# MATERIALS AND METHODS

## Field Data Collection for Occupancy Analysis

### Tiger Sign Surveys

The entire study area was divided into 10 km x 10 km grids. Each grid that contained potential tiger habitat (forest) was surveyed by replicate search paths for tiger sign. The number of surveys per grid ranged from 3 to 35, and was proportional to the amount of tiger habitat within each grid. Each survey consisted of a 5 km search for tiger signs. Surveys were not random, but instead conducted along features that were likely to have tiger sign e.g. dirt roads, dry water courses, and animal trails (Jhala et al. 2011). Surveys were conducted by the local guard and a local assistant who had intimate knowledge of the forest and were trained to observe and record tiger sign in pre-designed datasheets. All encounters of tiger pugmark track sets and scats were recorded. These were distinguished from those of other carnivores based on criteria described by (Jhala et al. 2009 and Karanth and Nichols 2002). A total of 44,8005 km of search effort was invested in 89,600 replicate surveys between December 2009-February 2010 (cold and dry season) across the entire country to adhere with the assumption of occupancy closure (MacKenzie et al. 2006) and have minimal influence of weather (rainfall) on sign detections and distribution. A total of 9309 grids were sampled.

### Prey Assessment

Within each forest beat, one or two permanent line transects of 2 to 4 km in length were delineated. Each transect was walked on two or three subsequent mornings (06:30 to 08:30 hrs) by two observers to record encounter rates of wild ungulates and domestic livestock. Data on number of each species seen and the length of transect were recorded to compute encounter rates of each species. In disturbed forests (outside of Protected Areas) wild ungulate densities were low, animals were shy, and difficult to record using line transects. Therefore, at every 400 m along the line transect we also sampled a plot of 20 x 2 m to record ungulate dung. Dung was visually distinguished to species (Jhala et al. 2009) and dung density for each species, wild ungulates as a group, and domestic livestock was computed separately. Encounter rates of ungulates and dung density were used as indices of ungulate abundance. The number of transects within each 100 km$^2$ grid ranged from 1 to 74, and were proportional to the quantum of tiger habitat within that grid. Total effort invested in transect survey was 1,79,202 km of walk in 89600 replicates.

Human Disturbance - At every 400 m along transects established for ungulate assessment a plot of 15 m radius was sampled to assess indices of human impact. Presence of (a) human/livestock trails within the plot, and (b) sighting of humans and livestock from the plot were recorded (Jhala et al. 2009) The number of plots within a 100 km$^2$ grid ranged from 5 to 147. The total number of plots sampled across the country was 4,48,000.

### Remotely Sensed Variables

Remotely sensed data that depict landscape characteristics and human impacts were obtained from various sources and extracted at the 10 X 10 km grid. Forest cover was obtained from the Forest Survey of India (FSI 2009) that is based on IRS 1D LISS III satellite with 4 multispectral band data at 23.5 m resolution. Normalized Differential Vegetation Index (NDVI) information were derived from 1 km$^2$ Advanced Very High Resolution Radiometer (AVHRR) data, acquired from the National Aeronautics and Space Administration's (NASA) Television Infrared Observation Satellite (TIROS) (http://science.nasa.gov/missions/tiros/; accessed Dec 23, 2010). Road and drainage information were obtained from Digital Chart of the World (http://statisk.umb.no/ikf/gis/dcw/; accessed Dec 20, 2010). Protected Area shape files were obtained from the wildlife database at the Wildlife Institute of India, National Tiger Conservation Authority and State Forest Departments of India. The

Shuttle Radar Topography Mission has produced the most complete, high-resolution digital elevation model of the earth (Rodriguez et al 2005). Within each 1 $km^2$ grid, this information was used for computing average elevation and the coefficient of variation of elevation used as a measure of terrain ruggedness. Night light data was obtained from U. S. Air Force Defense Meteorological Satellite Program (DMSP) and National Oceanic and Atmospheric Administration's (NOAA) Operational Linescan System (OLS) (http://www.ngdc.noaa.gov/dmsp/sensors/ols.html; accessed Dec 18, 2010). Density of roads (length of paved road per $km^2$), and Euclidean distances to roads, Protected Areas and Night Lights were computed in ArcGIS 9.3 (www.esri.com) software.

## Occupancy Modeling

Though sampling was done at the level of the forest beat so as to ensure an even distribution of sampling effort across the landscape, analysis was done at the scale of 9309 grids, each of size 10x10 $km^2$. This grid size was chosen since it was larger than the size of an average tiger home range (Sharma et al. 2010, Karanth KU and Sunquist ME 2000) and the size was relevant for subsequent administrative and managerial inputs. Sign surveys of 5 km independent spatial replicates within each grid (Kendall WL and White GC 2009) were modeled to address the issue of imperfect detections of tiger sign using program PRESENCE (Hines 2006). Detection of tiger signs was likely to depend on the abundance of tigers within a grid (Karanth et al. 2011). We first modeled the detection process by i) keeping detection ($\hat{P}$) constant across surveys, ii) $\hat{P}$ varying across surveys and iii) $\hat{P}$ as a function of tiger abundance in that grid, wherein we used average encounter rate of tiger sign as an index that surrogated tiger abundance (Jhala et al. 2011, Karanth et al. 2011). The model that best explained the detection process based on Akaike Information Criteria (AIC) was then used in all subsequent models of tiger occupancy.

Tiger site occupancy was a *priori* expected to be positively influenced by a) prey abundance, and b) amount and quality of tiger habitat, and negatively influenced by c) human disturbance (Jhala et al. 2011, Karanth et al. 2011, Harihar and Pandav 2012). We tested these hypotheses by modeling variables representing these factors as covariates using the logit link function in PRESENCE (MacKenzie et al. 2006, Hines 2006). We initially generated data on 23 site covariates that represented landscape and habitat features (Forest area, Core Forest area, Forest patch size, Normalized Differential Vegetation Index (NDVI), Elevation, Ruggedness, drainage density, rainfall, distance to protected area), Prey availability (Chital, Sambar, wild pig and Gaur encounter rates on line transect walks, and wild ungulate dung density), human disturbance (distance to night lights, distance to roads, humans and livestock encountered on transect walks, human/livestock trails within sampled plots, and livestock dung density) that could potentially explain tiger occupancy. These covariates were examined with exploratory data analysis for their interrelationships and relationship to tiger presence (by scatter plots, box plots, and correlation analysis). The variables were modeled as covariates in a logit link function to model tiger occupancy in the program PRESENCE available for download from http://www.proteus.co.nz/]. Model selection was done using AIC and model fit was assessed by comparing the actual detection histories with simulations generated from 50,000 parametric bootstrap runs of the target model in PRESENCE. Models were built using prey abundance, human disturbance and habitat quality, these were evaluated against the null model and the full model by their delta AIC values. A total of six models were evaluated for modeling tiger occupancy and coefficient estimates for all models with delta AIC $< 2$ were averaged based on model weights (MacKenzie et al. 2006) to arrive at occupancy probability ($\Psi$) in each grid (Yumnam et. al. 2014).

## Tiger Population Extents and Occupied Habitats

We used two approaches to estimate population extents and area of occupied habitats; (i) a more conservative approach wherein we considered only those grids that detected tiger sign as being occupied (the naïve estimate) and (ii) model inferred occupancy that corrected for detection bias and covariates in PRESENCE. Herein, landscape scale occupancy was computed by sum of cell occupancy probability values and divided by the total number of cells. Tiger habitat (forested area) in each grid was weighted by the tiger occupancy probability of that grid and summed across all grids to arrive at occupied tiger habitat for the landscape (Karanth et al 2011). All adjacent tiger sign detected cells were joined and were considered to be occupied by a single tiger population.

## Habitat Corridor Modeling

Grid based tiger occupancy probability ($\Psi$) obtained from PRESENCE was used as a measure of habitat suitability for tigers (Boyce et al. 1999, MacKenzie et al. 2006). A cost surface for tiger habitat suitability across grids was generated as $1-\Psi$. This was used as a resistance layer for modeling habitat connectivity using least cost (Sawyer et al. 2011) and circuit theory (McRae  et al. 2008) analyses. Least-cost pathways (LCP) were modeled using PATHMATRIX (Ray 2005), and resistance pathways were modeled using CIRCUITSCAPE (McRae and Shah 2009). Core areas of tiger reserves were considered as "sources" or areas of high potential from which tiger movement across paths of least resistance were modeled across the landscape. PATHMATRIX models several potential routes in a radiating manner from the "source" to connect to another adjacent "source". It then selects a single "least cost" pathway as the best alternative. CIRCUITSCAPE models connectivity through habitat swaths, considering resistance to movement based on pixel cost and corridor width (McRae et al. 2008). It provides one to several potential alternatives for joining sources and helps in identifying bottlenecks within the corridors. Since Central Indian Landscape is a human dominated landscape with clearly defined and limited forested habitat, we could overlay LCP on high resolution Google Earth images and align them to match geographical features within occupancy grids, to delineate realistic corridors. These least cost corridors buffered by 1.5 km (LCC) were considered the minimal essential corridors joining two tiger reserves.