

# **Evaluation of Prey Availability and Habitat Suitability for Tigers and its Ranging Patterns in Sanjay Tiger Reserve, Madhya Pradesh**



## **FINAL REPORT**



**भारतीय वन्यजीव संस्थान  
Wildlife Institute of India**

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**Evaluation of Prey Availability and Habitat Suitability for Tigers and its Ranging patterns in Sanjay Tiger Reserve, Madhya Pradesh**

**Final Project Report**

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## ABSTRACT

Tiger conservation in human dominated landscape such as Sanjay Tiger Reserve (STR) has always been challenging for the managers and conservation planners. Anthropogenic factors have affected the area negatively, causing habitat degradation, depletion of prey base and unviable tiger population. STR is considered to be low density tiger population area and require recovery strategy, involving translocation from other areas, since natural colonization is not possible to boost the population to viable state. As a precursor to active population recovery, the project was conceived and implemented to establish baseline on prey availability and habitat suitability for tigers, which also involved understanding ranging patterns of tigers using radio-telemetry.

Prey availability in terms of density of wild ungulate was estimated and was found to be low ( $8.2 \pm 0.8$  animals per  $\text{km}^2$ ), but there is an increasing population trend during the study period (2014-2017), largely owing to active protection measures. Amongst the wild ungulates, density of chital was the highest ( $3.0 \pm 0.6/\text{km}^2$ ) followed by wild pig ( $2.0 \pm 0.6/\text{km}^2$ ), nilgai ( $1.8 \pm 0.3/\text{km}^2$ ), chinkara ( $1.1 \pm 0.3/\text{km}^2$ ) and four horned antelope ( $1.0 \pm 0.4/\text{km}^2$ ). Livestock ( $11.6 \pm 5.5/\text{km}^2$ ) was the most abundant animal using the reserve throughout, also contributing to prey base to some extent. Home range of one radio-collared adult male tiger was estimated to be  $208.6\text{km}^2$  during May 2015 to July 2015 and the animal got killed to a territorial fight with another male tiger. Similarly, home range of radio-collared (captive-raised) tigress was estimated to be  $154.1\text{ km}^2$  during October 2016 - May 2017. Exploring large areas could be attributed to limitation of mate choice and a depleted prey base. Habitat suitability of tiger was assessed based on habitat covariates and it was found that 44% of the total area of tiger reserve is potentially suitable habitat in the current status of prey availability, but the suitability can increase to 61% if prey base can be restored in other areas of the reserve.

Carrying capacity of tiger was determined for STR based on the current prey density. It was found that STR can support 11 tigers in this present situation. Population Viability Analysis (PVA) with the carrying capacity of 11 tigers and current population (four individuals, one adult male, two adult females and one juvenile) of tiger in STR showed a poor survival probability ( $0.12 \pm 0.03$ ) over a time span of 25 years. However, given the availability of habitat space and potential to increase prey base, doubling of carrying capacity from 11 to 22 tigers is possible with a supplementation of two tigers in every three years until year ten and it will ensure very high survival probability ( $0.87 \pm 0.03$ ). Active recovery strategy should target the futuristic carrying capacity and management actions would have to be geared towards this. In this context, active population recovery and long-term monitoring strategy has been proposed towards successful population recovery and establishment of viable tiger population, along with other habitat covariates.

# 1. INTRODUCTION

## 1.1 Context

Species do not occur uniformly over space, they are often found in patches influenced by other local and landscape factors that provide them with the suitable environment for their survival and multiplication. Population influx and out flux caused by individual immigrations and emigrations determine the viability of a population (Bowers and Matter 1997). This perspective is clearly relevant when considering species such as tiger (*Panthera tigris*) that occupies large home ranges utilizing variedly distributed habitat and prey species populations. Based on a number of studies it has been established that when tigers are protected from poaching they tend to thrive in landscapes that have an abundance of wild prey, relatively free of disturbance and large areas linked by a number of corridors (Smith *et al.* 1998, Karanth *et al.* 1999, Sunquist *et al.* 1999, Seidensticker *et al.* 1999, Wikramanayake *et al.* 1998, 2004, Johnsingh *et al.* 2004, Sanderson *et al.* 2006, Jhala *et al.* 2011). Habitat fragmentation has become one of the main factors for the change in the tiger's landscape (Smith *et al.* 1998). The geographic range occupied by tigers has declined by 40% in the last decade and is only 7% of their historic range today (Dinerstein *et al.* 2007, Sanderson *et al.* 2006). Conservation efforts such as 'Project Tiger' have been attempting to arrest the decline in populations of tiger, their prey and habitats, very rarely most of the reserves are large enough to support long term conservation of these populations (Woodroffe and Ginsberg 1998, Johnsingh *et al.* 2004, Wikramanayake *et al.* 2004). The ever-expanding human population coupled with controversies over land tenure and local rights of the rural poor (Tharoor 2007), these reserves have become interspersed within area of human land use (Johnsingh *et al.* 2004, Wikramanayake *et al.* 2004, Ranganathan *et al.* 2008).

Population decline of tiger relates not only to anthropogenic causes, but also to reproductive success of the population, which depends entirely on the availability of suitable habitat space and sufficient prey base. In habitats, where surplus proportions of the suitable habitat is available and a good number of individuals are produced, any alteration in the habitat resulting due to natural or anthropogenic reasons immediately has an effect on the stability and survival of the population (Pulliam 1988; Pulliam and Danielson 1991). Hence, fragmentation, loss of habitat and increasing rate of habitat degradation resulting in loss of habitat quality, inadequate prey base, increasing the demand on forest based resources affect tiger conservation in India (Panwar 1987, Johnsingh *et al.* 1991). Habitat characteristics, tiger's requirements for prey, selectivity of different prey species and the habitat requirement of essential prey species are the aspects need to be addressed for effective management of populations. Therefore, evaluating the habitat in terms of habitat suitability and prey base availability were considered as the first step for conservation management of tiger population in STR, and thus, this project was conceived and implemented, with specific strategy for active recovery and monitoring of the population and habitat in STR.

## 2. STUDY AREA

### 2.1 Overview

Sanjay Tiger Reserve (STR) is situated in the northeastern part of Madhya Pradesh (Figure 1 & 2) and is bordered by Guru Ghasidas National Park of Chhattisgarh. The park has a total geographical area of 1643.83 km<sup>2</sup> consisting of Sanjay National Park and Dubari Sanctuary as core (831.25 km<sup>2</sup>) and buffer area (812.58 km<sup>2</sup>) in Sidhi and Shahdol districts of Madhya Pradesh. Core area is situated in the district of Sidhi and buffer zone cover parts of Beohari Tehsil (District Shahdol), Majhauri and Kusmi Tehsil of District Sidhi. The entire tract of the Core and Buffer of Sanjay Tiger Reserve is situated between longitude of 82 10' 48" to 82 14' 40" and latitude of 23 48' 57" to 23 49' 06". It is a part of Bandhavgarh-Sanjay-Guru Ghasidas-Palamau landscape and has been identified as one of the potential tiger meta- population landscapes.

The plains lay in the catchment areas of river Gopad, Banas, Son, Hasdo, Mawai and their tributaries. There are plenty of rivers and *nulla* in and around the park and sanctuary area. Some rivers are perennial and some are seasonal, however water lasts only for 4-6 months' post monsoon period. Water shortage reaches acute levels in the years when rainy season falls much below the optimum annual rainfall. Apart from the natural water sources, there are some artificial water holes created by the management. Consequently, populations of tigers are confined to forest patches interspersed within protected area, multiple use forests, agricultural land and human habitation. Some parts are under severe anthropogenic pressure, so it is important to focus on the habitat and prey distribution and their influence on tiger population across the landscape.

The general topography of the reserve is hilly and undulating over greater portion especially towards plateau portions. The elevation of STR varies from 425m to 732m above mean sea level (MSL). The mean annual rainfall is 1303.00 mm. The normal fluctuations of the mean annual rainfall are expected to have the range of 1059.70 mm to 1277.10 mm. Annual Temperature is found to range between 41.8 °C to 7.4 °C . Almost 95% of the precipitation is received from the South-East Monsoon and a very small portion from the North- East Monsoon during winter. The relative humidity ranges between 80 and 90% during the monsoon period.

### 2.2 Vegetation

According to the "Revised Classification of Forest type of India" by Champion and Seth (1968), the forest area of the STR comes under "North Indian Moist Deciduous forest sub group 3C, with sub type moist Sal bearing forest – CZ with sub division moist peninsular Sal. The general type is 3C/CZ. Sal forest (*Shorea robusta*) is a dominant plant community both in the National Park and Dubari WLS, occupying about 80% of the entire area followed by Mixed Forest, Bamboo Forest, Bamboo mixed forest, Scrubland, and Grass land.

### **2.3 Faunal Attributes**

Sanjay Tiger reserve is found to hold a variety of fauna. For its structural diversity and wide array of fauna, including the 'key species' tiger (*Panthera tigris*), other prominent carnivores are leopard (*Panthera pardus*), jungle cat (*Felis chaus*), hyena (*Hyaena hyaena*), jackal (*Canis aureus*), Indian fox (*Vulpes bengalensis*). STR also supports sizable population of sloth bear (*Melursus ursinus*). The major ungulates that form prey for these carnivores are chital (*Axis axis*), nilgai (*Boselaphus tragocamelus*), sambar (*Rusa unicolor*), four horned antelope (*Tetracerus quadricornis*), chinkara (*Gazella bennettii*), barking deer (*Muntiacus muntjak*) and wild pig (*Sus scrofa*). The grey langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mullata*) are the two primate species found in the tiger reserve.

### **2.4 Human settlements**

There are 39 villages inside STR with a sizable population. The entire population depends upon natural resources for their livelihood including for fuel-wood, agriculture equipment, food security, minor forest produce etc. from both the buffer and core zone areas. The discontinuity in habitat due to interspersed villages and agricultural areas in the matrix has resulted in isolation of habitats. The increasing human population in these areas adds additional pressure on the habitat. Livestock population surrounding the Tiger reserve is very high, which poses serious problems of over-grazing, man-animal conflict issues, spread of invasive weeds and thereby destruction of habitat.

## **3. OBJECTIVES**

1. To evaluate the current status of prey base in STR
2. To assess the habitat suitability for tigers in STR
3. To study the ranging and spatial dispersal patterns of tigers using radio- telemetry
4. Equip the forest department staff at the ground level with enough knowledge resources so as to continue the monitoring of tigers in the park after the project is completed.

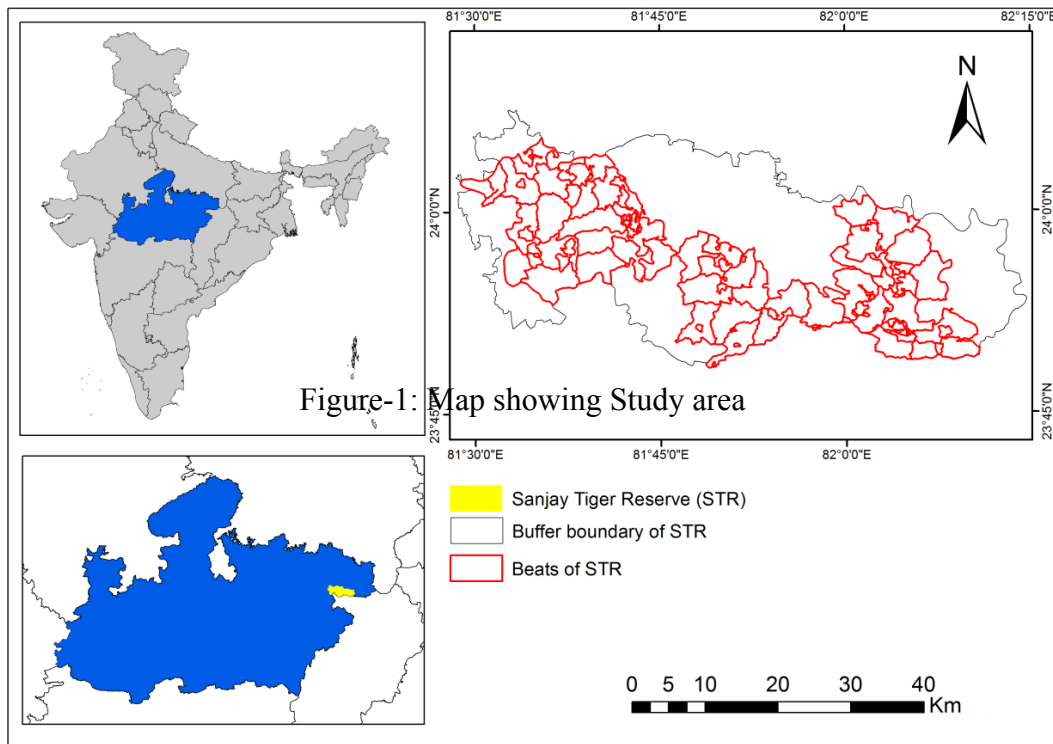


Figure 1: Map showing study area (Sanjay Tiger Reserve)

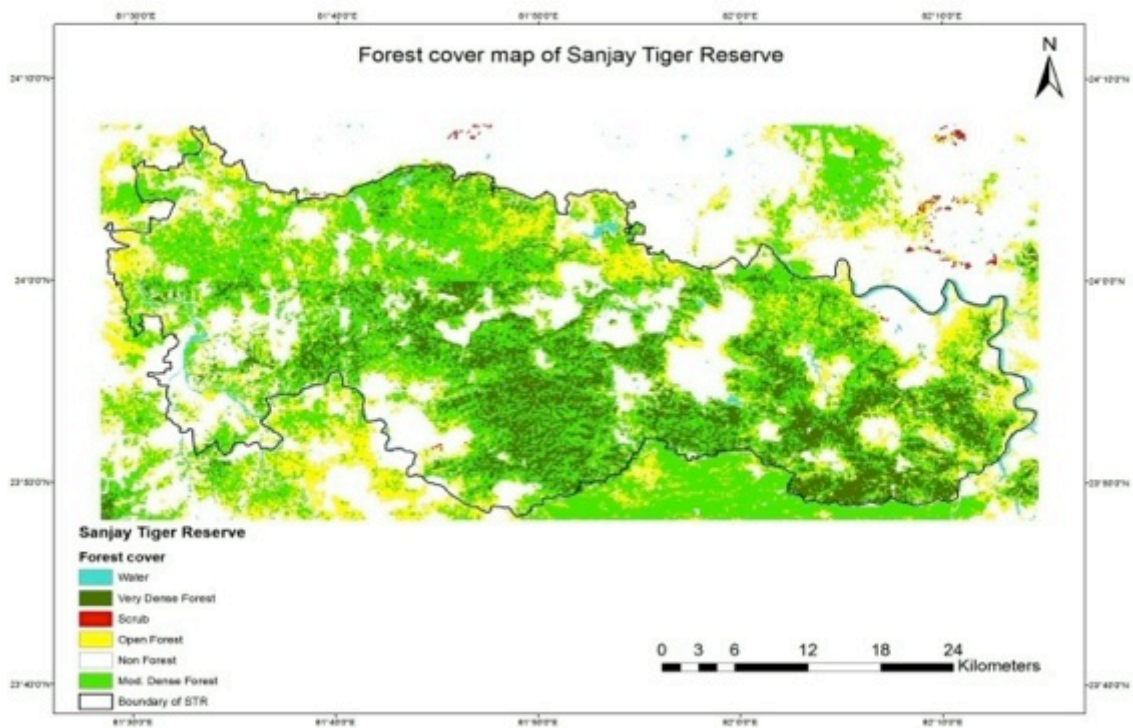


Figure 2: Map showing forest cover of Sanjay Tiger Reserve

## **4. OCCUPANCY AND ABUNDANCE OF CARNIVORES**

### **4.1 Study design and methods**

#### **4.1.1 Carnivore sign survey**

Carnivore sign survey closely followed All India Tiger Population Estimation and Monitoring Project (Jhala *et al.* 2011) and was carried out in selected beats during summer (March 2015- June 2015 and March 2016- June 2016) and winter (November 2014- February 2015, November 2015- February 2016 and November 2016- February 2017) to establish presence/absence of tigers and other carnivores. Sampling was carried out along forest roads, minor forest trails, river beds and streams. The signs observed were scats (old, fresh and very fresh), scrapes, rakes and pugmarks, were recorded. A team of two persons along with a forest guard walked a trail of 15 km in three segments (spatial replicate) in each beat. Other parameters like GPS location, forest type, terrain type, elevation, sign type and conditions were recorded for every sign that was encountered during the survey. A total of 363.56 kilometers, 425.25kilometers and 491.48 kilometers were covered during November 2014 to February 2015, March to June 2015 and November 2015 to February 2016, respectively. During summer of March to June 2016 and winter of November 2016 to February 2017, 611.14 kilometers and 985 kilometers were covered throughout the core area of tiger reserve. The encounter rate of carnivore species was also calculated for different seasons. Occupancy estimation of four carnivore species namely tiger, leopard, sloth bear and hyena were analyzed using PRESENCE software (Hines *et al.* 2010, Mackenzie and Hines 2012) with a data string of 0's and 1's where 1 represents the presence of an animal and 0 indicates absence or non-detection, at a particular site (in this case a Forest Beat).

#### **4.1.2 Camera trapping**

To assess the abundance of tigers in STR, camera trapping was carried out in three sessions during winter (November 2014 to February 2015) and summer (March 2015 to June 2015) followed by another three sessions (November 2015 to February 2016 and March 2016 to June 2016) to cover the entire core area of tiger reserve. Camera trap sampling design was in line with the Phase IV protocol of All India Tiger Population Estimation and Monitoring Project (Jhala *et al.* 2011). The whole area was gridded into 4 km<sup>2</sup> (2 \* 2 km<sup>2</sup> grid) and one pair of camera was deployed in each grid. Each session was continued for 45 days. A total of 37, 33 and 35 locations were selected and camera traps were deployed during three consecutive sessions (November 2014 to June 2015) resulting in 1665, 1485 and 1575 trap nights, respectively. Similarly, 20, 111and 65 locations were selected and camera traps were deployed (November 2015 to June 2016). Out of 195 locations throughout the tiger reserve, data obtained only from 161 locations (Figure 3) due to technical faults, theft and other logistic constraints. A total of 7245 trap nights in winter (2015-2016) and summer (2016) were sampled using 161 pairs of camera traps. In December, 2016, camera traps were deployed in 89 locations (pre-defined) to

cover the National park area of the tiger reserve which yielded 4005 trap nights. Photographs were downloaded regularly in the field using portable computer. Subsequently, individual identification was done using standardized methods and creation of matrices was done based on the photographs of both flanks of tigers.

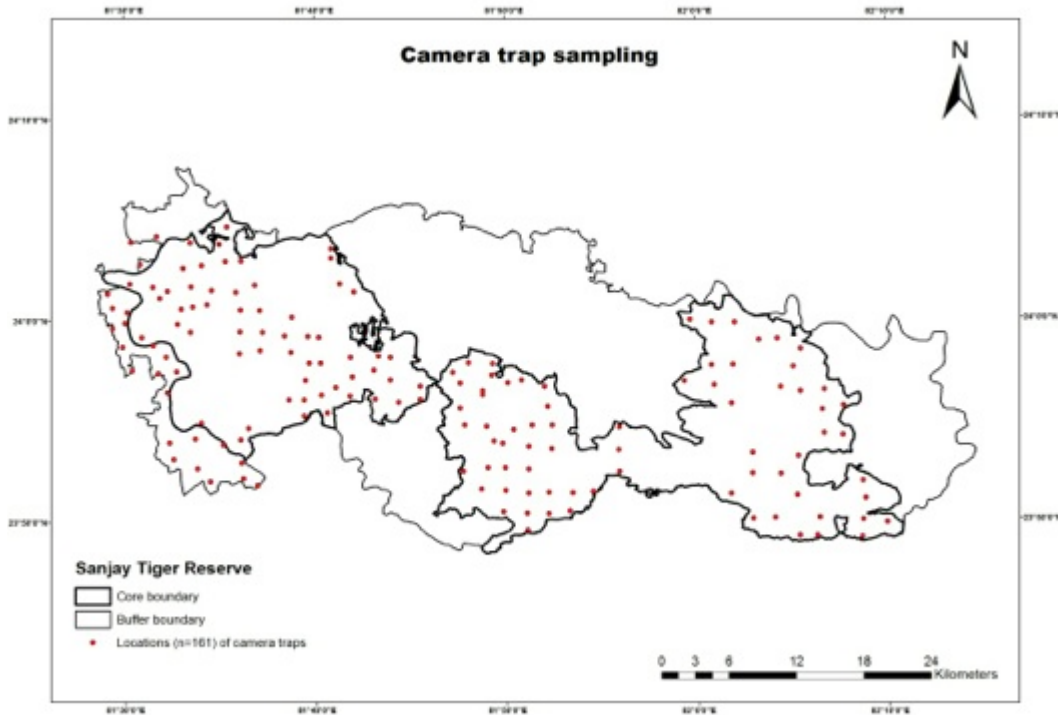


Figure 3: Map showing camera trap locations in Sanjay Tiger Reserve

## 4.2 Results

### 4.2.1 Carnivore sign survey

Encounter rate and proportion of sites occupied (psi) by tiger, leopard, sloth bear, hyena and other carnivores were calculated season wise and shown in Table 1 and Table 2. The encounter rate and psi value were found to be highest for sloth bear across the seasons. After sloth bear, leopard and hyena were found to be the widely distributed carnivores in terms of psi value. Proportion of site occupied by tiger ranged from 28% to 68%, indicating high uncertainly level and has very low intensity of space use (Table 1 & 2).

Species	Encounter Rate (No. signs/total distance surveyed)					
	Monsoon (2014) (72.11 km)	Winter (2014-2015) (363.56 km)	Summer (2015) (425.22 km)	Winter (2015-2016) (491.48 km)	Summer (2016) (611.14 km)	Winter (2016-2017) (985 km)
Tiger	0.11	0.03	0.02	0.05	0.02	0.05
Leopard	0.12	0.26	0.05	0.11	0.05	0.14
Sloth bear	0.45	0.49	0.39	0.57	0.64	0.26
Hyena	0.08	0.15	0.09	0.12	0.09	0.09
Wolf	0.01	0.03	-	0.01	0.01	0.01
Jackal	0.17	0.08	0.15	0.32	0.22	0.14
Jungle cat	-	0.03	-	0.12	0.02	0.02
Fox	-	0.04	0.01	0.02	0.01	0.01
Wild dog	-	-	-	0.01	-	-

Table 1: Encounter rate of carnivores in different seasons

Species	Winter 2014- 2015	Summer 2015	Winter 2015- 2016	Summer 2016	Winter 2016- 2017
	Psi (SE)	Psi (SE)	Psi (SE)	Psi (SE)	Psi (SE)
Tiger	0.68 (0.21)	0.44 (0.29)	0.32 (0.1)	0.20 (0.09)	0.28 (0.06)
Leopard	1	0.52 (0.15)	0.81 (0.11)	0.59 (0.18)	0.63 (0.07)
Sloth bear	1	1	1	1	0.94 (0.03)
Hyena	1	0.98 (0.14)	1	0.74 (0.1)	0.79 (0.07)

Table 2: Proportions of site occupied by carnivores in different seasons

#### 4.2.3 Population estimation of tigers

In total 11 tigers (four adults and seven cubs) are found in STR. However, during camera trapping, five tigers (Table 3) were identified in the study area during November 2014 to June 2015. Out of five, two were adult females (T-001 and T-003) and three were adult males (T-002, T-004 and T-005). Two male tigers (T-002) and (T-004) were found dead during the above-mentioned period.

During November 2015 to June 2016, three adult tigers (Table 4) were identified based on camera trap photographs in the study area. Out of these, two were adult females (T-001 and T-003) and one was adult male (T-005). Two of the females T-001 and T-003 had given birth to eight cubs and the litter size was 5 and 3 respectively. The cubs' presence was confirmed by direct sighting, placing of opportunistic camera traps and pugmark tracking methods. Out of eight cubs, only five cubs attained the age to disperse. One adult female (T-001) was found dead as a result of electrocution. During December 2016 to February 2017, two adult tigers were

identified, of which one was an adult male (T-005) and another one was a male sub-adult (approx.15 months old, T-013) detected for the first time in STR.

Currently, during the ongoing the camera trapping session (March 2017-May 2017), three adult tigers (T-003, T-011 and T-005) were identified. T-011 is one radio-collared female tiger translocated from Bandhavgarh Tiger Reserve and was released into the wild about which details are provided in Chapter-5.

Apart from the identification of tigers, capture rates were determined for co-predators and prey species from each of the location of camera trap. Since prey density was found to be low in STR, due to poor detection in distance sampling method, capture rate could be useful to reflect the current status of prey base in STR.

Session	Camera trap locations	Trap nights	Number of tiger photographs	Number of individual tigers	Sex			Cubs
					Male	Female	Unknown	
I	37	1665	56	4	3	1	-	-
II	33	1485	18	1	1	-	-	-
III	35	1575	8	2	2	-	-	-

Table 3: Total number of tigers found in STR based on camera trap method (2014-2015)

Session	Camera trap locations	Trap nights	Number of tiger photographs	Number of individual tigers	Sex			Cubs
					Male	Female	Unknown	
IV	20	900	2	1	1	-	-	-
V	111	4995	5	1	1	-	-	-
VI	65	2925	109	6	1	1	-	4
VII	89	4005	11	2	1	-	1	-

Table 4: Total number of tigers found in STR based on camera trap method (2015-2016)

## **5. RANGING PATTERNS OF TIGER**

### **5.1 Methods**

Knowledge on home range and ranging pattern is a prerequisite not only to understand the biology of the species, but for the development of successful conservation action plan. To study the ranging patterns of tigers as a part of this project, an adult male tiger (P-212 or T-002) was radio-collared on 06.05.2015 by the team from WII with the support of Dr. Nitin Gupta, Veterinary Officer, Bandhavgarh Tiger Reserve (BTR) and Forest Department, Sanjay Tiger Reserve, under the leadership of Field Director. The animal was fitted with a Very High Frequency (VHF) radio-collar. Unfortunately the tiger was found dead on 19.07.2015 due to territorial fight with another adult male (T-005). Radiolocations of the aforesaid tiger were determined by “Homing in” and “Triangulation” from three to four known reference points (White and Garrot 1990). Coordinates of these reference points were taken with the help of Global Positioning System (GPS). A total of 38 locations were obtained from the collared tiger till 19.07.2015 to estimate the home range. Home range estimation was carried out using Hawth’s tool in Arc Map 9.3. 100% minimum convex polygon (Mohr, 1947) method was followed to analyze the home range.

Subsequently, a sub-adult semi wild tigress was translocated from BTR to STR on 11.03.2016. Initially the tigress was released at Kanjra enclosure which was equipped with CCTV camera for intensive monitoring and kept there for the next seven months. On 18.10.2016, this female tiger (T-011) was captured, radio-collared and released into the wild by the team from WII with active support and cooperation of Dr. Abhay Sengar, Veterinary Officer, STR, Dr. Nitin Gupta, Veterinary Officer, BTR and the frontline staff of Forest Department, STR, under the leadership of Field Director. As a post release monitoring, 24x7 intensive tracking by two teams (one from WII and another from Forest Department, STR) was implemented. Radio locations (n=772) from October 2016 to May 2017, were obtained and home range was estimated by the same technique mentioned earlier.

### **5.2 Results**

Home range of the collared adult male tiger (T-002) was estimated based on 38 radio locations obtained from 8<sup>th</sup> of May to 19<sup>th</sup> of July were plotted on a map (Figure 4). During this period, the animal had covered 208.62km<sup>2</sup> area within the Dubari Sanctuary, Sanjay National Park and buffer (Beohari) area of Sanjay Tiger Reserve, MP. The large home range of the T-002 can be attributed to less number of breeding females and sub-optimal habitat in terms of substantially low wild prey base and high anthropogenic pressure in the study area.

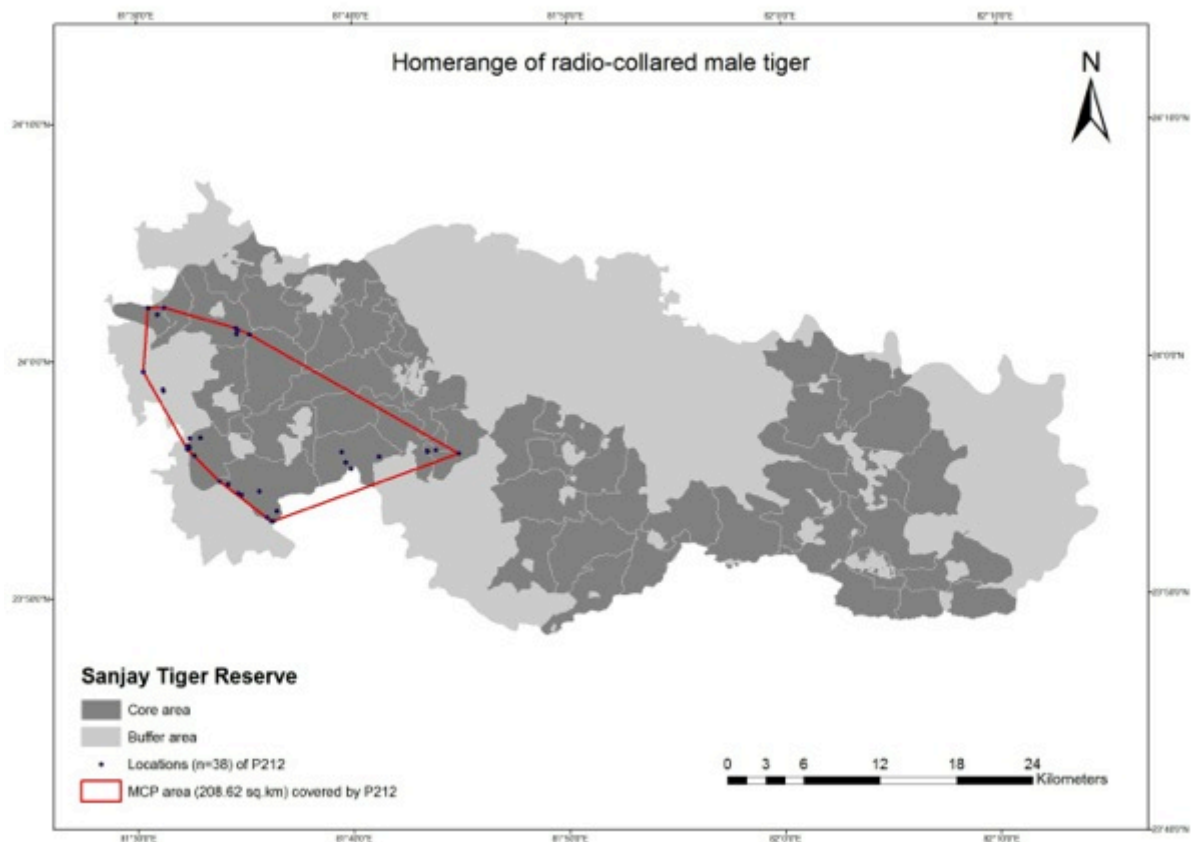


Figure 4: Home range of radio-collared male tiger (P-212)

Similarly, a total of 772 locations were used to estimate the home range of the radio-collared tigress (T-011). It was found that, during October 2016 to May 2017, the animal covered an area of 154.12 km<sup>2</sup> (Figure 5). The movement was mostly restricted to Dubari and Bastua Ranges of Dubari Wildlife Sanctuary. The large size of home range for a female tiger can be attributed to initial exploration done by the animal in order to establish its own territory and a low prey base with relatively high anthropogenic pressure persist in the study area.

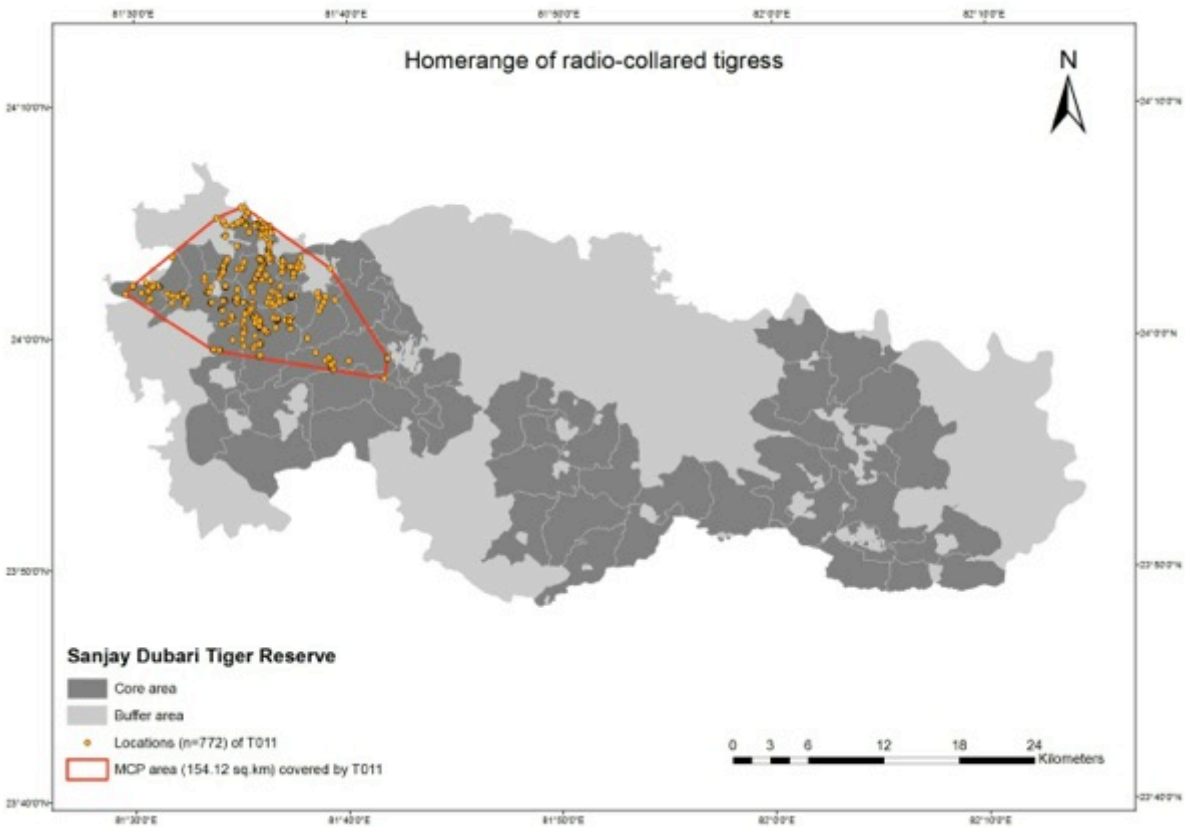


Figure 5: Home range of radio-collared tigress (T-011)

## 6. EVALUATION OF PREY BASE

### 6.1. Method

Population estimation of the prey species was carried out by using distance-sampling protocol (Burnham *et al.*, 1980, Buckland *et al.*, 1993). A total of 44 line transects (one line in each beat; Figure 6) were laid across the study area. It was ensured that these transects covered all the different habitats of prey species. The length of each line transect was fixed at 2 kilometers, suited for efficient sampling for prey species in such habitats. Initially each transect was walked in the morning hours in between 6:00am to 8:00am and repeated (temporal replicate) for two more times in both summer and winter seasons. Since heavy underestimation in detection of livestock during morning hours, one replicate was walked in the early evening hours between 4:00 pm to 6 pm. During summer of March 2015 to June 2015 and March 2016 to June 2016, 29 and 43 line transects were selected and walked between 6:00am to 8:00am, respectively. During winter of November 2014 to February 2015, November 2015 to February 2016 and November

2016 to February 2017, 28, 44 and 55 line transects, respectively were walked twice between 6:30am to 8:30am and 4:00 pm to 6pm. Altogether, the total effort on the line transect during the reporting periods was 346 kilometers in summer and 652 kilometers in winter. The count included visual encounter of prey species along with group (cluster) size, sighting distance and sighting angles for each observation. Vegetation sampling and estimation of parameters such as ground cover, canopy cover, weed abundance, pellet count, human disturbance were also collected during the transects at an interval of 400m. Aforesaid plot sampling method was followed in each forest beat to estimate the status of prey distribution and densities and to evaluate habitat conditions including anthropogenic disturbance (Jhala *et al.* 2011). The Program DISTANCE 6.0 (Thomas *et al.* 2010) was used to estimate the density of prey species. The individual prey density and pooled density for all prey species were estimated, the half normal key function with cosine adjustment was the best fitted model for density estimation of all prey species. This was selected on the basis of the lowest Akaike Information Criteria (AIC).

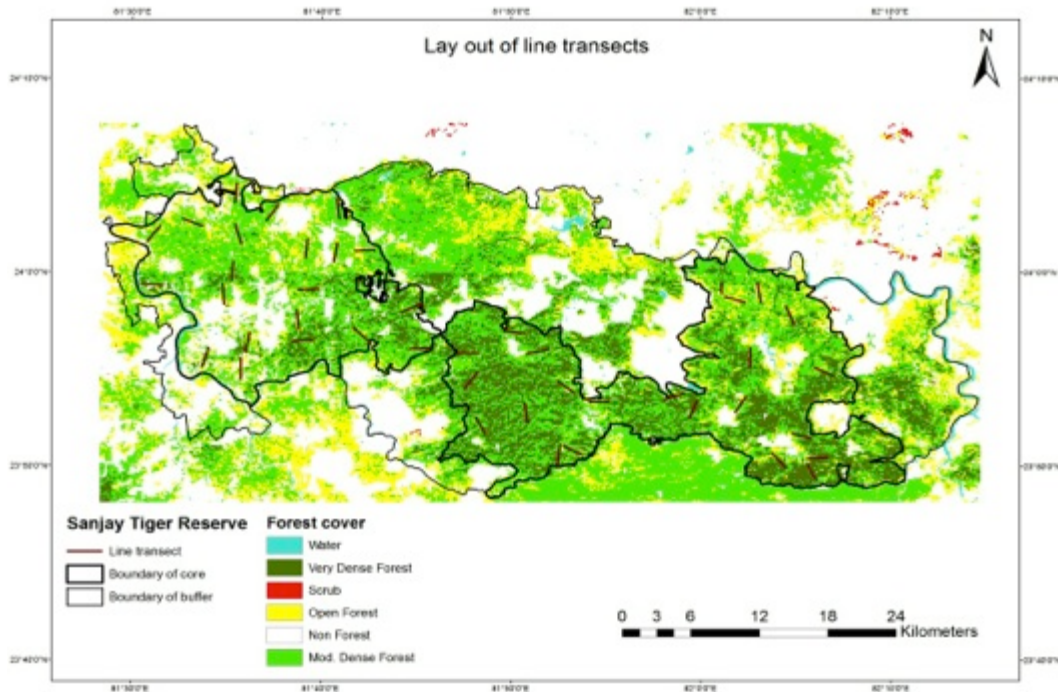


Figure 6: Map showing distribution of line transects in Sanjay Tiger Reserve

## 6.2 Prey density

The prey species in STR includes chital, sambar, nilgai, barking deer, four horned antelope, chinkara, livestock, grey langur and peafowl. However, for most of the species numbers of detection were found to be too low to estimate the density which can be reflected by the high standard error associated with density. Table 5-9 showed the year wise and season wise density

estimates of wild ungulates, livestock and langur and lastly, Table 10 showed the all over species wise prey density during the study period (2014-2017).

Species	AIC	Model	N	D	DS	% of CV		ESW
						D	DS	
Wild Ungulates	492.59	Half-normal – Cosine	52	2.83 ± 0.6	1.63 ± 0.3	24.47	22.62	71.68 ± 12.6
Langur	280.48	Uniform – cosine	34	25.89 ± 7.4	1.96 ± 0.4	28.59	21.46	38.88 ± 3.8
Rhesus macaque	60.61	Uniform – cosine	7	2.19 ± 1.3	0.38 ± 0.1	60.77	41.22	48.04 ± 9

Table 5: Prey density in 2015 (winter and summer) AIC-Akaike information criteria, n-number of sightings, D-Density, DS-Group density, ESW-Effective strip width

Species	AIC	Model	N	D	DS	% of CV		ESW
						D	DS	
Wild Ungulates	690.75	Uniform – cosine	79	17.42 ± 3.0	5.75 ± 0.79	17.53	13.87	43.76 ± 3.56
Langur	511.45	Half normal – Cosine	57	17.66 ± 3.73	1.41 ± 0.24	21.14	17.20	49.75 ± 5.7
Rhesus macaque	38.21	Uniform - Simple polynomial	6	4.58 ± 2.64	0.30 ± 0.12	57.54	40.32	24.14 ± 0
Livestock	181.75	Half normal – Cosine	21	11.60 ± 5.46	0.71 ± 0.27	47.08	0.27	36.20 ± 10.4

Table 6: Prey density in 2016 (winter and summer) AIC-Akaike information criteria, n-number of sightings, D-Density, DS-Group density, ESW-Effective strip width

Species	AIC	Model	N	D	DS	% of CV		ESW
						D	DS	
Overall	301.78	Half-normal – Cosine	132	21.37 ± 3.51	4.06 ± 0.49	16.43	12.19	44.83
Barking deer	53.45	Half-normal – Cosine	6	0.25 ± 0.13	0.19 ± 0.09	52.31	50.37	44.16 ± 13.72
Livestock	0.00	Half-normal – Cosine	1	0.12 ± 0.12	0.00 ± 0.00	99.97	99.97	Nil
Chinkara	130.17	Half-normal – Cosine	14	0.51 ± 0.18	0.33 ± 0.11	35.97	34.23	59.00 ± 12.65
Chital	86.54	Hazard rate – Cosine	9	0.37 ± 0.21	0.13 ± 0.07	55.82	52.52	95.16 ± 33.64
Four-horned antelope	43.54	Half-normal – Cosine	5	0.46 ± 0.43	0.12 ± 0.13	95.31	72.56	38.66 ± 22.32
Black naped hare	50.29	Half-normal - simple polynomial	6	0.24 ± 0.14	0.24 ± 0.14	59.45	59.45	33.93 ± 9.84

Jungle fowl	10.33	Half-normal - simple polynomial	2	0.57 ± 0.64	0.57 ± 0.64	113.06	113.06	4.86 ± 4.31
Langur	467.96	Half-normal - simple polynomial	57	20.03 ± 4.94	2.18 ± 0.4	24.66	18.36	36.14 ± 3.72
Nilgai	220.29	Hazard rate - Cosine	23	0.82 ± 0.28	0.47 ± 0.14	34.14	30.84	67.49 ± 13.82
Rhesus macaque	54.07	Half-normal - Cosine	6	1.32 ± 0.78	0.18 ± 0.09	59.38	52.35	46.51 ± 11.47
Wild pig	40.14	Hazard rate - Cosine	5	0.80 ± 0.73	0.18 ± 0.12	91.35	66.39	36.39 ± 18.19

Table 7: Individual prey density in 2014-2015 (winter and summer) AIC-Akaike information criteria, n-number of sightings, D-Density, DS-Group density, ESW-Effective strip width

Species	AIC	Model	N	D	DS	% of CV		ESW
						D	DS	
All prey	301.78	Half-normal - Cosine	132	39.95	4.06 ± 0.49	16.43	12.19	44.83
Barking deer	54.27	Uniform - simple polynomial	6	0.23 ± 0.12	0.18 ± 0.08	51.59	49.70	56.09 ± 16.43
Livestock	49.24	Uniform - simple polynomial	7	7.34 ± 4.20	0.53 ± 0.27	57.26	51.90	21.92 ± 4.90
Chinkara	116.33	Uniform - simple polynomial	13	0.72 ± 0.26	0.36 ± 0.13	36.38	34.48	58.79 ± 12.89
Chital	153.18	Uniform - simple polynomial	17	1.69 ± 0.66	0.43 ± 0.12	39.15	27.49	65.64 ± 6.26
Black naped Hare	22.64	Half-normal - Cosine	3	0.26 ± 0.27	0.26 ± 0.27	105.97	105.97	18.91 ± 16.85
Langur	382.46	Half-normal - Cosine	45	27.24 ± 6.48	1.75 ± 0.33	23.80	19.06	42.41 ± 4.58
Nilgai	186.07	Uniform - Cosine	19	0.84 ± 0.34	0.47 ± 0.18	40.97	37.81	67.00 ± 19.59
Rhesus macaque	54.14	Half-normal - simple polynomial	6	1.59 ± 1.20	0.21 ± 0.1	75.53	47.32	46.77 ± 11.72

Table 8: Individual prey density in 2015-2016 (winter and summer) AIC-Akaike information criteria, n-number of sightings, D-Density, DS-Group density, ESW-Effective strip width

Species	AIC	Model	N	D	DS	% of CV		ESW
						D	DS	
Wild ungulates	895.74	Half-normal – Cosine	102	18.81 ± 3.6	5.35 ± 0.93	19.50	17.50	48.63 ± 7.13
Langur	331.17	Uniform – cosine	39	29.76 ± 7.7	2.16 ± 0.38	26.08	17.91	45.89 ± 4.8
Rhesus macaque	61.59	Uniform – cosine	8	4.01 ± 1.8	0.43 ± 0.1	46.62	34.06	46.98 ± 0

Table 9: Prey density in 2017 (winter) AIC-Akaike information criteria, n-number of sightings, D-Density, DS-Group density, ESW-Effective strip width

Species	AIC	Model	N	D	DS	% of CV		ESW
						D	DS	
Sambar	30.14	Uniform/Cosine	4	0.12 ± 0.64	0.56 ± 0.27	51.04	49.82	43.30 ± 0
Chital	479.95	Uniform/Cosine	55	3.0 ± 0.62	0.64 ± 0.10	20.79	16.62	52.02 ± 3.97
Nilgai	636.64	Half-normal/Cosine	68	1.84 ± 0.30	0.72 ± 0.10	16.77	14.19	57.12 ± 4.29
Chikara	482.03	Half-normal/Cosine	53	1.14 ± 0.27	0.59 ± 0.13	23.88	22.88	54.39 ± 9.98
Four horned antelope	56.63	Uniform/Polynomial	7	0.95 ± 0.38	0.74 ± 0.27	40.17	37.52	57.11 ± 0
Barking deer	126.99	Uniform/Polynomial	15	0.15 ± 0.42	0.13 ± 0.33	26.89	25.38	68.93 ± 0
Wild pig	264.16	Uniform/Cosine	31	1.97 ± 0.64	0.46 ± 0.10	32.40	22.02	40.14 ± 5.15
Langur	1155.15	Uniform/Cosine	133	22.99 ± 3.13	1.79 ± 0.18	13.64	10.34	45.01 ± 2.6
Rhesus macaque	169.71	Uniform/Cosine	21	4.80 ± 2.23	0.39 ± 0.11	46.47	29.75	31.90 ± 6.63
Wild ungulates	2090.47	Half-normal/Cosine	233	8.18 ± 0.78	2.77 ± 0.21	9.62	7.74	50.96 ± 1.81

Table 10: Density estimates of all prey species during the study period (2014-2017) AIC-Akaike information criteria, n-number of sightings, D-Density, DS-Group density, ESW-Effective strip width

## 7. HABITAT SUITABILITY ANALYSIS

Tiger, being a threatened species and in the need of conserving it, habitat evaluation could be considered a very first step towards a meaningful conservation (Kushwaha 2002). Habitat may be characterized by an array of the environmental features that are important for a species to survive. Such knowledge is often based on field experience and non-quantifiable human perceptions (Burgman and Lindenmayer 1998), which could be used to construct habitat suitability models (Pearce and Boyce 2006, Hirzel *et al.* 2006, Smith *et al.* 2007, Braunisch *et al.* 2008). One of the widely used methods to evaluate suitability of a habitat for a particular species is habitat suitability index (HSI) modeling (USFWS 1980, 1996, Burgman *et al.* 2001). HSI modeling can be helpful not only to evaluate the habitat suitability but also identify potential risks to the species, understand the implications of different land use practices and to identify sites for the reintroduction of an endangered species. This chapter explains a methodology that utilized Remote Sensing and Geographical Information System (GIS) and an extensive field survey to elicit habitat suitability of tiger in STR.

### 7.1 Material and Methods

#### 7.1.1 Spatial database:

The data collection involved downloading of Landsat 8 satellite image of 23rd Oct, 2016 (Image ID: LC81430432016297LGN00) from the USGS earth explorer. The boundary map of STR and other required data were collected from the database of Wildlife Institute of India. Table 11 shows different database and its sources

Sl.No.	Map/Data	Source	Primary layer	Output layer
1	Land use land cover (LULC)	Landsat 8	LULC	Forest cover map
2	Human settlement	Landsat 8 and database of WII	Village locations	Distance to nearest village
3	STR Boundary	Database of WII	STR Boundary	Boundary map with core and buffer
4	Elevation	Database of WII	Digital Elevation Model (DEM)	Elevation map
5	Slope	Database of WII	DEM	Slope map
6	Prey availability	Field data	Photo capture rate of prey animals	Surface map of prey availability
7	Location of Tiger	Field data	GPS points	Tiger location map

Table 11: Spatial and non-spatial data sources used and output maps generated

#### 7.1.1.1 Software used:

ERDAS Imagine 13: Used for digital image processing, while Arc GIS 9.3: Used to create vector and raster database.

### **7.1.1.2 Image classification and preparation of LULC map**

Classification of satellite image has a major role to create thematic map and spatial database for various objectives. For this study, unsupervised classification of satellite image was followed to obtain various land use and land cover classes. The resulting classified image is comprised of a mosaic of pixels, each of which belongs to a particular theme, and is essentially a thematic "map" of the original image.

After following the unsupervised classification, the image was classified into six classes, which are dense forest, open forest, scrub land, barren land, water bodies and agricultural land. All these classes are believed to affect the suitability of habitat of tiger in various ways.

### **7.1.1.3 Preparation of elevation and slope map from DEM:**

DEM is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum in the landscape (Meijerink *et al.* 1994). DEM of India was acquired from database of Wildlife Institute of India and was extracted by using the boundary polygon of the STR. It was further used to prepare slope and elevation map for STR since elevation and steepness of terrain can be important factors for habitat suitability of tiger.

### **7.1.1.4 Distance from nearest village:**

Human disturbance is considered to be one of the key factors which has a direct impact on the habitat of tiger. Hence, Euclidean distance from nearest village/settlement was calculated.

### **7.1.1.5 Prey availability:**

Availability of prey animals is a deterministic factor for the distribution of tiger (Schaller 1967, Karanth and Sunquist 1995, Karanth *et al.* 2004). Since STR comes under a sub-optimal habitat for tigers and its prey base, the detection probability of prey species on the line transect was also found to be low which gives a low density estimate. Although the animals were present there, but the density estimate got underestimated due to low detection probability. Hence, instead of using line transect data, capture rate of prey species from camera trap locations was used to create prey availability map. Taking each 2x2km<sup>2</sup> grid as a sampling unit, each value of capture rate for each species, was assigned to that particular location of camera trap placed inside the grid to generate an interpolation map for each prey species (Annexure-6). After that, layers prepared for each prey species, were combined together to get one single layer of prey availability.

All the above-mentioned spatial layers were used to generate habitat suitability maps by using rule based modeling.

### **7.1.1.6 Rule based modeling using Boolean Logic:**

Based on the field experience and locations of tiger obtained from both collared and non-collared individuals and existing literature regarding the habitat use of tiger, the output layers of aforementioned variables were reclassified by "0" or "1" to construct the rule based model. This

model works on the basis of Boolean logic, which relies on prior knowledge of the species and prescribes the area to be either suitable (1) or unsuitable (0) without any other middle level (Lenton *et al.* 2000). Unique numbers were assigned for each category in all the variables and then union analysis was performed to obtain final map of the potentially suitable areas for tiger in STR.

## 7.2 Results and Discussions

### 7.2.1 Thematic database generation:

- LULC map with six classes (dense forest, open forest, scrub land, agricultural land, barren land and water body) was prepared based on unsupervised classification. Amount of area (Table 12) was also calculated for each class.

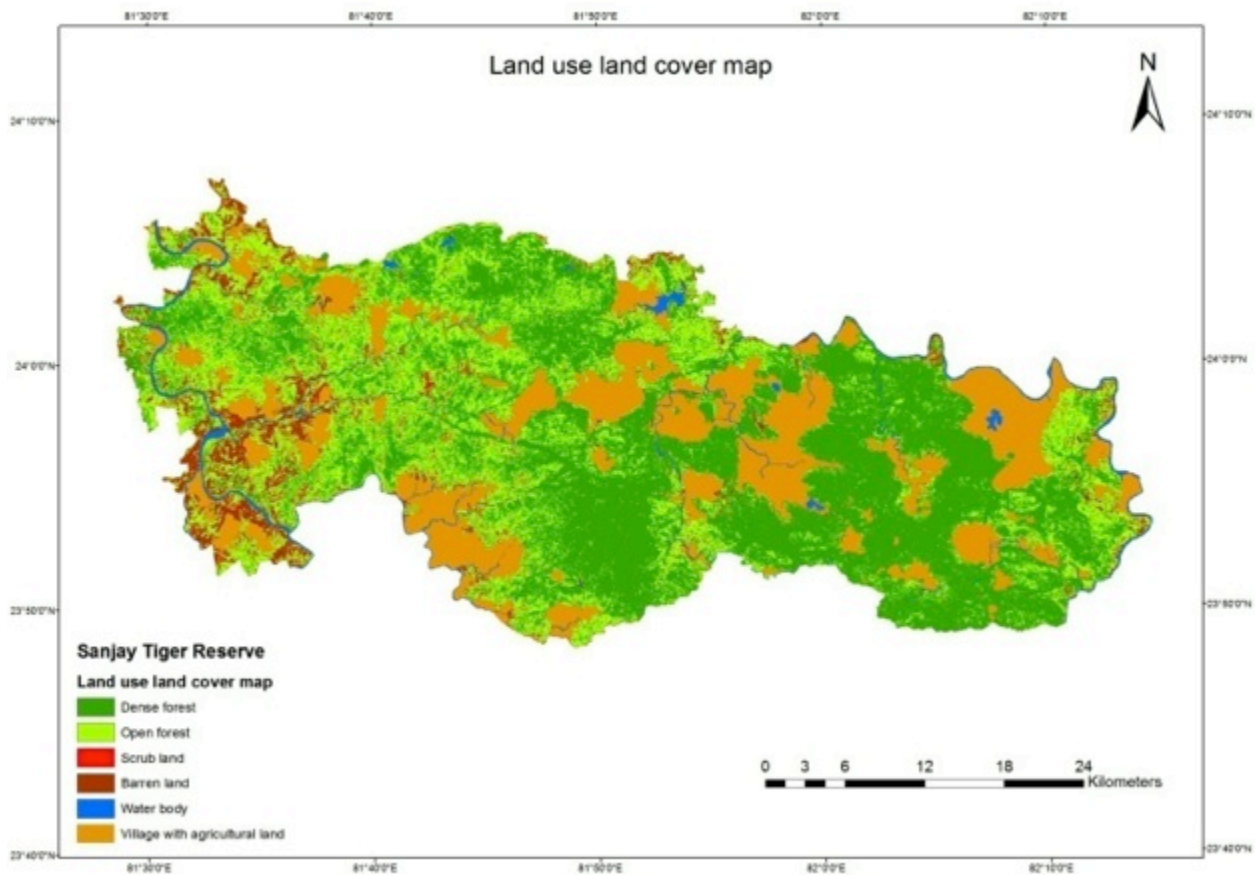


Figure 7: LULC map of STR

LULC classes	Area (in km <sup>2</sup> )
Dense forest	707.66
Open forest	447.19
Scrub land	66.76
Agricultural land	303.25
Barren land	41.80
Water body	37.95

Table 12: Area in km<sup>2</sup> of each LULC class

- Elevation map and slope map were generated from DEM of STR. Elevation ranges between 239 m and 771 m and the mean elevation is 510.29 m. Slope ranges from 0 degree to 60.46 degree.

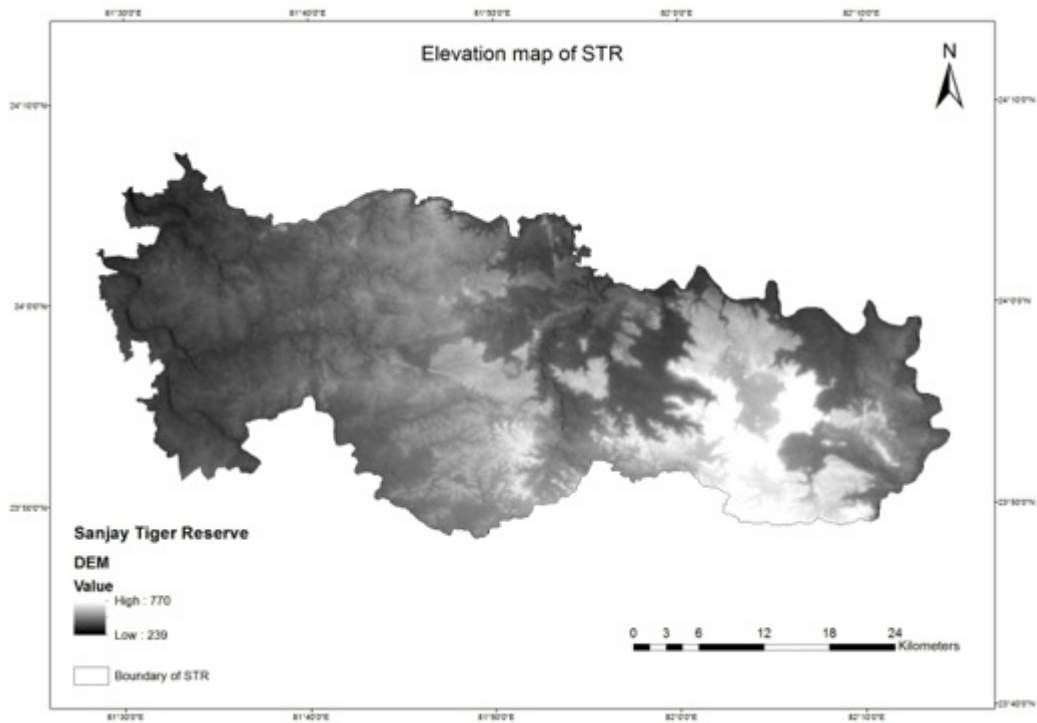


Figure 8: Elevation map of STR

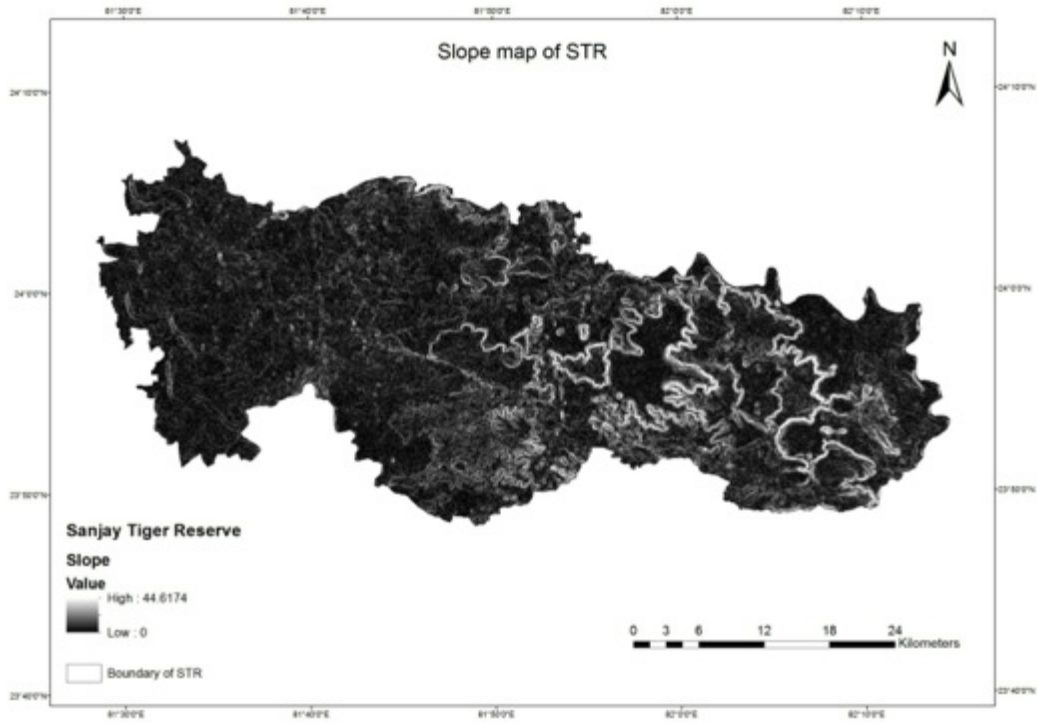


Figure 9: Slope map of STR

- Distance from the nearest village in terms of Euclidean distance was calculated. Euclidean distance from village showed a maximum distance of 6994.12 m.

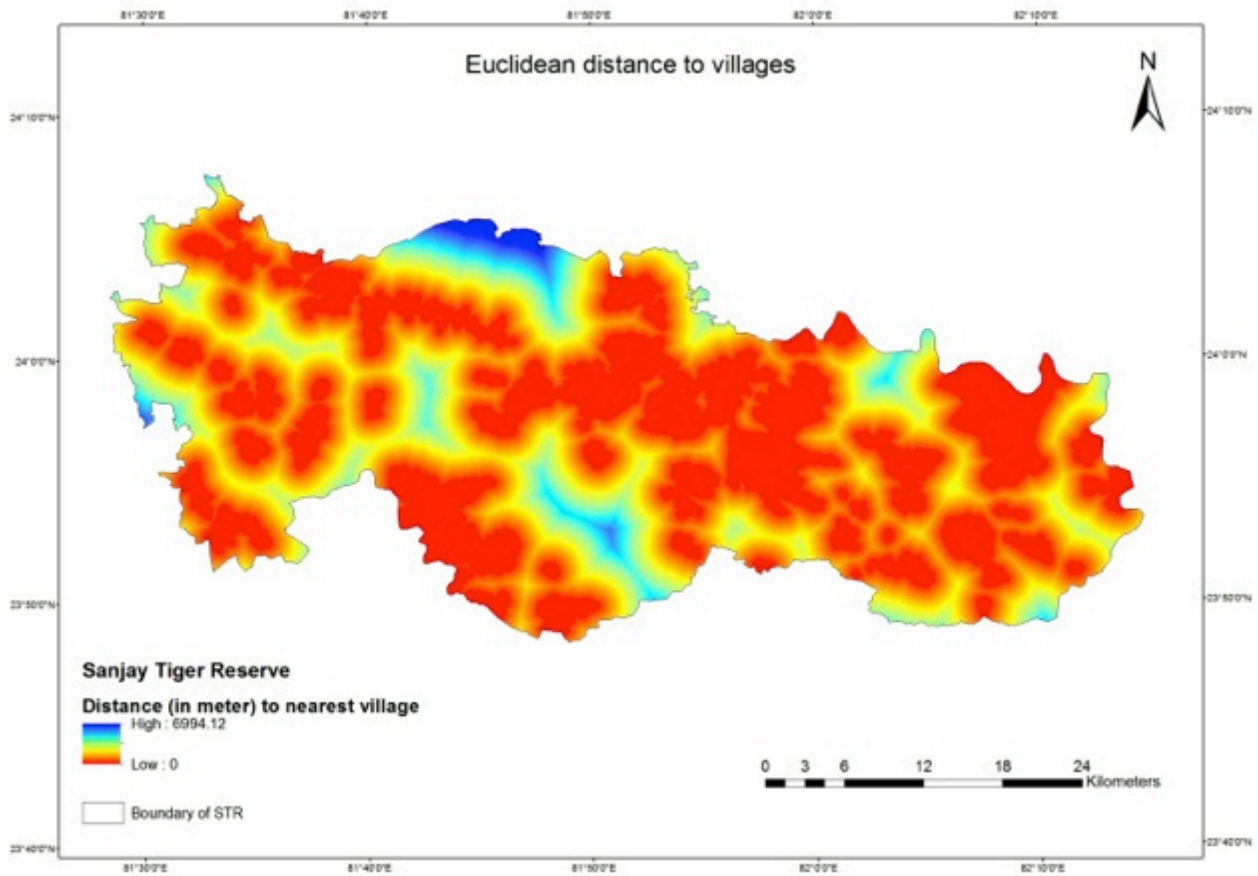


Figure 10: Map showing Euclidean distance from nearest village

- Distribution of prey species based on their photographic capture rate from camera trap locations was shown in the surface map generated by interpolation technique.

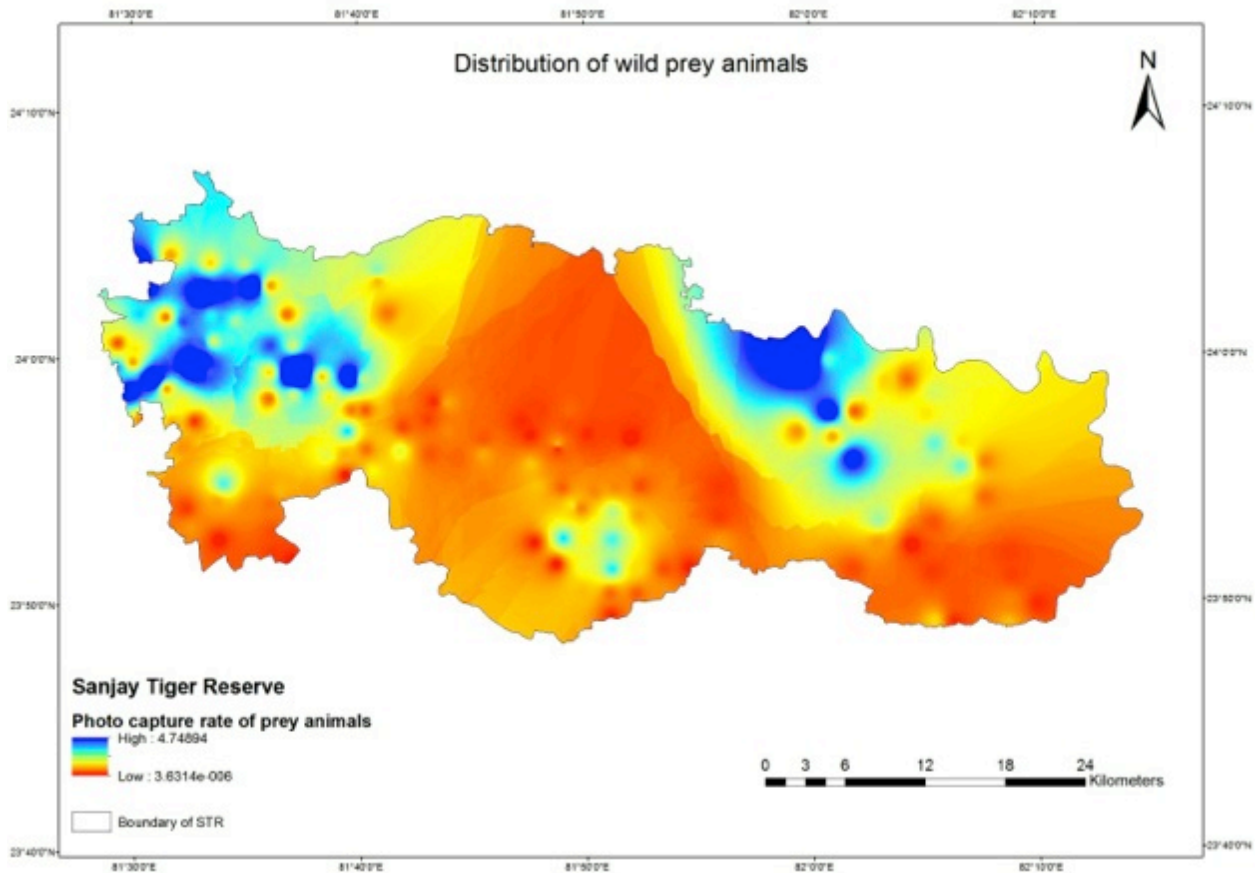


Figure 11: Distribution of prey animals based on photographic capture rate throughout STR

### 7.2.2 Habitat suitability of tiger

Based on the earlier studies and expert knowledge, the habitat suitability parameters are classified either to be suitable (1) or unsuitable (0).

Habitat suitability classes	Suitability parameters			
	LULC	Slope (degree)	Prey availability (photo capture rate)	Distance from village (m)
Suitable (1)	Dense forest, open forest	0-18	0.35-4.75	>1000
Unsuitable (0)	Scrubland, barren land, agricultural land	>18	<0.35	0-1000

Table 13: Suitability rating assigned for different parameters

Threshold map for each suitability parameter was generated, integrated together and rule based modeling was executed in GIS framework to evaluate the habitat suitability for tiger in STR. In order to get more precise result, two maps were generated-

1. Habitat suitability with wild prey availability and
2. Habitat suitability without wild prey availability

Both the maps of habitat suitability for tigers in STR were shown in Figure 12 and Figure 13. There is a marked difference of the suitable area for tigers observed between these two maps. Map which takes an account of prey availability, showed lesser amount of area (729.46 km<sup>2</sup>) suitable than that of the map which excludes prey availability (1017.37 km<sup>2</sup>). This result clearly indicates that prey availability and human disturbance play a major role by influencing the habitat suitability of tiger in STR. GPS locations (n=623) of tigers obtained from the radio-collared as well as non-collared individuals were plotted on the map (Figure 14) and it was found that tigers are using a mosaic of suitable and unsuitable areas. However, a larger proportion of the area (61.3%) comes under potentially suitable habitat if availability of prey is excluded. This result certainly has great conservation implication which says improvement of habitat quality and prey augmentation will ensure the revival of tiger population in STR. Being a fragmented habitat due to the presence of number of villages with vast areas of agricultural land inside the tiger reserve, relocation of villages will create more inviolate space to re-grow the population of tiger and its prey base in STR.

Accuracy testing for the output layers obtained from the habitat suitability modeling was done based on Kappa statistics, assuming that tigers currently use the suitable habitat only. A total of

600 GPS locations of tiger obtained from the field (2014-2017) were used to estimate the accuracy. Overall classification accuracy was found to be reasonably high (Table 14 and Table 15) for both the output layers. Class 1 and Class 2 were considered to be unsuitable and suitable habitat, respectively.

<b>Class name</b>	<b>Reference totals</b>	<b>Classified totals</b>	<b>Numbers correct</b>	<b>Producers accuracy</b>	<b>Users accuracy</b>	<b>Overall classification accuracy</b>	<b>Overall Kappa statistics</b>
Class 0 (blank)	4	5	4	81.88%	100%	82%	0.06
Class 1 (unsuitable)	0	107	0				
Class 2 (suitable)	596	488	488				

Table 14: Accuracy of classification for habitat suitability without prey availability

<b>Class name</b>	<b>Reference totals</b>	<b>Classified totals</b>	<b>Numbers correct</b>	<b>Producers accuracy</b>	<b>Users accuracy</b>	<b>Overall classification accuracy</b>	<b>Overall Kappa statistics</b>
Class 0 (blank)	5	5	5	79.66%	100%	79.83%	0.07
Class 1 (unsuitable)	0	121	0				
Class 2 (suitable)	595	474	474				

Table 15: Accuracy of classification for habitat suitability with prey availability

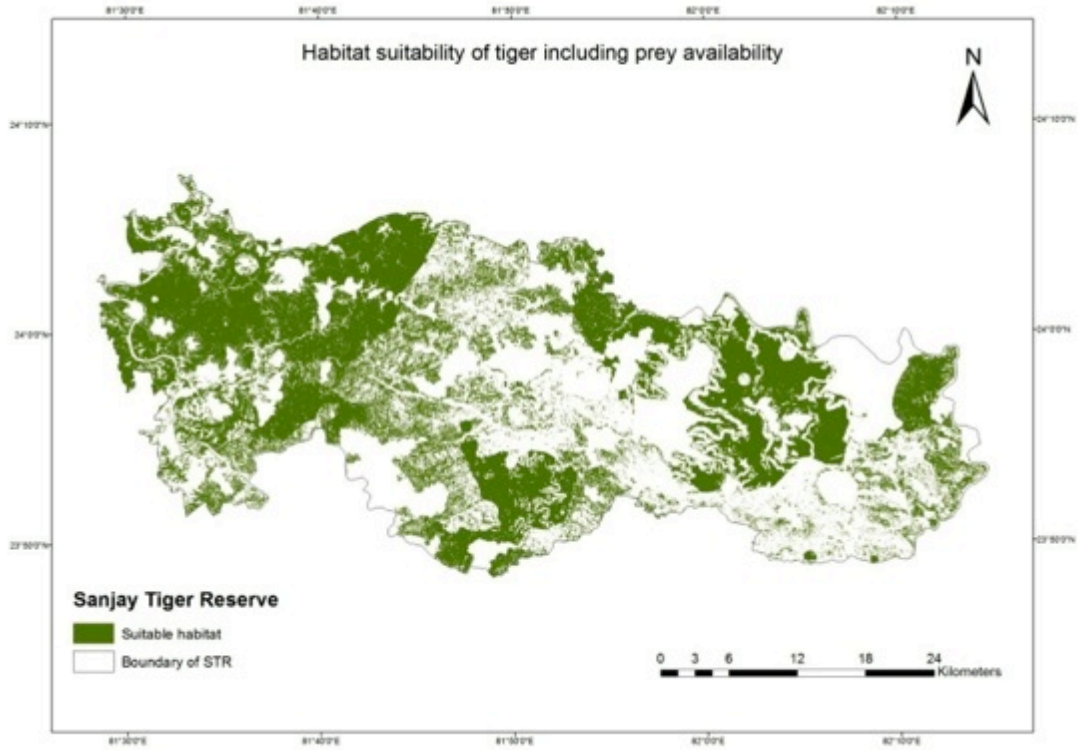


Figure 12: Habitat suitability map of tiger including prey availability

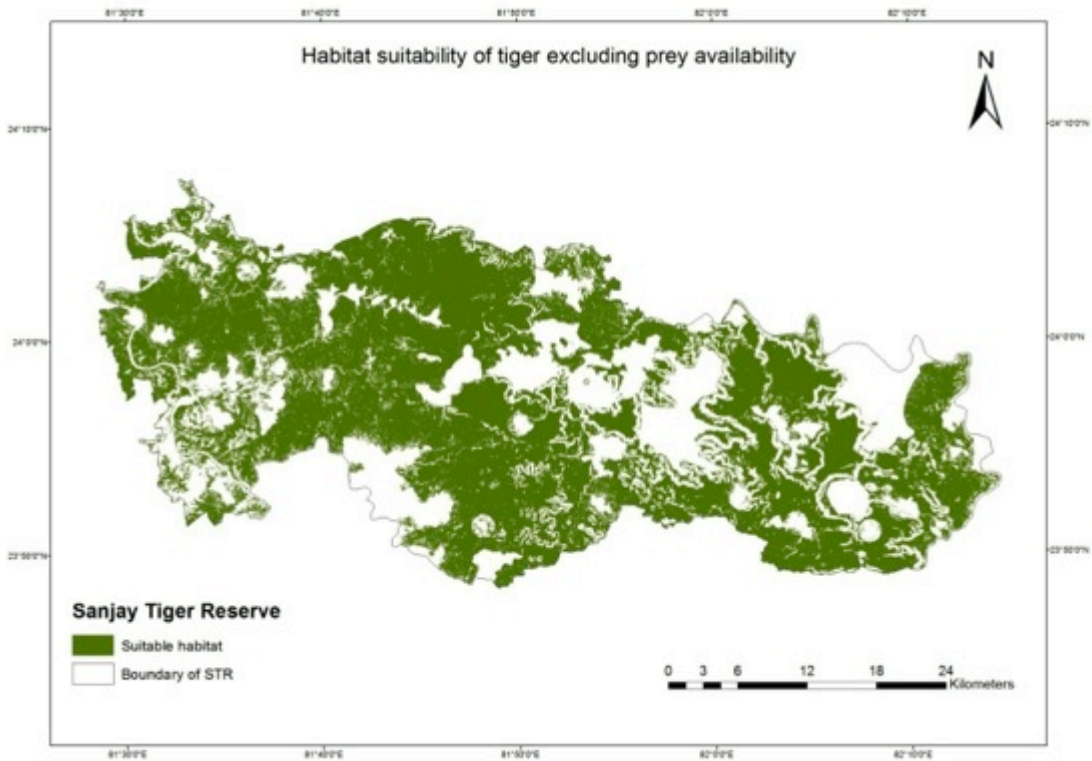


Figure 13: Habitat suitability map of tiger excluding prey availability

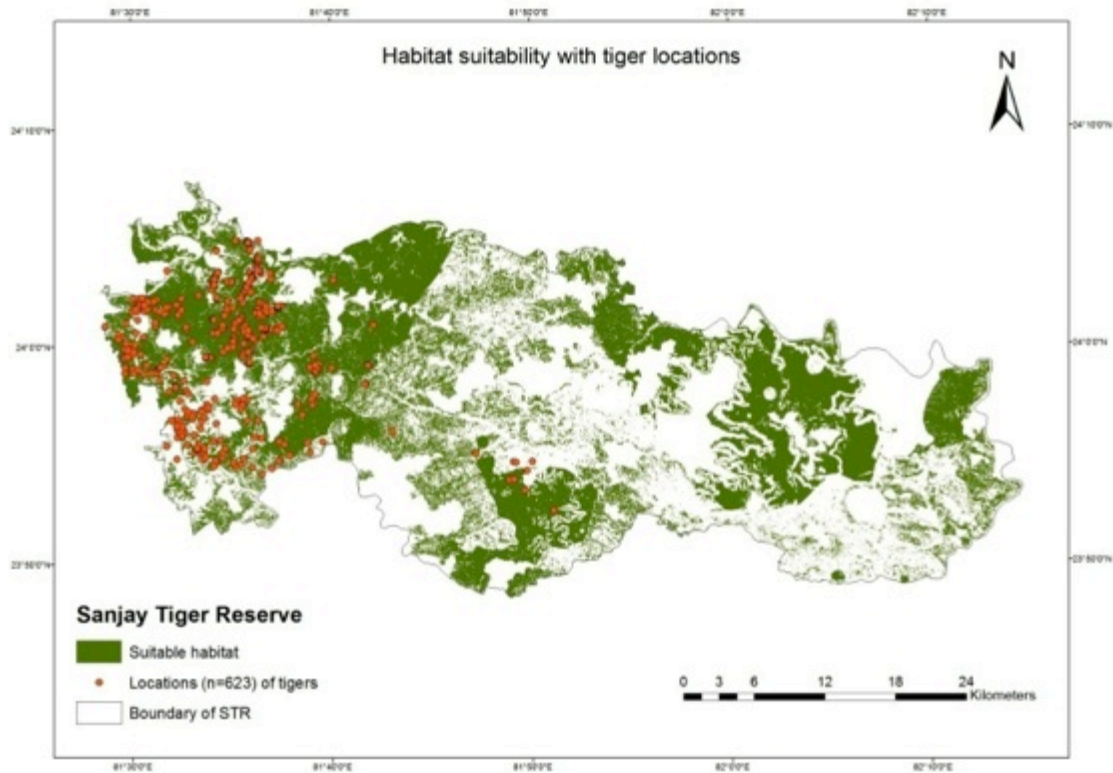


Figure 14: Habitat suitability map of tiger with tiger locations

Habitat quality assessment in terms of anthropogenic pressure and weed abundance was carried out based on the plot sampling done for vegetation quantification along the line transects. A total of 657 plots were sampled over a period of two years (2015-2016) consisting of four consecutive seasons, throughout the core area of STR. Overall as well as year wise changes of habitat quality were determined. For more detailed investigation, range wise habitat quality was also assessed. It was found that anthropogenic pressure in terms of cutting, lopping and grass cutting is decreasing (Annexure-7) over this time period. However, livestock dung/pellet and weed abundance were found to be broadly the same.

## 8. CARRYING CAPACITY AND POPULATION VIABILITY ANALYSIS

Given the availability of large prey (6.84 individuals/ km<sup>2</sup>), carrying capacity of tiger in STR was predicted by using the equation developed by Karanth *et al.* (2004)

$$T_j = AU_j^b \delta_j$$

where A = 0.247 (95% confidence interval 0.181 to 0.336)  $U_j$ = prey density/km<sup>2</sup>, b= 1 and  $\delta_j$ =1, derived from the relationship between tiger and prey densities, based on harvest rate by tiger (i.e.50 ungulates per year). Based on the above-mentioned equation, a carrying capacity of 11 tigers (Standard Error 6.81) was worked out for STR.

A population Viability Analysis was performed using VORTEX Program (Version 10.2.7.0; Lacy and Pollack, 2017) to understand the fate of the tigers in terms of population growth and survival probability in the 25 years' time scale.

Population parameters of tiger including life history data were taken from the literature; Smith and McDougal (1991), Bailey (1993), Mazak (1981), Sunquist & Sunquist (2002), Wilkinson & Oregon (2003), Karanth (1999).

### Life history data used in the model

Year 1	40%
Year 2	25%
Year 3	25%
Year 4	10%
Cub mortality (%)	50 (in both male and female)
Adult mortality (%)	10 (in both male and female)
Maximum breeding age	15
Start of breeding	4 (males) and 3 (females)
Sex ratio at birth	50%
Adult males in breeding pool	33%
Adult females in breeding pool	50%
Mean progeny per female	2.5 (1 SD)

In addition to the above mentioned population parameters, environment catastrophe (0.2 probability, once in 5 years), inbreeding depression (default value of lethal equivalents=6.29 and percent due to recessive lethal alleles=50) and harvesting in terms of poaching (1 per year) were also considered, in order to obtain the most robust population predictions. Two types of modeling were done based on one hypothetical scenario and the current scenario of the tiger population of STR. A total of nine scenarios were constructed under the two aforementioned broad scenarios and 100 iterations were performed on the population for each scenario to estimate the survival and extinction probability and mean population size.

**Hypothetical Scenario:** It considers six tigers (two adult males and four adult females) as a founder population.

**Scenario 1:** Model with only demography parameters and does not include catastrophe, inbreeding depression harvest and supplement

In 100 simulations of the population for 25 years, 53 went extinct and 47 survived, giving a probability of survival 0.47 (0.05 SE) and mean final population was 4.02 (0.41 SE). The mean time to first extinction to occur was 16.06 years (0.84 SE). Across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was 0.041 (0.006 SE). The final observed heterozygosity was 0.58 (0.04 SE). However, this scenario is an ideal one as the environmental stochasticity and other unforeseen losses are likely to happen.

**Scenario 2:** Model with demography and includes catastrophe and inbreeding

In 100 simulations of the population, 74 went extinct and 26 survived which yielded a probability of survival of 0.26 (0.04 SE). The mean final population size and mean time for first extinction were found to be 1.94 (0.29 SE) and 15.8 years (0.70 SE), respectively. Across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was 0.007 (0.006 SE). The final observed heterozygosity was 0.68 (0.06 SE). Since the extinction probability (0.74, 0.04 SE) is very high in this model, the population would not be viable.

**Scenario 3:** Model with demography and includes catastrophe, inbreeding and one poaching per year

In 100 simulations for 25 years, 100 went extinct and 0 survived which suggested that removal of individuals at a rate of one per year can easily wipe out the entire population. The mean time to extinction was 5.51 years (0.19 SE). Across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was -0.09 (0.02 SE). This result clearly indicates that poaching must not be tolerated; otherwise it will make all the efforts futile.

**Scenario 4:** Model with demography and include catastrophe, inbreeding, no poaching and supplement of 2 tiger every three year for three consecutive years, until year 12.

With strict control over poaching and simultaneous supplementation of at least two tigers (one male, equal or greater than 4 years and one female, equal or greater than 3 years) in every three years until year 12, predicted a relatively higher survival probability of 0.65 (0.05 SE) than rest of the scenarios constructed. The mean time to first extinction was 18.53 years (0.76 SE) and the mean final population was 4.79 (0.37 SE). During years of supplementation and across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was found to be 0.068 (0.006 SE). The final observed heterozygosity was 0.90 (0.01 SE). In this scenario, the population will reach its peak in 4th year (10.43) and will begin to decline from 11th year onwards. This suggests that

further supplementation may be required only when the prey base and hence the carrying capacity of tiger will be increased at the same time. Carrying capacity played a crucial role even after the supplementations for quite a long period which clearly indicates increasing the prey base is a must thing for the survival of tigers in STR. The translocated tigers should be from different populations to avoid inbreeding and maintain a good genetic vigor among the progeny.

**Current Scenario:** It considers the current population of STR, i.e., one adult male and two adult females and one sub-adult male.

**Scenario 1:** Model with only demography parameters and does not include catastrophe, inbreeding depression harvest and supplement

In 100 simulations of the population for 25 years, 72 went extinct and 28 survived, giving a probability of survival 0.28 (0.04 SE) and mean final population was 2.17 (0.35 SE). The mean time to first extinction to occur was 10.39 years (0.75 SE). Across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was 0.021 (0.008 SE). The final observed heterozygosity was 0.65 (0.05 SE). Although this is one ideal scenario, the probability of survival was found to be much less.

**Scenario 2:** Model with demography and includes catastrophe and inbreeding

In 100 simulations of the population, 88 went extinct and 12 survived which translated into a very less probability of survival of 0.12 (0.03 SE). The mean final population size and mean time for first extinction were found to be 0.75 (0.17 SE) and 12.52 years (0.71 SE), respectively. Across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was -0.005 (0.008 SE). The final observed heterozygosity was 0.84 (0.06 SE). This is a more realistic scenario but being a very high extinction probability, the population would not be viable at all without taking proper conservation measures.

**Scenario 3:** Model with demography and includes catastrophe, inbreeding and one poaching per year

In 100 simulations for 25 years, 100 went extinct and 0 survived which suggested that poaching of individuals at a rate of one per year can easily be the cause of extirpation of the entire population. The mean time to extinction was 2.72 years (0.12 SE). Across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was -0.13 (0.03 SE). Once again it was proved that poaching will be a major limiting factor for the population to be survived.

**Scenario 4:** Model with demography and include catastrophe, inbreeding, no poaching, given a carrying capacity of 22 tigers.

In 100 simulations of the population, 82 went extinct and 18 survived which yielded a very less probability of survival of 0.18 (0.04 SE). The mean final population size and mean time for first

extinction were found to be 1.57 (0.36 SE) and 12.06 years (0.75 SE), respectively. Across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was -0.008 (0.007 SE). This model suggested that prey augmentation and increasing of carrying capacity would not be necessarily adequate to establish a viable population unless a simultaneous supplementation process was performed.

**Scenario 5:** Model with demography and include catastrophe, inbreeding, no poaching and supplement of 2 tigers every three year for three consecutive years, until year 10, given a carrying capacity of 22 tigers

In situations where poaching does not occur and simultaneously, population is supplemented with at least 2 tigers (one male, equal or greater than 4 years and one female, equal or greater than 3 years) every three years for the initial period, until year 10, of the 100 simulations, only 13 went extinct and 87 survived which translated into a high survival probability of 0.87 (0.03 SE). The mean time to first extinction was 18.92 years (1.65 SE) and the mean final population was 10.67 (0.64 SE). During years of supplementation and across all years, prior to carrying capacity truncation, mean growth rate ( $r$ ) was found to be 0.049 (0.005 SE). The final observed heterozygosity was 0.88 (0.01 SE). In this scenario, the population will reach its peak in 8th year (17.03, 0.46 SE), and will begin to decline from 10th year onwards. This scenario suggested that with an improved protection, good prey-base and subsequent supplementation programme, the tiger population of STR is the most likely to survive. This scenario was found to be the most plausible one for the long term survival of tiger population in STR, given the prey-augmentation and hence an increased carrying capacity of tiger. Based on this model, all the strategies relevant to improve the prey-base, supplementation and protection would be considered well in advance.

### **Recommended Actions:**

After carefully analyzing the situations, it is recommended that prey-augmentation and subsequent supplementation of tigers are two major steps to secure the long term viability of tiger population in STR. Based on the two broad level scenarios (Hypothetical and Current scenario) and a subset of nine scenarios, it was found that the hypothetical population of six tigers would only be viable if supplementation programmes are carried out simultaneously, given a carrying capacity of 11 tigers. In current scenario, the response of the population towards increased carrying capacity and supplementation was found to be much logical. Hence doubling the current prey-base would invariably increase the carrying capacity of tiger. With subsequent supplementations and improved protection from poaching and other unnatural causes (poisoning etc.), will ensure the long-term survival of the population. It is also suggested that close monitoring of both the resident tigers as well as translocated tigers, be made after performing supplementation programmes.

## 9. CAPACITY BUILDING OF FOREST STAFF

As a part of this ongoing project, equipping the Forest Department staff with enough technical knowledge and resource is an essential part so that they can continue monitoring of tigers and assessment of its habitat even after the completion of the project. In order to achieve this goal, a number of training programmes throughout the tiger reserve, were organized by the Forest Department with the help of WII as a technical expertise. The programme was initiated at the ranges where movement of tiger is frequent followed by other ranges of core and buffer area of tiger reserve. From November 2015 to April 2017, ten such programmes (Table 16) were organized covering all the core and buffer ranges of STR. These capacity building programmes were attended by staff like chowkidars, Beat Guards, Deputy Rangers, Range Assistants and Range Officers. Sometimes the presence of Assistant Conservator of Forest and Field Director, STR has encouraged the ground level staff in various ways.

The things on which the staff were trained to develop and enhance their capability, were listed below-

1. Use of GPS, compass, range finder while doing field surveys
2. Systematic (grid based) deployment of camera traps
3. Training on the field data collection for animal abundance estimation from direct and indirect evidences (line transect and sign survey)
4. Techniques of monitoring tigers through tracking of radio collared and non-collared individuals with the help of tracking devices, camera traps, and indirect signs (pugmark, scat etc.)

Sl. No.	Date	Staff of the Range/Ranges involved	Topic discussed
1.	November, 2014	Dubari and Beohari	Deployment of camera traps
2.	March, 2015	Pondi and Bastua	Deployment of camera traps
3.	June, 2015	Mohan	Deployment of camera traps
4.	November, 2015	Mohan, Pondi, Bastua, Dubari and Beohari	Handling of equipments and deployment of camera traps
5.	February, 2016	Mohan, Pondi, Bastua, Dubari and Beohari	Line transect, sign survey and deployment of camera traps
6.	April, 2016	Mohan	Line transect, sign survey and handling of equipments
7.	December, 2016	Mohan and Pondi	Laying of line transect, sign survey and deployment of camera traps
8.	December, 2016	Bastua, Dubari and Beohari	Laying of line transect, sign survey and deployment of camera traps
9.	January, 2017	Mohan, Pondi, Bastua, Dubari and Beohari	Use of GPS
10.	April and May, 2017	Bhuimad, Tamsar and Madwas	Deployment of camera traps and use of GPS

Table 16: Details of capacity building programmes organized in STR during 2014 to2017

## **10. SYNTHESIS AND WAY FORWARD**

Evaluation of prey availability and habitat suitability of tigers in STR should be seen in the context of sub-optimal habitat. As discussed earlier, availability of prey is one of the key factors which govern the distribution of large carnivores. In STR, prey density was found to be low as a result of immense anthropogenic pressure and fragmented and poor habitat quality. Depletion of prey base causes low density of tigers and other co-predators to occur. In 2015, density estimate of wild ungulate was found to be extremely low ( $2.83 \pm 0.6$ ) which can be attributed to short sampling. However, prey density was observed to increase gradually as a probable result of prey augmentation in terms of translocation of chital from Bandhavgarh Tiger Reserve to STR. Subsequently, village relocation will accelerate the growth of the population of prey species. Hence, village relocation followed by prey augmentation will certainly increase the carrying capacity of tiger in STR. Once the carrying capacity increases, restocking/translocation of tigers from other tiger reserves can be initiated as per the management recommendations given in Chapter-7. Furthermore, intensive monitoring of radio-collared as well as non-collared tigers should be done in a regular basis.

In current situation, movement of tigers was found to be mostly restricted to the eastern most part (Beohari, Dubari and some part of Bastua) of the tiger reserve. However, this study clearly indicates that there are other areas (Mohan and Pondi Range) in STR which can be considered as potentially suitable for tiger but currently not being used. In the absence of tigers, leopard population is flourishing in those areas. Hence prey augmentation in these particular sites followed by relocation of adjacent villages will certainly increase the chance of being occupied those sites by tigers and also provide the suitable release site of tigers to be translocated. In addition to active population recovery efforts, long term monitoring of tigers, its prey and habitat condition will be required to undertake science-based management efforts.

## **11. ACTIVE RECOVERY AND MONITORING PLAN**

Although it is a tiger reserve, the tiger population status is precariously low in STR. Three adult male tigers and two adult tigresses were reported from the reserve and this included one male that was had been translocated from Panna Tiger Reserve (PTR). However, this translocated male died due to fight with other resident male, perhaps after mating with resident female and contributing to gene pool. Currently, the total population size is 11 individuals that include two adult-males, two adult-females (including one translocated semi-wild tigress from Bandhavgarh TR), four sub-adult males and three newborn cubs (one month old). However, the major issue is that the habitat and prey species populations require significant improvement/recovery in order to manage this as self-sustaining population. In the absence of a comprehensive habitat, prey and tiger population recovery strategy, it is unlikely to maintain the growth phase and it might lead to serious conflict situations, which will be counterproductive to tiger conservation efforts.

### **1. Goal and Objectives**

The overall goal of the project is to recover habitat, prey populations and tiger population by 2026. The following are the specific objectives;

1. To undertake habitat recovery and prey augmentation towards preparing and enabling suitable core area for tiger recovery including active reinforcement efforts (Action: STR& WII).
2. To ensure demographically, genetically and physically (health-wise) viable population of prey populations, tiger and its offspring, by undertaking population management such as translocation from other suitable sites (Action: STR& WII).
3. To devise and execute monitoring strategy providing security based monitoring of founder individuals and remote monitoring of selected animals involving radio telemetry and GPS-satellite/GSM tracking technology (Action: WII &STR).
4. To study prey-predator relationship and undertake population estimation and monitoring as per NTCA Phase IV monitoring protocol (Action: WII &STR).
5. To undertake conservation education program for local people and capacity building trainings for field staff towards social acceptability and technical skill development respectively for effective implementation of tiger recovery program (Action: STR& WII).

### **2. Institutional Framework and Core Team Constitution**

Tiger Recovery Program is a long-term investment and commitment, and involves multitude of scientific, administrative and political inputs. However, the program will be owned by the State Forest Department, with technical support from Wildlife Institute of India, National Tiger Conservation Authority and other stakeholders. If there is strong institutional mechanism in place, it is very likely that the project will achieve desired outcome. In line with IUCN and NTCA protocols, a management and technical team with the following members will be constituted to oversee and execute the recovery process;

1. Team Leader
2. Program Coordinator
3. Principal Investigator
4. Co-investigators
4. DIG/AIG, National Tiger Conservation Authority, New Delhi/Nagpur
5. Field Director, Bandhavgarh and Panna Tiger Reserve, Madhya Pradesh
6. Veterinary Officers, Bandhavgarh and Panna Tiger Reserve, Madhya Pradesh

### 3. Background and Feasibility Analyses

While the Tiger Recovery Program is a long-term strategy in terms of the planning, execution and success evaluation, it needs to be approached in a step-wise process. In order to understand the specific issues, carrying capacity of tiger and future projections, it is necessary to undertake Feasibility Study looking into habitat, prey and habitat integrity including spatial configuration, anthropogenic issues, opportunities and threats. This will essentially decide the future course of action in terms of specific focal areas and actions in a time-bound manner. The feasibility study will focus on the following activities;

- a) **Assessment of Carrying Capacity:** There is already some information regarding prey availability based on the on-going project. Given the availability of large prey (6.84 individuals/ km<sup>2</sup>), carrying capacity of tiger in STR was predicted by using the equation developed by Karanth *et al.* (2004)

$$T_j = AU_j^b \delta_j$$

where A = 0.247 (95% confidence interval 0.181 to 0.336)  $U_j$ = prey density/km<sup>2</sup>, b= 1 and  $\delta_j$ =1, derived from the relationship between tiger and prey densities, based on harvest rate by tiger (i.e.50 ungulates per year). Based on the above mentioned equation, a carrying capacity of 11 tigers (Standard Error 6.81) was worked out for STR. Carrying capacity of the STR would essentially determine the number of founders to be considered for translocation if need be and what are the preparations need to be done in a phases manner towards achieving the larger goal of establishing viable population in STR. It would also involve detailed mapping process looking into landuse and landcover characteristics in the context of habitat suitability for tigers, which has already been accomplished as a part of the ongoing project. Evaluation of connectivity and landscape permeability for tiger has also to be determined to naturally colonize the STR from other source areas such as Bandhavgarh Tiger Reserve.

- b) **Habitat Suitability and Evaluation of Release Site:** It is apparent that although STR is low-density tiger area, it has significant potential to hold significant tiger population due to habitat availability in the core and buffer area. Based on the findings of the ongoing project only 46.9% of the total area was found to be suitable, given the current status of

prey availability. If prey availability is excluded from the analysis, 61% of the total area was found to be suitable for tiger. This result clearly indicates STR can harbor significant tiger population, provided the prey base has been augmented. Given the connectivity and improved habitat condition, STR can become another important Tiger Reserve, supporting the national and global target of doubling the tiger population. Enhanced protection measures are already accorded to STR and processes are underway to free human occupied areas so that inviolate space could be created for tiger to breed and have sense of security, which are critical elements for population growth. SWOT analyses would be performed to define broad scale and micro-scale issues including staff strength and acceptability level of people for such program.

- c) ***Assessment of Founder Individuals:*** It is entirely possible that tiger population growth in STR would take place with existing tiger population and with few inflows from other areas including translocation and natural colonization may also be possible if existing corridors were strengthened. However, this may take prolonged period unless credible outcome has been achieved in short span of time. Therefore, it is always important to consider founder individuals which demographically, genetically and behaviorally suitable for tiger recovery program. Information generated based on spatio-temporal movement and occupancy of the tigers from other source areas, a list of suitable animals for translocation would be prepared in consultation with the Field Director of respective Tiger Reserves. This should become basis for selecting animals for translocation and for future reinforcement. However, the dossier of suitable release animals needs to be constantly updated and ready for considering as suitable founder animals. It may also be necessary to radio-collar and monitor selected few animals from the source areas in order to understand the behavior so that adequate response mechanism at release site can be established.
- d) ***Population Viability Analysis:*** Population Viability Analysis (PVA) was performed using VORTEX Software Program to understand the performance of founder individuals (naturally colonized as well as translocated) in terms of population growth and survival probability in the 25 years time scale which has been detailed in chapter-7. Two types of modeling were done based on one hypothetical scenario consisting of six founder individuals (two adult males and four adult females) and the current scenario of the tiger population (one adult male, two adult females and one sub-adult male) of STR. A total of nine scenarios were constructed under the two aforementioned broad scenarios and 100 iterations were performed on the population for each scenario to estimate the survival and extinction probability and mean population size. In order to provide a robust estimation of population survival or extinction prediction over 25 years time scale, the knowledge of life history trait of tiger would be taken into account as it provides the basis for PVA modeling and scenario analyses. In addition to the life history parameters, environment

catastrophe, inbreeding and possible poaching will also be considered in the PVA to obtain the most robust and realistic population predictions. After carefully analyzing all the scenarios, it is found that increasing the carrying capacity of tiger by prey-augmentation and subsequent supplementation of tigers are two major steps to secure the long term viability of tiger population in STR. The result suggests that the founder population of six tigers will only be viable (survival probability 0.65, standard error 0.05) if subsequent supplementation is carried out, whereas the current population with a higher carrying capacity and subsequent supplementation showed a much better survival probability (0.87, standard error 0.03). This would provide sound scientific basis for undertaking recovery program in the short as well as long-term after observing the response of the population towards an increased carrying capacity and supplementation programmes.

#### **4. Capture, Transport and Health Issues**

Standard protocol of immobilization and transportation has already been established for the reserve, following experiences from Panna Tiger Reserve, Madhya Pradesh and Sariska Tiger Reserve, Rajasthan. It is critical to involve full-time veterinarian in this program. The field team will have to be exposed to enough experience before the capture and such capacity building activity can easily be organized from other experienced places, both in India and abroad, where such capture and translocation are every day activity (e.g. South African Reserves). We also need to equip the field team with sophisticated capture and transport kits, and need to make provision for procuring these items in order to be professional in undertaking this important conservation activity. All the NTCA protocols with respect to reintroductions will have to be adhered to.

It is important to profile each animal in terms of health and behavior. Visual examination, scat samples and biological samples would be used to periodically to measure stress and reproductive hormones, endo/ecto parasites and genetic analysis. Provisions will have to make to procure equipments to measure these in the field without relying on external agencies heavily. The research team of WII would handle this activity and regular update would be done in the field itself. It may be worth profiling individual animals in terms of genetic and reproductive health, in order to effect specific administrative action on timely basis.

#### **5. Release Process**

In such program, the precautionary principle demands establishing soft-release facility for (a) enabling the animal to settle down after capture and transportation stress and (b) for monitoring health of the animal after having been chemically immobilized. These are some of the veterinary requirement. However, in the case of STR, both soft release and hard options have been exercised. Therefore, it would be useful to consider maintaining the holding/soft release facility for such purposes, but hard release can be considered as long as the animals are tagged/collared and proper monitoring strategy are in place. In this program, both these options would be considered for prey augmentation and translocation of founder individuals. It was also possible

to understand from the available experience in Panna that release site does not have any effect on movement and habitat choice of the released animals, and thus, there may be not the need for elaborate release site establishment. Such activity can be guided by the ease of operation without much stress to the capture animals and should have consideration for monitoring team, as it is critical to have round the clock monitoring during initial months.

## **6. Post Release Monitoring Protocol**

Post release monitoring is a key for success/failure of such recovery projects and there are enough evidences to back this claim. Therefore, as much as effort or resource invested for the reintroduction program, as much if not more to be allocated for monitoring activities. It is important that all the founder animals and certain dispersing animals are radio-collared with VHF/GPS/Satellite or GSM collars and this should become integral part of the project until the population has reached its carrying capacity or target level as set out by the carrying capacity analysis. The monitoring would involve two types of dedicated teams (1) Security-based Monitoring by the Field Staff using VHF tracking method and (2) Technical-oriented Monitoring by WII team using VHF as well as GPS/Satellite/GSM tracking method. While the former would be done round the clock during initial months until the animals establish home range before switching over to systematic monitoring, the latter would undertake systematic monitoring and would gather all the scientific information to guide the management action as required in the field based on the response of these animals.

As stated above, security based tracking would be undertaken for newly translocated animals until they establish and all the animals would be monitored everyday basis, but the information flow would be through a joint Field Coordinators (one from STR and WII) so that there is no communication gap and that information could be synthesis quickly for understanding the process and management interventions. The information would be synthesizes on fortnightly basis by the field team and a monthly reporting would be done by WII team on the movement and home range of the tracked animals. From the WII team's perspective, the entire activity would be structured and dedicated team would be deployed for different purposes such as (1) radio-tracking and monitoring of prey and tiger populations, (2) camera trapping and population estimation of tiger and co-predators, (3) line transect sampling for estimating prey/ungulate abundance across space and time and (4) genetic and reproductive health monitoring. Tiger Recovery Program is a long-term effort and therefore, these activities ought to be visualized in the same time scale, although it may be phases due to resource limitation. Success/failure of the program is linked to proper and effective protection of the released animals and round the clock monitoring and surveillance with co-ordination of WII team and park staff will ensure this. In addition to the monitoring involving radio-collar, regular monitoring involving camera traps should be deployed in order to understand the effect/benefit of tiger recovery in the area. If resource permits, advanced technology such as Wireless Sensor Network and Un-manned Aerial Vehicle may also be considered for tracking and surveillance purposes.

## **7. Habitat Recovery Activities and Monitoring Protocol**

Village relocation is key management inputs in order to enhance habitat availability. However, the quality of habitat being added through this effort would stem from the way the habitat being management, in addition to dealing with already degraded habitat areas due to excessive exploitation for livelihood activities including grazing. It is therefore proposed that a comprehensive habitat recovery and monitoring strategy would be executed. This entails relocation of villages in entirety, followed by habitat improvement activities that would involve (a) weed removal, (b) removal of un-palatable grass species, (c) planting of suitable grass species and (d) establishment of monitoring activities. There is already process in few of the Tiger Reserves in Madhya Pradesh and a similar model would be executed, along with monitoring of these areas based on Remote Sensing and GIS tools, and field based plots including enclosures/enclosures.

## **8. Short Term Success Indicators**

1. Approval of project concept and resource allocation, and endorsement from key stakeholders
2. Completion of feasibility analyses and development of protocol for habitat recovery and prey augmentation.
3. Establishment of coordination with source population sites and identification of potential candidate animals for translocation.
4. Successful tranquilization, radio collaring and revival of the targeted animal for reinforcement with minimal stress after taking morphological data and biological samples. Successful release of the targeted animal (either hard or soft release depending on the health condition of the animal).
5. Formation of joint tracking team (WII and STR) and coordination mechanism established including reporting arrangement and response strategies during crisis situation. Signing of MoU between STR and WII, and establishment of WII's Field Station for Long-term Research and Training in STR.
6. Assessing demographic characteristic such as sex ratio of the established populations by the end of 2020 and take appropriate decisions of further reinforcement of prey and tiger population by reintroducing more individuals if required.

## **9. Long term Success Indicators**

1. Successfully reaching carrying capacity/target population size, consolidating and safeguarding foundation population and its offspring with sign of population growth.
2. Establishing natural connectivity between STR and other source populations, and ensuring functional connectivity for tiger movement between these sub-populations.

3. Achieving the carrying capacity of tigers in STR (which will likely increase with more village relocations), and maintaining the population and genetic viability in the STR.
4. Securing the threat free environment and well-trained management team for safeguarding of the tigers, possibly supported by technological integration.
5. Understanding their population dynamics, prey-predator relationship and response to disturbance, with constant management inputs for regular and crisis management strategies.

## **10. People Participation and Livelihood Activities**

IUCN Reintroduction Specialist Group and NTCA Protocol lay emphasis on social acceptance for such conservation program, as it involves the species that carries flagship value, but also conflict risk for local dependent communities. In this case, tiger population recovery is likely to increase the interface issues with the human population in the landscape. While general conservation education may be required to share the project need and the outcome, it would be critical to engage the people in the landscape, especially in the notified buffer area. Specific package may be worked out and specific experts from WII and NGOs may be integrated in the project. This will integrate the interests/concerns of the local communities and will be helpful tiger recovery in the immediate and long-term.

## **11. Ecological Research and Long-term Monitoring**

*(a) Rationale:* Under the larger tiger recovery program, the sub-component will exclusively deal with ecological research and scientific monitoring. This is essential because not only it enables effective information gathering, technical support, documentation and for guiding the management interventions on regular basis and also in crisis situations. The research would focus on home range and movement pattern, predator co-occurrence variations, prey-predator relationship and disturbance factors. The huge efforts placed on the re-building exercise will generate much more knowledge than the movement and home range information, and clearly, it is one of the rare opportunities for understanding several facets of tiger conservation biology, testing traditional and modern methods including estimating low-density population, sensitivity of estimates to population recruitments, and tiger response to local and landscape variables. All these would be critical for developing tiger conservation plan in the long-term. While the information is obtained regularly by the monitoring team and mapped in GIS appropriately, the linkages with various factors need to be understood at the landscape scale. As a follow up, the proposed project in addition to monitoring the radio-collared individuals, would aim to understand the prey-predator relationship, landscape ecology of tiger, and population estimation protocol for tiger and associated species. In addition to the specific objectives mentioned in Section 2 of this project document, following objectives are visualized for scientific management of the tiger recovery program in particular and STR in general.

**(b) Specific Objectives:** The following are the specific objectives of the project;

1. To undertake post-release monitoring of prey and tiger populations looking into population growth, movement pattern, behavior, genetic structure and physiological profile.
2. To estimate population size of tiger, co-predator and prey species, and model the habitat correlates to understand the species-habitat relationship, and support the ongoing Phase IV monitoring activity.
3. To map landscape composition and configuration, and estimate patch properties, connectivity and landscape permeability within and across the landscape.
4. To quantify human-wildlife interface issues and ecological correlates linked to economics and system services.

**(c) Design and Methods:** Sampling design would involve hierarchical procedure, with mean home range size of the tiger to be largest cell size and within which habitat types and administrative units such as beat boundary and compartment boundary would be studied. During the feasibility analyses, intensive efforts would be made to quantify prey abundance, habitat quality, carnivore occupancy and abundance, socio-economic assessment of representative population and perception analyses of the people. All radio-collared prey species and tigers would be monitored by VHF tracking involving modified home-in method (occasionally by triangulation) and by GPS telemetry using satellite or GSM tracking process. Data collection would be carried out round the clock in the initial period until the tigers settled down in the area, and thereafter, a sampling strategy targeting data collection at regular interval would be developed. Based on the number of VHF receiver equipment and trained man power, data collection will be done at regular intervals, with specific days for triangulation and home-in, which will be done both round the clock, and at regular intervals (e.g. every three days). The locations would be plotted on GIS map, and estimates would be derived based on home range analysis in ArcGIS Software or in other relevant software.

Grid based sampling would be done for analyzing movement pattern and for estimating population status of predators and prey species. Camera trap would also be done simultaneously to understand the variation associated with low density population estimates of tiger and to estimate population sizes of co-predators on spatio-temporal scale, towards gaining insight on the responses shown by individual species with increasing tiger numbers and movement. The sensitivity of population estimate would also be understood, with variation in the number and movement of target species in the camera locations. Several thematic layers in GIS would be used to study habitat recovery and the landscape ecology of prey and tiger in the landscape, looking into patch size and configurations, surrounding matrix and permeability for animal movement, etc. The study would also target certain human-wildlife interface issues relevant for planning tiger conservation strategies for the Reserve in particular, and the tiger landscapes in

general, possibly for the entire state. Existing collaboration with other technical institutions will also be explored to integrate sophisticated technology for research and management purposes.

**(d) *Expected Outcome:*** The project would provide a detailed analysis of the behavior and movement pattern of the tigers in STR and surrounding landscape, and would identify the correlates of positive and negative sensitive areas. Home range estimates and territoriality would be mapped. Identification of local and landscape variables that determine tiger distribution would be done, including the key disturbance elements. Occupancy and abundance estimates for prey and predator, and co-occurrence pattern would be estimated on spatio-temporal scales, and would support the Phase IV activity in terms of capacity building and monitoring. Socio-economic profile of people in and around the area, and issues related to livestock population and use of the area would be provided. The knowledge generated at the landscape scale would offer basis for management of the growing tiger populations and to deal with human-carnivore conflict issues in STR and also in the entire region. Integration of technology would open up new avenue for the wildlife management in STR and also in the rest of the state.

**(e) *Review Process:*** The progress of the work, success indicators and other relevant issues would be reviewed periodically, (a) with quarterly report every three months, (b) a high level review either (coinciding with Annual Research Seminar of WII) or end of financial year after completing annual report, and (c) every three months at the field level between Field Director and Principal Investigator of the Project. All concerned would participate and provide inputs in the annual review process. This will be strictly adhered to. Meanwhile, if there is any activity or strategy that is found wanting, it will be addressed on immediate basis. Revision of decision, rescheduling etc., will be undertaken as and when necessary based on the reviews.

**(f) *Technical Reports and Publications:*** Annual Technical Report shall be produced by WII, with equal sharing of credit and any publication that may come of the project would be shared equally, with authorship based on inputs/contributions. A mutually agreeable MoU shall also be signed between STR (Field Director) and WII (Principal Investigator).

## **12. Budgetary Requirement and Commitment**

Tiger recovery program is a long-term endeavor, and there is definitive requirement to visualize and make available required resources and commitments of all stakeholders are required. Without such long-term vision and strategy, recovery efforts would not yield desired results and there are ample examples across the country and in other parts of the world, where success of conservation programs have relied on institutional mechanism, long-term commitment of resources, periodic review process and course correction strategies. It is expected that the Madhya Pradesh Tiger Foundation would fund the project or any other resource such as CAMPA that may be sourced locally.

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**ANNEXURE-1**  
**Photographic ID of Tigers (2014-2015)**



T-001 (Left flank)



T-001 (Right flank)



T-002 (Left flank)



T-002 (Right flank)



T-003 (Left flank)



T-003 (Right flank)



T-004 (Left flank)



T-004 (Right flank)



T-005 (Left flank)



T-005 (Right flank)

**ANNEXURE-2**  
**Photographic ID of Tigers (2015-2016)**



T-001 (Left flank)



T-001 (Right flank)



T-005 (Left flank)



T-005 (Right flank)



T-006 (Left flank)



T-006 (Right flank)



T-007 (Left flank)



T-007 (Right flank)



T-008 (Left flank)



T-008 (Right flank)



T-009 (Left flank)



T-009 (Right flank)



T-010 (Left flank)



T-010 (Right flank)



T-011 (Right flank)



T-012 (Left flank)



T-012 (Right flank)

## ANNEXURE-3

### Sample pictures of other animals captured in camera traps



Leopard (*Panthera pardus*)



Sloth bear (*Melursus ursinus*)



Hyena (*Hyaena hyaena*)



Indian Wolf (*Canis lupus pallipes*)



Golden jackal (*Canis aureus*)



Indian fox (*Vulpes bengalensis*)



Jungle cat (*Felis chaus*)



Palm civet (*Paradoxurus hermaphrodites*)



Small Indian civet (*Viverricula indica*)



Honey badger (*Mellivora capensis*)



Chital (*Axis axis*)



Sambar (*Rusa unicolor*)



Barking deer (*Muntiacus muntjac*)



Wild pig (*Sus scrofa*)



Nilgai (*Boselaphus tragocamelus*)



Chinkara (*Gazella bennettii*)



Four horned antelope (*Tetracerus quadricornis*)



Indian porcupine (*Hystrix indica*)



Black naped hare (*Lepus nigricollis*)



Grey langur (*Semnopithecus entellus*)



Rhesus macaque (*Macaca mulatta*)



Indian peafowl (*Pavo cristatus*)

## ANNEXURE-4

### Photographs of capacity building programme



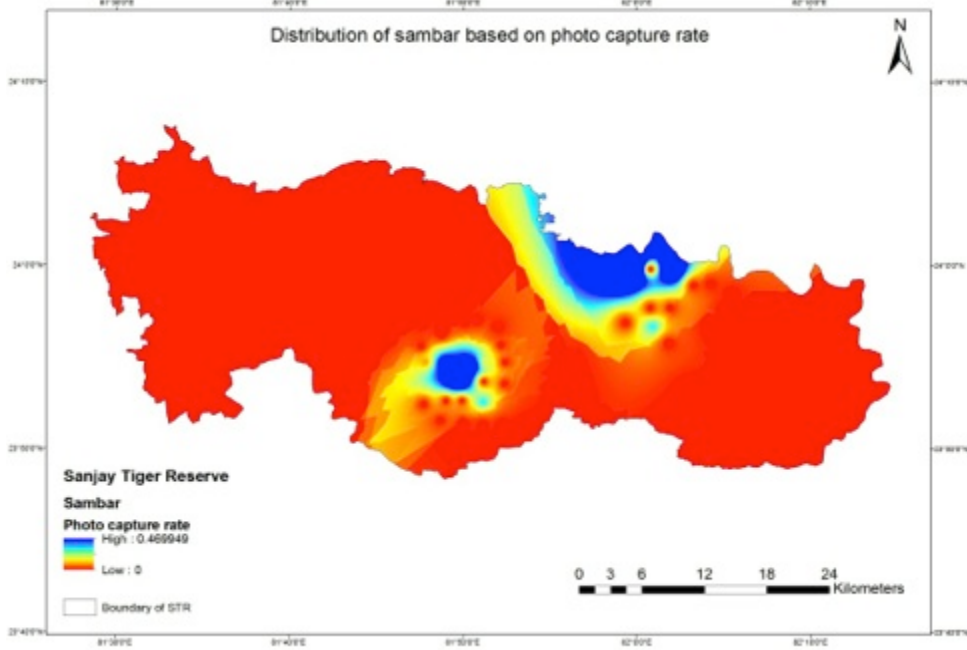
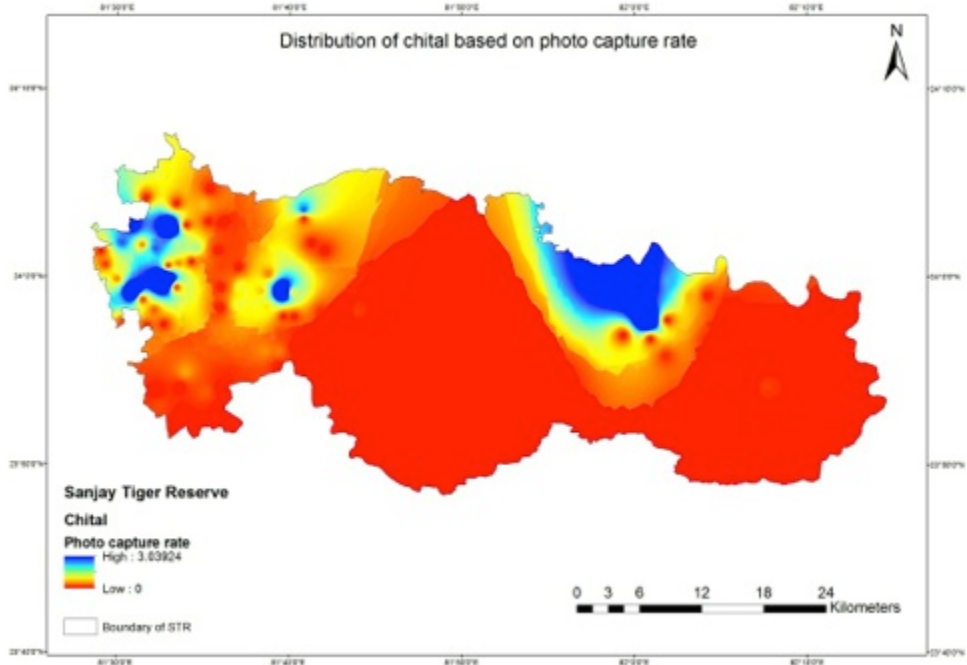
## ANNEXURE-5

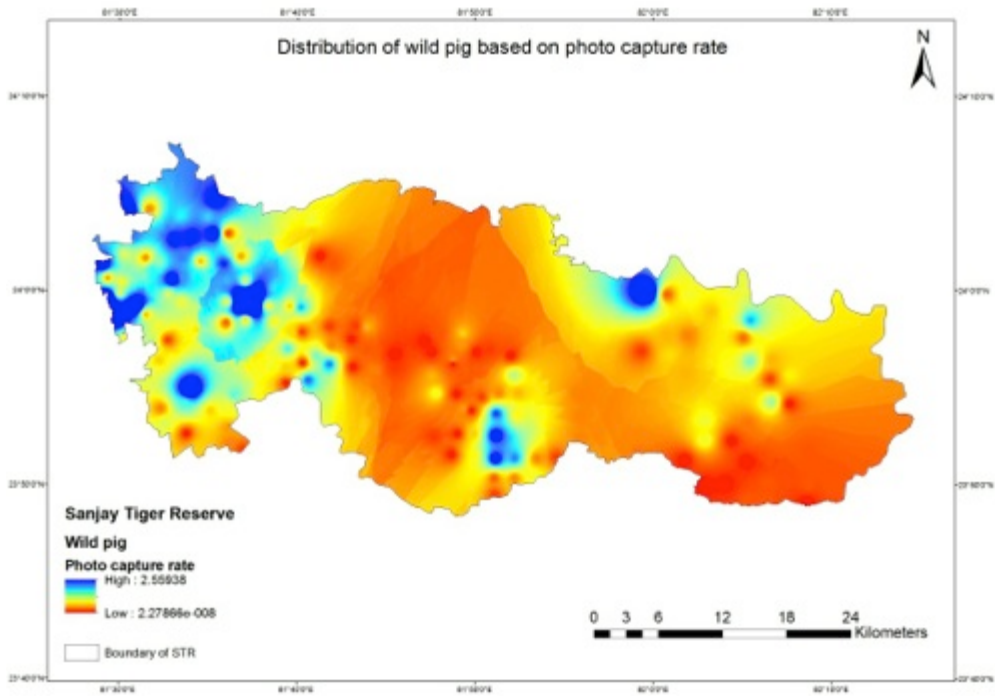
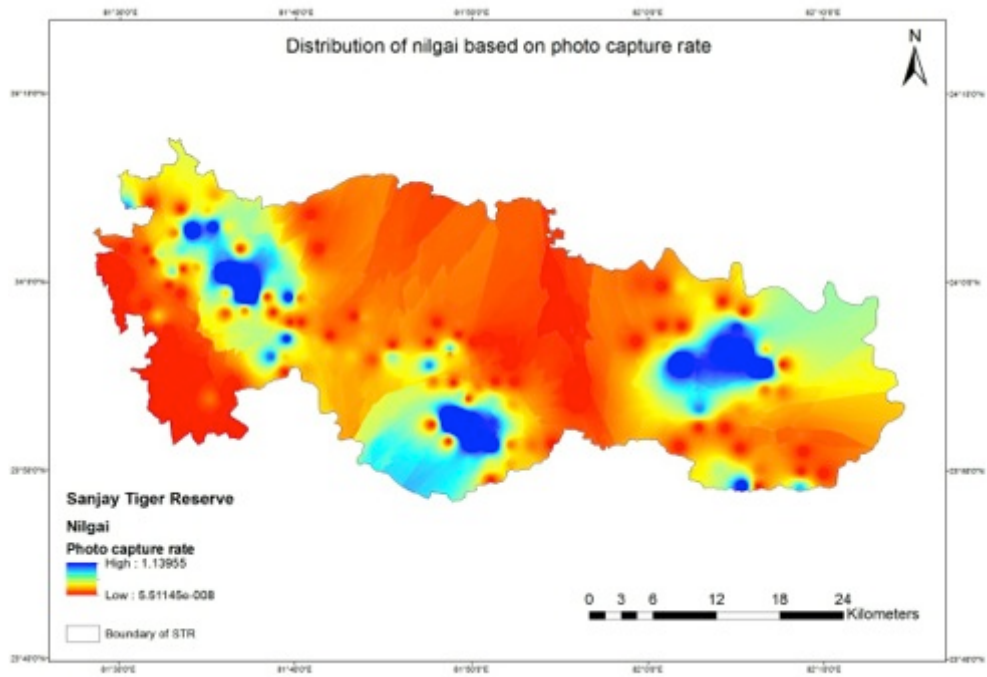
### Photographs during radio-collaring of tigers

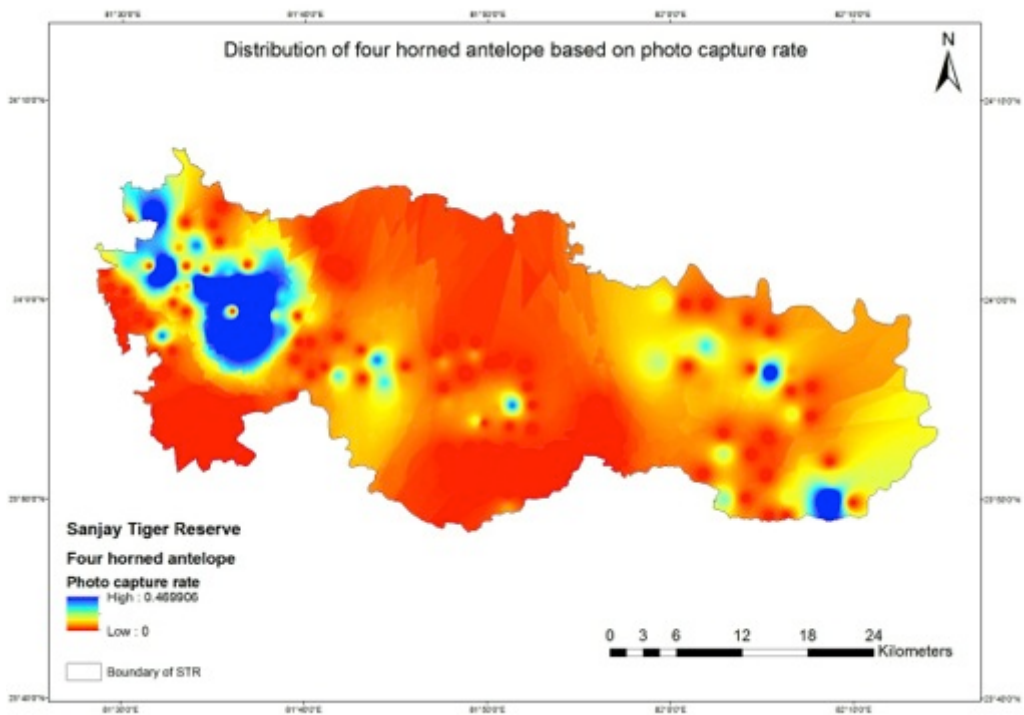
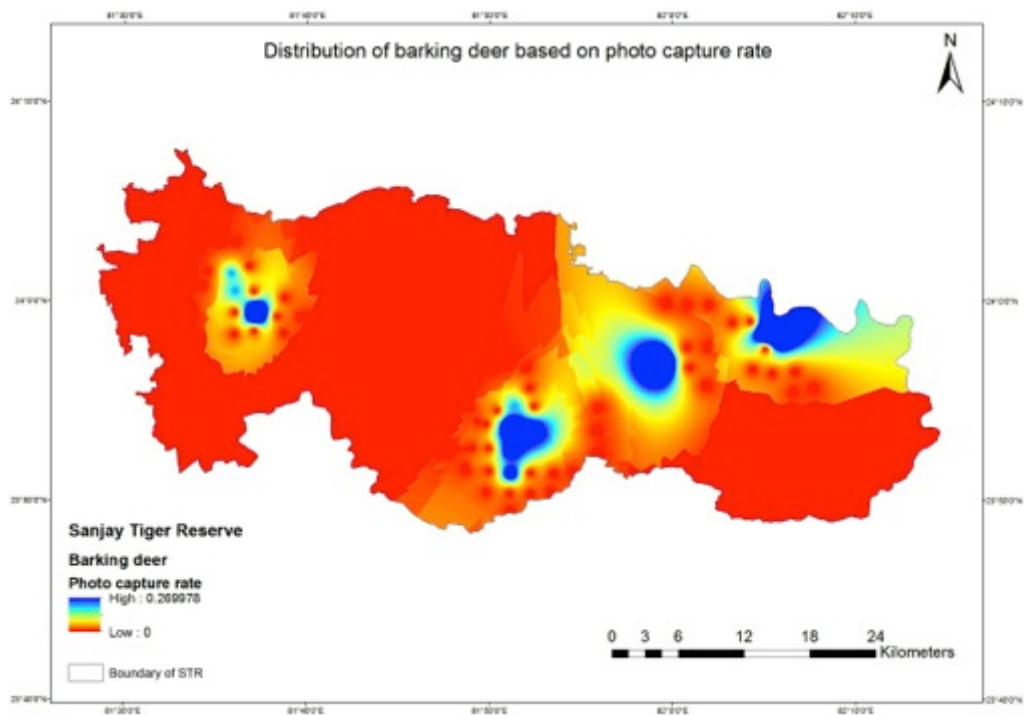


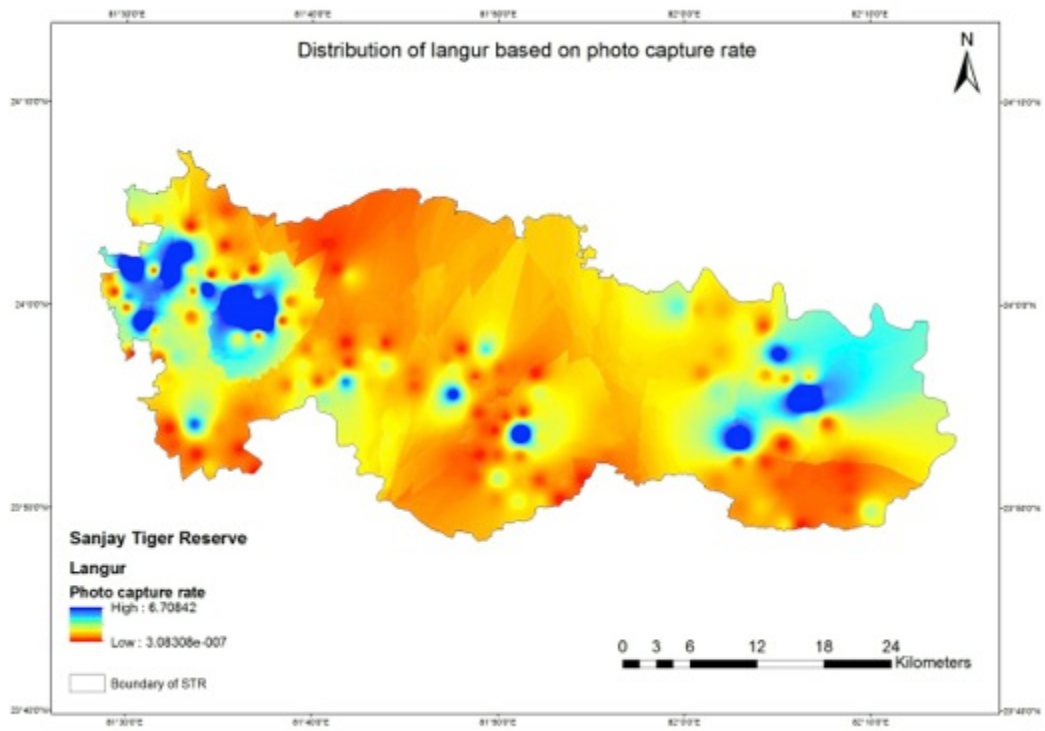
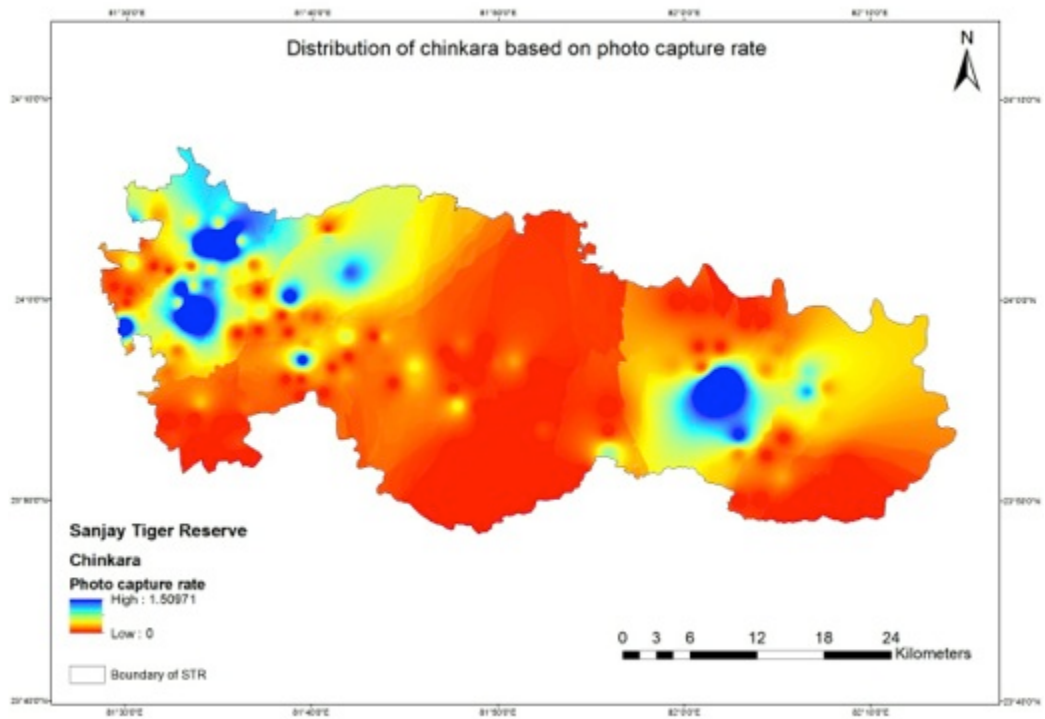
# ANNEXURE-6

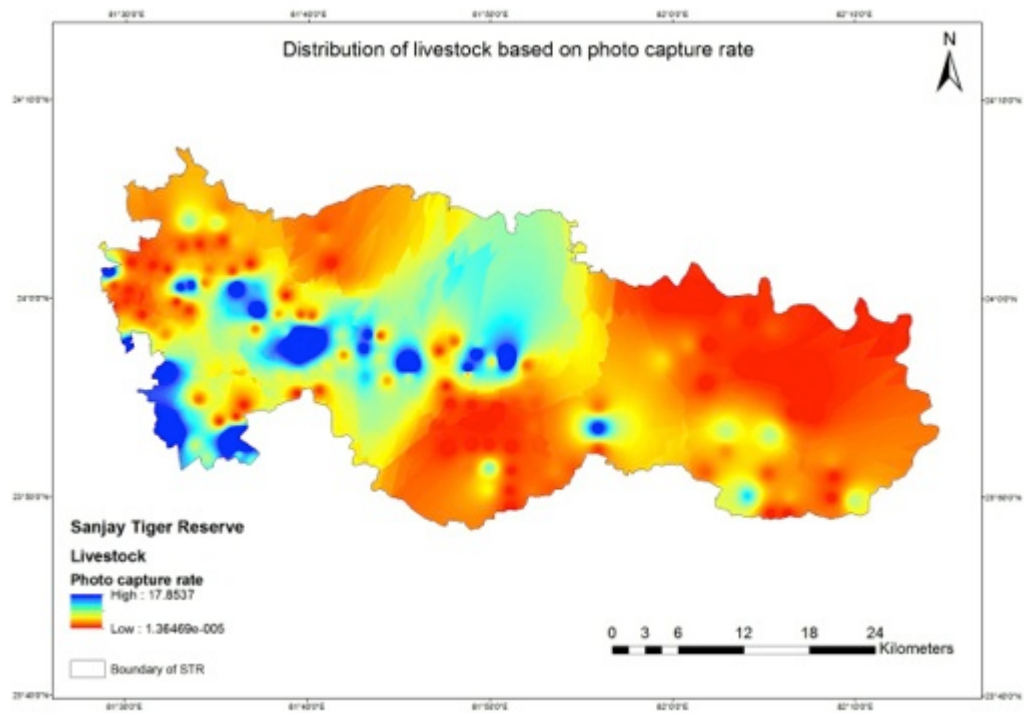
## Distribution maps of prey species based on photographic capture rate











## ANNEXURE-7

### Change in habitat quality in terms of anthropogenic pressure and weed abundance

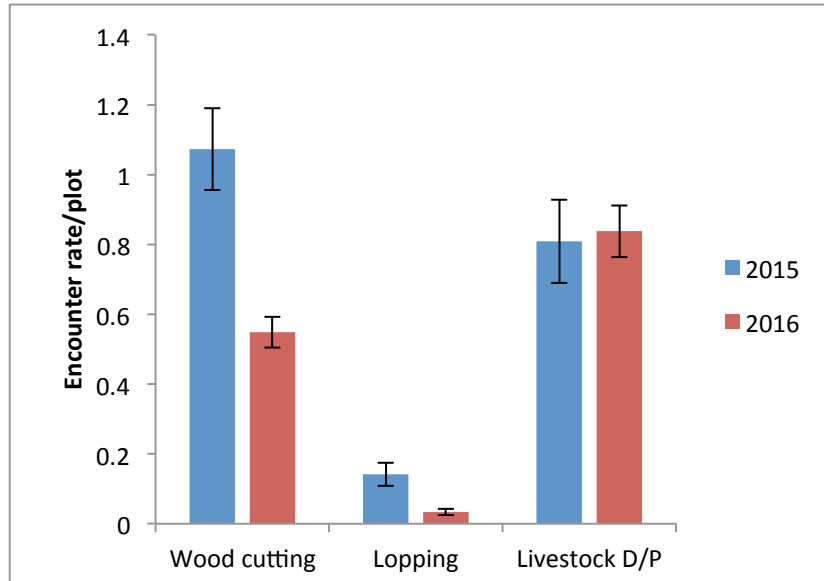


Figure 1: Change in anthropogenic pressure from 2015 to 2016

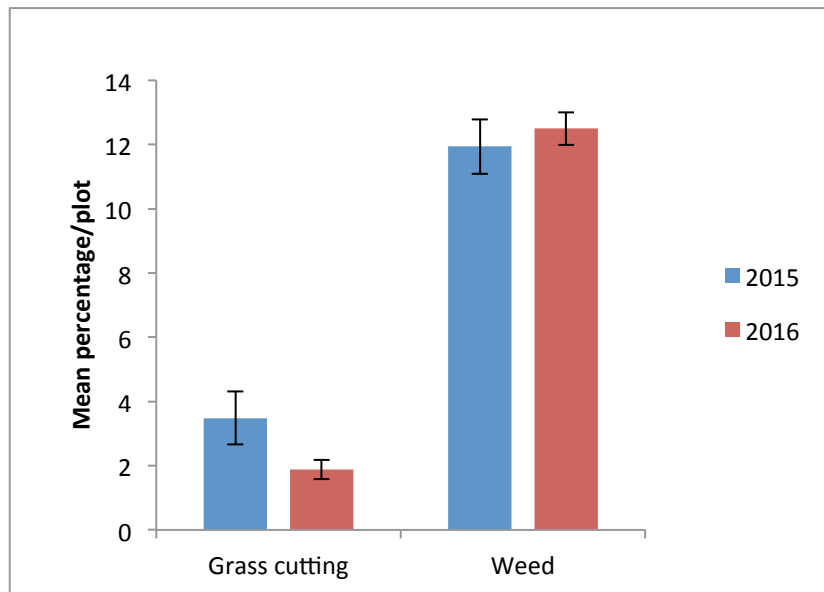


Figure 2: Change in grass cutting and weed abundance from 2015 to 2016

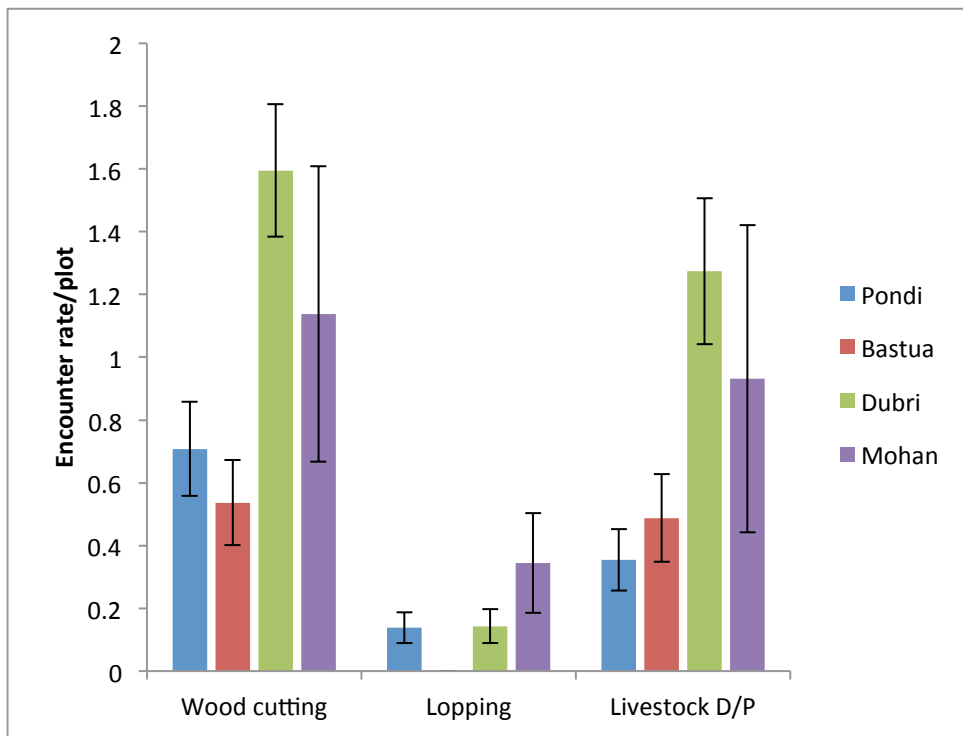


Figure 3: Range wise changes in anthropogenic pressure in 2015

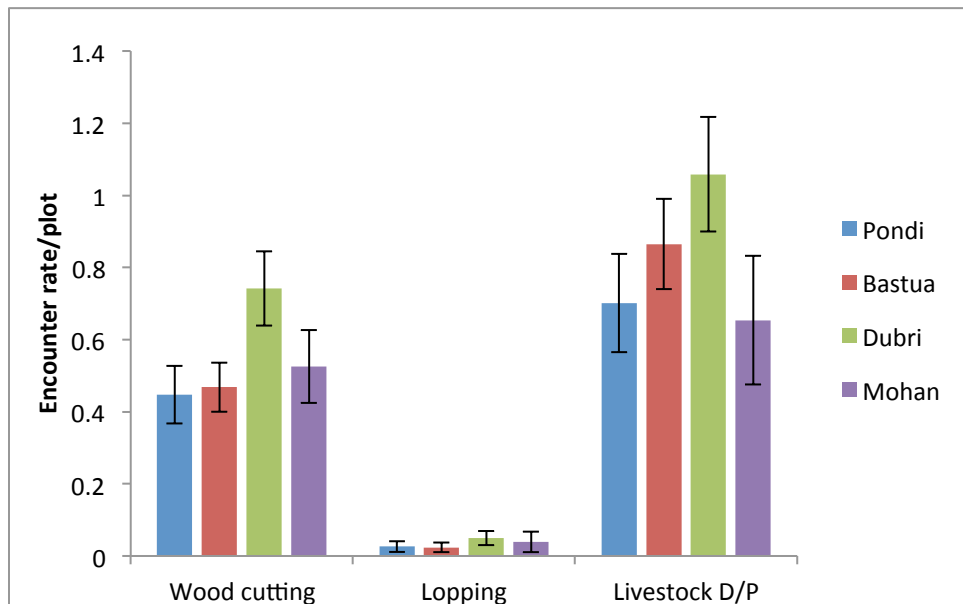


Figure 4: Range wise changes in anthropogenic pressure in 2016

	Encounter rate $\pm$ SE
<b>Wood cutting</b>	0.72 $\pm$ 0
<b>Lopping</b>	0.065 $\pm$ 0
<b>Livestock Dung/Pellet</b>	0.82 $\pm$ 0.03
<b>Grass cutting (%)</b>	2.41 $\pm$ 0.09
<b>Weed (%)</b>	12.31 $\pm$ 0.48

Table 1: Overall anthropogenic pressure (2015 and 2016)

	Encounter rate $\pm$ SE 2015	Encounter rate $\pm$ SE 2016
<b>Wood cutting</b>	1.07 $\pm$ 0.12	0.55 $\pm$ 0.04
<b>Lopping</b>	0.14 $\pm$ 0.03	0.03 $\pm$ 0.01
<b>Livestock Dung/Pellet</b>	0.81 $\pm$ 0.12	0.84 $\pm$ 0.07
<b>Grass cutting (%)</b>	3.48 $\pm$ 0.82	1.88 $\pm$ 0.30
<b>Weed (%)</b>	11.94 $\pm$ 0.85	12.50 $\pm$ 0.51

Table 2: Year wise (2015-2016) anthropogenic pressure

Encounter rate $\pm$ SE								
	Pondi		Bastua		Dubri		Mohan	
	2015	2016	2015	2016	2015	2016	2015	2016
<b>Wood cutting</b>	0.71 $\pm$ 0.15	0.45 $\pm$ 0.08	0.54 $\pm$ 0.14	0.47 $\pm$ 0.07	1.60 $\pm$ 0.21	0.74 $\pm$ 0.10	1.14 $\pm$ 0.47	0.53 $\pm$ 0.10
<b>Lopping</b>	0.14 $\pm$ 0.05	0.03 $\pm$ 0.02	0	0.02 $\pm$ 0.01	0.14 $\pm$ 0.05	0.05 $\pm$ 0.02	0.34 $\pm$ 0.16	0.04 $\pm$ 0.03
<b>Livestock Dung/Pellet</b>	0.35 $\pm$ 0.10	0.70 $\pm$ 0.14	0.49 $\pm$ 0.14	0.87 $\pm$ 0.13	1.27 $\pm$ 0.23	1.06 $\pm$ 0.16	0.93 $\pm$ 0.49	0.65 $\pm$ 0.18
<b>Grass cutting (%)</b>	0.15 $\pm$ 0.16	0.04 $\pm$ 0.04	8.66 $\pm$ 2.64	2.77 $\pm$ 0.66	4.38 $\pm$ 1.61	3.92 $\pm$ 0.80	1.03 $\pm$ 0.76	0
<b>Weed (%)</b>	17.43 $\pm$ 1.75	17.47 $\pm$ 1.39	11.83 $\pm$ 1.07	10.44 $\pm$ 0.56	7.85 $\pm$ 1.41	9.28 $\pm$ 0.81	11.62 $\pm$ 2.00	13.49 $\pm$ 0.91

Table 3: Range wise anthropogenic pressure in 2015 and 2016