2019

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

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Phase IV Monitoring Report 2019
Spatially Explicit Space Use and Activity

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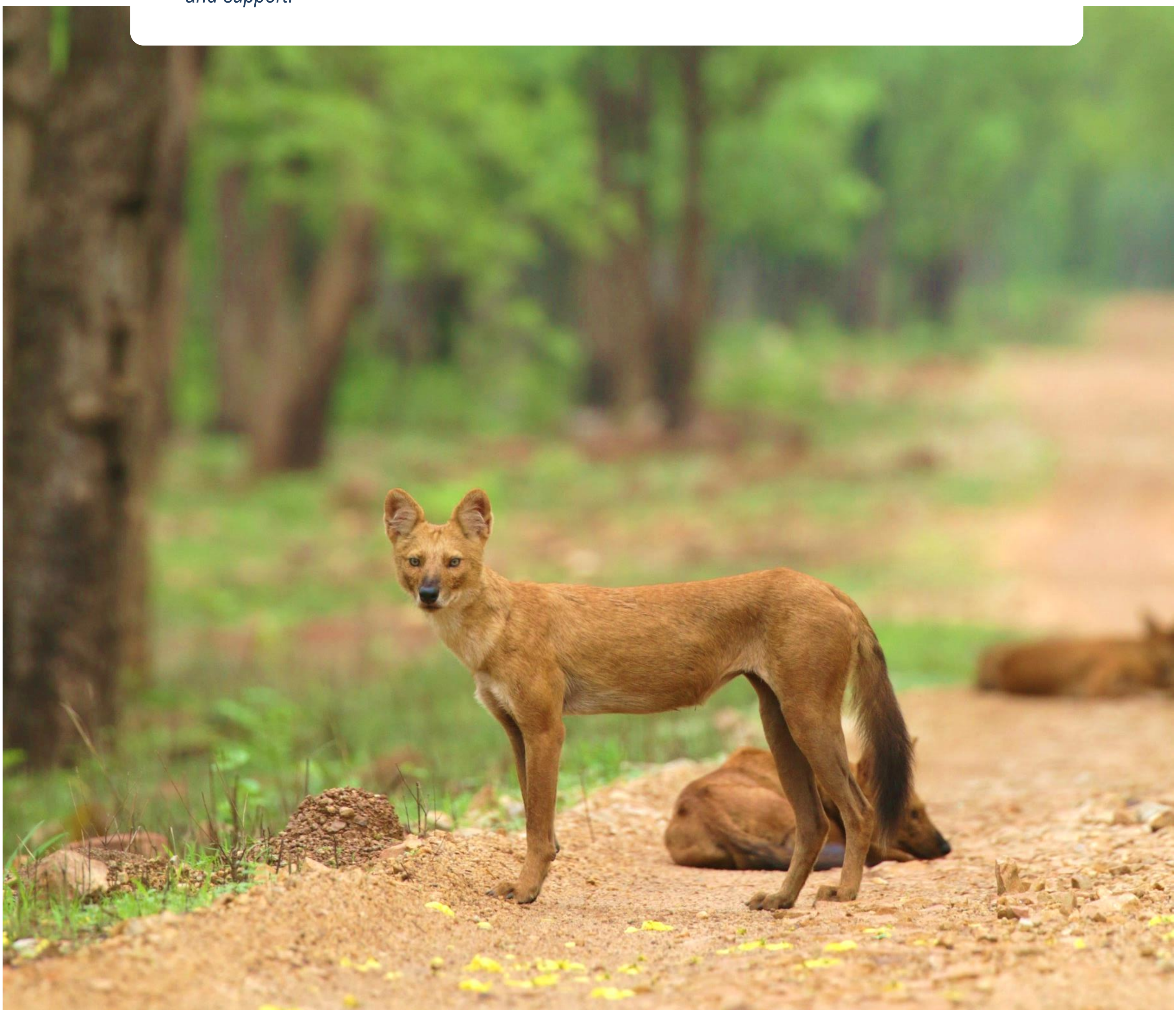
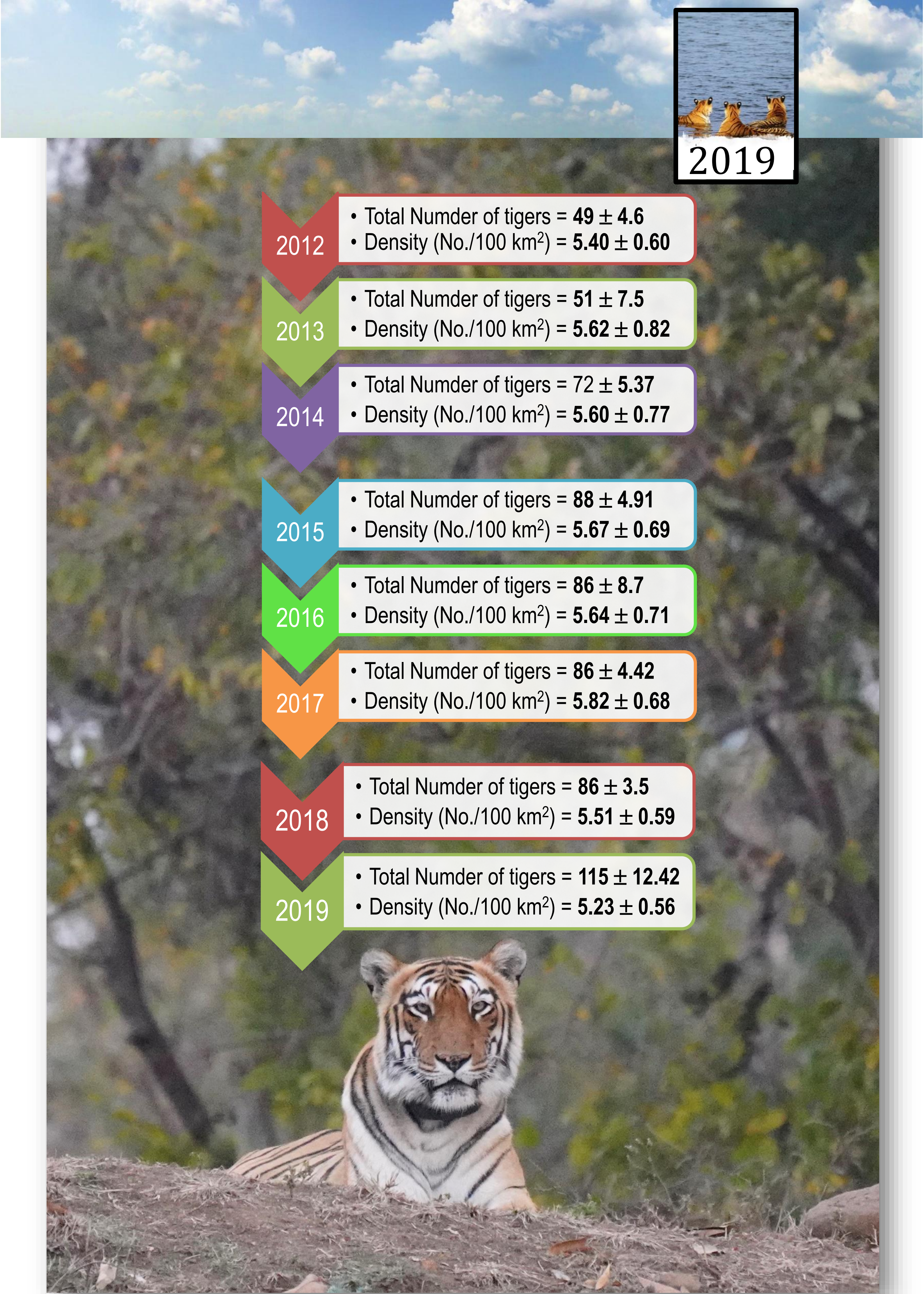


We would like to dedicate this report to the sub-adult cub of T-12 who died of natural causes during the year 2019. She and her brother would regale us after the end of a hard day's work making us even more determined to keep working hard.

TATR Field Team


2019
2012
• Total Numder of tigers = 49 ± 4.6
• Density (No./100 km²) = 5.40 ± 0.60
2013
• Total Numder of tigers = 51 ± 7.5
• Density (No./100 km²) = 5.62 ± 0.82
2014
• Total Numder of tigers = 72 ± 5.37
• Density (No./100 km²) = 5.60 ± 0.77
2015
• Total Numder of tigers = 88 ± 4.91
• Density (No./100 km²) = 5.67 ± 0.69
2016
• Total Numder of tigers = 86 ± 8.7
• Density (No./100 km²) = 5.64 ± 0.71
2017
• Total Numder of tigers = 86 ± 4.42
• Density (No./100 km²) = 5.82 ± 0.68
2018
• Total Numder of tigers = 86 ± 3.5
• Density (No./100 km²) = 5.51 ± 0.59
2019
• Total Numder of tigers = 115 ± 12.42
• Density (No./100 km²) = 5.23 ± 0.56

Contents

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Executive Summary

The Phase IV monitoring for the TATR core and buffer was conducted from November – April 2019 as part of the project "Long Term Monitoring of Tigers, Co-Predators and Prey species in Tadoba-Andhari Tiger Reserve, Maharashtra India". The exercise aimed to cover an area of 1700 km^2 but excluding the areas with villages and inaccessible locations. 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. 359 camera traps were placed in the core and buffer area of TATR following a sampling grid of 2.01 sq. km in three blocks. In each sampling block camera traps were active for 25-30 days. 150 days of camera trapping survey with sampling effort of 31,000 trap nights yielded data used for further analysis. Tiger density per 100 km^2 based on Spatially Explicit Capture-Recapture (SECR) model was 5.23 in the Tadoba Andhari Tiger Reserve while that of Leopards based on the same method was 6.86. In order to estimate prey density, 20 line-transects in core area and 67 line transects in buffer area were sampled 3- 7 times during the sampling period, with a total walking effort of 280 km and 914 km in core and buffer area respectively. The overall density of major prey species as estimated using distance sampling was 18.67 (±2.42) /sq. km whereas it was 17.67 (±2.43)/sq. km in buffer and 30.11 (±4.26)/sq. km in core respectively. The density of major prey species in core were Sambar 6.22(±2.16); Chital 8.21 (±2.69); Gaur 2.19 (±1.09); Wild pig 3.92 (±1.43); Langur 10.58 (±5.69); Nilgai 1.43 (±0.95); Barking deer 1.19 (±0.38)) ; Black-naped hare 0.72 (±0.37);Peafowl 4.18 (±1.10) ; Jungle fowl 0.35 (±0.28) per sq. km. The density of major prey species in buffer were Sambar 1.87 (±0.27); Chital 6.16 (±1.43); Gaur 2.60 (±0.97); Wild pig 9.08 (±5.22); 8.45 (±51.23); Nilgai 0.86 (±0.25); Barking 0.25 (±0.09) ; Black-naped hare 0.54 (±0.17), Peafowl 0.69 (±0.28) ; Jungle fowl 0.29 (±0.07) per sq. km.

In order to study space use pattern and activity we used camera-trapping data from both core and buffer area of Tadoba-Andhari Tiger Reserve. Camera trap locations with 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 course of 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.

Section – I: Introduction

Introduction

India, as of today, has 50 Tiger Reserves of which 6 are in the state of Maharashtra. Located, in the Chandrapur district between 20º 04´ 53˝ to 20º 25´ 51˝ N and 79º 13´ 13˝ to 79º 33´ 34˝ Tadoba Andhari Tiger Reserve, with an area of 1,727 km^2 is one of the largest tiger reserves in the state. Tadoba was declared as a National park in 1955 with an area of 116.55 km^2. The adjoining forested area of the Andhari river was declared as Andhari Wildlife Sanctuary in 1986. Finally, in 1993, a total area of about 625 km^2 was declared as the Tadoba Andhari Tiger Reserve (TATR). In 2012, an additional area of 1127.17 km^2 was annexed to the previously protected areas as the buffer area thereby making it one of the TATR the largest tiger reserve in the state of Maharashtra.

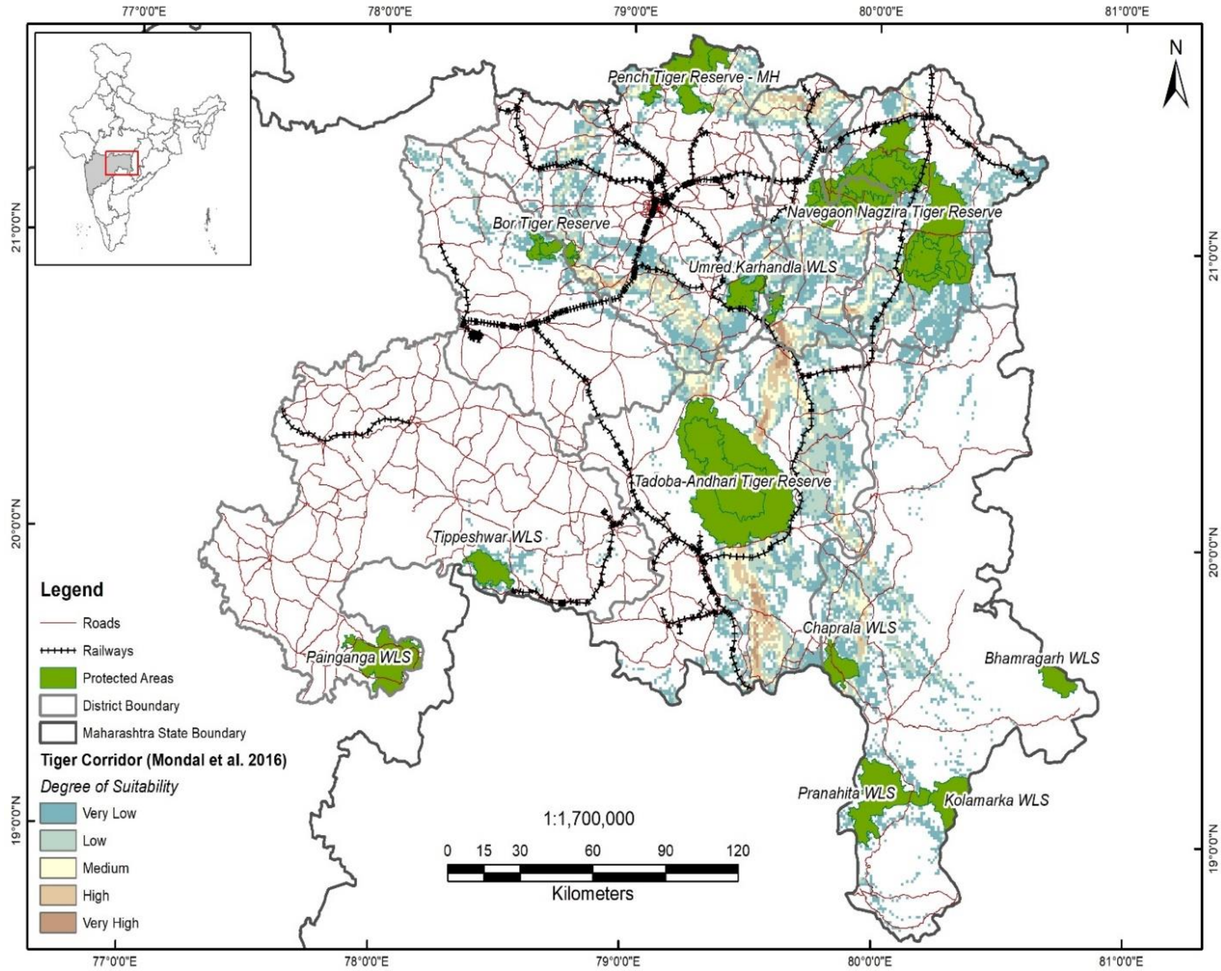


Figure 1: Connectivity Map of Eastern Vidarbha Landscape

Owing to an endeavor to render protection to the enigmatic big cats, the forest department has been successful in establishing TATR as an example of an important tiger population source. In fact, TATR serves as a major source population of large carnivores in the entire Central India landscape. It also has vital connectivity with other protected areas such as Pench and Navegaon-Nagzira Tiger Reserve through Umred Karhandla Wildlife Sanctuary, Bor Tiger Reserve and Indravati and Kawal Tiger Reserves through the forests of Chandrapur in the northern side and the districts in Gadchiroli towards the south. This connectivity further extends in the north-west towards Kanha National Park.

Landscape Characteristics and Climate

Landscape structure and composition are vital for supporting and sustaining biodiversity. The different characteristics of a landscape also govern the distribution and abundance of different species (Paliwal & Mathur, 2014). The northern part of the reserve (western boundary of Moharli and Tadoba range) is slightly undulating and hilly interspersed with woodlands and grasslands. These hilly areas give rise to a number of streams such as Andhari, Bhanuskhindi and Hirdi. Important catchment areas of these streams occur at Bhanuskhindi, Pandharpauni and Kolsa. The Tadoba Lake, the park's perennial water body, also lies in the basin area of the hills. It not only provides water for the animals but is also home to marsh crocodiles TATR is drained by two rivers- the Andhari river which originates in Pandharpauni and flows in the eastern half and the Erai river which flows in the western half. Both the rivers have base flow or dry weather flow which indicates that they are recharged from the ground water. Both the rivers flow from north to south; Andhari river joins the Wainganga, a distributor of Godavari while the Erai is fed by the Bhanuskhindi nala. The southern parts of TATR are mostly plains and comprises of grasslands in Botezari, Karwa, Piperheti and Kolsa.

TATR, experience 3 major seasons annually-summer (March- May, monsoon (June-September) and winter (October-February). The summers are prominent and characterized by very high temperatures reaching up to 47°c during its peak and characterized by hot and dry winds. Summers are followed by monsoon which cools the region. During a normal monsoon season the region receives about 1175mm of annual rainfall between June and September (Kumbhar, 2003). The winters are cold and dry with temperatures falling as low as 12°c. Generally, the region is very dry with very low humidity of about 20 – 25 % which rise only during the peak monsoon period to almost 70%.

Flora and Fauna of Tadoba Andhari Tiger Reserve

TATR is a typical example of a dry deciduous forest ecosystem. In accordance with Champion and Seth's classification (1968) the vegetation is Southern Tropical Dry Deciduous Forest with Teak (*Tectona grandis*) being the dominant species. Other prominent tree species found here include 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. Pilot studies have shown TATR to be comprised of several different vegetation classes including, dry deciduous forest mixed bamboo forest, open forest, riparian forest and scrubland. Vegetation classes are interspersed with water bodies and grasslands (Mathur & Paliwal, 2008). Much recent studies have shown that TATR is comprised of 6 vegetation classes amongst which mixed bamboo forest is dominant occupying 77.99% of the total area (Paliwal & Mathur, 2014).Vegetation ecology study done in TATR showed that the largest genus of grasses in the park belongs to genus Eragrostis with 14 species. Digitaria and Aristida are next abundant genus with 6 species each. The dominant species include *Heteropogon contortus, Chysopogon fulvus* and *Sporobolus tenassissima* (Cheravengat & Rao, 2013).

Majority of TATR harbors bamboo (*Dendrocalamus strictus*), a species which plays an important role in the life cycle of Tadoba. It has also been called as the “keystone” species for the Reserve. In absence of extensive meadows, bamboo forms an important food source for the herbivores in the forest. Bamboo flowers every 40 years in the reserve. The next flowering is expected soon thereby making this time period extremely crucial for decisive measures, intensive monitoring and planned management.

Beside these, there exists several edible plant species which are used for food and fodder by the local villagers. Many of these traditional resources are seasonal and include 10 terrestrial species, 2 aquatic species, 4 tubers, 7 climbers and a mushroom species which are consumed in form of curries, dry vegetable, round cakes, boiled or fried (Sawarkar & Kulkarni, 2015)

TATR harbours a rich diversity of fauna comprising a total of 62 species of mammals, over 250 species of birds, 174 species of butterflies and 34 species of reptiles. TATR is best known for its healthy population of tigers (*Panthera tigris*) that it supports. However, the forest is also home to several other species besides the tiger such as leopard (*Panthera pardus*), dhole (*Cuon alpinus*), gaur (*Bos gaurus*), sambar (*Rusa unicolor*), chital (*Axis axis*), chausingha (*Tetracerus quadricornis*), sloth bear (*Melursus ursinus*), honey badger (*Mellivora capensis*), rusty-spotted cat (*Prionailurus rubiginosus*) etc. In the recent years, birders have also taken a keen interest in Tadoba’s avian biodiversity. The diverse forms of habitats available in both the buffer and core areas of the park, contributes towards the abundance and variety of avian fauna found in TATR. About 255 different bird species including 5 species endemic to India have been spotted in TATR (Bayani & Dandekar, 2017).Several threatened and vulnerable species such as Steppe eagle (*Aquila nipalensis*), Egyptian vulture (*Neophron percnopterus*), grey headed fish eagle (*Ichthyophaga ichthaaetus*), red-necked falcon (*Falco chicquera*), painted stork (*Mycteria leucocephala)* to name a few.

In the past few years, TATR reflects the fruits of a well-planned management in terms of habitat improvement and population of tigers. In the coming years, the main challenge that needs to be tackled is maintaining the habitat quality, prey number and ensuring safe movement of tigers through the connecting corridors of the park aiding in ensuring a viable population.

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 5 years. The objectives of the project as approved were as follows:

1. Mapping of current land use 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 program, 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 2019. As a part of the long term monitoring program the focus of the research during the said year was:

I. Population density and abundance estimation of key prey species in landscape for the year 2019.

II. Population density, abundance and demographic structure of tigers in TATR landscape for the year 2019.

III. Activity pattern of tigers, co-predators & prey species in Tadoba-Andhari Tiger Reserve for the year 2019.

IV. Modeling Spatially Explicit Intensive Use Areas by Predator and Prey Species for the year 2019.

Section II - Status of Prey Species in TATR

Introduction

The success of any conservation effort may be gauged from the importance imparted to the prey population of the landscape. Knowledge of animal abundance is critical to the ecological theory and practice of studies in both population biology (Krebs 1985; Soule 1986) and wildlife resource monitoring One of the central themes of ecological studies is to understand the importance of predator-prey interactions for species diversity and community composition (Sandom, et al., 2013). In theory, it has been established that a complex food web would enhance the stability of a given ecosystem. Both prey composition and prey diversity are a determining factors of predator stability where different types of prey and each level of prey diversity affects the predator-prey dynamics (Petchey, 2000). Ungulate population is pivotal in increasing and supporting a growing carnivore population. Decline of prey base would hamper the predators and lead to increase carnivore competition and deaths (Wolf & Ripple, 2016). Ungulate population also shapes the ecological community thereby making it crucial to monitor ungulate population to meet the ulterior conservation goal. 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 (Bagchi and Ritchie 2010). Maintaining and monitoring ungulate populations is therefore an important objective of conservation management. Estimating ungulate abundance in dense forested areas especially remains a challenge due to their low visibility and low detection probability.

Distance Sampling

One of the most common forms of distance sampling is the 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 on pre-structured sheets.

A total of 20 transects in core –zone and 67 transects in buffer-zone of 2 km length were marked in Tadoba-Andhari Tiger Reserve. Figure 1 shows the 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 3-7 times during the period from 1st February 2019 to 7th February 2019 to record prey species across the whole area of TATR. Thus a total of 1778 km effort have been invested on line transect surveys which generated 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.

Limitations of the data

Data from a few ranges have not been included owing to non-availability of the raw data since the data sheets were lost while being sent from Range offices to Head office. However, despite these drawbacks, we believe the results extracted are rigorous and defensible after appropriate cleaning of the raw data.

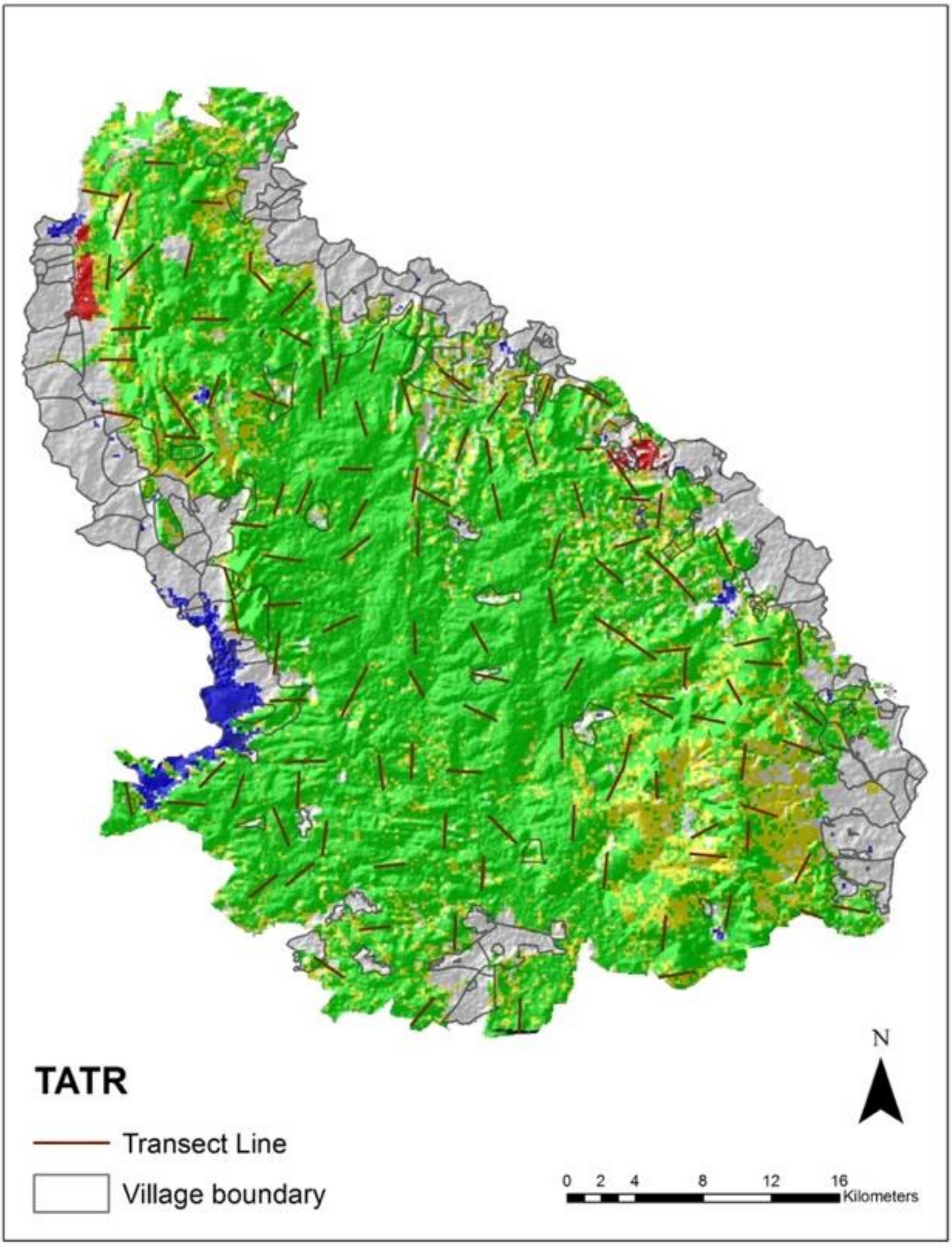


Figure 2.1: Distribution of line-transects in Core and Buffer area monitored during the year 2019 (Tadoba-Andhari Tiger Reserve, Maharashtra, India).

Table 2.1: Transect monitoring efforts and species reported from Core and Buffer Area of TATR during Phase IV Monitoring 2019.

Transect Details			**Core***			**Buffer#**
Number of transects			20			67
Length of each transect			2 km			2 km
Number of replicates			7			7
Total distance covered			280 km			914 km
Number of species recorded			10			10
	Core			**Buffer**		
Species	**Number of sightings**	**Individuals recorded**	**Average group size (min-max)**	**Number of sightings**	**Individuals recorded**	**Average group size (min-max)**
Sambar	20	43	2.1(1-8)	27	64	2.4 (1-10)
Chital	23	116	5.04(1-13)	64	435	6.7 (1-18)
Nilgai	6	7	1.6(1-2)	31	90	2.9 (1-19)
Gaur	13	41	3.1 (1-12)	31	136	4.3 (1-20)
Wild pig	18	86	4.7 (1-13)	30	155	5.16 (1-17)
Langur	11	155	14.0(1-24)	14	163	11.6 (2-22)
Barking deer	13	14	1-2(1-2)	13	20	1.5 (1-3)
Hare	7	7	1	19	22	1.1 (1-2)
Peafowl	24	56	2.3 (1-5)	17	36	2.1 (1-5)
Grey jungle fowl	4	6	1.5 (1-2)	4	5	1.25 (1-2)

- * Core total effort has been calculated for 2 ranges only-Moharli and Kolsa.
- # Buffer effort has been calculated for only those ranges for which data was available. Additionally a few of the transects were monitored for only 3 days thereby modifying total effort calculation.

Table 2.2: Individual Density, Group Density, Effective Strip Width, Average Group Size and Encounter Rate of all Prey Species Reported during the Phase IV Monitoring 2019 in the **Core** Area of Tadoba - Andhari Tiger Reserve, India

Parameters	Sambar	Chital	Gaur	Wild pig	Langur	Nilgai	Barking deer	Hare	Peafowl	Grey jungle fowl
Individual density (No of Animals/Km^2)	6.22	8.21	2.19	3.92	10.58	1.43	1.19	0.72	4.18	0.35
Standard error	2.16	2.69	1.09	1.43	5.69	0.95	0.38	0.37	1.10	0.28
Percent CV	34.76	32.79	50.04	36.62	53.81	66.43	38.44	52.26	26.45	80.33
95% confidence interval	3.16-12.25	4.33-15.56	0.84-5.70	1.92-8.02	3.79-29.51	0.40-5.11	0.86-1.53	0.25-2.05	2.48-7.04	0.07-1.78
Group density (No of groups/Km^2)	2.91	1.37	0.69	1.46	0.56	0.94	0.99	0.75	2.02	0.23
Standard error	0.87	0.35	0.27	0.38	0.27	0.60	0.34	0.42	0.47	0.17
Percent CV	29.98	26.23	39.40	26.22	48.00	64.14	37.99	51.09	23.44	73.09
95% confidence interval	1.61-5.29	0.81-2.31	0.32-1.51	0.86-2.46	0.22-1.43	0.27-3.28	0.42-1.30	0.23-2.06	1.26-3.23	0.05-1.08
Effective strip width	12.23	29.96	33.37	21.98	28.43	14.49	25.83	17.21	21.14	29.99
Standard error	2.36	5.00	9.26	3.83	7.08	5.97	4.38	6.26	2.97	17.06
Percent CV	19.31	16.71	27.76	17.44	24.92	41.18	16.96	36.39	14.08	56.89
95% confidence interval	8.18-18.28	21.24-42.26	18.43-60.42	15.25-31.67	16.14-50.09	5.24-40.10	17.89-37.28	6.95-42.63	15.81-28.27	5.56-61.78
Average group size	2.15	5.04	3.15	4.77	14.22	1.20	1.07	1.02	2.33	1.50
Standard error	0.40	0.73	0.97	1.04	2.68	0.20	0.07	0.02	0.25	0.50
Percent CV	18.87	14.67	30.85	21.97	41.02	16.67	7.14	6.89	10.84	33.33
95% confidence interval	1.45-3.18	3.72-6.82	1.63-6.08	3.02-7.55	0.01-0.07	1.00-1.90	1.00-1.25	0.08-1.09	1.86-2.91	1.00-4.21
Encounter rat3	0.07	0.08	0.04	0.06	0.03	0.01	0.04	0.02	0.08	0.01
Percent CV	22.94	20.22	27.96	19.58	18.85	49.20	33.99	37.51	18.73	45.88
95% confidence interval	0.04-0.11	0.05-0.12	0.02-0.08	0.04-0.09	9.24-21.88	0.006-0.04	0.02-0.09	0.01-0.05	0.05-0.12	0.005-0.02
Probability of a greater chi-square value, P	0.45	0.81	0.43	0.26	0.19	0.25	0.47	0.13	0.50	0.28

Table 2.3: Individual Density, Group Density, Effective Strip Width, Average Group Size and Encounter Rate of all Prey Species Reported during the Phase IV Monitoring 2019 in the **Buffer** Area of Tadoba - Andhari Tiger Reserve, India

Parameters	Sambar	Chital	Gaur	Wild pig	Langur	Nilgai	Barking deer	Hare	Peafowl	Grey jungle fowl
Individual density (No of Animals/Km^2)	1.87	6.16	2.60	9.08	8.45	0.86	0.25	0.54	0.69	0.29
Standard error	0.27	1.43	0.97	0.67	1.23	0.25	0.09	0.17	0.28	0.07
Percent CV	31.77	23.24	37.26	32.40	35.64	29.49	37.88	31.31	41.37	79.97
95% confidence interval	1.47-2.62	3.91-9.68	1.27-5.32	9.10-10.40	7.73-9.87	0.49-1.54	0.12-0.52	0.29-0.99	0.31-1.54	0.08-0.4
Group density (No of groups/Km^2)	0.84	0.91	0.62	0.50	0.36	0.36	0.15	0.48	0.29	0.07
Standard error	0.14	0.17	0.18	0.11	0.12	0.08	0.05	0.15	0.10	0.05
Percent CV	27.52	19.22	29.50	22.34	33.19	23.33	35.45	30.64	36.44	77.43
95% confidence interval	0.40-1.23	0.62-1.32	0.35-1.11	0.32-0.77	0.19-0.69	0.22-0.56	0.07-0.29	0.27-0.88	0.14-0.60	0.01-0.3
Effective strip width	36.47	38.45	27.11	32.76	21.03	47.10	47.13	21.21	29.44	21.64
Standard error	6.82	3.86	8.11	3.75	3.64	6.35	7.78	3.17	7.28	7.16
Percent CV	18.72	10.06	5.99	11.47	17.35	13.50	16.51	14.97	24.75	33.10
95% confidence interval	24.82-53.59	31.467-46.98	17.33-42.40	25.9-41.40	14.50-30.51	35.7-61.97	32.97-67.38	15.5-29.00	17.51-49.51	7.75-60.39
Average group size	2.52	6.79	4.38	5.16	11.64	2.90	1.53	1.15	2.12	1.25
Standard error	0.44	0.68	0.86	0.93	1.48	0.72	0.18	0.08	0.35	0.25
Percent CV	17.78	10.12	19.68	18.14	12.72	24.82	11.90	7.42	16.57	20.00
95% confidence interval	1.74-3.63	5.55-8.31	2.94-6.53	3.57-7.46	8.85-15.30	1.76-4.78	1.18-1.99	1.00-1.35	1.49-3.01	1.00-2.34
Encounter rate	0.02	0.07	0.03	0.03	0.01	0.03	0.01	0.02	0.01	0.004
Percent CV	20.17	16.37	19.53	19.17	28.29	19.03	31.37	26.73	26.74	48.79
95% confidence interval	0.01-0.03	0.05-0.09	0.02-0.04	0.02-0.04	0.008-0.02	0.02-0.04	0.007-0.02	0.01-0.03	0.01-0.02	0.001-0.01
Probability of a greater chi-square value, P	0.95	0.82	0.12	0.48	0.60	0.59	0.47	0.72	0.66	0.15

Table 2.4: Comparison of prey density of **Core** area of TATR, Maharashtra, India (2002-2019). Standard errors are given in parentheses.

Species	*2002*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*
Sambar	3.33	6.5 (±1.1)	3.9 (±1.1)	4.68 (±0.76)	5.27 (±1.16)	3.47 (±0.74)	1.76 (±0.58)	7.0 (±1.62)	6.22 (±2.16)
Chital	3.2	8.6 (±1.8)	6.3 (± 1.5)	5.10 (± 1.22)	7.42 (±2.36)	8.48 (± 2.03)	6.69 (±1.71)	10.81 (±2.24)	8.21 (±2.69)
Gaur	1.8	6.6 (±1.4)	1.7 (± 0.3)	2.03 (± 0.56)	1.58 (±0.45)	2.64 (± 0.74)	2.12 (±0.46)	6.60 (±2.0)	2.19 (± 1.09)
Langur	-	-	-	9.47 (± 1.90)	9.70 (±2.42)	10.32 (±2.86)	9.89 (±1.72)	11.81 (±2.80)	10.58 (±5.69)
Wild Pig	2.6	7.3 (±1.6)	3.7 (± 1.5)	5.42 (±2 .08)	4.49 (±1.73)	4.19 (±1.36)	3.97 (±0.46)	6.58 (±2.05)	3.92 (±1.43)
Nilgai	0.7	-	1.3 (± 0.5)	1.09 (± 0.36)	1.01 (±0.37)	0.42 (± 0.16)	0.33 (±0.12)	2.00 (±0.66)	1.43 (±0.95)
Barking Deer	0.9	5.2 (±1.2)	-	0.96 (± 0.23)	0.98 (±0.21)	1.16 (± 0.29)	1.12 (±0.45)	1.26 (±0.42)	1.19 (±0.38)
Hare	-	-	-	1.70 (± 0.36)	2.23 (±0.65)	0.49 (± 1.15)	1.23 (±0.54)	2.62 (±0.65)	0.72 (±0.37)
Peafowl	-	-	-	3.92 (± 0.72)	3.36 (±0.81)	3.25 (± 0.67)	3.45 (±0.73)	6.87 (±1.59)	4.18 (±1.10)
Grey Jungle Fowl	-	-	-	1.43 (± 0.53)	2.58 (±0.78)	3.19 (± 0.9)	2.93 (±0.19)	0.82 (±0.40)	0.35 (±0.28)

Table 2.5: Comparison of prey density of **Buffer** area of TATR, Maharashtra, India (2015-2019). Standard errors are given in parentheses.

Species	2015	2016	2017	2018	2019
Sambar	1.88 (± 0.71)	1.22 (± 0.76)	1.58 (±0.40)	2.83(±0.89)	1.87 (±0.27)
Chital	4.09 (± 0.92)	8.73 (± 1.93)	11.09 (±2.07)	8.86(±1.58)	6.16 (±1.43)
Gaur	1.63 (± 0.59)	6.88 (± 1.87)	3.54 (1.07)	1.65(±0.50)	2.60 (±0.97)
Langur	14.64 (± 5.98)	28.52 (±8.75)	11.10(±3.75)	18.93(±5.16)	8.45 (±1.23)
Wild Pig	4.56 (± 1.73)	9.82 (±6.23)	11.82 (±2.98)	16.29(±4.93)	9.08 (±0.67)
Nilgai	0.74 (± 0.29)	5.91 (± 1.96)	5.22 (±1.66)	4.37(±1.35)	0.86 (±0.25)
Barking Deer	0.68 (± 0.31)	3.62 (± 1.11)	2.82 (±0.31)	1.42(0.80)	0.25 (±0.09)
Hare	0.99 (± 0.37)	1.51 (± 0.43)	1.02 (±0.31)	1.73(±0.46)	0.54 (±0.17)
Peafowl	2.28 (± 0.79)	4.18 (± 0.9)	4.06 (±1.39)	2.37(±0.69)	0.69 (±0.28)
Grey Jungle Fowl	0.59 (± 0.41)	1.03 (± 0.24)	1.43 (±0.54)	0.69(±0.53)	0.29 (±0.07)

Section III - Status of Predators in TATR

Introduction

Maintenance and even restoration of an ecosystem depends on its biodiversity. Predators are important for maintaining the health and integrity of an ecosystem (Talbot, 1978). Around the world, the importance and the ecological role of predators is being widely recognized. The combination of biological characteristics of tigers - extensive distributional range, low densities, elusiveness, wide ranging behaviors, low detectability of tiger signs – 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 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.

Camera traps offer a reliable, minimally invasive, visual means of surveying wildlife that substantially reduces survey effort. Camera trapping has become an increasingly popular method in ecological studies and they provide a wealth of information that is often of considerable conservation value (Burton et al. 2015).

Monitoring of large carnivore populations is important to guarantee their survival, to adapt management practices to changing situations and for the conservation of habitat in the long run. 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.

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.

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 TATR, there is a record of animal movements for each beat in TATR. However, locations followed for the camera trapping in the year 2012, 2013, 2014, 2015, 2016, 2017 and 2018 were again referred and revised if there was any change in the existing movement pattern of animals. Since newer locations had been cleared by the department in the buffer area, these were also included in the camera trapping exercise. This exercise followed the protocol prescribed by Karanth and Nichols (1998) Potential locations of camera trap stations were then mapped using ArcGIS 9.3 (ESRI, Redlands, CA, USA). This year a sampling grid of 2.0164 sq. km. (1.42 km x 1.42 km) for camera trapping was selected. A total of 359 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. A pair Cuddeback Ambush camera traps (http://cuddeback.com/cameras/ambush.aspx) 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 5 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.

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 9528 camera trap nights was used during the 2019 Phase IV monitoring in Tadoba Andhari Tiger Reserve. Every tiger and leopard photograph was given a unique identification number after examining the stripe and rosette pattern on the flanks, limbs and forequarters Individual capture histories of tiger and leopard were developed in a standard “Xmatrix format” (Otis et al., 1978). One critical assumption for closed population estimate is that the population should be demographically and geographically closed (Otis et al., 1978) to follow our closure assumption the sampling duration was kept as minimum. Capture histories were analyzed using the software R package ‘secr’ (Efford, 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'.

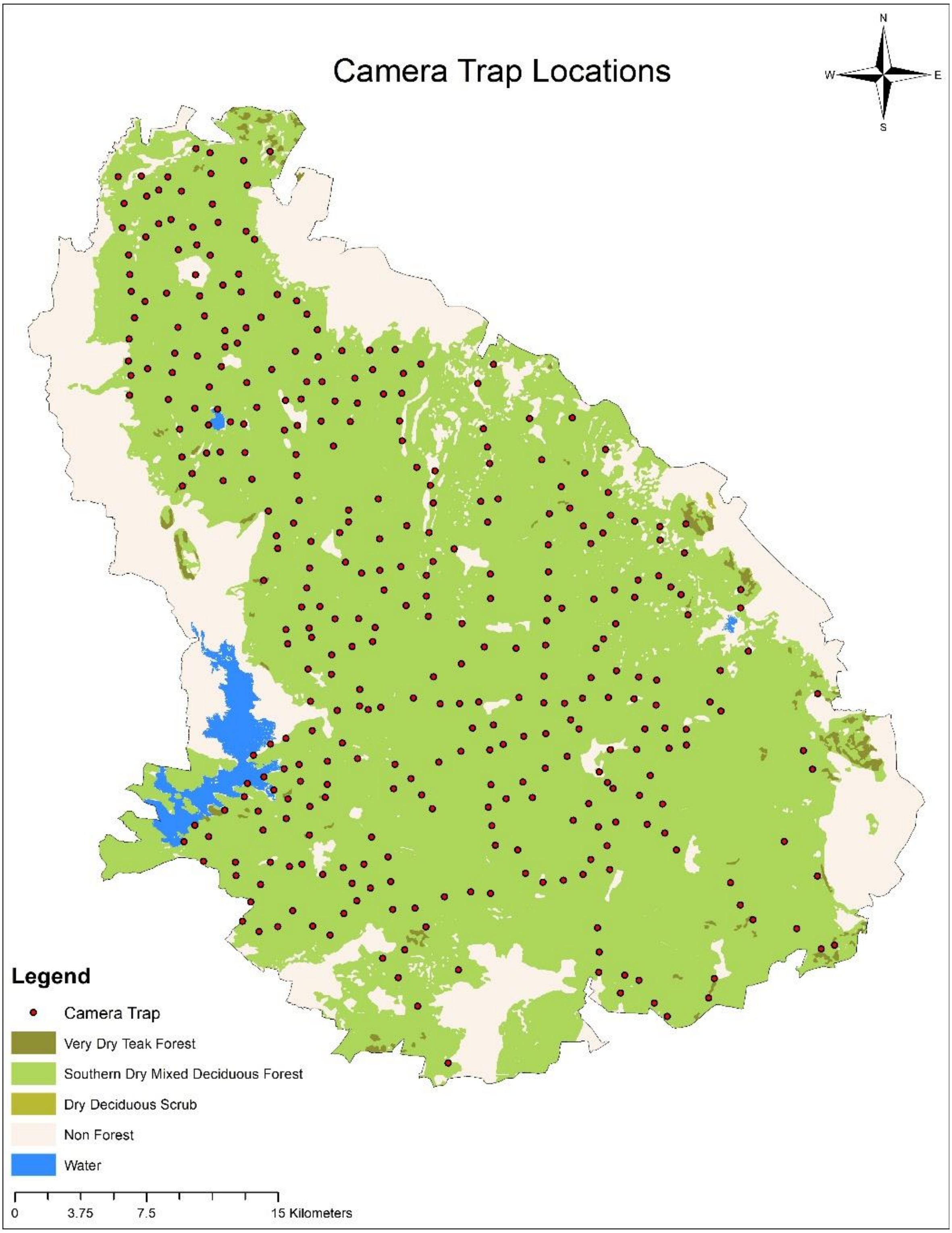


Figure 3.1: Camera trapping locations for 2019 in Core and Buffer area of Tadoba - Andhari Tiger Reserve, Maharashtra, India

Population Estimation of Predators:

During 150 days of camera trapping for tigers and leopards i.e., a total sampling effort of 57,000 trap nights 88 adult individual tigers where photographed within the core and buffer area of TATR. 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, 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 population is density instead of 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 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 centres), 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 km^2 based on SECR. Heterogeneity model was estimated to be 5.23 for TATR. Best model for the density estimate are chosen according to the AIC (Alkaike Information Criterion). The details are provided in Table 3.1 and Table 3.2 along with the comparison of capture and density estimate 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 average movement of the animal. It increases if the individuals are captured at very far away locations. Table 3.3 give details of tigers captured within core and buffer area of tiger reserve.

Table 3.1: Density estimates of tigers using Spatially Explicit Capture-Recapture Models in Tadoba - Andhari Tiger Reserve, Maharashtra, India for the year 2014 – 2019.

Parameters	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Model	**Heterogeneity**	**Heterogeneity**	**Heterogeneity**	**Heterogeneity**	**Heterogeneity**	**Heterogeneity**
Detection function	Half Normal	Half Normal	Half Normal	Half Normal	Half Normal	Half Normal
Density Estimate	5.609	5.673	5.648	5.823	5.51	5.23
Density SE	0.773	0.698	0.713	0.683	0.598	0.564
Density CI	4.28-7.34	4.46-7.21	4.93-6.36	4.79-7.12	4.46-6.81	4.24-6.46
g0 Estimate	0.305	0.499	0.407	0.512	0.607	0.392
g0 SE	0.022	0.098	0.091	0.056	0.050	0.027
g0 CI	0.264-0.352	0.340-0.731	0.313-0.689	0.40-0.624	0.51 – 0.71	0.34-0.45
Sigma Estimate	4.283	3.309	3.354	3.237	2.07	3.83
Sigma SE	0.305	0.239	0.431	0.318	0.533	0.988
Sigma CI	3.725-4.925	2.871-3.814	2.716-3.972	2.659-3.946	0.974 – 2.184	3.64-4.03

Table 3.2: Comparative density estimates of tigers using Spatially Explicit Capture-Recapture Models in Tadoba - Andhari Tiger Reserve, Maharashtra, India.

Year	**Effective trapping area**	**No of individuals captured**	**Estimate**	**Density per 100 km^2**
2010	321	15	17 (± 3.6)	5.29 (± 1.12)
2012	603	47	49 (± 4.6)	5.40 (± 0.60)
2013	603	50	51 (± 7.5)	5.62 (± 0.82)
2014	1170	65	72 (± 5.37)	5.60 (± 0.77)
2015	1310	71	88 (± 4.91)	5.67 (± 0.69)
2016	1310	69	86 (± 8.7)	5.64 (± 0.71)
2017	1310	75	86 (± 4.42)	5.82 (± 0.68)
2018	1310	81	86 (± 3.5)	5.51 (±0.59)
2019	**1682**	**88**	**115** (±12.42)	**5.23 (±0.56)**

Table 3.3: Comparison of density of tigers across the years 2010 – 2019 for Tadoba-Andhari Tiger Reserve, Maharashtra, India.

Details	2013	2014	2015	2016	2017	2018	2019
Tigers (Exclusively Core)	50	51	51	48	50	39	44
Tigers (Exclusively Buffer)	NA	10	14	17	19	22	23
Tigers (Core and Buffer)	NA	04	06	04	06	20	21

SECR was also used to estimate density for leopards in TATR for 2019 as well and has been shown in the table below.

Table 3.4: Density estimates of leopards using Spatially Explicit Capture-Recapture Models in Tadoba - Andhari Tiger Reserve, Maharashtra, India for the year 2019.

Parameters	2019
Model	Heterogeneity
Detection function	Half Normal
Density Estimate	6.86
Density SE	0.689
Density CI	5.65-8.33
g0 Estimate	0.25
g0 SE	0.014
g0 CI	0.21-0.27
Sigma Estimate	5.41
Sigma SE	0.15
Sigma CI	5.12-5.72

Table 3.5: Estimates of leopards using Spatially Explicit Capture-Recapture Models in Tadoba - Andhari Tiger Reserve, Maharashtra, India.

Year	Effective trapping area	No of individuals captured	Estimate	Density per 100 km^2
2019	1682	106	151(±15.29)	6.86 (±0.68)

Section IV – Spatial Pattern of Tigers and Leopards

We mapped the home range (minimum area usage) for both tigers and leopards for which we had at least 3 or more than 3 camera trap locations. This gives basic idea of space use by the predators across the reserve. The details of such figures are shown in respective maps.

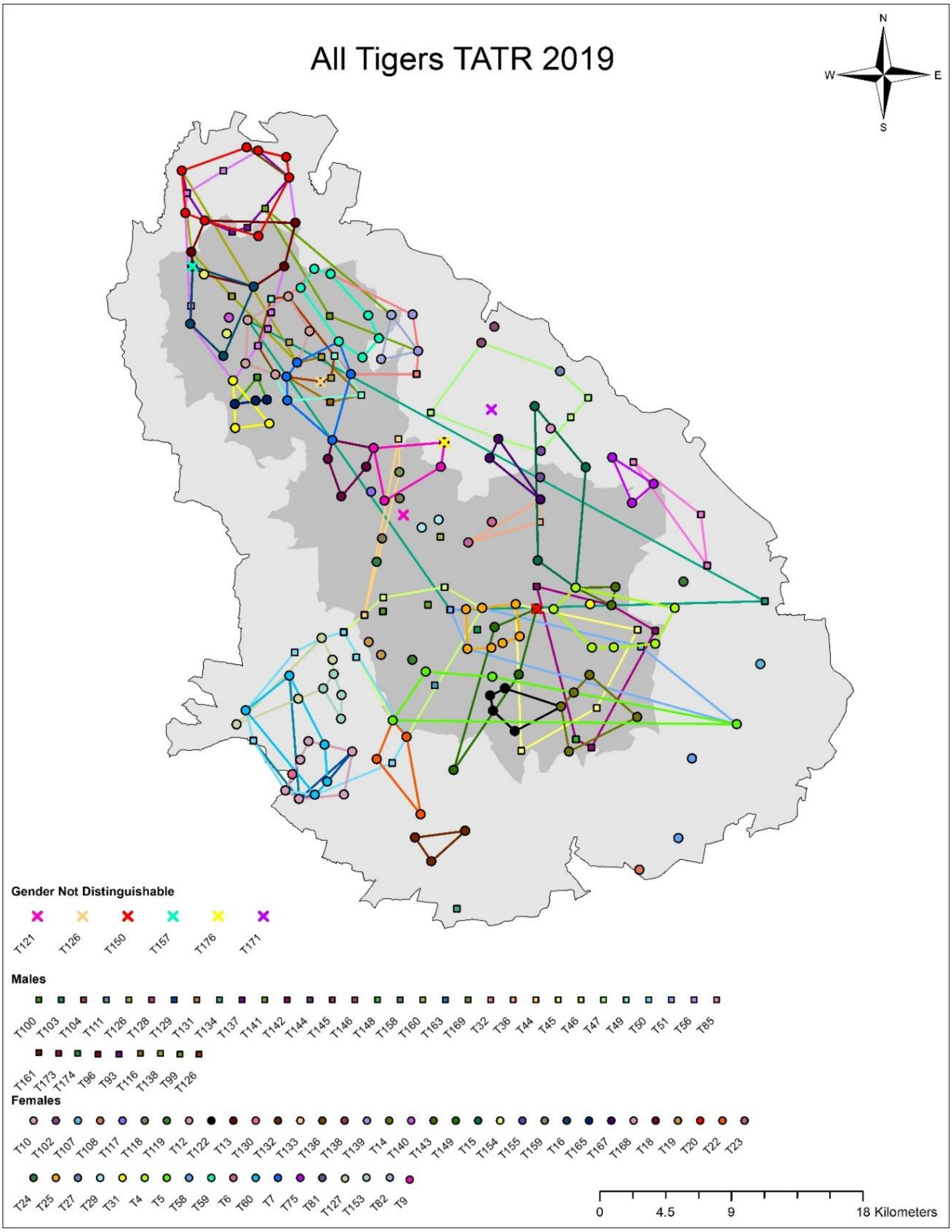


Figure 4.1: Spatial pattern of Tigers Inside TATR for the year 2019.

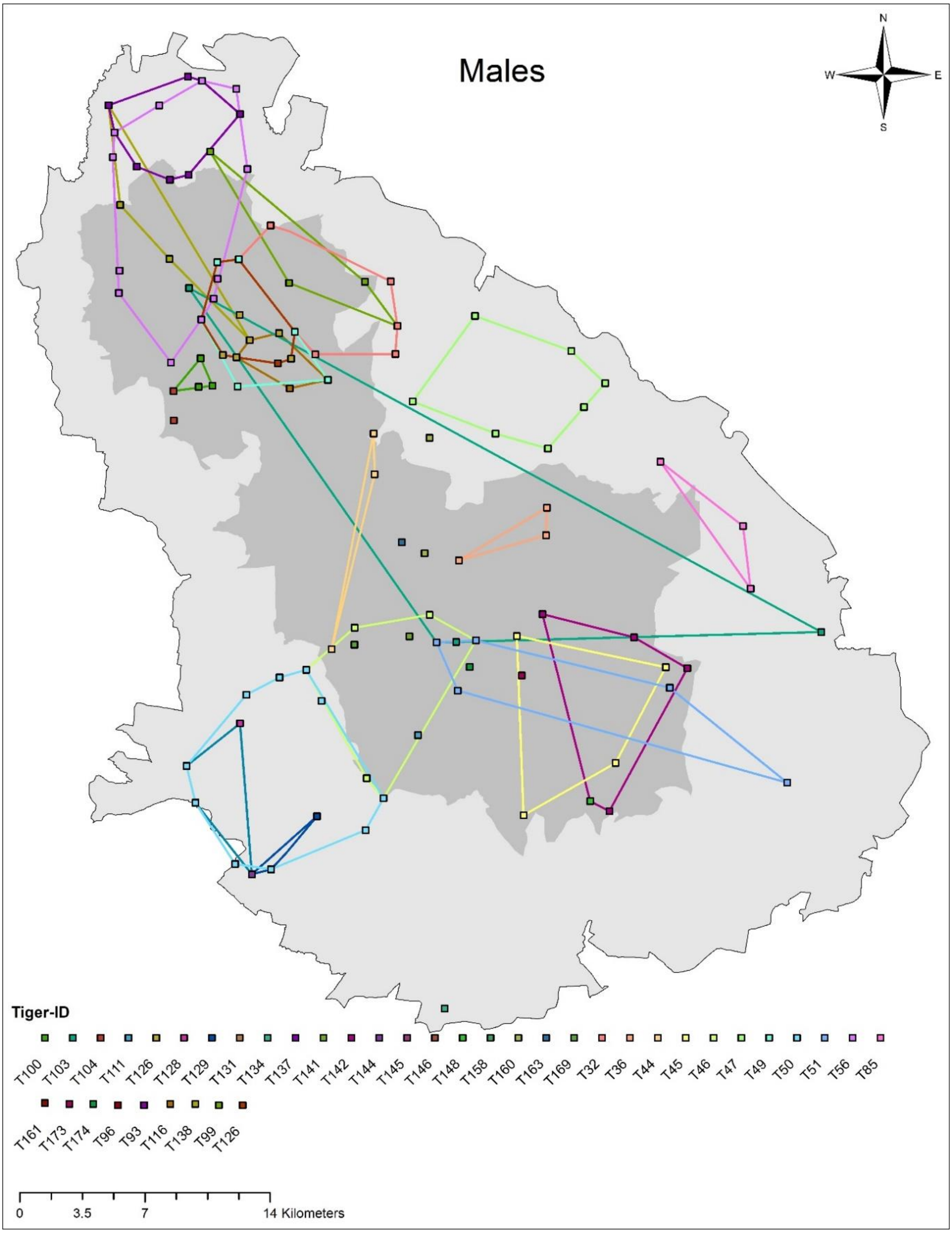


Figure 4.2: Spatial pattern of Tigers (Males) Inside TATR for the year 2019.

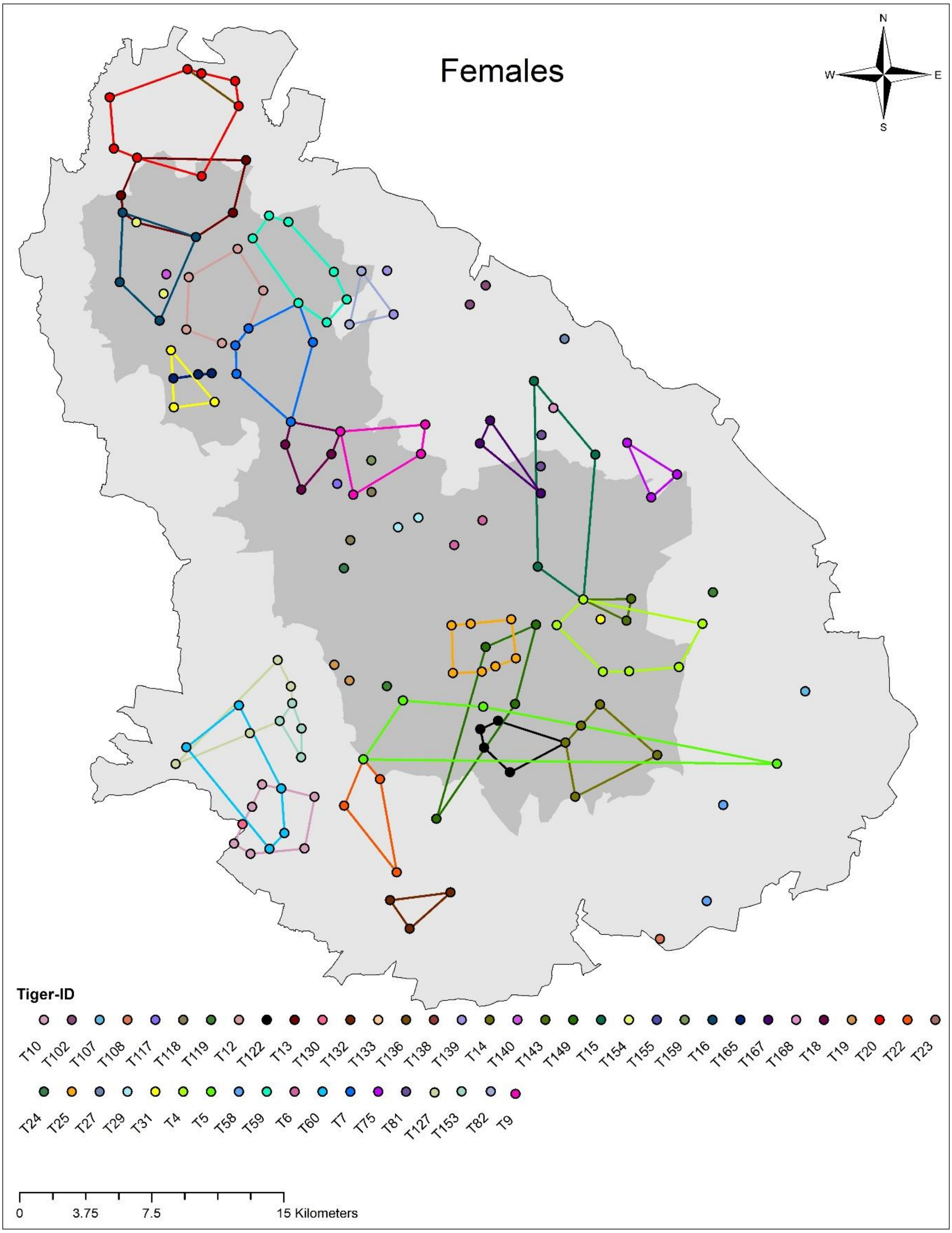


Figure 4.3: Spatial pattern of Tigers (Females) Inside TATR for the year 2019.

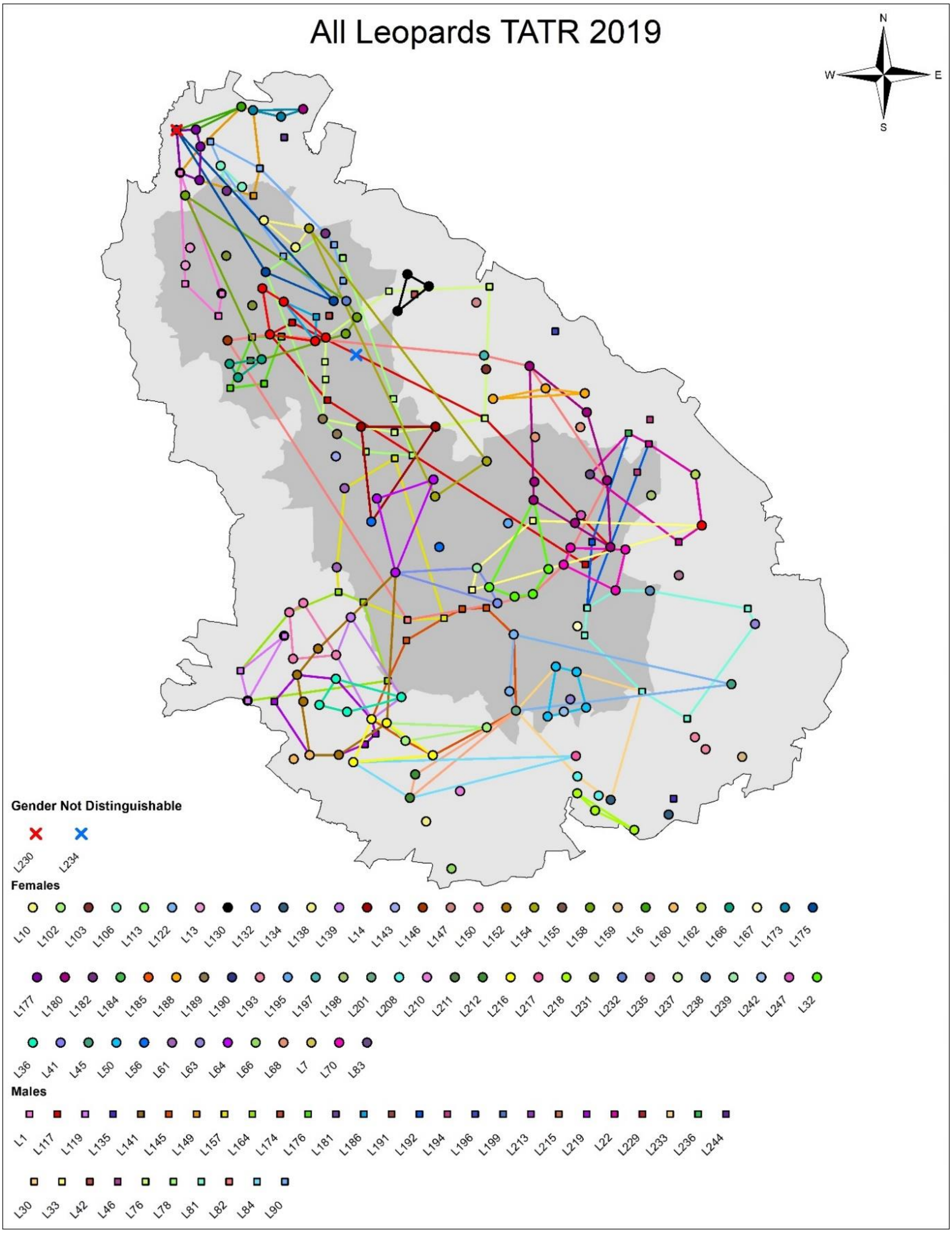


Figure 4.4: Spatial pattern of Leopards Inside TATR for the year 2019.

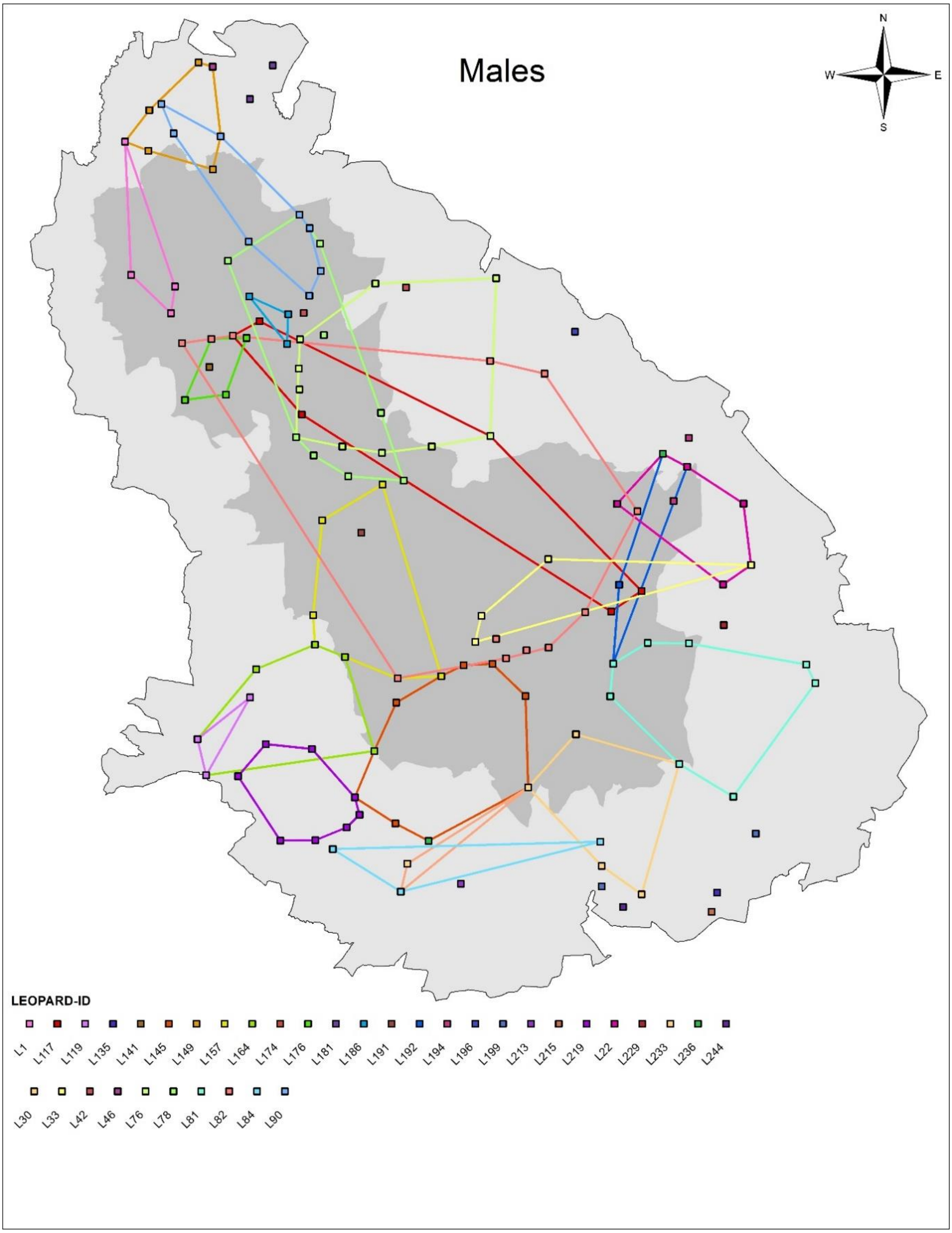


Figure 4.5: Spatial pattern of Leopards (Males) Inside TATR for the year 2019.

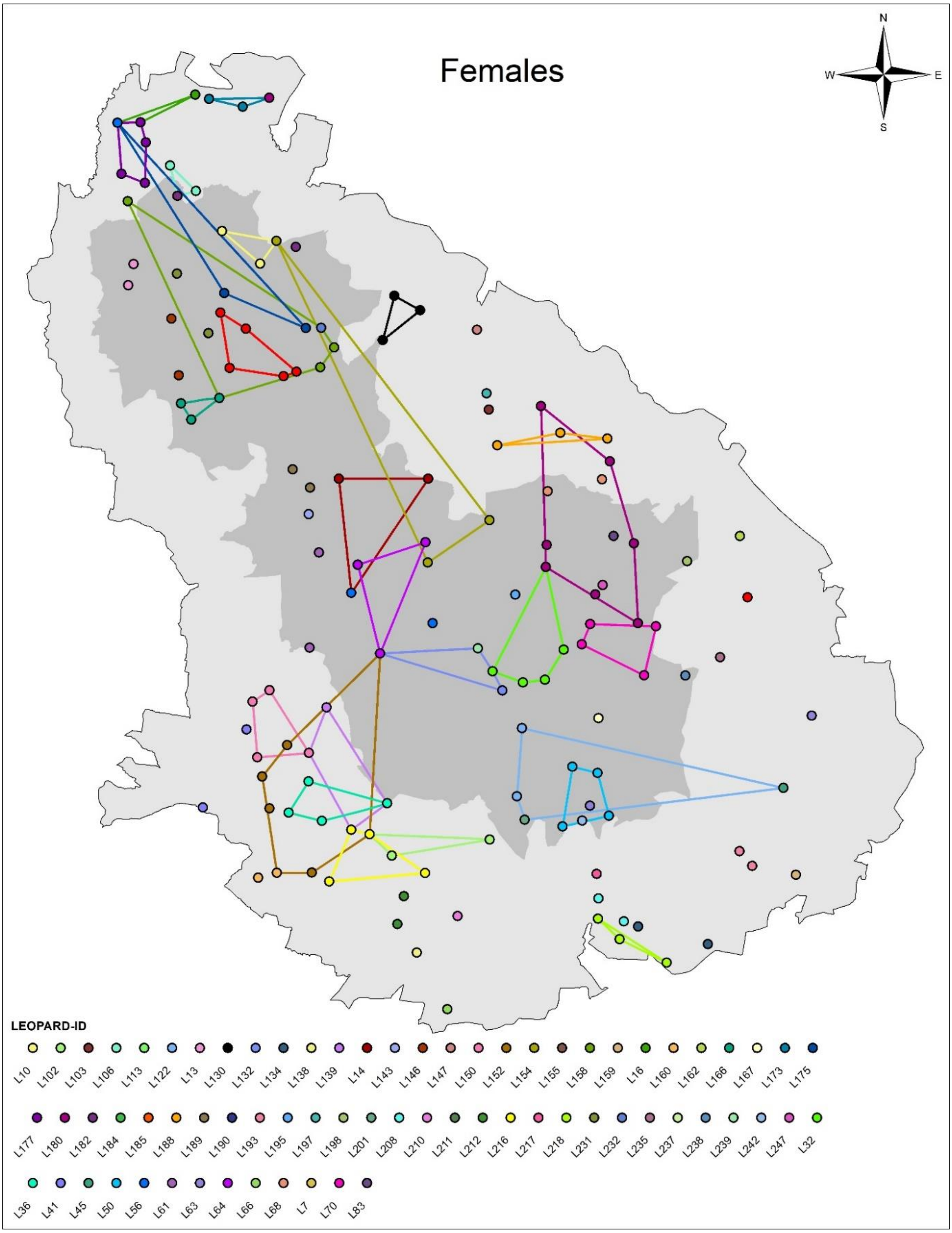


Figure 4.5: Spatial pattern of Leopards (Females) Inside TATR for the year 2019.

Section V – Temporal Activity of Predators & Prey Species in TATR

Introduction

Predators and prey are locked in an evolutionary arms race that shapes their behavior and life history. Predators target prey vulnerabilities to maximize hunting success, while prey trade-off foraging against predation avoidance. Depending on the intensity of competition among predators and predator-prey interactions, activity peaks may be dynamic (Lima 1988) and site specific conditions may force animals to change their conventional activity pattern. Avoidance behaviors reflect the need to balance the benefits of an activity against its attendant risks, including potentially lethal encounters with a predator. Most activity of animals is dedicated to 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 data are increasingly used to study temporal patterns in species and community ecology, including species' activity patterns and niche partitioning. However, studies which deal with comparison of activity patterns of large sympatric carnivores with respect to their prey are few in India. The camera trap photographs have a record of the time during which the species is most active. Number of photographic records of a species are more frequent when the species is active. Species that are active during the same time period in a day may be predator-prey or competitors.

Methods and Results

The temporal pattern of the predators and their prey was analysed using R statistical software (version 3.4) (R Development Core Team 2017 http://www.R-project.org) and Microsoft Office Excel 2018. The approach established by Linkie and Ridout (2009) was used to study temporal activity pattern 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 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. 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:

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

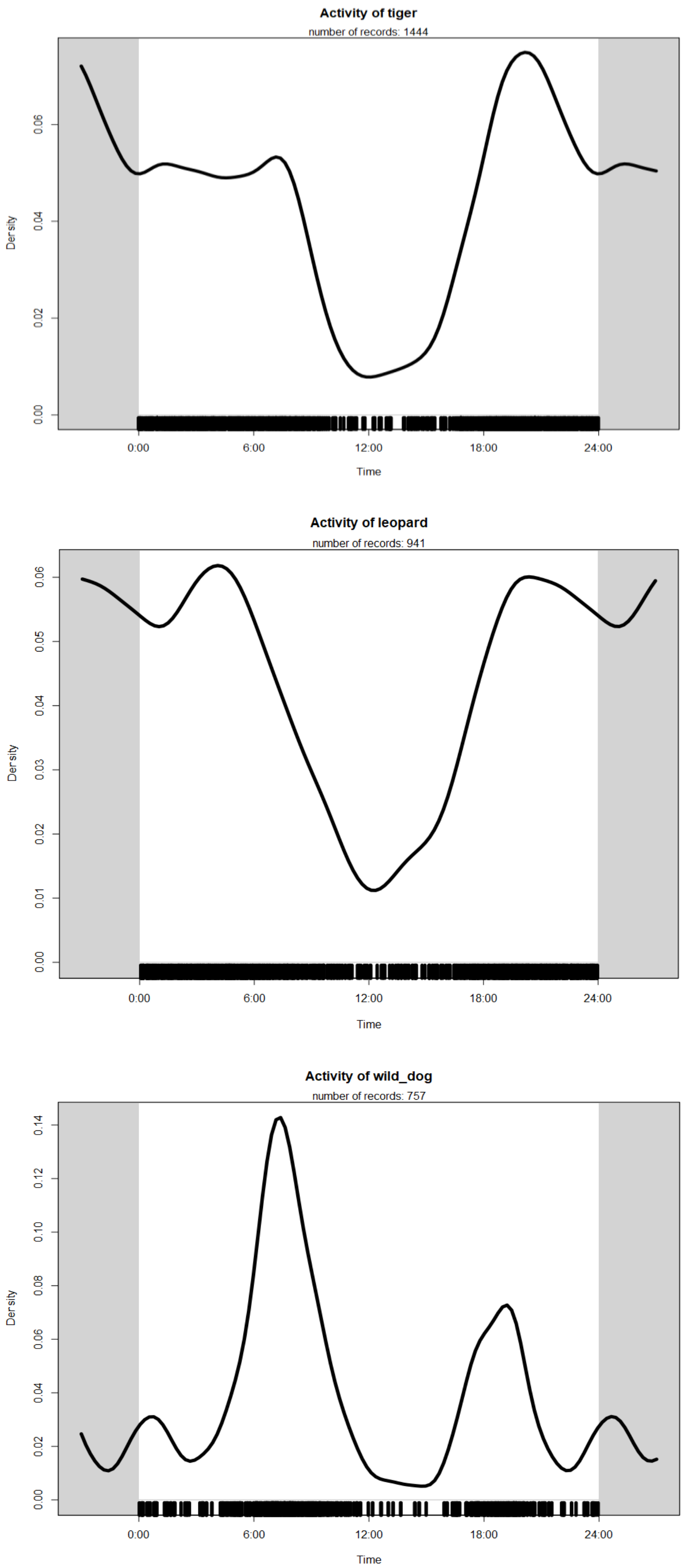
$$\hat{\Delta}_5 = \frac{1}{n}\sum_{i=1}^{n} \mathrm{I}\{\hat{f}(t_i) < \hat{g}(t_i)\} + \frac{1}{m}\sum_{j=1}^{m} \mathrm{I}\{\hat{f}(y_j) \geq \hat{g}(y_j)\}$$

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

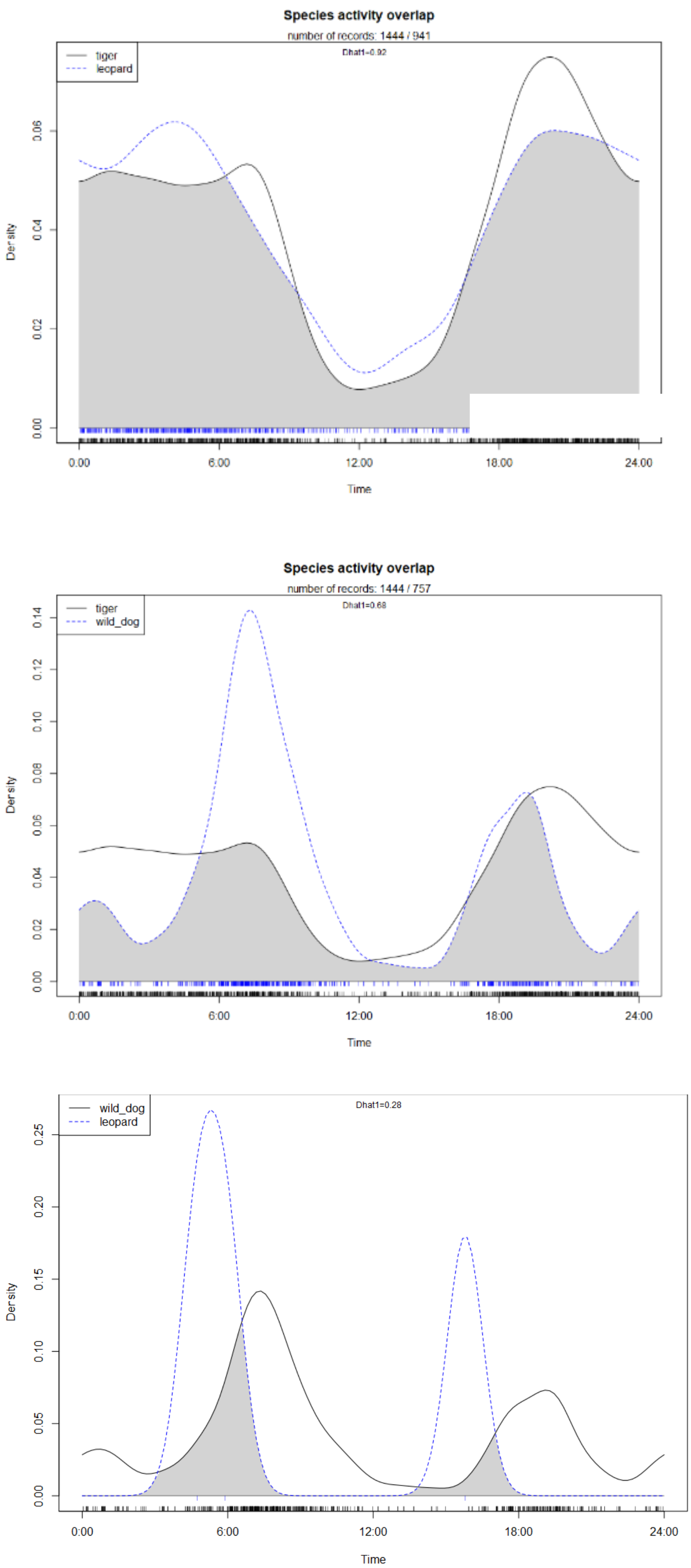
The Kernel density estimates of daily temporal activity patterns of different predator species are shown in Figure 5.1. From the kernel density estimators, the tiger and leopard were observed to have a high degree (0.94) of overlap as indicated by the estimated overlap coefficients in Table 5.1.

Table 5.1: Activity Overlap of Other Prey Species of Tadoba-Andhari Tiger Reserve with the three sympatric Species

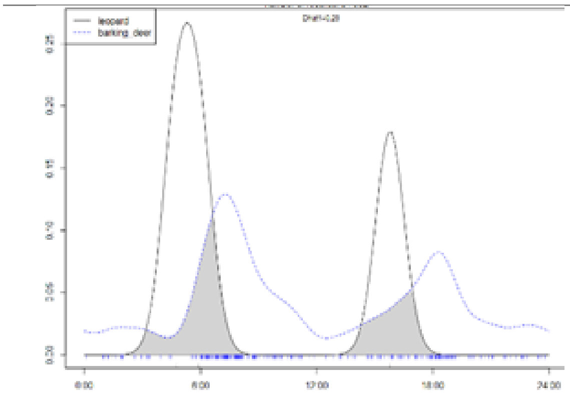
Species	Tiger	Leopard	Dhole
Sambar	0.82	0.32	0.68
Chital	0.56	0.29	0.69
Gaur	0.83	0.27	0.69
Wild Pig	0.62	0.29	0.82
Black-naped Hare	0.68	NA	0.44
Barking Deer	0.65	0.29	0.86
Chausingha	0.53	0.26	0.60
Nilgai	0.52	0.29	0.60
Langur	0.39	0.28	0.50
Honey Badger	0.7	0.17	0.41
Tiger	NA	0.92	0.68
Leopard	0.92	NA	0.28
Dhole	0.68	0.28	NA



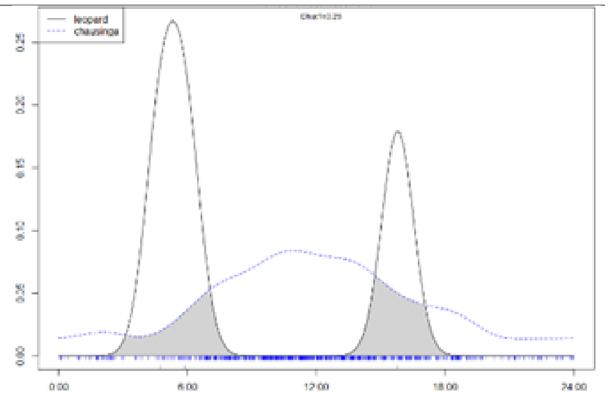
Figures 5.1 (a-c): Kernel density estimates of daily temporal activity patterns of (a) tiger, (b) leopard and (c) dhole - 3 sympatric carnivores in TATR, Maharashtra



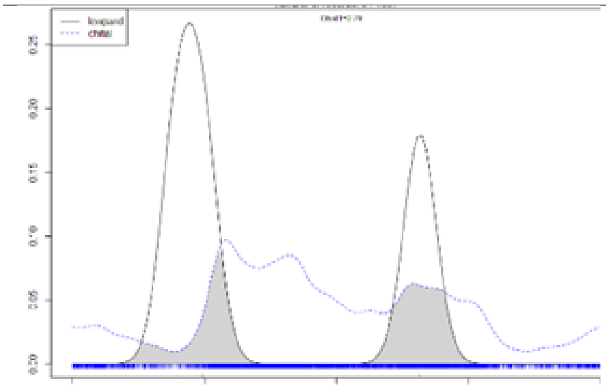
Figures 5.2(a-c): Daily temporal activity pattern overlap between co-predators. a) leopard vs. tiger; b) tiger vs dhole; c) dhole vs. leopard in TATR, India. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot.



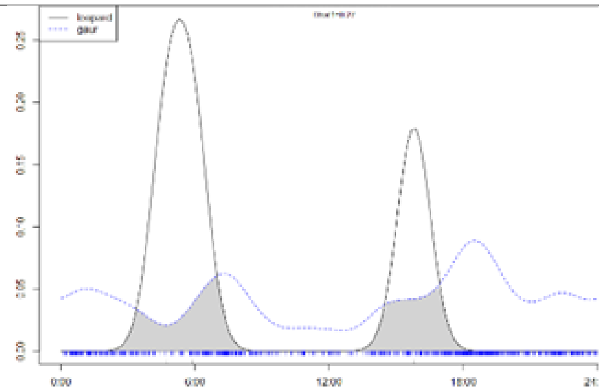
Leopard vs Barking Deer



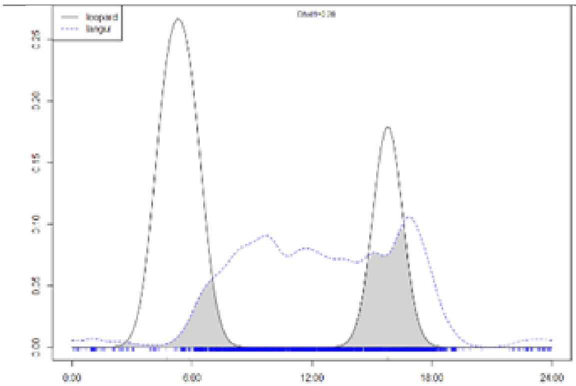
Leopard vs Chousingha



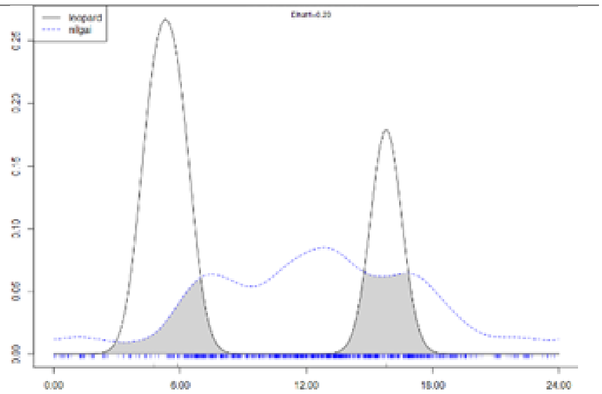
Leopard vs Chital



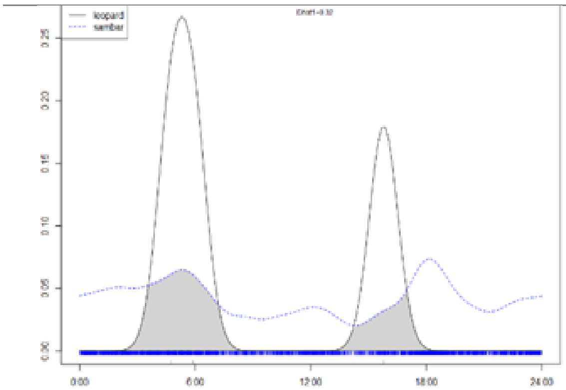
Leopard vs Gaur



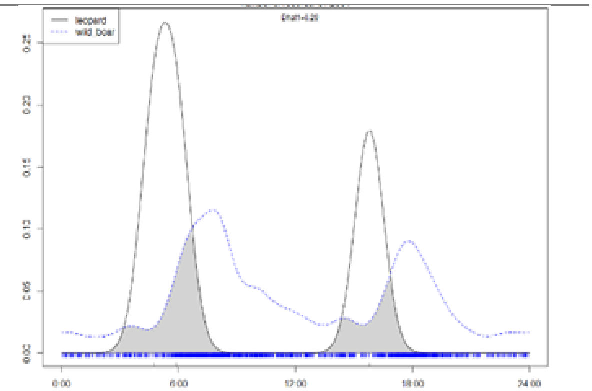
Leopard vs Langur



Leopard vs Nilgai

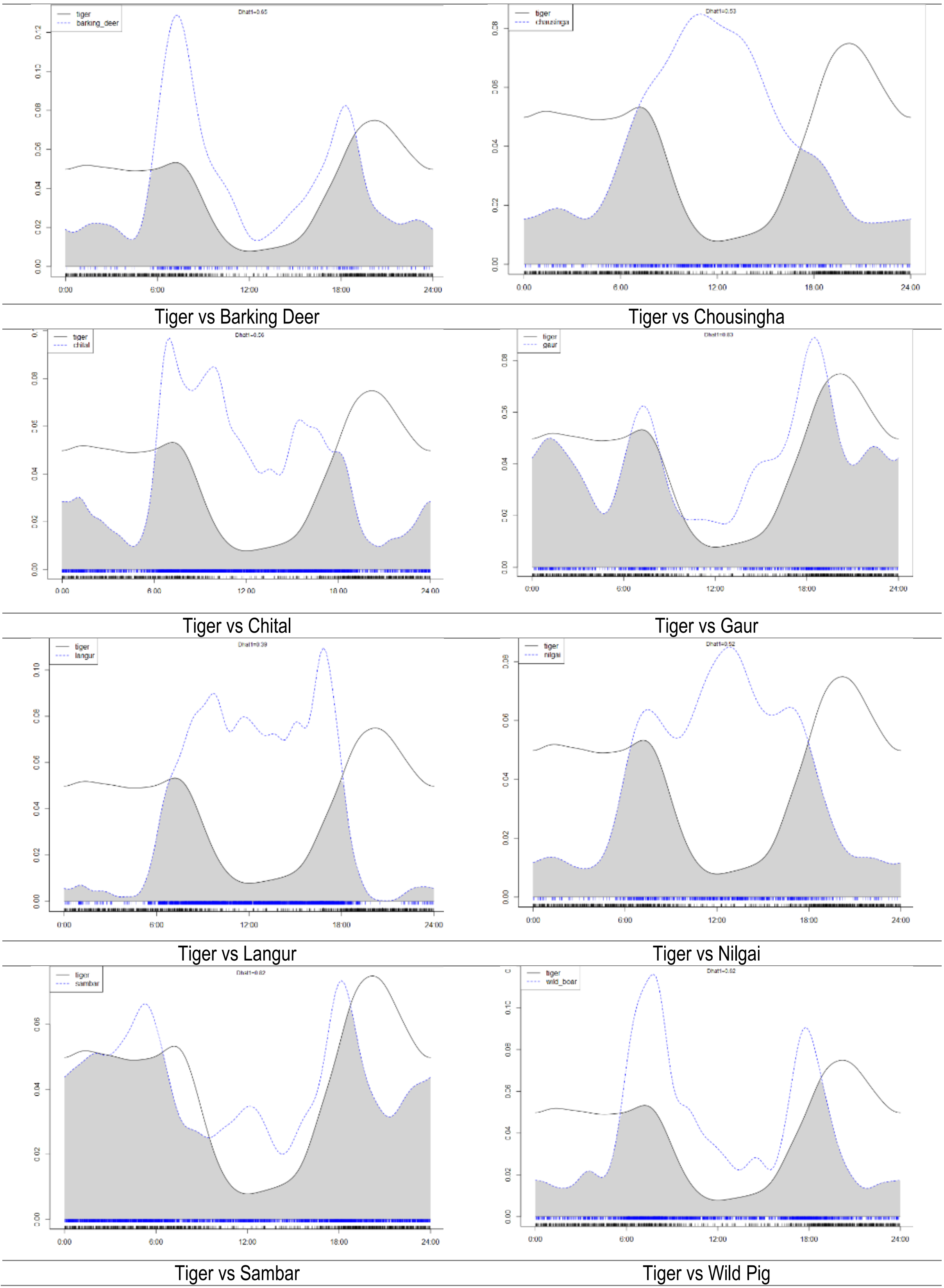


Leopard vs Sambar

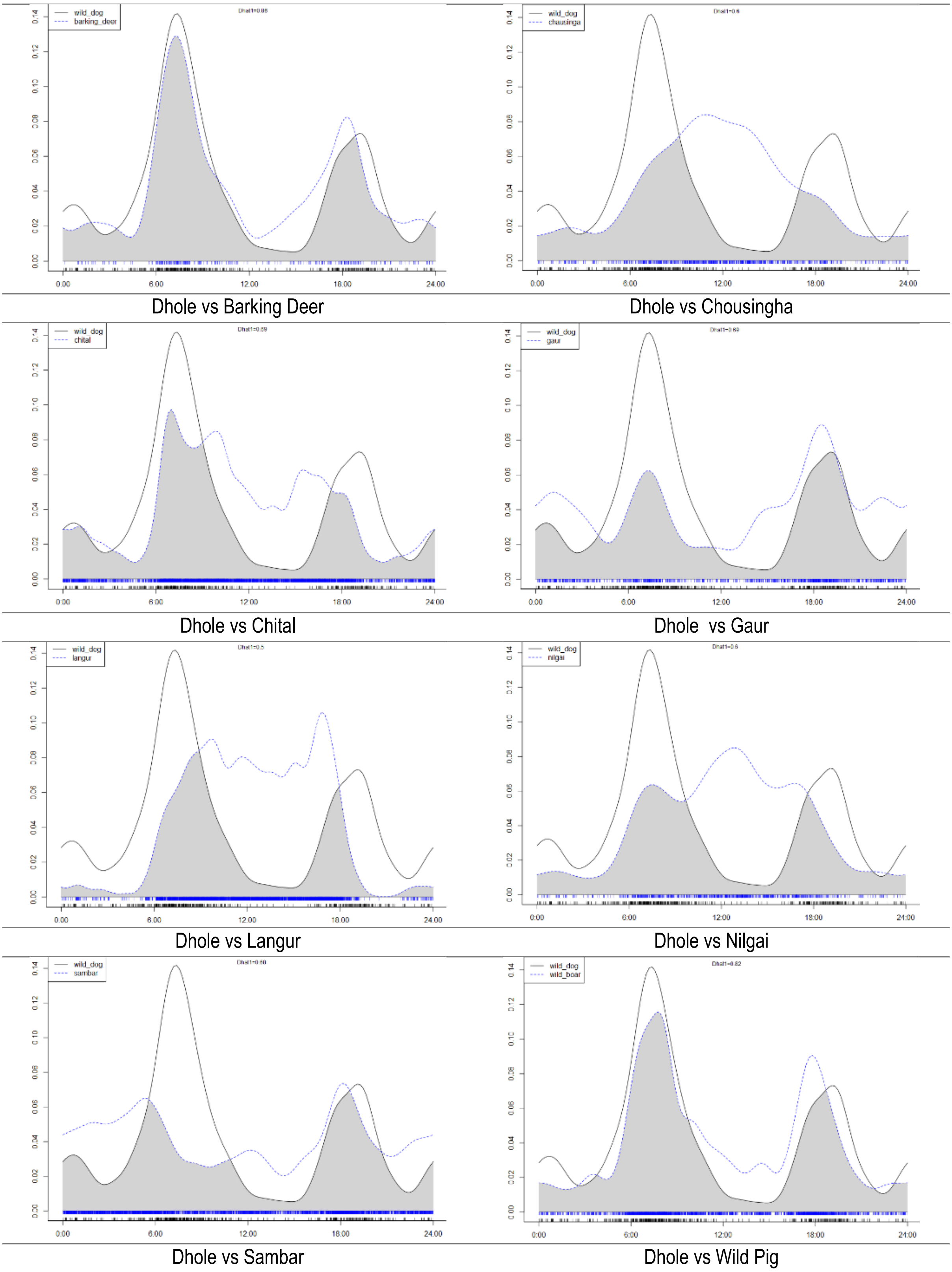


Leopard vs Wild Pig

Figures 5.3 (a-h): Daily temporal activity patterns of Leopard vs. prey species 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.



Figures 5.4 (a-h): Daily temporal activity patterns of the Tiger vs. prey species 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.

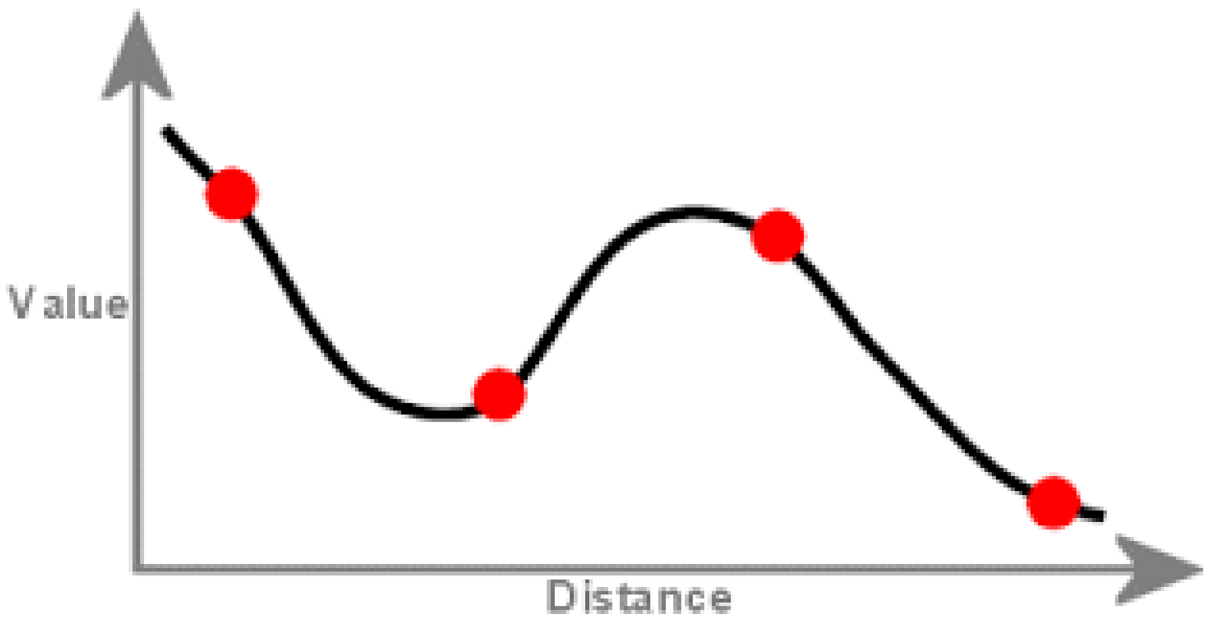


Figures 5.5(a-h): Daily temporal activity patterns of Dhole vs. prey species in TATR, India. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot.

Section VI – Modelling Spatially Explicit Intensive Use Areas: Predator & Prey Species

Introduction

Camera trap locations with 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. 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 modeled is driven by local variation, which can be captured (modeled) by defining an adequate search neighborhood.



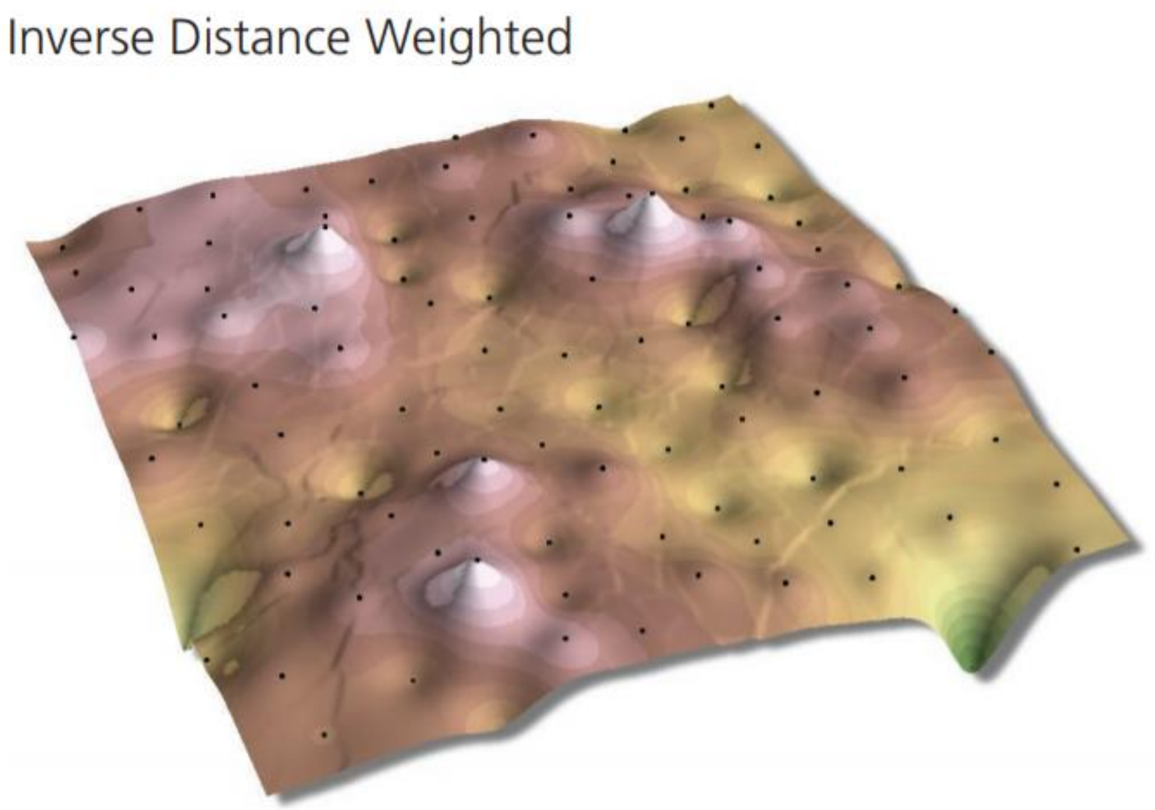
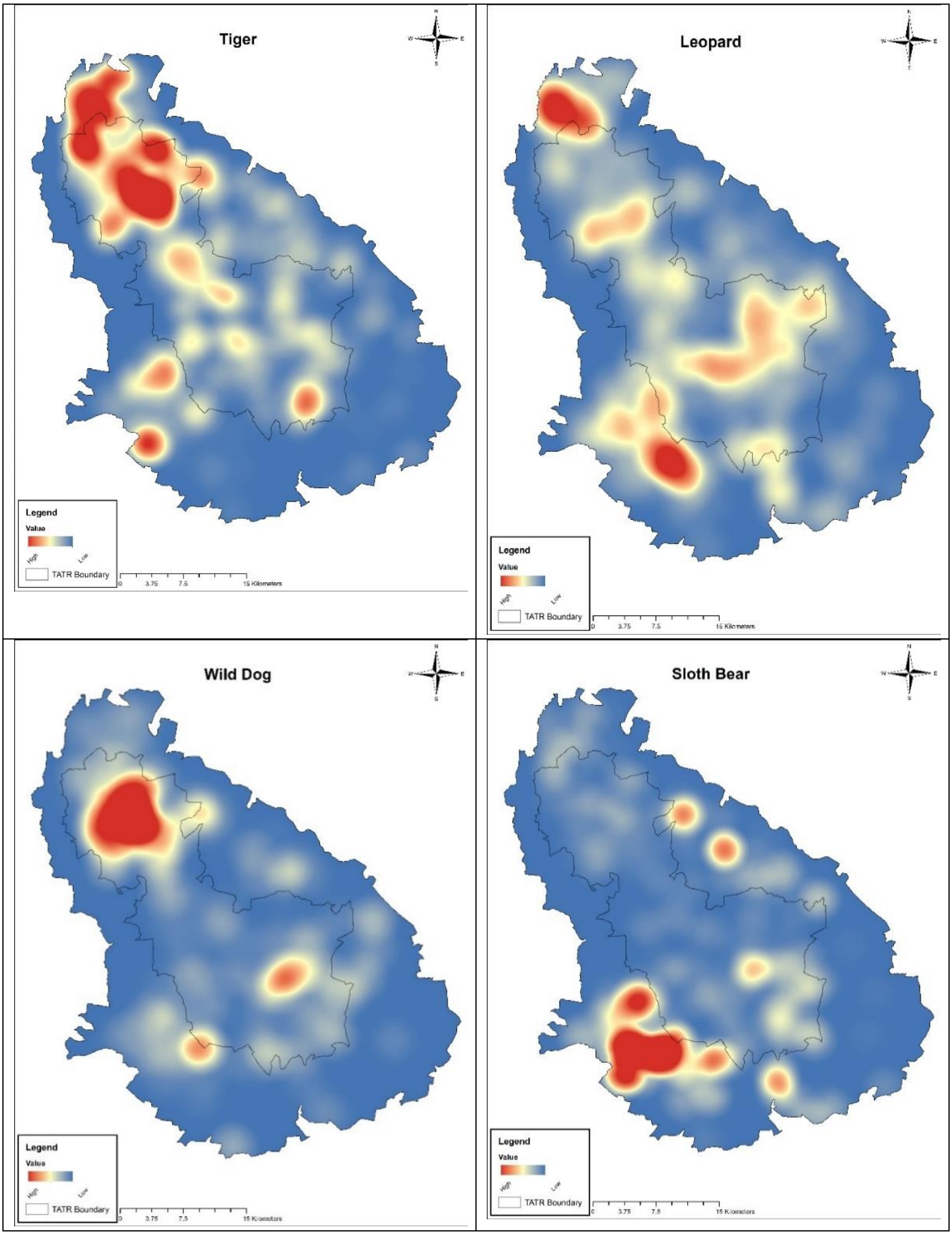


Figure 6.1: An example of IDW surface from points.

Using IDW technique we developed spatially explicit intensive use area maps (Based on camera trap location and number of photographs at each location) for four predator species namely Tiger, Leopard, Dhole and Sloth Bear core area of TATR. Figures 6.2 (a-f) show intensive use areas by four species Tiger, Leopard, Dhole and Sloth Bear.



Figures 6.2 (a-d): Intensive area use of Tiger, Leopard, Dhole and Sloth bear at Tadoba-Andhari Tiger Reserve, Maharashtra, India during the 2019 Phase IV Monitoring.

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