback (C1 & Ambush) cameras were deployed at each site facing each other to capture both of the flanks of the tiger, leopard, and other co-predators. The camera traps were tied up on tree trunks 35-40 cm (knee height) above the ground. Each camera was set at no delay, multiple shot mode. It should be mentioned that both cameras should not face each other directly because the flash from one might burn the image of the other. The tigers are identified individually by matching their stripe patterns with each other. The existing tiger booklet has been used to do that. Similarly, leopards are identified individually by matching their rosette pattern.

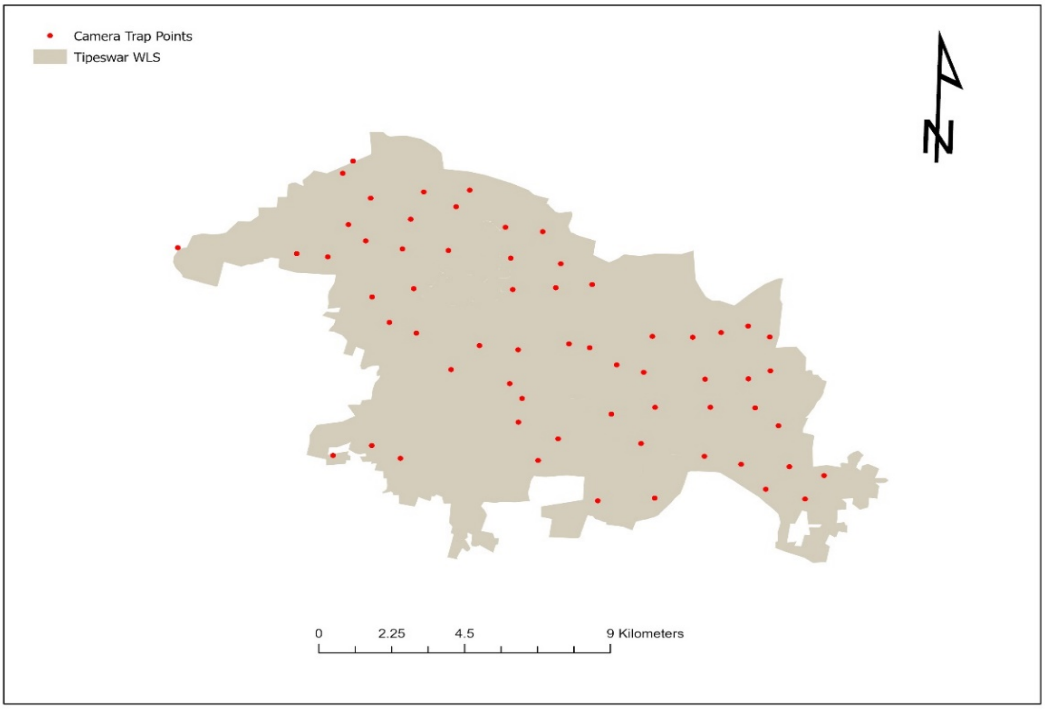


Figure 4: Camera trap locations at TWLS surveyed during phase-IV monitoring 2020-21

Each camera trap was operational for 24 hours. Each trap was given a unique ID and each capture recorded the time, date, and temperature of every occasion. Every tiger and leopard were given a unique id after examining the stripe and rosette patterns respectively. For the closed population estimation, there is one critical assumption which is that the population is supposed to be demographically and geographically closed (Otis et al. 1978). To maintain that, the sampling effort was kept minimum (25-30 days). Capture history was analysed using the R package of 'secr' (Efford, 2015) using a model developed for closed populations. The best model was chosen based on the Akaike information criteria (AIC). The density was estimated with the maximum likelihood calculated from the model fitted with 'SECR'.

Population estimation of predators

During 30 days of camera trapping for tigers and co-predators, a total sampling effort of 2206 trap nights in Tipeshwar wildlife sanctuary. For estimating the density, we used Spatially Explicit Capture-Recapture (SECR) method.

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 (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. 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.

Tiger density per 100 sq.km based on SECR heterogeneity model was estimated to be 7.07 (SE ±0.21) and leopard density per 100 sq.km based on SECR null model was estimated to be 3.86 (SE ±0.16) for Tipeshwar WLS. The best model for the density estimate is chosen according to the AIC (Akaike Information Criterion). Details are given in Table 6. Table 7 shows the comparison of tiger and leopard densities in Tipeshwar WLS in 2020 and 2021. MCPs of tigers and leopards in Tipeshwar WLS are given in Figures 5 - 8.

Table 6: Density estimates of tigers and leopards using Spatially Explicit Capture-Recapture Models in Tipeshwar WLS, Maharashtra, India for the year 2020-21.

Parameters	Tiger	Leopard
Model	Heterogeneity	Null
Detection Function	Half-normal	Half-Normal
Density Estimate (Individuals/100 sq.km)	7.07	3.86
Density SE	0.218	0.165
Density CI	3.9- 12.7	1.70-8.6
g0 Estimate (pmix1)	0.1045	0.017
g0 Estimate (pmix2)	0.045	0.017
g0 SE(pmix1)	0.0123	0.004
g0 SE(pmix2)	0.0071	0.004
g0 CI (pmix1)	0.083-0.131	0.01-0.028
g0 CI (pmix2)	0.033-0.0616	0.01-0.028
Sigma Estimate(pmix1)	1.743km	2.747km
Sigma Estimate(pmix2)	2.494km	2.747km
Sigma SE(pmix1)	0.096km	0.33km
Sigma SE(pmix2)	0.183km	0.33km
Sigma CI(pmix1)	1.565-1.943km	2.166-3.482km
Sigma CI (pmix2)	2.16-2.88km	2.166-3.482km
Estimated Population	11	6
Estimate population SE	0.72	0.767
Estimated population CI	11-14	5 -10

Table 7: Comparison of density of tiger and leopard in Tipeshwar WLS (2020 and 2021)

Species	2020	2021
Tiger (individuals/100km^2)	6.18 (+/- 1.637)	7.07(+/- 0.218)
leopard	2.39	3.86

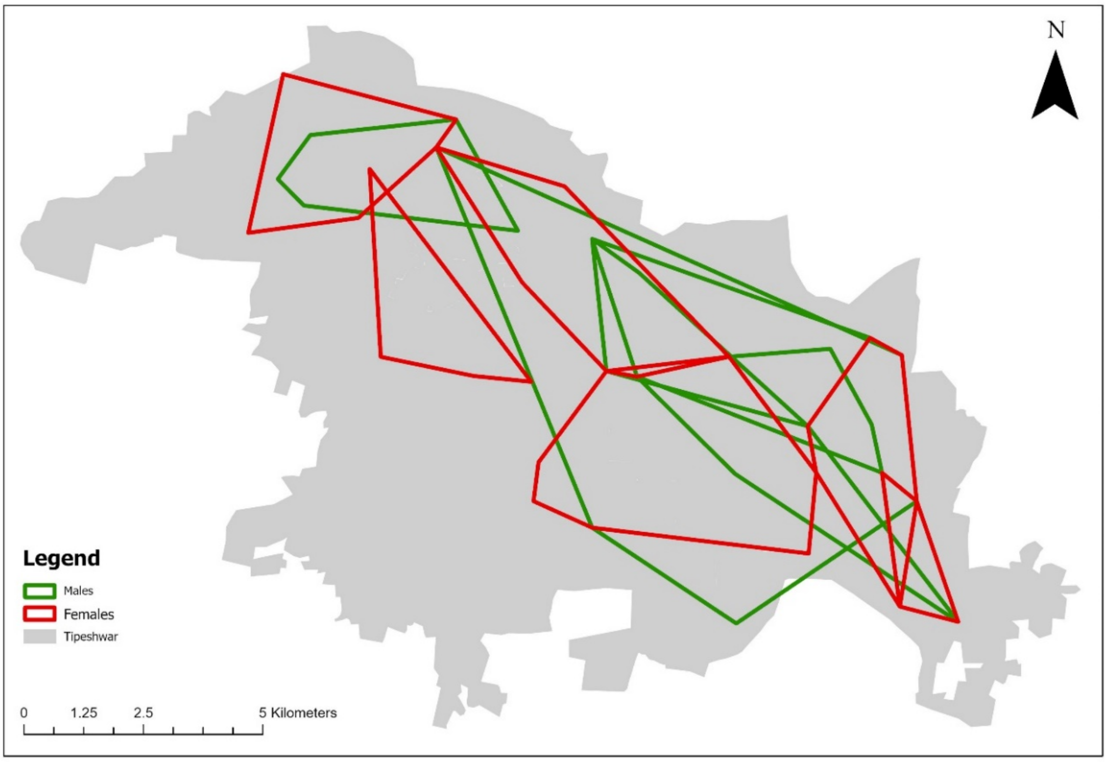


Figure 5: Minimum Convex Polygon of Male and Female tigers of Tipeshwar WLS, Phase-IV monitoring, 2021

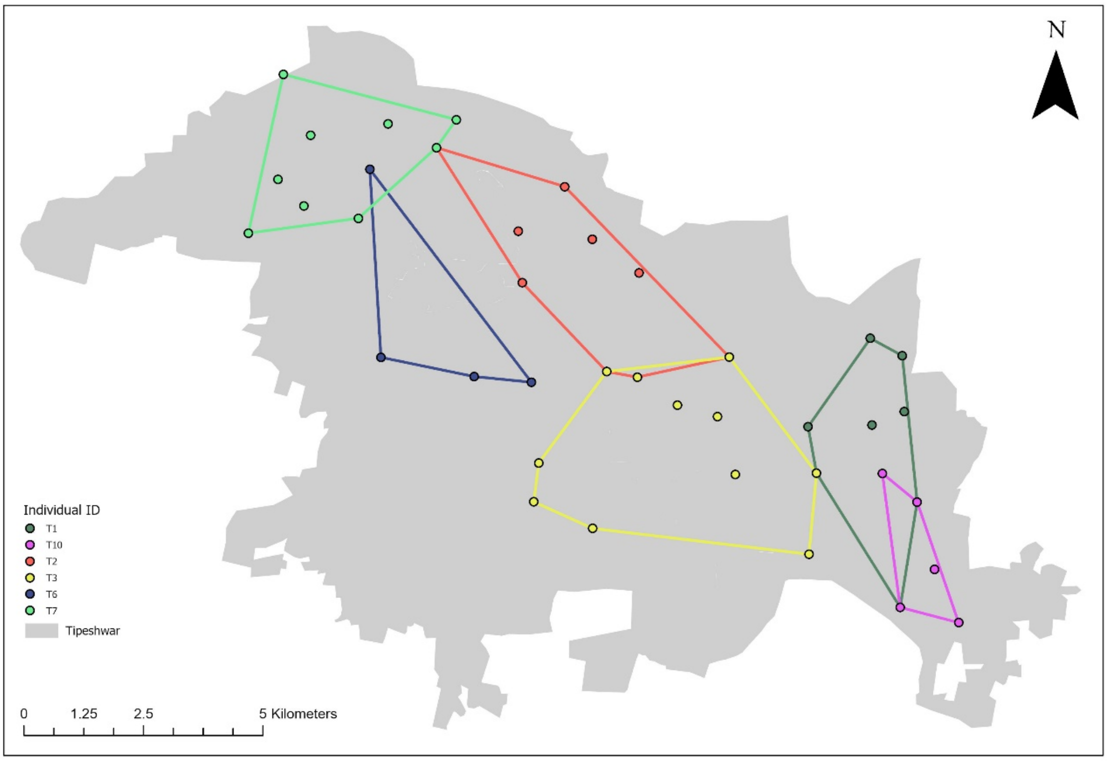


Figure 6: Minimum Convex Polygon of Female tigers of TWLS, Phase-IV monitoring, 2021

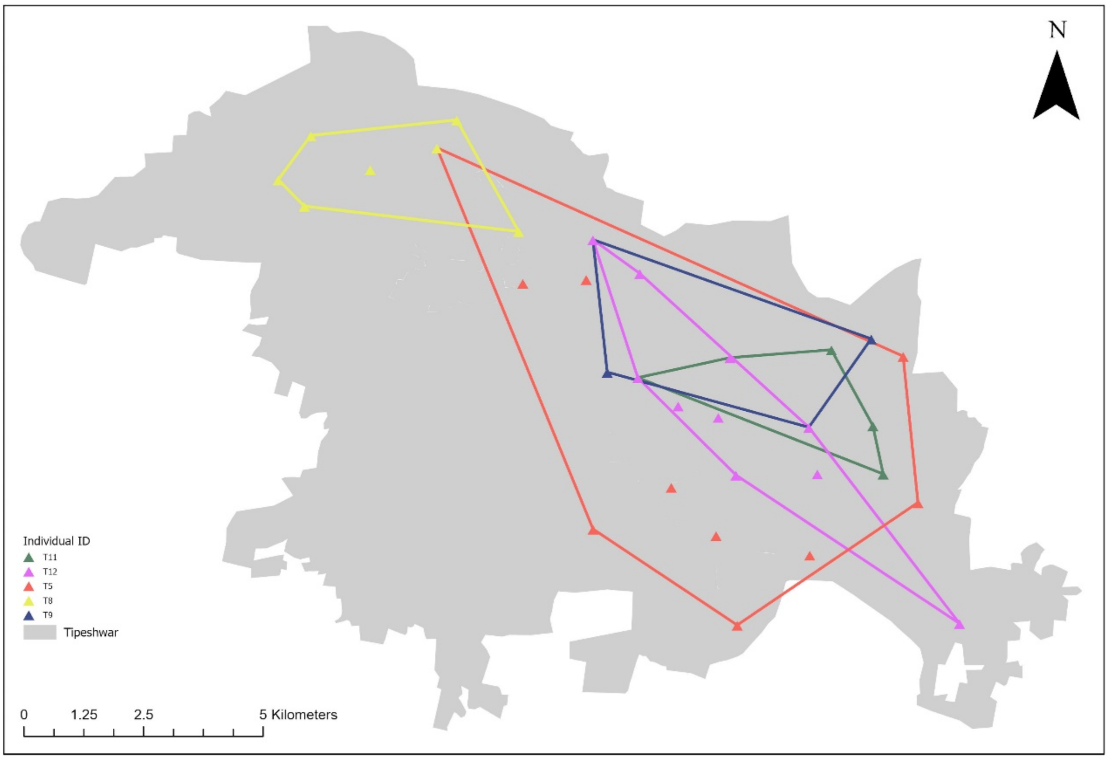


Figure 7: Minimum Convex Polygon of male tigers of Tipeshwar WLS, Phase-IV monitoring, 2021

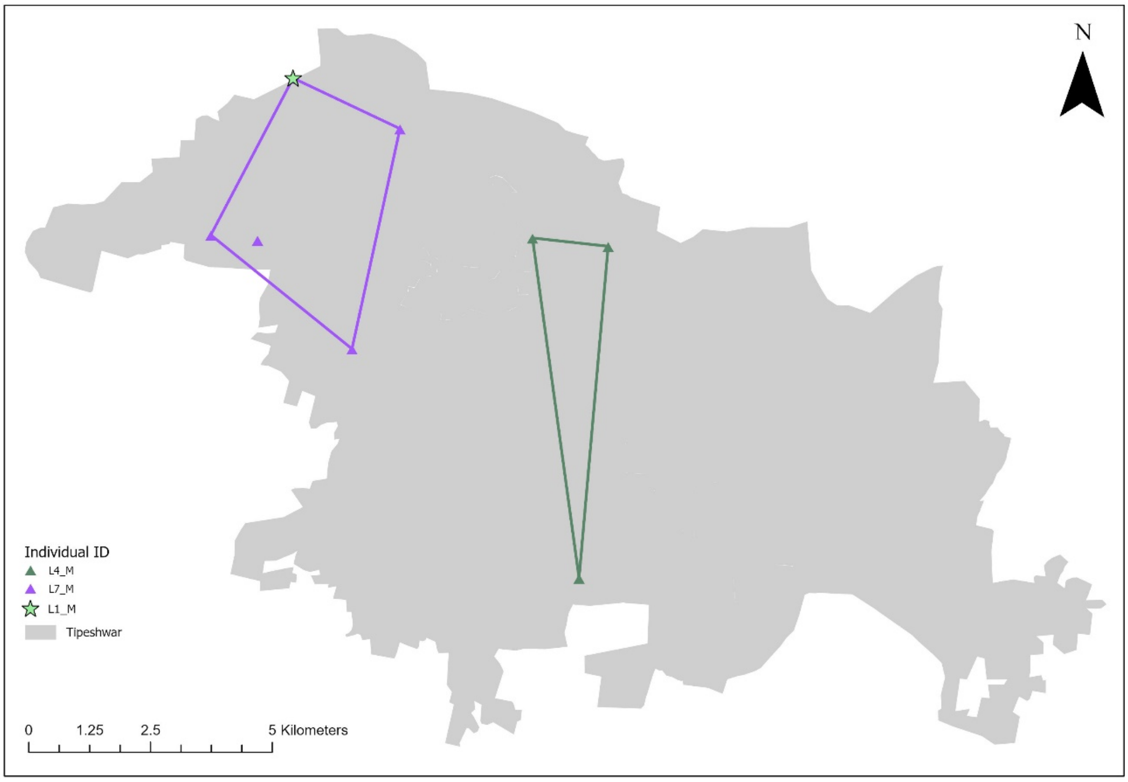


Figure 8a: Minimum Convex Polygon Male leopards of Tipeshwar WLS, Phase-IV monitoring, 2021

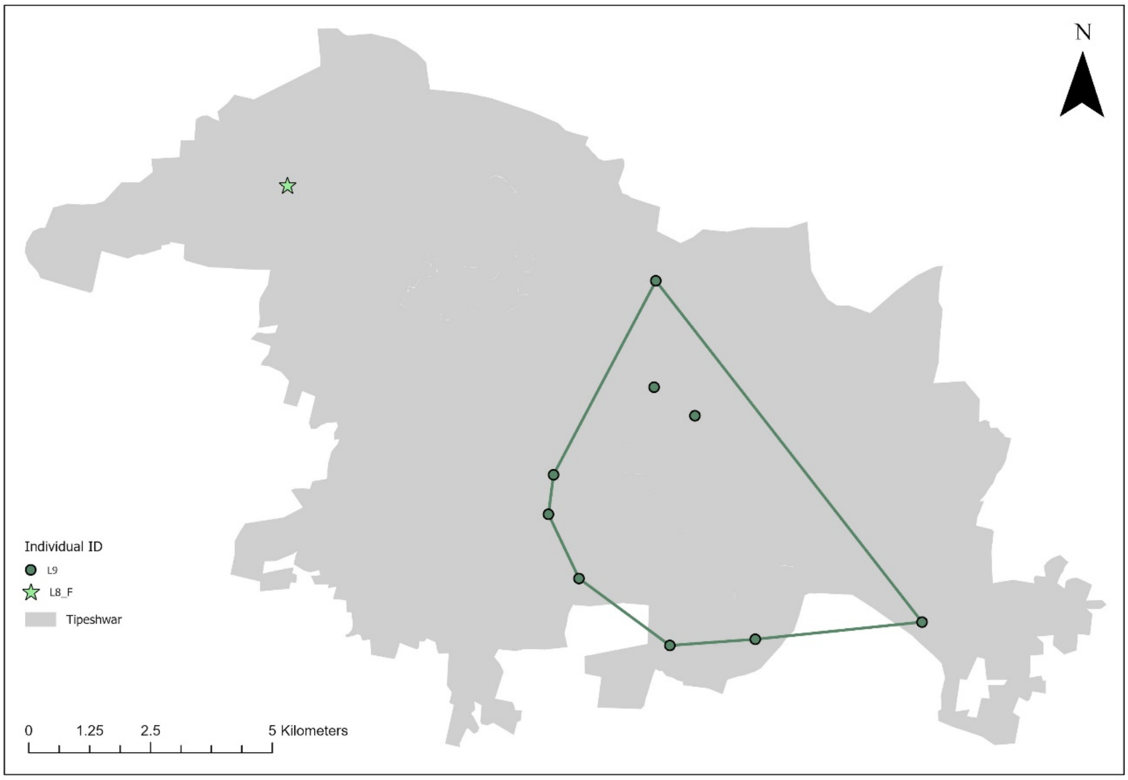


Figure 8b: Minimum Convex Polygon Female leopards of Tipeshwar WLS, Phase-IV monitoring, 2021

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

Introduction

Camera trap locations with the 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 (Figure) 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. Intensive use areas of various species in Tipeshwar WLS are given in Figures 10 – 21.

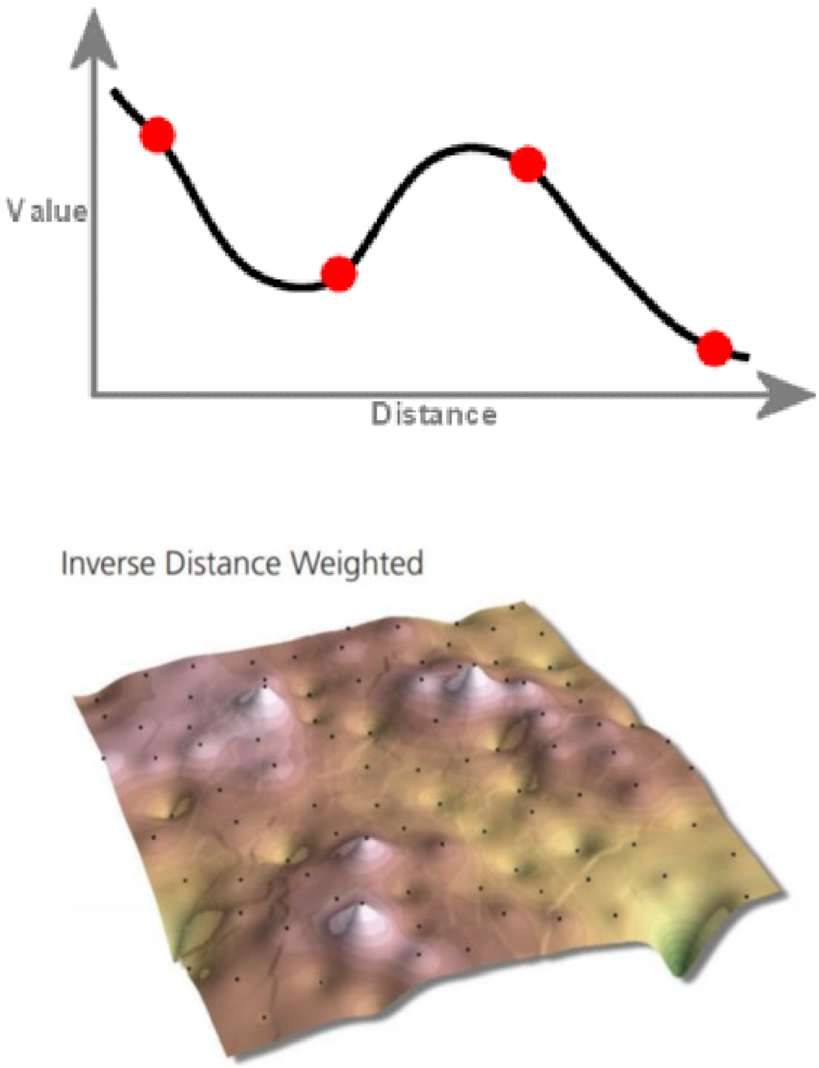


Figure 9: Visual representation of Inverse distance weighted (IDW)

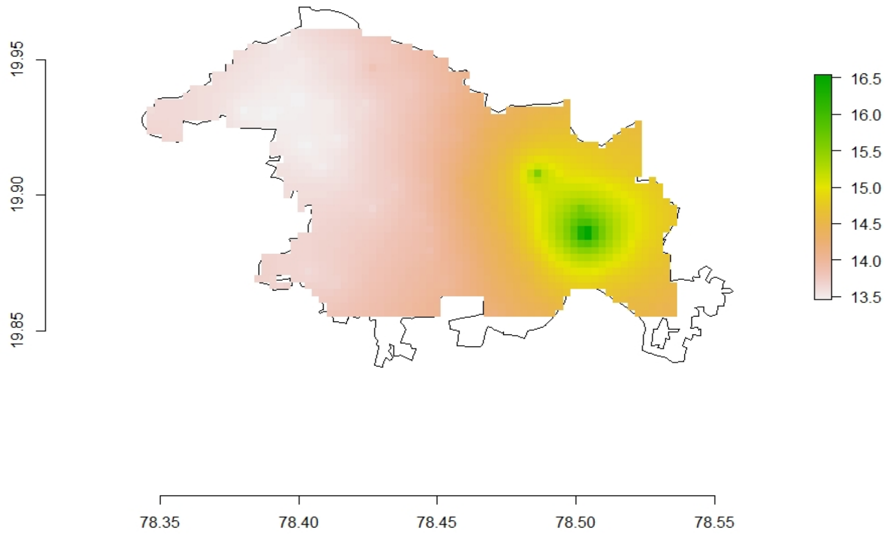


Figure 10: Intensive area used by tiger in Tipeshwar WLS, Maharashtra

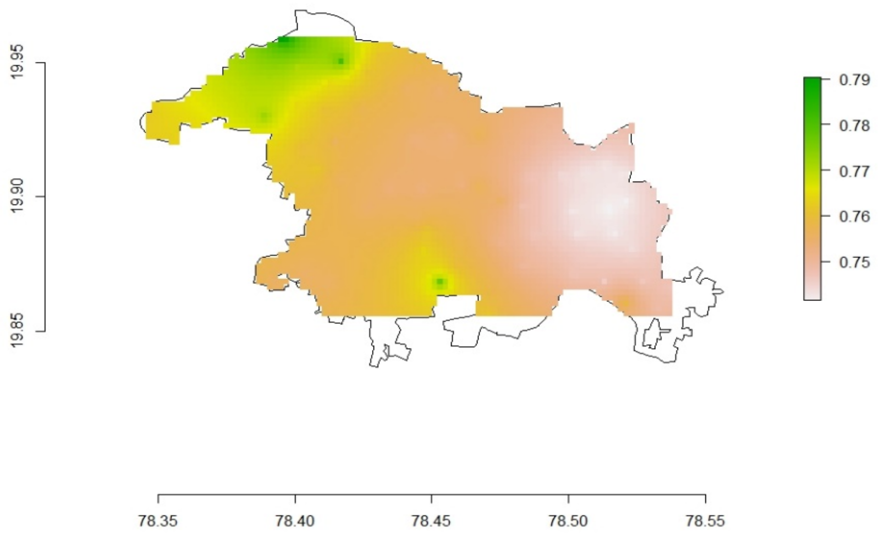


Figure 11: Intensive area used by leopard in Tipeshwar WLS, Maharashtra

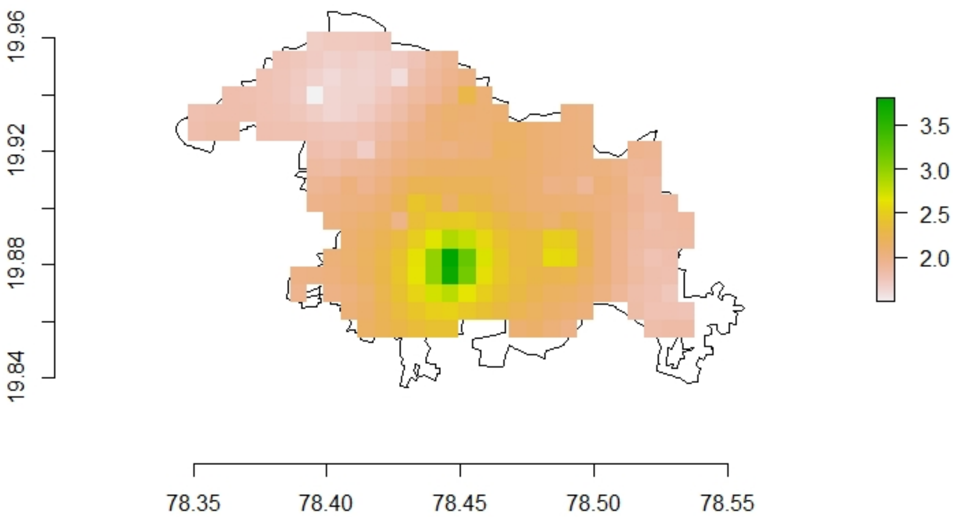


Figure 12: Intensive area used by Sloth Bear in WLS, Maharashtra

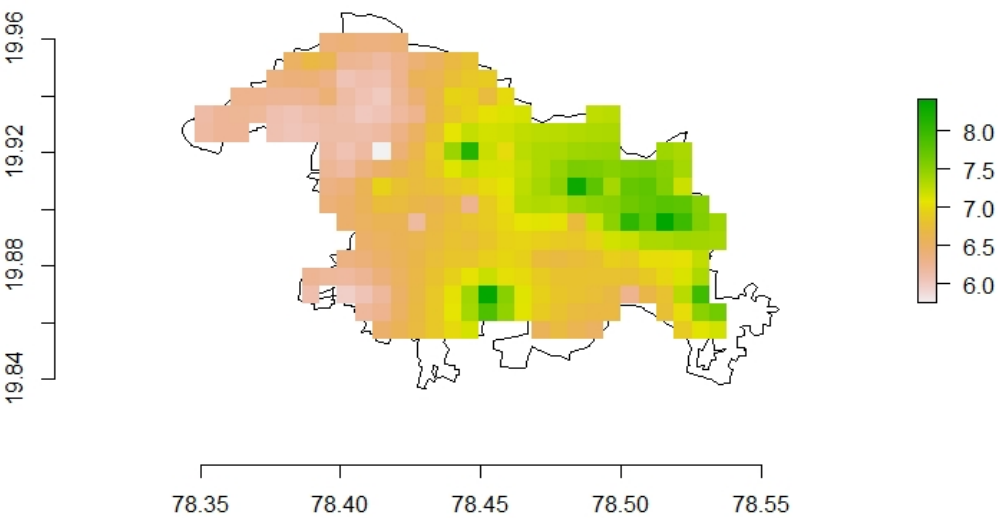


Figure 13: Intensive area used by Jungle Cat in Tipeshwar WLS, Maharashtra

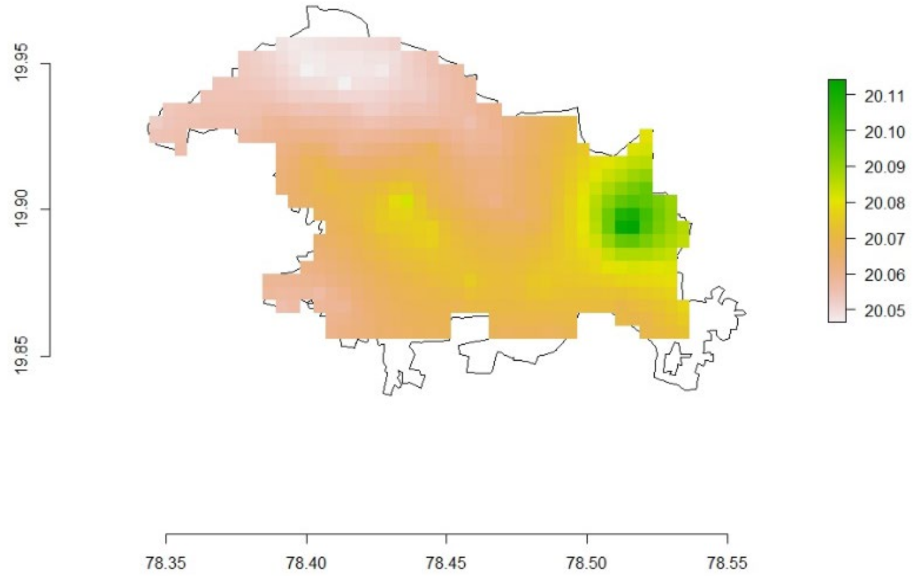


Figure 14: Intensive area used by Nilgai in Tipeshwar WLS, Maharashtra

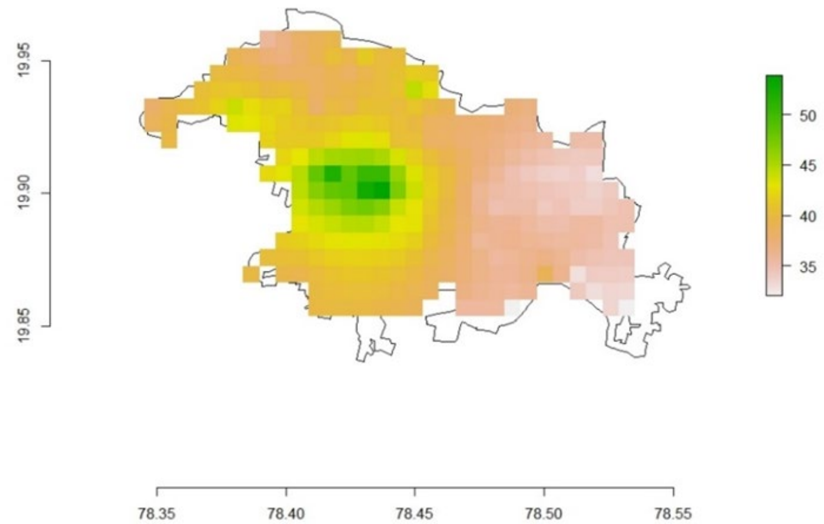


Figure 15: Intensive area used by Wild boar in Tipeshwar WLS, Maharashtra

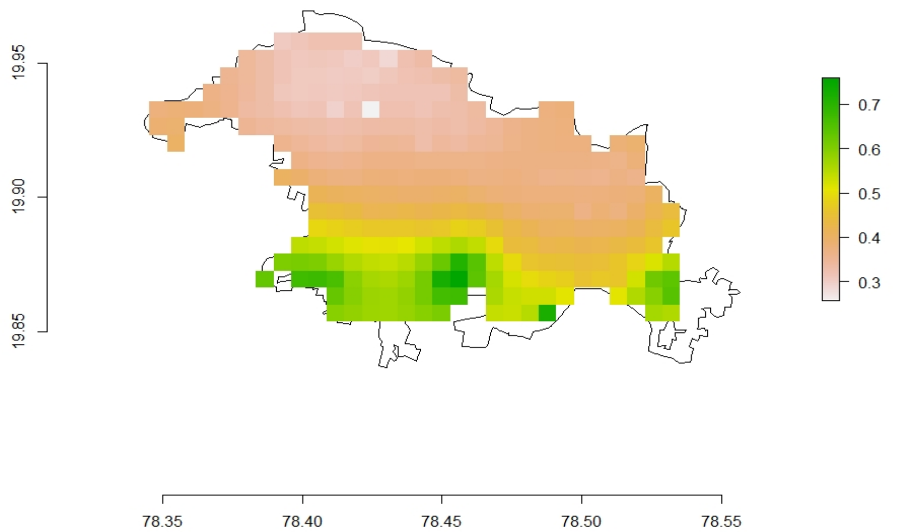


Figure 16: Intensive area used by Chousingha in Tipeshwar WLS, Maharashtra

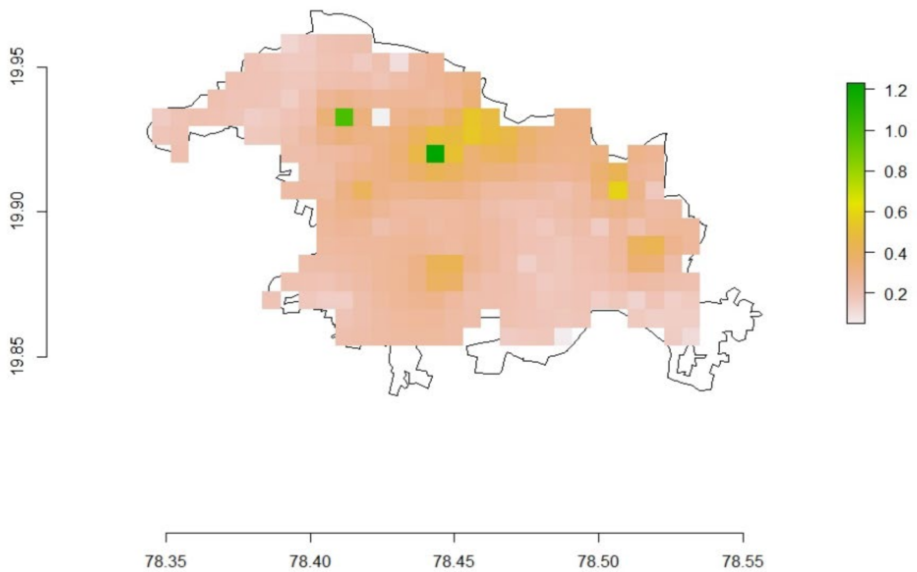


Figure 17: Intensive area used by Ratel in Tipeshwar WLS, Maharashtra

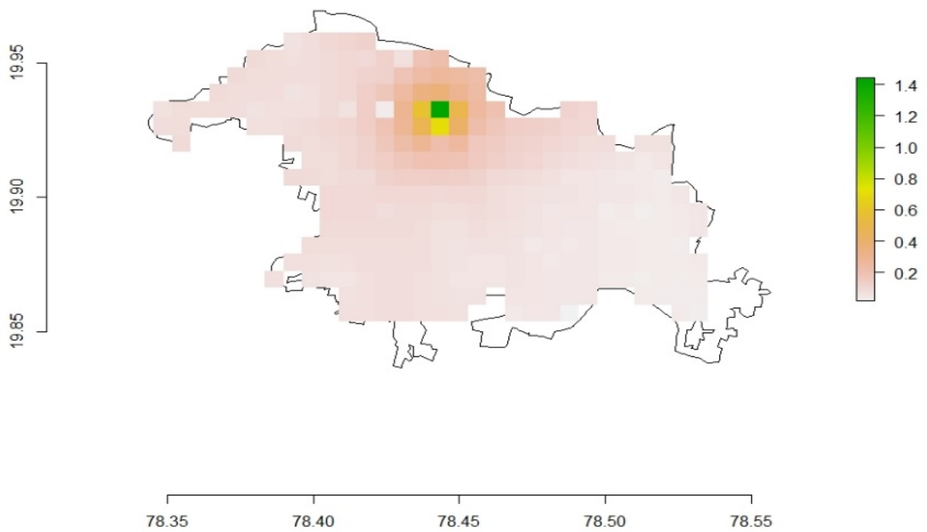


Figure 18: Intensive area used by Sambar in Tipeshwar WLS, Maharashtra

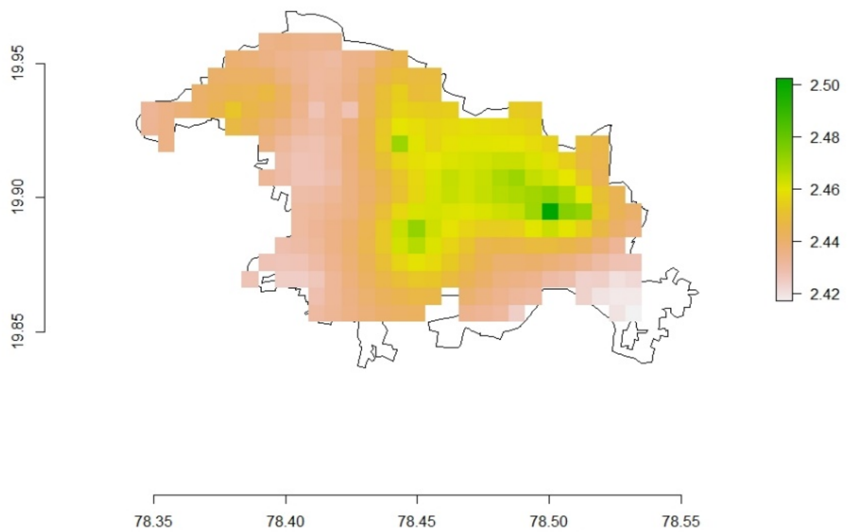


Figure 19: Intensive area used by Dholes in Tipeshwar WLS, Maharashtra

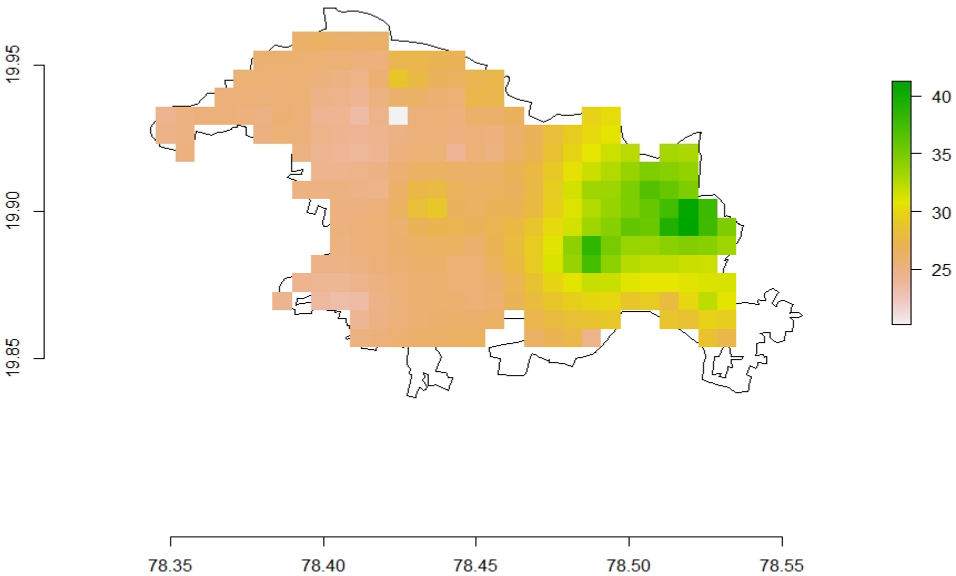


Figure 20: Intensive area used by Chital in Tipeshwar WLS, Maharashtra

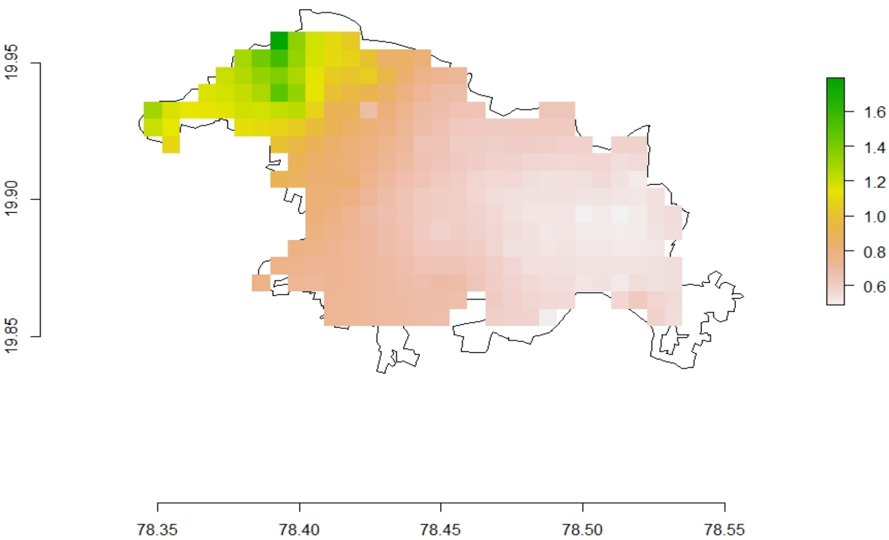


Figure 21: Intensive area used by Wolf in Tipeshwar WLS, Maharashtra

5. Temporal Activity of Predator and Prey Species in Tipeshwar Wildlife Sanctuary

Introduction

Predator and prey are involved in an evolutionary arms race which modifies their behaviour and activity. Predators always look to exploit the vulnerability of prey to maximize hunting success and prey, in response, trade-off optimal foraging area to avoid the predator. Depending on the intensity of the competition among the predators and the interaction with prey species the activity pattern changes (Lima 1988). Landscape characteristics also play a crucial role in shaping up this dynamic relationship. The activity of animals is primarily dependent on the 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. Time-stamped camera trap images are widely used to study the temporal activity pattern of different species in a community, such as a niche partitioning and activity overlap. The camera trap photographs have the time which shows when the animal was active. The number of photographs of a particular species will be more frequent in its activity period. Activity overlap indicates inter-specific competition or predation.

Methods and Results

The temporal pattern of the predators and their prey was analysed using R statistical software (version 3.6) and Microsoft Office Excel 2016. 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 $<1–\Delta$. 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.

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.

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

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

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

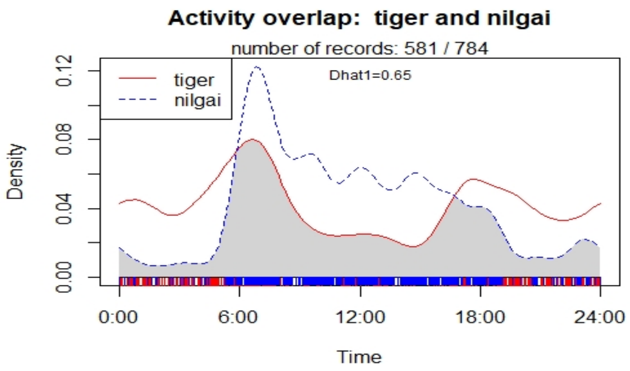
Where n, m are the sample sizes and I is the indicator function (1 if the condition is true, 0 otherwise).

The kernel density estimates of overlap of daily temporal activity patterns of different predator-prey species are shown in Table 8 and overlap of predator-predator species if given in Table 9. From the kernel density estimators, the tiger-wolf and tiger-dhole were observed to have a high degree (0.73 and 0.72 respectively) of overlap as indicated by the estimated overlap coefficients. Similarly, it has been observed that tiger has a high degree of overlap with chital (0.78) which is one of its main prey species. Dhole has also been observed to have a high degree of overlap with chital (0.73) whereas leopard has been observed to have highest degree of overlap with hares (0.70).

Table 8: Activity overlap of predator and prey in Tipeshwar WLS

Species	Tiger	Leopard	Dhole
Chital	0.78	0.38	0.73
Nilgai	0.65	0.27	0.61
Wild boar	0.79	0.48	0.72
Hare	0.52	0.70	0.45

Daily temporal activity overlap between the predator and prey species in Tipeshwar WLS, Maharashtra are given in the pages. The red and blue lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot (Figure 22 and Figure 23).



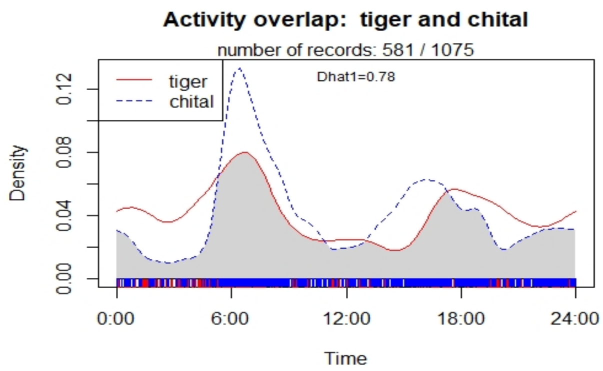
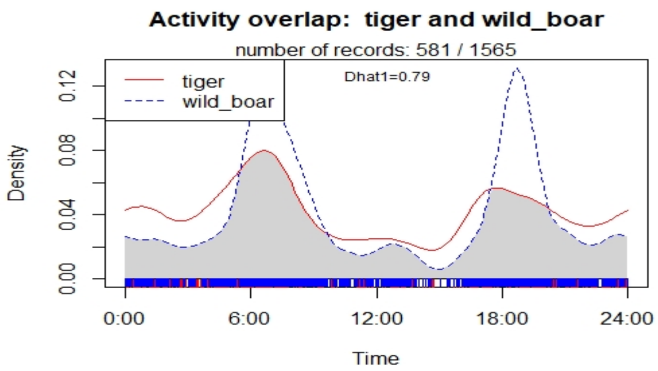


Figure 22a: Tiger vs Nilgai

Figure 22b: Tiger vs Chital



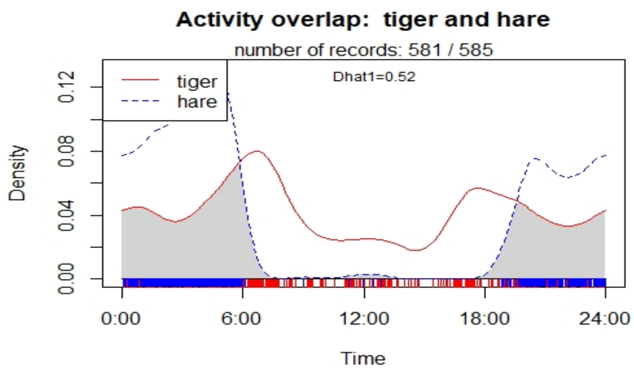
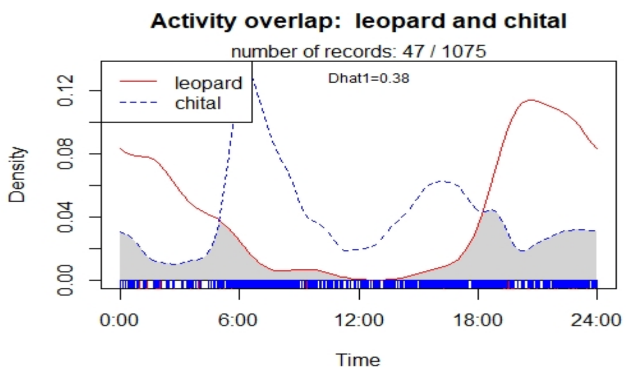


Figure 22c: Tiger vs Wild Boar

Figure 22d: Tiger vs Hare



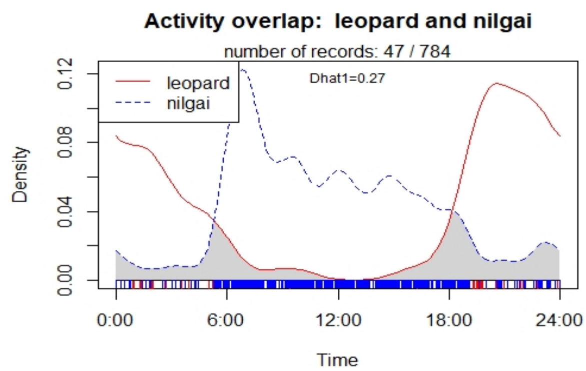
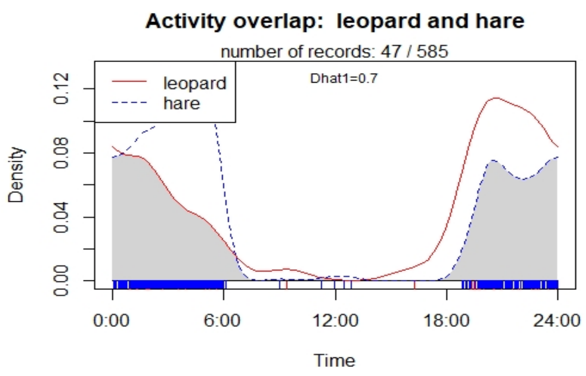


Figure 22e: Leopard vs Chital

Figure 22f: Leopard vs Nilgai

Figures 22 (a-f): Daily temporal activity overlap between the Predators (Tiger, Leopard and Dhole) and prey species in Tipeshwar WLS, Maharashtra during the year 2021



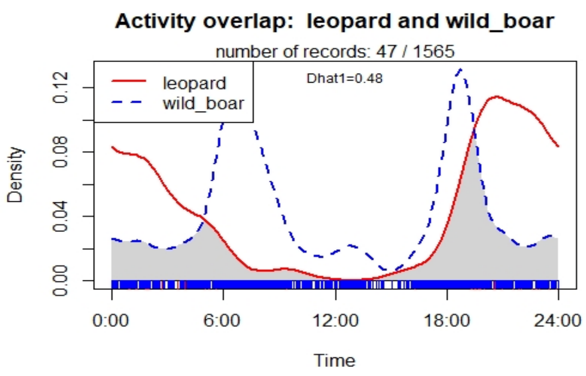
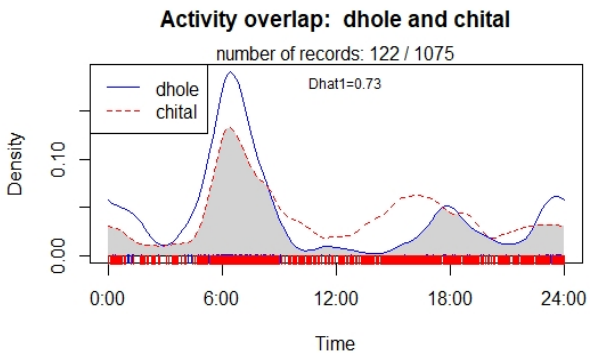


Figure 22g: Leopard vs Hare

Figure 22h: Leopard vs Wild Boar



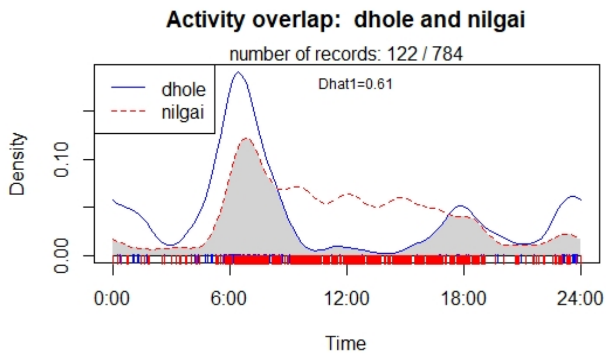
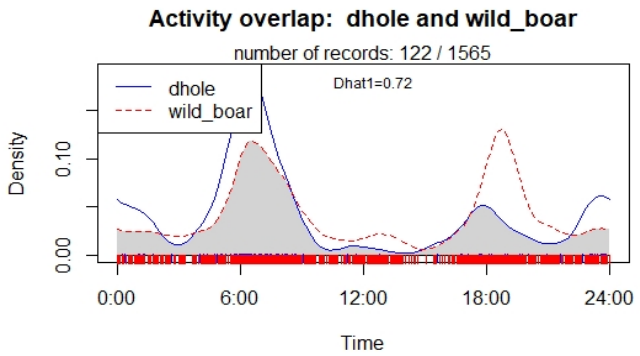


Figure 22i: Dhole vs Chital

Figure 22j: Dhole vs Nilgai



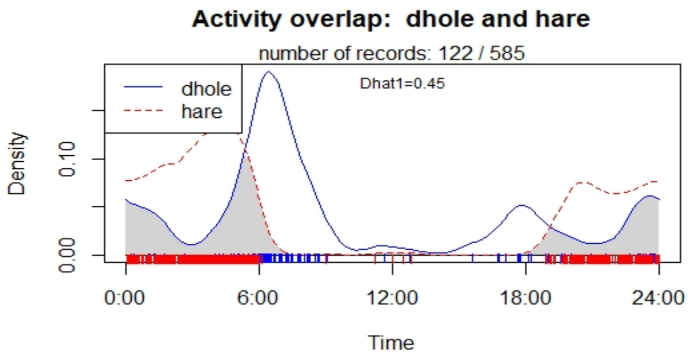
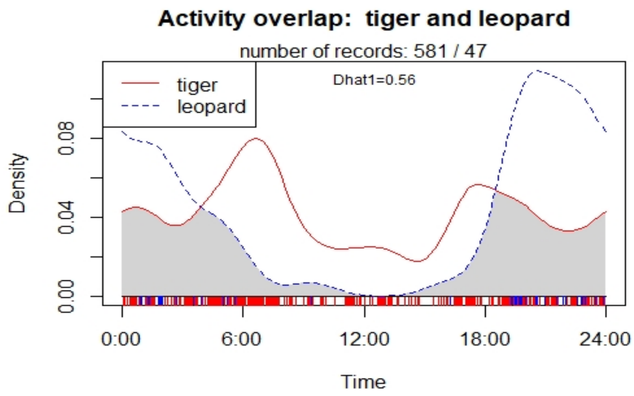


Figure 22k: Dhole vs Wild boar

Figure 22l: Dhole vs Hare

Figures 22 (g-l): Daily temporal activity overlap between the Predators (Tiger, Leopard and Dhole) and prey species in Tipeshwar WLS, Maharashtra during the year 2021



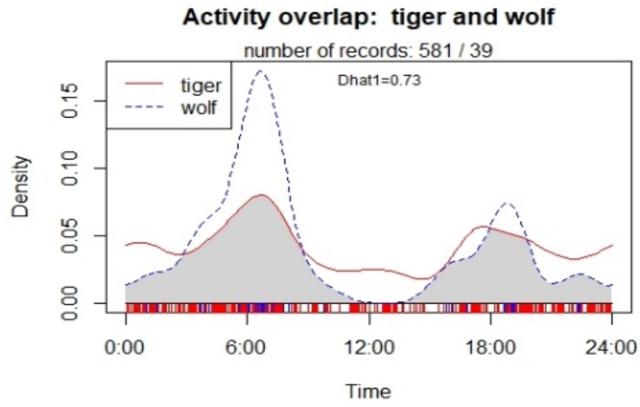
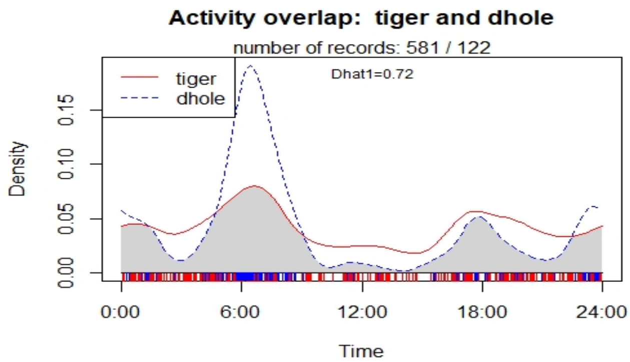


Figure 23a: Tiger vs Leopard

Figure 23b: Tiger vs Wolf



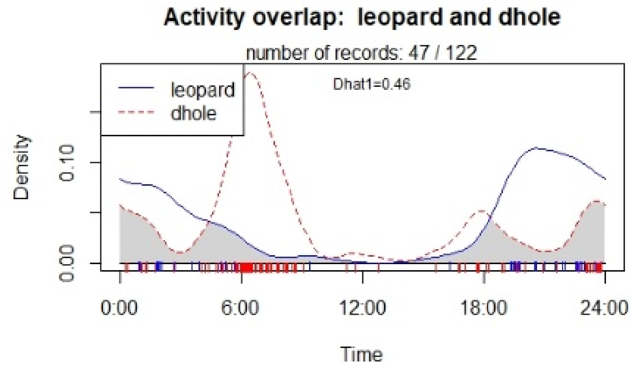
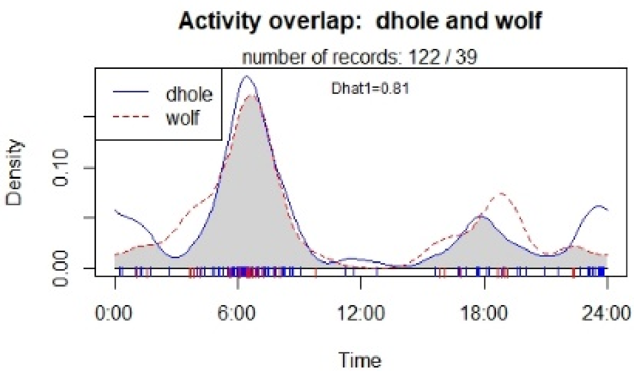


Figure 23c: Tiger vs Dhole

Figure 23d: Leopard vs Dhole



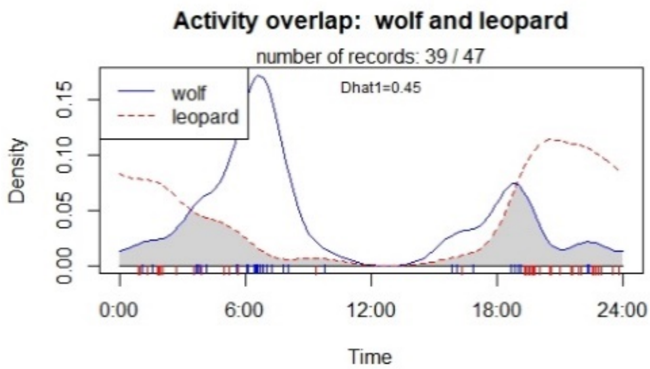


Figure 23e: Dhole vs Wolf

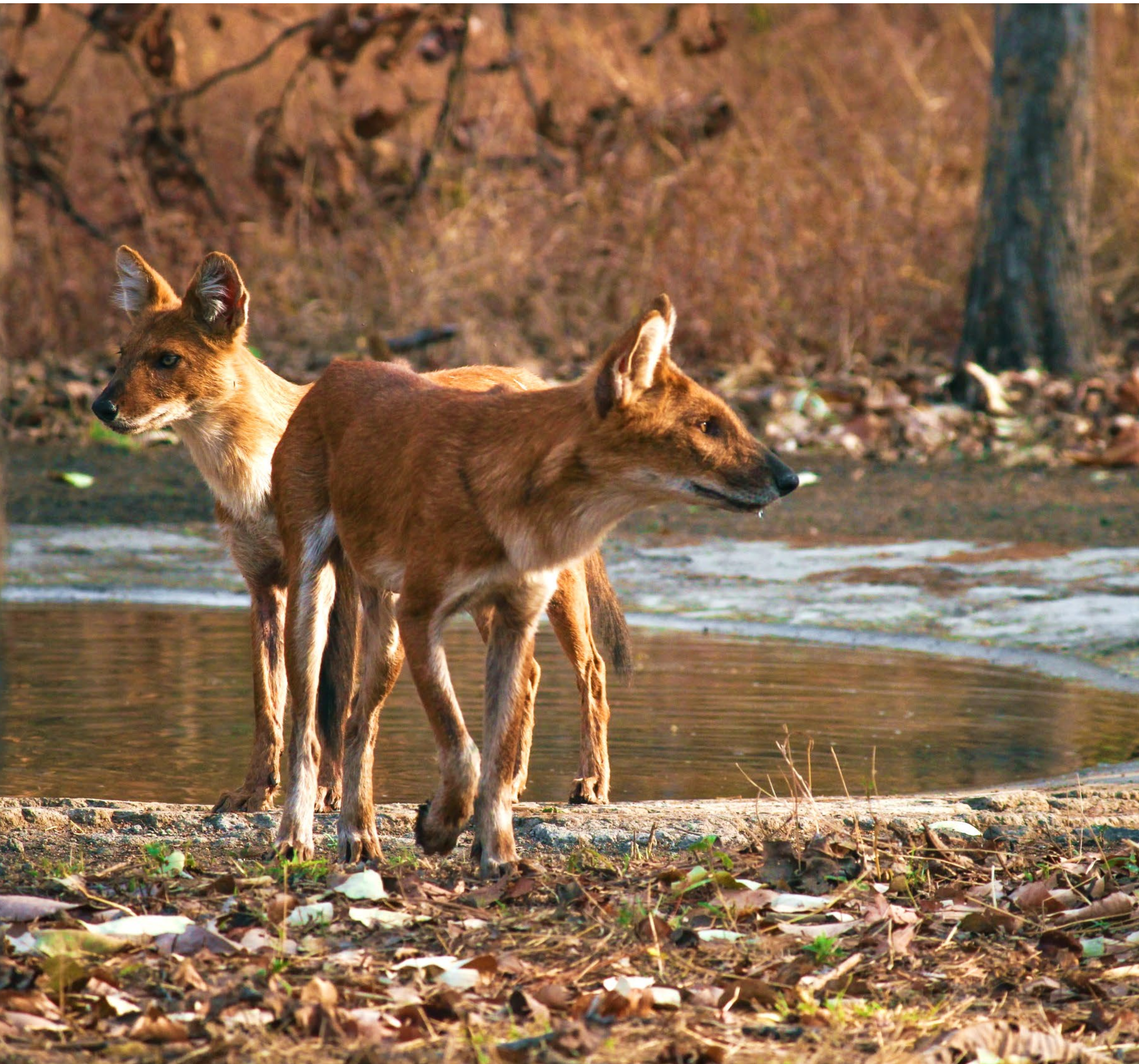
Figure 23f : Wolf vs Leopard

Figure 23 (a-f): Temporal activity overlap between predators in Tipeshwar WLS, Maharashtra.

The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot. Temporal activity overlap of predators of Tipeshwar WLS is given in Table 9.

Table 9: Temporal activity overlap among predators in Tipeshwar WLS, Maharashtra

Species	Tiger	Leopard	Dhole	Wolf	Sloth Bear
Tiger	NA	0.56	0.72	0.73	0.69
Leopard	0.56	NA	0.46	0.45	0.70
Dhole	0.72	0.46	NA	0.81	0.57
Wolf	0.73	0.45	0.81	NA	0.60
Sloth Bear	0.69	0.70	0.57	0.60	NA



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