Navegaon Nagzira Tiger Reserve

Status of Tigers, CoPredators & Prey

2021

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

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

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Executive Summary

The Phase IV monitoring for the NNTR core and buffer was conducted from December 2020 – March 2021 as part of the project "Long term Monitoring of Tiger, Co-predator and their Prey in Tiger Reserves and other Tiger Bearing Areas of Vidarbha Maharashtra". The field site for this exercise was Navegaon-Nagzira Tiger Reserve. The core and buffer areas of the tiger reserve were covered under this exercise. The objective of 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.518 camera traps were placed in the core and buffer area of NNTR following a sampling grid of 2.01 sq. km in two blocks. An average camera trapping survey of 33 days in each block (Nagzira and Navegaon) with a sampling effort of 15,692 trap nights yielded data used for further analysis. Tiger density per 100 km^2 based on the Spatially Explicit Capture-Recapture (SECR) model was 0.64 in the Navegaon-Nagzira Tiger Reserve while that of leopards based on the same method was 8.21. To estimate prey density, 172 line-transects were sampled 7 times during the sampling period, with a total walking effort of 2382 km. The individual densities in Nagzira and Navegaon Core for Sambar, Chital, Nilgai, Wild pig, and Gaur were estimated to be 1.26 ± 0.39, 8.89 ± 1.77, 9.14 ± 1.94, 8.27 ± 4.85, 5.50 ± 1.08 and 0.56 ± 0.25, NA, 10.42 ± 2.61, NA, 5.93 ± 1.68 respectively whereas the individual density estimates for Nagzira and Navegaon buffer for Sambar, Chital, Nilgai, Wild pig, and Gaur were 0.15 ± 0.13, 10.29 ± 1.96, 7.13 ± 1.43, 13.92 ± 8.29, NA and 0.49 ± 0.18, 7.61 ± 2.15, 11.75 ± 1.97, 12.03 ± 8.12, NA respectively.

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

Species distribution was mapped seasonally using direct sighting data of wild ungulates from all the three seasons i.e. from winter 2019 to monsoon 2020 that was collected through regular patrolling using the MSTrIPES, a patrolling protocol mandated by NTCA to use in tiger reserves. MaxEnt, ArcGIS software was used for data preparation and final analysis. Factors that influence species distributions and habitat selection are of great importance to researchers and managers of wildlife. Here we used habitat variables namely: Land use Land cover (LULC), Digital Elevation Model (DEM), slope, aspect, stream delineation (Distance to streams), distance to the village, distance to road, distance to the railway line, and distance to the waterhole.

1. Introduction

Conservation of biodiversity requires an understanding of the population and distribution of any species. Additionally, monitoring of a population over time is crucial in understanding the existing ecological processes which reveal valuable information on demographic and behavioural aspects, as well as in evaluating the effectiveness of management actions (Nichols and Williams 2006).
The tiger (*Panthera tigris*) is the largest extant cat species. 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.

In India, Central India is one of the last strongholds of the tiger population. As the apex predator, tigers regulate the population of prey through predation and other small carnivores through intraguild competition. Therefore the project "Long term Monitoring of Tiger, Co-predator and their Prey in Tiger Reserves and other Tiger Bearing Areas of Vidarbha Maharashtra" was initiated by Wildlife Institute of India under the aegis of the Maharashtra Forest Department with the vision of understanding of tiger, co-predator and prey ecology through rigorous field studies and to objectively evaluate the success of management measures and conservation interventions (Figure 1).

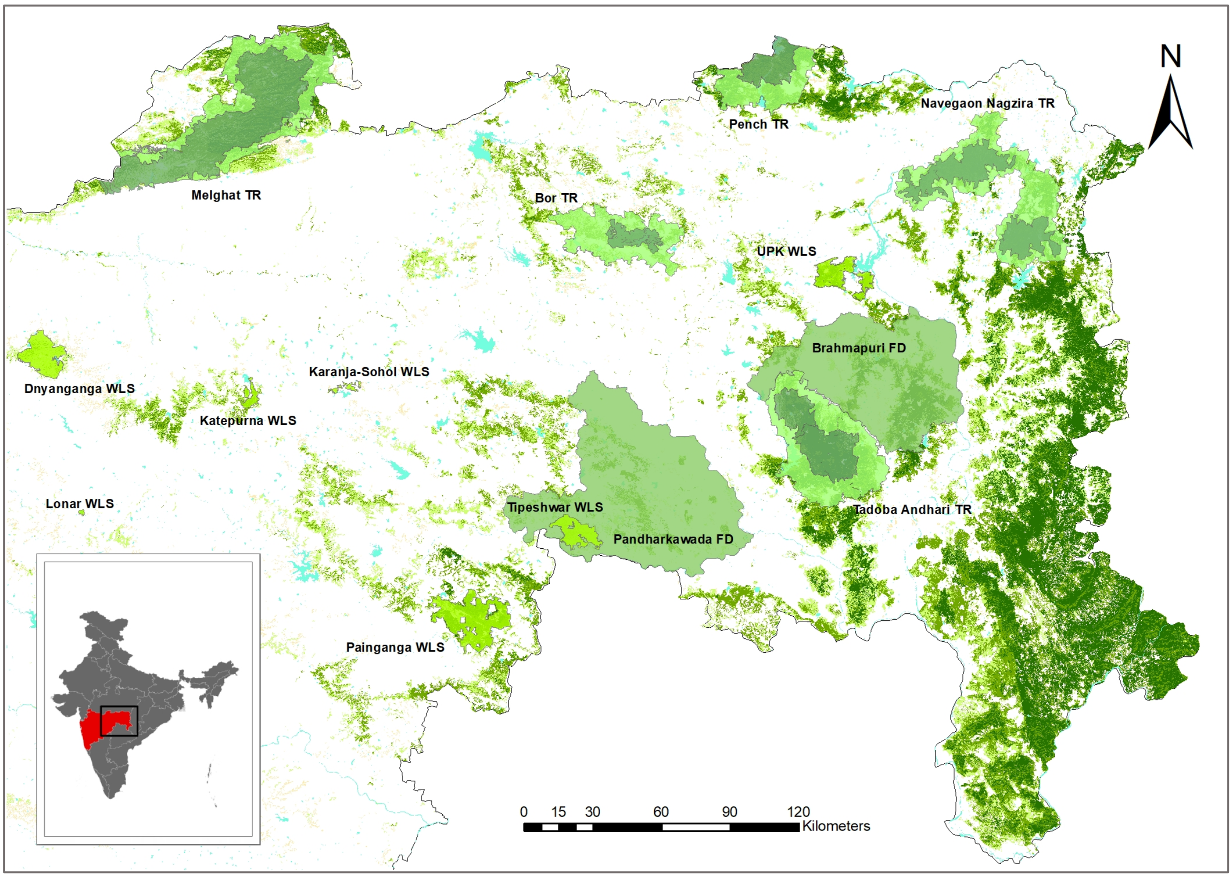


Figure 1: Map of study area showing study sites in Vidarbha Landscape, Maharashtra, India

The tiger-bearing areas of Vidarbha include Navegaon Nagzira Tiger Reserve, Tadoba-Andhari Tiger Reserve, Melghat Tiger Reserve, Pench Tiger Reserve Maharashtra, Brahmapuri and Pandharkawada

(Territorial) Forest Divisions, Umred Karhandla Wildlife Sanctuary, Tipeshwar 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.

Navegaon Nagzira Tiger Reserve (NNTR) is located at N 79.98, E 21.25 with a total area of 656.36 km² (core) and 1241.24 km² (buffer) spread over districts of Bhandara and Gondia of Eastern Vidarbha, Maharashtra, India. It comprises five protected areas (PAs) including Nagzira Wildlife Sanctuary (152 km²), New Nagzira Wildlife Sanctuary (151 km²), Navegaon National Park (133 km²), Navegaon Wildlife Sanctuary (123 km²), and Koka Wildlife Sanctuary (97 km²) (Figure 2). In the southern boundary of this Tiger reserve, the river Wainganga flows which acts as the only water source in the landscape. The buffer of NNTR is a matrix of ~ 185 villages, tourist rest houses, and farmlands.

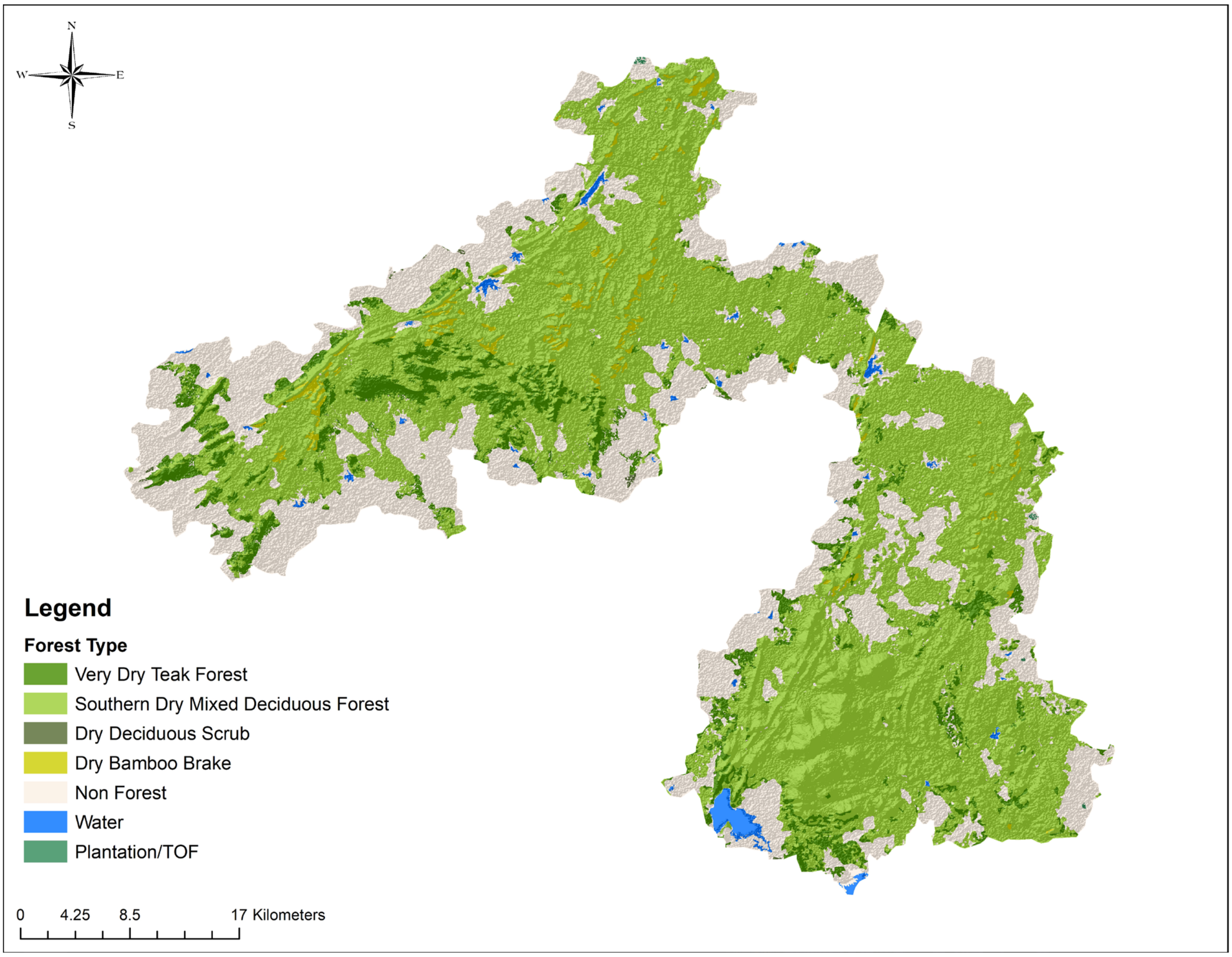


Figure 2: Map showing Forest type map for Navegaon-Nagzira Tiger Reserve

As per the biogeographic classification adopted by the Wildlife Institute of India, this Tiger reserve is classified as Bio-geographic Zone – 6 – Deccan Peninsula and Biotic Province – 6 B – Central Deccan. Being connected to Kanha Tiger Reserve in the northeast through Balaghat corridor, Indravati Tiger Reserve, Telangana in the southeast, Tadoba Andhari Tiger Reserve in the south west through Brahampuri Forest Division, Pench Tiger Reserve in the northwest through forests of Umred Karhandla

Wildlife Sanctuary, NNTR act as stepping stone for dispersing tiger populations in this landscape. Wainganga is the perennial river flowing in the south of this Tiger reserve. A dam site is located in Navegaon National Park which receives migratory species of birds every year. The area is mostly undulating and hilly in the northern part of the reserve whereas it is plain in the southern part. It has a subtropical climate with three distinct seasons- summer, monsoon, and winter. The Reserve receives southwest monsoons and rainfall persists from June to September.

NNTR comes within the category of southern tropical dry deciduous forest. Teak (*Tectona grandis)* is the most characteristic species of this forest type. The major tree species are *Terminalia tomentosa, Lagerstroemia parviflora, Anogeisus lotifolia, Pterocarpus marsupium, Diospyrus melanoxylon, Ougenia oogensis, Tectona grandis Bombax ceiba, Lannea grandis, Boswella serrata, Adina cordifolia, Xylia xylocarp*. Along the nallas, *Terminalia arjuna*, *Syzygium cumini*, *Schleichera oleosa*, *Terminalia chebula* are found. Grasses that occur here are *Themeda quadrivalvia, Iseilema laxum, Apluda varia, Eragrostis tennella*, *Cynodon dactylon, Imperata cylindrical*, near the water body - *Vetiveria zizyniodes, Heteropogan contrortus, Schima nervosum* occur. A bamboo species *Dendrocalamus strictus* occurs in abundance on the slope and along nallas in all five PAs of the Tiger Reserve where there is deep soil mixed with moisture. It grows as a middle story in teak as well as mixed forest.

NNTR harbors large carnivores like Tiger (*Panthera tigris*), Dhole (*Cuon alpinus*), Leopard (*Panthera pardus*) and Sloth bear (*Melursus ursinus)*, other carnivores like Jungle cat (*Felis chaus*), Rusty-spotted cat (*Prionailurus rubiginosus*), Palm civet (*Paradoxurus hermaphrodites*), Small Indian civet (*Viverricula indica*), Common mongoose (*Herpestes edwardsi*), Ruddy mongoose (*Herpestes smithii)* and Ratel (*Mellivora capensis*). Prey base comprises of Chital (*Axis axis*), Sambar (*Cervus unicolor*), Nilgai (*Bosephalus tragocamelus*), Gaur (*Bos gaurus*), Wild pig (*Sus scrofa*), Barking deer (*Muntjacus muntjak*), Black-naped hare (*Lepus nigricollis*), Langur (*Semnopithecus entellus*) and Porcupine (*Hystrix indica*).

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

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

a) Field surveys will be conducted to detect the presence of tigers, co-predators, and prey species using animal signs (tracks, scats, direct sightings, calls, etc) in an occupancy-based framework. The data will be analyzed in the occupancy framework to estimate the occupancy of the target species. Single-season or multiple-season occupancy models will be used depending on data collection approaches. These occupancy field surveys will be carried in all the tiger areas. The data collection will be followed by modelling and estimation approaches described in detail by Mackenzie et al., (2002, 2006).
b) Density, abundance and demography of tigers and co-predators will be carried by using camera traps in all the tiger areas followed by analyzing the data in capture–recapture frame work. Rigorous field methods will be followed to achieve a small CV and high precision. These field surveys will be conducted in all the tiger areas.
c) Estimation of abundance and density of the key ungulate species will be conducted using distance sampling employing line-transect survey protocols. The survey protocols and analyses of this data set will be based on modelling and estimation approaches developed by Buckland et al. (2001, 2004).
d) Estimation of recruitment, survival, transience, temporary emigration, permanent emigration and dispersal rates of tigers and leopards will be based on data collected from camera trapping and radio-telemetry.
e) Scat analysis is indirect, non-invasive and unbiased technique for recording frequency of occurrence of prey in the diet of large carnivores and hence it is most widely used (Johnson et al., 1983; Leopold and Krausman, 1986; Jhala, 1993; Mukherjee et al., 1994a, b; Spaulding et al., 1997; Jethva, 2002; Biswas and Sankar, 2002). Scats will be collected at regular time intervals, generally every week. The scats will be collected in polythene bags, labelled and sun-dried in the field. Information on habitat, substratum where scat will be found and its GPS location will also be recorded.

Objective 2: Development of database on tigers across the landscape

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

Objective 3: Identification of tiger dispersal in the landscape

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

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

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

2. Status of Prey Species in Navegaon Nagzira Tiger Reserve

Introduction:

As wild ungulates are the major diet of large carnivores, their abundance is directly correlated with ungulate densities (Karanth and Nichols 1998). The future survival of top predators like tigers depends largely on the availability of suitable prey and habitat (Karanth et al. 2004). Hence, maintaining a good prey population is essential for ecosystem health and the maintenance of a viable carnivore population.

Line transect-based distance sampling method is used to estimate the density of prey species majorly ungulate species. A total of 172 transects (Figure 3) were walked with seven replicates of each to maximize the number of observations. Transects were walked early in the morning in December. Information of sightings such as species, distance to the animal, angle, and habitat was recorded by staff.

Analysis was done using DISTANCE 7.3 software. Different detection functions along with the key adjustment terms were used to fit the different models and the best fit model was selected on the basis of Akaike Information Criterion (AIC). Post-priory binning of the data was done to fit the model and get a decent chi-square *p*-value.

Analysis was done into four parts where global detection function was used to pool observations of all the sites to fit the detection function and density was obtained as per the stratum.

1. **Nagzira core:** This includes data of Pitezari, Umarzari, Nagzira, Koka ranges.
2. **Nagzira buffer:** includes Bhandara, Lakhni, Sakoli, Tumsar, Gondia, Tirora, Goregaon ranges.
3. **Navegaon core:** includes Navegaon National Park, Bonde, and Dongargaon ranges.
4. **Navegaon buffer:** includes Sadak Arjuni, Jambhadi-1, Jambhadi-2, North Deori, and South Deori.

Distance Sampling:

The line transect-based distance sampling approach is the most widely used method for estimating the size or density of biological populations. This method has been effectively used to determine animal densities under similar tropical conditions. Line transects were laid in a stratified random framework to ensure spatial coverage of all vegetation types.

The total number of transects in NNTR was 174 (Table 1). The transects were 1-2 km in length and each transect was temporally replicated seven times. The transect surveys were conducted in December 2020 in NNTR. Data for species, group size, and composition, GPS (global positioning system) location of every observation, bearing of the animal using a compass, and angular sighting distance using laser range finders, was recorded whenever species were observed on the line transects.

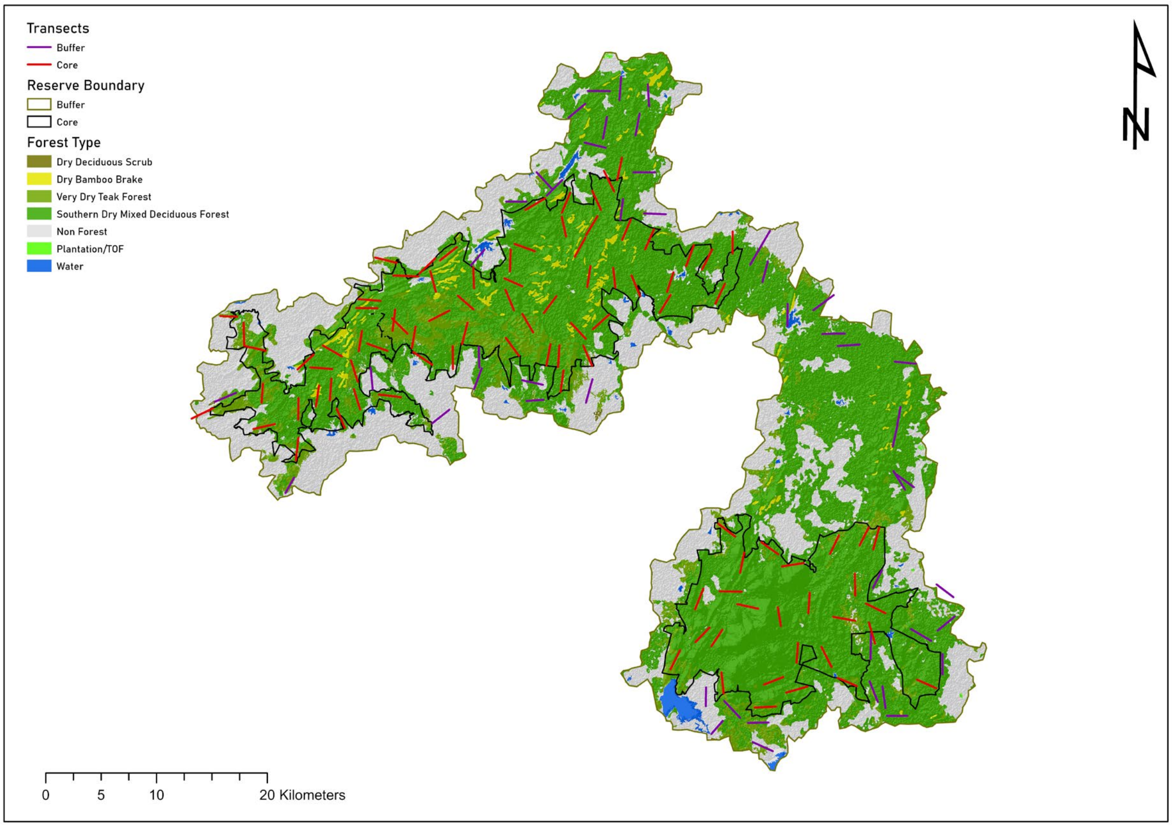


Figure 3: Map showing Line transect locations with respect to forest cover for Navegaon-Nagzira Tiger Reserve, Maharashtra, India

During the line transect survey, a total of 10 prey species were sighted. Nilgai was the most frequently sighted species with 108 sightings. But the most number of individuals were sighted for Langur (1557 individuals in 125 sightings) (Table 2). Due to the low number of sightings for a few species, we analyzed line transect data of core, only for Sambar, Chital, Nilgai, Wild pig, Gaur, and langur. The individual densities in Nagzira and Navegaon Core for Sambar, Chital, Nilgai, Wild pig, and Gaur were estimated to be 1.26 ± 0.39, 8.89 ± 1.77, 9.14 ± 1.94, 8.27 ± 4.85, 5.50 ± 1.08 and 0.56 ± 0.25, NA, 10.42 ± 2.61, NA, 5.93 ± 1.68 respectively whereas the individual density estimates for Nagzira and Navegaon buffer for Sambar, Chital, Nilgai, Wild pig, and Gaur were 0.15 ± 0.13, 10.29 ± 1.96, 7.13 ± 1.43, 13.92 ± 8.29, NA and 0.49 ± 0.18, 7.61 ± 2.15, 11.75 ± 1.97, 12.03 ± 8.12, NA respectively (Table 3, 4, 5 and 6). Detection function graphs for each species are provided in figure 4.

Table 1: Transect Monitoring Effort and Species Reported for Navegaon-Nagzira Tiger Reserve during line transect survey 2020 (December) (Transect of length 1- 2 km walked for 7 days each beat for direct sightings)

Survey Details	
Number of transects	174
Length of each transect	1-2 Km
Number of replicates	7
Total Distance Covered	2382 Km
Beats	169
Number of species Recorded	10

Table 2: Details of species recorded in the Navegaon Nagzira Tiger Reserve

	Sites		**Sambar**	**Chital**	**Nilgai**	**Gaur**	**Wild Pig**	**Langur**
No. of Sightings	Nagzira	Core	26	55	53	61	19	36
		Buffer	6	41	43	1	25	28
	Navegaon	Core	8	5	32	33	2	10
		Buffer	11	36	65	7	25	51
Total Individuals Counted	Nagzira	Core	60	300	101	311	145	365
		Buffer	17	322	142	1	202	371
	Navegaon	Core	13	36	56	172	7	62
		Buffer	18	158	190	23	161	759
Average Group Size	Nagzira	Core	2.30	3.97	1.88	5.08	7.58	9.80
		Buffer	1	5.14	1.51	1	8.08	10.91
	Navegaon	Core	1.62	7.2	1.75	4.97	3.5	6.20
		Buffer	1.63	3.99	1.51	3.28	6.44	12.28

Table 3: Individual Density, Group Density, Effective Strip Width, Detection probability, Average Group Size and Encounter Rate of Various Ungulate Species Reported During 2020 Survey in Nagzira (Core)

Nagzira Core	Chital	Sambar	Nilgai	Gaur	Wild pig
No. of Line transects	55	55	55	55	55
Total effort	770	770	770	770	770
Total Observation	55	26	53	61	
Individual density	8.89	1.26	9.14	5.50	8.27
SE	1.77	0.39	1.94	1.08	4.85
% CV	19.92	31	21.22	19.61	58.69
95% CI	6.02-13.14	0.69-2.3	6.03-13.85	3.75-8.08	2.81-24.32
Group density	2.24	0.55	4.84	1.08	1.09
SE	0.38	0.14	0.95	0.15	0.61
% CV	17.00	25.61	19.53	13.85	55.75
95% CI	1.6-3.13	0.33-0.9	3.3-7.11	0.82-1.43	0.39-3.07
Effective strip width	15.96	30.93	7.11	36.57	11.31
SE	1.30	4.46	0.65	2.75	5.81
% CV	8.17	14.43	9.19	7.53	51.43
95% CI	13.58-18.75	23.18-41.27	5.93-8.52	31.51-42.45	4.3-29.71
Avg group size	3.97	2.31	1.89	5.08	7.58
% CV	10.39	17.46	8.28	13.69	18.38
95% CI	3.23-4.89	1.62-3.3	1.6-2.23	3.87-6.67	5.17-11.11
Encounter rate	0.071	0.034	0.069	0.079	0.025
% CV	14.91	21.16	17.24	11.86	21.53
95% CI	0.053-0.096	0.022-0.051	0.049-0.097	0.063-0.1	0.016-0.038
Probability of a greater chi-square value, P	0.690	0.777	0.961	0.755	0.67

Table 4: Individual Density, Group Density, Effective Strip Width, Detection probability, Average Group Size and Encounter Rate of Various Ungulate Species Reported During 2020 Survey in Nagzira (Buffer)

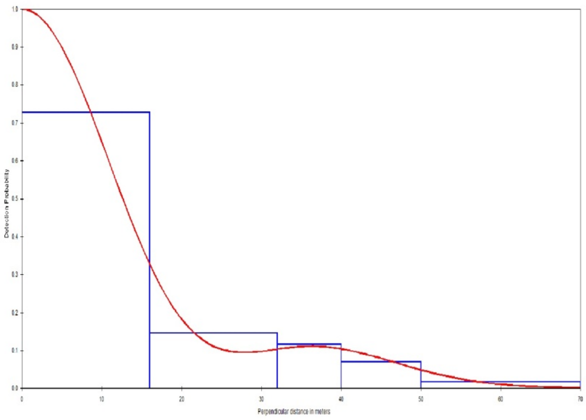
Nagzira Buffer	Chital	Sambar	Nilgai	Gaur	Wild pig
No. of Line transects	48	48	48	48	48
Total effort	641.7	641.7	641.7	641.7	641.7
Total Observation	41	6	43	1	25
Individual density	10.29	0.15	7.13		13.92
SE	1.96	0.13	1.43		8.29
% CV	19.09	88.26	20.05		59.57
95% CI	7.07-14.958	0.03-0.88	4.81-10.56		4.67-41.49
Group density	2.00	0.15	4.71		1.72
SE	0.32	0.07	0.85		0.97
% CV	16.21	47.42	17.97		56.01
95% CI	1.4533-2.7586	0.06-0.37	3.31-6.72		0.61-4.86
Effective strip width	15.96	30.93	7.11		11.31
SE	1.30	4.46	0.65		5.81
% CV	8.17	14.43	9.19		51.43
95% CI	13.57-18.74	23.18-41.27	5.93-8.52		4.3-29.71
Avg group size	5.14	1.00	1.51		8.08
% CV	10.07	74.44	8.90		20.27
95% CI	4.19-6.29	1-6.35	1.26-1.81		5.34-12.23
Encounter rate	0.064	0.009	0.067		0.039
% CV	14	45.17	15.44		22.21
95% CI	0.05-0.08	0.004-0.022	0.049-0.091		0.02-0.061
Probability of a greater chi-square value, P	0.690	0.777	0.961		0.67

Table 5: Individual Density, Group Density, Effective Strip Width, Detection probability, Average Group Size and Encounter Rate of Various Ungulate Species Reported During 2020 Survey in Navegaon (Core)

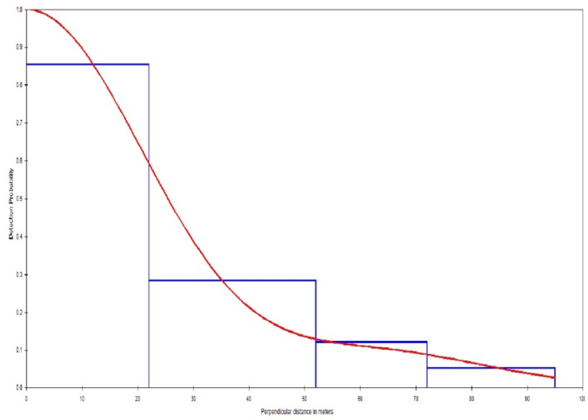
Navegaon Core	Chital	Sambar	Nilgai	Gaur	Wild pig
No. of Line transects	27	27	27	27	27
Total effort	378	378	378	378	378
Total Observation	5	8	32	33	2
Individual density		0.56	10.42	5.93	
SE		0.25	2.61	1.68	
% CV		44.48	25.06	28.35	
95% CI		0.24-1.31	6.37-17.07	3.4-10.34	
Group density		0.34	5.96	1.19	
SE		0.13	1.26	0.26	
% CV		38.03	21.22	21.97	
95% CI		0.16-0.72	3.9-9.1	0.77-1.86	
Effective strip width		30.93	7.11	36.57	
SE		4.46	0.65	2.75	
% CV		14.43	9.19	7.53	
95% CI		23.18-41.27	5.93-8.52	31.51-42.45	
Avg group size		1.63	1.75	4.97	
% CV		23.08	13.33	17.91	
95% CI		1-2.78	1.34-2.29	3.46-7.14	
Encounter rate		0.021	0.085	0.087	
% CV		35.18	19.13	20.64	
95% CI		0.01-0.04	0.06-0.12	0.06-0.13	
Probability of a greater chi-square value, P		0.777	0.961	0.755	

Table 6: Individual Density, Group Density, Effective Strip Width, Detection probability, Average Group Size and Encounter Rate of Various Ungulate Species Reported During 2020 Survey in Navegaon (Core)

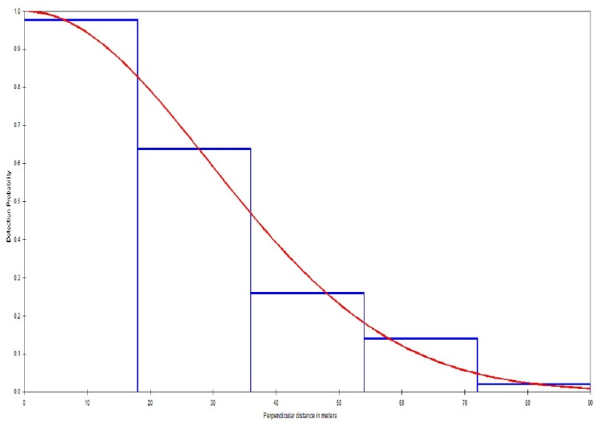
Navegaon Buffer	Chital	Sambar	Nilgai	Gaur	Wild pig
No. of Line transects	42	42	42	42	42
Total effort	592	592	592	592	592
Total Observation	36	11	65	7	25
Individual density	7.61	0.49	11.75		12.03
SE	2.15	0.18	1.97		8.12
% CV	28.26	35.93	16.77		67.53
95% CI	4.38-13.21	0.25-0.98	8.45-16.33		3.58-40.45
Group density	1.91	0.30	7.72		1.87
SE	0.46	0.10	1.18		1.20
% CV	24.20	32.69	15.34		64.23
95% CI	1.18-3.08	0.16-0.57	5.71-10.46		0.58-5.99
Effective strip width	15.96	30.93	7.11		11.31
SE	1.30	4.46	0.65		5.81
% CV	8.17	14.43	9.19		51.43
95% CI	13.57-18.74	23.18-41.27	5.93-8.52		4.3-29.71
Avg group size	3.99	1.64	1.52		6.44
% CV	14.60	14.91	6.78		20.87
95% CI	2.97-5.37	1.18-2.28	1.33-1.74		4.21-9.86
Encounter rate	0.061	0.019	0.110		0.042
% CV	22.77	29.33	12.28		38.48
95% CI	0.039-0.096	0.01-0.033	0.086-0.14		0.02-0.089
Probability of a greater chi-square value, P	0.690	0.777	0.961		0.67



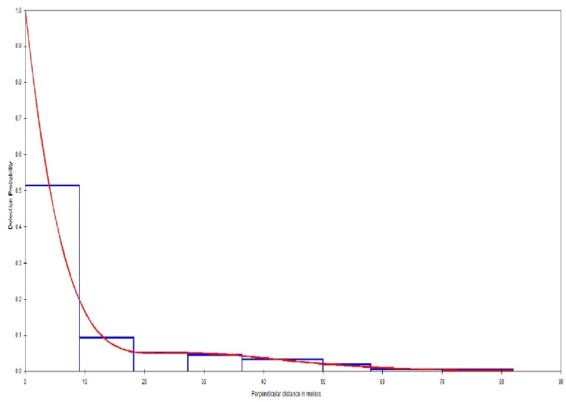
(a): Chital (Half normal with Cosine adjustment), *P* value= .690



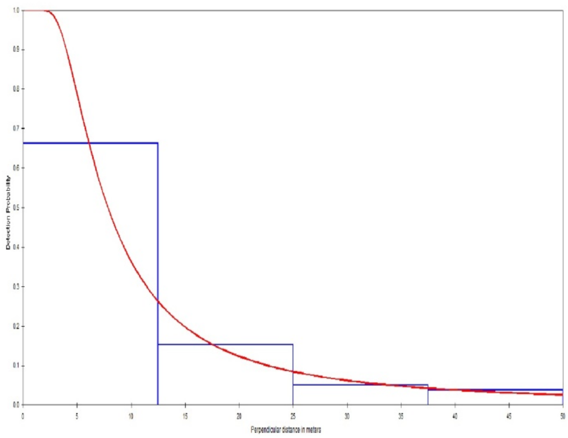
(b): Sambar (Half normal with Cosine), p value= .777



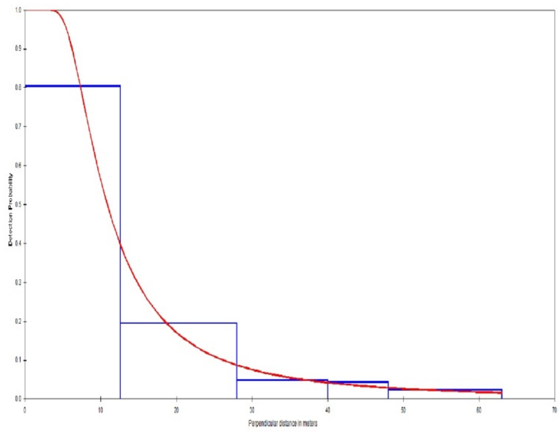
(c): Gaur (Half normal), p value= .755



(d): Nilgai (Negative exponential with simple polynomial), p value=.961

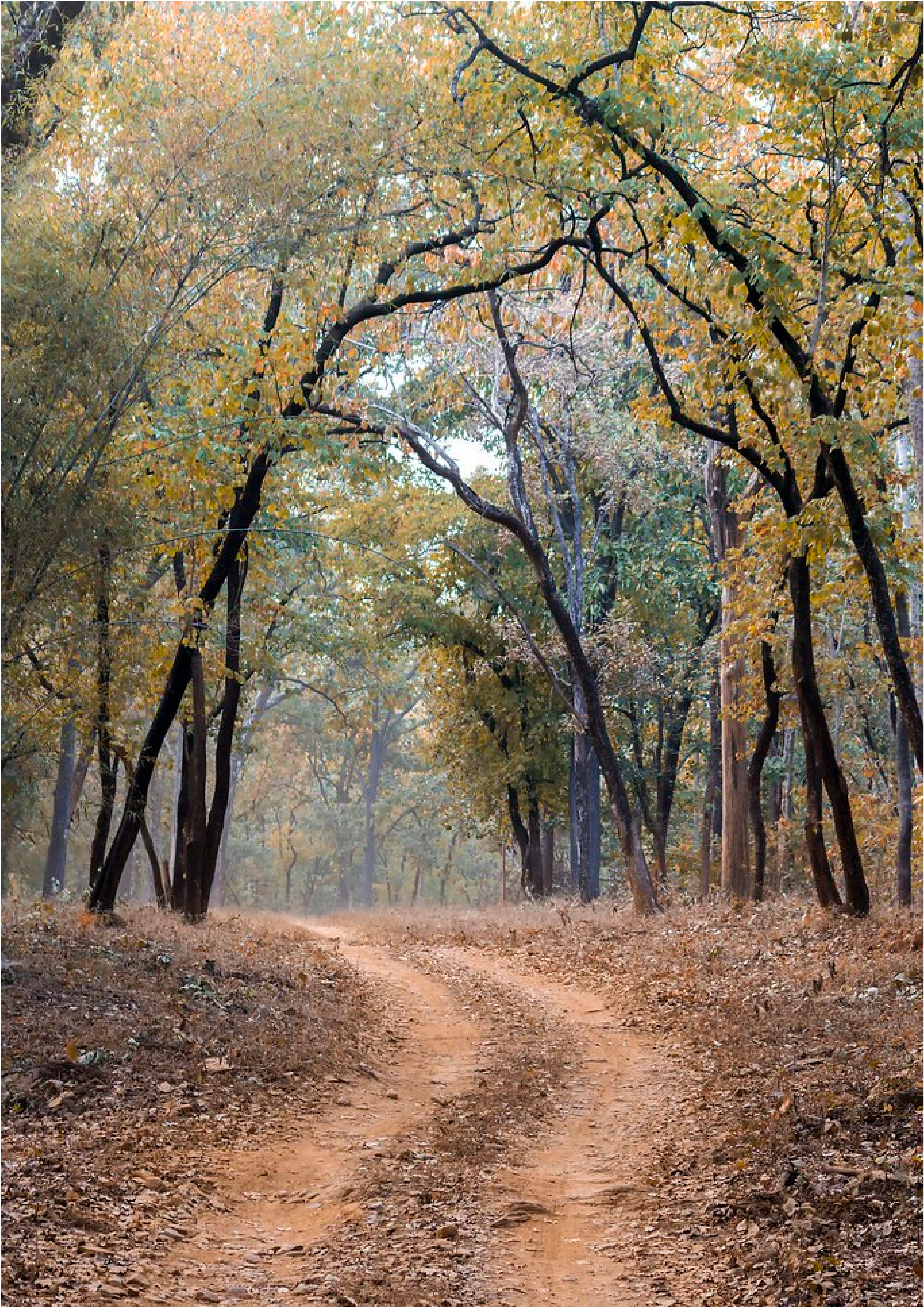


(e): Wild pig (Hazard rate), p value= .672



(f): Langur (Hazard rate), p value= .797

Figure 4: Detection functions of the best-selected model from the pooled data for prey species during line transect survey in Navegaon Nagzira Tiger Reserve (Core) 2020.



3. Status of Predators in Navegaon Nagzira Tiger Reserve

Introduction:

A desirable goal of nature management is to establish self-sustaining ecosystems that ensure the persistence of natural habitats and species without requiring active human intervention. Large carnivores are top predators that can play important roles in structuring ecosystems and regulating ecosystem function (Ripple et al., 2014). Hence, the persistence of large carnivore populations and understanding of their interactions with prey and small carnivores is crucial to ensure a self-sustaining ecosystem.

The long-term scientific monitoring of large carnivore populations is crucial for the following reasons:

1) To improve our basic understanding of tiger, co-predator, and prey ecology through rigorous field studies, to develop a body of theoretical knowledge that can generate predictive capacity to deal with new situations and contributes to the general advancement of scientific knowledge.
2) Large carnivore demographic understanding also provides long-term datasets for scientific studies, often helpful to evaluate conservation efforts and management implications like translocations and population recovery programs.
3) To objectively audit or evaluate the success or failure of earlier management measures and conservation interventions to react adaptively and solve problems.
4) To establish benchmark data that can serve as a basis for specific objectives for management and conservation efforts.

However, the elusive nature and long-ranging behaviour of large carnivores require rigorous field efforts and huge spatial coverage to estimate the large carnivore population. Out of all the population estimation methods, the camera trapping-based capture-mark-recapture approach is the most widely used method to estimate the population of large carnivores.

Camera Trapping:

The success of camera-trapping depends on the selection of ideal locations to deploy the camera traps to maximize the number of captures. Before 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). 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 518 sites were selected for the deployment of camera traps in the core area and buffer area of NNTR. The location of the camera traps overlaid on the forest cover map of NNTR has been shown in Figure 5. A pair of motion-triggered camera traps were placed opposite to each other to photograph both flanks of tiger and leopard simultaneously during the camera-trap exercise. The camera delay was set at multi-shot mode with a delay of 5 seconds. Cameras were tied up on tree trunks or poles at the height of 25-35 cm opposite each other. It is advised not to put the cameras facing each other exactly to miss the animal sight in the photograph in case of over-illumination of flashes if triggered at the same time.

We used the flanks which yielded maximum unique individuals for abundance estimation. For the present analysis, all photographs of both flanks have been used to identify the individual tigers. The cameras were active for a 24-h period that accounted for one sampling occasion. Each camera was assigned a unique identification number. Date, time, temperature, and camera-ID were recorded for every capture.

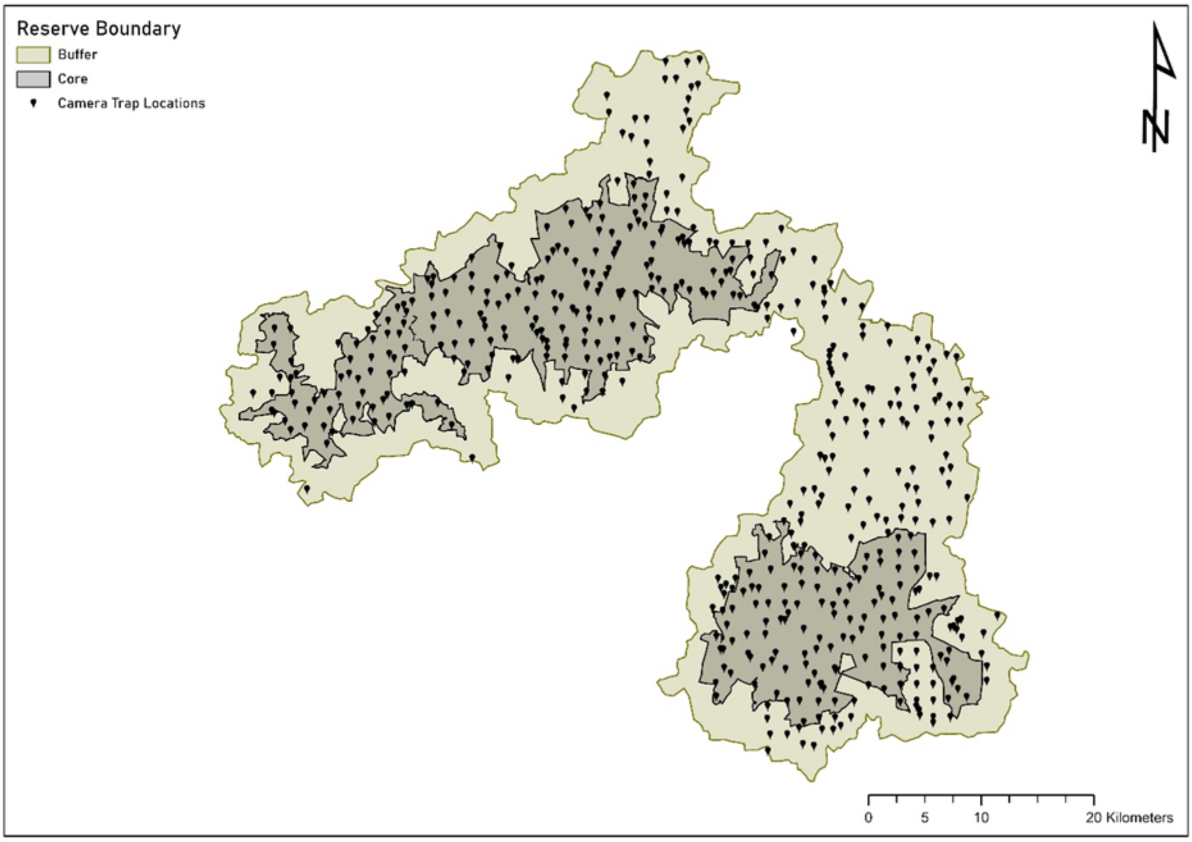


Figure 5: Map depicting camera trap placement locations with respect to LULC map in Navegaon-Nagzira Tiger Reserve

An effort of 15692 camera trap nights was used during the 2020-2021 Phase IV monitoring in Navegaon Nagzira 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 a minimum. Capture histories were analyzed using the software R package 'secr' (Efford, 2015) using a 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'.

Population Estimation for Tigers and Leopards:

During 90 days of camera trapping for tigers and leopards i.e., a total sampling effort of 15,692 trap nights, 11 individual tigers (both flanks) and 123 individual leopards (right flank) were photographed within the core and buffer area of NNTR. For estimating the density and population we used “SECR” instead of the conventional capture-recapture model.

Spatially explicit capture-recapture (SECR) is a set of methods for 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 the conventional capture-recapture estimation of animal populations (Otis et al. 1978). Here detectors are camera traps that take photographs of tigers and leopards and they are recognized by their natural marks and stripes. Camera traps are proximity detectors because they can detect multiple animals within an occasion, and they do not detain detected animals, which remain free to be detected by other camera traps within each occasion. Like other statistical methods for estimating animal abundance, SECR also combines a state model and an observation model. The state model describes the distribution of animal home ranges in the landscape, and the observation model (a spatial detection model) relates the probability of detecting an individual at a particular detector to the distance of the detector from a central point in each animal’s home range. Unlike the maximum-likelihood and Bayesian estimation methods, it is not based on an explicit likelihood function and does not have the same inference foundation as these methods. In SECR the basic parameter for a population is density instead of the number. The detectors in this case are the camera traps. The photographs are then manually scanned for identification of individuals based on their stripe or rosette pattern. SECR combines both the state model and the observation model. The state model describes the distribution of animal home ranges in the landscape, and the observation model (a spatial detection model) relates the probability of detecting an individual at a particular detector to the distance of the detector from a central point in each animal’s home range. The distances are not observed directly (usually we don’t know the range centers), so conventional distance sampling that we would normally apply to study prey species do not apply (Efford, 2017). The key additional data that SECR analyses require, over and above the data used in non-spatial capture-recapture studies, are the locations of traps at which individuals were captured. Hence, to develop SECR models, we need some notation for trap location. Tiger density per 100 km^2 based on SECR, heterogeneity model was estimated to be 0.58/100 km^2 for NNTR. Whereas, leopard density based on the heterogeneity model was estimated to be 9.51/100 km^2 in NNTR. The best model for the density estimates is chosen according to the AIC (Akaike Information Criterion). The details are provided in Table 5 to 7, g0 is the detection probability for the species, it is assumed to be constant or variable depending on the distribution. Sigma is the distribution of the average movement of the animal. It increases if the individuals are captured at very far away locations.

The spatial distribution of the individual tigers and leopards have been provided as Minimum Convex Polygons (MCPs) from Figure 6(a) to 6(e).

Table 5: Density estimates of tiger and leopard using Spatially Explicit Capture-Recapture Models Navegaon-Nagzira Tiger Reserve, Maharashtra, India for the year 2020 – 2021

Parameters	Tiger	Leopard
Model	Heterogeneity	Heterogeneity
Detection function	Half normal	Half normal
Density estimate (per 100 km^2)	0.64	8.21
Density SE	0.20	0.75
Density Confidence Interval	0.35-1.15	6.87-9.82
g0 estimate	0.02	0.02
g0 standard error	0.002	0.002
g0 confidence interval	0.016-0.023	0.01-0.02
sigma estimate (km)	3.39	1.57
sigma standard error	0.61	0.004
sigma confidence interval	1.42-5.89	1.23-1.96

Table 6: Density comparison of tigers in Navegaon-Nagzira Tiger Reserve

Species	2020	2021
No. of Individuals Captured	9	11
Estimate	9 (±0.06)	11.07 (±3.4)
Density per 100 sq. km.	0.58 (±0.2)	0.64 (±0.20)

Table 7: Density comparison of leopards in Navegaon-Nagzira Tiger Reserve

Species	2020	2021
No. of Individuals Captured	126	123
Estimate	162 (±15)	142.8 (±13.01)
Density per 100 sq. km.	9.51 (±0.91)	8.21 (±0.75)

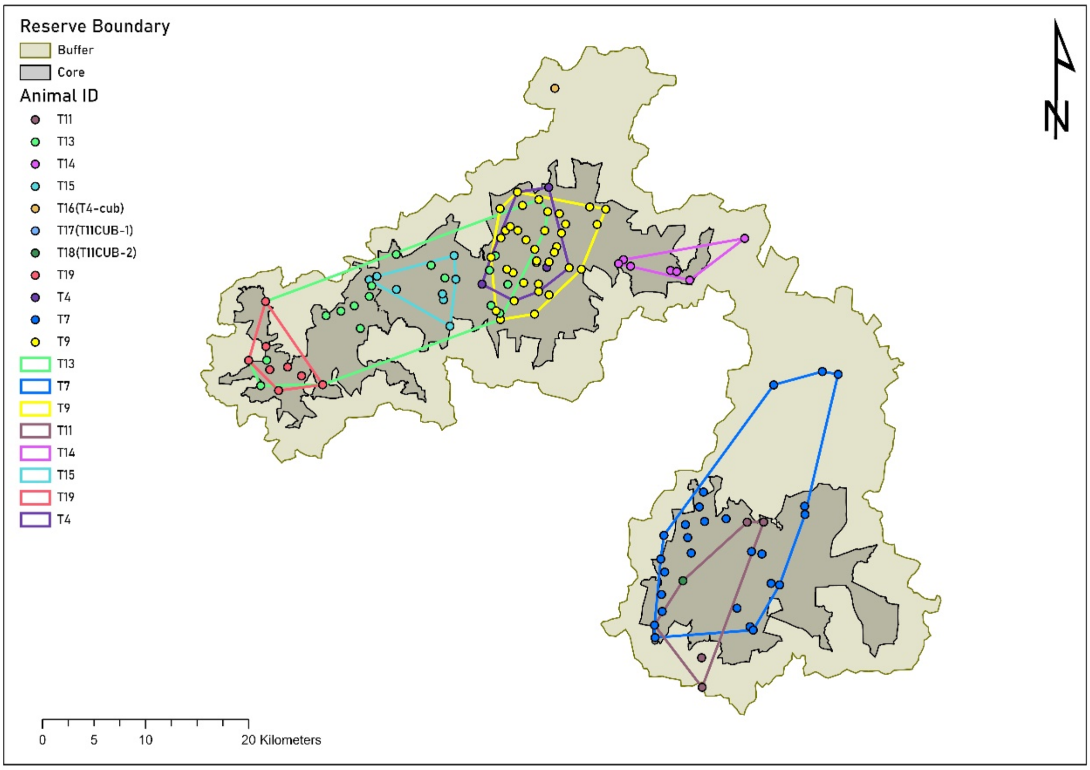


figure 6(a): Overlap in Minimum Convex Polygon of Tigers (Males & Females) in Navegaon Nagzira

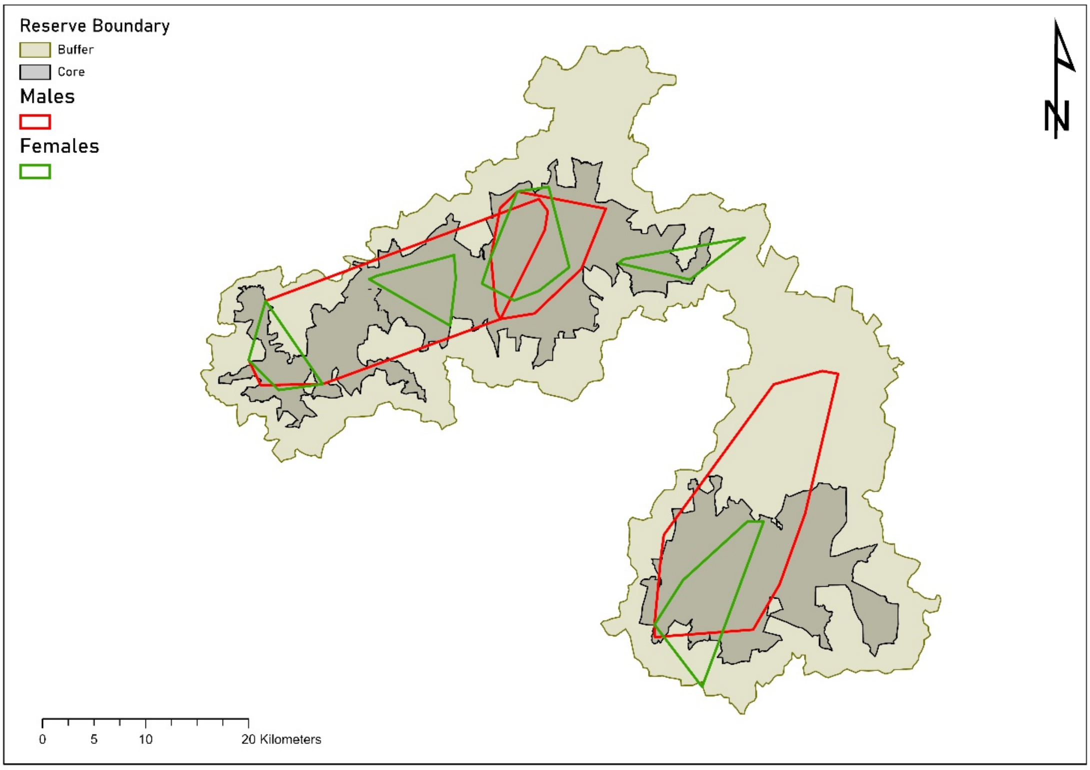


Figure 6(b): Overlap in Minimum Convex Polygon of Tigers (Males & Females) in Navegaon Nagzira Tiger during the year 2021

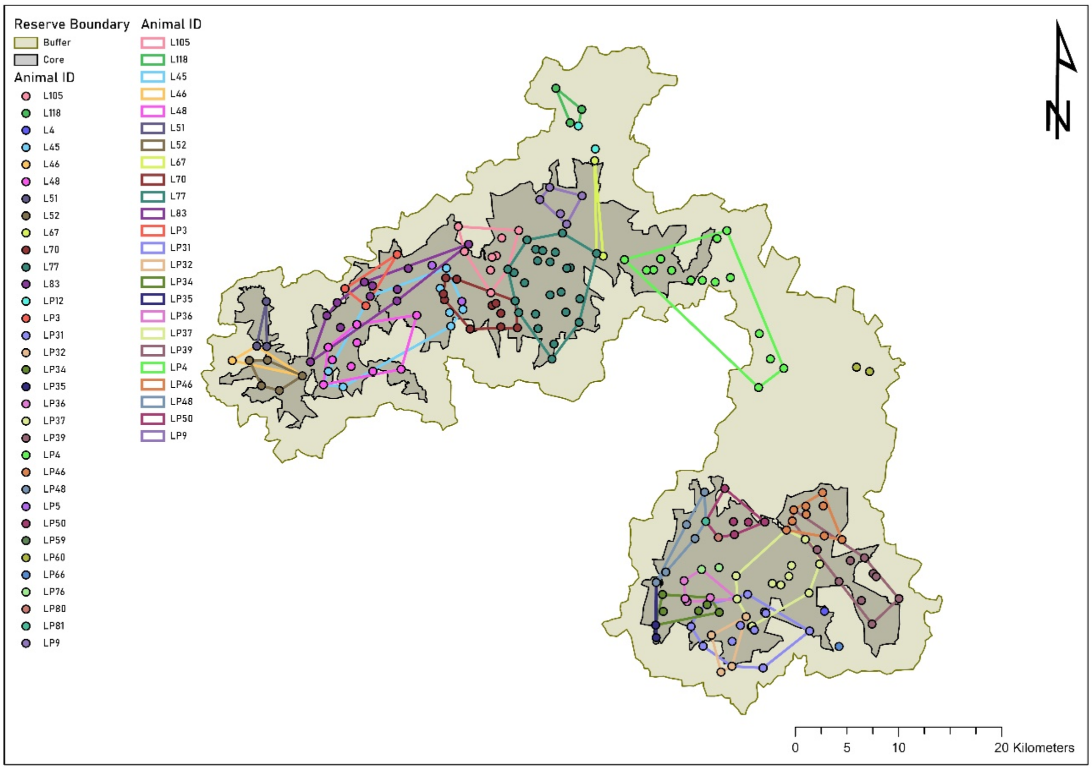


Figure 6(c): Minimum Convex Polygon of leopards (Males) in Navegaon Nagzira Tiger during the year 2021

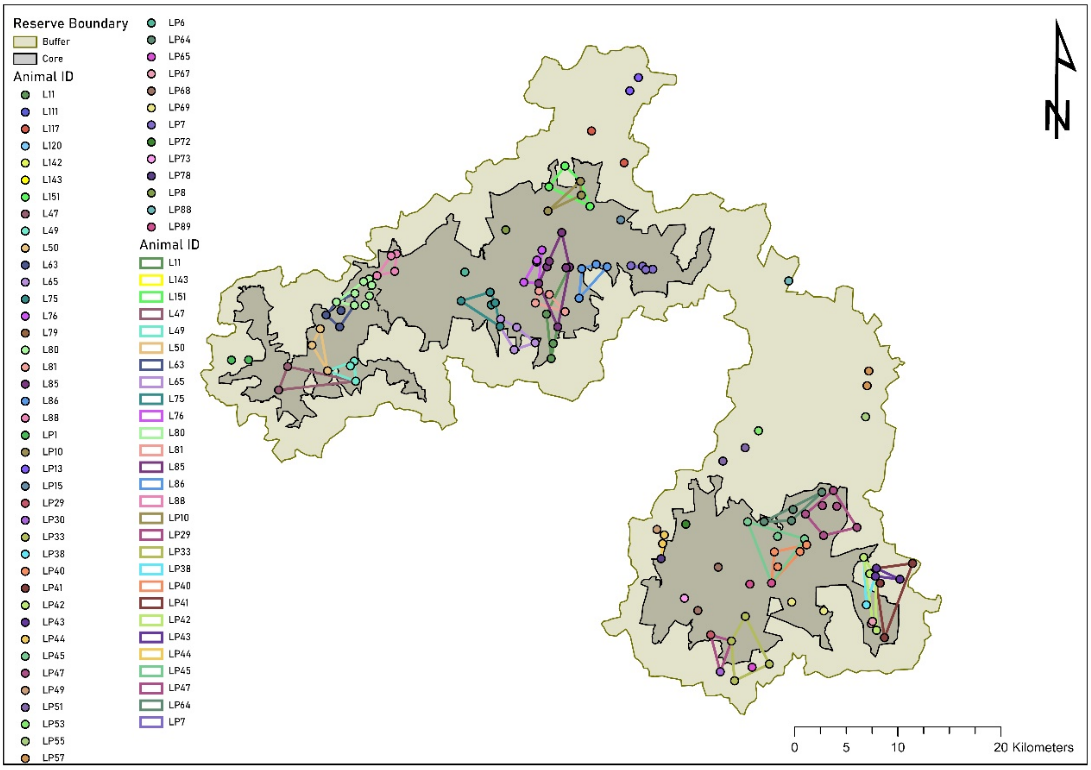


Figure 6(d): Minimum Convex Polygon of leopards (Females) in Navegaon Nagzira Tiger during the year 2021

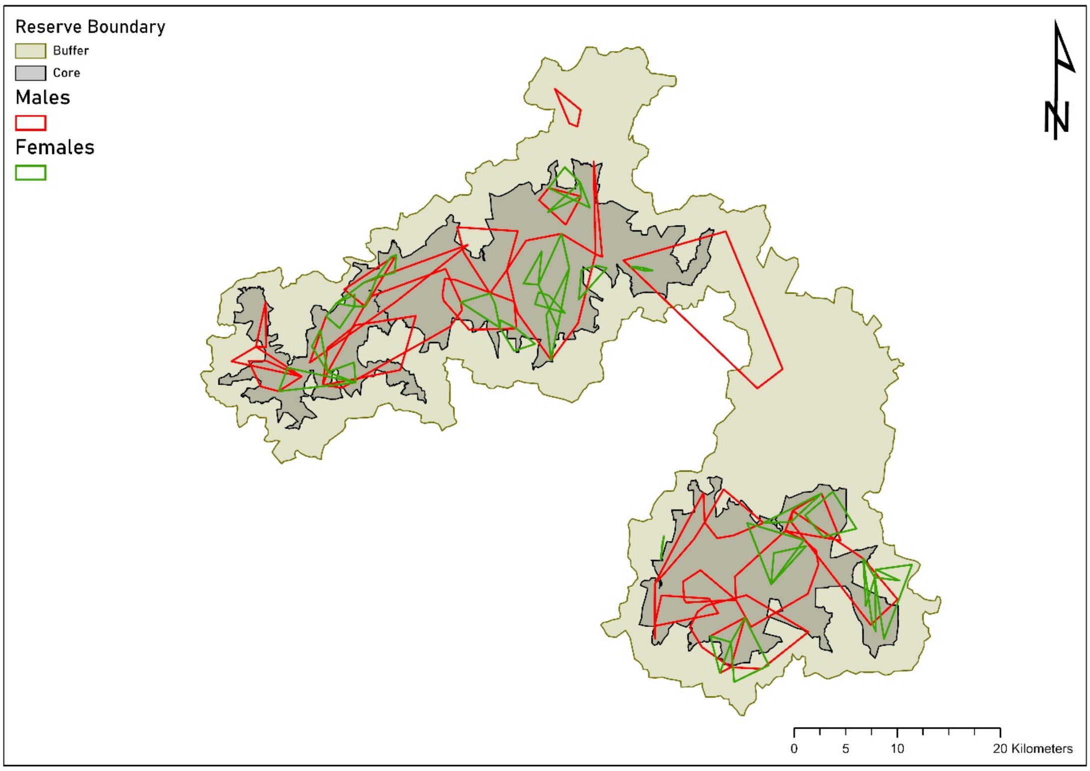


Figure 6(e): Overlap in Minimum Convex Polygon of Leopards (Males & Females) in Navegaon Nagzira Tiger during the year 2021

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

Introduction:

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

Methods and Results:

The temporal pattern of the predators and their prey was analyzed using R Studio in R statistical software (version 3.6.2). The approach established by Linkie and Ridout (2009) was used to study temporal activity patterns and the package "overlap" which estimates the coefficient of temporal overlap non-parametrically using kernel density estimates was used. In the package 'overlap', data are regarded as a random sample from the underlying distribution that describes the probability of a photograph being taken within any particular interval of the day. The probability density function of this distribution is then referred to as the activity pattern, which assumes that the animal is equally likely to be photographed at all times when it is active (Ridout & Linkie 2009). It is a two-step process. In the first step, each activity pattern is estimated 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, favoring 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 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. From the kernel density estimators, the tiger and leopard were observed to have a high degree (0.85) of overlap as indicated by the estimated overlap coefficients in Table 7. Details of temporal activity overlap between predators and prey are provided in Figures 7 to 10.

Table 7: Temporal activity overlap of predator and prey species

Species	Tiger	Leopard	Wild Dog
Chital	0.59	0.71	0.81
Sambar	0.87	0.82	0.63
Barking Deer	0.48	0.58	0.76
Chousingha	0.52	0.62	0.82
Sloth Bear	0.85	0.83	0.56
Gaur	0.92	0.79	0.59
Langur	0.33	0.47	0.67
Leopard	0.81	NA	0.72
Tiger	NA	0.81	0.59
Wild Dog	0.59	0.72	NA
Nilgai	0.68	0.82	0.86
Wild Boar	0.89	0.83	0.58
Honey badger	0.73	0.57	0.35
Wolf	0.59	0.73	0.66
Hare	0.73	0.59	0.33

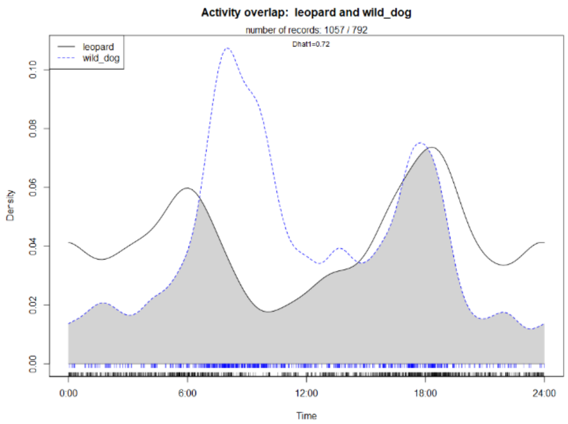


Figure 7(c) Leopard-wild dog

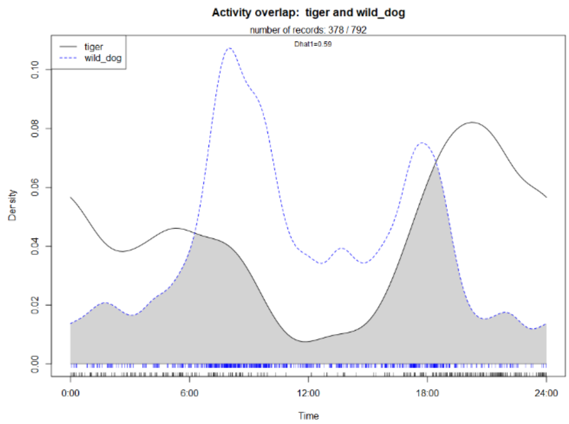


Figure 7(b) Tiger-wild dog

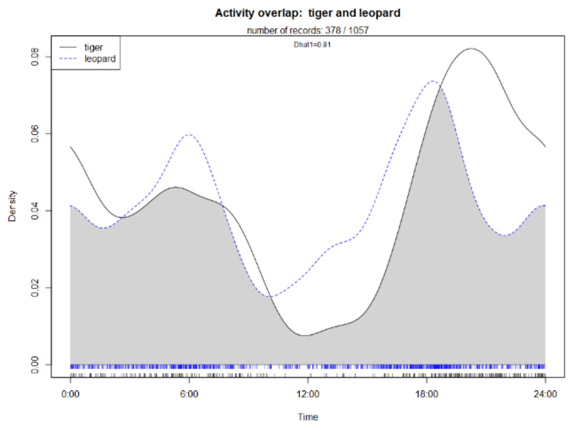


Figure 7(a) Tiger-leopard

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

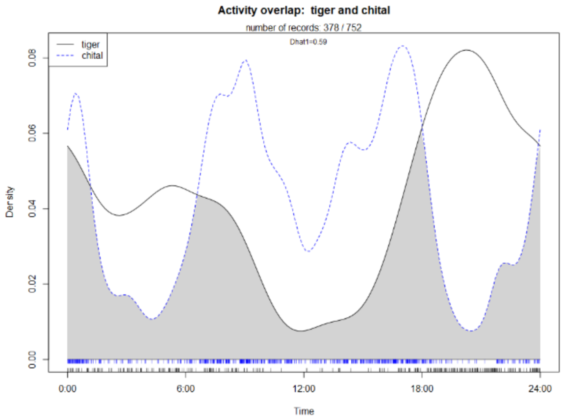


Figure 8(a) Tiger and Chital

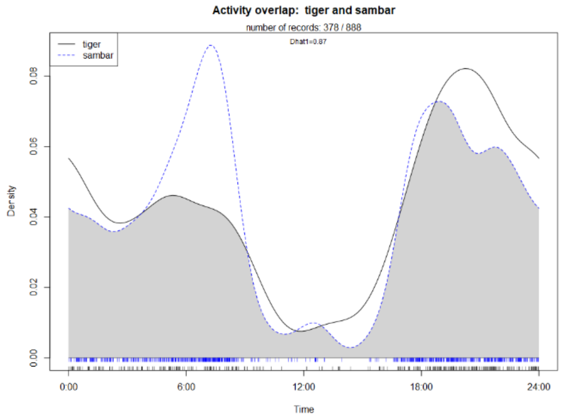


Figure 8(b) Tiger and sambar

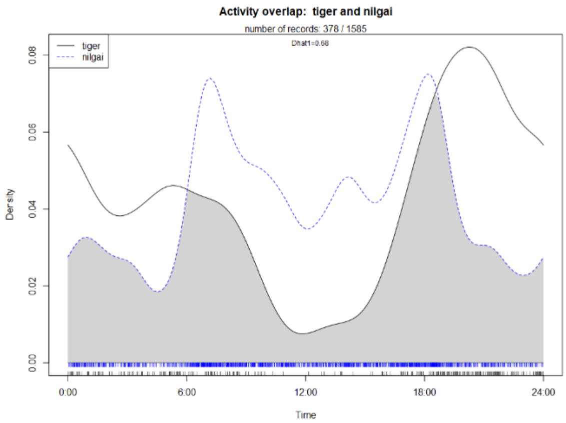


Figure 8(c) Tiger and Nilgai

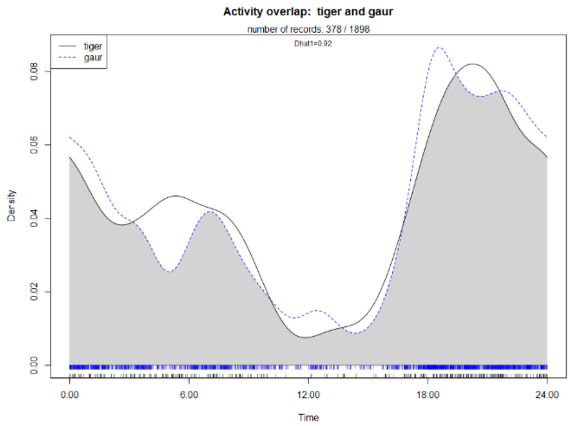


Figure 8(d) Tiger and Gaur

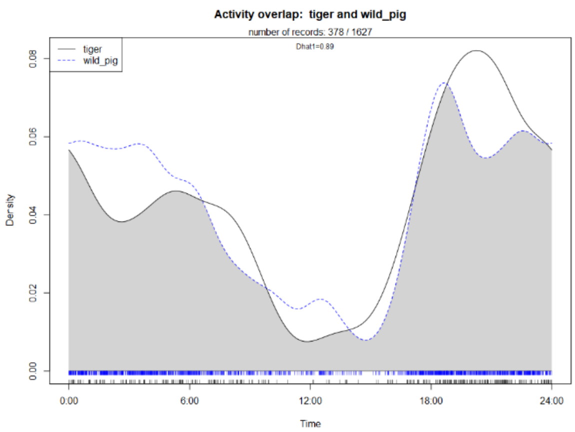


Figure 8(e) Tiger and Wild pig

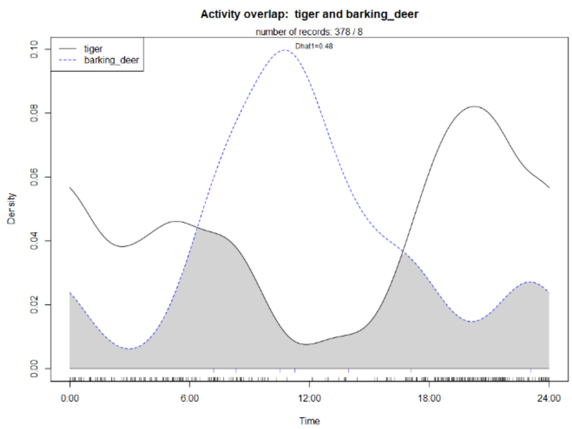


Figure 8(f) Tiger and Barking deer

Figures 8 (a-f): Daily temporal activity patterns of the Tiger vs. prey species in NNTR, India during the year 2020. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot

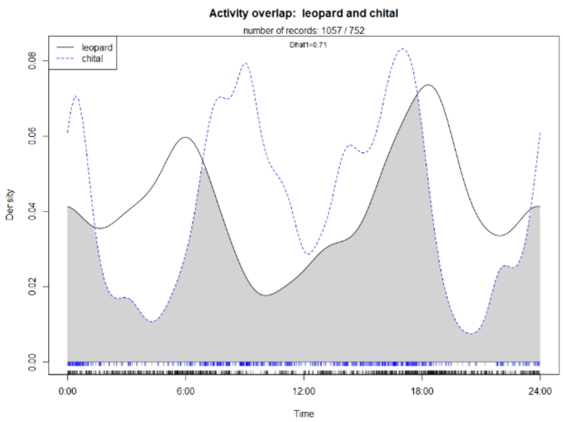


Figure 9(a) Leopard and Chital

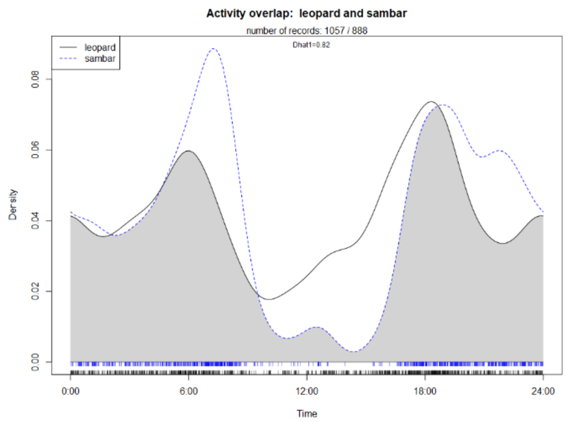


Figure 9(b) Leopard and sambar

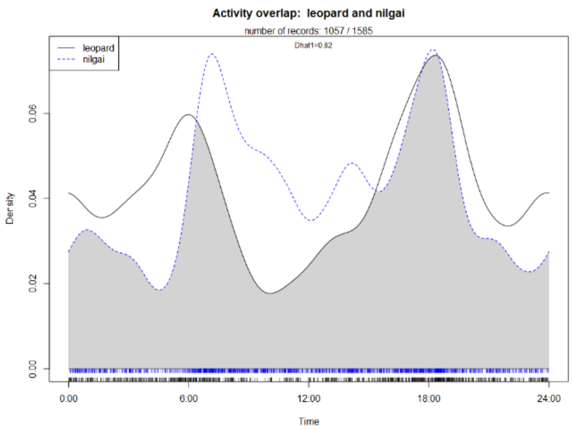


Figure 9(c) Leopard and Nilgai

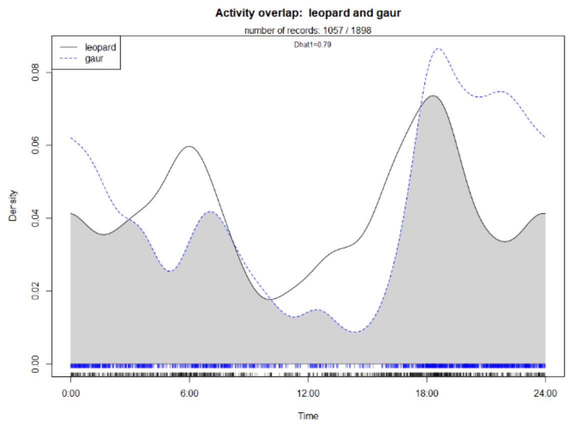


Figure 9(d) Leopard and Gaur

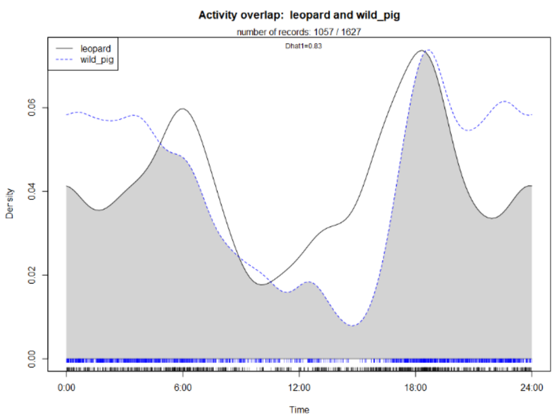


Figure 9(e) Leopard and Wild pig

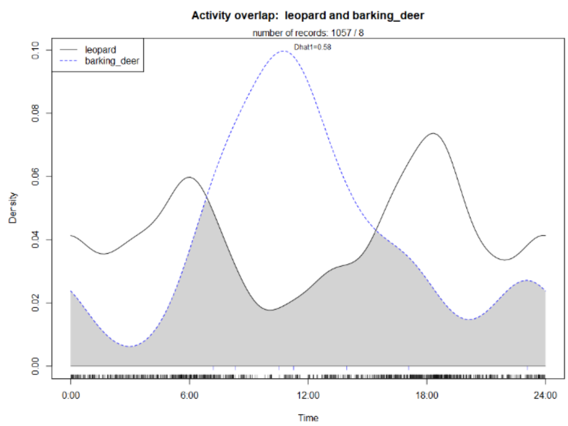


Figure 9(f) Leopard and Barking deer

Figures 9 (a-f): Daily temporal activity patterns of the Leopard vs. prey species in NNTR, India during the year 2020. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot.

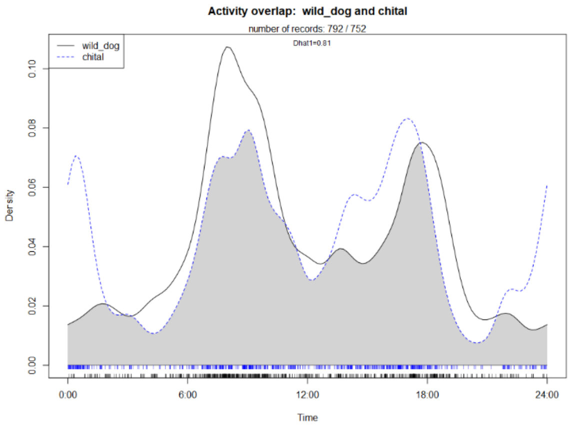


Figure 10(a) Wild dog and Chital

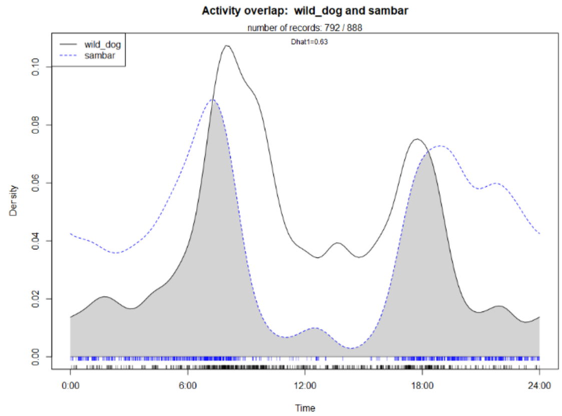


Figure 10(b) Wild dog and sambar

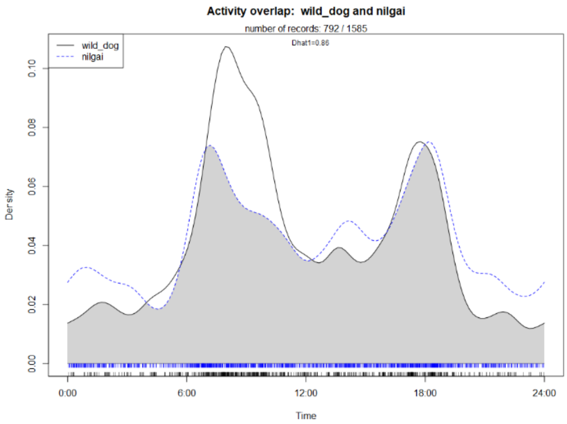


Figure 10(c) Wild dog and Nilgai

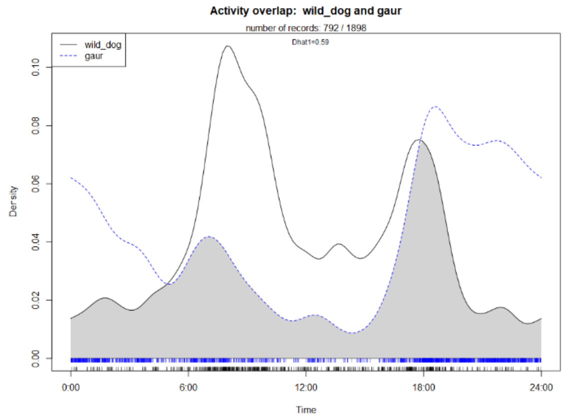


Figure 10(d) Wild dog and Gaur

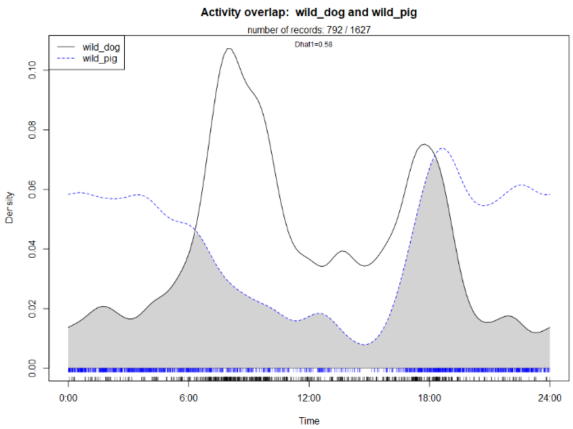


Figure 10(e) Wild dog and Wild pig

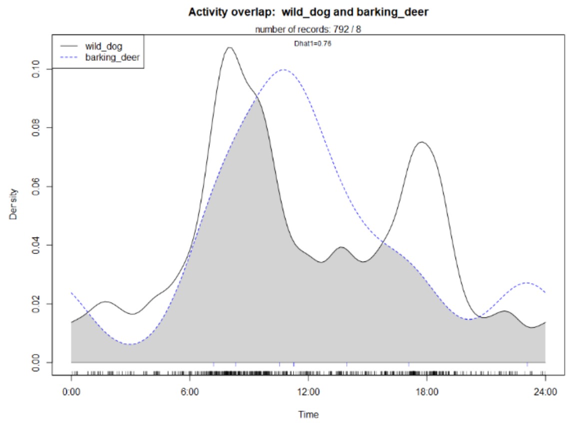


Figure 10(f) Wild dog and Barking deer

Figures 11 (a-f): Daily temporal activity patterns of the Wild dog vs. prey species in NNTR, India during the year 2020. The lines represent the kernel density estimates based on individual photograph times. The overlap is shown by the shaded area in each plot

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

Introduction:

Camera trap locations with 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 11) in the interpolated surface can only occur at sample points. The output surface is sensitive to clustering and the presence of outliers. IDW assumes that the phenomenon being modelled is driven by local variation, which can be captured (modelled) by defining an adequate search neighbourhood.

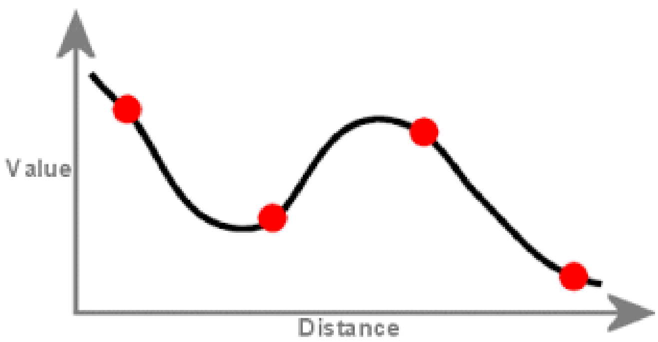


Figure 11: IDW (Inverse distance weighted) interpolation

Using IDW technique spatially explicit intensive use area maps (Based on camera trap location and number of photographs at each location) has been developed for predator and prey species, Fig. 12 (a - o) shows intensive use areas by different species in the sampled area of Navegaon-Nagzira Tiger Reserve.

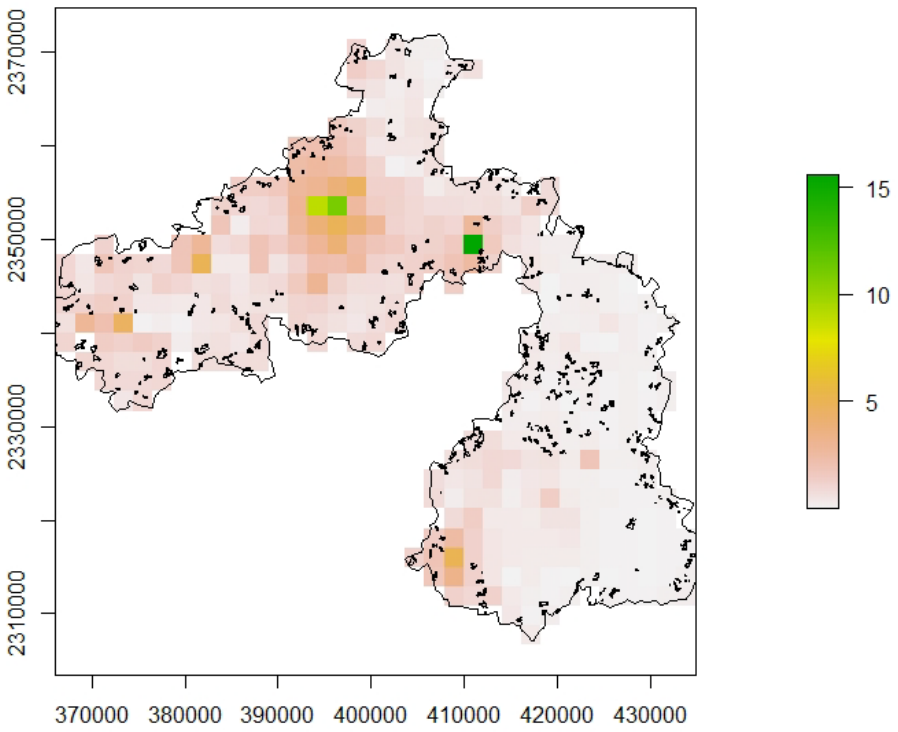


Figure 12 (a): Intensive Use area map for Tiger in NNTR

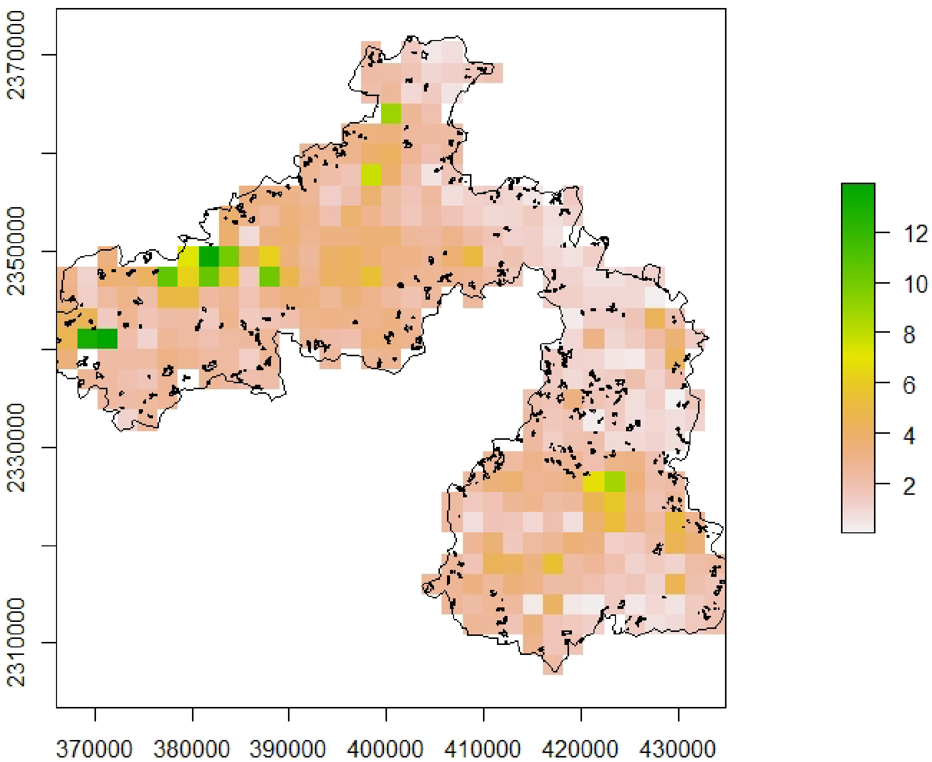


Figure 12 (b): Intensive Use area map for Leopard in NNTR

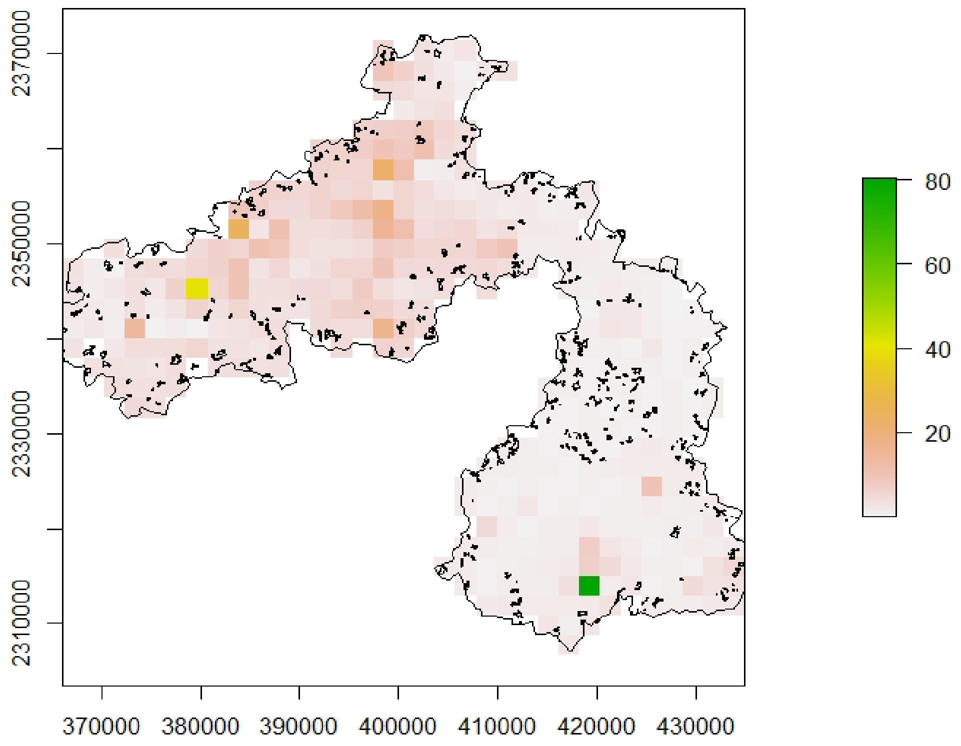


Figure 12 (c): Intensive Use area map for Wild dog in NNTR

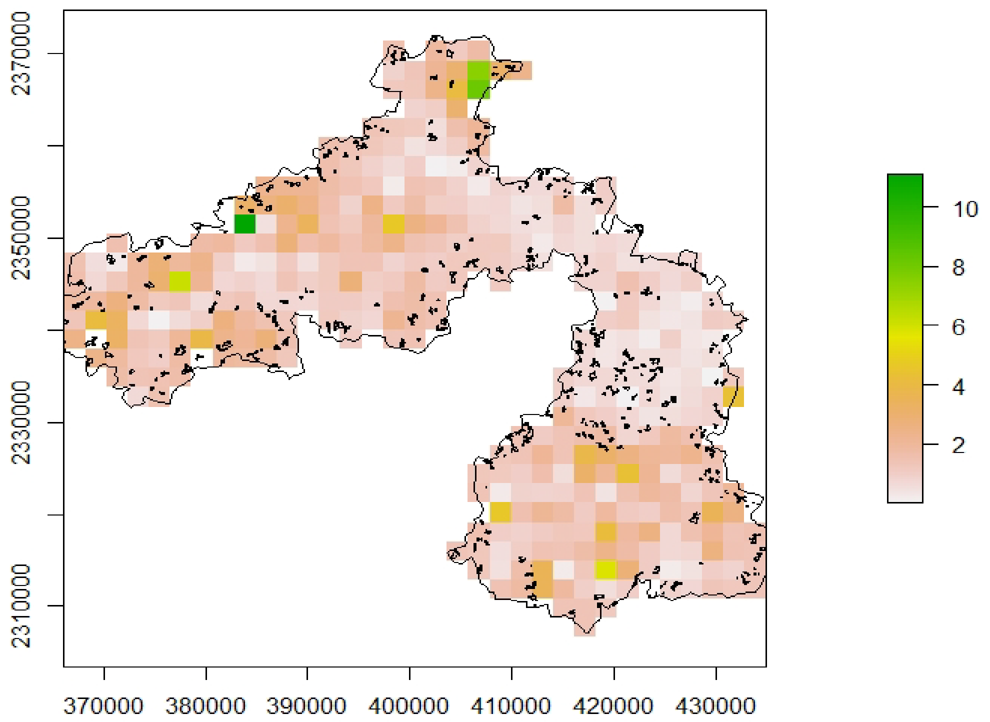


Figure 12 (d): Intensive Use area map for Sloth bear in NNTR

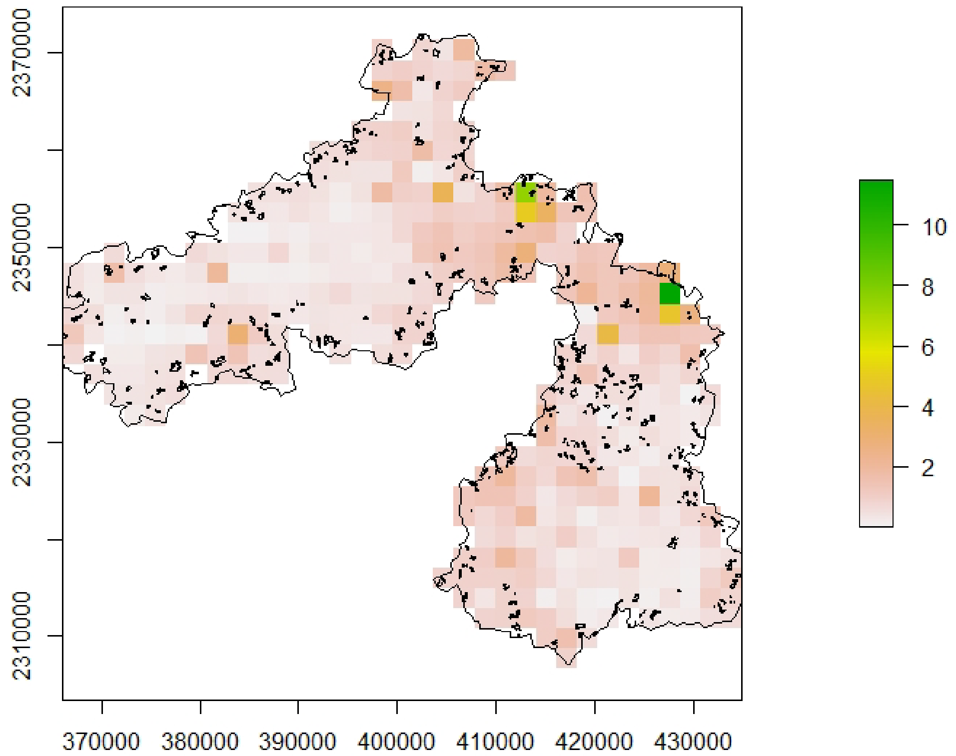


Figure 12 (e): Intensive Use area map for Jungle cat in NNTR

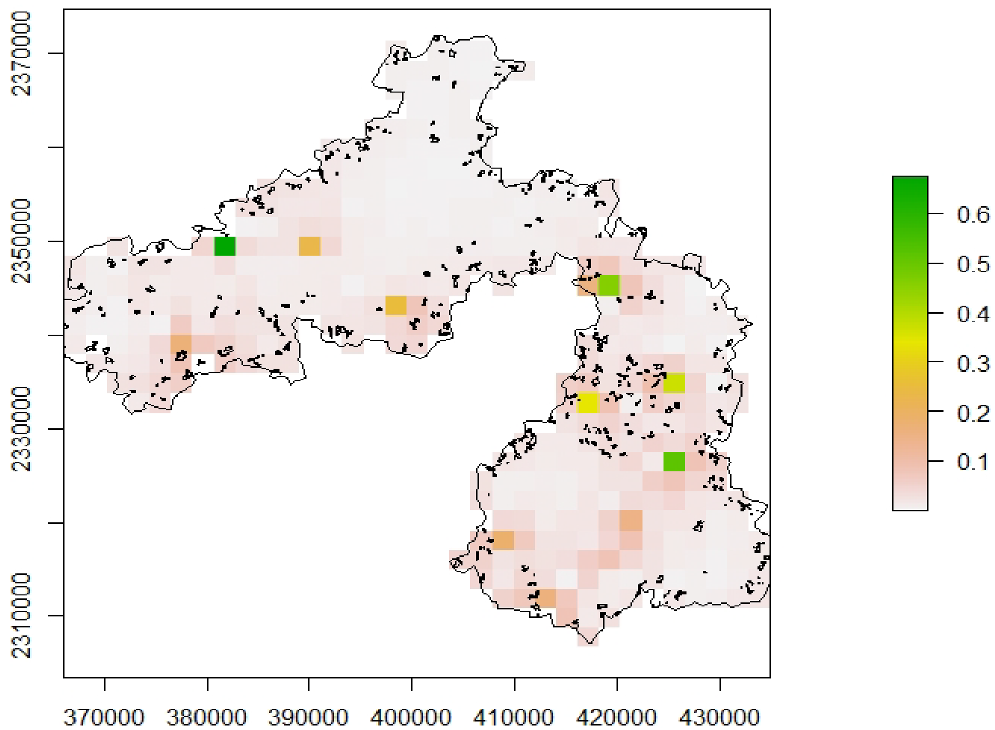


Figure 12 (f): Intensive Use area map for Rusty-spotted cat in NNTR

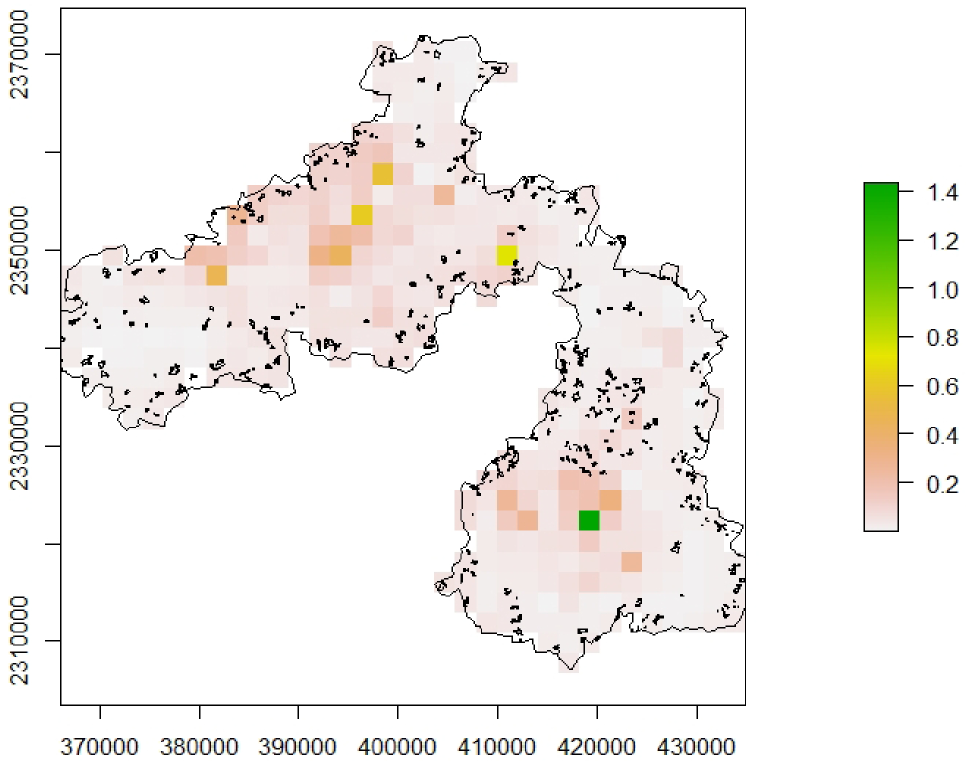


Figure 12 (g): Intensive Use area map for Ratel in NNTR

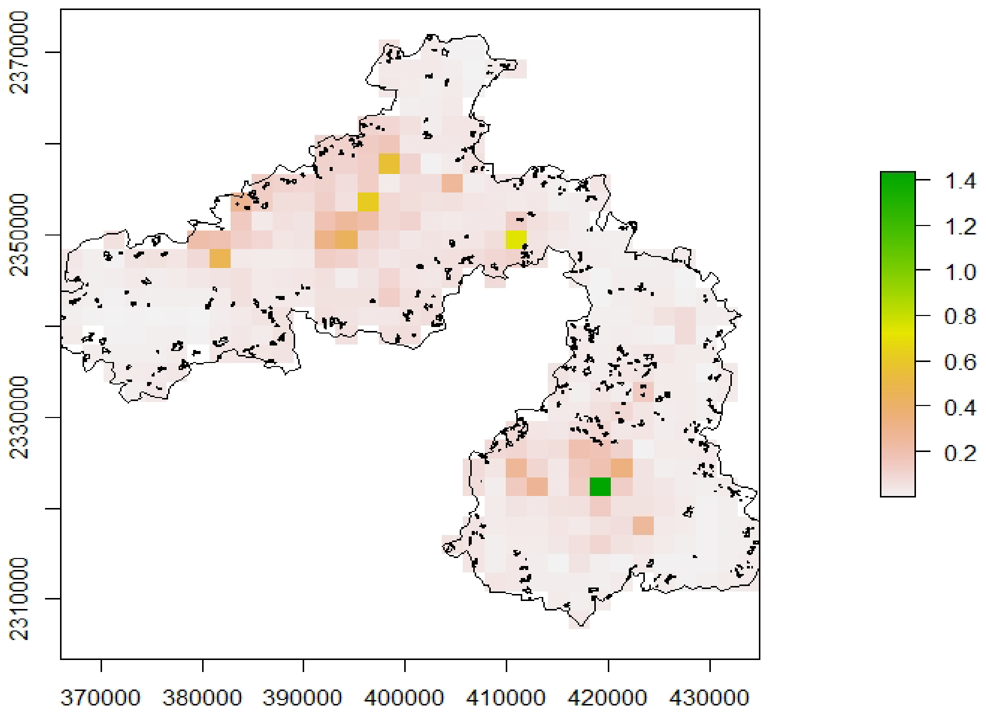


Figure 12 (h): Intensive Use area map for Chital in NNTR

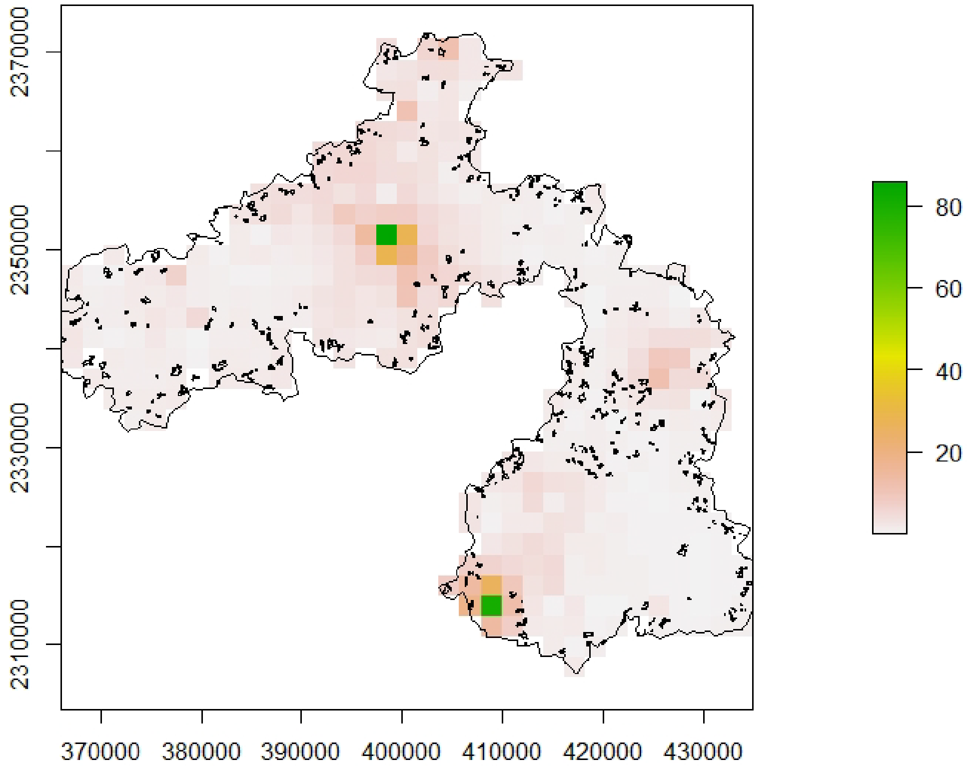


Figure 12 (i): Intensive Use area map for Sambar in NNTR

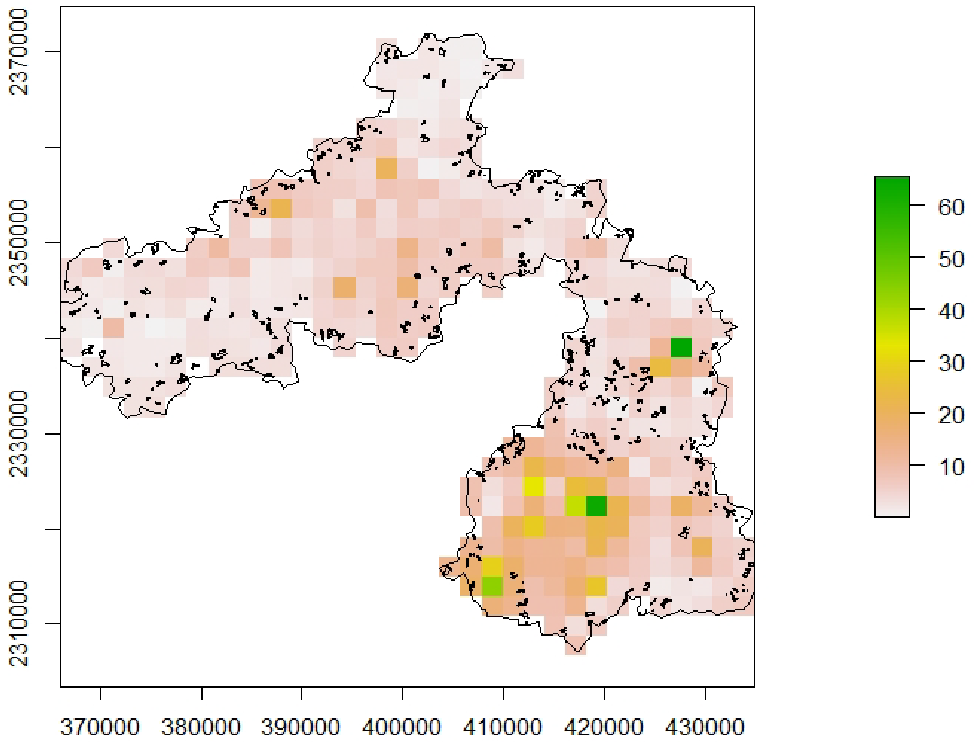


Figure 12 (j): Intensive Use area map for Gaur in NNTR

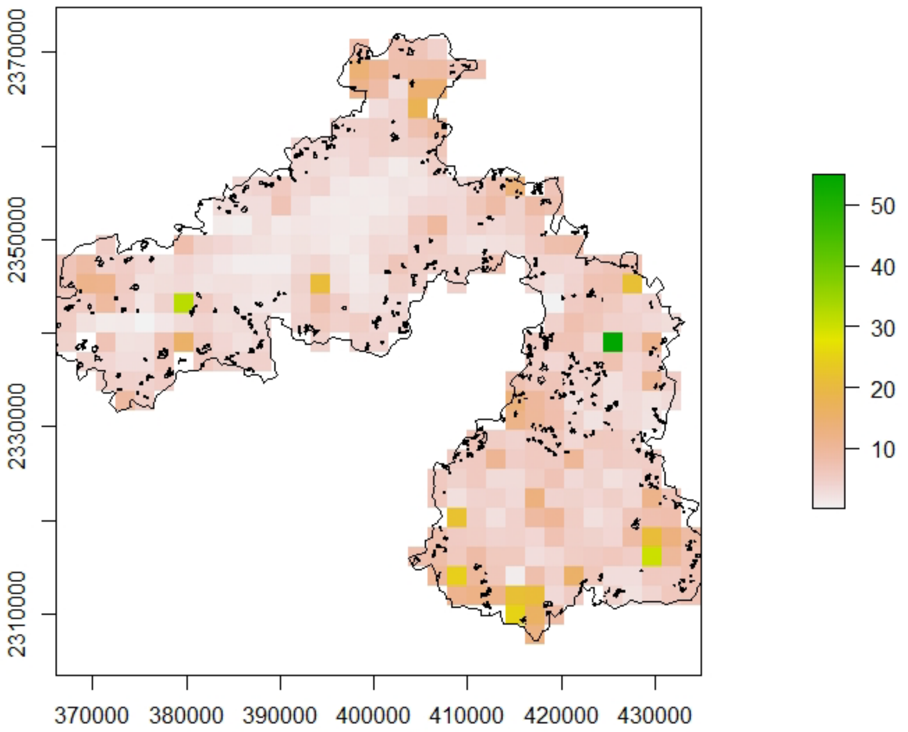


Figure 12 (k): Intensive Use area map for Wild pig in NNTR

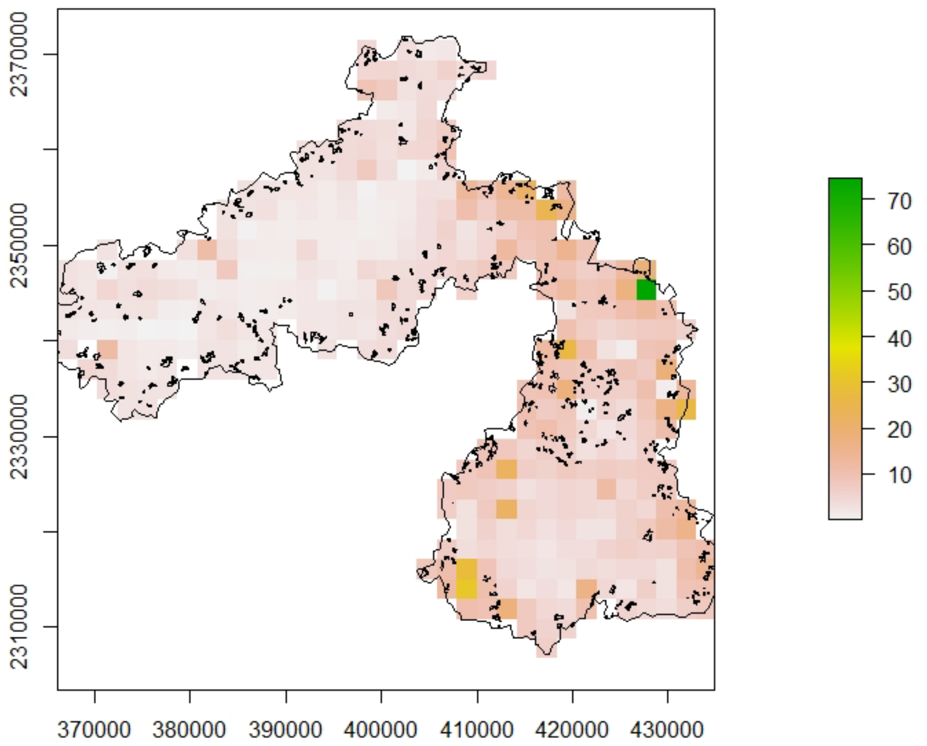


Figure 12 (l): Intensive Use area map for Nilgai in NNTR

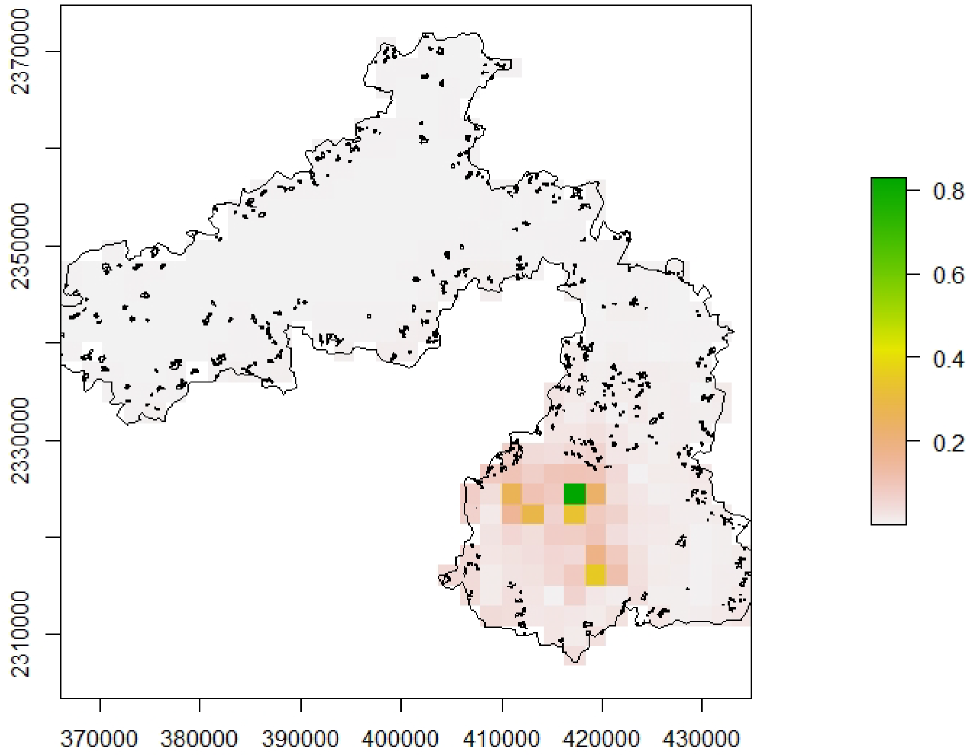


Figure 12 (m): Intensive Use area map for Barking deer in NNTR

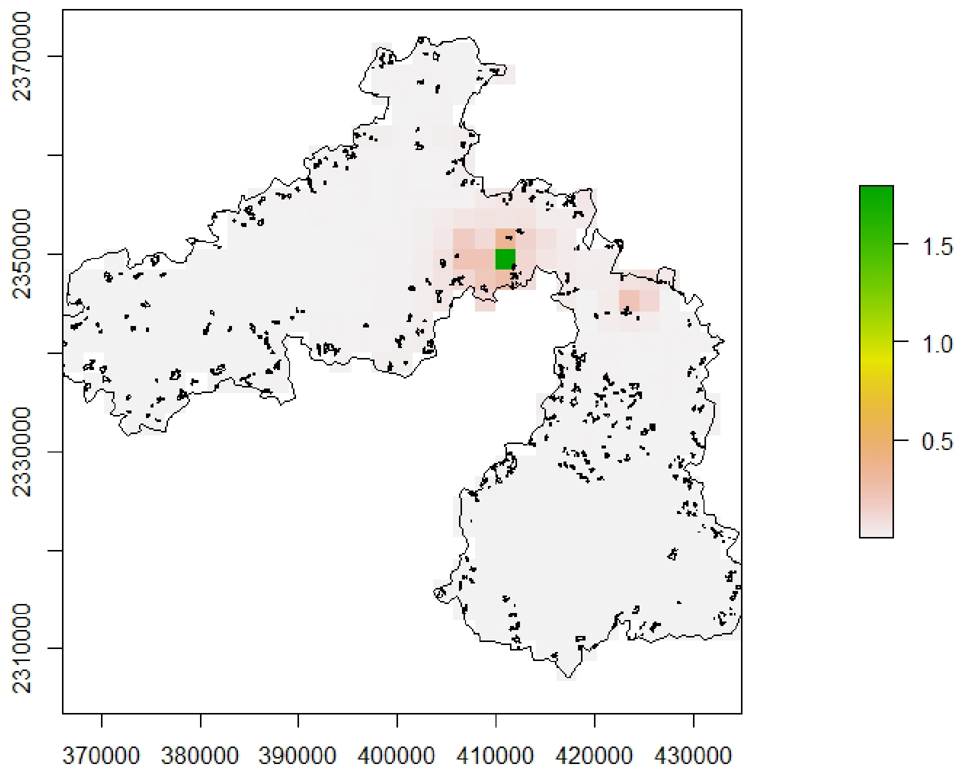


Figure 12 (n): Intensive Use area map for Blackbuck in NNTR

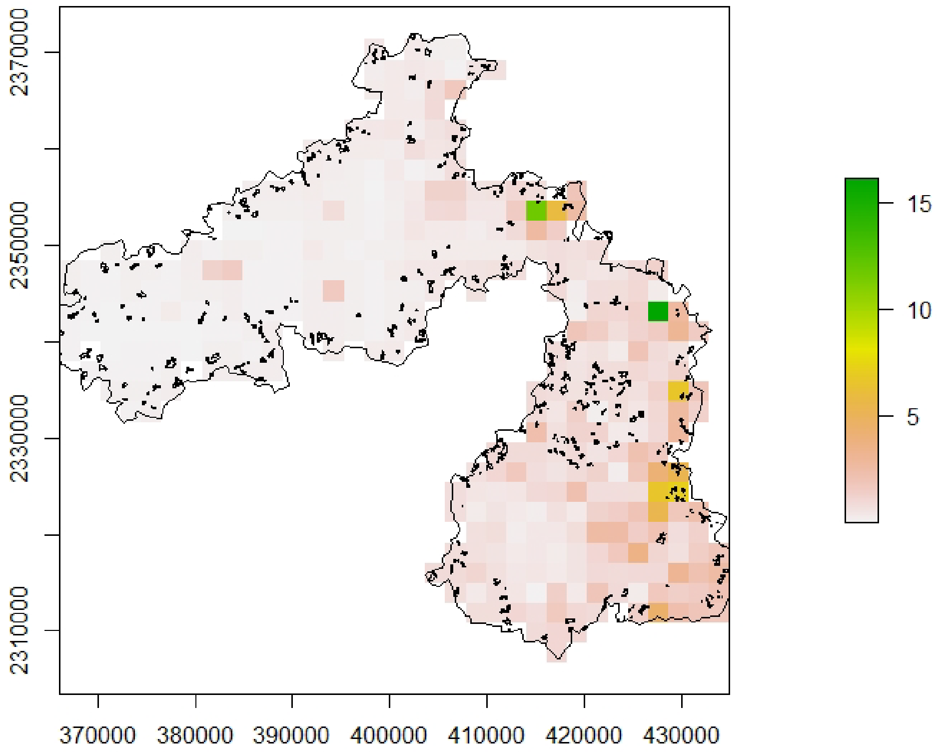


Figure 12 (o): Intensive Use area map for Chousingha in NNTR

6. Distribution of wild ungulates in NNTR based on MSTrIPES

Introduction

Ungulates are a major ecological driver, affecting both animal and plant communities by forming interlinks between different trophic levels (McNaughton et al. 1989; Schaller 1967). They shape the structure and functioning of plant community by regulating interspecific competition, enhancing nutrient cycling, changing soil structure and succession with their presence, activity, and behavior, mainly by feeding (McNaughton 1985; McNaughton et al. 1997; Crawley 1983). Alongside, Carnivore population density is primarily determined by ungulate biomass (Carbone and Gittleman 2002; Karanth et al. 2004). In India, over the last 100 years, their historical range has decreased by nearly 52% (Karanth et al. 2010). Moreover, nearly 80% of India's forest cover has been lost in the past 300 years (Sanderson et al. 2006). India’s remaining ungulate habitat is largely shared with humans and livestock. Relatively undisturbed ungulate habitats are confined mostly to the protected areas that constitute less than 5% of the surviving forests (Karanth et al. 2009, 2010). As wild ungulates are the major diet of large carnivores, their abundance is directly correlated with ungulate densities (Karanth and Nichols 1998; Miquelle et al. 1999; Carbone and Gittleman 2002). Conservation and management of ungulates are dependent upon reliable knowledge of their density and habitat distribution (Schaller 1972) but this information is lacking for the majority of species on earth (Williams *et al*. 2002). Understanding the intricate spatial and temporal dynamics of an ecological system required long-term monitoring of populations spread over the spatial and temporal scale. A long-term perspective allows an empirical examination of biological populations and of ecological processes designed to inform policy and decision-making processes (Williams *et al.* 2002). Species distribution was mapped seasonally.

Methods and results

We used direct sighting data of wild ungulates from all three seasons i.e. from winter 2019 to monsoon 2020 that was collected through regular patrolling using the MSTrIPES, a patrolling protocol mandated by NTCA to use in tiger reserves. MaxEnt, ArcGIS software was used for data preparation and final analysis. The analyses were done for chital, sambar, gaur, nilgai, and wild pig, which are the major ungulate species found in NNTR

Factors that influence species distributions and habitat selection are of great importance to researchers and managers of wildlife. Here we used habitat variables namely: Land use Land cover (LULC), Digital Elevation Model (DEM), slope, aspect, stream delineation (Distance to streams), distance to the village, distance to road, distance to a railway line, and distance to a waterhole.

The results of chital distribution using MaxEnt have been given as in Figures 13 (a) to (d). The maps and results for sambar distribution are shown in Figures 14 (a) to (d). Spatial use and response to LULC of NNTR by gaur in different seasons are given in Figures 15 (a) to (d). Maps and responses for LULC classes for nilgai distribution in various seasons are given in Figures 16 (a) to (d). The spatial and model results for the wild pig seasonal distribution model are shown in Figures 17 (a) to (d).

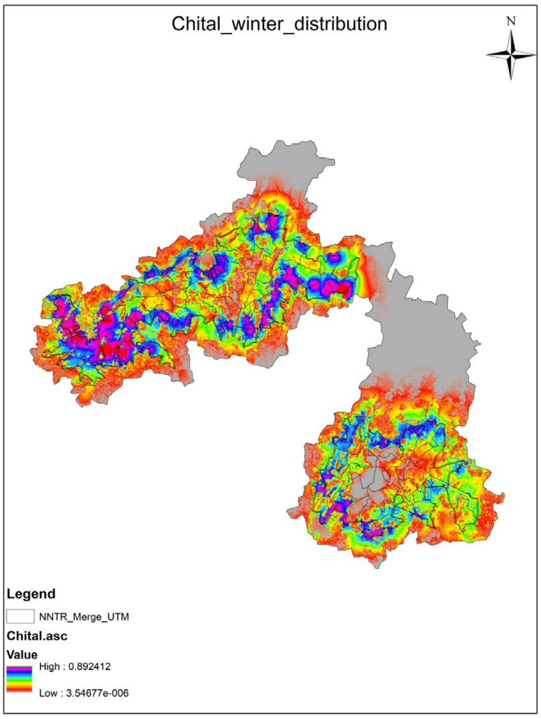


Fig 13 (a): Modelling of distribution of Chital in NNTR during winter season using MaxEnt

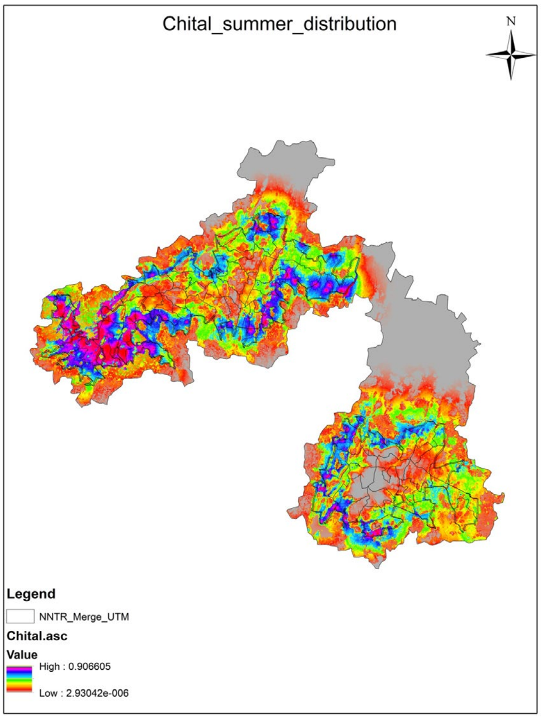


Fig 13 (b): Modelling of distribution of Chital in NNTR during summer season using MaxEnt

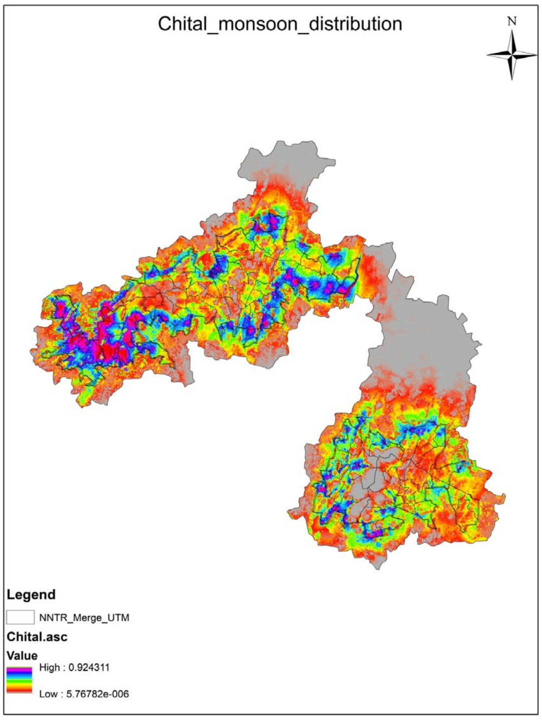


Fig 13 (c): Modelling of distribution of Chital in NNTR during monsoon season using MaxEnt

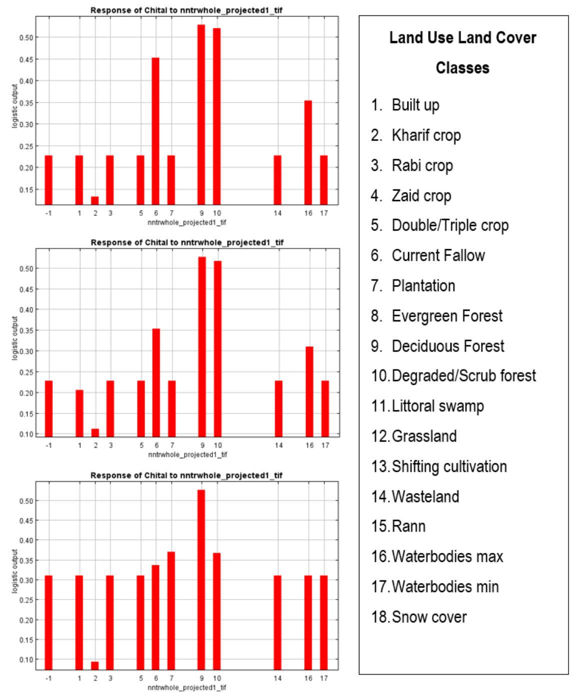


Fig 13 (d): Modelling of the response of Chital in NNTR to various land use classes using MaxEnt

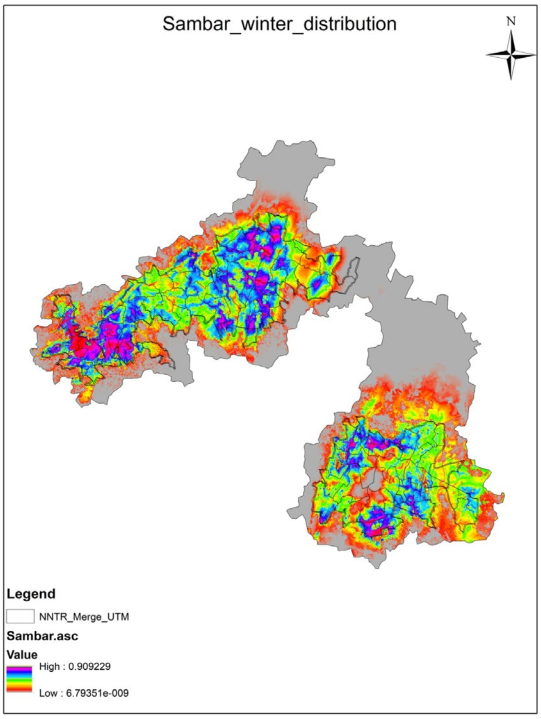


Fig 14 (a): Modelling of distribution of Sambar in NNTR during winter season using MaxEnt

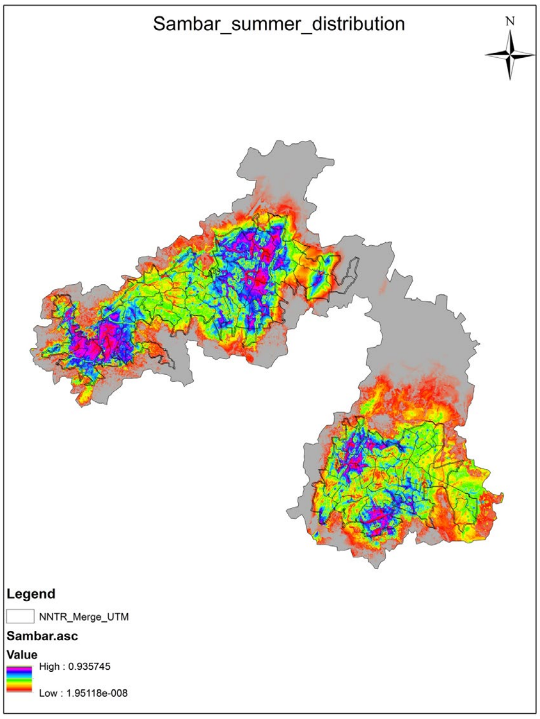


Fig 14 (b): Modelling of distribution of Sambar in NNTR during summer season using MaxEnt

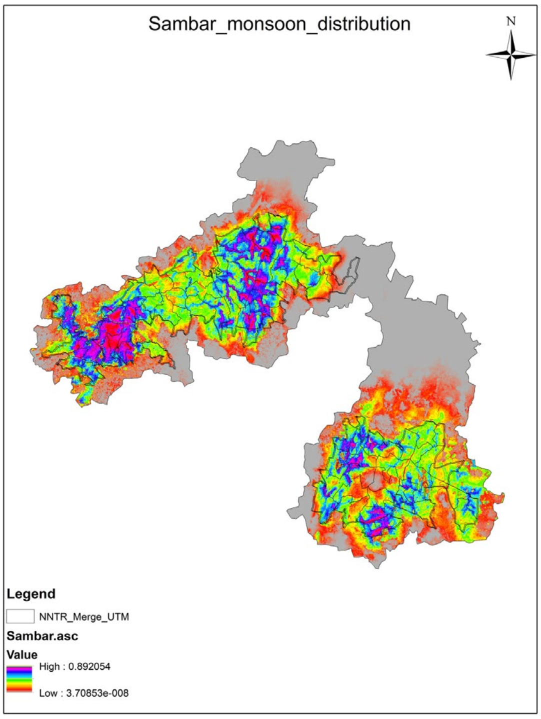


Fig 14 (c): Modelling of distribution of Sambar in NNTR during monsoon season using MaxEnt

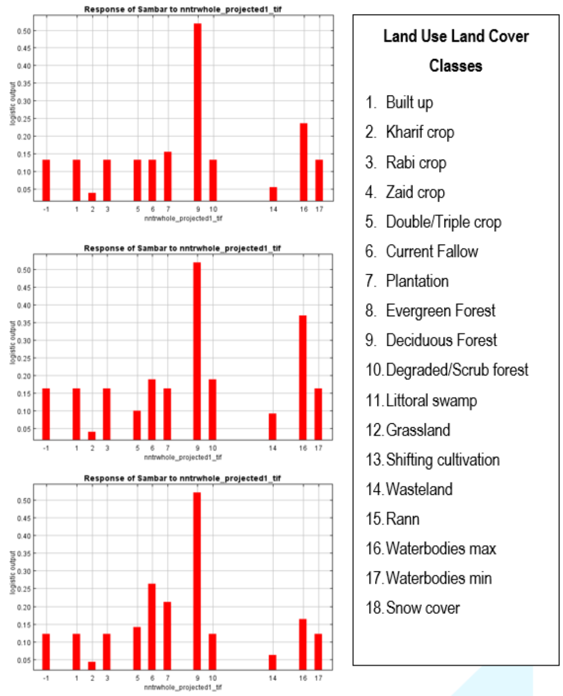


Fig 14 (d): Modelling of the response of Sambar in NNTR to various land use classes using MaxEnt

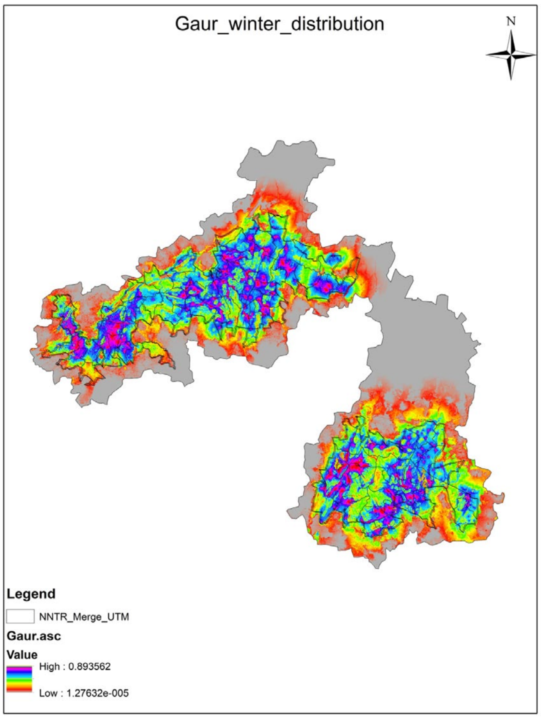


Fig 15 (a): Modelling of distribution of Gaur in NNTR during winter season using MaxEnt

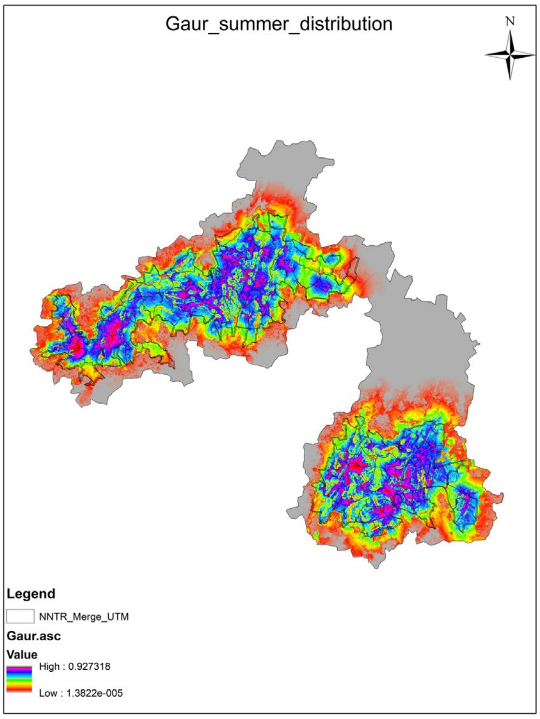


Fig 15 (b): Modelling of distribution of Gaur in NNTR during summer season using MaxEnt

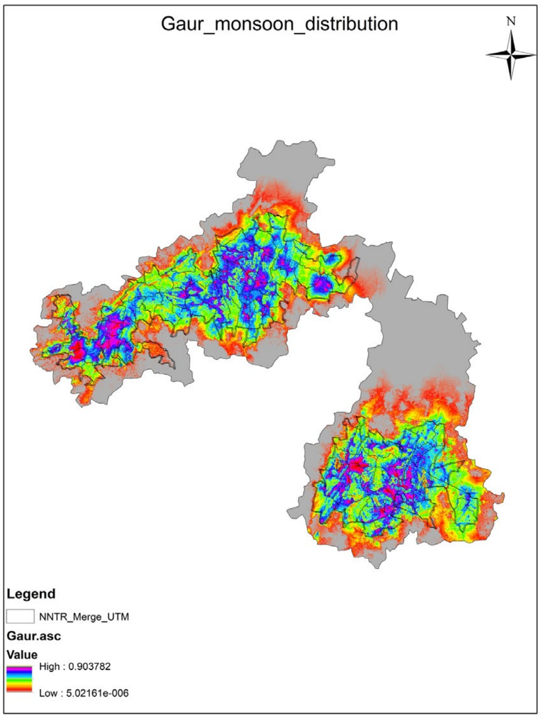


Fig 15 (c): Modelling of distribution of Gaur in NNTR during monsoon season using MaxEnt

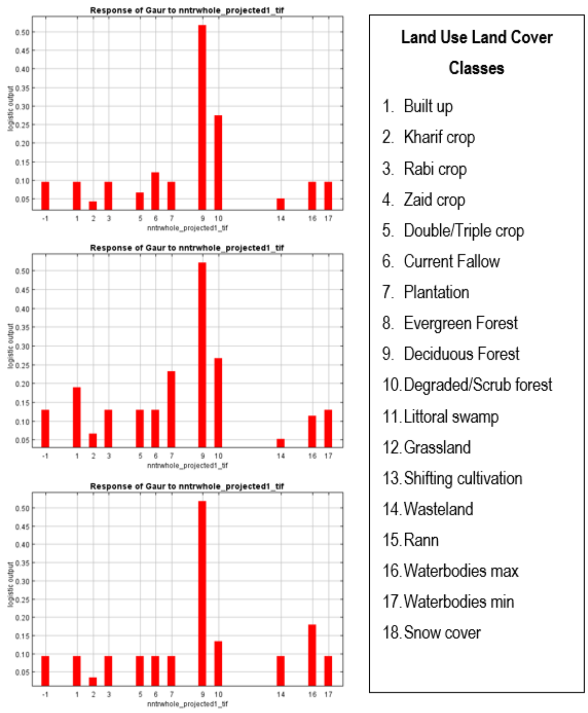


Fig 15 (d): Modelling of the response of Gaur in NNTR to various land use classes using MaxEnt

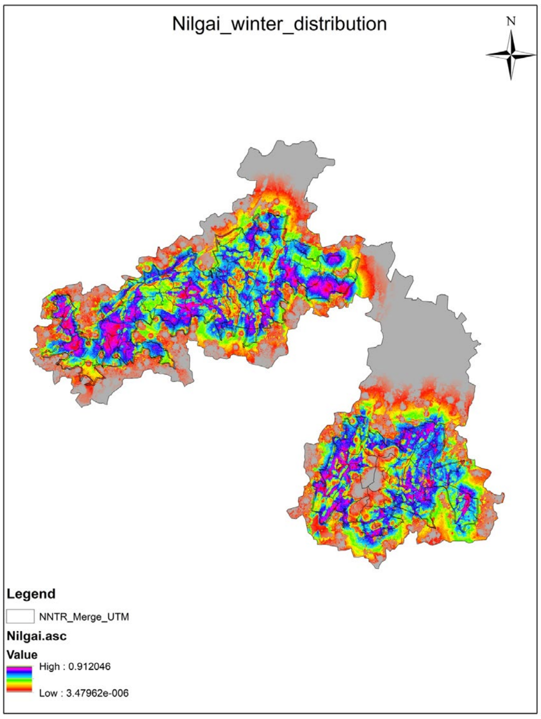


Fig 16 (a): Modelling of distribution of Nilgai in NNTR during winter season using MaxEnt

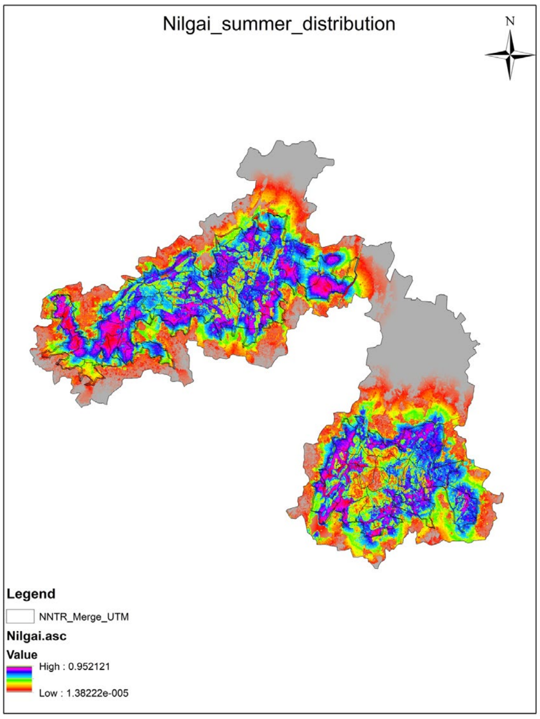


Fig 16 (b): Modelling of distribution of Nilgai in NNTR during summer season using MaxEnt

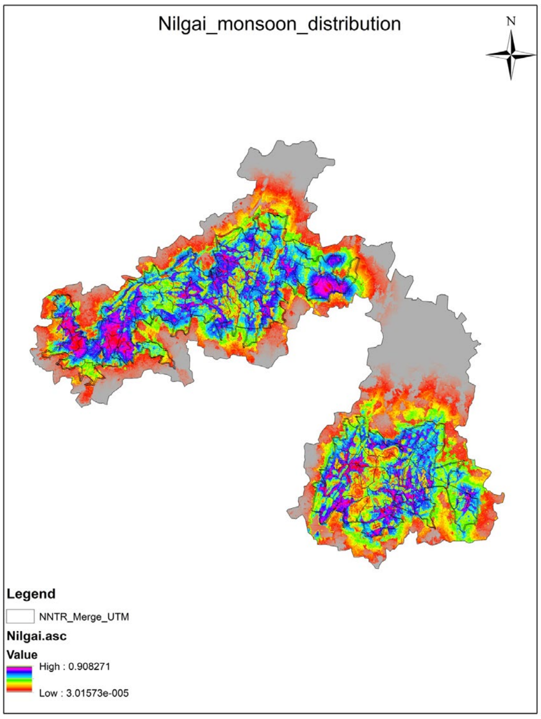


Fig 16 (c): Modelling of distribution of Nilgai in NNTR during monsoon season using MaxEnt

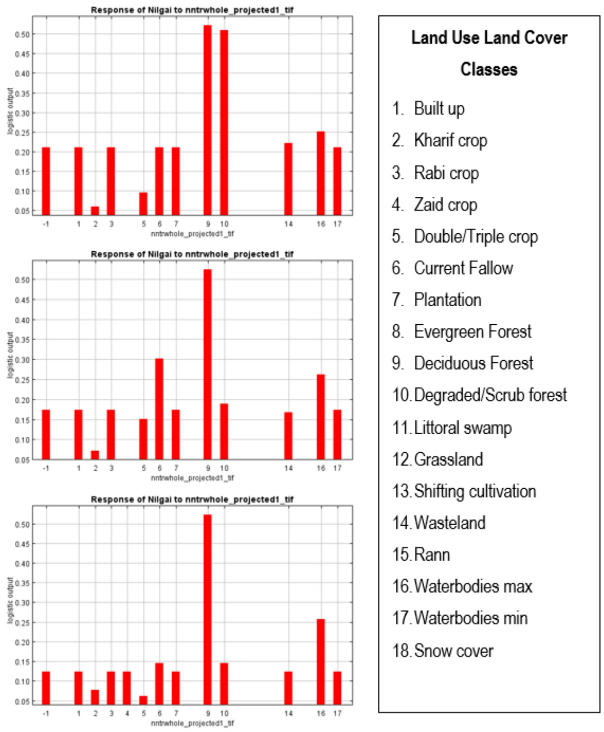


Fig 16 (d): Modelling of the response of Nilgai in NNTR to various land use classes using MaxEnt

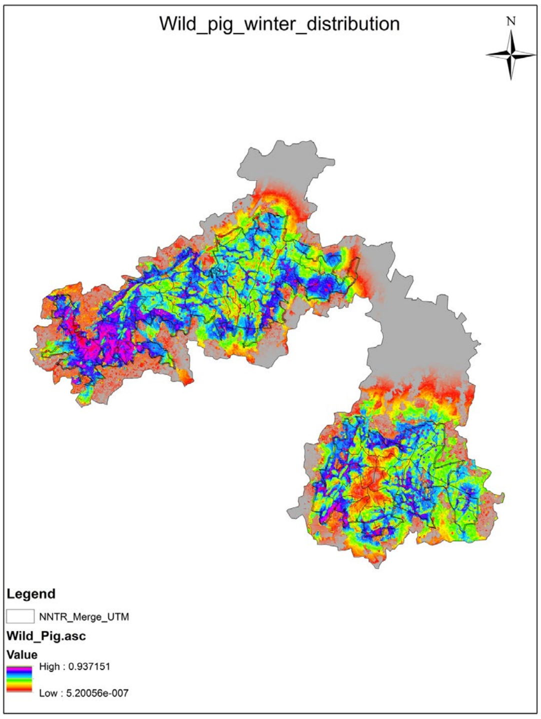


Fig 17 (a): Modelling of distribution of Wild Pig in NNTR during winter season using MaxEnt

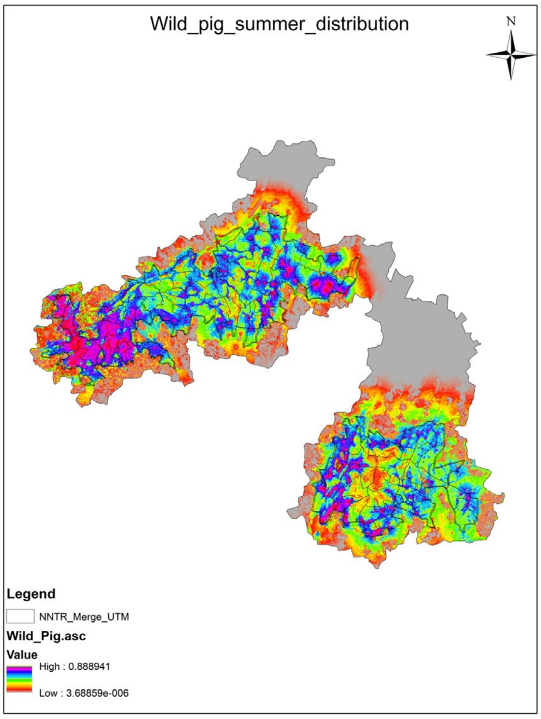


Fig 17 (b): Modelling of distribution of Wild Pig in NNTR during monsoon season using MaxEnt

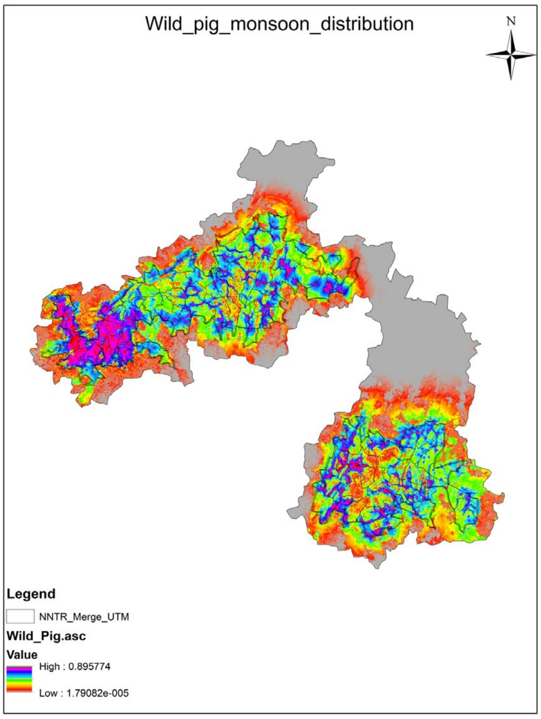


Fig 17 (c): Modelling of distribution of Wild Pig in NNTR during monsoon season using MaxEnt

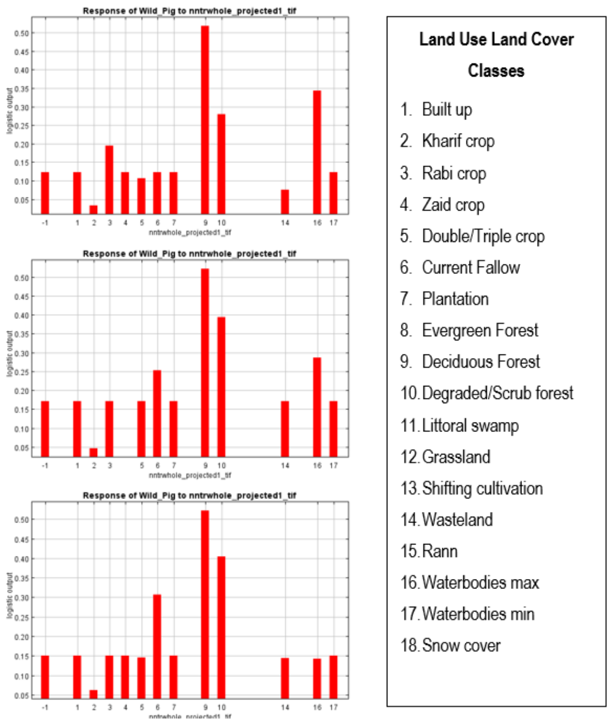


Fig 17 (d): Modelling of the response of Wild Pig in NNTR to various land use classes using MaxEnt

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महाराष्ट्र वन विभाग

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