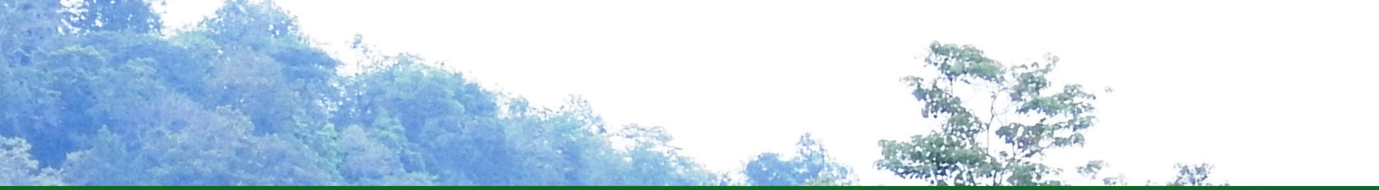

NATIONAL ELEPHANT SURVEY REPORT

Status of the mega-herbivore in Bhutan

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Suggested citation:

NCD, 2018. National Elephant Survey Report. Nature Conservation Division, Department of Forests and Park Services, Ministry of Agriculture and Forests, Thimphu, Bhutan.

Photo credits: Department of Forests and Park Services, Gem Tshering and Sonam Wangdi, Nature Conservation Division, Dorji Rabten, Phibsoo Wildlife Sanctuary

ISBN-978-99936-620-8-2

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ROYAL GOVERNMENT OF BHUTAN
Ministry of Agriculture & Forests
Tashichhodzong, Thimphu : Bhutan

དྲུང་ཆེན།
SECRETARY

8th August 2018

Foreword

The elephants have long captivated the imagination of human beings. They are an integral part of religion and culture. In Bhutanese culture, elephants are portrayed as an important figure; the most prominent observed in the 'four harmonious friends' or *Thuenpa Puenzhi*. Further, the elephant also constitutes one of the important elements of the seven precious possessions or *Rinchen Nadun*. Despite reverence, elephants have suffered range loss and population decline due to habitat fragmentation and poaching. Elephants are classified as endangered by the International Union for Conservation of Nature (IUCN). In Bhutan, elephants are protected under Schedule I of the Forest and Nature Conservation Act, 1995.

This report will be immensely helpful in developing the conservation management or action plan for elephants in Bhutan. The findings show that Bhutan is doing pretty fine in terms of wildlife conservation per se. Given the habitat and available space, a total population of more than 600 elephants seems to be reasonable. This indicates that our conservation policies are on the right track. While we celebrate another milestone in our conservation journey, we also need to be cautious about the emerging challenges.

I am delighted to share that, with this report, we now have national figures on most megafauna species (such as tiger, snow leopard, grey langur, golden langur and now elephant). With the start of the Twelfth Five Year Plan, it gives us an opportunity to plan and prepare for the conservation management of important megaherbivore and to strive to strike the balance between conservation and development.

I congratulate the Department of Forests and Park Services and in particular Nature Conservation Division for producing this report. I also thank all field crews who were part of this survey. Lastly, my sincere gratitude and appreciation to the donors for supporting Bhutan in her endeavor to achieve conservation success.

Trashi Delek!

(Rinzin Dorji)

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Royal Government of Bhutan
Ministry of Agriculture and Forests
Department of Forests and Park Services
Thimphu

DIRECTOR 8th August 2018

Preface

Elephant, the largest living terrestrial mammal is greatly revered and worshiped throughout the Asian culture and religion. In Bhutan, elephants are respected as godly creatures often depicted as wall paintings, statues and in religious ceremonies. However, the Asian elephant is listed as "Endangered" by the IUCN and found only in 13 range countries including Bhutan. It is indeed very sad that their population in the wild is declining due to habitat loss, conflict with humans and poaching and illegal trade. Nevertheless, Bhutan stands today as one of the most important habitats for this mega herbivore.

As part of the global effort for conservation of the Asian elephants, Bhutan completed the third nation-wide elephant survey recently. I am very glad to introduce this National Elephant Report which is a testimony to Bhutan's commitment in conserving these giant pachyderms. I am also pleased to state that this report is a product of latest survey methods and robust statistical data analyses by our own team.

This scientific report discusses in detail about how the camera trap data along with home range data are being used for estimation of Asian elephant population and distribution in Bhutan. We estimated 678 (605-761) elephants in Bhutan at a density of 0.29 individuals/100km^2 with estimated habitat use probability of 81% of potential elephant habitat in southern Bhutan. The report recommends increased habitat connectivity to reduce conflict with humans besides habitat improvement and increasing protection against poaching for ivory.

I would like to express my appreciation and congratulations to the Nature Conservation Division for coming up with this report. I acknowledge the hard work and dedication by all the field staffs and others involved during the survey and data analyses. Lastly, I thank the generous financial support from our conservation partners particularly WWF Bhutan in this survey.

Best Wishes and Tashi Delek!

(Phento Tshering)

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Ministry of Agriculture and Forests
Department of Forests & Park Services
NATURE CONSERVATION DIVISION

"Managing Bhutan's Natural Heritage"

8th August 2018

Acknowledgement

The Nature Conservation Division would like to sincerely thank all the Chief Forestry Officers and survey team members from the elephant range protected areas and Territorial Divisions for painstakingly collecting the data. Without your dedication and enthusiasm, a survey of this intensity and size would not have been possible.

We gratefully acknowledge the contributions of Mr. Phurba Lhendup and Mr. Kuenley Tenzin (WWF Bhutan), Mr. Rinzin Dorji (Gedu Territorial Division), Mr. Ugyen Tshering, Mr. Leki Chaida and Mr. Chaten (Jomotshangkha Wildlife Sanctuary), Mr. Kinley Gyeltshen and Mr. Kinga Norbu (Phibsoo Wildlife Sanctuary), Ms. Tshewang Jaimo (Royal Manas National Park), Mr. Chimi Dorji (Samdrup Jongkhar Forest Divisio), Mr. Yeshi Dorji (Samtse Territorial Division) and Mr. Jigme Tenzin (Sarpang Territorial Division) in formulation of this technical report.

We also remain highly indebted to Dr. Raman Sukumar and Dr. Varun R. Goswami for their valuable feedbacks and inputs in finalizing this report.

We would like to extend our heartfelt gratitude to the generosity extended by our partners in conserving and promoting our rich biodiversity. In particular, we acknowledge the generous financial support rendered by WWF Bhutan and Bhutan Trust Fund for Environmental Conservation in the field data collection and data analyses.

Nature Conservation Division 2018

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Executive summary

In addition to the nation-wide surveys for tiger and snow leopard, in 2016 Nature Conservation Division, Department of Forest and Park Services with the support of field divisions and protected areas conducted National Elephant Survey. This survey spanned the whole southern districts covering almost an area of 8000 km^2 of potential Asian elephant habitat in Bhutan. This survey combined multiple methods of detection using camera traps in conjunction to dung DNA sample collection in 129 of each 25km^2 grid cells. The survey was conducted between March and June 2016. The survey aimed to estimate the elephant density and abundance, assess the distribution and habitat use and develop a national database of the elephant.

The analytical method for estimating elephant density and abundance involved the use of ensemble models. The photographic records were analyzed under various modeling frameworks such as N-mixture, Royle-Nichols, and occupancy models. The feat in the use of these models lies in the flexibility and conspicuousness of model building. A user can explicitly account for detection probability which is an inherent idiosyncratic problem in ecological studies. However, there are certain model assumptions that must be adhered to achieve reliable estimates.

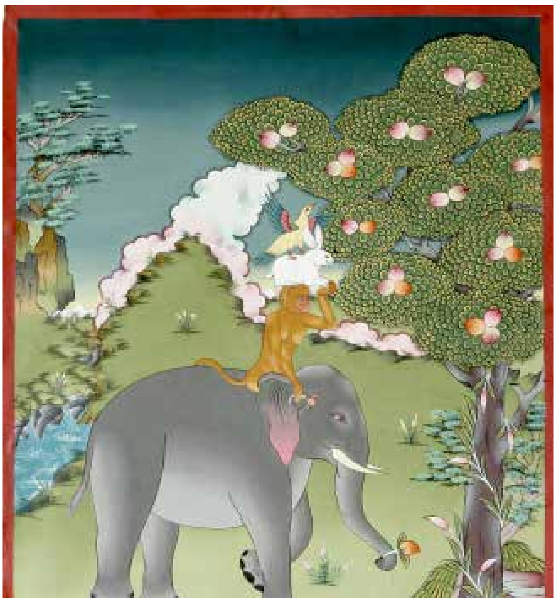
The camera traps were retrieved from 123 out of 129 camera stations. The elephants were detected at 90 out of 123 stations over the effort of 6564 trap days. For analyses, 446 images from 123 stations were used. The elephant density is estimated at 0.29 individual per 100 km^2 (95% confidence interval 0.26 – 0.33) and the total elephant numbers are estimated at 678 (range 605-761). The estimated occupancy probability is 81% (meaning 81% of the *c.* 8000 km^2 potential elephant habitat have a high use probability by the elephants).

The adult male to female sex ratio estimated from the photographic record is 1:2.3 indicating a stable ratio. This also implies that the current regime of intensive protection is paying dividends. Elsewhere, the population stability is grappling with skewness due to mortality of male (bull) elephants to poaching.

The elephant abundance and habitat use are favored by high forest cover with a mosaic of the river system and the abundance and habitat use decrease with increased elevation. The population is shared between Bhutan and India and conservation entails transboundary cooperation. Further, it is recommended to perform periodic monitoring of elephant population and demography. Furthermore, stringent anti-poaching/counter-poaching measures should be enhanced and strengthened to ensure the safety and perpetuity of this majestic mega-herbivore.

1. Introduction

The Asian elephant (*Elephas maximus*) is feared and revered for its magnificence and sheer power in history and culture. Elephants are portrayed as an important figure in Bhutanese culture. The most prominent one seen in the 'four harmonious friends' (or *Thuenpa Puenzhi)* paintings on the walls of Bhutanese structures (Jigme and Williams, 2011). Here one can see an elephant supporting the monkey who in turn supports a rabbit and a pheasant collaborating together to harvest the fruits of wisdom. Elephant constitutes an important element of the seven precious possessions (or *Rinchen Naduen*), *Langpo Rinpoche* (or the Precious Elephant) which signifies strength and power (Phuntsho, 2017). Further, elephants are also revered as a form of Buddha (*meme Sangay* literally translating to 'grandpa Buddha' in *Sharchop kha*, one of the local dialects of Bhutan). Further, in Hindu culture elephants are worshipped as Lord Ganesha (son of mighty Lord Shiva). Elephants, in addition to value as a charismatic mega-vertebrate, is also considered as premier flagship and umbrella species (Fernando et al., 2008). Elephants are known seed dispersers across different habitats and potentially disperse seeds over long distances thus helping in the key process of the population and community dynamics in plants (Corlett, 1998; Wang and Smith, 2002; Campos-Arceiz, et al., 2008).



The historical range of the Asian elephant extended from west Asia through the Iranian coast to the Indian subcontinent, eastwards into south-east Asia, including Sumatra, Java and Borneo and Yangtze-Kiang in China, covering an area of approximately 9 million km^2 (Olivier, 1978; Sukumar, 2003). Today, the range of this mega-herbivore is much reduced, and it is considered to be under grave threat from habitat loss, degradation, conflict and ivory poaching (Leimgruber et al., 2003; Sukumar, 2003; Goswami et al., 2007). So much so that the species is classified as endangered under the International Union for Conservation of Nature (IUCN) Red List of Threatened Species and listed on Appendix I of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the only living species of genus *Elephas* (Sukumar, 2006).

In Bhutan, elephants are totally protected under Schedule I of the Forest and Nature Conservation Act of Bhutan, 1995 and distributed throughout the southern belt of Bhutan (Samtse, Chhukha, Dagana, Phibsoo Wildlife Sanctuary, Sarpang, Royal Manas National Park, Samdrupjongkhar and Jomotshangkha Wildlife Sanctuary). They have been recorded from elevations as low as 100m to above 2000m, and have been found to use diverse habitats ranging from subtropical forests to cool broadleaved forests.

The first nation-wide elephant survey was conducted in 2005 based on the direct observation and block count method (Jigme and Williams, 2011). The results from this survey were accompanied by high uncertainties because of a limited number of direct sightings. In 2010, another survey in high elephant occurrence sites (in Samtse, Sarpang, and Phibsoo Wildlife Sanctuary; the total studied area of 800 km^2) was conducted using a more refined method: dung transect surveys of 4-km each in grid quadrats of 25 km^2 (Jigme and Williams, 2011). This survey estimated the density of elephants to be 0.641 individuals per km^2 and a total number of 513 elephants (range 30-1797; Jigme and Williams, 2011). However, this method still yielded a very variable estimate given that the confidence interval ranged from 30 to 1797 elephants. The most recent survey was conducted in 2016 using a much-refined survey methodology in all sites in the southern part of Bhutan where elephant presence was previously recorded (see details in Methodology). This method, unlike the previous methods, combined different data collection strategies to yield better estimates of elephant abundance. The main aim of the 2016 survey was to estimate with confidence the elephant abundance in Bhutan. With discontinuous elephant population estimates throughout the range countries, the need was felt to provide empirical evidence to effectively manage the population that is found in Bhutan.

One of the fundamental objectives of wildlife population management, or rather any ecological investigation, is to understand the relationship between abundance and habitat association (Royle, 2004). The main objectives of the 2016 survey were:

i. Reliable estimation of Asian elephant density and abundance in Bhutan.
ii. Understand the distribution and habitat use of Asian elephants in Bhutan.
iii. Develop a national database (photographic record) of elephants.

2. Materials and Methods

2.1. Study area

Bhutan is a small landlocked country sharing borders with China in the north and India to the east, west, and south. The survey was conducted in the southern region encompassing Samtse Territorial Division, Chhukha (Gedu Territorial Division), Phibsoo Wildlife Sanctuary, Sarpang Territorial Division, Royal Manas National Park, Samdrupjongkhar and Pemagatshel (Samdrup Jongkhar Territorial Division) and Jomotshangkha Wildlife Sanctuary (Figure 1).

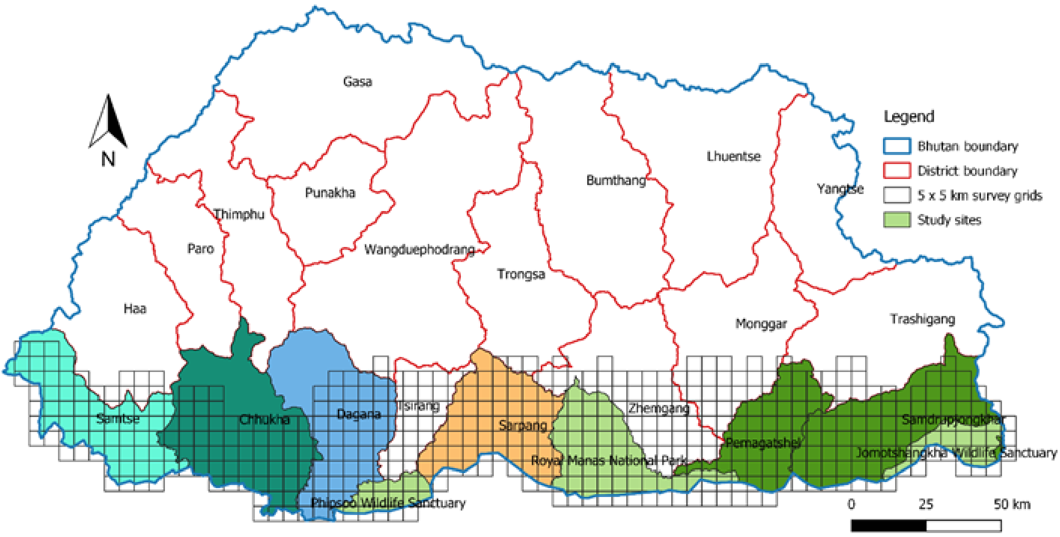


Figure 1. Study area and survey grids

All the study sites share an international border with the Indian states of West Bengal and Assam. The forest type throughout the study range is a mix of subtropical forest and warm broadleaved forest on the higher slopes. The rainfall pattern in the study sites is heavy during the monsoon between June and September. Spring (February – April) and fall (September – October) are warm and winter (November – January) is cool and dry. The elevation ranges from 100m in the plains to above 2500m in the northern part of these study sites.

2.2. Field survey

The field survey was conducted between March and May in 2016 (but some camera traps were left for more than three months due to heavy rainfall during this period). The study area was overlaid with square grid cells of 5 x 5 km (25 km^2 area; Fig. 1). Sign surveys were conducted in those grid cells to ascertain the presence of elephants and the grid cells were identified where camera traps would be installed. In each grid cell, paired camera traps were installed facing each other at least 5m apart to avoid the flash of one camera trap spoiling the image taken by the other. The cameras were positioned at a height of 100cm above the ground to capture the full image of the elephants. Five different camera models were used (Bushnell, Cuddeback, HCO, Uway and Panthera). Further, dung samples were also collected during the transect walk in each grid cell to extract DNA samples. This was intended to identify individual animals from their DNA to be later used for analysis using spatial capture-recapture. However, due to unavailability of fresh dung piles and small sample size, the DNA analysis could not be conducted. Therefore, we heavily relied on the camera trap images to estimate relative abundance. The camera traps were deployed for 90 days in the field. The field team visited the camera station every 30th day to retrieve data, change batteries, clear obstacles in front of lenses and replace any cameras damaged by animals.

2.3. Data analysis

2.3.1. Covariate preparation

Site covariates were selected based on literature on elephants and field knowledge. Covariates for the whole of the study area were processed using QGIS 2.18 (QGIS Development Team, 2017) and ArcGIS 10.3 (ESRI, 2011). Covariate value for each site was the mean of raster (pixel value at 90m resolution) cells bound within the circular buffer of 2 km around each camera station (see below for the details of covariates used). This radius distance was chosen to represent the average site characteristics around each camera station and to avoid spatial correlation between covariate values by taking larger radial distance. The mean value was calculated using the 'zonal statistics' tool in QGIS. Vegetation data were derived from two sources: 1) a 30-m resolution global forest change (GFC) cover (Hansen et al., 2013) and 2) a 250-m resolution vegetation continuous field (VCF; DiMiceli et al., 2011).

Elevation, aspect and slope values were extracted from a 30-m resolution raster digital elevation model (DEM; USGS, 2016). Distance to settlement, road, protected area, river was generated using 'Euclidean distance' tool in ArcGIS. The vector layers were first rasterized and then we generated distance in meters. Detection covariates were survey areas (site) and the number of active camera traps days per station (effort). All continuous site covariates were standardized to have a zero mean and a unit standard deviation. Standardization facilitates model convergence and comparison amongst the covariates. The covariates were tested for collinearity using Pearson correlation and any pairwise combination with a coefficient greater than 0.6 was considered correlated. Thus, only one covariate from the correlated pair which performed better in the univariate modeling based on the lower AIC_c value was retained.

Table 1: Pearson's correlation matrix of continuous site covariates

Covariates	ELE	GFC	VCF	RIV	SET
ELE	1				
GFC	0.31	1			
VCF	0.672	**0.767**	1		
RIV	0.203	0.035	0.026	1	
SET	-0.059	0.425	0.266	-0.117	1

ELE, elevation, GFC, forest cover (Global Forest Change); VCF, forest cover (Vegetation Continuous Field); RIV, distance to river; SET, distance to settlement; bold figure indicates high correlation between covariates (GFC and VCF)

2.3.2. Abundance Estimation

The camera trap images were retrieved and segregated for each grid cell. All study sites had separate folders for each camera station/grid cell. Two datasets were prepared for analyses. First, the elephant captures were converted into binary detection history representing 1 for detection or captured in image and 0 for non-detection. This was done for individual grid cells separately and for the whole 90 days. The 90-day sampling period was further collapsed into different sampling occasions, whereby each occasion spanned 10, 12 or 15 days, such that we could increase temporal independence and improve detection probability (Otis et al., 1978; Dillon and Kelly, 2007). The 12 days/occasion formulation proved optimal and was used for further analyses. The binary detection history was used in conjunction with the Royle-Nichols detection heterogeneity model (Royle and Nichols, 2003) to estimate the relative abundance of elephants. The second dataset prepared was the spatially replicated counts of elephants captured per station for each day. For this, elephants captured in the photo frame were counted and this was further authenticated with a blind count by a second person to avoid any bias induced by the first person. The count data were analyzed using an N-mixture model (Royle, 2004) to estimate the relative abundance of elephants.

2.3.2.1. Royle-Nichols model

The two main conceptual core assumptions of Royle-Nichols model (Royle and Nichols, 2003) are 1) animals across the survey sites are spatially distributed following some prior distribution, such as Poisson distribution, and 2) the probability of detection of an animal at a site is a function of how many animals are actually present at that site. Other assumptions equally important are no change in animal population during the course of study (demographically closed population) and independence of animal present and detection between sites. All animal captures were converted to 1s indicating detection and non-captures to 0s indicating non-detection for each camera station. There is a substantial loss of information in this case because irrespective of the number of animals captured (photographed per frame), the data are just converted to detection/non-detection (1/0). The function 'occuRN' in the 'unmarked' package (Fiske and Chandler, 2011) developed for program R was used to run the Royle-Nichols model and estimate the relative abundance of elephants (Royle and Nichols, 2003).

2.3.2.2. N-mixture model

The N-mixture model (also known as binomial mixture model) is a hierarchical model that estimates animal abundance from a set of count data using spatial and temporal replication while also accounting for imperfect detection (Royle, 2004). Within limited finance and logistics where complete enumeration or count of animal is not possible, the N-mixture model can be used to estimate relative abundance provided underlying assumptions are met. The main assumptions of N-mixture model are 1) there is no change in population demography during the course of study, 2) the count in one site is independent of counts in other sites (no double count and independent detections), 3) the probability of detection is same for all individuals within a sample and 4) the animals present in a study site follow some form of prior distribution (binomial or Poisson). Extension of this model includes modeling abundance and detection as a function of covariates to examine the spatial patterns and creation of spatial abundance maps. Every individual animal captured in a single photographic frame was counted using the double-blind method and for every single day (t = 90 days) in all the grid cells (i = 124 camera stations). The counts n_{it} at site i at time t are

$$n_{it} \sim \text{Bin}(N_i, p)$$

where N_i is the unknown population size at site i and p is detection probability. Assuming N_i to be an independent random variable with probability function $f(N;\theta)$, such as Poisson or negative binomial, the likelihood (Royle, 2004) is

$$L(p, \theta; \{n_{it}\}) = \prod_{i=1}^{R} \{ \sum_{N=max_t n_{it}}^{K} (\prod_{t=1}^{T} Bin\ (n_{it}\ ; N, p)) f(N;\theta) \}$$

The 'pcount' function in R package 'unmarked' was used to estimate the relative abundance of elephants at each site under a Maximum Likelihood framework (Fiske and Chandler, 2011). The appropriate statistical distribution for the station level (survey site) elephant abundance N_i was considered as a Poisson random variable. The upper index of integration (K) was set to 100 (minimum) so that it did not affect parameter estimates (Hill and Llyod, 2017). In grid cells where camera traps were lost to theft and animal vandalism, the dung evidence (either 1 or 0) was used as a surrogate of the count. It was not possible to ascertain if the dung piles came from same or different individuals, hence the evidence of dung was indicated as 1 for elephant presence and 0 for absence. This will lead to the loss of information but was the only best information we have had for the grids with lost cameras but evident for elephant presence.

To explain the variation in elephant abundance and detection, site and survey covariates were used in the models. Covariates for abundance included site-level data on elevation, distance to river, distance to the settlement, distance to road, distance to protected area edge, forest cover, slope, and aspect. Detection probability was modeled as a function of site and effort. Sites are the different survey areas, which are the different protected areas and divisions. Imperfect detection is inherent in ecological studies and there will always be variation in the detection probability of elephants at different sites due to various factors such as disturbance level and or topography of the site (site is the study area, e.g. protected area or territorial division; Tan et al., 2017; Penjor et al., 2018). The effort is the number of active camera trap days for each station during each sampling occasion.

The two-stage modeling approach was adopted to reduce the number of combinations of every possible covariate. First, abundance was modeled as a function of site covariates by

keeping detection constant and retained significant abundance covariates (additively only and no interaction terms were tested) to sufficiently general model (global model). Using the global model of abundance, the detection probability was modelled as a function of detection covariates (see below for details of covariates used). This was done in order allow maximum likelihood estimation process to fully explore the likelihood space and to identify best covariate structures for detection probability (Varun Goswami *personal communication*). Then the multivariate models of abundance with site covariates were run. Comparisons between all possible models were made using the R package "AICcmodavg" (Mazerolle, 2015) and AIC corrected for small sample size (AIC_c) was used for model selection. All multivariate models within delta AIC_c 2 score were considered to be strongly supported by the data (Burnham and Anderson, 2004).

2.3.3. Home range size and effective sampled area

A total of five elephants (three males and two females) were radio-collared to study the movement ecology and pattern in 2015 in the south (Sonam Wangdi, *unpublished data*). The telemetry data were used to estimate the home range of elephants and calculate the minimum convex polygons (MCP) for male and female elephants. The main aim of estimating home range was to determine the effective area of local abundance estimated throughout the study range using camera traps and to convert local abundance to density by dividing it by this area (Furnas et al., 2017). The home range estimates at 100% MCP was calculated for the period coinciding with camera trap exercise (March – June; Sonam Wangdi, *unpublished data*). The home range calculated within this period was used as the effective areas with our predicted values of camera station-level abundance throughout the study range. The simple average of male and female (March – June) home range predictions were used and calculated effective survey area to apply to all camera locations (Soisalo and Cavalcanti, 2006; Furnas et al., 2017). However, differences in home range between sexes can lead to heterogeneous detection or capture probabilities with wider-ranging sex having a greater probability (Foster and Harmsen, 2012). In such cases, it is advisable to estimate density for separate sexes allowing a more appropriate effective sampled area to be applied to abundance estimates of each sex (Foster and Harmsen, 2012). We also estimated abundance using the home ranges for camera trapping period (March – May) as well as entire home range estimate (2015 - 2017).

2.3.4. Habitat use analysis

The detection/non-detection data from the camera trap survey were used to assess habitat use probability of elephants. Photographic records were converted to 1 representing animal 'capture' and 0 representing 'non-capture' (Fig. 2). To minimize the risk of violating the closure assumption, only 90 days of each camera station's history were used (Rota et al., 2009). The 90 days were further collapsed into sampling occasion of 10-day per occasion to increase temporal independence and overall detection probability (Dillon and Kelly, 2007; Tan et al., 2017; Penjor et al., 2018).

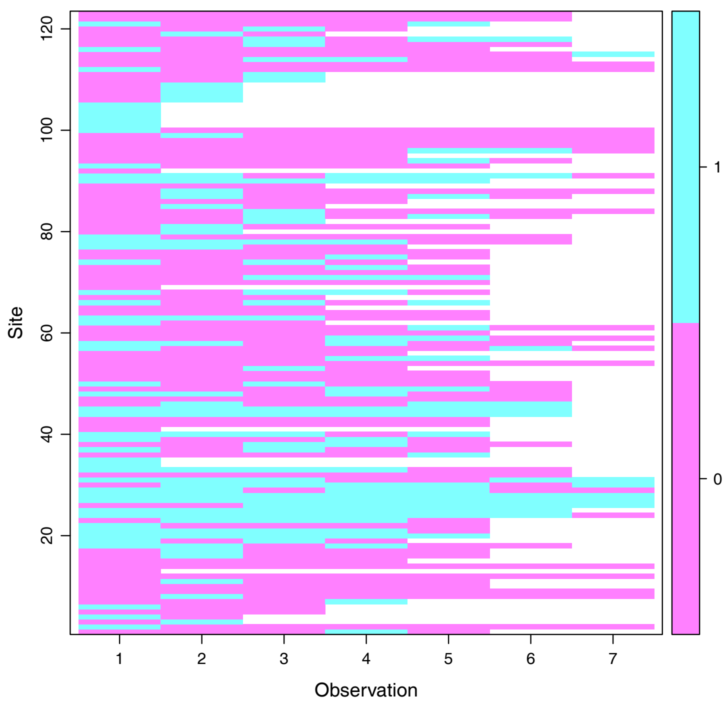


Figure 2. Detection/non-detection matrix from elephant survey camera trap data

The hierarchical occupancy models under the maximum likelihood framework were used to evaluate the habitat use probability of elephants in Bhutan. Occupancy is defined as the probability that a species will occupy a random site at a given time period (MacKenzie et al., 2002). One of the important assumptions of occupancy is the independence of capture between sites. Due to violation of this assumption due to elephants having large home ranges, we refer to occupancy as the probability of use (MacKenzie et al., 2006), whereby the presence of elephants at a given sampling unit occurs at random points in time (MacKenzie et al. 2006; Goswami et al. 2014). The sampling unit here is each camera trap station. Occupancy models can also accommodate covariates and hence detection and occupancy probabilities can be modeled as a function of a survey and site-specific covariates (MacKenzie et al., 2002). The occupancy covariates used were forest cover (VCF), distance to river (RIV), distance to road (ROA), distance to settlement (SET), slope (SLO), and elevation (ELE). Detection covariates included different camera models (CAM) and the number of active camera-trap days (EFFORT). The different camera models were used during the survey and the nuances in capture probability due to differences in camera models were expected. Further, some camera traps were lost to animal vandalism, hence the detection probability was also modeled as a function of active camera traps days. All the site covariates were standardized to the mean zero and unit standard deviation to facilitate model convergence.

The single-season, single-species occupancy analyses were performed in R (R Core Team, 2018) using the package 'unmarked' (Fiske and Chandler, 2011). The model of habitat use probability contained all covariates that appeared in the models within delta AIC_c 2 score, and the model structure was,

$$\text{logit}(\psi_i) = \beta_0 + \beta_1 \text{ Dist. River}_i + \beta_2 \text{ Dist. Road}_i + \beta_3 \text{ Dist. Settlement}_i + \beta_4 \text{ Slope}_i + \beta_5 \text{ Elevation}_i + \beta_6 \text{ Forest cover}_i$$

and detection probability as,

$$\text{logit}(p_{i,j}) = \alpha_0 + \alpha_1 \text{ Effort}_{ij}$$

where β_0 and α_0 are the intercepts and β_n and α_n are the coefficient estimates of the covariates, *i* is the site surveyed.

The untransformed beta coefficient values at 95% confidence interval were used to examine the degree and direction of the covariate effect on elephant abundance. Covariates were considered to having a strong influence on occupancy if their 95% interval excluded zero. The coefficient estimates were used to predict the habitat use probability of elephant across the study area. All covariates were rasterized at a 90m resolution for use in the prediction mapping.

3. Results

Camera traps from 123 stations out of 129 were retrieved by the field teams. Five camera stations were lost to animal vandalism and malfunction. Elephants were detected in 90 out of 123 stations.

To estimate the relative abundance of elephants, 446 images from 123 camera stations were used. The effort was 6564 trap days. The mean spacing between the successful stations was 3 km (±2.8 km SD) but the distance was not uniform due to terrain (range: 500m to 7.6km).

3.1. Detection probability and abundance

Results from the Royle-Nichols and N-mixture models are presented in Table 2-9. The results from Royle-Nichols and N-mixture models are compared but for the final reporting the estimates from N-mixture model are used. The main reason for reporting the N-mixture model is due to low standard errors and narrower confidence intervals. Also because the Royle-Nichols model assumes that detection probability (*p*) increases with abundance (N) but given the relationship is logistic, one could very well be at a space where *p* = 1 and N could range anywhere between the point where *p* became 1 (say N = 100) to any unknown number thereafter within realistic bounds (say N = 1000; Varun Goswami *personal communication*). The global model for abundance included elevation, forest cover, distance to river and distance to settlement (Table 2). The best model for detection probability in N-mixture model contained both sites (survey areas) and effort (number of active camera trap days). Detection probabilities differed amongst sites (Table 6) and increased as the number of active camera days increased, (SE) = 0.218 (0.02). The best model for explaining abundance had two covariates: elevation and forest cover (Table 4). It outperformed the null model ($\Delta AICc_{best\ model} = 0$ vs. $\Delta AICc_{null\ model} = 353.90$). The best abundance model was positively associated with forest cover ($\beta = 2.95$) but negatively associated with elevation ($\beta = -1.39$). Average predicted relative abundance (untransformed) at camera stations was 0.074 (SD = 0.0043) elephants.

Table 2: Abundance model with *p*(.)

Model	AIC_c	ΔAIC_c	weight	-2LL	K
ELE + FOR + RIV + SET	7712.07	0.00	0.7	-3649.67	6
ELE + FOR + SET	7713.81	1.74	0.3	-3851.65	5

Covariates are elevation (ELE), forest cover (FOR), distance to river (RIV) and distance to settlement (SET). AIC_c, Akaike information criterion corrected for small sample size; ΔAIC_c, relative difference between AIC_c of subsequent models compared to the top model; weight, AIC_c weight; -2LL, -2 times log likelihood and K, number of parameters. Detection was held constant *p*(.).

Table 3: Detection models for N-mixture models

Model	AIC_c	ΔAIC_c	weight	-2LL	K
SITE + EFFORT	7290.35	0	1	-3630.51	13
SITE	7487.71	197.36	0	-3730.44	12
EFFORT	7527.58	237.23	0	-3756.30	7
NULL	7712.07	421.72	0	-3849.67	6

Covariates are different survey areas (SITE) and number of active camera trap days (EFFORT). AIC_c, Akaike information criterion corrected for small sample size; ΔAIC_c, relative difference between AIC_c of subsequent models compared to the top model; weight, AIC_c weight; -2LL, -2 times log likelihood and K, number of parameters. Abundance was held at global model λ(ELE + FOR + RIV + SET).

Table 4: Abundance (λ) models for N-mixture models

Model	AIC_c	ΔAIC_c	weight	-2LL	K
ELE + FOR	7286.69	0	0.67	-3631.16	11
ELE + FOR + SET	7288.09	1.4	0.33	-3630.63	12

Covariates are elevation (ELE), forest cover (FOR), distance to river (RIV) and distance to settlement (SET). AICc, Akaike information criterion corrected for small sample size; ΔAICc, relative difference between AICc of subsequent models compared to the top model; weight, AICc weight; -2LL, -2 times log likelihood and K, number of parameters. Detection was held at best model p(SITE + EFFORT).

Table 5: Untransformed coefficients (λ; Abundance) from N-mixture models

Covariates	coefficient	SE	LCL	UCL
Intercept	0.28	0.21	-0.13	0.7
Elevation	-1.38	0.06	-1.5	-1.26
Forest cover	2.91	0.23	2.46	3.37
Distance to settlement	-0.03	0.03	-0.09	0.03

SE, standard error; LCL, lower confidence limit; UCL, upper confidence limit

Table 6: Untransformed coefficients (detection) from N-mixture models

Covariates	coefficient	SE	LCL	UCL
Intercept	-7.12	0.54	-8.18	-6.05
Effort	0.22	0.02	0.18	0.25
Site 1 (Gedu)	2.78	0.67	1.46	4.10
Site 2 (Jomotshagkha WS)	2.91	0.52	1.88	3.93
Site 3 (Phibsoo WS)	3.51	0.52	2.50	4.52
Site 4 (Royal Manas NP)	3.69	0.52	2.68	4.70
Site 5 (Sarpang)	2.47	0.53	1.43	3.51
Site 6 (Samdrupjongkhar)	2.31	0.53	1.28	3.34

WS, Wildlife Sanctuary; NP, National Park; SE, standard error; LCL, lower confidence limit; UCL, upper confidence limit

Table 7: Detection models for Royle-Nichols model

Model	AIC_c	ΔAIC_c	weight	-2LL	K
SITE + EFFORT	685.5	0	0.53	-334.12	8
SITE	685.77	0.27	0.47	-333.09	9
EFFORT	705.12	19.62	0	-349.46	3
NULL	705.74	20.23	0	-350.82	2

Covariates are different survey areas (SITE) and number of active camera trap days (EFFORT). AICc, Akaike information criterion corrected for small sample size; ΔAICc, relative difference between AICc of subsequent models compared to the top model; weight, AICc weight; -2LL, -2 times log likelihood and K, number of parameters. Abundance was held constant $\lambda(.)$.

Table 8: Abundance models for Royle-Nichols model

Model	AIC_c	ΔAIC_c	weight	-2LL	K
ELE	685.07	0	0.32	-331.55	10
NULL	685.77	0.7	0.22	-333.09	9
ELE + RIV	686.14	1.07	0.18	-330.88	11
RIV	686.42	1.35	0.16	-332.23	11
FOR	687.07	1.99	0.12	-332.55	10

Covariates are elevation (ELE), forest cover (FOR), distance to river (RIV) and distance to settlement (SET). AICc, Akaike information criterion corrected for small sample size; ΔAICc, relative difference between AICc of subsequent models compared to the top model; weight, AICc weight; -2LL, -2 times log likelihood and K, number of parameters. Detection was held at best model p(SITE + EFFORT).

Table 9: Coefficient (untransformed) for Royle-Nichols model

Covariates	coefficient	SE	LCL	UCL
Intercept	0.86	0.31	0.26	1.47
Elevation	-0.11	0.14	-0.48	0.04
Distance to river	-0.04	0.08	-0.31	0.07
Forest	-0.07	0.28	-1.79	0.56

SE, standard error; LCL, lower confidence limit; UCL, upper confidence limit

3.2. Home range size

The annual home range size (100% MCP) varied with gender (Table 10). Female elephants had a larger home range (400.95 km^2) than male (232.78 km^2) and the combined average home range is 316.86 km^2 for the telemetry points between the year 2015 and 2017. The effective studied areas (ESA) are 10301.13 km^2 for female, 7908.26 km^2 for male and 9136.26 km^2 for combined. The home range between March and June (coinciding with camera trapping period) is 514. 46 km^2 for female and 216.32 km^2 for the male. The combined home range during this period is 393.88 km^2. The ESAs for the period between March and June are 11671.45 km^2 for female, 7632.72 km^2 for male and 10211.11 km^2 for combined.

Table 10: Home range estimates from the five collared elephants in Bhutan. Pink cells contain female elephant data and gray cells contain male elephant data (Sonam Wangdi, *unpublished data*).

Elephant ID	Overall (no of loc)	Year	MCP (Km²) Overall	Ann	loc	Season Dry	loc	Wet	loc	CA (Kernal) Km² Overall OV_95	OV_75	Annual A_95	A_75	OV_D_95	Seasonal OV_W_95	OV_D_75	OV_W_75	Over lap Home (MCP)Area Overlap Annual_ season_ mcp	95_dry/wet	Core (Kernal)Area Overlap 75_dry/wet
Dema	7036	2015	789.07	355.98	1199	68.5	92	354.4	1107	378.47	160.17	241.87	120.01	84.43	242.20	38.78	121.08	68.38	76.81	29.43
		2016		781.78	5221	551.6	2848	767.2	2367			357.02	144.41	264.00	412.17	127.07	160.85	539.24	220.81	93.76
		2017		421.97	616	422.0	616					233.49	109.76	233.57		109.83				
		AVG		519.91		347.35		560.81		378.47	160.17	277.46	124.73	194.00	327.19	91.89	140.97	303.81	148.81	61.60
		SD		229.17		250.06		291.88				69.03	17.80	96.10	120.19	46.80	28.12	332.95	101.82	45.49
Jetsun	Overall (no of loc)		Overall	Ann	loc	Dry	loc	Wet	loc	OV_95	OV_75	A_95	A_75	OV_D_95	OV_W_95	OV_D_75	OV_W_75	Annual_ season_mcp	95_dry/wet	75_dry/wet
		2015	783.61	597.36	1953	450.6	878	568.2	1075	566.91	268.84	476.04	217.55	393.38	335.36	209.36	127.22	429.18	188.52	61.19
	7759.00	2016		681.19	5187	508.5	2820	594.2	2367			485.54	231.55	376.14	368.34	164.57	169.93	464.90	198.71	56.29
		2017		433.65	597	433.7	597					305.93	156.44	305.77		156.36				
		AVG		570.73		464.26		581.21		566.91	268.84	422.50	201.85	358.43	351.85	176.76	148.58	447.04	193.62	58.74
		SD		125.90	2358.16	39.24		18.38				101.07	39.94	46.41	23.32	28.53	30.20	25.26	7.21	3.46
Timuraja	Overall (no of loc)		Overall	Ann	loc	Dry	loc	Wet	loc	OV_95	OV_75	A_95	A_75	OV_D_95	OV_W_95	OV_D_75	OV_W_75	Annual_ season_mcp	95_dry/wet	75_dry/wet
		2016	438.54	438.54	4440	349.2	2366	96.8	2074	180.25	70.55	185.58	75.28	191.90	69.84	80.80	28.61	63.15	56.52	11.04
	4819.00	2017		0.00	379	0.0	379					10.78	4.99	10.78		4.99				
		AVG	438.54	219.27	2409.5	174.591		96.81		180.25	70.55	98.18	40.135	101.34	69.84	42.895	28.61	63.15	56.52	11.04
Jigme	Overall (no of loc)		Overall	Ann	loc	Dry	loc	Wet	loc	OV_95	OV_75	A_95	A_75	OV_D_95	OV_W_95	OV_D_75	OV_W_75	Annual_ season_mcp	95_dry/wet	75_dry/wet
		2014	108.36	84.03	1255	18.5	241	63.8	1012	70.77	37.52	95.24	49.70	24.59	49.19	15.18	24.41	6.59	9.36	2.64
	2308.00	2015		67.28	1033	67.0	1038	0.0	15			74.34	39.62	45.61	4.02	24.62	1.82	0.01	3.81	1.67
		AVG	108.36	75.655		42.755		31.9175		70.77	37.52	84.79	44.66	35.1	26.605	19.9	13.115	3.302	6.585	2.155
		SD		8.375		24.245		31.9025		0	0	10.45	5.04	10.51	22.585	4.72	11.295	3.288	2.775	0.485
Thubten	Overall (no of loc)	Year	Overall	Ann	loc	Dry	loc	Wet	loc	OV_95	OV_75	A_95	A_75	OV_D_95	OV_W_95	OV_D_75	OV_W_75	Annual_ season_mcp	95_dry/wet	75_dry/wet
			126.29																	
	3019	2014		123.47	1373	20.1	273	43.0	1102	66.14	25.37	39.87	17.55	19.95	69.84	7.94	28.61	3.64	5.59	3.07
		2015		67.50	1646	115.9	1081	42.1	563			56.93	15.38	60.55		21.67		37.64	8.80	3.20
		AVG		95.49		68.00		42.55		66.14	25.37	48.40	16.47	40.25	69.84	14.81	28.61	20.64	7.20	3.14
		SD		27.99		47.91		0.45		0.00	0.00	8.53	1.09	20.30	0.00	6.87	0.00	17.00	1.61	0.07

3.3. Density and population size

For the subset of the home range estimated between March and June coinciding with camera trapping season (see above for details of home range estimates and ESA), average elephant density across the southern region was estimated at 0.24 elephants per 100 km^2 (95% CI: 0.21 – 0.27). The total (combined sex) population of wild elephants across the southern region is estimated at 609.7 (±35.7 SE; 95% CI: 544.1 – 684.4).

For the entire home range estimate between 2015 and 2017 (see above for details of home range estimates and ESA), elephant density mean is estimated at 0.297 individuals per 100 km^2 (95% CI: 0.26 – 0.33). The total abundance (combined sex) across the entire southern region is estimated at 678.1 (±39.7 SE; 95% CI: 605.1 – 761.2).

3.4. Sex-ratio from photographic capture-recapture

The adult elephant sex ratio is reported based on the number of adult male and female elephants encountered. However, the readers need to take caveats while interpreting this ratio because this sex ratio is based on the encounter rates of adult male and female elephants at camera traps and does not account for variation in detection probabilities of adult male and female elephants. Given the large number of encounters, the average sex ratio should be close to the true sex ratio in the population. The adult male to female (M: F) sex ratio is 1:2.3 (which means 1 male elephant for every 2 female elephants).

3.5. Habitat use probability

The naïve habitat use probability was 0.732. When accounted for imperfect detection the habitat use probability was 0.819 (0.10 SD; 95% CI: 0.535 – 0.949). The best detection probability model included different camera models as the covariate (Table 11). The goodness of fit test for the global model indicated a small overdispersion (*c-hat* = 1.68), thus the $QAIC_c$ (quasi AIC_c) as used for model selection (Table 11). The habitat use probability was negatively associated with distance to river, slope, distance to road and elevation, while positively associated with forest cover (Table 13). Only distance to the river had a strong influence on habitat use probability because the 95% CI excluded zero (-1.44, - 0.21). The other covariates, however, were at best, weak with their 95% CI including zero (Table 13).

Table 11: Detection models for occupancy models (habitat use probability)

Model	AIC_c	ΔAIC_c	weight	-2LL	K
CAMERA	728.95	0	0.44	-361.37	3
CAMERA + EFFORT	728.98	0.03	0.43	-360.32	4
EFFORT	732.74	3.79	0.07	-362.27	3
NULL	732.8	3.85	0.06	-364.35	2

Covariates are different camera models (CAMERA) and number of active camera trap days (EFFORT). AICc, Akaike information criterion corrected for small sample size; ΔAICc, relative difference between AICc of subsequent models compared to the top model; weight, AICc weight; -2LL, -2 times log likelihood and K, number of parameters. Occupancy was held constant ψ(.).

Table 12: Occupancy models (Habitat use probability)

Model	$QAIC_c$	$\Delta QAIC_c$	weight	-2LL	K
RIV + SLO	435.5	0	0.32	-355.13	5
RIV	436.1	0.6	0.23	-357.49	4
RIV + SLO + FOR	436.74	1.24	0.17	-354.28	6
RIV + ROA + SLO	437.02	1.52	0.15	-354.52	6
ELE + RIV	437.3	1.8	0.13	-356.64	5

Covariates are elevation (ELE), forest cover (FOR), distance to river (RIV), distance to road (ROA), slope (SLO) and distance to settlement (SET). QAICc, Akaike information criterion corrected for small sample size; ΔQAICc, relative difference between QAICc of subsequent models compared to the top model; weight, AICc weight; -2LL, -2 times log likelihood and K, number of parameters. Detection was held at best model p(CAMERA).

Table 13: Beta (*β)* coefficients (untransformed) for occupancy models (Habitat use probability)

Covariates	coefficient	SE	LCL	UCL
Detection				
Intercept	0.14	0.24	-0.34	0.62
camera	-0.14	0.06	-0.26	-0.01
Occupancy				
Intercept	1.76	0.4	0.98	2.54
Distance to river	-0.83	0.31	-1.44	-0.21
Slope	-0.47	0.47	-1.51	0.03
Forest cover	0.1	0.27	-0.31	1.4
Distance to road	-0.06	0.19	-1.07	0.29
Elevation	-0.04	0.13	-0.78	0.16

SE, standard error; LCL, lower confidence limit; UCL, upper confidence limit

4. Discussion

4.1. Abundance

The estimates of elephant abundance and the fine-scale distribution maps are produced using the large-scale camera trap data. The use of N-mixture model to estimate elephant abundance is attributed to the following reasons: 1) the replicated count data from camera trap survey was convenient to process and with double-blind count method, the bias in counts in the camera trap images was minimized and 2) the effective surveyed area was calculated using the home range estimates form 5 collared elephants in the study region (Sonam Wangdi *unpublished data*; Foster and Harmsen, 2012). Previously, Jigme and Williams (2011) estimated 513 elephants (range 30 – 1797) in 800 km^2 using dung transect survey method; remarkably, similar (a slightly higher) estimate is obtained by N-mixture model for a potential elephant habitat of *c.* 10000 km^2 in Bhutan. Our results suggest that elephants in Bhutan are found mostly in the lower altitudes and perhaps highly dependent on forest cover.

Elephant abundance was positively associated with forest cover while negatively with elevation (β_{forest} = 2.90; $\beta_{elevation}$ = -1.38; Fig. 3). There is a gradual decrease in elephant abundance as the elevation increases and the abundance reaches zero as the elevation approaches about 2000m. Higher abundance of elephants is expected in areas with high forest cover. The effect of these covariates was strong as the 95% confidence intervals did not include zero. Chartier et al., (2011) suggested that a critical threshold for conflict between 30% and 40% forest cover, the fall of forest cover below this threshold is expected to cause conflict. This also suggests that elephants are tolerant to mild development but to the limit where there are adequate resources to sustain them in the forest. Such understanding is required in the management of natural landscape in relation to development where both people and elephants can seemingly coexist.

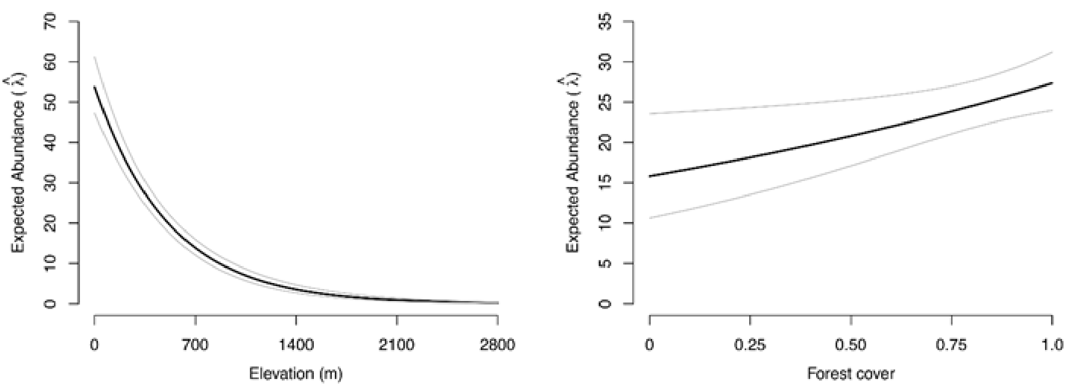


Figure 3. Abundance in relation to elevation and forest cover.

Distance to river and distance to settlement did not have a significant impact on abundance. Distance to settlement showed positive influence meaning increase in abundance closer to the settlement, however, the effects were uncertain with high standard errors and overlapping confidence intervals ((SE) = -0.01(0.02); 95% CI: -0.09 – 0.03).

Male elephant home range in Bhutan was smaller compared to female (see Results and Table 10). A similar finding was reported by Fernando et al., (2008) in Sri Lanka where the male elephant home range for the most time of the year was small, except during *musth* where the home range increased in search of a potential mating partner. Since elephants are social living in herds and led by a matriarch, larger home range for the female is justifiable in the sense that more elephant numbers would require a huge feeding area.

Home range size variation is attributed to differences in resource requirement due to body size, sex, reproductive status and sociality (Fernanda et al., 2008). However, variation in the home range also occurs due to divergent strategies of migration and residence within a single population (Fernando et al., 2008). Variation in home range size may also be the result of habitat fragmentation (larger in fragmented habitat and smaller in contiguous habitat). Delineating core areas based on collar data can provide better information on the use of home ranges (Powell, 2000). Studies have shown that core area comprised of meager onefourth of the home range suggesting dispersed resource such as food rather than water was the main determinant of larger cruising radius (Fernando et al., 2008). Significant utilization of non-conservation areas indicate that there was an evidence of intensive habitat use with higher positive association with forest cover both in terms of abundance and habitat use. For the large energetic requirement of mega-herbivore, habitat inside and outside protected area is critical for long-term *in situ* conservation and management.

Put simply, elephants are found in abundance in low altitude and selects habitat with high forest cover (Fig. 4).

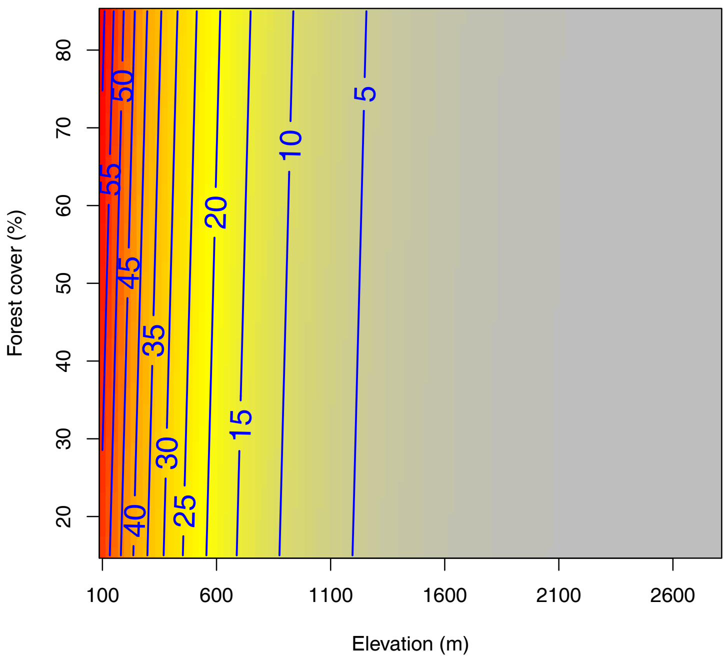


Figure 4. Bivariate prediction of elephant abundance in Bhutan in relation to elevation and forest cover.

The adult male to female (M: F) sex ratio of 1:2.3 corroborated with the findings from the region (e.g. Sukumar, 2003; Goswami et al., 2007). This skewness in adult sex ratio is attributed to differential mortality. Male Asian elephants possess tusks for which the poachers primarily target bull elephants. Further, bull elephants display a greater tendency to raid crops and enter into conflict with people (Madhusudan and Mishra, 2003; Sukumar, 2003). Given the higher vulnerability of male elephants to mortality from poaching and conflict, it is of utmost importance and urgency to focus on gathering information on the male segment of the Asian elephant population and impose stricter protection (Goswami et a., 2007). Information gathering not only pertains to understanding state variables such as abundance and density but also on the vital rates such as mortality, recruitment, and movement (Goswami et al., 2007).

4.2. Habitat use

The naïve habitat use probability (71%) was lower than the overall estimated probability (81%) for the potential elephant habitat in the southern region of Bhutan. This reconfirms the need to account for imperfect detection and doing so improved the predictive ability of occupancy models. The best model for predicting elephant habitat use probability included distance to the river and slope covariates. However, other covariates (elevation, distance to road, distance to river and forest cover) were competitive because they were present in models within delta AIC_c 2 score (Table 12).

The probability of habitat use decreased farther away from rivers (Fig. 5). The finding is consistent with the ecological expectations where elephants used locations closer to rivers than those farther away. Elephants avoided habitat on steeper slopes. Elephants are huge-bodied animals and can only balance their weight on the gentle slope. There are few incidences in Bhutan where elephants have been observed to use steep slopes. The reason behind the use of steep slopes are not known but possibly speculated a lost individual who strayed away from the herd or lone bulls in search of new territory. However, such behaviors come with the cost and few observations are made where elephants succumbed to accidents and fall.

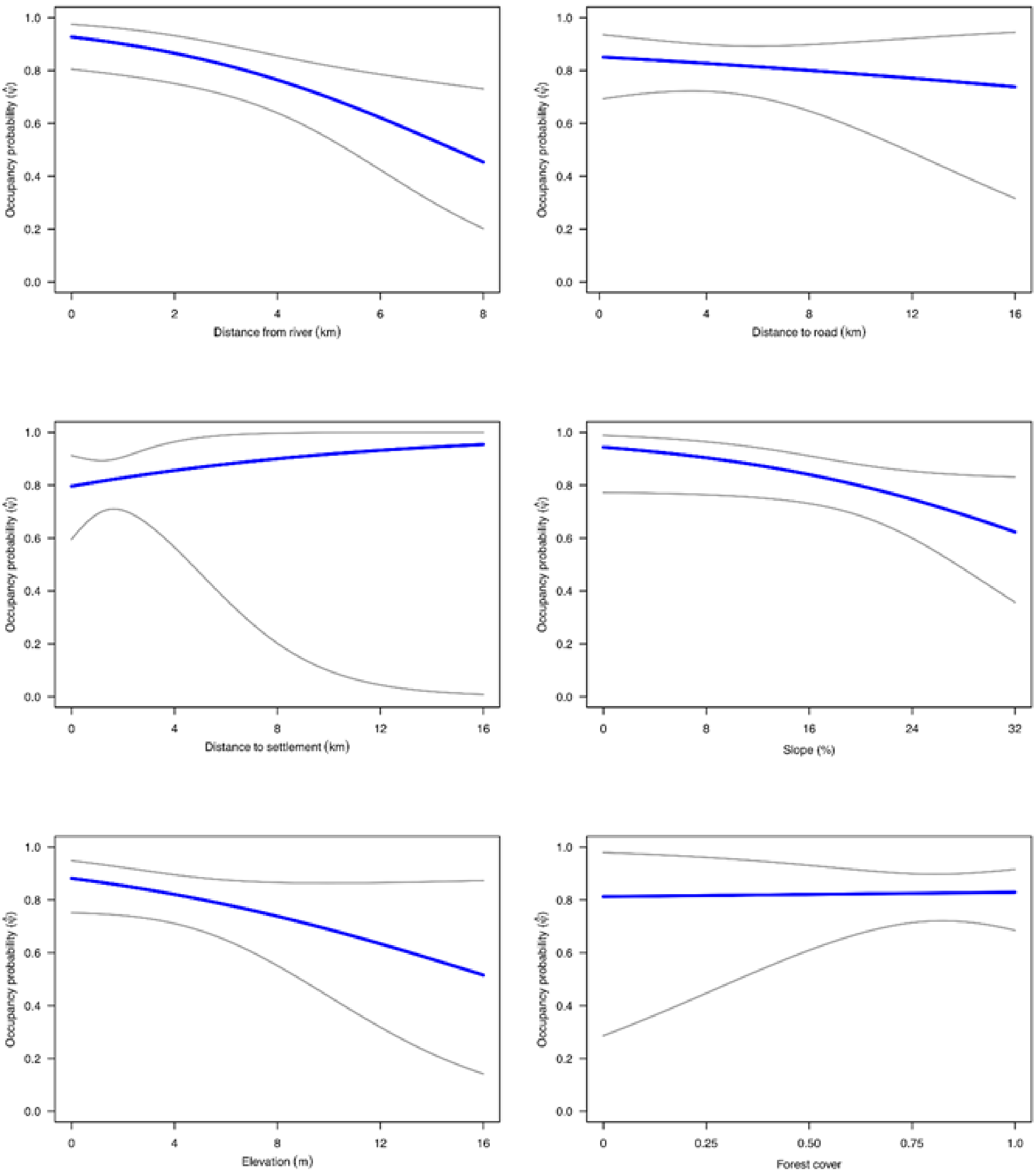


Figure 5. Habitat use probability in relation to covariates (distance to river, distance to road, distance to settlement, slope, elevation and forest cover). Blue lines represent mean and grey lines represent 95% CIs.

Forest cover had a positive influence on habitat use. Elephants need large amounts of forest cover (open and closed) to meet their ecological needs. Forests provide forage and shelter, serve as breeding grounds, and closed forests can potentially also help with thermoregulation during the day. Asian elephants inhabit a wide range of habitats from rainforests and dry scrub to savannahs with historical accounts even depicting occurrence from sea level to snow line (Sukumar, 1989). This shows their generalist behavior and behavioral plasticity. Due to the ruggedness of terrain, elephants would not be able to use all forested habitat in Bhutan and thus warrants the importance of conservation of available habitat.

Elephants are found only in the southern part of the country and our analysis with elevation is in congruence to this observation (Fig. 5 and 6). Elephant body is covered with minimum hair and unlike their extinct cousin (the mammoth), Asian elephants cannot withstand cold. We found that the habitats farther from the road had least use probability. This relationship is unclear because roads have been found detrimental to elephants use due to fatal collision with the vehicle. However, the relationship between the two was weak for a conclusive finding. Future studies need to elaborate on these relationships to better understand the habitat use of elephants in Bhutan. We did not model detection probability as a function of distance to roads and we suspect the above finding may be an outcome of the observation process (i.e., higher detection near roads because of easy access for sampling) compared to the underlying ecological process.

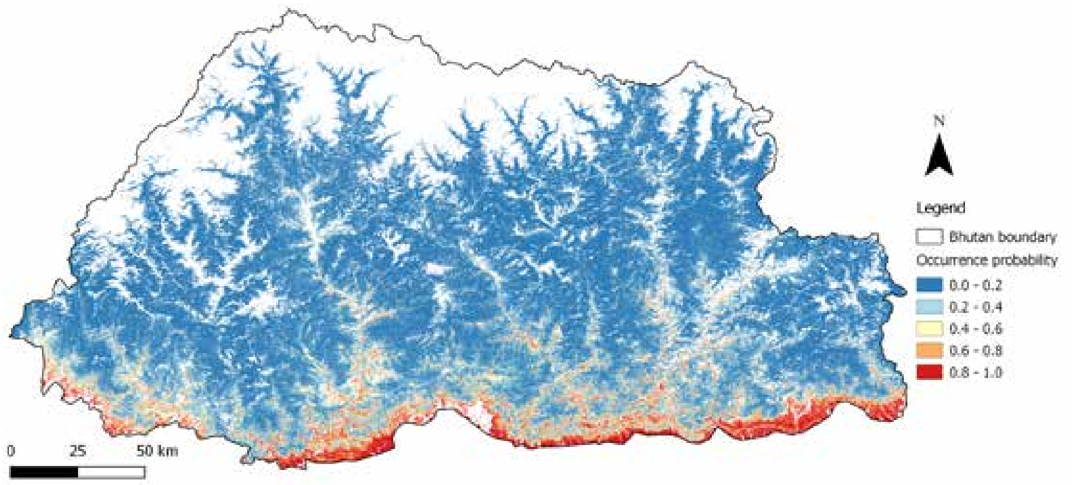


Figure 6. Predicted Asian elephant distribution in Bhutan

4.3. Management implications

Habitat loss and fragmentation have been attributed as main drivers of Asian elephant population decline (Sukumar, 1989; Leimgruber et al., 2003). Asian elephants require large space and play important role in shaping the landscape (Sukumar, 1989). Conservation of large contiguous forest areas will be vital to elephant conservation and to minimize conflict (Leimgruber et al., 2003; Goswami at et al. 2014). Habitat loss and fragmentation results in increasing forest-to-cultivated land perimeter which could bring elephants in contact with agriculture and settlement in the course of their seasonal movement thus escalating the conflict (Sukumar, 1989, 2003). Furthermore, increased anthropogenic impacts such as cattle grazing and fuelwood collection could also attribute to crop raiding behavior of elephants (Kumar et al., 2004).

Almost half of Asian elephants dwell close to human habitation and populated areas (Leimgruber et al., 2003). Elephants are attracted to cultivated land possibly due to high mineral content or value (Sukumar, 1989). For elephants living in close proximity to settlement, the conflict is inevitable (Santiapillai, 1997).

Infrastructure development such as new settlement planning, road, and agriculture expansion will block migratory routes or convert feeding ground. Such incidences are evident in the southern district of Samtse and Sarpang. We have observed higher conflict incidences in these districts. The situation will further aggravate if development planning does not account for the need of elephant habitat use. Thus, future planning should assess the critical use area by elephants through the fine-scale habitat use and migratory pattern studies. Physical barriers have to factor ecological issues such as facilitating corridors and smooth movement (Gubbi, 2012; Goswami and Vasudev, 2017). Change in the land-use pattern including infrastructure development causes fragmentation. These changes could lead to higher conflict causing greater economic damage to farmers. Regulation of land-use and conversion should be the priority of government and conservation agencies (Gubbi, 2012). Mitigating conflict should involve multi-level participation by relevant stakeholders; such as wise land-use planning by the government in consultation with farmers and community and strengthen crop guarding and vigilance.

Our finding of elephants avoiding settlement highlight the need to take precautions in course of infrastructure development. Though elephants tend to avoid settlements, with decreasing foraging ground and increasing habitat fragmentation, elephants will be forced to come into contact with people, leading to increased human-elephant conflict.

4.4. Recommendations

Increased connectivity of elephant habitats to reduce conflict and facilitate movement (see Goswami and Vasudev, 2017). The elephants share habitat between India and Bhutan and any prevalent impact on either side will result in disharmonic exodus across borders causing conflicts. This entails coordination and cooperation between the two countries.

Legal options to prevent and or regulate land-use change in elephant habitat or corridors need to be explored and implemented strictly. Integrated land-use policy for cultivated land within and around the landscape need to be identified and advocate crop cultivation appropriate for the region.

The landscape approach to management such as habitat management, protection against ivory poaching and population monitoring has to be undertaken. The current transborder initiative like TraMCA (Transboundary Manas Conservation Area) could be used to jointly study conflict intensity, illegal activities and habitat use.

In elephant conflict areas, it is advisable to cultivate crops which are least palatable to elephants such as chilies. However, this would also require a deeper understanding of the conflict pattern in the area.

4.5. Study limitations

Photographic capture-recapture methods are also used to estimate abundance in elephants elsewhere (e.g. Goswami et al., 2007). We caution while interpreting our results from N-mixture models. Elephants in herd are not independent. This easily violates the assumptions of the Poisson distribution. Thus, we considered herd as an independent unit. This still risks in violating the assumption of Poisson distribution because there were more than one camera stations in the home range of single elephant. Using negative binomial distribution in N-mixture models would result in extreme dispersion and the results cannot be relied upon (Mike Meredith personal communication). The abundance we estimate from this model only gives us the relative abundance. In order to get the density and population estimate, we have to use home range data from the site-specific study as we did in our case. Extrapolation of home range estimates between different sites (or different countries) is inappropriate. The size of the grid should be based on the home range radius. However, during the camera trapping exercise, this information was not available. Therefore, we suspect the grid cell size of 25 km^2 was too small to estimate elephant occupancy. This might have led to the violation of the assumption of independent capture between sites for abundance and occupancy estimation. We suspect the same herd of elephants might be captured at multiple stations/locations and might have led to possible double counting which will inflate the estimates of abundance.

We did not account for possible spatial autocorrelation between sites. Failure to correct for spatial autocorrelation will lead to spurious estimates and hence biased decision or management interventions. We recommend future studies explore more on this. However, we used spatial covariates that could potentially explain the spatial variation in abundance or habitat use. It is advisable to account for spatial autocorrelation in occupancy models to better understand the variation in use probability and remove bias that may arise due to the placement of more than one camera traps within a home range of an elephant. Future studies could potentially look into it. Furthermore, we derived our covariates from GIS-based data and not primary data. We expect variation in responses of elephant habitat use to GIS-derived covariates and covariates collected in the field. Sex-based identification of elephants was not possible from camera trap images and we do not report sex-based population estimates. We can estimate state variables with non-capture-recapture (CR) methods but they do not provide information on demographic rates and are limited by logistic considerations (Goswami et al., 2007). Lastly, estimating sex ratio from photographic capture-recapture (without identifying individuals) may result in overestimation because we risk double counting the same herd unless a peculiar herd identity or conspicuous character is assigned. We tried to minimize this risk by comparing the herd images by two independent observers and identifying and recording any peculiar herd identity such as torn ear or docking in tails of individuals in a herd.

4.6. Conclusion

We found that elephant conservation in Bhutan needs to focus on maintaining continuous forest cover. Socio-economic development is inevitable but we need to strike balance between conservation and development. Not jeopardizing the conservation, development needs to account for mitigation measures that are beneficial to both elephant (and wildlife in general) and humans. Road construction should be accompanied by viaduct options and underpasses that will facilitate smooth movement of elephants. Permanent infrastructure should also consider the migration route or foraging grounds of elephants. With burgeoning illegal markets and wildlife trade, conservation interventions require copious boots on the ground to facilitate intensive anti-poaching and monitoring. SMART patrolling and zero-poaching strategy should be implemented throughout the elephant range in Bhutan.

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ISBN-978-99936-620-8-2

Designed and Printed by Bhutan Printing Solutions