Status of Great Indian Bustard and Associated Wildlife in Thar

Survey Report 2014

Wildlife Institute of India
&
Rajasthan Forest Department

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Cover Photo: Ashok Choudhary (Great Indian Bustard)

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Executive Summary

Despite unique biodiversity values and dependency of traditional agro-pastoral livelihoods, arid open habitats of India are facing imminent risk due to our neglect and mismanagement. The Critically Endangered Great Indian Bustard (GIB) acts as a flagship and indicator of this ecosystem, for which Governments are planning conservation actions that will also benefit associated wildlife. Persistence of this species critically depends on the Thar landscape, where ~75% of the global population resides, yet their status, distribution and ecological requirements remain poorly understood.

This study aimed at assessing the status of Great Indian Bustard, Chinkara and Fox alongside their habitat and anthropogenic stressors across ~25,500 km^2 of potential bustard landscape in Thar spanning Jaisalmer and Jodhpur districts of Rajasthan. Systematic surveys were conducted in 144 km^2 cells from slow-moving vehicle along 15-20 km transects to record species' detections, habitat characteristics in sampling plots, and secondary information on species' occurrence. Eighteen teams comprising of field biologists and Forest Department staff sampled 118 cells along 1924 km transect in March 2014. Species' detection data were analyzed in Occupancy and Distance Sampling framework to estimate area of occupancy and density/abundance of key species.

Our key findings were that Great Indian Bustard occupied 5.8 ± 4.4 % of sites, although information from local community questionnaire surveys recorded usage in 27% of sites. Bird density was estimated at 0.61 ± 0.36 /100 km^2, yielding abundance estimates of 103 ± 62 in the sampled area (16,992 km^2) and **155 ± 94 GIB in Thar landscape** (25488 km^2 area). During the survey, 38 individual birds were detected. Bustard-habitat relationships, assessed using multinomial logistic regression, showed that disturbances, level of protection and topography influenced distribution. Chinkara population occupied 91.0 ± 3.4% of sites at overall density of 378 ± 57 animals/100 km^2 and abundance of 96,291 ± 14,556 in the landscape. Desert Fox population occupied 53.5 ± 8.8 % of sites, at overall density of 33.58 ± 8.17 animals/100 km^2 and abundance of 8,558 ± 2,081 in the landscape. Seventy-five percent of priority conservation sites were outside Protected Area. Although some of them benefit from community protection, majority are threatened by hunting and unplanned landuses.

This study provides robust abundance estimates of key species in the Thar landscape. It also provides spatially-explicit information on species' occurrence and ecological parameters so as to guide *in-situ* site-specific management and policy. Thar landscape supports the largest global population of GIB with the best hope for the species' future survival. Since this survey was a snapshot at GIB distribution, landscape-scale seasonal use information is lacking but critically required. A satellite telemetry based study should be urgently implemented to prioritize areas for conservation investment.

1. Introduction

The Great Indian Bustard (*Ardeotis nigriceps*) is Critically Endangered (IUCN 2011) with ~300 birds left. Rajasthan holds the largest population and prime hope for saving the species (Dutta et al. 2011). As the range states are developing action plans for their recovery (Dutta et al. 2013), baseline information on current distribution, abundance and habitat relationships are scanty. Such information are essential for conservation planning and assessing the effectiveness of management actions. Great Indian Bustard inhabit open, semiarid agro-grass habitats that support many other species like Chinkara *Gazella bennettii*, Desert Fox *Vulpes vulpes pusilla*, Indian fox *Vulpes bengalensis* and Spiny-tailed Lizard *Saara hardwickii* that are data deficient and threatened. This survey aimed at generating information on population and habitat status of these species for the crucial bustard landscape of western Rajasthan.

Bustards are cryptic and vagile birds occupying large landscapes without distinct boundaries that make complete enumeration of population impractical and unreliable. Estimation of their population status requires robust sampling techniques that are replicable, not biased by imperfect detection, and allow statistical extrapolation of estimates to non-sampled areas. Through this survey, we have developed a protocol for monitoring Great Indian Bustard population and associated wildlife across the country.

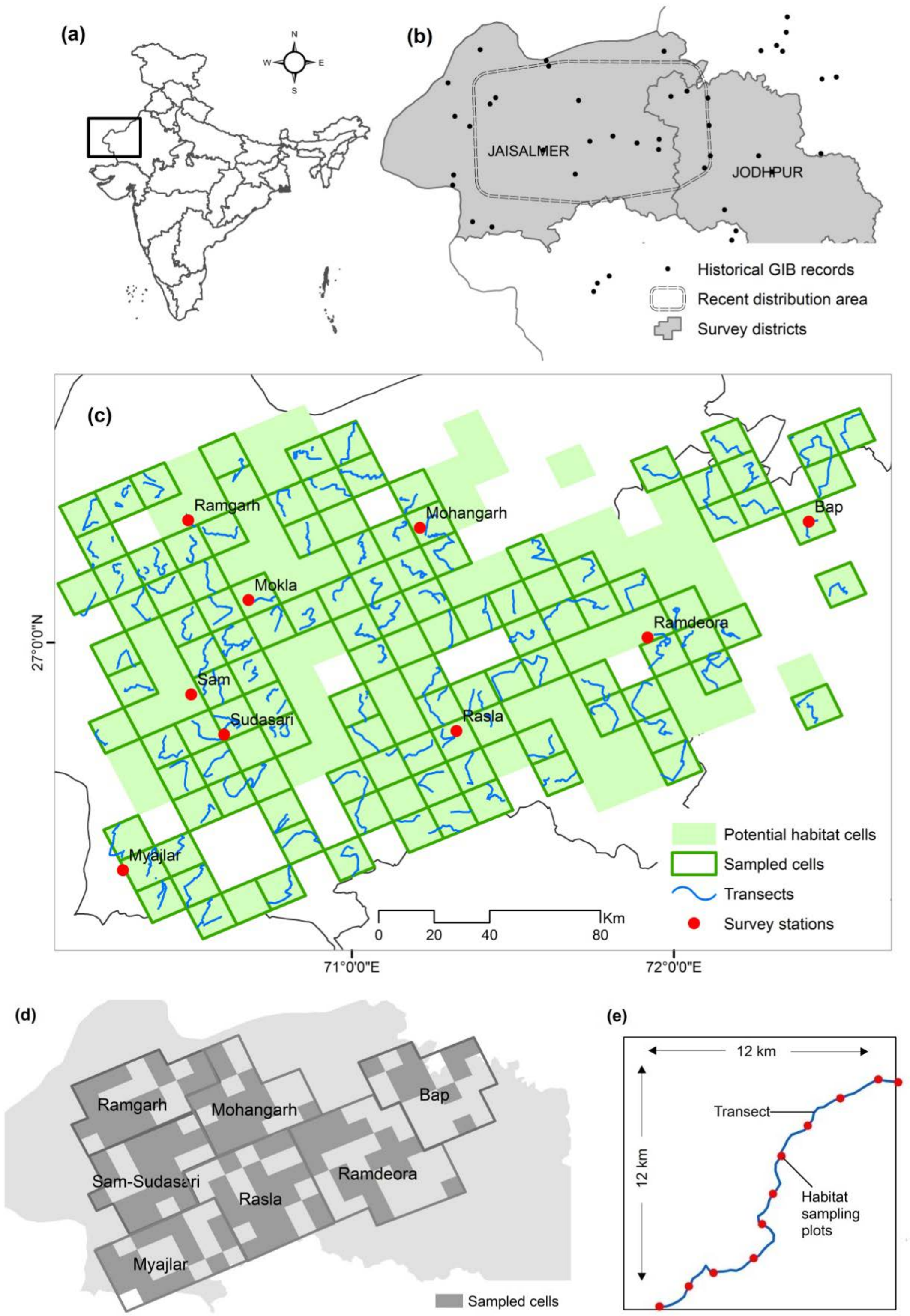
Our survey covered the potential bustard habitat in Jaisalmer and Jodhpur districts (hereafter, Thar landscape). Ground data collection was carried out by researchers, qualified volunteers and Forest Department staff who were trained through workshops and field exercises prior to the survey. This report provides the first robust abundance estimates of the aforementioned species along with spatially explicit information on key ecological parameters to guide managers in implementing *in-situ* management actions as prescribed by the bustard recovery plans (Dutta et al. 2013).

2. Thar landscape

The potential bustard landscape in Thar region was identified in a stepwise manner. Past records (post 1950s) of Great Indian Bustard in western Rajasthan were collected from literature (Rahmani 1986; Rahmani and Manakadan 1990) and mapped. The broad distribution area was delineated by joining the outermost locations; and streamlined using recent information on species' absence from some historically occupied sites (sources: Rajasthan Forest Department, Ranjitsinh and Jhala 2010). Herein, human-built areas, extensive sand dunes, and irrigated intensive agriculture were considered unsuitable for bustard based on prior knowledge (Dutta 2012). These areas were identified from night-light layers in GIS domain and Google Earth imageries. The remaining landscape, a consolidated area of 25,500 km^2, was considered as potentially habitable for bustard and subjected to sampling.

The study area falls in Desert Biogeographic Zone (Rodgers et al. 2002). Aridity regime ranges from Arid (Jodhpur), Superarid (Jaisalmer and Bikaner) to Semiparched (Barmer) conditions. Rainfall is scarce and erratic, at mean annual quanta of 100-500 mm that decreases from east to west (Pandeya et al. 1977). The climate is characterized by very hot summer (temperature rising up to 50^{o}C), relatively cold winter (temperature dropping below 0^{o}C), and large diurnal temperature range (Sikka 1997). Broad topographical features are gravel plains, rocky hillocks, sand-soil mix, and sand dunes (Ramesh and Ishwar 2008). The vegetation is of Thorny Scrub type, characterized by open woodlot dominated by Khejri *Prosopis cineraria* and *Acacia* trees, scrubland dominated by *Capparis*, *Zizyphus*, *Salvadora*, *Calligonum*, *Leptadenia* and *Aerva* shrubs, and grasslands dominated by *Crotalaria* and Sewan *Lasiurus*. Notable fauna, apart from the ones mentioned before, include mammals like Caracal *Felis caracal* and Desert Cat *Felis* silvestris, birds like Macqueen's bustard *Chlamydotis macqueenii*, Cream-coloured Courser *Cursorius cursor*, Sandgrouses *Pterocles* spp., larks, and several Raptors. Thar is the most populated desert, inhabited by 85 persons/km^2, who largely stay in small villages and *dhanis* (clusters of 2-8 huts), and depend on pastoralism and dry farming for livelihoods. A fraction of this landscape (3,162 km^2) has been declared as Desert National Park, which is not inviolate and includes 37 villages (Rahmani 1989).

Figure 1 Sampling design for Great Indian Bustard population and habitat assessment in Thar landscape (March 2014): (a) location of study area; (b) delineation of potential bustard landscape from existing information; (c) distribution of transects in 144 km^2 cells; (d) habitat sampling plots at 2 km interval on transect; and (e) simultaneously operated survey blocks



3. Methods

3.1. Organization of survey

The potential bustard landscape in Thar was divided into seven sampling blocks which were simultaneously surveyed by 18 teams to circumvent the issue of covering such large expanse within a brief time to minimize bird/animal movements between survey areas. Three teams operated for five days (March 22-26) in each of these sampling blocks, named after their respective field-stations, as: a) Ramgarh, b) Mohangarh, c) Bap, d) Ramdeora, e) Rasla, f) Myajlar, and g) Sam-Sudasari. Each team comprised of a researcher/volunteer and two Forest Department guards adept with the locality. Field activities in a sampling block were supervised by a research biologist from the Wildlife Institute of India with field experience on wildlife surveys. Team members were trained through workshops and field exercises on a standardized data collection protocol prior to block surveys (March 20-21). Data collected by different teams were collated after the completion of surveys (March 27) and analyzed (April-May). Subsequently, a follow-up survey was conducted in June to model habitat-specific detection widths that enabled estimation of bird densities from these extensive surveys.

3.2. Sampling design

Species and habitat status were assessed using vehicle transects in a systematic sampling design. Grid-cells of 144 km^2 size (12 km x 12 km) were overlaid on the potential bustard habitat (~25,000 km^2) and realized on ground by handheld GPS units and Google Earth imageries. Subsequently, 65% of cells were selected for sampling. Each cell was surveyed along dirt trail of $16_{Mean} \pm 4_{SD}$ km length (single continuous or broken into two transects) on a slow moving (10-20 km/hr) vehicle. Surveys were conducted in early morning (0600-1100) and late afternoon (1600-1900), when bird/animal activity was highest. This sampling scheme was selected because it optimized the combination of cell-size and transect length required to cover ≥10% of cell-area (assuming that species' would be effectively detected within ~250m strips, following Dutta 2012) given our target (systematic coverage of~18,000 km^2) and logistic constraints (maximum six survey days, eight survey hours/day and 18 teams were feasible).

3.3. Data collection

3.3.1. Species' information

Data on Great Indian Bustard, key associated species (Desert Fox, Indian Fox, Chinkara and Nilgai *Boselaphus tragocamelus*), and biotic disturbance agents (feral dogs and livestock) were collected in 2 km segments along transect (data sheet in appendix 1). Corresponding to these species' sightings, number of individuals, GPS coordinates, and perpendicular distances from transect were recorded. Distances were measured through calibrated visual assessment in broad class-intervals (0-10, 10-25, 25-50, 50-100, 100-150, 150-200, 200-300, 300-400, 400-600 & 600-1000 m) to reduce inconsistency of observation errors between teams. Corresponding to bustard sightings, associated terrain, substrate, land-cover and three dominant plant species were also recorded.

3.3.2. Habitat information

Habitat features that could potentially influence species' distribution, such as, land-cover, terrain, substrate, vegetation structure, and human artifacts were recorded at 2 km intervals along transect (see data sheet in appendix 2). The dominant land-cover type (barren/agriculture/grassland/scrub- or wood- land), terrain type (moderately or extremely flat/sloping/ undulating), and substrate type depending on soil characteristics (rock/gravel/sand/soil) were recorded within 100 m radius of the point. Vegetation composition was recorded as percentage of ground covered by short grass and herb (<30cm), tall grass and herb (>30cm), shrub (<2m) and tree (>2m) within 20-m radius of the point. Vegetation cover was recorded in broad class-intervals (0-10, 10-20, 20-40, 40-60, 60-80, and 80-100 %) to reduce inconsistency of observation errors between teams. Presence of human structures (settlement/farm-hut/metal-road/power-lines/wind-turbine/pond or water-hole) was recorded within 100-m radius of the point. Status of spiny-tailed lizard, another key associate of bustards with a relatively small activity range (Dutta and Jhala 2014), was assessed by recording presence of their burrow(s) within 10 m radius of the point.

3.3.3. Secondary information

Secondary information on Great Indian Bustard and associated species' occurrence were collected from $3.04_{Mean} \pm 1.81_{SD}$ respondents, preferably adult villagers and agro-pastoralists with local knowledge (see data sheet in appendix 3).

3.4. Data analysis

3.4.1 Population status assessment

Occupancy and density/abundance are commonly used parameters to assess population status. The proportion of sites occupied by a species (i.e., its occupancy rate) was estimated using Occupancy analysis in program PRESENCE (Mackenzie et al. 2006). Species present at a site might not be always detected that could underestimate the proportion of sites occupied by it. The technique adopted by us corrected for such imperfect detectability by using detection/non-detection data from repeated surveys at each site. Here, species' sightings in 2 km segments of transect (primary data) and occurrence reports from multiple respondents in a cell (secondary data) were used to estimate accurate occupancy rates. For Great Indian Bustard, Chinkara, and Desert Fox, three occupancy models were tested: a) constant detection probability (across transect-segments) and occupancy rate (across cells), b) detection probability modeled on habitat types (see below) and constant occupancy rate, and c) Royle-Nichols model (Royle and Nichols 2003) which assumes that detection probability corresponds to differences in species' abundance between cells. Occupancy estimates were derived from the best model (least AIC, Burnham and Anderson 2002). For spiny-tailed lizard, we used burrow detection in 10 m radius plots to estimate occupancy.

Species' density was estimated using Distance sampling based analysis in program DISTANCE (Thomas et al. 2010). This technique modeled the probability of detecting individual(s) along distance (a declining function), wherefrom Effective Detection/Strip

Width ($\overline{ESW}$) and Effective Sample Area ($\overline{ESA}$) were derived. This metric was used to convert encounter rate (count/transect-length) into density estimate ($\overline{D}$) (demonstrated in the footnote, also see Buckland et al. 2001). Subsequently, abundance ($\overline{N}$) was estimated by extrapolating density to the potential landscape area (inclusive of sampled and non-sampled cells).

There were sufficient spatially representative observations of Fox and Chinkara to develop detection function from survey data. Since Great Indian Bustard sightings were fewer and spatially unrepresentative, its detection function was modeled by augmenting observations with a subsequent survey using Great Indian Bustard dummies. Herein, sampled cells were classified into three broad habitat types based on land-cover – factor that might largely influence detectability. Thereafter, 18 cells were selected (six per habitat) by stratified random sampling, and variable number of dummy birds (2.9_{Mean}, $1\text{-}5_{Range}$) were deployed along $8.6_{Mean} \pm 2.8_{SD}$ km transect in each, at randomly chosen perpendicular distances, such that there were uniform distribution of dummies across distance classes of: 1-150, 151-300, 301-450, 451-600, 601-750 m (8 dummies/distance-class/habitat). Three teams, each comprising of a researcher/volunteer and Forest guard, conducted independent surveys along these marked transects (following similar protocol as status surveys) to detect dummies in a blind test. Resulting detection data was used to model detection functions and estimate Effective Detection/Strip Width for each habitat. This exercise allowed us to estimate Great Indian Bustard density for each cell which was averaged to generate overall density and subsequently abundance. For species such as feral dogs and livestock, whose observation distances were not recorded, mean ± standard error of encounter rates were estimated.

3.4.2. Assessment of habitat status and use

Habitat characteristics of a cell were summarized from covariate data collected at $8.9_{Mean} \pm 2.1_{SD}$ sampling plots. a) For categorical variables (land-cover and substrate types), frequency of occurrence of each category (in percentage) was estimated. Terrain types were scored as '1' for extreme level of that category (e.g., extremely flat), '0.75' for moderate level (e.g., moderately flat), '0.5' if there were two co-dominant types (e.g.,

ESW: perpendicular distance within which as many individuals are missed as detected outside
ESA = Transect length x 2*ESW
Density = Number / ESA

flat-undulating mix), otherwise '0'. These values were averaged across plots to generate an index for each terrain type. b) For interval variables (vegetations structure), mid-values of class-intervals were averaged across plots. c) Disturbance variables were grouped into: infrastructure – measured as summed occurrence of metal road, power lines and wind turbines; and human use – measured as summed occurrence of settlement (weighted twice) and farm hut. Thereafter, these values were averaged across plots to generate disturbance indices for each cell.

Since cell-habitat was characterized by multiple and inter-correlated variables (see Results), Principle Component Analysis was carried out in program SPSS (Quinn and Keough 2002), to extract synthetic variables that surrogated prominent and independent habitat gradients. Separate principle components were extracted for topography and substrate variables, land-cover variables, and vegetation variables.

Great Indian Bustard habitat use was assessed by modeling its detection (sighting/signage) and secondary reports vs. absence on potential habitat covariates using multinomial logistic regression in program SPSS (Quinn and Keough 2002). Alternate models were built on ecologically meaningful combinations of habitat covariates and tested using Information Theoretic approach to identify combination of factors that best explained bustard distribution. Inferences on covariate influence were based on the model with minimum AIC value (Burnham and Anderson 2002).

3.4.3. Spatially explicit information on ecological parameters

Spatially explicit information on species and habitat status helps prioritize conservation areas and target management actions. For this reason, surface maps of habitat covariates were generated by interpolating values from sampled 144 km^2 cells using kriging technique in program ArcMap (ESRI 1999-2008). Species' encounter rates were also mapped across cells. A conservation priority index was generated by transforming species' encounter rates into ranks and summing the latter, weighted by species' endangerment level (3 for Great Indian Bustard, 2 for Chinkara and 1 for Fox).

4. Results and Findings

4.1. Population status

Total 118 cells covering 16,992 km^2 area was surveyed along 1924 km transect (figure 1). Data generated from these surveys (table 1) provided estimates of species' occupancy, density and abundance.

Table 1. Sampling efforts, number of sightings (rows in bold) and mean (standard error) sightings per 100 km of wild and domestic fauna in seven survey blocks of Thar landscape (March 2014)

Block	Cells	Transect (km)	GIB	Fox	Chinkara	Nilgai	Dog	Cattle	Sheep & Goat
Ramgarh	16	255	**0**	**6**	**80**	**5**	**29**	**860**	**4534**
			0 (0)	2.3 (0.8)	30.3 (8.6)	2.2 (2.2)	10.5 (6.3)	296.4 (160.3)	1902.9 (431.5)
Mohangarh	17	252	**0**	**9**	**166**	**5**	**0**	**385**	**1853**
			0 (0)	2.9 (1.4)	78.2 (32.5)	1.5 (1.5)	0 (0)	143.7 (53.8)	792.4 (271.2)
Bap	11	171	**0**	**7**	**439**	**12**	**42**	**444**	**2758**
			0 (0)	3.7 (1.8)	224 (77.9)	6.7 (3.8)	21.3 (5.5)	234.2 (53.3)	1546.8 (282.1)
Ramdeora	19	315	**4**	**12**	**256**	**4**	**1**	**1018**	**2182**
			2.1 (2.1)	4.2 (1.5)	90.3 (24.7)	1.3 (0.9)	0.3 (0.3)	311.9 (107.2)	628.1 (155)
Rasla	20	342	**0**	**8**	**141**	**10**	**0**	**198**	**2088**
			0 (0)	3 (1.5)	45.1 (12.8)	2.4 (2.4)	0 (0)	59.4 (20.4)	585.1 (199)
Myajlar	16	285	**0**	**15**	**227**	**0**	**0**	**731**	**5827**
			0 (0)	5.1 (2)	83.9 (19)	0 (0)	0 (0)	250.9 (46.3)	1980.7 (393.3)
Sam-Sudasari	19	303	**7**	**15**	**142**	**25**	**0**	**847**	**5542**
			1.9 (1.2)	5.3 (2)	48.5 (12.7)	8.3 (7.9)	0 (0)	256.4 (67.8)	1661.3 (337.7)

4.1.1. Great Indian Bustard

Extensive search from 22–26 March recorded 38 unique individuals (range 34-43 encompassing errors due to double counting), comprising of observations along transects and those enroute or while returning from sampling sites. Only five flocks were detected during transect surveys at encounter rate of $0.31_{Mean} \pm 0.19_{SE}$ flocks/100 km and the flock size estimated from extensive search was 1.59 ± 0.18 individuals. In our detectability experiment, 120 dummy birds were deployed (40 in each habitat type), out of which 65 were detected (26 in agro-grassland, 22 in grassland and 17 in woodland). Best-fit detection models differed between habitat types: hazard-rate polynomial function for agro-grassland (χ^2=0.10, df=2, p=0.95), half-normal cosine function for grassland (χ^2=0.04, df=1, p=0.84), and half-normal hermite function for woodland (χ^2=0.04, df=2, p=0.98). These models showed that 50 (woodland) – 64 (agro-grassland) percent of individuals within visible range (750 m) could be detected (figure 2). Habitat-specific Effective Detection Widths were estimated at 378 (woodland), 385 (grassland) and 480 (agro-grassland) meters. Correcting Great Indian Bustard encounter rates along transects by habitat-specific detection widths returned an overall density of 0.61 ± 0.36 birds/100 km^2. Extrapolation of this estimate yielded abundance of 103 ± 62 in the sampled area (16992 km^2) and 155 ± 94 in the potential landscape area (25488 km^2). Birds were sighted in only 4 transects. Occupancy analysis showed similar support between the constant detection probability and occupancy model and the Royle-Nichols (2003) model (ΔAIC = 0.02). Hence, we selected the former (parsimonious) model for inference which estimated the probability of sighting the species in a 6 km segment (if present in transect) at 0.25 ± 0.20. Correcting for this imperfect detection, 5.8 ± 4.4 % of transects were occupied. Supplementing this data with interviews of local people (bird records in last 3 months) and our auxiliary surveys (February-June 2014) indicated Great Indian Bustard usage in 32 (27%) cells (figure 3).

4.1.2. Chinkara

During transect surveys, 1451 Chinkara were detected in 511 herds at encounter rate of $77.63_{\text{Mean}} \pm 11.09_{\text{SE}}$ individuals/100 km and herd size of 2.82 ± 0.14 individuals. Hazard-rate polynomial function fitted the detection data best (χ^2=1.66, df=4, p=0.80), based on which detection probability of herd was estimated at 0.10 ± 0.006 and Effective Detection Width was found to be 103 ± 6 m. Chinkara density was estimated at 378 ± 57 animals/100 km^2, yielding abundance estimate of 64194 ± 9704 in the sampled area and 96291 ± 14556 in the landscape area. Chinkara was detected in 85% of transects (naïve occupancy). Royle-Nichols (2003) model performed better than other models (AIC-wt = 1.00, see section 3.4.1) and estimated occupancy in 91.0 ± 3.4% of sites (figure 4).

Figure 2. (a) Proportion of dummy Great Indian Bustard detected along increasing distance classes from transect; and (b-c) functions relating probability of detecting individual along distance from transect for Chinkara and Fox, in Thar landscape during March 2014

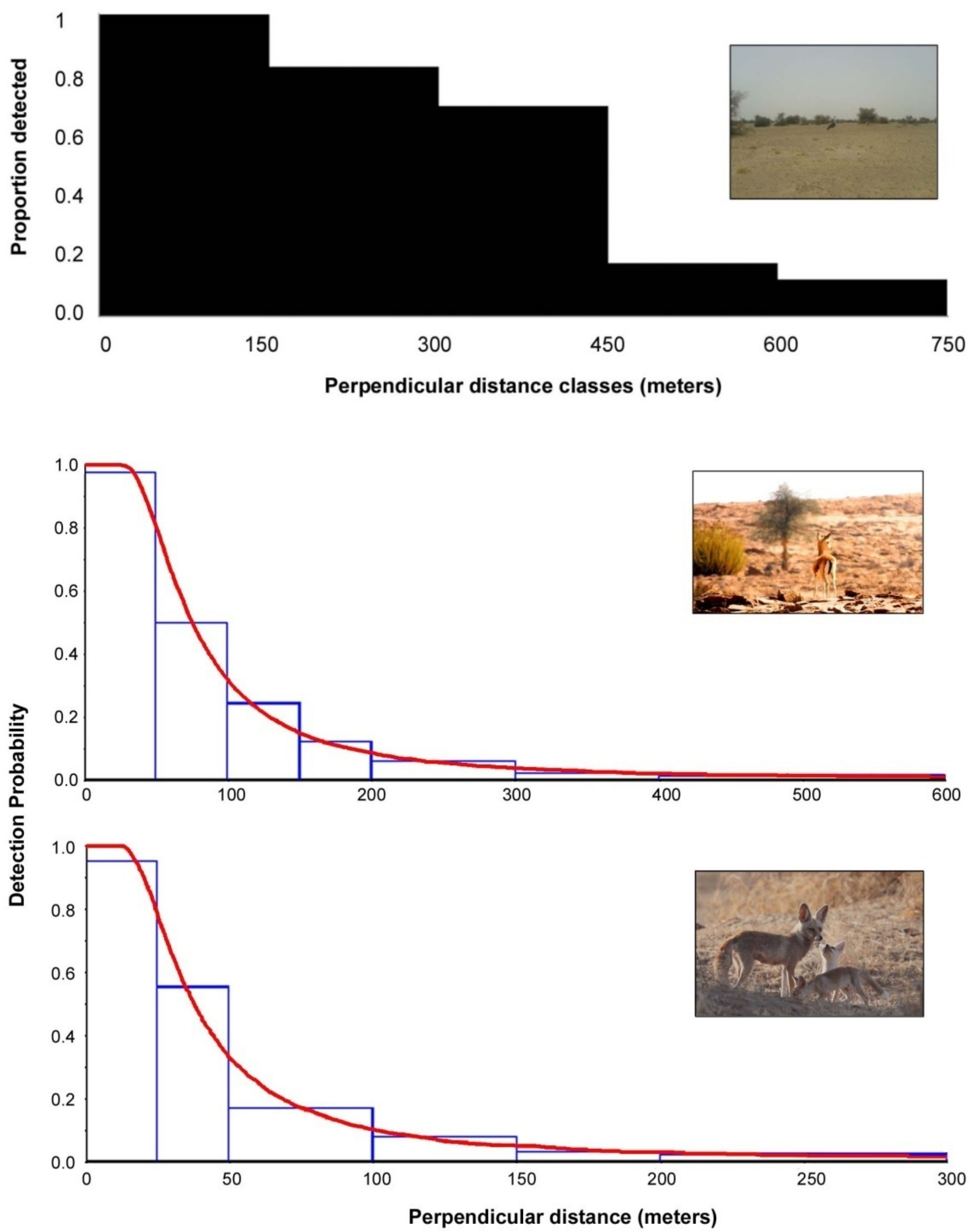


Figure 3. Great Indian Bustard sightings and occurrence status in 144 km² cells based on surveys (primary data) and reports by local people (secondary data) in Thar landscape (February-June 2014)

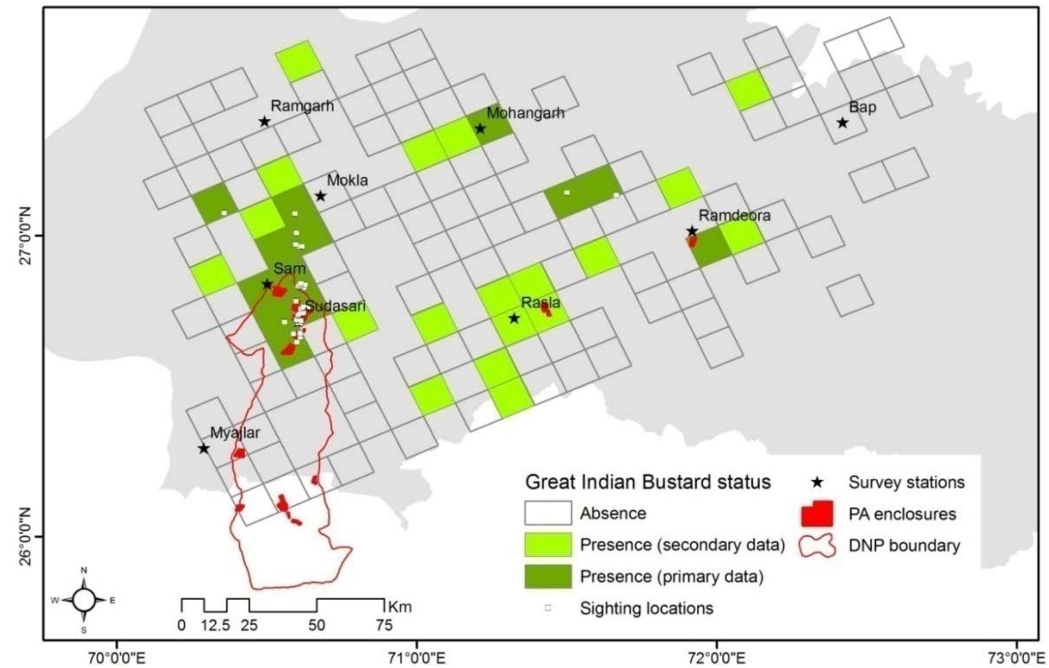
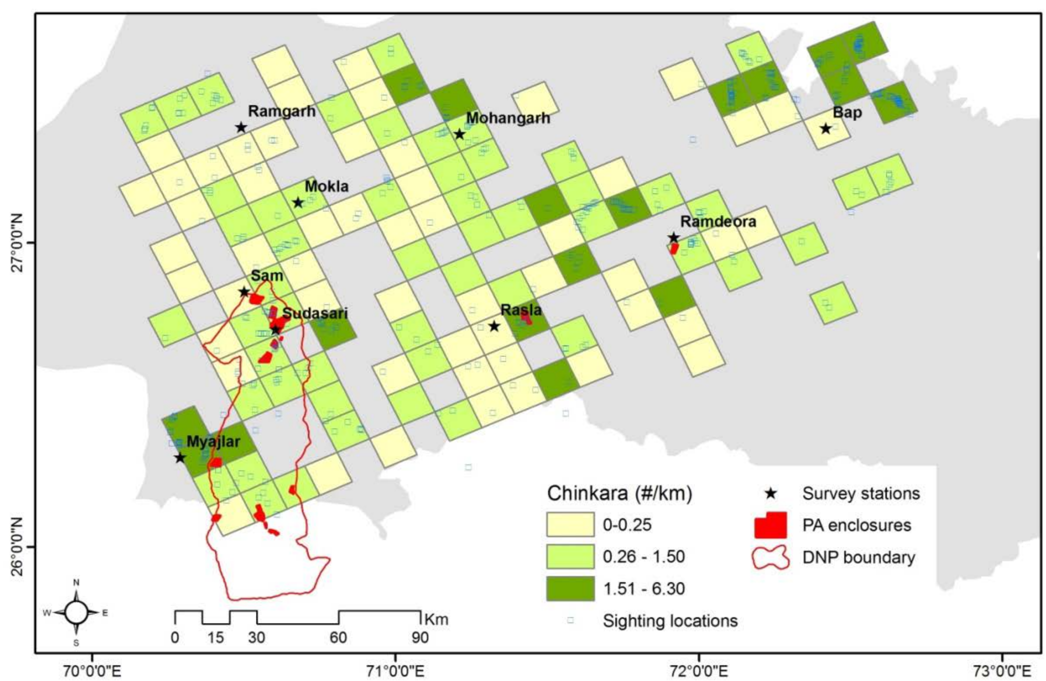


Figure 4. Chinkara sightings and encounter rates in 144 km² cells of Thar landscape (March 2014)



4.1.3. Fox

Sixty seven Desert Fox and 4 Indian Fox were detected along transects at encounter rates of 3.60 ± 0.60 individuals/100 km and 0.21 ± 0.12 individuals/100 km, respectively. Both species were observed mostly solitarily (10% sightings were in pairs), yielding group size estimate of 1.13 ± 0.04 individual. Since these species have similar body size, a common detection function was built by pooling their data. Hazard-rate polynomial function fitted the data best (χ^2=0.35, df=3, p=0.95), estimating detection probability at 0.18 ± 0.03 and Effective Strip Width at 53 ± 10 m. Species' densities were estimated at 33.58 ± 8.17 Desert Fox/100 km^2 and 1.92 ± 1.21 Indian Fox/100 km^2. Accordingly, their abundances were 5705 ± 1387 (Desert Fox) and 326 ± 205 (Indian Fox) in the sampled area, while 8558 ± 2081 (Desert Fox) and 489 ± 308 (Indian Fox) in the landscape area. Desert fox was detected in 34% of transects (naïve occupancy). Since the constant detection probability and occupancy model found similar support as Royle-Nichols (2003) model (ΔAIC < 1), we selected the former (parsimonious) model for inference. Probability of detecting a Desert Fox (if present in transect) was 0.12 ± 0.02 and 53.5 ± 8.8 % of sites were likely occupied.

4.1.3. Other fauna

Our surveys also yielded sightings of Nilgai *Bosephalus tragocamelus* (61 individuals, encounter rate 3.07 ± 1.42 individuals/100 km) and Wild pig *Sus scrofa* (17 individuals, encounter rate 0.85 ± 0.85 individuals/100 km). Pooling data of all three ungulate species: Chinkara, Nilgai and Wild pig, total density of wild ungulates was estimated at 403 ± 59 animals/100 km^2. Sightings of domestic animals included 71 Dogs (encounter rate 3.47 ± 1.15/100 km), 4121 Cattle (218.35 ± 32.25/100 km) and 21557 Sheep and Goat (1252.75 ± 123.96/100 km). Livestock were converted into Animal Units and their encounter rates were mapped across cells to surrogate grazing intensity, wherefrom areas of high overlap between wild and domestic species could be identified (figure 6).

Figure 5. Fox sightings and encounter rates in 144 km² cells of Thar landscape (March 2014)

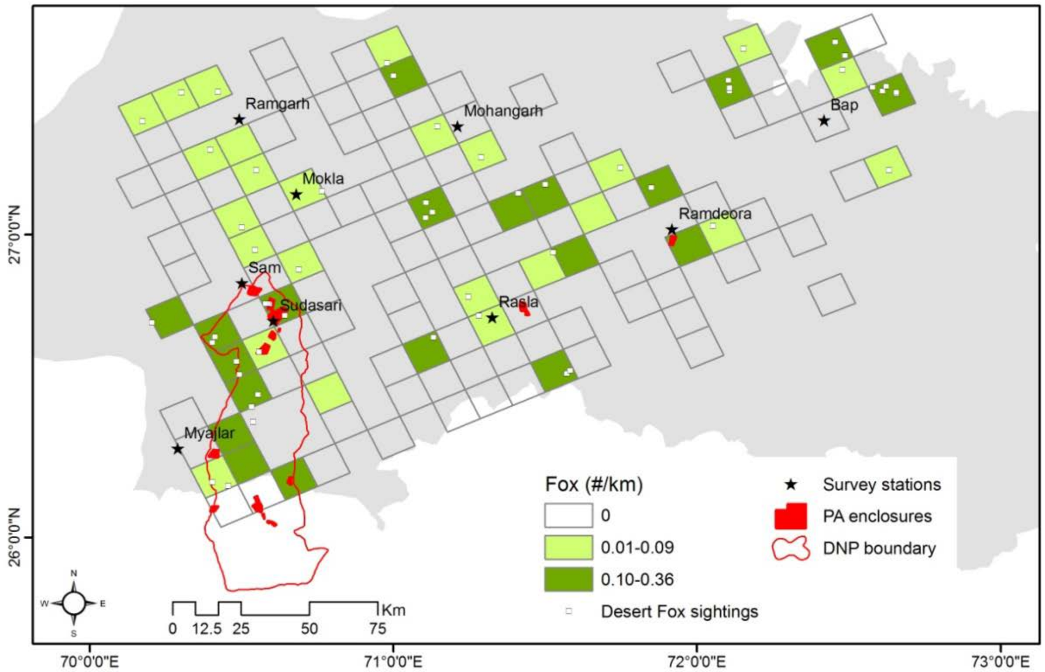
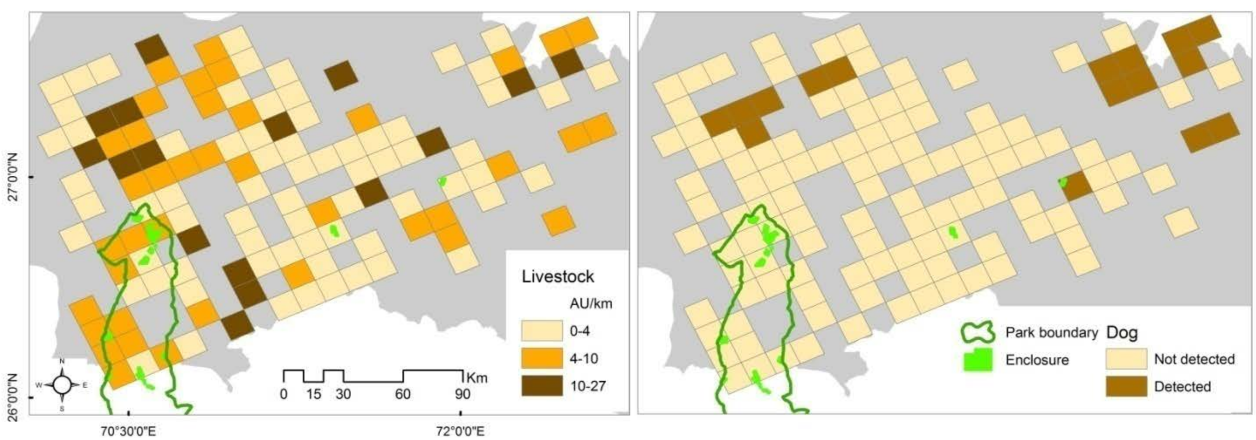


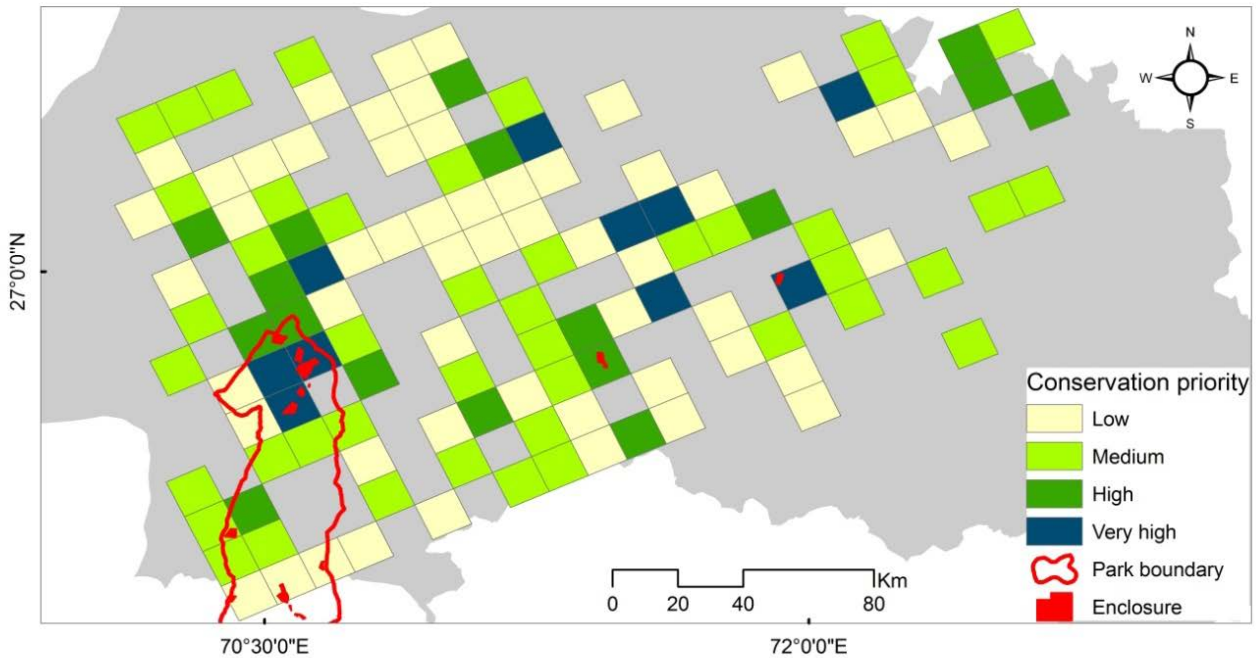
Figure 6. Livestock and dog detections rates in 144 km² cells of Thar landscape (March 2014)



4.1.4. Conservation Prioritization

Conservation priority index, generated from population status of key species in 144 km² cells, ranged between 0-3.67. On classifying this range into four ranks (low: 0-0.33, medium: 0.33-1.33, high: 1.33-2.33 and very high: 2.33-3.67), 21% cells (26) were attributed high and very high priority, and 79% cells (98) were attributed low and medium priority for conservation (figure 7). Thirty percent (3 cells) of the very high priority cells (10) were protected by enclosures (Sudasari, Gajaimata amd Ramdeora); while 26% (6) of the high-very high priority cells overlapped with the Desert National Park and its satellite enclosures (Ramdeora and Rasla).

Figure 7. Conservation Priority Index of 144 km² cells in Thar landscape (March 2014)



4.2. Habitat status and use

Habitat characterization in 144 km² cells showed dominance of flat to undulating terrain, soil and sandy substrate, and grassland followed by agriculture and scrub/wood cover. Vegetation structure was characterized by relatively even mix of short and tall grasses, shrub and tree species. Among disturbance variables, some forms of human presence (settlements or farm-huts) and infrastructure (metal roads, power-lines, and wind-turbines) were found in 30% and 22% of plots, respectively (table 2). There was strong inter-correlation between topography, substrate, land-cover and vegetation structure variables (table 3).

Table 2. Descriptive statistics of habitat variables indicating factors important to wildlife in 144 km² cells of Thar landscape (March 2014)

Factor	Variable	Measurement	Mean	SE	Median
Terrain	Flat	Prevalence of the category in 100m radius plot, scored as 0 (absent)-1 (dominant) and averaged across plots within cell [index]	0.49	0.03	0.54
	Sloping		0.09	0.01	0.00
	Undulating		0.29	0.02	0.24
Substrate	Rocky	Frequency of occurrence of the category in 100m radius plots within cell [proportion]	0.03	0.01	0.00
	Gravel		0.12	0.01	0.06
	Sand		0.29	0.03	0.22
	Soil		0.55	0.02	0.59
Land-cover	Barren	Frequency of occurrence of the category in 100m radius plots within cell [proportion]	0.08	0.01	0.00
	Agriculture		0.29	0.02	0.19
	Grassland		0.41	0.02	0.37
	Woodland		0.22	0.02	0.14
Vegetation structure	Short grass (<30cm)	Proportional cover of vegetation type in 20m radius plots within cell	0.33	0.01	0.32
	Tall grass (>30cm)		0.20	0.01	0.17
	Shrub (<2m)		0.27	0.02	0.25
	Tree (>2m)		0.14	0.01	0.12
Human artifacts	Human incidence	Summed occurrence of settlement (weight 2) and hut (weight 1) [index]	0.46	0.04	0.40
	Infrastructure	Summed occurrence of power-lines, roads & wind-turbines [index]	0.30	0.03	0.20
	Water	Occurrence of water-points [proportion]	0.06	0.01	0.00

Table 3. Pair-wise correlation between habitat variables collected in 144 km² cells of Thar landscape

		TF	TS	TU	SR	SG	SSD	SSL	LB	LA	LG	LW	VSG	VTG	VS	VT	HH	HI	HW
Terrain	Flat (TF)		**-.43***	**-.84***	.08	.19*	**-.55***	**.48***	.07	.28*	-.27*	-.05	.30*	-.35*	-.03	.01	.27*	.01	0
	Sloping (TS)			-.06	-.03	-.12	.31*	-.26*	.04	-.09	.20*	-.14	-.09	.33*	-.20*	0	-.12	.17	-.06
	Undulating (TU)				-.06	-.12	**.49***	**-.45***	-.06	-.30*	.16	.19*	-.28*	.18	.18*	-.02	-.26*	-.14	-.03
Substrate	Rocky (SR)					0	-.24*	-.04	.25*	-.19*	-.08	.16	.06	-.25*	.14	.08	.07	.08	-.11
	Gravel (SG)						-.39*	-.17	**.52***	-.20*	-.05	-.04	.22*	-.14	-.01	0	-.05	.17	-.08
	Sand (SSD)							**-.81***	-.16	-.15	.25*	-.02	-.37*	**.42***	.06	-.06	-.16	-.15	-.03
	Soil (SSL)								-.20*	.34*	-.22*	0	.26*	-.30*	-.10	.05	.19*	.04	.12
Land-cover	Barren (LB)									-.23*	-.21*	-.11	.07	-.16	.05	.10	-.14	-.04	-.05
	Agriculture (LA)										**-.50***	**-.40***	-.04	-.12	0	.03	.38*	-.04	.06
	Grassland (LG)											**-.44***	.22*	.37*	-.24*	**-.40***	-.34*	.06	.09
	Woodland (LW)												-.24*	-.19*	.24*	.35*	.04	0	-.14
Vegetation structure	Short grass (VSG)													-.26*	**-.48***	-.21*	-.16	.09	-.09
	Tall grass (VTG)														**-.44***	-.26*	-.32*	-.16	.08
	Shrub (VS)															-.09	.26*	.01	-.11
	Tree (VT)																.21*	.16	-.01
Human artifact	Human (HH)																	.18	-.08
	Infrastructure (HI)																		-.12
	Water (HW)																		

Significant correlations (p<0.05) indicated by(*); strong correlations (|r|>0.4, p<0.05) indicated in bold

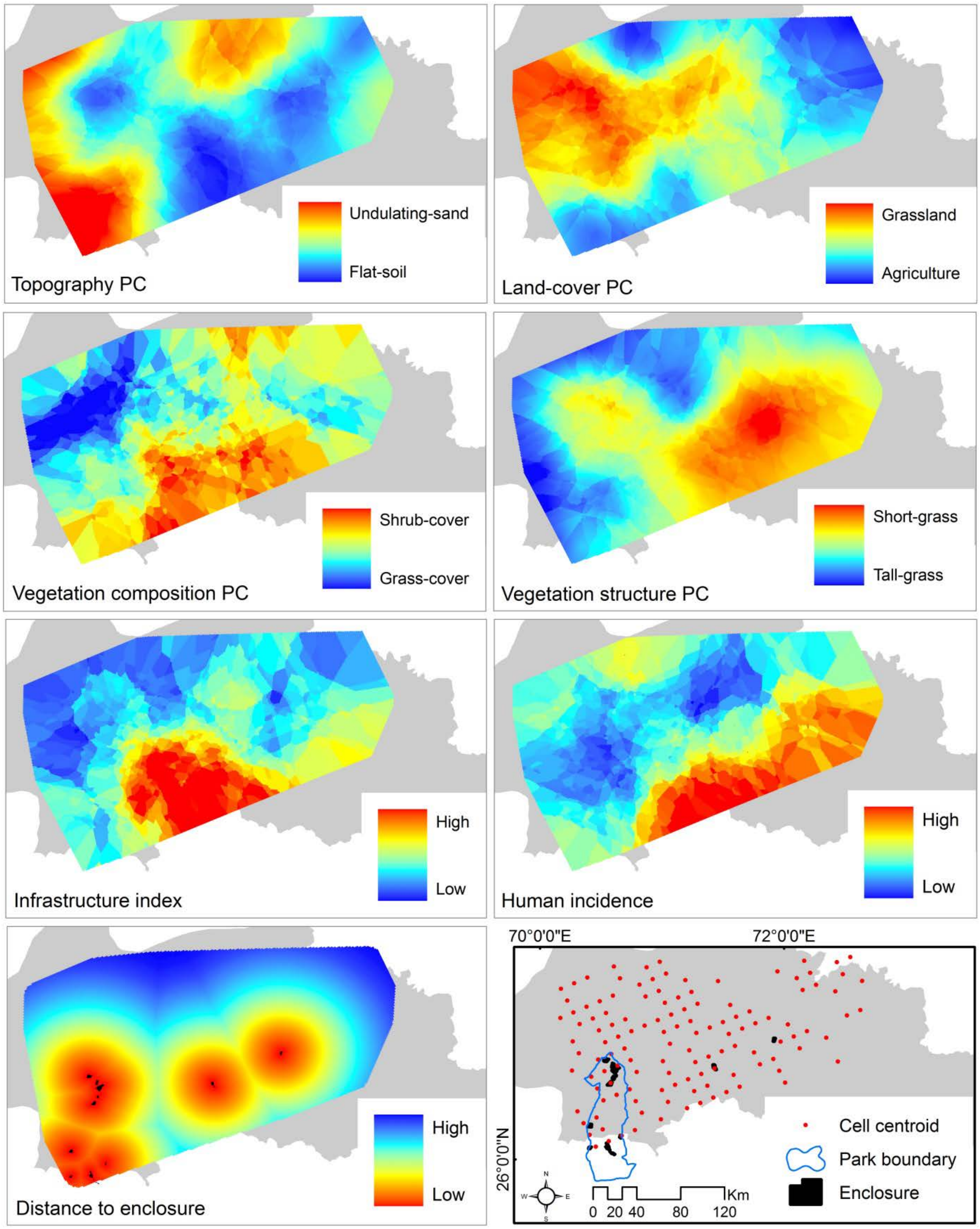
Ecologically meaningful gradients were identified using Principle Component Analysis (PCA) on habitat variables (table 4). The first PCA was conducted on terrain, substrate and land-cover variables, which extracted three components cumulatively explaining 58% of information in the data. Of these, two components were considered important for explaining distribution patterns of Great Indian Bustard: one surrogating undulating, sandy (positive values) versus flat, soil-rich (negative values) substrates, and the other surrogating grassland (positive) versus agriculture (negative) land-covers. The second PCA was conducted on vegetation variables, which extracted three components cumulatively explaining 97% information in data. Of these, two were considered important: one surrogating shrub (positive) versus grass (negative) cover, and another surrogating short (positive) versus tall (negative) grass (table 4).

Table 4. Summary of Principle Component Analysis: variable loadings, information explained, and ecological interpretation of extracted habitat components in Thar landscape (March 2014)

Variables	Principle Component Analysis 1			Principle Component Analysis 2		
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Flat	-0.84					
Sloping						
Undulating	0.78					
Rocky						
Gravel		0.81				
Sand	0.85					
Soil	-0.81					
Barren		0.89				
Agriculture			-0.78			
Grassland			0.87			
Woodland						
Short grass				-0.60	0.75	
Tall grass				-0.57	-0.80	
Shrub				0.88		-0.42
Tree						0.90
Information explained (%)	27	17	14	39	32	26
Ecological interpretation	Undulating sand (+) vs. flat soil (-)	Bare area (+)	Grassland (+) vs. agriculture (-)	Shrub (+) vs. grass (-)	Short (+) vs. tall (-) grass	Tree (+) vs. shrub (-)

There were distinct gradients of potentially important habitat covariates across the landscape (figure 8).

Figure 8. Important habitat gradients in Thar landscape (March 2014), interpolated (by kriging) from variables collected and analyzed at 144 km² cells, along with reference map of the study area



Among alternate hypotheses explaining distribution pattern of Great Indian Bustard, two models including anthropogenic disturbances along with topography, protection-level and livestock grazing obtained maximum support from data (models 1 & 2, table 5a). The more parameterized model 2 was selected for inference since its predictive power and classification accuracy were higher. Parameter estimates of this model (table 5b) indicated that Great Indian Bustard preferred flat, soil-rich substrate over undulating sandy ones, avoided human incidence and infrastructure, and were found relatively closer to enclosures (see negative β±SE values of covariates *Topo*, *Dst-encl*, *Hum*, *Infra*). The positive association between GIB and livestock (*Grz*) was probably due to similar resource requirements (productive grasslands) by both taxa.

Table 5. (a) Alternate hypotheses explaining distribution of Great Indian Bustard in 144 km² cells of Thar landscape, and (b) influence of important covariates on species' occurrence (primary & secondary data) analyzed using multinomial logistic regression (March 2014)

(a)	Model	ΔAIC	AIC	Deviance	K	R^2	CC%
1	**Hum + Infra**	**0.00**	**163.04**	**151.04**	**6**	**0.11**	**75**
2	**Topo + Hum + Infra + Grz + Dst-encl**	**0.64**	**163.68**	**139.68**	**12**	**0.37**	**81**
3	Topo + Hum + Infra + Dst-encl	7.48	170.52	150.52	10	0.28	78
4	Hum + Infra + Dst-encl	11.16	174.20	158.20	8	0.21	76
5	Topo + Landcov + Vegcomp + Vegstr + Hum + Infra + Grz + Dst-encl	11.66	174.70	138.70	18	0.37	81
6	Topo + Dst-encl	14.37	177.41	165.41	6	0.15	75
7	Topo + Hum + Infra	14.69	177.73	161.73	8	0.18	76
8	Dst-encl	16.70	179.74	171.74	4	0.09	75
9	Topo + Landcov + Hum + Infra	16.88	179.92	159.92	10	0.20	76
10	Topo + Landcov + Vegcomp + Vegstr + Hum + Infra + Dst-encl	17.38	180.42	148.42	16	0.30	77
11	Topo + Landcov + Vegcomp + Vegstr + Dst-encl	18.30	181.34	157.34	12	0.22	74
12	Topo + Landcov + Vegcomp + Vegstr + Hum + Infra + Grz	18.41	181.45	149.45	16	0.29	77
13	Topo	19.60	182.64	174.64	4	0.06	75
14	Topo + Landcov	19.78	182.82	170.82	6	0.10	75
15	Vegcomp + Vegstr	20.02	183.06	171.06	6	0.09	75
16	Topo + Vegcomp + Vegstr + Hum + Infra	20.20	183.24	159.24	12	0.20	76
17	Topo + Vegcomp + Vegstr	21.66	184.70	168.70	8	0.12	75
18	Topo + Landcov + Vegcomp + Vegstr + Hum + Infra	23.30	186.34	158.34	14	0.21	75
19	Topo + Landcov + Vegcomp + Vegstr	24.23	187.27	167.27	10	0.13	74

(b)	Primary data		Secondary data	
Covariate	$\hat{\beta}$	SE	$\hat{\beta}$	SE
Topo	-0.83	0.45	-0.60	0.32
Dst-encl	-0.05	0.02	-0.02	0.01
Hum	-3.87	1.70	0.38	0.62
Infra	-2.61	1.54	-0.43	0.83

Covariates (further details in tables 2 & 4)
Topo: Principle component surrogating undulating-sand (+) vs. flat-soil (-)
Landcov: Principle component surrogating grassland (+) vs. agriculture (-)
Vegcomp: Principle component surrogating shrub (+) vs. grass (-) cover
Vegstr: Principle component surrogating short (+) vs. tall grass (-)
Dst-encl: Mean distance to protected enclosures (km)
Hum: Human incidence at 2 km intervals along transect
Infra: Infrastructure index along transect
Grz: Livestock encounter rate in Animal Units/km

Abbreviation: AIC (Akaike Information Criteria); K (parameters); R^2 (Pseudo coefficient of determination); CC (Correct classification rate)

5. Discussion

By adopting a standardized, spatially representative sampling and analysis design that accounts for imperfect detectability, we have generated the first-ever robust estimates of population distribution and abundance for the endangered Great Indian Bustard and its associated Chinkara and Desert Fox in 25,500 km^2 expanse of Thar landscape. This landscape is critical to the persistence of these species and many more depending on arid eco-climate.

Comments on our population enumeration technique

Thar bustard landscape extends over a vast area with little barrier to bird/animal movements, thereby rendering total population counts unfeasible. Comparing Great Indian Bustard numbers observed in traditional surveys to that reported by local informants, Rahmani (1986) speculated that only 10-20% of population might be detectable. This impeded earlier efforts to arrive at population estimate with confidence. Similarly, our repeated transect surveys in seven cells within 18 days returned counts that varied by 80-173%, indicating that proportion of individuals missed during a survey could differ between sites depending on habitat characteristics. Our approach of estimating habitat-specific detection widths provides an unbiased framework to assess density/abundance from a sample of sites. Additionally, sampling sites based on random probability design allows extrapolation of this sample statistic into robust population density/abundance estimate. Detection parameters for Great Indian Bustard were generated via dummy based experiment rather than solely on sighting distances, since the latter were too few and unrepresentative of habitats available in the landscape over which abundance had to be extrapolated. We considered the use of dummies reasonable because detectability predominantly depended on habitat and/or terrain at this large landscape-scale, while flushing movement of live birds, which could have rendered them more detectable than dummies, was negligible as birds were relatively stationary compared to survey vehicles. An alternative approach for such rare and patchily distributed species would be to conduct extensive survey for identifying occupied areas followed by intensive survey in the latter for counting all individuals (see

Conroy et al. 2008 for advancement on this approach). Occupancy analysis showed that ~6% of sampled area, or 1500 km^2, is occupied. Even this area is too large and logistically constraining for total count. However, substituting total counts in occupied cells by abundances estimated from repeated transect based densities in those cells returned an overall abundance very similar to what was obtained by us.

The precision of our estimate is relatively poor, as can be expected for such extremely small population distributed patchily over a vast landscape. Sub-sampling of transect data indicates that estimator precision cannot be significantly improved by increasing survey efforts. Perhaps the only way to improve estimator precision would be to design a population enumeration technique based on individual recognition (possibly by tagging birds and/or through molecular tools) in a capture-recapture based framework. For the purpose of monitoring, we recommend similar surveys on an annual basis in priority conservation cells (identified by this study) that would allow more confidence on population estimates and trends.

Conservation Implications

Rahmani (1986) assessed Great Indian Bustard status in this landscape, but direct comparison between the two studies is not possible as the survey methods differ considerably. However, broadly, numbers and area of occupancy have seemingly declined in these three decades. Rahmani (1986) reported Great Indian Bustard sightings in Bap, Sam-Sudasari, Khuri-Tejsi, Khinya, Rasla and Sankara; whereas, we detected the species in Sam-Sudasari, Salkha and Ramdeora. Typical number of birds seen by respondents in their localities has also reduced from earlier times.

Our results on habitat relationships of bustards indicated that disturbance was the prime factor influencing their distribution in this region. Great Indian Bustard did not use areas with high incidence of humans or infrastructure. Their occurrence also depended on level of protection and declined with distance from protected enclosures. Other habitat factors had relatively less influence on their distribution. Hence, reduction of anthropogenic stressors in select areas by creating enclosures and/or providing alternate arrangements to local communities should be the priority conservation action. This proposition is supported by recent observations that Great Indian Bustard are frequently using and breeding in Ramdeora enclosure after anthropogenic disturbances were excluded from the site by chain-link-fencing. It was also found that three-fourth of priority conservation areas occurred outside of Desert National Park (figure 7). Although some of these areas benefit from protection by Bishnoi community (Bap area) and inviolate space created for defense activities (Ramdeora area), larger expanses are threatened by hunting, development projects (e.g., wind power generation), and resource over-extraction (e.g., livestock overgrazing). Responses to our questionnaires suggested general lack of support among local communities towards bustard conservation. These findings indicated that effective wildlife conservation in Thar would require a multi-pronged approach involving multiple stakeholders such as Forest Department, Indian Army, local communities and research/conservation agencies. Apart from protecting key breeding areas as enclosures, conservation funds should also be utilized on activities to maintain these anthropogenic stressors below species' tolerance threshold by involving communities in participatory-planning that balances conservation and livelihood concerns. However, since some level of bustard use (but not occupancy) is spread across ~7,000 km^2 expanse (primary and secondary records in 27% cells), comprehensive insights into their ranging patterns, using biotelemetry based research, are required for fine-tuning these conservation actions.

Recommendations

The Great Indian Bustard population and their habitats are declining drastically across the distribution range. Thar landscape is the only remaining habitat supporting a viable (and the largest) breeding population across its erstwhile distribution. In order to bring this landscape under the umbrella of Protected Area based conservation, a representative fraction (3162 km^2) was notified as sanctuary (the Desert National Park or DNP) in early eighties. However, the park authorities have control over only 4% of this area (in the form of enclosures), leaving the remaining habitat beyond the scope of management as this land is not owned by Forest Department. The role of Forest

Department in the rest of the park has been viewed as anti-development, denying even basic amenities to local communities (73 villages), resulting in strong antagonism and poor conservation support for bustard and associated wildlife. Besides, the Park area encompasses a mere proportion of the priority conservation areas in Thar. Therefore, we strongly recommend rationalizing the DNP boundary with the objectives of: a) notifying the northern Sudasiri-Sam area (500 km^2) as National Park with appropriate relocation of villages; b) selectively declaring other priority conservation areas in Thar landscape as Community/Conservation Reserves where human landuses can be regulated; and c) notifying areas equal to the denotified DNP area (2600 km^2) as PA in the relatively less populated Shahgarh Bulge (or similar habitat elsewhere). This strategy will balance biodiversity conservation and livelihoods by providing local people with basic amenities, gaining their support in conservation efforts, and deterring commercial misuse of this landmass which is a hot spot for desert biodiversity.

In terms of management activities, we recommend: a) strengthening of existing enclosures with chain-linked fencing, b) creation of new enclosures in other priority conservation areas, c) smart and intensive patrolling to check poaching possibilities, d) scientific and targeted research and monitoring of Great Indian Bustard and associated fauna by engaging research organizations, and e) involving local communities to monitoring bustard occurrence and illicit activities through reward and incentive schemes. e) Additionally, we recommend the removal of feral- dogs and pigs as well as natural nest predators like corvids, foxes and monitor lizards from core enclosures (~ 25 km^2 cumulative areas) to ensure bustard nesting success.

Ex-situ conservation/captive breeding program following the national guidelines should be immediately initiated as an insurance policy for survival of the species.

Sincere efforts towards protecting wildlife, scientifically managing their habitat, sensible planning of landuses, and providing basic amenities and livelihood options to local communities in priority conservation areas are the key to successful biodiversity conservation in this vital yet neglected landscape.

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Appendix 1: Datasheet for Great Indian Bustard and associated species' sightings

Date: ___________ Cell-ID: ____________ Team: ____ (Obs.) Trail-length: _______ (km)

GPS at every 2-km		Sighting information				Associated habitat characteristics (Great Indian Bustard)			
SN	**Latitude, Longitude**	**Species**	**Number**	**Perp. Dist.**	**Projected Lat, Long**	**Terrain (100m)**	**Substrate (100m)**	**Landcover (100m)**	**Vegetation (3 dominant sp)**
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	
						F / S / U (M / V)	R / G / S / s	B / A / G / W	

Notes:

Species to record: Great Indian Bustard, Chinkara, Blackbuck, Nilgai, Wildpig, Fox, Dog, Sheep & Goat, Cattle
Perpendicular distance classes: 0-10, 10-25, 25-50, 50-100, 100-150, 150-200, 200-300, 300-400, 400-600 & 600-1000 meters

Appendix 2: Datasheet for habitat characterization at every 2-km along transect route

Date: ___________ Cell-ID: ___________ Team: ____ (Obs.)

SN	**Latitude dd—mm—ss**	**Longitude dd—mm—ss**	**Time (hrs)**	**Terrain (100m radius)**	**Substrate (100m radius)**	**Land-cover (100m radius)**	**Vegetation composition (% area in 20m radius)**					***Sandha* Pr (10m radius)**	**Human structure (100m radius)**
							Short grass/ herb(<30cm)	**Tall grass (>30cm)**	**Shrub (<2m)**	**Tree (>2m)**	**Crop (with name)**		
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P
				F / S / U (M / V)	R / G / S / s	B / A / G / W						1 / 0	S / H / R / E / W / P

Notes:

Abbreviations: **Terrain** – **F** (flat**) / S** (sloping) / **U** (undulating) with qualifier **M** (moderately) / **V** (very)
Substrate – **R** (rock) / **G** (gravel) / **S** (sand) / **s** (soil)
Land-cover – **B** (barren) / **A** (agriculture) / **N** (natural vegetation)
Human structure – **S** (settlement) / **H** (farm hut) / **R** (metal road) / **E** (electricity lines) / **W** (wind turbine) / **P** (pond / water-hole)

Vegetation composition classes: 0-10, 10-20, 20-40, 40-60, 60-80, 80-100 %.

Appendix 3: Datasheet for secondary information on Great Indian Bustard occurrence

Date: ___________ Cell-ID: ____________ Team: ____ (Obs.)

Village	Respondent Name	Latitude, Longitude	Q1. How many GIB have you seen in last 3 months?	Q2. When & where was the last that you have seen GIB?	Q3. Is there a threat to GIB from a) hunters, b) development and c) agriculture here?	What other species occur here?
1)	1)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
	2)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
	3)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
2)	1)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
	2)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
	3)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
3)	1)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
	2)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha
	3)				a) b) c)	Chinkara / Blackbuck / Nilgai / Wild pig / Fox / Sandha