



**COMPARATIVE ANALYSIS OF ABUNDANCE ESTIMATION  
METHODS FOR UNGULATES, ALONG WITH THEIR  
SPATIO-TEMPORAL INTERACTION AND HABITAT USE IN  
PAKKE TIGER RESERVE, ARUNACHAL PRADESH**

**Thesis Submitted by  
TARUN SINGH**

**For the award of the Degree of  
MASTERS IN WILDLIFE SCIENCE**

**Under the Guidance of  
Dr. Vishnupriya Kolipakam  
Prof. Qamar Qureshi  
Dr. S. Sathyakumar**



**भारतीय वन्यजीव संस्थान  
Wildlife Institute of India**

**Saurashtra University  
Rajkot - 360005 (Gujarat)**

**July, 2021**



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Wildlife Institute of India

## DECLARATION

I, **Tarun Singh**, hereby declare that the research work entitled “**Comparative analysis of abundance estimation methods for ungulates, along with their Spatio-temporal interaction and habitat use in Pakke Tiger Reserve, Arunachal Pradesh**”; carried out in partial fulfillment of M.Sc. (Wildlife Science) degree of Saurashtra University, Rajkot is an original piece of research work. This research work was carried out under the supervision of Dr. Vishnupriya Kolipakam, Prof. Qamar Qureshi, and Dr. S. Sathyakumar at the Wildlife Institute of India from January 2021 to June 2021. I hereby declare that this work has not been submitted for any other degree of any university.

(Tarun Singh)  
XVII M.Sc. Wildlife Science

Date: 6<sup>th</sup> August 2021  
Place: Dehradun

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## CERTIFICATE

This is to certify that Mr. Tarun Singh has carried out original research titled “Comparative analysis of abundance estimation methods for ungulates, along with their Spatio-temporal interaction and habitat use in Pakke Tiger Reserve, Arunachal Pradesh” in partial fulfillment of Master’s Degree in Wildlife Science from Saurashtra University, Rajkot. This study was carried out under our supervision from January 2021-June 2021. We hereby certify that this work has not been submitted for any other degree to any other university.

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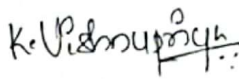
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## Glossary of Abbreviations

Pakke Tiger Reserve	<b>PTR</b>
Camera Trap Distance Sampling	<b>CTDS</b>
Random Encounter Model	<b>REM</b>
Relative Abundance Index	<b>RAI</b>
Spatially Explicit Capture-Recapture	<b>SECR</b>
Standard Error	<b>SE</b>
Confidence Interval	<b>CI</b>
Field Of View	<b>FOV</b>

## Summary

Abundance estimation and habitat utilization of species are critical for the conservation of any species. The forests of North-Eastern India are challenging due to the low abundance of ungulates, dense undergrowth, and logistic feasibility. In this study, we attempt to use camera trap-based methods (distance sampling and random encounter model) to estimate the abundance and habitat use of five ungulate species in the Pakke Tiger Reserve of western Arunachal Pradesh. This study was conducted from February 2021 to May 2021. The density of Barking deer was found to be highest ( $4.01 \pm 1.41$ ) followed by Sambar ( $3.30 \pm 0.68$ ), Gaur ( $1.72 \pm 0.61$ ), Wild pig ( $0.67 \pm 0.17$ ), and Hog deer ( $0.39 \pm 0.23$ ). In comparison to camera trap-based distance sampling, the area covered in sampling in the same region using other approaches such as line transect is 75-95 percent less in a considerably shorter time frame. We found that ungulates segregate based on habitat. Hog deer, Wild pig, and Barking deer being similar in size occur in different habitats, i.e., grasslands and woodlands. While wild pig and barking deer are comparable in size and use similar habitats, because the wild pig is an omnivore, they can partition their niches. This study provides crucial information on abundances and habitat use, which can be used for focussed conservation efforts for ungulates occurring in low densities.

## Chapter 1: Introduction

The role of ungulates in the African savanna ecosystem is widely pronounced. They play a crucial role in structuring the grazing ecosystem (McNaughton 1979) and therefore are of immense conservation value. But despite the important functional roles which the ungulates perform, such as seed dispersal (Wang *et al.* 2006), changing the vegetation structure through herbivory (Augustine & McNaughton 1998), and as a major source of prey to the carnivores (Wolf & Ripple 2017), the significance of ungulates in the tropical forest ecosystem is not widely studied and very little is known about their natural history and conservation value. This lack of knowledge is a serious concern because tropical forests are under immense human pressure and are exploited heavily for bushmeat and timber, which results in the loss of biodiversity and affects the ecological functioning of the ecosystem (Fa *et al.* 2002). As human activities are modifying and altering the natural habitats, monitoring of animal population changes over time in response to the anthropogenic pressure becomes a crucial task (Everatt *et al.* 2014). Monitoring tropical forest ungulates is not an easy task (Steinmetz *et al.* 2010). The commonly used line transect method to estimate the population of ungulates is based on the direct sighting of the animal and works well for common and diurnal species inhabiting open forests (Rovero & Marshall 2004). But in the case of rare and elusive species that are hard to see in the forest, indirect methods such as interviews (Chanchani *et al.* 2010), track counts, fecal or dung counts, drive counts (Koster & Hart 1988) are often used for estimating the population. The extrapolation of abundance or density estimate from indirect signs involves a lot of methodological problems (Bowkett *et al.* 2007). The camera trap has emerged as an important tool for ecological research and its use in various studies has increased over the past decades (Karanth 1995, Rovero & Marshall 2009, Jhala *et al.*

2019). The camera-trap data is widely used to estimate the abundance and density of individuals that have unique body marking using capture-recapture models (Karanth 1995, Karanth & Nichols 1998). For individuals that lack natural body markings, the Relative Abundance Index (RAI) is a common method for quantifying changes in abundance over time and area. (O'Brien 2011). But the practicality of using RAI as an index of abundance is often questioned because this method assumes that the detection rate remains constant for every species across space and time (Jennelle *et al.* 2002), which is not true (Pollock *et al.* 2002). Spatially explicit capture-recapture (SECR) models for unmarked populations use the spatial correlation of count data at different sampling locations to estimate the population densities. In this method, the cameras are placed close to each other to detect the same individuals at multiple locations. However, this method requires intensive sampling and the results are not precise if the sample size is small (Chandler & Royle 2013). The Random Encounter Model (REM) given by (Rowcliffe *et al.* 2008) estimates the density of unmarked animals with a known average speed and sensor detector parameter. REM assumes that the placement of cameras is random to animal movement and thus estimates the density from the rate of contact between animal and camera trap. REM gives a robust density estimate but it has some limitations; especially when it comes to estimation of parameters such as animal speed and average group size, which may be different for species inhabiting different habitats. The Camera Trap Distance Sampling (CTDS) method developed by (Howe *et al.* 2017) on the other hand is an extended form of the point transect method that uses camera-trap data to estimate the density and allow distance sampling theory and software to design and analyze the data (Buckland *et al.* 2001). Both REM and camera trap distance sampling methods give unbiased density estimates (Zero *et al.* 2013, Gray 2018, Pal *et al.* 2021). The applicability of these two

methods in the tropical forests of India, where the conventional line transect distance sampling method often fails to provide a robust estimate of the ungulates population, is yet to be tested.

## **1.1 Background**

North-East India is home to more than 200 local tribes. For the tribal people of North East India, hunting has a ritual, recreational, and subsistence value (Datta 2002). A study conducted in Arunachal Pradesh reveals that around 34 mammal species are hunted by local people as evident from the skins and skulls seen in the villages (Datta 2002). The major mammalian species that are illegally targeted by hunters in Arunachal Pradesh are Sambar, Barking Deer, Wild Pig, and Gaur (Datta *et al.* 2008). These species are major prey for carnivores such as tigers, leopards, and wild dogs (Karanth & Sunquist 1995). There is a lack of information on the status of prey and predators from the hills of North-East India. Estimating the abundance of species that are targeted by hunters and looking at the trends over time is therefore of critical importance in their conservation (Datta *et al.* 2008). The conventional sighting-based lines transect method which is widely to estimate ungulate abundance often fails in the hills of North East India (Datta *et al.* 2008). In this study, we looked at the precision and feasibility of two robust approaches for estimating the abundance of ungulates using camera traps in the forests of North East India.

## 1.2 Literature Review

Monitoring the ungulates population is crucial for effective wildlife management (Koster & Hart 1988). Distance Sampling is a popular method to survey ungulates (Buckland *et al.* 2001). It has been used as a population estimation method for a wide variety of species (Marshall *et al.* 2008). There are four assumptions in the distance sampling method, (1) At zero distance from the transect line all the animals are detected, (2) when detected, only the initial location of the animal is recorded, (3) the distance should be measured correctly and precisely, (4) the area surveyed is representative of the entire area and transects are placed randomly. Estimation of abundance depends on the detection function which is used to model the detection probability. The detection function is incorporated with the measured distance of the target species, which allows us to estimate the number of animals that were missed (Buckland *et al.* 2001). As this method requires visual detection to measure the distance of the animal to estimate the population, it fails in tropical forests where ungulates are hardly seen because of their cryptic and elusive behavior (Rovero & Marshall 2004). Indirect methods of population estimation based on dung or tracks encounter rate are used where direct sighting of ungulates is impossible. The sign densities are converted to give the estimate of animal density, but this gives a biased estimate in the absence of local sign deposition and rate of decay, and estimating them is a time-consuming task (Plumptre 2000). Camera traps are widely used to estimate the population in individually identifiable species with natural markings (Karanth & Nichols 1998). Capture-recapture models have a long history of being used to predict abundance from individual detection and non-detection (Otis *et al.* 1978). It has successfully estimated the density and abundance of tigers (Karanth 1995), leopards (Chapman & Balme 2010), Sunda clouded leopard (Wilting *et al.* 2012), and leopard

cat (Selvan *et al.* 2014b). But this method is mostly restricted to carnivores that have unique body markings (Karanth & Nichols 1998). In nature, very few animals have body markings and therefore this method is often ineffective for unmarked animals. (Royle & Nichols 2003) used a variation of the occupancy model to estimate the abundance of unmarked individuals. He assumed that the probability of finding an animal in a sampling unit is proportional to the abundance of that animal in that unit. This method has some drawbacks, according to (Sunarto *et al.* 2012) It can be difficult to convert a point estimate of abundance into a significant estimate of overall abundance or to convert it into a density estimate for a study site. (O'Brien *et al.* 2003) used indices to conclude variances in abundance over time, space, and species. Any metric that correlates with real abundance can be used as an index of abundance. (Caughley 1977). The Relative Abundance Index (RAI), is a widely used indicator of abundance that measures the variation in the number of pictures of individual species per trap day. (O'Brien *et al.* 2003, O'Brien 2011). This method gives a relative abundance of the species, but it requires a separate estimate of density for correction when used to estimate absolute abundance or density. (Carbone *et al.* 2001). The relative abundance estimated from RAI is often controversial because to compare the estimates across space, time, and species we need to assume that the detection probability remains constant across dimensions (Jennelle *et al.* 2002). But in reality, the detection probability varies across space, time, and species (Pollock *et al.* 2002). The change in the index of abundance across sites cannot be attributed to the change in abundance; it may be due to the change in detection probability (Pollock *et al.* 2002). Therefore RAI gives a wrong abundance estimate for species (Sollmann *et al.* 2013). RAI is also used widely in studying habitat use and activity patterns of various species. For example, (Bowkett *et al.* 2007) used a camera-trapping rate to assess the

habitat use of two antelope species, and (Li *et al.* 2014) assessed the relationship between habitat and camera trapping rate of four sympatric ungulates. The detection probability co varies with habitat variables that influence the presence and absence of the species and the results of habitat use assessed from camera-trapping data can be biased if imprecise and spatially varied detection is not taken into account (Gu & Swihart 2004). Even sampling design, camera type, and camera sensor can result in variation in detection probability. This variation in the detection across surveys can be reduced by having a standardized study design and standardized equipment (Sollmann *et al.* 2013).

(Rowcliffe *et al.* 2008) formulated the Random Encounter Model (REM), which is based on the modification of the ideal gas model (Hutchinson & Waser 2007). REM provides for the estimation of animal density from unmarked animals having speed data and sensor detection variables. (Rowcliffe *et al.* 2008). The REM is based on three assumptions: (1) random target movement; (2) detections indicate independent camera-animal encounters; and (3) population closure. The assumption that the movement of animals is random often gets violated, because, in reality, animals move non-randomly, but this model is robust against such violations (Rowcliffe *et al.* 2013). REM has given unbiased estimates of densities for many elusive species (Manzo *et al.* 2012, Gray 2018). Many studies used independent estimates of densities and correlated them with the densities estimated by REM. The density estimates of European wildcat produced by capture-recapture models and REM gave the same result (Anile *et al.* 2014). In the case of Grevy's zebra, the density estimates obtained from both line transect sampling and capture-recapture models were similar to the density estimate produced from REM (Zero *et al.* 2013). (Caravaggi *et al.* 2017) Found that both REM and distance sampling yield density and abundance estimates

that reflect local hare density fluctuations. Although REM gave comparable results in some studies, others found considerable discrepancies in this method (Rovero & Marshall 2009, Cusack *et al.* 2015). The major drawback lies in the estimation of animal speed and group size, as these two factors differ from species to species and are not easily obtained (Borges *et al.* 2014). This constraint is corrected by (Howe *et al.* 2017) in his camera trap-based distance sampling method. This method uses the basic assumption of distance sampling (Buckland *et al.* 2001) and gives unbiased estimates of density using camera-trap data. Unlike REM which requires the average speed of the animal, camera trap-based distance sampling methods require an estimate of the percentage of time animals are present for detection. In India, REM and camera-based distance sampling methods are slowly gaining popularity as population estimation methods for individuals that lack body marking. REM has been successfully used in estimating the density of ungulates in the Corbett Tiger Reserve of India (Banerjee, unpublished report). (Pal *et al.* 2021) successfully used a camera trap-based distance sampling method to estimate the density for two mountain ungulates, Himalayan blue sheep and Himalayan musk deer in the Upper Bhagirathi basin of Uttarakhand. The applicability of these two methods in the tropical forests of India is yet to be tested.

### **1.3 Study Objectives**

1. To estimate the abundance of ungulates using Random Encounter Model (REM) and Camera Trap Distance Sampling (CTDS) in the tropical forest of Western Arunachal Pradesh.
2. To assess the habitat use and Spatio-temporal interaction of sympatric ungulates using camera traps.
3. To assess the Spatio-temporal interaction between ungulates and carnivores.

### **1.4 Hypothesis**

1. In tropical forests, due to the elusive and cryptic behavior of the animals, camera trap-based abundance estimation methods give a more precise estimate than the line transect sampling method.
2. Ungulates spatially or temporally avoid habitat patches that have a high predation risk.

### **1.5 Research Questions**

1. Which of the following methods (REM or Distance sampling with camera traps) is more precise in estimating the abundance of ungulates in tropical forests?
2. What influence do habitat variables have on the habitat use and activity pattern of ungulates?
3. Is there any overlap in the activity pattern of ungulates and carnivores?

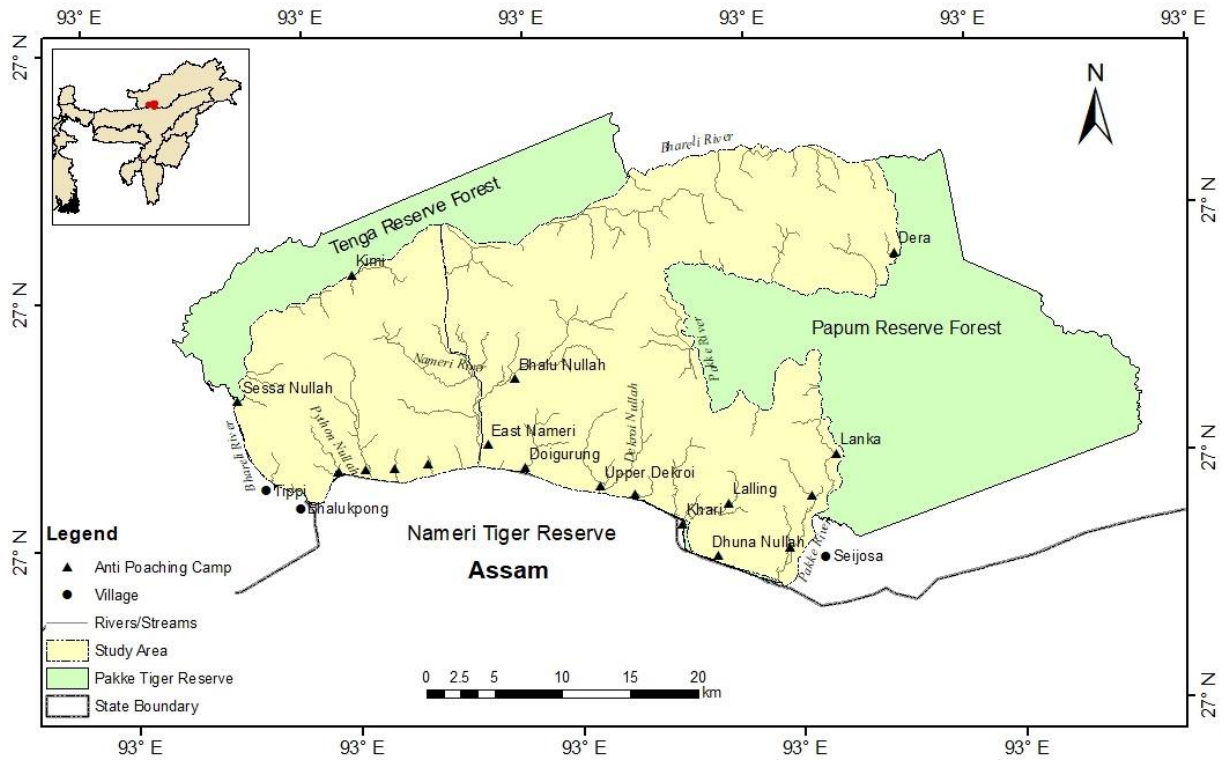
## Chapter 2: Study Area

### 2.1 Location and Area

Arunachal Pradesh is situated in the north-eastern region of India, between 26°28' N and 29°30' N latitude and 91°30' E and 97°30' E longitude. Arunachal Pradesh lies at the junction of the Oriental and Indo-Malayan eco-region and is therefore rich in species diversity and endemism, due for this reason it is considered an important biodiversity hot-spot (Myers *et al.* 2000). Arunachal Pradesh is a forest-rich state with dense vegetation dominated by tropical rainforests. The state has a forest cover of 66,687.78 sq. km which is 79.63% of the total geographical area of Arunachal Pradesh (Forest Survey of India 2019).

This study was done in the Pakke Tiger Reserve (92° 39' to 92° 44' E and 27° 01' to 27° 11' N) located in the Pakke Kessang district of Western Arunachal Pradesh (Figure 1). Pakke TR expands over an area of 1276.95 sq. Km, out of it 861.95 sq. Km is the core and 515.00 sq. Km is the buffer area. PTR lies north of the river Brahmaputra in the foothills of the Eastern Himalaya. The river Kameng (called Bhareli in Assam) flows along the northern and western border of the park and the river Pakke flows to the south of the park. The perennial streams of the river Kameng and Pakke along with other small rivers criss-cross the tiger reserve and join with the Brahmaputra River. PTR is surrounded by dense and contiguous forests from all sides, Tenga Reserve Forest lies to the North of the tiger reserve, Doimara Reserve Forest lies West, Papum Reserve Forest lies on the East while Nameri Tiger Reserve lies on the South. Pakke Tiger Reserve along with Eaglenest Wildlife Sanctuary, Sessa Orchid Wildlife Sanctuary, Sonai Rupai Wildlife Sanctuary, sizes and Nameri Tiger Reserve in Assam, and the reserve forests of Papum, Doimara, Shergaon, and Amortola

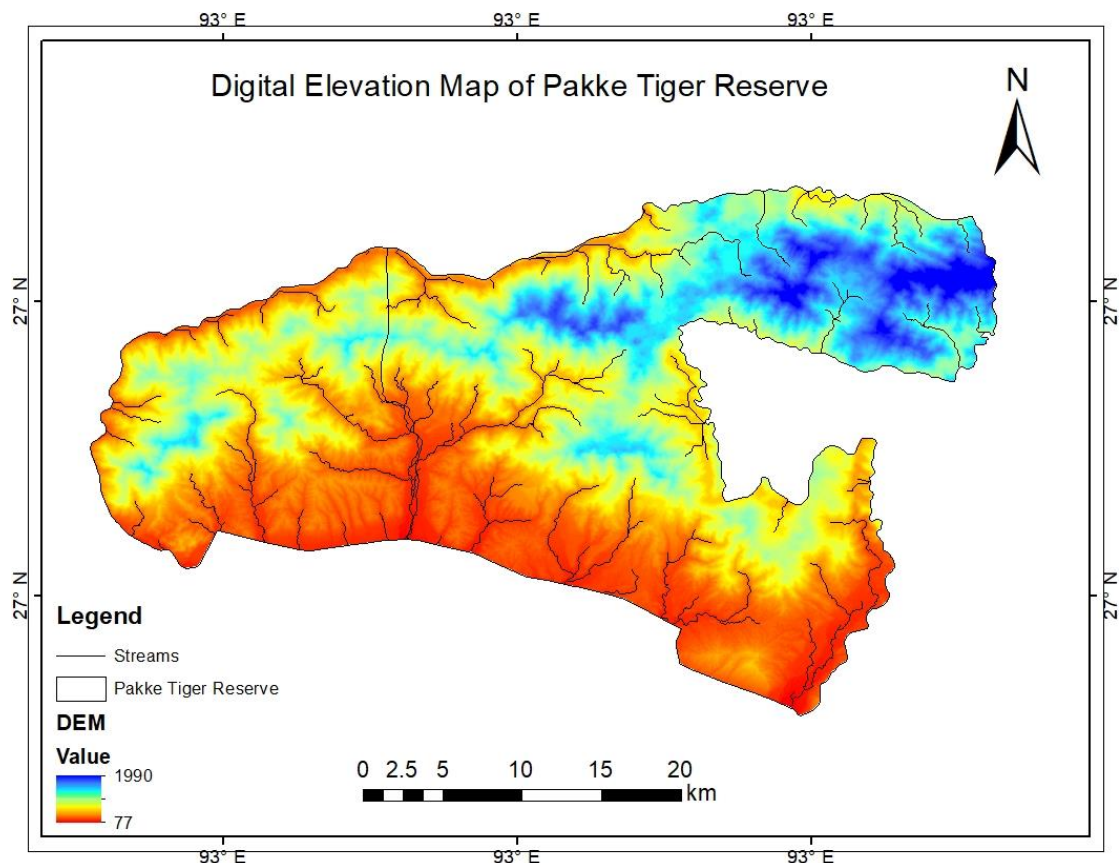
together forms the Kameng Protected Area Complex (KPAC). The complex covers an area of about 3,500 sq. Km with an elevation of 100m to 3,300m ASL. This makes it the largest protected area network of Arunachal Pradesh.



**Figure 1: Map of Pakke Tiger Reserve showing boundary of tiger reserve, anti-poaching camps and surrounding villages**

## 2.2 Topography

The terrain of the Pakke Tiger Reserve is very undulating and hilly. The altitude ranges from 77m to over 1990m above sea level (Figure 2). The hills are divided into three formations: Dafla, Subansiri, and Kimin, which closely correlate to the Siwalik Group's Lower, Middle, and Upper sub-divisions and are made up of sandstone, shale, and conglomerate rock formations (Karunakaran & Ranga Rao 1979). The lowland area is characteristic of bhabar tract and comprises gravel and cluttered sediment deposits. It is crisscrossed by many perennial and ephemeral streams.



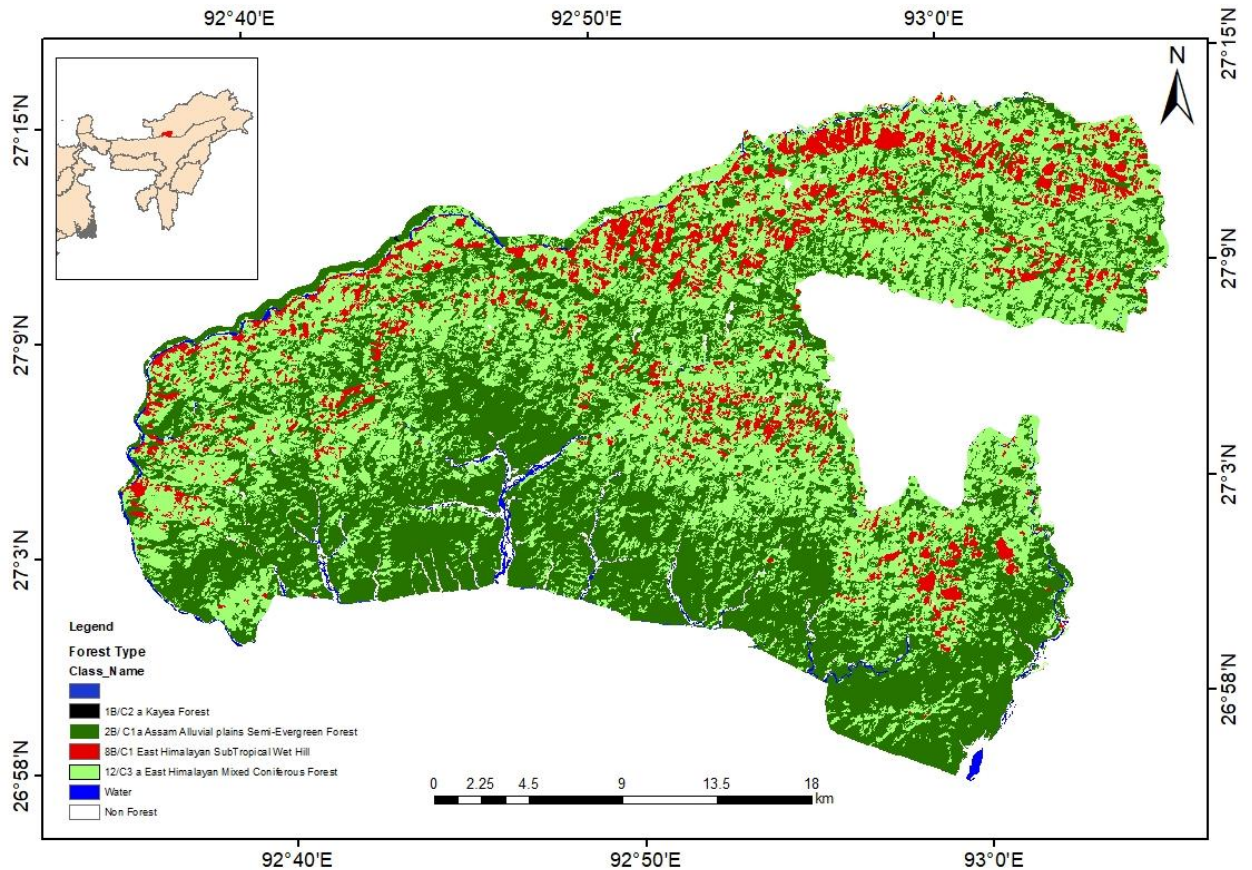
**Figure 2: Digital Elevation Map (DEM) of Pakke Tiger Reserve**

## 2.3 Climate

The climate in the study area is tropical and subtropical; the winter season starts from November to February. The rainfall is received from the southwest monsoon in May to September and the northeast monsoon which starts from December and lasts up till April; more than three-quarters of the annual rainfall is caused by the former. The dry months of October and December are followed by the hottest months of May and June. The monsoon season finishes in September, but rain can be expected at any time during the year. In March and April, thunderstorms are not uncommon. Pakke receives an average annual rainfall of 2500 mm.

## 2.4 Vegetation

The general vegetation type of the Pakke Tiger Reserve is classified as Assam Valley tropical semi-evergreen forest (Champion & Seth 1968) (Figure 3). The forest is rich in epiphytic flora and dense lianas. The major emergent trees are Jutuli *Altingia excelsa* and Bhelu *Tertameles nudiflora*. The lowland areas and foothills are dominated by Hollock *Terminalia myriocarpa*, Dhuna *Canarium resiniferum*, Borpat *Ailanthus grandis*, Hathi Paila *Pterospermum acerifolium*, Amari *Aglaia spectabilis*, Udal *Sterculia villosa*, Banderdima *Dysoxylum binectariferum* and *Beilschmiedia sp.* The moist and shady areas along streams and *nullah* have dense growth of cane and bamboo. Tokko palm *Livistonia jenkinsii* also occur in moist places and is widely used as thatch by local people. The riverine species that are found along large perennial streams and rivers include Khokhan *Dubanga grandifolia*, Molita *Macaranga denticulata*, Semul *Bombax ceiba*, Outenga *Dillenia indica*, *Magnolia hodgsonii*, *Endospermum chinense*, *Sterculia foetida*, *Syzygium sp.* The grasslands are dominated by *Saccharum spontaneum* and *Imperata cylindrical*. Rapik *Alpinia nigra* grows along with the grasslands and is eaten by local people.



**Figure 3: Vegetation Map of Pakke Tiger Reserve, as classified by Champion and Seth 1968**

## 2.5 Fauna

Around 60 mammal species are known to occur in Pakke Tiger Reserve. Major herbivore species found in PTR are Asian elephant *Elephas maximus*, Gaur *Bos gaurus*, Sambar *Rusa unicolor*, Barking Deer *Muntiacus muntjak*, Wild Boar *Sus scrofa*, and Hog Deer *Hyelaphus porcinus*. The major carnivore fauna inhabiting PTR includes the Tiger *Panthera tigris*, leopard *Panthera pardus*, wild dog *Cuon alpinus*, Clouded leopard *Neofelis nebulosa*, and Asiatic black bear *Ursus thibetanus*. Small cats such as Marbled cat *Pardofelis marmorata*, Golden cat *Catopuma temminckii*, and Leopard cat *Prionailurus bengalensis* are also found in Pakke. Some 256 bird species were recorded from Pakke Tiger Reserve (Datta *et al.* 1998). Four species of hornbills are found in PTR, namely, Great hornbill *Buceros bicornis*, Wreathed

hornbill *Rhyticeros undulatus*, Oriental pied hornbill *Anthracoceros albirostris*, and Rufous-necked Hornbill *Aceros nipalensis*. The Rufous-necked hornbill occurs at higher elevation whereas the other three are found in the lowland forests (Datta *et al.* 1998). 31 species of amphibians and 30 species of fish are also recorded from Pakke Tiger Reserve (Kamei *et al.* 2012).

## **Chapter 3: Study Design and Methodology**

The fieldwork (i.e. data collection) was carried out from February 2021 to May 2021.

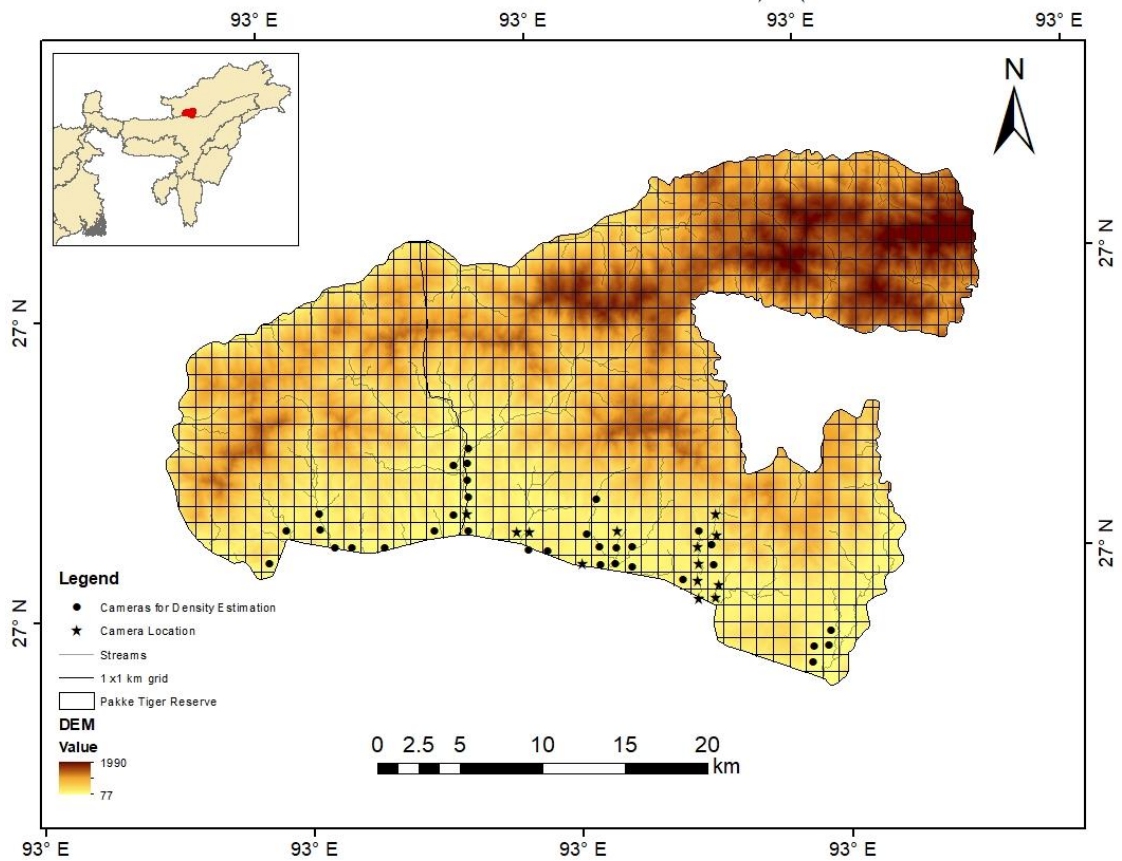
The data analysis was done in June and July.

### **3.1 Estimation of Ungulate Abundance**

#### **3.1.1 Field Methods**

##### ***3.1.1. (A) Camera Trapping***

Camera traps were used in estimating the density of ungulates in the Pakke Tiger Reserve. The study area of 861.95 sq. km was overlaid with a grid size of 1km x 1km, and a centroid was generated for every grid using ArcGIS software. The terrain of Pakke Tiger Reserve is undulating and hilly, and a major portion of the park is inaccessible, which made sampling in those portions logistically impossible. To overcome this logistical constraint we sampled grids in the lowland areas of the reserve (Figure 4). Following a systematic random sampling, a single IR camera was deployed at the centroid of each grid. This way of camera placement ensures that the cameras are placed at random to animal movement and hence do not bias density estimates due to any preferential selection of points (Rowcliffe *et al.* 2008, 2013). A GPS device (Garmin eTrex 30x) was used to navigate to the centroid of the grid to install camera traps. Some of the randomly generated centroids of the grids turned out to be on a cliff or inside a water body. In such cases, the camera was placed at another random location within the grid, and this new location deviated from the centroid by as much as 100m to 250m.



**Figure 4: Map showing camera trap locations in the study area**

The camera was mounted on a tree at a height of 50cm above the ground, so that smaller-sized animal are not missed. In riverine and grassland habitats, where trees were absent, a pole was used to mount the cameras. The orientation of the camera was chosen randomly and in the case of dense vegetation, the camera was oriented to the direction where the vegetation was less dense so that clear pictures of animals could be obtained.

A total of 52 camera traps (Cuddeback Blue Series, Model: 1279, Cuddeback, De Pere, U.S.A) were deployed from 12-02-2021 to 29-05-2021, covering the major vegetation types. For each camera, the delay between images (both day and night) was set to FAP (fast as possible which is about 1 second) and the number of images to

record with each detection was set to 5 images (both day and night). The image resolution was set at 5 megapixels for all the cameras.

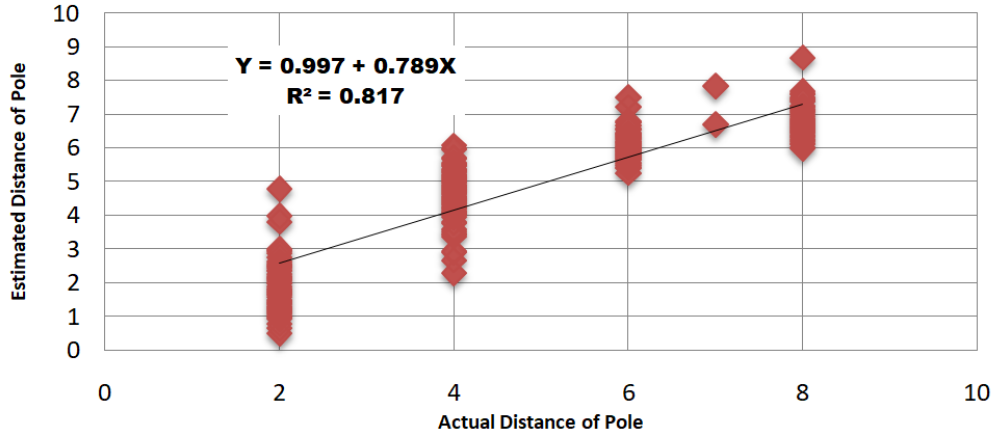
### **3.1.1. (B) Camera Calibration**

The Random Encounter Model (REM) and Camera Trap Distance Sampling (CTDS) both require the distance of photo-captured animals from the camera trap to estimate the density. The distance from the camera was measured while setting up the camera traps. Three measuring tapes were laid in front of each camera trap and a researcher holding a 2m long pole (having 10cm alternate bands) and a distance marker was photographed at every 2m interval from the camera, up to the visible distance available in front of the camera (refer to Figure 1, 2, 3 of Appendix A). For example, if the visible distance, which is defined as the point beyond which an ungulate will not trigger the camera while being in the field of view, was 10 meters, then the image of a researcher holding the distance marker and the pole was taken at 2m, 4m, 6m, 8m, and 10m respectively. This was done in the center and on both sides of the camera's field of view (FOV). The animal distance was estimated by comparing their location to those of the researcher in the reference photograph using image processing software.

### **3.1.2 Analytical Methods**

All the photographs of ungulates from the main data set were segregated into a specific folder using the software CaTRAT (Camera Trap data Repository and Analysis Tool) (Jhala *et al.* 2019). The pictures of researchers holding distance markers and poles were sorted out for each distance class and only the images where the pole was visible were retained. Photographs that were obscured by dense vegetation were discarded from the analysis. The distance of an animal from the camera was estimated using ImageJ software (Schneider *et al.* 2012), It is an image

processing software that allows you to scale and measure distances on photos. This software has been successful in measuring the body dimensions of leopards from camera trap photos (Tarugara *et al.* 2019). The photographs of the researcher holding calibration poles at known distances were used for reference measurements for each camera. A perpendicular measurement was taken from the base of the pole touching the ground to the base of the image. The ImageJ software converts this perpendicular distance into pixels. In the *Set Scale* function of the software, the known distance of the calibration pole from the camera and the unit of measurement were defined so that the measurements could be made in the calibrated units. After assigning the known distance and unit, the software calculated a scaling factor i.e. pixels/meters. Next, the *Global* option in the *Set Scale* function was selected to fix the scaling factor for all the images of that particular camera. The perpendicular distances from the base of the animal to the base of the image were measured for that camera. The *Measure* function of the software was used to convert this measured distance into meters. To check the accuracy of the measurements, we estimated the distances of the calibration pole from the camera (whose actual distance was already known to us) using ImageJ. We used calibration poles at 4m, 6m, and 8m distances as the reference measurements for each camera to estimate the known distance. A correction factor was calculated by using a regression equation to correct the estimated distance (Figure 5). In this equation, the dependent variable was the estimated distance of the calibration pole from the camera, and the explanatory variable was the actual distance of the calibration pole from the camera.



**Figure 5: Regression analysis between distances (in m) estimated by ImageJ software and actual known distances.**

The density of ungulates was calculated using the formula for Camera Trap Distance Sampling by (Howe *et al.* 2017) and Random Encounter Model (REM) by (Rowcliffe *et al.* 2008).

### **3.1.2. (A) Camera Trap Distance Sampling (CTDS)**

In CTDS, the density was estimated using the following equation given by (Howe *et al.* 2017):

$$\hat{D} = \frac{\sum_{k=1}^K n_k}{\pi w^2 \sum_{k=1}^K e_k \hat{P}_k}$$

Where  $n_k$  is the number of observations of animals at a camera point  $k$ ,  $e_k$  is the temporal effort and  $\hat{P}_k$  is the detection probability of an animal that is within  $\theta$  degrees (angle covered by the camera),  $K$  represents the total number of camera traps used,  $w$  represents truncation distance beyond which any recorded distances are not used. If the camera covers an angle  $\theta$  degree, then  $\frac{\theta}{2\pi}$  is the proportion of a circle that is covered by the camera, hence, the total sampling effort at point  $k$  can be defined

as  $\frac{\theta T_k}{2\pi t}$ . Where,  $T_k$  is the total time the camera was active and  $t$  is the unit of time in seconds used to determine a finite set of image moments within  $T_k$ .

### **3.1.2. (B) Random Encounter Model (REM)**

The REM estimates density from the rate of contact between animal and camera trap and requires speed of animal and sensor detection parameter (Rowcliffe *et al.* 2008) :

$$\hat{D} = \frac{y}{t} \frac{\pi}{vr(2 + \theta)}$$

Here,  $y$  is the total number of photographs captured,  $t$  is the total effort of the camera trap survey;  $v$  is the average speed of the animal;  $\theta$  and  $r$  define the angle and radius of the camera trap field of view. The number of independent capture occurrences divided by the number of camera trap days yielded the wild pig camera trap rate. An independent capture event was considered when an individual first appeared in front of the camera. If an individual left the camera field of view and returned after few minutes, in that case the first capture was considered as an independent capture event. The analysis was performed in R using (Rowcliffe *et al.* 2008).

## **3.2 Activity Pattern and Habitat Use**

### **3.2.1 Field Methods**

Habitat-related variables were collected at each camera trap location to assess the habitat use of ungulates. A circular plot of 10m radius was laid at the camera trap location and all the tree species occurring in that plot were recorded. Any vegetation that was greater than 6ft/2m in height was classified as a tree (Jhala *et al.* 2019). Canopy cover was estimated for each plot using a densiometer and the estimated

percent canopy cover was classified into four categories: Open (0%), low (1-30%), medium (31-69%), and high (>70%). The vegetation type in front of the camera field of view was recorded. The vegetation type was classified into six categories based on the habitat variables: riverine, grassland, moderately dense, and dense. The presence of ungulate dung was recorded in a 10x2m plot in front of the camera trap.

### **3.2.2 Analytical Methods**

#### **3.2.2. (A) Activity Pattern**

The activity pattern of animals is a result of circadian rhythm which response to the daylight and night hours. Animals can be divided into three categories based on the time of their activity pattern i.e. diurnal (active during daytime), nocturnal (active during the night), and crepuscular (active during dusk and dawn). It is during the civil and nautical twilight time, that 80 % of the change in sunlight intensity occurs, in Northern Hemisphere (Hut *et al.* 2013). When the sun is between 0 and 6 degrees below the horizon, it is civil twilight; when the sun is between 6 and 12 degrees below the horizon, it is nautical twilight. We, therefore, defined our crepuscular period as both civil and nautical twilight combined i.e. when the sun is between 0 to 12 degrees below the horizon. The civil and nautical times, as well as the sunrise and sunset times, were derived from (Thorsen 2008). The diurnal period is defined as the time between dawn and sunset, while the nocturnal period is defined as the astronomical twilight, which occurs when the sun is between 18 and 12 degrees. The analysis was done in the “overlap” package (Meredith & Ridout 2021) in R (R Development Core Team 2020).

### **3.2.2. (B) Temporal Overlap**

Temporal overlap was measured using the co-efficient of overlap ( $\Delta$ ). The value ranges from 0 (no overlap) to 1 (identical overlap of activity pattern). This method fits kernel density function to times of observation of the animals. We used overlap co-efficient  $\Delta_1$  when the sample size of any species was less than 75 (Ridout & Linkie 2009). We ran 1000 bootstrap samples to obtain a 95% confidence interval of  $\Delta_1$  (Linkie & Ridout 2011). The analysis was done in the “overlap” package (Meredith & Ridout 2021) in R (R Development Core Team 2020).

### **3.2.2. (C) Habitat Use**

Habitat use was estimated using Ivlev’s Index (Ivlev 1961) and chi-square statistics were used to compare the use versus availability.

$$PI = \frac{(U - A)}{(U + A)}$$

Where U = proportion of habitat used and A = proportion of habitat available

The availability and utilization approach by (Neu *et al.* 1974) was also used after accounting for Bailey’s correction for Bonferroni’s confidence intervals.

### **3.2.2. (D) Species Co-Occurrence**

To see if there was any pair-wise trend of species co-occurrence that is statistically significant, the probabilistic model of species co-occurrence was applied. It measures co-occurrence simply as the number of sampling sites where two species occur. This model determines the likelihood that two species would co-occur at a frequency that is either less than ( $P_{lt}$ ) or more than ( $P_{gt}$ ) what has been observed. If ( $P_{lt}$ ) < 0.05 then two species are found to co-occur negatively and if ( $P_{gt}$ ) < 0.005 then two species are found to co-occur positively. We clubbed together tiger, leopard, wild dog, and

Asiatic black bear into ‘large carnivores’, as they individually occurred at very few sites. The analysis was done in the “co-occur” package (Griffith *et al.* 2016) in R (R Development Core Team 2020).

## **Chapter 4: Results**

### **4.1 Estimation of Ungulate Abundance**

Due to paucity of time, data from 33 camera traps out of the 46 traps was analyzed to estimate the abundance of ungulates in Pakke Tiger Reserve.

#### **4.1.1 Camera Trap Distance Sampling**

The abundance of ungulates was estimated through distance sampling using camera traps with a total effort of 14514740 capture events possible. The data from the camera trap was collected for five ungulate species, Sambar, Barking Deer, Gaur, Wild Pig, and Hog Deer. The detections of all the species were good enough to fit the detection function and obtain the reliable density estimate (refer to Figures in Appendix B), except for hog deer ( $n= 12$ ) (Buckland *et al.* 2001). The number of detection of each species is given in (Table 1). Barking Deer was found to be the most abundant ungulate in Pakke Tiger Reserve, followed by Sambar. The density of Barking deer and Sambar was estimated to be  $4.01 \pm 1.41$  individuals /sq.km and  $3.30 \pm 0.68$  individuals/sq. km respectively. The density of hog deer ( $0.39 \pm 0.23$  individuals/sq.km) was found to be the lowest among all ungulates in Pakke Tiger Reserve.

**Table 1: Density of Ungulates in Pakke Tiger Reserve based on Camera Trap Distance Sampling (CTDS)**

Species	No. of observations (n)	Encounter Rate (n/K)	Effective Detection Radius (EDR)	Chi Square GOF	Detection Probability $\hat{p}$ (SE)	Model	Density (per sq km) $\hat{D}$ (SE)
Sambar	654	4.50576E-05 (9.35E-06)	5.9 (0.72)	0.99	0.43 (0.1)	Half Normal Cosine	3.30 (0.68)
Barking Deer	965	6.64841E-05 (2.34E-05)	6.5 (0.11)	0.97	0.48 (0.01)	Hazard Rate Cosine	4.01 (1.41)
Gaur	173	1.19189E-05 (4.19E-06)	4.2 (0.33)	0.92	0.22 (0.03)	Half Normal Cosine	1.72 (0.61)
Wild Boar	214	1.47436E-05 (3.92E-06)	7.5 (0.2)	0.96	0.71 (0.05)	Hazard Rate Cosine	0.67 (0.17)
Hog Deer	12	8.26746E-07 (4.86E-09)	2.31 (0.58)	0.72	0.14 (0.07)	Half Normal Cosine	0.39 (0.23)

**K is the total effort calculated as maximum capture event possible K= 14514740), GOF: Goodness of fit, SE: Standard Error**

### 4.1.2 Random Encounter Model (REM)

The data of only Wild Pig *Sus scrofa* was analyzed to estimate the density using REM because of the time constraint. This analysis requires estimation of the distance and speed of the animal, through a separate method that is time-consuming. 79 captures (initial encounters) of wild boar were recorded from 33 camera traps that were active for 1346 trap nights. We were unable to generate the speed of wild boar from our field site; hence the speed estimate for wild boar was borrowed from the REM study done in Corbett Tiger Reserve (Banerjee, unpublished report). The results obtained from the REM analysis are shown in (Table 2 and Appendix C). The density estimate for wild pig in Pakke Tiger Reserve using REM was found to be  $0.74 \pm 0.22$ / sq km.

**Table 2: Density Estimate of Wild Pig in Pakke Tiger Reserve using Random Encounter Model**

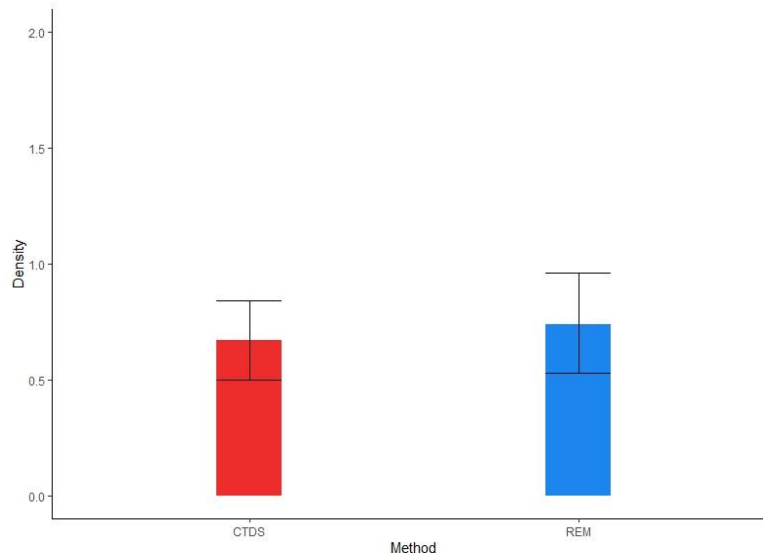
REM Parameters	Estimate	SE	% CV	95% CI
Trap Rate	0.06	0.01	24.47	0.03
Effective Distance (m)	7.03	0.23	3.34	0.46
Effective Angle	0.49	0.07	14.34	0.14
Activity Level	0.40	0.05	12.87	0.10
Speed (m/s)	0.41	0.06	14.63	0.12
Density (sq.km)	0.74	0.22	28.90	0.43

### 4.1.3 Comparison of CTDS and REM Density Estimate

In the limited time, I could only estimate the density of wild boar using REM. Hence, I am comparing the densities obtained from camera trap distance sampling and the random encounter model for wild pigs. We found no difference between the density estimates from the two different estimates.

**Table 3: Density estimates of wild pig from Camera Trap Distance Sampling (CTDS) and Random Encounter Model (REM)**

Method	Wild pig Density (per sq.km)	% CV	95% CI	Upper 95% CI	Lower 95% CI
CTDS	0.67	26.70	0.3332	1.0032	0.3368
REM	0.74	28.90	0.4312	1.1712	0.3088



**Figure 6: Bar plot comparing density estimate of wild pig using CTDS and REM.**

#### 4.1.4 Relative Abundance Index

The relative abundance index was calculated for all the five species of ungulates and the results are shown in Table 4. We also calculated the number of days required to obtain a single image of the species ( $RAI_2$ ). The RAI for sambar was the highest at  $20.2 \pm 4.3$  followed by barking deer  $18.5 \pm 3.5$ . Hog deer had the lowest RAI  $0.4 \pm 0.2$ .

**Table 4: Relative Abundance Index of ungulates in Pakke Tiger Reserve**

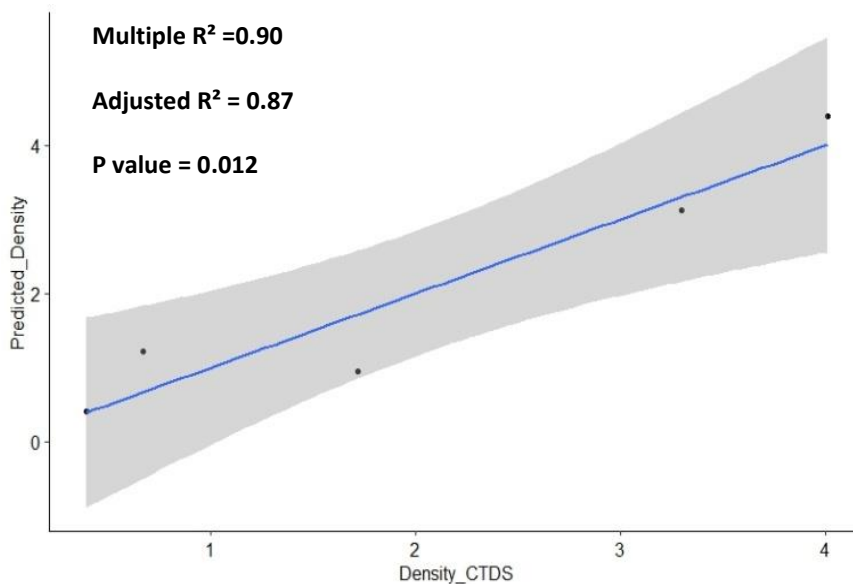
Species	Independent Picture (A)	Trap Night (N)	$RAI_1$	$RAI_2$
Sambar	272	1344	$20.2 \pm 4.3$	4.9
Barking Deer	248	1344	$18.5 \pm 3.5$	5.4
Gaur	45	1344	$3.3 \pm 1.3$	29.9
Wild Boar	64	1344	$4.8 \pm 1.2$	21
Hog Deer	6	1344	$0.4 \pm 0.2$	224

A regression analysis was performed between the density estimates of five ungulates species obtained from camera trap distance sampling as the dependent variable and their RAI as the independent variable. A regression equation  $y = 0.04x + 0.50$  (adjusted R square value: 0.87, p-value: 0.01) was obtained from this analysis. This regression equation was used to predict the densities of ungulates if RAI is given.

**Table 5: RAI, CTDS Density and Predicted Density of ungulates (using regression equation)**

Species	RAI	CTDS Density	Predicted Density
Sambar	52.08	3.30	2.58
Barking Deer	75.89	4.01	3.54
Gaur	11.31	1.72	0.95
Wild Boar	16.22	0.67	1.15
Hog Deer	1.04	0.39	0.54

A regression analysis between observed densities of ungulates obtained from Camera Trap Distance Sampling (CTDS) and the predicted densities of ungulates using RAI showed that both densities were highly correlated (Figure 7), having an adjusted R square value of 0.87 and p-value of 0.012.



**Figure 7: Regression between densities obtained from camera trap distance sampling and predicted densities using RAI**

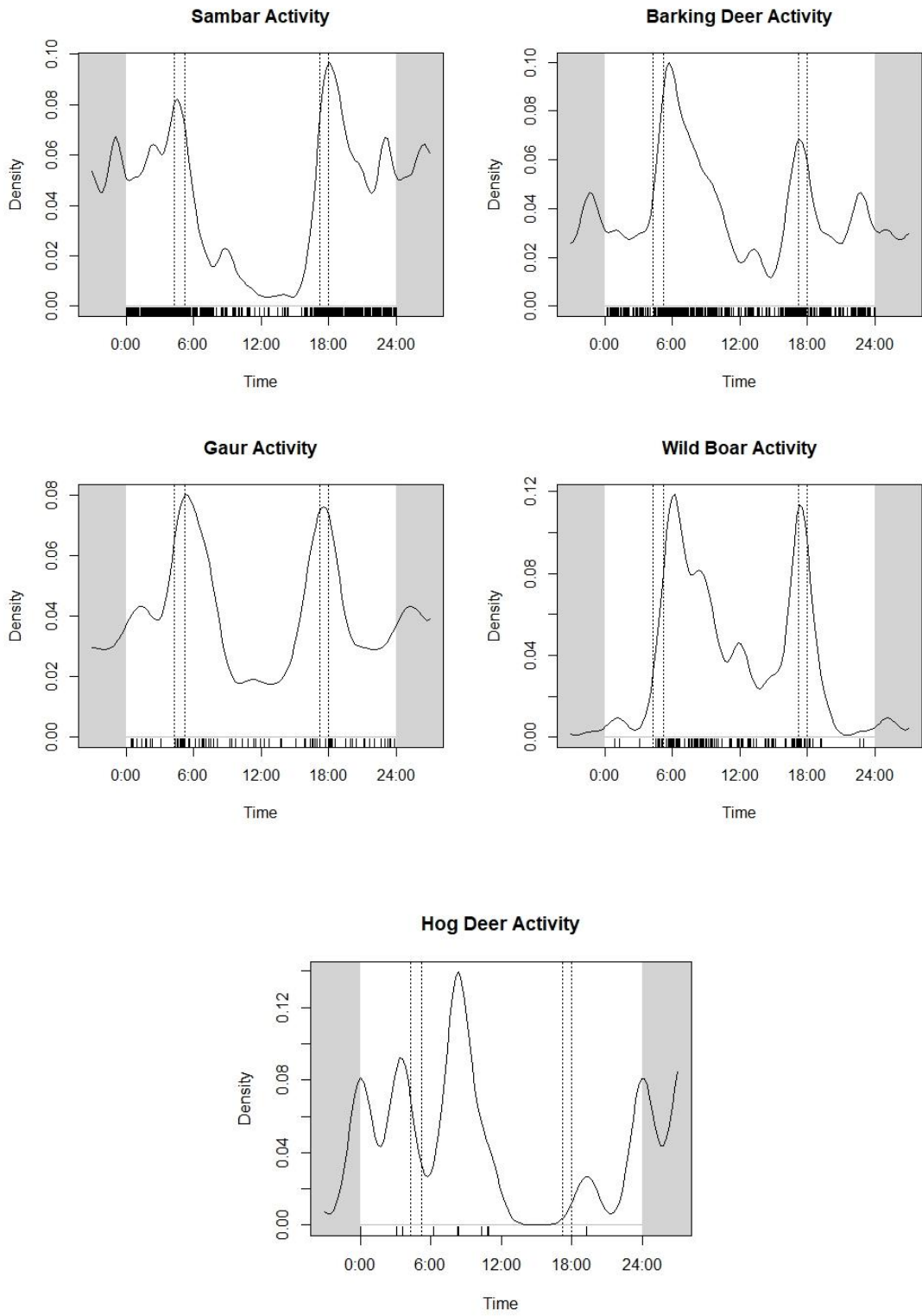
## **4.2 Activity Pattern and Habitat Use**

A total of five ungulate species were recorded in 46 camera traps during the sampling period of 1946 trap nights. Amongst the five species, Sambar and Barking deer had the highest detections (n= 1655, n= 1348 respectively) and Hog deer had the least detections (n= 29).

### **4.2.1 Activity Pattern**

All the ungulate species showed activity either during the crepuscular or diurnal periods (Figure 8). The activity of sambar starts from the midnight, reaches its peak in the early morning hours, and slowly declines after sunrise. The sambar remains inactive during the daytime and the activity reaches the lowest at the noon hours. There is a rise in the activity of sambar after sunset and it reaches the maximum in the late evening hours and declines thereafter. The barking deer show a similar kind of activity pattern as that of the sambar. It shows a bimodal peak in its activity period. The activity increases during the early morning hours and reaches a maximum just after sunrise and then slowly declines for the rest of the day. There is a peak in the activity period in the evening hours which reaches the maximum at sunset and then declines slowly. The gaur is active in the early morning and late evening hours and remains inactive during the daytime. Wild boar was active mostly after sunrise and sunset. The activity of wild boar reached a maximum after sunrise and gradually declined during the day, and again peaked after sunset. The captures for hog deer were least among all other ungulates, however, it showed a rise in activity after the sunrise and the activity reached a maximum during the late morning hours and declined after mid-noon.

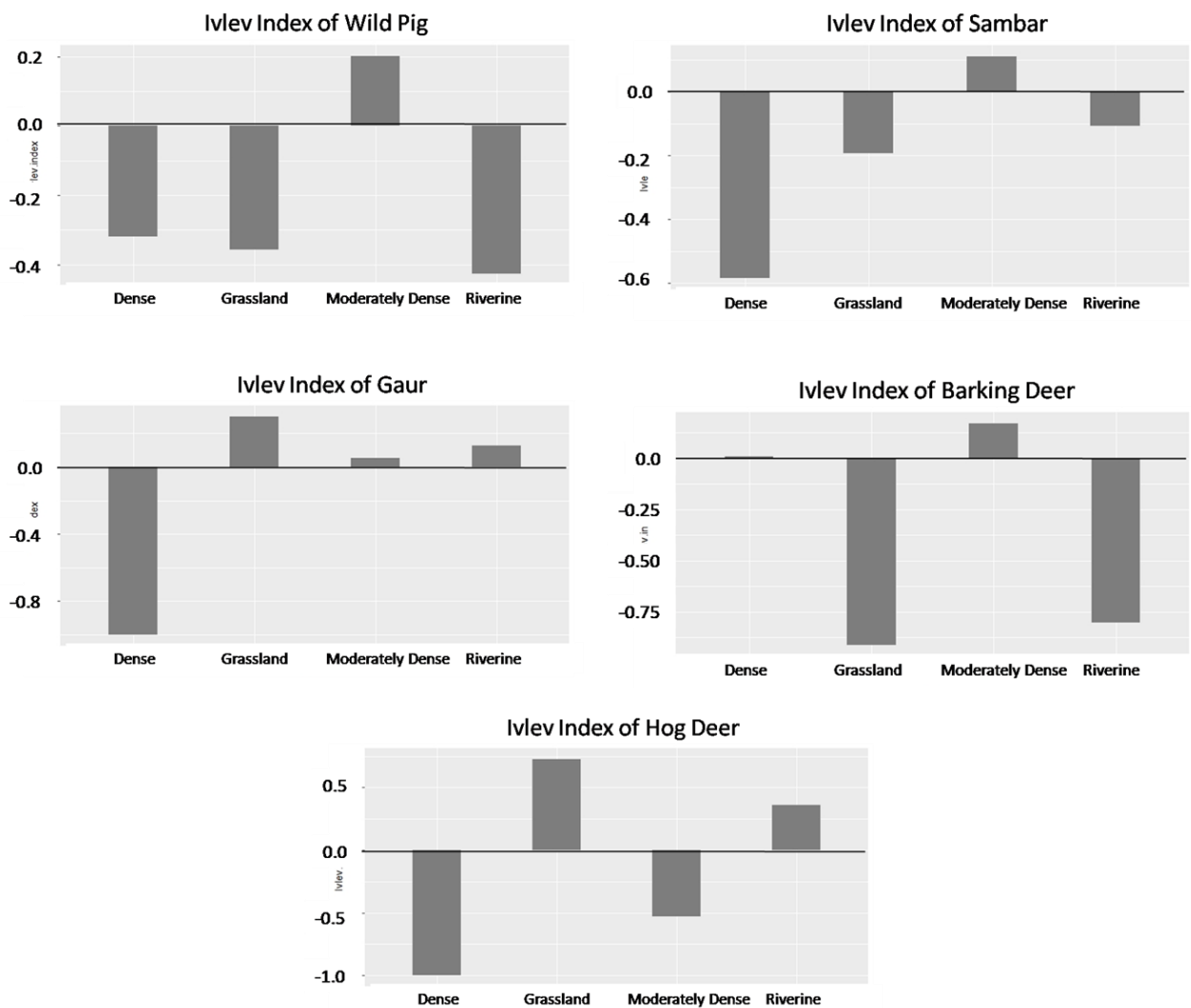
**Figure 8: Activity pattern of ungulates in Pakke Tiger Reserve, from 46 camera traps**



## 4.2.2 Habitat Use

The results of the Ivlev index suggest that Sambar, gaur, wild pig, and hog deer avoid habitats with dense vegetation growth (Figure 9). Sambar, barking deer, and wild pig preferred moderately dense habitats whereas gaur and hog deer preferred riverine and grassland habitats. Similar results were obtained after accounting for Bailey's correction for Bonferroni's confidence intervals (Table 6).

**Figure 9: Ivlev's index based on habitat use by ungulates, as calculated from 46 camera traps.**



**Table 6: Habitat use analysis to understand the use of different habitats by ungulate species, following Neu et al., 1974 after applying Baileys correction**

Sambar				
Habitat	Lower	Upper	Available	Level of Use
Riverine	0.14	0.17	0.20	Use less
Grassland	0.04	0.05	0.07	Use less
Moderately Dense	0.69	0.73	0.57	Use more
Dense	0.07	0.11	0.17	Use less

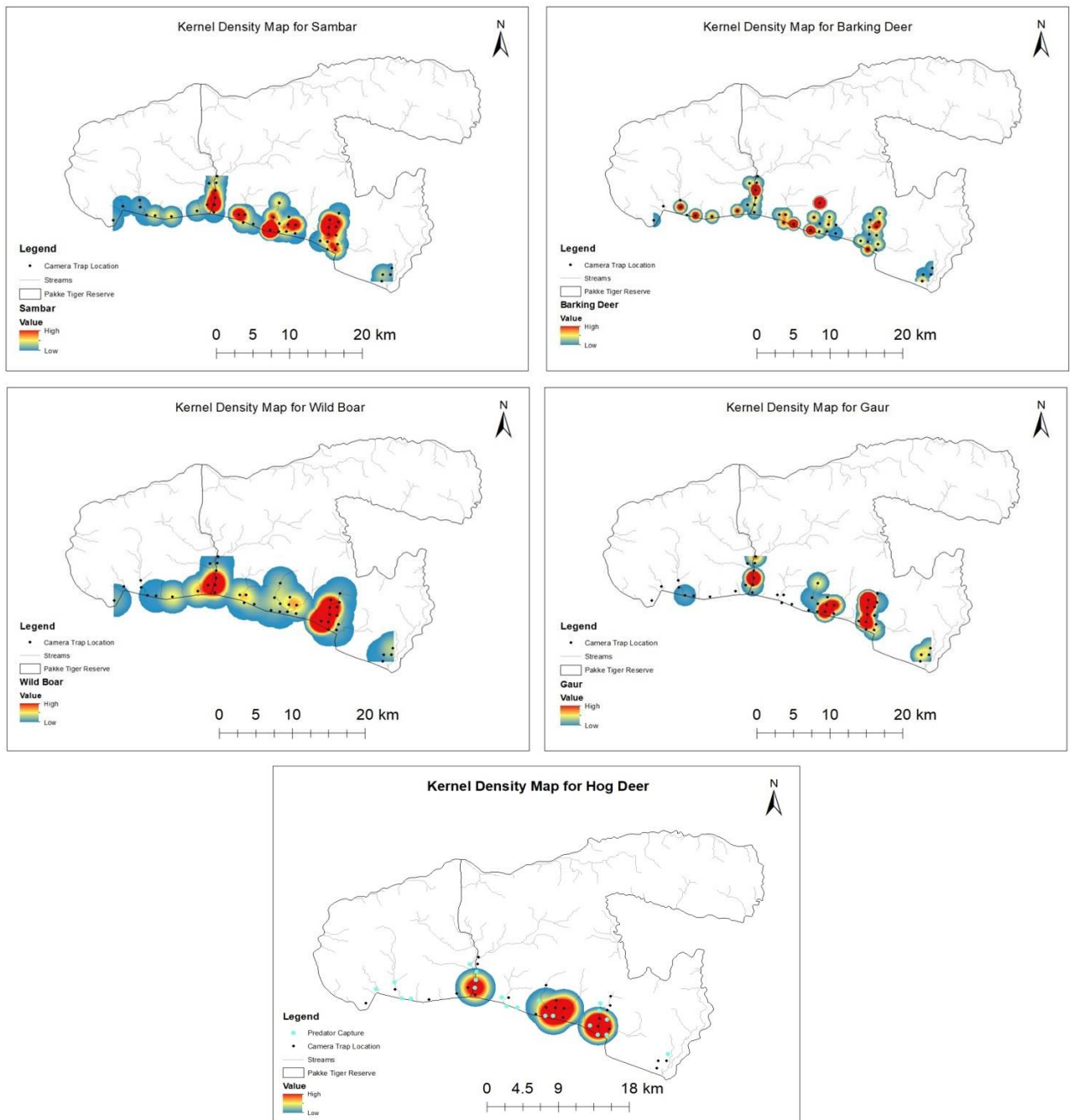
Barking Deer				
Habitat	Lower	Upper	Available	Level of Use
Riverine	0.01	0.03	0.20	Use less
Grassland	0.00	0.01	0.07	Use less
Moderately Dense	0.78	0.82	0.57	Use more
Dense	0.15	0.21	0.17	Use in proportion

Gaur				
Habitat	Lower	Upper	Available	Level of Use
Riverine	0.20	0.31	0.20	Use more
Grassland	0.08	0.17	0.07	Use more
Moderately Dense	0.56	0.68	0.57	Use in proportion
Dense	0.00	0.02	0.17	Zero use

Wild Pig				
Habitat	Lower	Upper	Available	Level of Use
Riverine	0.05	0.11	0.20	Use less
Grassland	0.02	0.05	0.07	Use less
Moderately Dense	0.81	0.88	0.57	Use more
Dense	0.02	0.07	0.17	Use less

Hog Deer				
Habitat	Lower	Upper	Available	Level of Use
Riverine	0.24	0.58	0.20	Use more
Grassland	0.24	0.58	0.07	Use more
Moderately Dense	0.06	0.33	0.57	Use less
Dense	0.06	0.16	0.17	Use less

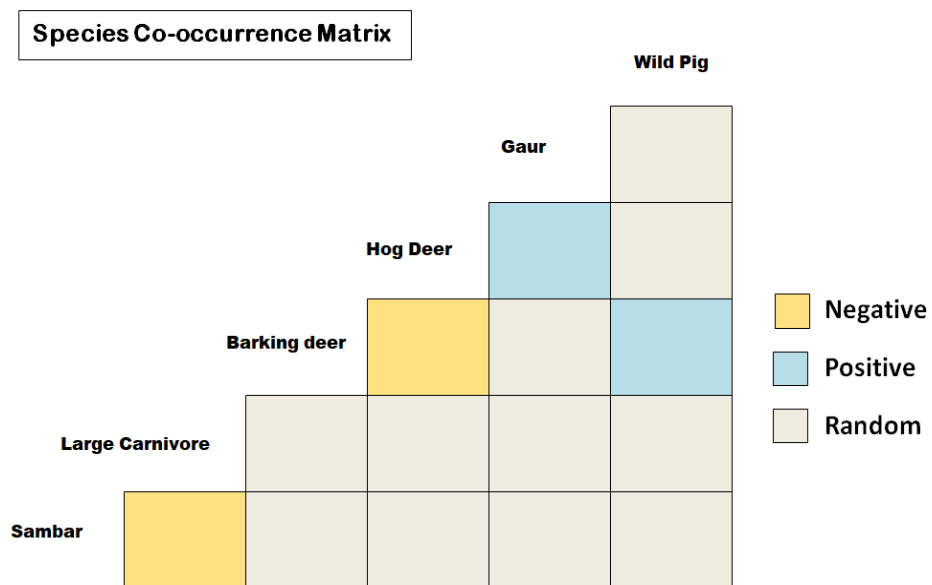
**Figure 10: Kernel density heat maps indicating spatial distribution of ungulates in study area.**



**Note: The cameras were deployed only along the southern boundary of the tiger reserve**

### 4.2.3 Species Co-Occurrence

The probabilistic pair-wise co-occurrence analysis of the data suggests that 11 out of 15 species pair combinations were random (Figure 11, Table 7). These 11 pairs did not have any positive or negative co-occurrence amongst them ( $P_{lt} > 0.05$ ,  $P_{gt} > 0.05$ ). A non-random positive co-occurrence was found between gaur and hog deer ( $P_{gt} = 0.006$ ) and barking deer and wild pig ( $P_{gt} = 0.005$ ). A negative co-occurrence was found between barking deer and hog deer ( $P_{lt} = 0.04$ ) and between large carnivores and sambar ( $P_{lt} = 0.03$ ). Sambar, wild pig, and barking deer are more widely distributed, while hog deer and gaur have clustered distribution (Figure 10). As seen from (Figure 10) there is a negative spatial correlation between sambar and large carnivores, barking deer, and hog deer. Whereas, there is a positive correlation between barking deer and wild pig, gaur, and hog deer. While no significant spatial correlation was found between other pairs.



**Figure 11: Species Co-Occurrence matrix based on probabilistic model of species co-occurrence.**

**Table 7: Pair wise spatial co-occurrence probability table as computed using “co-occur” package in R**

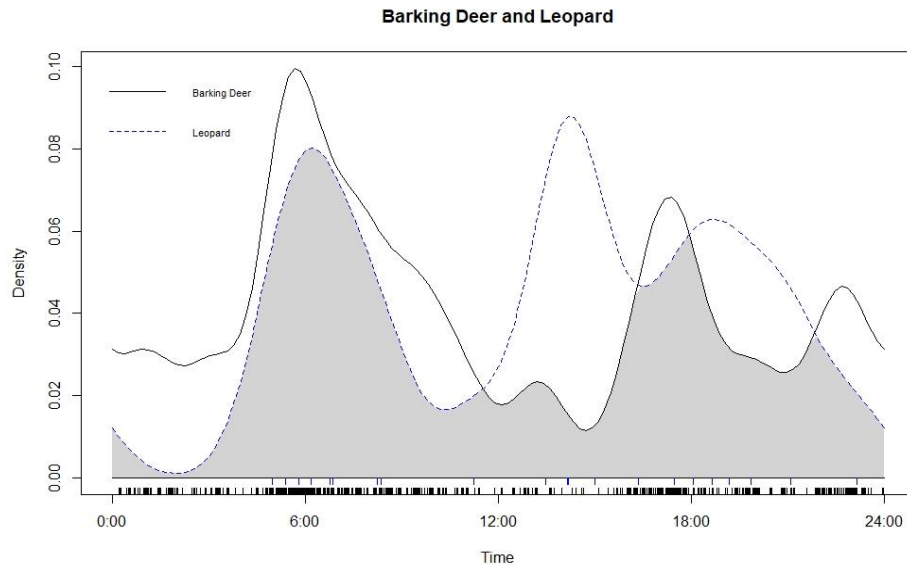
Species 1	Species 2	Sites with Species 1	Sites with Species 2	Obs_cooccur	Prob_cooccur	Exp_cooccur	Plt	Pgt
Sambar	Barking Deer	42	37	34	0.73	33.8	0.83	0.59
Sambar	Gaur	42	18	17	0.35	16.4	0.87	0.48
Sambar	Wild Boar	42	34	32	0.67	31.0	0.95	0.27
Sambar	Hog Deer	42	5	5	0.09	4.6	1.0	0.62
Barking Deer	Gaur	37	18	12	0.31	14.5	0.06	0.98
Barking Deer	Wild Boar	37	34	31	0.59	27.3	0.99	0.005*
Barking Deer	Hog Deer	37	5	2	0.08	4.0	0.04*	0.99
Gaur	Wild Boar	18	34	15	0.28	13.3	0.93	0.20
Gaur	Hog Deer	18	5	5	0.04	2.0	1.0	0.006*
Wild Boar	Hog Deer	34	5	4	0.08	3.7	0.79	0.60
Sambar	Large Carnivores	42	21	17	0.41	19.12	0.03*	1

**Obs\_cooccur** : Observed number of sites having both species, **Prob\_cooccur** : Probability that both species occur at a site, **Exp\_cooccur** : Expected number of sites having both species, **Plt** and **Pgt** : probabilities that those species could co-occur less than or greater than what is observed in our data, respectively.

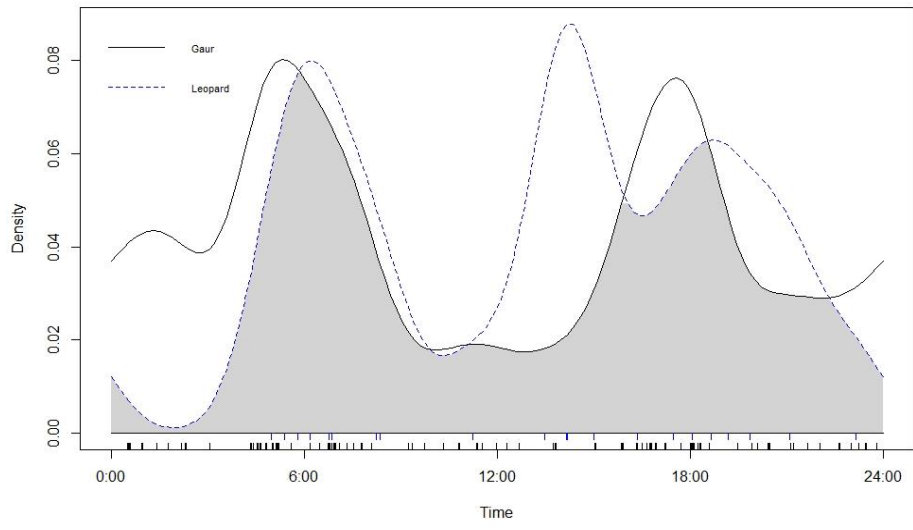
#### 4.2.4 Temporal Overlap between Prey and Predators

A total of 5 large carnivore species were recorded during the study period. The placement of cameras was random (not targeting trails or forest paths) which resulted in very few captures of carnivore species. The Leopard had the highest captures ( $n=24$ ), followed by wild dog ( $n=22$ ), Asiatic black bear ( $n=13$ ), tiger ( $n=10$ ), and clouded leopard ( $n=3$ ). The clouded leopard had the least detections and was therefore discarded from the analysis. The highest overlap was found between leopard and gaur ( $\Delta_1=0.71$ ), and leopard and barking deer ( $\Delta_1=0.70$ ) whereas, the overlap between wild dog and sambar was found to be least ( $\Delta_1=0.36$ ). The coefficient value between the tiger and wild pig was the highest ( $\Delta_1=0.67$ ) and the Asiatic black bear showed the highest overlap with sambar ( $\Delta_1=0.52$ ) (Table 8) (Figure 12).

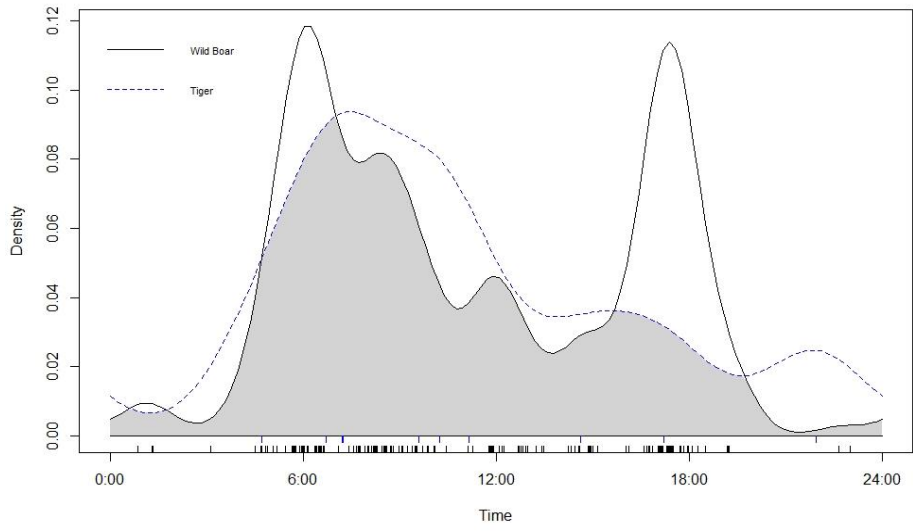
**Figure 12: Activity overlap between prey and predator**



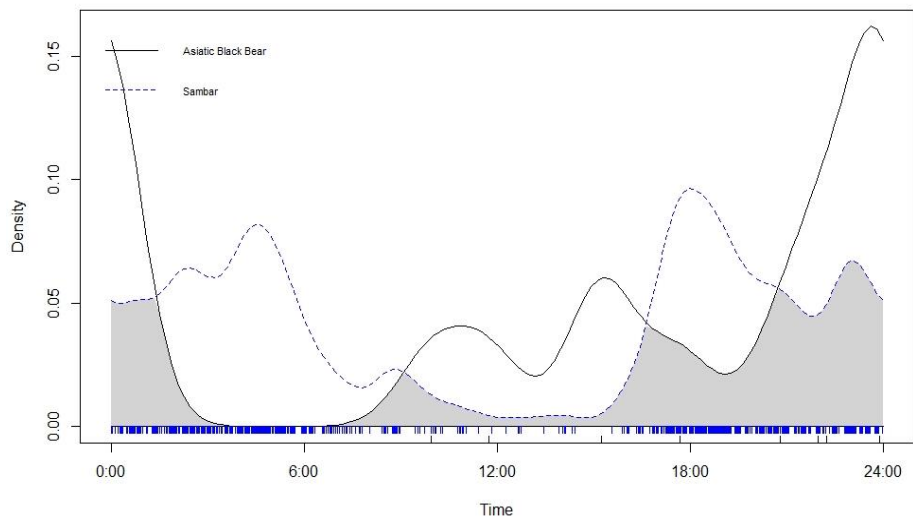
**Gaur and Leopard**



**Wild Boar and Tiger**



**Asiatic Black Bear and Sambar**



**Table 8: Temporal overlaps between prey and predators with the coefficient of overlap  $\Delta_1$  and 95% confidence interval (in brackets)**

	<b>Leopard (n= 24)</b>	<b>Wild Dog (n= 22)</b>	<b>Asiatic Black Bear (n= 13)</b>	<b>Tiger (n= 10)</b>
<b>Sambar</b>	0.57 (0.30-0.58)	0.36 (0.34-0.54)	0.52 (0.30-0.63)	0.45 (0.23-0.67)
<b>Barking Deer</b>	0.70 (0.57-0.84)	0.53 (0.35-0.55)	0.48 (0.31-0.64)	0.66 (0.53-0.90)
<b>Gaur</b>	0.71 (0.59-0.87)	0.52 (0.35-0.58)	0.50 (0.30-0.64)	0.60 (0.44-0.85)
<b>Wild Boar</b>	0.68 (0.51-0.80)	0.57 (0.38-0.58)	0.37 (0.18-0.55)	0.67 (0.57-0.91)
<b>Hog Deer</b>	0.47 (0.23-0.56)	0.44 (0.20-0.51)	0.39 (0.22-0.58)	0.58 (0.37-0.77)

## Chapter 5: Discussion

Estimating abundance and monitoring trends in abundance over time reveal the success or failure of any conservation program. Line transect (Burnham *et al.* 1980), is a well-known method that is used to estimate the abundance of ungulates (Koster & Hart 1988). But most of the studies that use line transect to estimate abundance are inaccessible forested areas, where one can easily walk transect (Bagchi *et al.* 2003, Chundawat & Sharma 2008). The forests of North East India pose a challenge for line transect sampling, firstly the animals occur at very low densities, and secondly, the undulating terrain, coupled with dense understory and ground vegetation, results in logistic difficulties, as well as lower detection of animals on the transect. A study conducted in Namdapha National Park, Arunachal Pradesh used line transect distance sampling to estimate the abundance of ungulates, but only 17 detections of two species with a total effort of over 740 km were observed (A. Datta *Unpubl. data*; Datta *et al.* 2008). Maintaining line transect over time is a challenge due to the fast growth of understory and accessibility. Cutting line transects and maintaining them by clearing the vegetation over the study period may attract or repel the animals which can bias density estimates. Therefore, using line transect distance sampling is logistically as well as methodologically challenging, especially in the hilly and undulating forests of North East India. Motion sensor cameras are widely used in monitoring wildlife populations. Camera trap requires investment of time during deployment. But once deployed they can take pictures 24x7 and also reduces the bias that is caused by transects. Because camera traps are active for 24x7 they can record elusive or cryptic species which are often missed in line transect sampling.

We estimated the abundance of ungulates using two newly developed methods i.e. Camera Trap Distance Sampling (CTDS) (Howe *et al.* 2017) and Random Encounter

Model (REM) (Rowcliffe *et al.* 2008). Both the methods use camera traps to estimate abundance. CTDS is much simpler than REM, as the latter requires an estimate of animal speed which is often hard to obtain with a cheaper camera. Both these methods required the estimation of the distance of the animal from the camera trap. While all ungulate abundances (except elephant) were estimated using CTDS, we were able to only estimate the density of wild pigs using REM, due to time constraints. Therefore, for the comparative analysis, I am using the density of wild pigs estimated by camera trap distance sampling and the random encounter model. The density estimate for wild pig obtained from CTDS was  $0.67 \pm 0.17$  individuals per sq. km, with a 26.70 percentage coefficient of variation associated with it. Using REM, the density of wild pig was estimated to be  $0.74 \pm 0.22$  individuals per sq.km with a 28.90 percentage coefficient of variation associated with it. The estimate obtained from both methods did not differ. Using CTDS, barking deer had the highest density of  $4.01 \pm 1.41$  individuals per sq. km and hog deer had the lowest density of  $0.39 \pm 0.23$  individuals per sq. km. Another study in the area using line transect-based estimates (Selvan *et al.* 2014a), covering 600 km in three years estimated wild pig density as  $6.7 \pm 1.2$ , sambar density to be  $3.8 \pm 0.5$ , and Gaur density as  $3.5 \pm 0.9$ . The precision on the density estimates was not different between CTDS and line transect-based sampling, the density estimate of combined three years differ significantly for Gaur, and wild pig, while similar for barking deer and sambar. However, it is difficult to compare these estimates with those calculated in the quoted study, in absence of simultaneous use of two methods.

Of more importance, we found hog deer to be distributed at low densities ( $0.39 \pm 0.23$  individuals per sq. km), and this species was not reported on the line transect-based sampling by (Selvan *et al.* 2014a) in their sampling. This exemplifies the need for

camera trap-based sampling methods, especially for species that are distributed in low densities and those species which are nocturnal and elusive. The area sampled by CTDS is much higher, ranging from 29 sq. km to 308 sq. km in 88 days, while through line transect, 15.6 sq. km of the area was sampled in 300 days, over three years. Through CTDS a wider coverage, in terms of area and time of day is achieved, when compared to the traditional line transect method.

Body size and physiology in ungulates play an important role in resource partitioning over space and time (Illius & Gordon 1992). Ungulates can be divided broadly into grazers that predominantly feed on grass and browsers that feed on shrubs, fruits, and woody plants. There is a decline in metabolic rate with an increase in body size. The length of the digestive tract increases with body size and therefore large body size ungulates have a low metabolic rate and can tolerate relatively poor quality of forage (Bell 1969). On the other hand, small body size ungulates have a small digestive tract and a high metabolic rate and energy requirements and are constrained by a high-quality diet (Belovsky 1986). Therefore, digestive physiology and body size both combined influence the ungulates niche and species coexistence (Illius & Gordon 1992). Ungulates with the same body size might use different habitats or patches to avoid competition over food. We expect a competition or partitioning between gaur and sambar, and hog deer, barking deer, and wild pig. Both sambar and gaur have large body sizes and both are found to segregate themselves spatially by using different habitats and forage selectivity (Ahrestani *et al.* 2012). The habitat use analysis of our study suggests that sambar uses moderately dense forest more than availability and riverine, grassland habitat less than availability. On the other hand, Gaur uses riverine and grassland habitat more than availability, and moderately dense habitat is used in proportion to availability. Sambar is predominantly a woodland

species and prefers forested habitats. Barking deer uses moderately dense and dense habitat more than availability and riverine and grassland habitats are used less than the availability. Hog deer which is of similar body size as barking deer show a contrasting difference in habitat use. Hog deer uses riverine and grassland habitat more than availability and moderately dense habitat are used less than availability. It completely avoids the use of forested habitats. Wild pig, which is in a similar size class, shows some overlap with barking deer, as it uses moderately dense habitat more than availability. However, Wild pig has an omnivorous diet and feeds on wide variety of food sources, and therefore shows dietary partitioning with barking deer. Temporally, there was ample overlap between ungulates and carnivores captured in the study area. However, the dataset of carnivore is very small to make any meaningful comparison.

## Chapter 6: Conclusion

In this study, we set out to understand the robustness of different abundance estimation methods for ungulate species. We found that CTDS provides a useful methodological tool for sampling ungulate populations, as it reduces human biases, is logistically simpler, and can sample a larger area, and more time of the day, when compared with other methods. Other methods like transects are only able to sample a small area, and ~12-15% of a day, which results in missing out on animals whose activity does not fall during this period or which are at lower densities. The diversity of species captured is also limited in line transect-based methods. While REM estimates were comparable to other methods, the technical difficulties in analyzing the camera trap images make CTDS a more feasible tool for density estimation. In comparison between the methods, we did not find any difference in the precision of estimates. Simultaneous use of CTDS and line transect methods, which was not possible during this study, will yield a better comparison between the methods. The camera trap tool also provides useful information on capturing ecologically meaningful activity patterns, unbiased habitat use, and association or competition amongst sympatric species. There are very few studies across similar habitats (Gray *et al.* 2012, Selvan *et al.* 2014a), which have quantified absolute abundances or habitat preferences of species, focussing on ungulates. This study was able to demonstrate the applicability of camera trap-based methods for obtaining information that is useful for conservation inputs. Habitat use indicates animal segregation on an ecological basis, i.e., similar body size animals segregate by adapting different habitat types, and food habits. This informs us on focused conservation efforts on improving certain habitats for low-density species.

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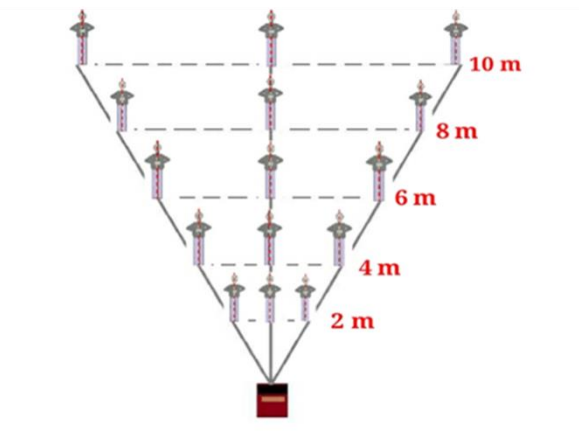
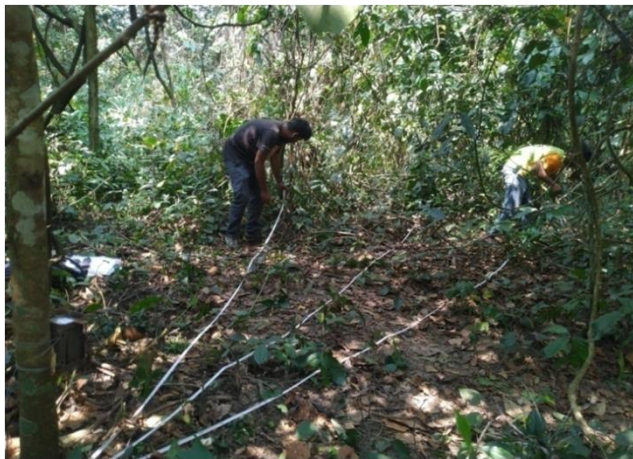
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# Appendix

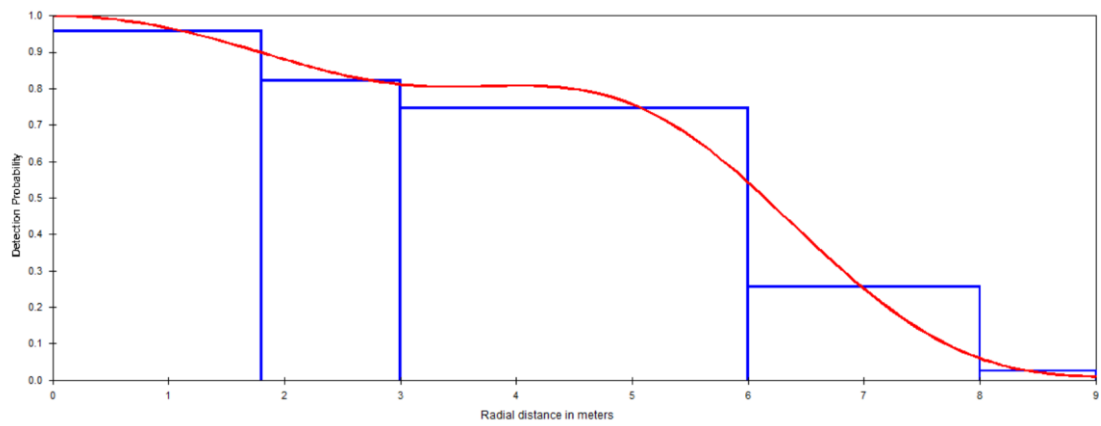
## Appendix A – Camera Calibration



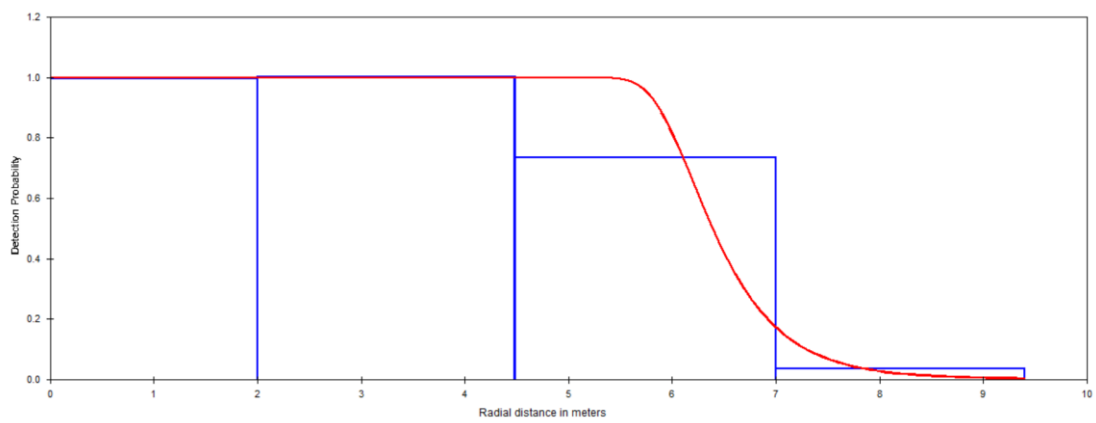
Three tapes were laid in front of the camera FOV and the researchers were photographed holding a pole of 2m length and a distance marker. This was done in the centre and on both sides of the camera's field of view (FOV)

## Appendix B – Detection function curves for ungulates

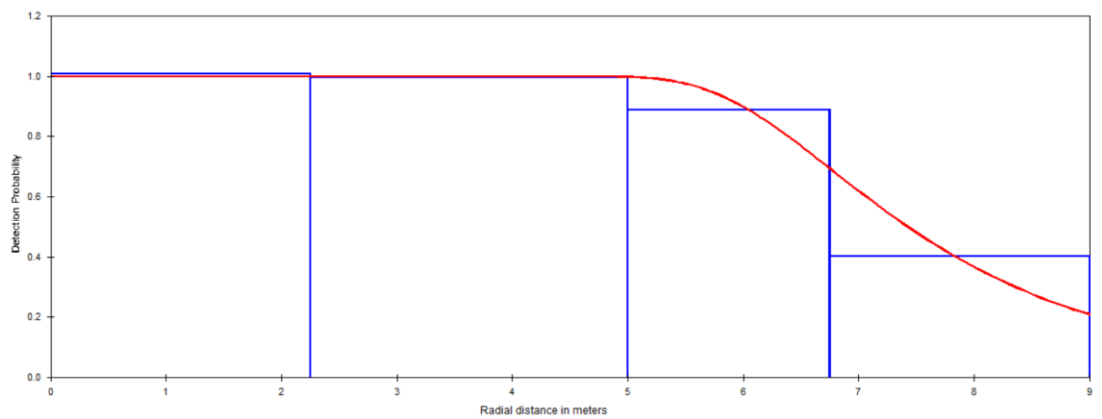
### 1. Sambar



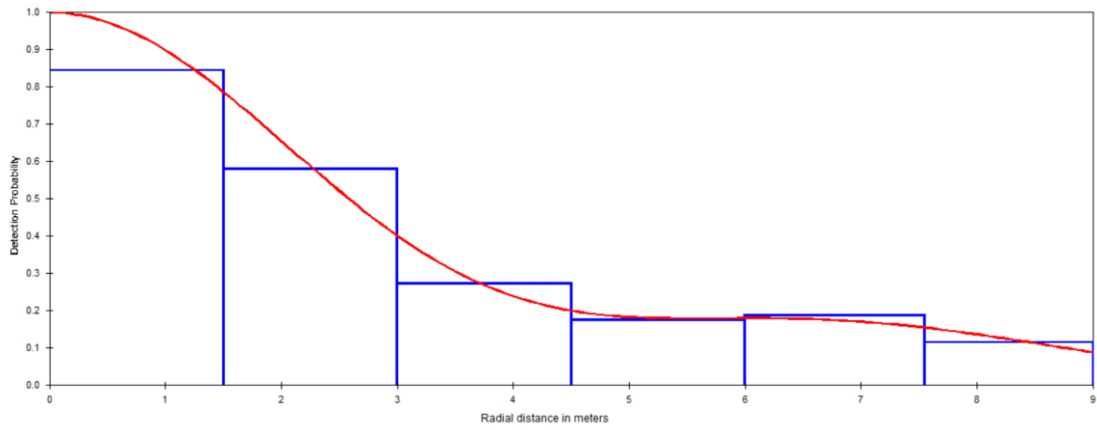
### 2. Barking Deer



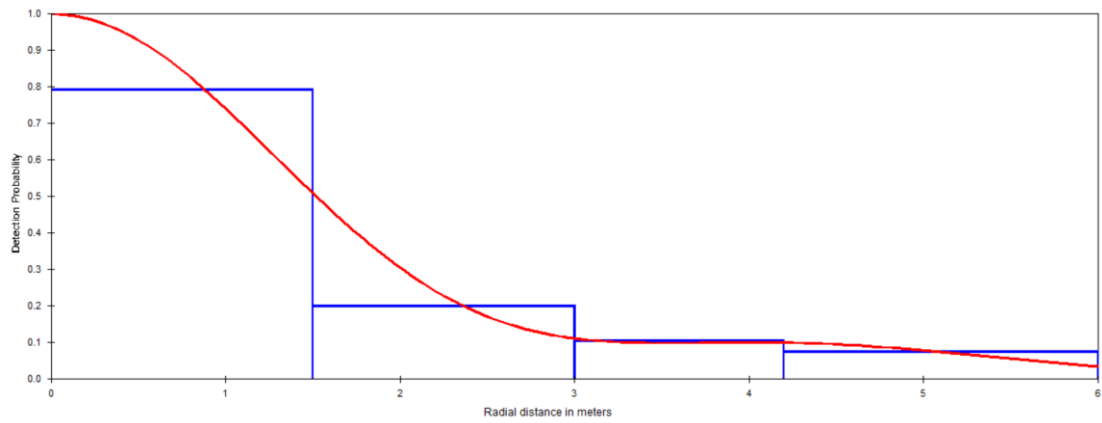
### 3. Wild Pig



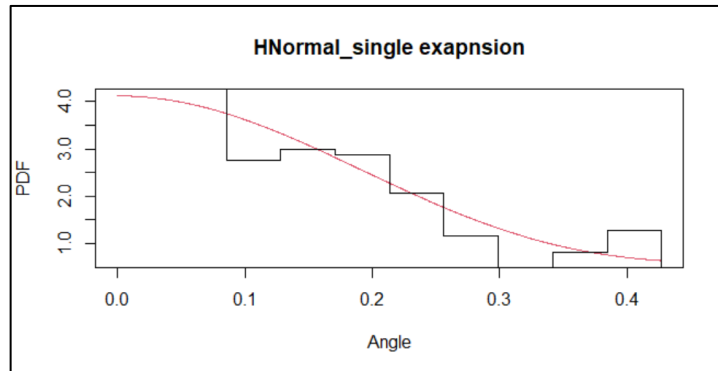
#### 4. Gaur



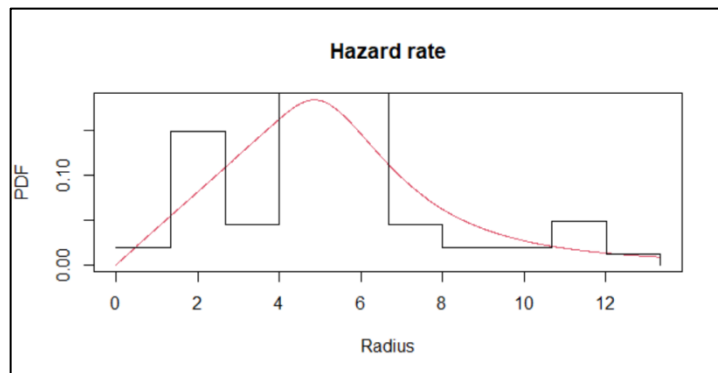
#### 5. Hog Deer



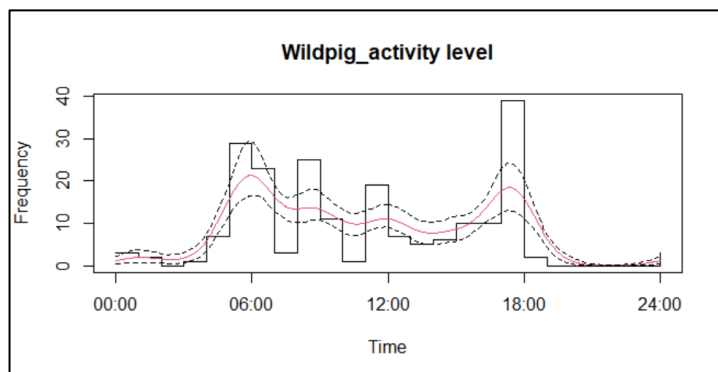
## Appendix C – Graphs from Random Encounter Model (REM) analysis



Probability densities function for detection angle for wild pig. The black bars represent density distribution of data and red curve represents best fitted model.



Probability densities function for detection angle for wild pig. The black bars represent density distribution of data and red curve represents best fitted model.



Activity Pattern of wild pig, the grey bars represents the observed frequency of wild boar's first detection, whereas the red curve represents fitted circular kernel distribution with 95 % confidence interval bands shown by grey dotted lines.

